FIBERGLASS REINFORCED PLASTICS

by

Nicholas P. Cheremisinoff
Paul N. Cheremisinoff

NOYES PUBLICATIONS
Park Ridge, New Jersey, U.S.A.

Library of Congress Catalog Card Number: 95-23436
ISBN 0-8155-1389-5
Printed in the United States

Published in the United States of America by
Noyes Publications
Mill Road, Park Ridge, New Jersey 07656

Library of Congress Cataloging-in-Publication Data

Cheremisinoff, Nicholas P.
Fiberglass reinforced plastics / by Nicholas P. Cheremisinoff and Paul N. Cheremisinoff.
p. cm.
Includes index.
ISBN 0-8155-1389-5
1. Glass reinforced plastics. I. Cheremisinoff, Paul N. II. Title.
TP1177.5.G5C48 1995
668.4'95--dc20 95-23436
CIP

ABOUT THE AUTHORS

Nicholas P. Cheremisinoff is Executive Director of the National Association of Safety and Health Professionals, Morganville, New Jersey and Director of the Center for Environmental Management Studies of Fairleigh Dickinson University. His responsibilities include the management and development of advanced training and educational programs in environmental compliance, safety management and engineering controls for industry applications involving hazardous materials. His expertise in the fields of elastomers technology and polymer processing spans over twenty years as industry consultant, R & D manager and product development manager for major polymer suppliers. Dr. Cheremisinoff is internationally recognized in the industrial and academic community, having authored, co–authored and edited over 100 books.

Paul N. Cheremisinoff has been involved for more than 45 years with industry and academia. He is experienced in research, design and consulting for a wide range of government and industrial organizations. His engineering, design and teaching span the broadest range of chemical, plastics, materials and industrial experience. He is author and co–author of numerous papers and books on materials, resources, environment, and energy. He is a licensed professional engineer, member of Sigma Xi and Tau Beta Pi, and a Diplomate of the American Academy of Environmental Engineers.

NOTICE

CONTENTS

PREFACE

This book has been prepared as a reference on manufacturing techniques and applications of fiberglass reinforced plastics. It provides discussion of properties, and concepts and is written for the potential user to summarize advantages in usage. The book contains 9 chapters of discussions on relationships between polymers, reinforcements, and uses as well as a useful glossary of plastics and engineering terms.

There is a wide interest in fiberglass reinforced plastics due to useful properties which meet a great many product and use requirements as well as the relative ease with which such products can be fabricated. Fiberglass reinforced plastics find applications in transportation, marine, construction, electronics, recreation, aircraft, aerospace and numerous manufacturing industries. These plastics have virtually displaced wood in the marine industry, and applications replacing metals in other areas continue to grow.

The user of this book will find practical and useful information for design, engineering, plant and maintenance. Presented is the technology and applications to serve the varied interests of readers in diverse industries.

Nicholas P. Cheremisinoff
Paul N. Cheremisinoff

CHAPTER 1

ENGINEERING PLASTICS

INTRODUCTION

Iron, copper, tin, zinc, brass, bronze and wood were man's primary materials of construction prior to the American Civil War. With the advent of the Bessemer and open–hearth processes and the subsequent generation of alloys, the steel industry began its adolescence during the post–Civil War years, and aluminum was introduced by the end of the century. Plastics did not become major engineering materials until the earlier part of this century although limited applications and interests developed in the mid–nineteenth century.

The earliest known plastic–molding techniques were practiced by Malayan natives in the early 1800s. They made utensils and artifacts from gum elastic (a vegetable material named gutta percha), softened in hot water and fashioned by hand. The art of molding plastic compounds was first brought to the United States by Alfred Critchlow, who, by 1850, developed shellac–molding compounds. The plastics industry during the 1850s was limited to the manufacturing of checkers, picture frames, buttons, combs and display plaques or cases molded from wood flour–filled shellac compounds.

The first synthetic plastic material produced was celluloid. Cellulose nitrate was first produced in 1835 by dissolving cellulosic products in nitric acid. Ten years later, a Swiss chemist by the name of Schonbein nitrated cellulose with sulfuric acid as a catalyst, and in 1854 an American scientist, J. Cutting, obtained patents for his process of gum camphor in collodion for photographic solutions. This marked the first use of camphor with cellulose nitrate. Evaporation of the photographic collodion by Alexander Parkes, an English scientist, produced a hard, elastic waterproof material that could be fashioned into useful articles.

Celluloid, although the first synthetic material, did not advance the molded products industry as it could not be molded. Shellacs and bituminous cold–mold plastics continued to dominate the industry until 1909, which marked the introduction of phenol–formaldehyde. Dr. Bakeland is accredited with invention of phenol–formaldehyde resin, which was the first synthetic, moldable plastic material. Since its debut, more than 50 distinct families of plastics have been invented with literally hundreds of variations of these materials. Table 1–1 summarizes the major developments in the plastics field up to 1909.

Today, when one refers to engineering plastics, those most frequently thought of are the acetals, nylons, phenolics, polycarbonates and fluorocarbons. The growth rate of plastics in industrial and commercial usage surpasses most conventional materials such as metals, rubber, ceramics, textiles and paper due to superiorities in flexibility, strength–to–weight ratio, abrasion resistance, energy absorption of foams, thermal and electrical insulation variety in color and clarity, and resistance to inorganic and/or organic chemicals. At the same time, plastics in general are plagued with a large number of deficiencies. Table 1–2 summarizes some of the general advantages and disadvantages of plastics. There are three general classes of plastics; Thermoplastics, Thermoset Plastics and Thermoplastic–Thermoset.

Thermoplastics

Thermoplastics are commonly converted into molded products through injection molding processes and, hence, are more commonly referred to as injection materials. Additives such as plasticizers, which are usually nonvolatile organics, are added by hot mixing or solution mixing with a solvent or by dry blending, to improve the material's flexibility and processability. Stabilizing agents are also added to thermoplastics to prevent thermal degradation and deterioration by light or oxidation. Fluorescent additives are sometimes added to certain thermal plastics to meet color specifications. A brief description of the major thermoplastic materials is in order.

Table 1–1: Chronological Development of Plastics to 1909

1820	First rubber processing plant was built.
1834	Liebig isolated melamine.
1835	Pelouze nitrated cellulose.
	Regnault developed vinyl chloride.

(continued)

Table 1–1: (continued)

1839	Goodyear introduced the vulcanization of rubber.
1845	Bewley designed extruder for gutta percha.
	Schonbein nitrated cellulose in H_2SO_4.
1847	Berzelius developed the first polyester.
1859	Butlerove made formaldehyde polymers.
1865	Schuzenberger prepared acetylated cellulose.
	Parkes's patented Parkesine process.
1866	Berthelot synthesized styrene.
1870	Hyatt patented basic celluloid.
1872	Hyatt patented first plastics injection molding machine.
	Bayer observed reactions between phenols and aldehydes.
	Baumann polymerized vinyl chloride.
1873	Caspery and Tollens prepared various acrylate esters.
1878	Hyatt developed first multicavity injection mold.
1879	Gray patented first screw extruder.
1880	Kahlbaum polymerized methylacrylate.
1884	Holzer isolated urea–formaldehyde condensation products.
	Chardonnet developed the first synthetic silk.
1894	Cross and Bevan patented the first industrial process for manufacturing cellulose acetate.
1899	Continuous cellulose nitrate film made by casting on a polished drum.
	Spitteler and Kritsche patented casein plastic.
1901	Smith studied alkyd resins in reaction of glycerol and phthalic anhydride.
1905	Milec prepared secondary cellulose acetate.
1909	Bakeland patented phenolic resins.

Table 1–2: General Advantages/Disadvantages of Plastics

Advantages	Disadvantages
With Reinforcement	Rigidity less than metals, ceramics, wood
Use in structural applications	

(continued)

Table 1-2: (continued)

Advantages	Disadvantages
Use over wide temperature range	Strength less than metals, ceramics
Withstand high mechanical strength	Brittleness greater than metals, wood
Withstand chemical attack	Low hardness/scratch easily
Transparency	Thermal expansion greater than metals
Self-Lubricating	Highly brittle at low temperatures
Economical Fabrication	Permeability greater than metals glass
Flexible	More flammable than metals, ceramics
Good Electrical Properties	Outdoor weather
Good Thermal Insulators	Soften sooner than metals, ceramics at high temperatures
Decorative Uses	Suffer thermal decomposition and oxidation at high temperatures
	Many have poor resistance to organic chemicals

Acrylic Plastics—These thermoplastics were first introduced commercially in 1931 and possess excellent properties in clarity, colorability and optics. In general, acrylic plastics have a low index of refraction, approximately 1.49. They display a high degree of uniformity and are scratch- and abrasion-resistant. They are resistant to food oils, nonoxidizing acids, petroleum lubricants and alkalies; however, they are easily attacked by alcohols, chlorinated hydrocarbons, fluorocarbons, phenols and ketones. They show good dielectric strength and low **moisture** absorption.

Cellulose Plastics—The first member of this family, cellulose acetate, was introduced in 1889 and has the properties of easy workability, clarity of colors, water resistance and good strength. Its primary disadvantages include gradual decomposition after extended exposure to heat and light. In addition, this material tends to become brittle with time.

Cellulose acetate, introduced in 1912, was a significant improvement over its counterpart in terms of toughness, colorability, high impact strength and vacuum–forming properties. It does display poor water resistance qualities.

Cellulose acetate butyrate, more commonly called acetobutyrate, marked an improvement over the acetate in being highly moisture resistant. It has good dimensional stability and is available in a wide range of colors.

Cellulose propionate is another member of this family having good weathering properties and color retention. It has a higher impact resistance and toughness than the materials described above.

Ethyl cellulose is capable of applications over a wide temperature range and is an odor–free compound. This material has better heat distortion temperatures and higher impact strength. This thermoplastic is employed in a large number of military applications because of its low temperature resistance.

Styrene Plastics—Styrene or styrol was first introduced in 1839. The chemical name for styrene is vinyl benzene. It is highly resistant to attack from organic acids, alkali, salts and many of the low–molecular weight alcohols. It is, however, subject to deterioration or softening when exposed to certain hydrocarbons, ketones, esters and essential oils. Its major disadvantage is that it is susceptible to stress cracks.

The first major product of this group that was widely applied was polystyrene, prepared from ethylene and benzene. Polystyrene has good electrical properties over a limited temperature range.

Styrene acrylonitrile (SAN) is a copolymer of styrene and acrylonitrile. Its qualities include rigidity, scratch, chemical and stress–crack resistance. Its heat resistance is about 75°C above general–purpose styrene.

Acrylonitrile, butadiene and styrene are the main constituents in ABS plastics. The butadiene compounds are rubber–like in properties, and the styrene polymers are resinous. These materials are superior to the standard styrenes and can be compounded to give a high degree of hardness or to provide flexibility with toughness. These plastics are little affected by alkalies, weak acids and inorganic salts. Alcohol and hydrocarbon solvents can attack them mildly.

Vinyl Plastics—Polyvinyl chloride (PVC) is the most widely used material in this group. It is potentially one of the most inexpensive plastics. It was first produced in 1835 and entered the commercial market in 1927. Its qualities include self–extinguishing properties, water, chemical and abrasion resistance. It is noted for having high strength properties and is available in a wide range of colors. PVC compounds are characterized by melting temperatures but will not burn. They are resistant to many fats, acids, salts and petroleum products. PVC materials have good break resistance, as good as polyethylene. It has advantages over polyethylene in resistance to permeation of several atmospheric gases and has a greater water vapor permeability. Polyvinyl acetate plastics are unaffected by petroleum, naphtha, mineral and vegetable oils. They are readily attacked by most solvents such as ketones and alcohols.

Polyvinylidene chloride is tasteless, odorless, nonflammable, and abrasion resistant. Its chief advantage lies in its high tensile strength and in its low water absorption and low vapor transmission. These copolymers are among the most inert of all the thermoplastics.

Polyolefin Plastics—Polyethylene, first introduced in 1933, is a wax-like polymer with wide application. This material is composed of ethylene molecules bound together in long chains. The properties of a particular formulation depend on the number of units comprising the chain and the particular method by which they are bound. Long chains formed with large molecules generate a product with poor processability while short chains produce a brittle, waxy material. Intermediate structures can be prepared with varying properties. Uncolored polyethylene is susceptible to weathering and becomes brittle when exposed to oxygen and light. Weathering resistance can be increased by the addition of carbon black. At elevated temperatures, polyethylene softens but retains its strength. At low temperatures, it becomes brittle. Its qualities include high resistance to chemical and acid attack as well as bases and salts. It has poor resistance to most solvents, hydrocarbons and strong oxidizing agents. High-density plastics are less susceptible than low-density materials. In general, it has high permeability unless special surface treatment is employed during manufacturing. Its use is often limited due to its large coefficient of thermal expansion. Attractive electrical properties include high dielectric strength and low power factor.

Ionomers, a copolymer of polyethylene has properties of glass-like transparency, resilience, low temperature characteristics, grease and solvent resistance. These materials consist of both organic and inorganic compounds interlocked. They are readily colored and are often prepared with fillers.

Ethylene vinyl acetate (EVA), a copolymer of polyethylene, is characterized by exceptional flexibility, toughness, clarity and stress-crack resistance. EVA resins retain their properties at low temperatures and are ultraviolet and ozone resistant. Its tensile strength is roughly twice that of low-density polyethylene.

At relatively low temperatures and pressures, propylene gas can be polymerized to a polypropylene resin. Polypropylene resins were first produced in 1954. The resin has a specific gravity of about 0.90 and in its natural state is translucent. It has a significantly higher thermal operating range than polyethylene. In addition, it has fair surface hardness and abrasion resistance. With fillers, it shows superior dimensional stability and chemical resistance at high temperatures. It is not attacked by inorganic salts, mineral acids and bases and its permeability is generally better than high-density polyethylene. Electrical properties are good.

Polyamide Plastics—One of the most well-known materials in this group is nylon, which was first introduced in 1938 as a toothbrush bristle material. There are a variety of manufacturing methods for making this material. Molded nylon products are characterized by their toughness, strength, low friction, abrasion and heat resistance. They are not attacked by common organic solvents, with the exception of some phenol and formic acids, and show good resistance to oils, greases and electrolytic attack. Strong mineral acids and oxidizing agents will decompose nylon. Electrical properties are considered good to fair for power frequency situations where it is advantageous for mechanical parts. Nylon has good colorability and can be made translucent. When combined with certain additives, it shows excellent weathering resistance.

Polycarbonates—These thermoplastics have superior heat resistance and impact strength, along with good dimensional stability. Polycarbonate, first produced in 1959, resulted from research on pure formaldehyde. It is chemically characterized by its resistance to water, mineral acids and organic acids. It is partially soluble in many aromatic hydrocarbons and very soluble in chlorinated hydrocarbons and readily decomposes in strong alkaline solutions. It is insoluble in aliphatic alcohol. Polycarbonate has good colorability properties and is available in transparent forms. Electrical properties are adequate for numerous applications within its temperature range. These properties include high insulation resistance, a stable dielectric constant over a wide temperature and frequency range, and a low power factor. Furthermore, it has good corona resistance, suggesting its usage to some high-voltage applications. Other electrical properties include good arc resistance for low-current arcs along with a tracking resistance that parallels the general-purpose phenolics. Its dielectric constant and power factor are relatively steady at power frequencies.

Phenoxy Plastics—This family was first introduced in 1962 for injection, blow and extrusion molding. These compounds have good dimensional stability and superior creep resistance. Permeability to CO_2 and oxygen is low and it is noted for its crystal clarity.

Polysulfone Plastics—First marketed in 1965 as an extrusion and injection molding material for high-temperature applications, its major use today is as a load-bearing, structural compound for continuous use at elevated temperatures, to an upper limit of 150°C. Basically, it is a linkage of isopropylidene, ether and sulfone. It has better than average resistance to heat and oxidation. Over a wide temperature range, it is resistant to mineral acids, salt and alkali solutions. At high temperatures and subject to moderate stress, it is resistant to several detergents, alcohols and oils; however, it is severely attacked by chlorinated and aromatic hydrocarbons and by ketones. Polysulfone compounds have good colorability and are self-extinguishing. Some of its electrical properties are comparable to those of polycarbonate.

Urethane Plastics—Urethane compounds were first introduced in 1955. They range from rigid and flexible foams to solids and highly abrasion-resistant materials. These plastics are prepared from the reaction of isocyanates with hydroxyl-bearing compounds. Urethane in the form of rigid foams displays superior thermal insulating qualities. It displays a high degree of hardness and toughness, mar-resistance, flexibility and good chemical resistance when used as a coating resin.

Fluorocarbons—Fluorocarbon is a fairly reactive compound that was first introduced to this country in 1938. The most common member of this family is tetrafluorethylene (TFE), which is highly moisture and ultraviolet resistant. Its most advantageous property is that adhesives will not stick to it. Both its static and dynamic friction are low, lending to its unique nonsticking properties. Electrical properties are fair over a wide temperature range. The dielectric constant and loss factor are independent of frequency changes up to 10,000 μc. The dielectric constant is relatively high (around 600 V/mil) within a continuous service temperature range of -205°-260°C, which is well above the other thermoplastics with the exception of the polyimides. TFE is a relatively nonrigid material that has a high coefficient of expansion.

Polyvinylidene Fluoride (VF_2)—The vinylidene fluoride plastics show good strength, mechanical durability, thermal resistance in a temperature range of -27°-150°C, and are solvent, chemical and ultraviolet resistant. These materials also display good weatherability, resistance to gamma radiation and low permeability. Electrical properties are considered to be excellent and it is available in colors or transparent forms. It shows good resistance to oxidation and thermal decomposition at excessive temperatures.

Chlorinated Polyether—This is a highly chemical-resistant compound that consists of roughly 46% chlorine. It is a superior corrosion-resistant material that has found numerous applications in the chemical process industry. It has a relatively high heat distortion temperature, which makes it suitable for hot processing equipment. Its electrical properties are fair, showing good stability at high temperatures. In addition, it shows good weatherability resistance and stability.

Polyimides—These plastics have a high heat resistance at continuous exposure to high temperatures (up to 260°C for long periods of time and 480°C for short periods). The polyimides tend to char slowly at high temperatures but retain some of their strength after prolonged exposure. These materials are competitive with the fluorocarbon compounds and glass–bonded mica in a temperature range of 200°–540°C. They are resistant to many acids, organic solvents, benzene, chloroform and hexene. It is readily attacked by strong alkalis, hydrazine and N_2O_4. In general, its weathering resistance is poor; however, volume resistivity, arc resistance and dielectric strength are high. In comparison to other thermoplastics, its resistance to radiation is well above average.

Not all thermoplastics have been discussed. Table 1–3 summarizes some of the properties and more common applications of the thermoplastic materials.

Thermosets

Thermoset plastics are wax–like compounds that may be softened by heating and fashioned into a desired shape, which, after cooling, acquires rigidity. Many of the thermoset compounds require a mixture of a filler material and a binder, which is a chemically produced resin. A combination of heat and pressure on the mixture of resin and filler cause the mixture to become plastic. Usually, continued heat and pressure affect curing. A discussion of fillers, a primary concern of this book, is deferred to a later section. A brief description of the major thermosetting compounds follows.

Phenolic Plastics—Phenolic plastics came into being in 1907, from a mixture of phenol carbolic acid and formaldehyde. There are a number of raw materials that can be used in preparing these resins. Phenol and cresol or a mixture of different phenolic bodies are generally used in preparing the phenol. For the aldehyde, formaldehyde and furfuraldehyde are most often used.

Phenol, or carbolic acid, can be derived as a by–product of coal distillation. Another source is from the synthetic production of benzene. Formaldehyde, normally a gas, is used as the aldehyde for this resin. When phenol and formaldehyde are mixed with an acid catalyst, permanently soluble and fusible resins are formed.

Table 1–3: General Properties and Uses of Thermoplastics

Plastic Material	First Introduced	Strength	Electrical Properties	Acids	Bases	Oxidizing Agents	Common Solvents	Product Manufacturing Methods	Common Applications
Acetal Resins	1960	H		P	P	P	G	Injection, blow or extrusion molded	Plumbing, appliance, automotive industries
Acrylic Plastics	1931		G	P	P	F-P	F-P	Injection, compression extrusion or blow molded	Lenses, aircraft and building glazing, lighting fixtures, coatings, textiles fibers
Arc Extinguishing Plastics	1964		E					Injection or compression molded and extruded	Fuse tubing, lightning arrestors, circuit breakers, panel boards
Cellulose Plastics									
Cellulose Acetate	1912	M					P	All conventional processes	Excellent vacuum-forming material for blister packages, etc.
Cellulose Acetate Butyrate		H				F	F	Molded with plasticizers	Excellent moisture resistance-metallized sheets and film, automobile industry
Cellulose Nitrate	1889	M						Cannot be molded	Little use today because of fire hazard
Cellulose Propionate		H						All conventional processes	Toys, pens, automotive parts ratio cases, toothbrushes, handles
Ethyl Cellulose		H+						All conventional processes	Military applications, refrigerator components, tool handles
Chlorinated Polyether	1959	M+	A+	VG	VG	VG	VG	Injection, compression, transfer or extrusion molding	Bearing retainers, tanks, tank linings, pipe, valves, process equipment

(continued)

Table 1–3: (continued)

Plastic Material	First Introduced	Strength	Electrical Properties	Acids	Bases	Oxidizing Agents	Common Solvents	Product Manufacturing Methods	Common Applications
Fluorocarbon (TFE)	1930	M	A	VG	VG	VG	VG	Molding by a sintering process following preforming	High-temperature wire and cable insolation, motor-lead insolation; chemical process equipment
Fluorinated Ethylene Propylene (FEP)		M+	A	G	G	G	G	Injection, blow molding, and extrusion and other conventional methods	Autoclavable laboratory ware and bottles
Glass-Bonded Mica	1919	M	G	VG	G	G	G	Moldable with inserts like the organic plastics	Are chutes, radiation generation equipment, vacuum tube components, thermocouples
								process, costing	laminates
Hydrocarbon Resins	1960	M	A	A	A	A	A	Molding with transfer and compression	Used as lamination resins for various industrial
Methylpentene Polymers (TPX)	1965	M+	E	F	F	F	F	Most conventional processes	Used for electrical and mechanical applications
Parylene (Poly-para-xylene)	1960							A monomer of the organic compound is vaporized and condensed on a surface to polymerize	Coating material for sensing probes
Phenoxy Plastics	1962	H-M	F	F	F	F	F	Injection, blow and extrusion molding, coatings and adhesives	Adhesives for pipe-bonding compounds, bottles
Polyamide Plastics									
Nylon	1938	H-M	A	P	P	P	VG	Injection, blow and extrusion molding	Mechanical components (gears, cams, bearings), wire insulation pipe fittings
Polycarbonate	1959	H-M[a]	VG[a]	GF[a]	GF	F[a]	F	All molding methods, thermoforming, fluidized bed coating	Street light globes, centrifuge bottles, high-temperature lenses, hot dish handles

(continued)

Table 1–3: (continued)

Plastic Material	First Introduced	Strength	Electrical Properties	Acids	Bases	Oxidizing Agents	Common Solvents	Product Manufacturing Methods	Common Applications
Polychlorotrifluoroethylene (CTFE)	1938	H	E	VG	VG	VG	VG	Molded by all conventional techniques	Wire insulation, chemical ware, pipe lining, pipe, process equipment lining
Polyester-Reinforced Urethane	1937	H		G[a]	G	G	G	Compression molded over a wide temperature range	For heavy-duty leather applications—industrial applications
Polyimides	1964	H-M	E[a]	G-VG	P[a]	P	G-VG	Molded in a nitrogen atmosphere	Bearings, compressors, valves, piston rings
Polyolefin Plastics									
Ethlene Vinyl Acetate (EVA)	1940	H		G	G	G-F	G-F	Most conventional processes	Molded appliance and automotive parts, garden hose, vending machine tubing
Polyallomers	1962	H	G-VG	F	F	F	F	Molding processes, all thermoplastic processes	Chemical apparatus, type writer cases, bags, luggage shells, auto trim
Polyethylene	1939	H	VG	G-VG	G-VG	P	P	Injection, blow, extrusion and rotational	Pipe, pipe fittings, surgical implants, coatings, wire and cable insulation
Polypropylene plastics	1954	H-M	VG	VG	VG	F	F	Same as PVC	Housewares, appliance parts, auto ducts and trim, pipe, rope, nets
Polyphenylene Oxide	1964	M	F-G	E	E	VG	VG	Extruded, injection molded, thermoformed and machined	Auto clavable surgical tools, coil forms, pump housings, valves, pipe
Polysulfone	1965	M	VG	VG	VG	F	P-F	Extrusion and injection molded	Hot water pipes, lenses, iron handles, switches, circuit breakers
Polyvinylidene Fluoride (VF_2)	1961	H	VG+	G-VG	G	G-VG	G-VG	Molded by all processes, fluidized bed coatings	High-temperature valve seats, chemical resistant pipe, coated vessels, insulation
Styrene Plastics									
ABS Plastics	1933	M-H	VG+	G-VG	G-VG	F-G	F	Thermoforming, injection, blow, rotational and extrusion molds	Business machine and camera housings, blowers, bearings, gears, pump impellers

(continued)

Table 1–3: (continued)

Plastic Material	First Introduced	Strength	Electrical Properties	Acids	Bases	Oxidizing Agents	Common Solvents	Product Manufacturing Methods	Common Applications
Polystyrene	1933	M-H	VG+	G	G	F	P-F	Most molding processes	Jewelry, light fixtures, toys, radio cabinets, housewares, lenses, insulators
Styrene Acrylonitrile (SAN)		H	VG	VG	G	G	G	Most molding processes	Lenses, dishes, food packages, some chemical apparatus, batteries, film
Urethane	1955	M-H+		G-VG	G	G	F-G	Extruded and molded	Foams for cushions, toys, gears, bushings, pulleys, shock mounts
Vinyl Plastics	1835								
Compolymers of Vinyl Acetate and Vinyl Chloride	1912	M+		G	GF	G	G	All molding processes	Floor products, noise insulators
Polyvinyl Acetate	1928	M		P-G	G	G	P	Coatings and adhesives	Adhesives, insulators, paints, sealer for cinder blocks
Polyvinyl Aldehyde	1940	H		VG	VG	VG	VG	Most molding processes	Used for coatings and magnet wire insulation, interlayer of safety glasses
Polyvinyl Chloride (PVC)	1940	M-H		VG	G	G	G	Extrusion, injection, rotational, slush, transfer, compression, blow mold	Pipe conduit and fittings, cable insulation, down spouts, bottles, film
PVC Plastisols	1940	M-H		VG	G	G	G	Slush and rotationally molded, foamed, extruded	Used in coating machines to cover paper, cloth and metal
Polyvinylidene Chloride	1940	H		VG	VG	VG	VG	Same as PVC	Auto seatcovers film, linings, paperboard coatings

[a] A = average; F = fair; H = high; P = poor; E = excellent; G = good; M = moderate; VG = very good.

These resins find wide use in paints, varnishes and wide use in paints, varnishes and in the two–stage process of molding resins. When an alkaline catalyst is used, an insoluble and infusible resin is formed, which is used in the one–stage method for molding resins. The one–stage process was the original method of manufacturing phenolic resins. The method involves piping proper molecular fractions of phenol and formaldehyde to a resin kettle, where an alkaline catalyst, usually ammonia or caustic soda, is added. Usually a stirred tank (batch reactor) is the vessel and heat is supplied to initiate the reaction. Water, generated from the reaction, must be removed. The remaining resin has a consistency similar to cold molasses, which cools to a clear, amber color. The resin is then hardened by heat and pressure. In a hardened state, the resin is called a resol. The curing stage is referred to as polymerization. The initial reaction between the formaldehyde and the phenol, in the presence of an acid or base catalyst, is called condensation. Curing times are generally longer.

In the two–stage process, the first step consists of preparing a soluble and fusible resin called novolak in the presence of an acid catalyst. The resin is next converted into a thermosetting compound by neutralizing it and then adding excess quantities of a formaldehyde–bearing mixture. This involves piping phenol and formaldehyde into the resin reactor with an excess of phenol. The acid catalyst used is generally sulfuric or hydrochloric acid. The condensation reaction is initiated by heat. The reaction is exothermic in nature and, hence, an adequate means of cooling the resin vessel must be provided. Water formed is removed via vacuum pumps. The resin can be poured onto a hardening floor for solidification.

General–purpose resins are usually manufactured by a dry–process mixing in which the resin is removed from the hardening floor and mechanically ground into powder form. The novolak resins are blended with lime, lubricant and hexa (hexamethylenetetramine). This powder is then mixed with filler materials and suitable dyes. Vegetable wax or calcium stearate is often added as a lubricant to reduce sticking during molding. It should be noted that the mixing procedure is a carefully designed operation that must provide a uniform compound suitable for molding.

Fillers and resins play a significant role in the various properties of phenol plastics.

In general, phenolics do not have as high a tensile yield or strength as metals such as steel. They do, however, display greater resistance to being pulled apart in comparison to different woods or some thermoplastics. They have a lower modulus of elasticity than metals and, hence, a greater volume of material is required for a given application. This is offset, however, by the favorable weight relationship since phenolics have a much lower specific gravity. Phenolics are extremely hard materials and are resistant to scratching. They thus find wide use in areas in which abrasion is a problem. Phenolic plastics also have low thermal conductivity, making them good thermal insulators. Heat distortion temperature is around 160°C although some specialized compounds can be prepared that will resist distortion up to 260°C.

Phenolics are good electrical insulators and have good self-extinguishing properties after exposure to fire. With the use of proper fillers, they have properties that are competitive with many structural materials. On a cents-per-cubic-inch basis, they are less expensive than metals. These compounds, because of their versatility and attractive properties, offer good replacements for metals and wood in numerous applications.

Allyl Plastics—The allyl plastics appeared on the U.S. market in 1955. These resins cure in the presence of peroxide catalysts forming heat and chemical-resistant compounds with excellent electrical properties and high dimensional stability. Mineral fillers often used include calcium silicate, clays and silica. Other fillers include Orlon, Dacron, and glass.

Diallyl phthalate compounds (DAP) are the most common resins in this group. They are characterized by superior chemical resistance to all reagents (with the exception of the strongest oxidizing agents). They show low electrical loss, excellent weather resistance, low mold shrinkage and are among the most stable compounds in the organic plastics. DAP compounds are highly stable and inert. They do not release any corrosive metal vapors to attack inserts and will not support galvanic corrosion in a moist environment. These materials retain a constant resistivity even in the most severe surroundings, whereas many thermoplastics will undergo large increases in the electrical conductivity at high temperatures and humidity. DAP prepolymers are employed for surface laminates on plywood, hardboard and particle board. When these compounds are combined with glass fillers they are used for rugged power-circuit breakers.

Alkyd Plastics—Alkyds were first introduced commercially in the U.S. in 1941. They are polyester derivatives that are generated by a reaction between an alcohol and an acid. Filler material is usually some mineral. They have good colorability. Typical uses of this material include electron tube bases, switches and automobile ignition parts. Since these compounds have the capability of low pressure molding, they have found large-volume applications as an encapsulating material for resistors and transformers. Some noteworthy properties include short cure times, freedom from volatiles and capability of undergoing molding by compression and transfer automatically. When combined with glass fillers, they acquire the property of high shock resistance.

Allyl Diglycol Carbonate (ADC)—This thermoset has optical properties similar to glass along with superior mechanical strength. It is often cast into transparent plates, tubes and solid rods. It is not, however, a moldable compound. It has scratch and abrasion resistance nearly 40 times greater than the acrylics It shows good solvent resistance against benzene, gasoline and acetone and has a distortion temperature above 100°C. Major uses include aircraft windows, safety goggles and watch crystals.

Amino Plastics—The major plastics in this class are the melamine formaldehyde and urea formaldehyde plastics. Amino resins are water clear and have the best colorability characteristics of all the thermosets. Typical filler materials include alpha cellulose (purified wood cellulose), cotton fabric, minerals, asbestos, glass fiber and paper. The melamine plastics found wide use in such applications as dinnerware and decorative overlays (because of its wide range of colors). Both melamine and urea compounds have high solvent and scratch resistance. Melamine is the hardest of all the plastics. When compounded with glass-fiber fillers, they can be used for high-shock, electrical arc applications. The urea compounds are available in an unlimited color selection and provide good dielectric strength, and strong resistance to solvents, greases and abrasion. Urea materials are employed extensively in lighting fixtures because of their heat and static resistance. The areas are also employed in foundry sand cores and for cold-setting adhesives. Urea and melamine resins are both applied to increasing the wet burst and tensile strength of paper board. When urea and melamine are prepared with the alkyd resins, they produce fine baking enamels. The urea-alkyd enamels are generally employed as finishes for appliances such as refrigerators or washers, whereas the melamine alkyds are used as outdoor metal finishes.

Polyesters—Saturated and unsaturated polyesters and alkyds are members of a class of plastics formed from reactions between alcohols and acids. When the saturated polyesters are combined with isocyanates, they produce polyester urethanes. The unsaturated polyesters are cured in the presence of a catalyst. These compounds find their greatest use in the reinforced fiberglass field. Usually, premixed compounds made from chopped glass fibers are compounded with the unsaturated polyester resin, a dye and a catalyst and then applied to the conventional compression and transfer molding process. The resins must be maintained at a low temperature or used shortly after the catalyst (hardener) has been added.

Silicone Plastics—Silicone plastics are organosilicon oxide polymers, that is, they are in a class somewhere in between the organic plastics and sand. They are considered molding products for high-temperature applications. Silicone plastics show a high degree of resistance to water, lubricants, coatings and high-temperature corrosive fluids. These materials are used extensively in the reinforced plastics field.

Epoxy Plastics—Epoxy resins were first introduced in 1947. Properties of these plastics include excellent adhesion, toughness, chemical resistance and high bonding strength. In addition, they display excellent electrical properties. A hardening or curing agent, usually an amine, acid, acid anhydride or dicyandiamide, is mixed in with the resin at the time of use to establish the desired curing time. These resins display freedom from reaction by-products or volatiles during hardening. This allows the making of relatively large castings.

Epoxy resins can be used as coatings to provide protection against chemical attack and corrosion. In addition, these coatings provide good waterproofing, wear resistance and abrasion resistance. The epoxy-bonded glass molding materials are used for making high-strength, high-electrical insulation pipe fittings and auto components. In the fiberglass reinforced field, epoxy resins produce extremely high strength materials. A typical application would be high-strength vessels and tanks.

Cold-Mold Plastics-These materials entered the market in 1909. They are fashioned into the final product in a mold and cured after removal from the mold. Cold-mold plastics are largely applied to high-temperature and flame-resistant applications that cannot be handled by the organic compounds. The products are specifically used as electrical switch parts, which are subjected to open flame or arc when breaking the circuit. Battery boxes, cooking-utensil handles and wire connectors are other examples.

There are two groups of cold-mold plastics, organic or nonrefractory, and inorganic or refractory. The organic compounds are general-purpose plastics. They are capable of withstanding temperatures up to 260°C. Typical chemical makeup for the binders of these reinforced plastics include raw linseed oil, East India copal gum flour, manganese linoleate drier, stearine pitch and linseed oil fatty acid. A typical filler mixture compounded with the binder consists of vinyl asbestos, sulfur, carbon black and kerosene.

Curing times for molded parts is a lengthy process. Small pieces must be cured by baking in an oven for more than a day; larger pieces require longer periods. Baking temperatures start around 150°-200°F increasing by 10°/hr intervals until an upper limit of 400°F is achieved. This upper temperature limit is maintained until the desired hardness is attained. Molded parts from these materials are subject to shrinking and warping. Pieces requiring close tolerances are usually allowed to air dry for three or four days and then are steam–oven baked at around 200°F, for a period of seven to ten days before undergoing the regular baking operation.

Inorganic, cold–molded products have high heat resistances (up to 1300°F). In addition, they are excellent electrical resistors. Cement, asbestos fibers, colloidal kaolin clay and water are the chief constituents in these materials. Molded pieces are usually air–dried for three or four hours to prevent swelling during the principal curing step. After air–drying they are treated in a fog oven overnight and then immersed in hot water for another 24 hours. The final curing stage involves baking for roughly 14 hours at temperatures from 250°–500°F.

Table 1–4 lists properties of a number of thermosetting materials.

Thermoplastic–Thermosets

Thermoplastic–thermosets are a group of plastics that have characteristics of both thermoplastics and thermosets. Thermoplastic materials derive their properties from molecular arrangements having a linear macromolecular structure. As such, they melt at elevated temperatures. They can be processed in molten form by various techniques the most widely used being extrusion and injection molding. After cooling, thermoplastics appear to take on a glass–like structure; however, these materials will undergo plastic flow to some extent when subjected to an external stress.

Thermoset materials derive their characteristics from a molecular arrangement that consists of a network structure of varying degrees of cross–link density with irreversible primary bonds. At elevated temperatures, thermoset compounds decompose. Finished products do not show any cold flow behavior when subjected to high stresses. These materials are characterized by high elongations and low moduli and, as such, have reversible elastic behavior. A class of thermosets that widely differs from the properties described is the elastomeric polymers. These materials are characterized by low elongations but have relatively high compressive strengths.

Thermoplastic–thermoset (T–T) materials combine some of the processing advantages of thermoplastics and the elastic properties of thermosets. At high temperatures, T–T molecular network structures undergo reversible dissociation, producing linear macromolecules displaying thermoplastic behavior.

Table 1–4: Properties of Thermosetting Plastics

Resin Material	Specific Gravity	Tensile Strength (psi x 10^3)	Compressive Strength (psi x 10^3)	Continuous °F Heat Distortion	Thermal Expansion (cm/°C x 10^{-5})	Thermal Conductivity (cal/sec/cm²/°C/cm x 10^{-4})	Volume Resistivity (Ω - cm)	Dielectric Constant (60 cycles)	Power Factor (60 cycles)	Water Absorption over 24 hrs (%)
Alkyd Glass-Filled General Purpose	1.93-2.32	5-9	21-29	300	5.1-12.7	10-15	1 x 10^{15}	6.7	0.01-0.02	0.07-0.2
Alkyd Mineral	2.17-2.24	3-8	16-20	275-400	5.1-12.7	15-25	10^{12}-10^{14}	5.7-6.3	0.030-0.045	0.05-0.12
DAP Glass MIL-M-19833 GDI-30	1.57-1.86	7.0-9.5	24-45	365-465	6.9-8.9	6-8	10^{12}	4.5	0.010-0.017	0.05-0.25
DAP Mineral (MDG) MIL-1-14F, MIL - P-4389	1.58-1.74	5.5-6.5	22-25	350-440	8.9-10.7	13.7	10^{13}+	5.2	0.06-0.40	0.2-0.5
DAP Unfilled	1.27	4	22-24	350	---	------	2 x 10^{16}	3.6	0.008	0.09
Epoxy Glass	1.8	11.5	30-38	300-500	2.7-3.0	8.5	3.8 x 10^{15}	---	0.015	0.03-0.05
Epoxy Mineral	1.60-1.52	5-10	25-35	210	5.1-14.5	7.0-10.1	0.8-2 x 10^{12}	7.9-9.5	0.03-0.08	0.1-0.6
Melamine Cellulose										
Melamine Cellulose	1.47-1.52	5-10	25-35	210	5.1-14.5	7.0-10.1	0.8-2 x 10^{12}	7.9-9.5	0.03-0.08	0.1-0.6
Melamine Cloth	1.40-1.50	7-10	30-35	250	6.4-7.6	10.6	1-3 x 10^{11}	8.1-12.6	0.1-0.34	0.3-0.6
Melamine Glass MMI 30	1.9-2.0	6-10	20-32	300-400	3.0-5.1	11.5	2 x 10^{11}	9.7-11.1	0.14-0.23	0.09-0.60

(continued)

Table 1–4: (continued)

Resin Material	Specific Gravity	Tensile Strength (psi x 10^3)	Compressive Strength (psi x 10^3)	Continuous °F Heat Distortion	Thermal Expansion (cm/°C x 10^{-5})	Thermal Conductivity (cal/sec/cm^2/°C/cm x 10^{-4})	Volume Resistivity (Ω · cm)	Dielectric Constant (60 cycles)	Power Factor (60 cycles)	Water Absorption over 24 hrs (%)
Phenolic Cloth CFI-10	1.36-1.40	6.5-7.0	20-25	275	5.1-7.6	9.3	5-8 x 10^{11}	6.1-21.2	0.16-0.64	0.8-1.0
Phenolic Cloth CFI-20	1.37-1.40	6.5-7.5	22-25	340	3.8-7.6	7.0	6 x 10^{10}	5.2-2.1	0.64	0.9-1.0
Phenolic Glass	1.70-1.90	7-11	14-35	335-450	2.0-4.1	9.7	1 x 10^{12}	5.6-7.2	0.02-0.05	0.5-1.0
Phenolic GP	1.34-1.46	6-9	25-35	300	7.6-11.4	4-8	2 x 10^{11}	5-10	0.05-0.5	0.2-1.0
Phenolic GPI-100	1.69	7.5-16.8	27-40	---	---	1-10	---	---	---	0.03-0.20
Phenolic MFE	1.70-1.85	9.2	32	---	2.8-4.6	10-14	---	---	---	0.03
Phenolic Mineral MFG	1.72-1.86	4-7	17.5-20	325-425	3.8-6.4	8-16	10^{12}	40-60	0.10-0.40	0.12-0.40
Phenolic Mineral MFH	1.6-2.0	5-8	25-35	400-450	3.8-5.1	8-16	10^{12}	8-15	0.08-0.20	0.07-0.20
Phenolic Mineral MFI-20	1.76	8.7	23-34.5	475	3.8	14	1.6 x 10^{10}	45	0.28	0.04-0.40
Phenolic Nylon	1.22	8	24	275	19.0	7.5-18	10^{12}	4	0.02	0.20
Phenolic Rubber/Flour	1.29-1.32	4	16-18	275	3.8-10.2	5.0	3.4 x 10^9	9	0.14	1.4-2.0
Urea Cellulose	1.47-1.52	5-10	25-38	170	6.9	7.0-10.1	0.5-5 x 10^{11}	7.0-9.5	0.035-0.040	0.5-0.7
Silicone Glass	1.88	4-8	10-13	450-700	2.0	7.5	3 x 10^{14}	4.35	0.003-0.02	0.10-0.30
Silicone Mineral	1.85-2.82	2.5-4.4	11-18	400-700+	6.4-15.2	4.0-10.0	10^{14}	3.4-4.5	0.002-0.01	0.05-0.22

After curing, the polymer's molecular arrangement takes the form of the network structure again and thermoset properties are retained.

Like thermoplastics, this class of polymers can be processed in short cycles; however, the forming cycle can be carried out at relatively low temperatures and pressures. The final product will have properties similar to typical thermoset materials. Thermoplastic–thermoset materials can be produced from a large number of different polymers including the ionomers, styrene–butadiene elastomers and a number of the polyurethanes.

Polyurethanes that fall into the T–T category are produced by the Reaction–Injection–Molding technique whereby the material is injected into a mold in a manner similar to the standard injection–molding method. The former approach, however, requires much lower pressures and temperatures only slightly above ambient. Little pressure is required as fluids handled are usually of low viscosity. It should be pointed out that sometimes reactants contain inert blowing agents that are used to reduce the overall density of the finished product. This can create slight pressures in the mold due to gas expansion if the reaction is exothermic. For most reactions, however, this pressure in only on the order of 2–5 lb/in^2. Consequently, high clamping pressures required for injection molding are not necessary.

Polyurethanes produced by this method are principally used as structural foams (densities range from 8–50 lb/ft^3). These materials are characterized by high compressive strengths, extreme toughness, good abrasion resistance and good flexibility at low temperatures. In addition, they show good resistance to hydrocarbon fuels. These properties can be obtained over a wide range of hardness. Table 1–5 summarizes some of the general properties of polyurethane foams produced by Reaction–Injection–Molding.

It should be noted that the properties of polyurethane structural foams vary greatly and, as such, Table 1–5 only gives a rough indication of their characteristics. Foams range from very tough, resilient, blown elastomers to highly rigid structural foams. Sandwich structures are also used widely. These products have solid facings that are chemically identical to the foam which they bound. This prevents any corrosion, stress concentration at the solid surfaces (or skins) and delamination from occurring. The actual properties of a specific foam depends on the application and, as such, the manufacturer should be consulted for specific details. As might be expected, strength properties are highly dependent on the foam's density.

Table 1–5: Average Properties of Polyurethane Foams

Property	Semi–Flexible Foam	Rigid Foams
Tensile Strength, psi	350–850	250–2,500
Elongation,	150–250	5–20
Compression Strength at Yield,psi	----	200–5,000
Impact Strength, ft–lb/in.	----	0.2–0.5
Density, lb/ft^3	40–50	10–40

The T–T materials vary greatly in properties. Information on specific products can be found in the literature and from manufacturers. In general, materials may range from highly elastic polymers to very rigid, depending on the particular need. Table 1–6 lists a number of common applications of T–T materials along with their competitors.

Table 1–6: Common Applications of Thermoplastic–Thermoset Materials

T-T Materials	Applications	Main Competitor
Ionomers	Refrigerator parts and other low-temperature appliances; automobile parts (because of resistance to petroleum products); specialty packaging items (*e.g.*, film).	Polyethylene, PVC
Styrene-Butadiene Elastomers	Shoe soles and heels; swim fins and masks; gaskets, pipe seals; grommets and bumpers; available in sheet form for various uses; pharmaceutical and food packaging.	PVC, thermoplastics
Polyurethane Plastics	Auto front end seals; permanently greased ball joints; oil-resistant O-rings and gaskets; flexible couplings; parts on textile equipment; drive chains and belts; drive wheels on snowmobiles; shoe soles; toplifts; extruded tubing and cable jacketing.	Steel, specialty rubbers, thermoplastics
Medium-Density, Semiflexible Foams (8-20 lb/ft^3)	Decorative items; safety padding on instrument panels; steering columns; sun visors; arm rests.	Thermoplastics, low-cost engineering materials
High-Density Foams	Front and rear collapsible bumpers; shock absorbers; engine mounts; elements in spring systems.	Thermoplastics, low-cost engineering materials

Industrial Plasticizers—A plasticizer is a high–boiling organic solvent or a low–melting solid which is added to a rigid material to impart flexibility. Most synthetic resins are useless without the addition of plasticizers to their composition. Without plasticizers, resins cannot be molded, case formed or worked. Usually, one or more plasticizers are added to a resin to take on processability. The modification of resin materials with plasticizers is referred to as plasticization. A plasticizers performance characteristics must be evaluated carefully before adding to a resin.

The principal ingredients in salable plastic products are resin and plasticizer. Combinations of plasticizers and resins can produce an almost unlimited number of compounds with a range of properties such as stone–like hardness, transparency, and rubber–like elasticity, as a few examples.

When plasticizers are selected for a particular resin mix, the following factors are considered:

1. Compatibility–The chemist must determine whether a plasticizer and resin will form a chemical union in solution rather than a physical mixture. This means that the optimum mixture ratio should also be determined. A plasticizer's compatibility with a resin depends on the polarity, structural configuration and size of the molecule.
2. Permanence–The permanence or how long a plasticizer will remain bound to a resin must be known. It must be known whether the plasticizer will remain in the resin permanently, escape as a volatile, ooze out, migrate or extract out and under what conditions? A plasticizer's permanence is an essential property. If it is lost out of solution, the plastic's flexibility will decrease, resulting in shrinkage. A plasticizer's permanence is governed by various physical properties including low volatility, resistance to migration, heat, light and solvents.
3. Performance–A plasticizer's performance is rigorously tested by a variety of testing methods. To achieve a good plastic to meet a specific application, it is essential to know the limitations of resin and plasticizer.

The ultimate choice of a specific plasticizer for a resin is determined by what is desired in the form of hardness, tensile strength, tear strength abrasion resistance, flame resistance, color and odor. Good resin–plasti–

cizer combinations show stability and resistance to weathering. A gel usually forms in thermosetting resins when contact is made with solids, liquids or weak solvents. Cured thermosetting resins are highly stable because of three-dimensional bonds that form a network pattern, making the material nearly insoluble.

Thermoplastics are permanently soluble and, as such, the resin-plasticizer combination usually does not stand up well to weathering or corrosive environments. The molecular structure is essentially linear. Solvents tend to act as infiltrates by penetrating the structure and weakening the bonds between plasticizer and resin. Gradual disintegration takes place as further penetration by infiltrates occurs, resulting in a final solution.

One of the earliest industrial plasticizers was camphor. When combined with nitrocellulose, the first industrial plastic material, celluloid, was produced.

The term plastisol refers to a dispersion of a resin in a plasticizer. As an example, a vinyl plastisol is a uniform dispersion of a vinyl resin in an appropriate plasticizer. When this liquid mixture is heated above 300°F, the vinyl resin dissolves in the plasticizer, resulting in a solid solution. This solidified plastisol changes to a tough, plastic material that is characterized by its outstanding chemical and abrasion resistance.

Most plasticizers at room temperature exert little solvency on resin, which means that the viscosity of the solution increases only slightly with time. When the plastisol is heated above a certain temperature, viscosity increases dramatically and a gel is formed, at which point the mixture stops flowing. The time and temperature required to form the gel depend on both the particular plasticizer and polymer.

The term organosol refers to a dispersion of a resin in a liquid plastizicer which has been thinned down with a volatile solvent. Prior to the actual fusion, the thinner or solvent is removed.

LAMINATED PLASTICS

Laminated products are prepared from layers of materials bonded together forming a unit body Laminated plastics are produced in large volumes by the industry in the form of laminated sheets, tubes, rods and a multitude of products employing such materials as paper, asbestos, cloth, wood cellulose, glass fabric, etc., bonded together by synthetic resins.

The resins used for laminating plastics are generally applied in the form of a varnish or in a water solution (the most common resins are phenolic, melamine and epoxy). The varnishes are prepared by dissolving the soluble and fusible form of the resin in an alcohol. The varnish is applied to several sheets, which are then pressed together (molding pressures usually between 1,200 and 2,500 psi). This causes the resin to flow and bond the various layers into a composite layer sheet. Once the resin has hardened, the product acquires a dense, strong, tough structure.

Many laminated applications require materials that can be easily and cleanly punched without generating surface cracks. In such cases, impregnating resins are employed These special–purpose varnishes consist of various oil additives that serve as softening or plasticizing agents. These varnishes help produce a sheet that is flexible and soft and which can be fabricated by punching.

Large hydraulic presses provide heat to cure the resins (temperature range around 300°–350°F) and pressures (1200–2500 psi) to bond layers to form finished sheets. Drilled holes are provided on the steel platens between press openings to allow circulation. Pressure applied by the press compresses the filler sheets causing resin to flow uniformly between the layers. During the compression process, the resin cures. Prior to reducing the pressure, the press platens are allowed to cool.

Laminated tubes and rods are manufactured either by a rolling process or a molding method. Rolled tubing is made by first treating the filler material, usually paper, in a resin bath. The treated paper is passed over a heated roll and wound on a steel mandrel of specified diameter, which is centered between three rollers. The purpose of the rollers is to provide pressure as the tube is wrapped. During the rolling process, the resin melts and bonds the paper roll as it covers the mandrel. After the desired number of layers has been applied, the sheathed mandrel is removed from the unit and allowed to cure in an oven tov 18–20 hours at roughly 275°F (this of course varies with the tube wall thickness). After curing, the tube is removed from the mandrel and a cut is usually taken on a lathe and the outer surface is ground to a desired smoothness and diameter in a centerless grinder.

Molded rods and tubes are made by wrapping the treated paper on mandrels and pressing and heating the entire unit in heated molds. Mandrels for molded rods are small in diameter and are removed prior to insertion of the unit in the mold. Final products have greater densities since resins are cured under greater pressures than rolled tubing. The disadvantage of these products is that they have a seam acquired from the closing of the two halves of the mold, which may cause a source of weakness.

There are a variety of filler materials for laminated applications. Rag paper, although one of the most expensive materials, provides the best properties. Surface sheets are usually made from alpha paper, which is produced from purified wood cellulose pulp. This material provides a uniform appearance along with good electrical properties. The least expensive paper material is kraft. Kraft paper can provide good mechanical and electrical properties and has adequate absorbent qualities.

Cloth fillers are also used for molded rods and tubing. They are available in a wide range of weights that can provide various properties to finished products. Cloth materials employed range from 1.5-oz fabric to heavy-duty 40-oz canvas.

For applications requiring temperature-resistant properties, asbestos paper or glass fabric is used as filler material. Glass fabrics are woven from fine filaments of glass and can provide properties such as high resistance to impact, moisture and heat.

Finished laminated sheets are comprised of an inner core of sheets with surface layers of higher quality and colorability. Sheets with high resin content generally produce a harder, higher quality product; as such, the top or surface sheets are usually made from purified wood cellulose with a high resin content. The surface sheets are generally treated on one side only. Table 1-7 lists some average properties of various phenolic laminated paper sheets. Table 1-8 lists properties of other standard laminated sheets.

REINFORCED PLASTICS

Reinforced plastics comprise a large portion of the industry, with fiberglass-reinforced materials playing perhaps the largest role. Before fiberglass-reinforced plastics (FRP) are discussed, a brief introduction to reinforced plastic materials is in order.

Reinforced plastics are generally similar to laminates in a number of applications. Basically, they differ in that the use of resins does not require high molding pressures as prescribed for laminates. Reinforced materials are referred to as composite or filled plastics. Filler materials or reinforcements can be glass, boron, graphite, carbon beryllia fibers, asbestos, alumina fibers, woven and unwoven textiles, sisal, wood flour and others. Fillers can be applied as a powder, pellet form in the shape of spheres or needles, granular form or can be fibrous in shape.

Table 1–7: Properties of Phenolic Resin, Laminated Paper Sheets

Grade	Properties and Applications	Color	Federal Specification	Specification Type
X	Good mechanical properties	Nat	X	I
XX	Excellent electrical properties	Nat Black	X XX	I I
XXX	Humidity control properties/used for minimum flow applications	Nat Black	XXX XXX	I I
XP	Punching applications	Nat Black Chocolate	P P P	I I I
XPC (XP-701)	Cold punching and shearing applications	Nat Black Chocolate	PC PC PC	I I I
XXP	Hot punching applications/electrical properties better than XX	Nat Black	XXP XXP	I I
XXXP (Hot punch) XXXP (Cold punch) FR-2 (XXXP-770)	Electrical properties better than XXX/ flame resistant	Nat	XXXP	I

The purpose of fillers is to enhance and or provide various properties to the plastics to which they are applied. They can reduce cost, provide body, minimize curing time, minimize shrinkage, improve thermal endurance, provide additional strength and mechanical properties and enhance electrical and chemical characteristics. Table 1–9 lists a number of different fillers and the properties they can provide to plastics.

There are a number of different resins employed with reinforced plastics. The primary ones include polyester, epoxy, phenolic and silicone. Polyesters are the leading resins used, primarily because they are comparatively low in cost and readily molded at moderate to low temperatures. A number of the polyesters are fire retardant. They are mainly used with fibrous glass for numerous applications such as airplane parts, building panels, electrical and motor components, automobile parts and ducting, to name a few. Low–pressure molding procedures employ a catalyst that must be mixed with a resin monomer and the filler at the time of molding.

Table 1–8: Properties of Standard Laminated Sheets

Base Material	Resin	Grade	Properties and Applications	Color	Federal Specification	Specification Type
Paper	Epoxy	FR-3(EXXXP-810)	Flame resistant	---	---	---
Paper	Epoxy	FR-3(EXXXP-845)	Flame-resistant/cold-punching grade	---	---	---
Cotton Fabric	Phenolic	CE	Better toughness properties than paper-base grades	Nat	CE	II
				Black	CE	---
Cotton Fabric	Phenolic	CG	Heavyweight cotton fabric base for heavy-duty gears	Nat	C	II
Cotton Fine Weave	Phenolic	LE	Electrical properties better than CE/ excellent moisture resistance	Nat	LE	II
				Black	LE	II
Cotton	Phenolic	LG	Fine-weave cotton fabric base used for small gears	Nat	L	II
Cotton Fabric	Melamine	MC (MCE-494)	Caustic and arc resistant	Nat	---	---
Asbestos Paper	Phenolic	A	Heat resistant	Nat	A	II
Asbestos Fabric	Phenolic	AA	Tougher than grade A	Nat	AA	II
Continuous Filament Glass Cloth	Phenolic	G-3	Excellent electrical properties when dry/ good mechanical and stability properties	Nat	G-3	IV
Continuous Filament Glass Cloth	Melamine	G-5-847	Excellent mechanicaml strength/flame, heat and arc resistant	Nat	G-5	IV
Continuous Filament Glass Cloth	Epoxy	G-10-773 FR-4(G-10-839 and G-10-852)	Excellent mechanical and electrical properties/flame retardant/low moisture adsorption	Nat	---	---

Table 1-9: Various Fillers and Property Contributions to Plastics

Filler Material	Chemical Resistance	Heat Resistance	Electrical Insulation	Impact Strength	Tensile Strength	Dimensional Stability	Stiffness	Hardness	Electrical Conductivity	Thermal Conductivity	Moisture Resistance	Handleability
Alumina Powder									X	X		
Alumina Trihydrate			X				X				X	X
Asbestos	X	X	X	X		X	X	X				
Bronze							X	X	X	X		
Calcium Carbonate		X				X	X	X				X
Calcium Silicate		X				X	X	X				
Carbon Black		X				X	X		X	X		X
Carbon Fiber									X	X		
Cellulose				X	X	X	X	X				
Alpha Cellulose			X		X	X						
Coal (Powdered)	X										X	
Cotton (Chopped fibers)			X	X	X	X	X	X				
Fibrous Glass	X	X	X	X	X	X	X	X			X	
Graphite	X				X	X	X	X	X	X		
Jute				X			X					
Kaolin	X	X				X	X	X			X	X
Mica	X	X	X			X	X	X			X	
Molybdenum Disulphide							X	X			X	X
Nylon (Chopped fibers)	X	X	X	X	X	X	X	X				X
Orlon	X	X	X	X	X	X	X	X		X	X	
Rayon			X	X	X	X	X	X				
Silica, Amorphour			X								X	X
TFE-Fluorocarbon						X	X	X				
Talc	X	X	X			X	X	X			X	X
Wood Flour			X		X	X						

The catalyst promotes hardening of the mixture without the need of external pressure. Pressure can be applied to improve density, speed up curing and achieve desired surface textures. The mixing of the catalyst and resin generates an exothermic reaction, which converts the resin and filler into a hard integral mass. Under normal conditions, the chemical reaction will take place without releasing volatile substances. Figure 1–1 illustrates the general procedure for manufacturing a reinforced molded material.

Phenolic resins are used to provide high mechanical strength. They also provide excellent high–temperature resistance and can produce a reinforced product that is a good thermal and electrical insulator. In addition, products are resistant to chemical attack. Phenolics can be combined with glass fillers to provide exceptionally high–strength materials.

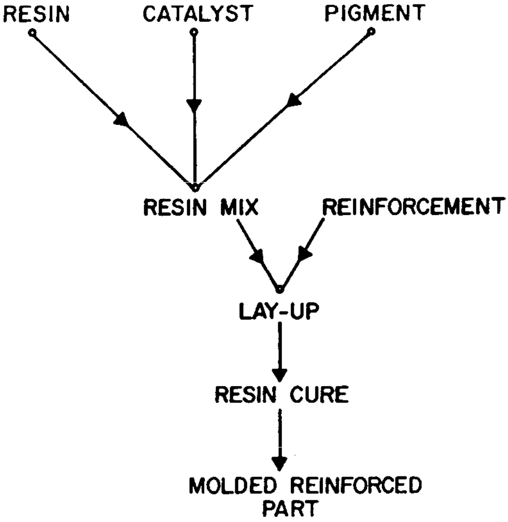


Figure 1–1: General procedure for the manufacture of reinforced plastic parts.

Epoxy resins give reinforced plastics high mechanical and fatigue strength, excellent dimensional stability and provide corrosion resistance, good electrical properties and low water absorption characteristics. Printed circuits, for example, usually employ epoxy–glass or epoxy–paper mixtures.

Silicone resins provide the highest electrical properties of all the filler resin combinations. Products have high thermal stability, retaining their mechanical and electrical properties under long exposures in temperatures ranging from 500°–1000°F. These high temperature products use asbestos or high–silica glass fillers.

Melamine resins are used widely because of their availability in a wide range of colors. They have good color retention, are abrasion resistant and can provide such properties as resistance to alkalis and flames. In addition, they have good electrical properties. Melamine resins are used widely with rayon paper for dinnerware, wall tiles, decorative counter tops, wall panels and furniture. When combined with glass they provide industrial laminates.

Table 1–10 lists some general properties of various reinforced plastics.

Table 1–10: Properties of Reinforced Plastics

Resin	Filler	Tensile Strength (psi x 10^3)	Compressive Strength (psi x 10^3)	Heat Resistance to Continuous Exposure (°F)	Specific Gravity
Epoxy	Glass cloth	20-60	50-70	330-500	1.9-2.0
	Glass mat	14-30	30-38	330-500	1.8-2.0
	Paper	10-19	20-28	260-300	1.4-1.5
Phenolic	Glass Cloth	40-60	35-40	350-500	1.8-2.0
	Glass mat	5-20	17-26	350-500	1.7-1.9
	Asbestos	40-65	45-55	350-600	1.7-1.9
	Paper	8-20	20-40	225-250	1.3-1.4
	Cotton cloth	7-16	30-44	225-250	1.3-1.4
	Nylon cloth	5-10	28-36	150-165	1.1-1.2
Polyester	Glass cloth	30-70	20-50	300-350	1.5-2.1
	Glass mat	20-25	15-50	300-350	1.3-2.3
	Asbestos	30-60	30-50	300-450	1.6-1.9
	Paper	6-14	20-25	220-250	1.2-1.5
	Cotton cloth	7-9	23-24	230-250	1.2-1.4
Silicone	Asbestos cloth	10-25	40-50	450-730	1.7-1.8
	Glass cloth	10-35	25-46	400-700	1.6-1.9

INTRODUCTION TO FIBERGLASS REINFORCED PLASTICS

FRP comprise a special group of the reinforced plastics. These materials are a combination of flexible strands of fibrous glass and a plastic. The plastics normally employed are the thermosetting materials.

Glass can be prepared in a variety of forms including bi-directional fabrics, unidirectional fabrics, mats, yarns, continuous strands, chopped strands, etc. The properties of the final product can be predetermined by the proper combination of thermosetting plastics and glass filler forms.

FRP products are used in applications requiring high mechanical strengths but with lightweight requirements. Combining fiberglass with plastics increases the materials' physical strength, stiffness, impact resistance and dimensional stability, and increases its use over wider temperature ranges. In general, the degree of property improvement increases with the volume of glass used as filler (Figure 1-2). The specific arrangement of a particular geometry of glass filler will determine which properties will improve. For example, glass strands can be placed directionally in the mixture to resist specific loads or they may be arranged randomly to provide uniform strength properties in all directions.

There is a wide variety of thermosetting resins that are employed with fiberglass. Some of these already discussed include phenolics, epoxies, melamines and silicones. In addition, a number of the thermoplastics such as polystyrene, polyvinyl chloride and the polyesters can be combined with fiberglass.

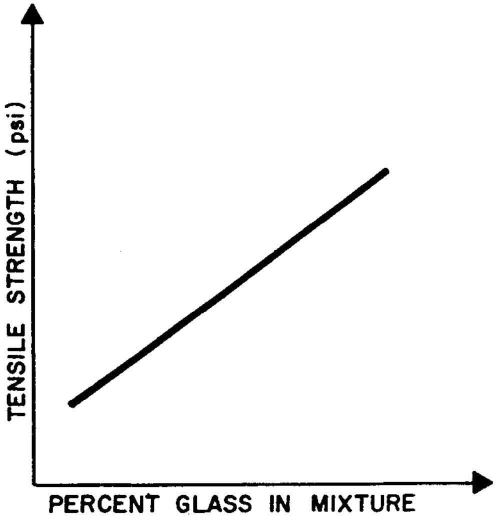


Figure 1-2: In general, the properties of a plastic will increase proportionally to the amount of glass reinforcement added.

The specific gravity of FRP is roughly one–fifth that of steel and, as such, its use covers a wide range of applications when light weight is important. FRP products have strengths that are competitive with many structural materials. Depending on the amount of glass reinforcement used and its particular geometry and arrangement in the resin mix, strengths can range from roughly half to several times those of structural steel.

Polyester–fiberglass combinations, the most widely used, have exceptional strength properties at relatively low temperatures. In fact, they actually become stronger under extremely cold conditions. When combined with special resins, polyester reinforced fiberglass parts can function in temperatures exceeding 400°F.

Polyester resins are clear, usually with a light straw color. Pigments and dyes can be added for desired colors. These resins have excellent resistance to many mild acids, alkalies and various chemicals. As such, they are well suited for many industrial applications (e.g., chemical tanks and pipelines). The polyesters provide excellent electrical insulating properties and, when combined with fiberglass, provide good thermal and shock resistance.

FRP parts have a large number of other excellent characteristics. Various FRP combinations have coefficients of thermal expansion similar to aluminum and steel. The amount of glass in the mixture plays a large role in this property. Low thermal expansion qualities are extremely important in applications involving attaching of parts to metals (an significant differences in the coefficient of thermal expansion would cause high stresses during temperature changes). FRP materials show good dimensional stability. They will not expand or contract greatly over wide variations in moisture and absorb only a fraction of a percent of moisture.

FRP have good processability properties and can be shaped or molded into extremely complex and intricate shapes.

Molded parts can be repaired readily with little effort. There are basically four types of damages that can be experienced with FRP components: cracks or fractures, delamination (usually occurs in fabric laminates), demolished sections that must be entirely replaced and small holes. Experience has shown that most repair work required is localized and usually no elaborate equipment or procedure is necessary for restoration.

Small cracks or fractures can usually be repaired with a mixture of catalyzed resin and chopped strands of glass. Inorganic fillers can also be mixed in to provide a putty–like consistency for application purposes. Pigments or dyes may also be added for color matching. Small holes can be filled with a piece of fiberglass fabric cut to size and impregnated with resin. For added strength, additional ply is applied to both sides of the damaged area.

Direct impact on FRP components can sometimes cause delamination without any surface rupture. For minor damage, repairs can be effected by drilling small holes in the material and loading them with catalyzed resin. The resin should be forced evenly through the holes to cover the delaminated regions. For large areas of delamination, it is often necessary to cut out the entire damaged portion and repair it as if it were a hole.

It is often advisable to provide some pressure and heat to effect curing. Room temperature cures are most common in many household repair operations; however, the use of an infrared lamp can significantly increase curing times. A wide range of cure rates can be achieved by the use of the proper catalyst.

Intricate parts that have been damaged may require some elaborate and careful repairs. For example, for components bonded to metal parts, care must be taken in selecting the proper resin and in matching wall thicknesses. Usually this application requires the use of epoxy resins. Tailored fits may be necessary to effect various types of repairs.

Although FRP products can be colored with dyes and pigments, they have the advantage over many thermosetting plastics that they can be painted as well. Either air–drying paints or enamels requiring baking can be applied. The part must first, however, be primed and degreased, usually in a solvent bath. The surface is then prepared by sanding and thoroughly cleaned again. A surface coat or primer is normally baked on. Surface roughness can be removed by further sanding with fine sandpaper, and, after cleaning, one or more coats of paint can be applied. It should be noted that special care must be taken in preparing the surface. Pits, cracks, ripples, etc. can cause blistering and poor paint adhesion. Surface defects should be repaired prior to painting, as they will entrap paint solvents.

FRP molding can be accomplished without high temperatures and pressures. As such, extremely large and intricate parts can be fashioned in single units on relatively simple equipment. Low molding pressures make it possible for low–cost molds to be used. Molds can be constructed from a variety of inexpensive materials because of the low molding pressure requirements. Plaster molds are normally used for four or five moldings. Wood, aluminum or zinc alloy, iron or steel molds can be used for mass production.

There is a variety of molding processes for FRP. The most widely used are:

- Contact molding
- Vacuum bag molding
- Pressure bag
- Flexible plunger molding
- Vacuum injection
- Matched dye
- Compression molding
- Transfer
- Injection molding

Contact Molding

Contact molding (Figure 1–3) employs one of the least expensive types of molds. Layers of reinforcing media are applied to the mold by hand. Resin is either sprayed or brushed on after each layer is positioned. The mats or cloths are applied until a desired thickness is achieved. The layup usually cures at room temperature; however, heat may be applied to accelerate curing. A smooth surface may be achieved by placing cellophane over the exposed side. For plaster molds, cellophane may also be applied to the mold surface; this will ensure easy removal of the hardened component.

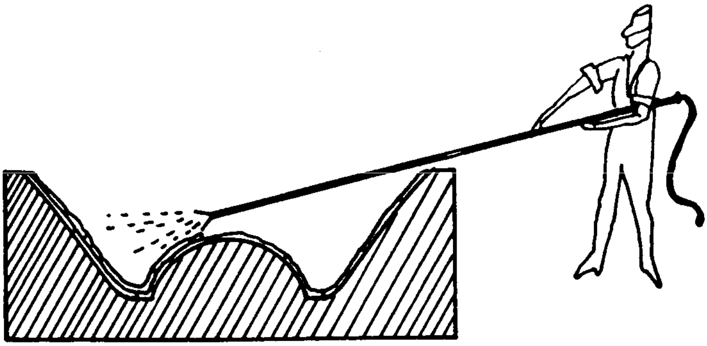


Figure 1–3: Contact molding in which resin is allowed to dry in air.

Vacuum Bag Molding

Vacuum bag molding (Figure 1–4) is a similar technique; however, when the layup is completed, a flexible sheet (usually cellophane or polyvinyl acetate) is placed over the lay–up. Joints and seams are sealed and a vacuum is drawn between the mold surface and the bag's inner wall. The vacuum causes the bag to collapse over the face of the product not contacting the mold. The resultant pressure tends to eliminate voids and forces out any excess resin or entrapped air.

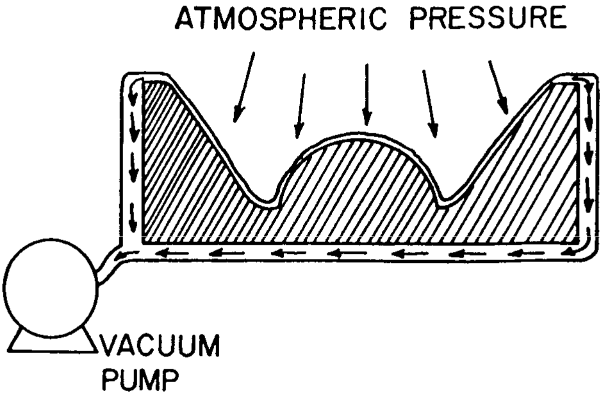


Figure 1–4: Vacuum bag molding.

Pressure Bag Molding

Pressure bag molding (Figure 1–5a) is essentially the reverse of the process just described. A tailored rubber sheeting is usually used as the bag. The sheeting is normally placed over the exposed face of the product and a seal or pressure plate is secured over the top of the mold. Air or steam pressure as high as 50 psi is applied between the exposed lay–up surface and the bag.

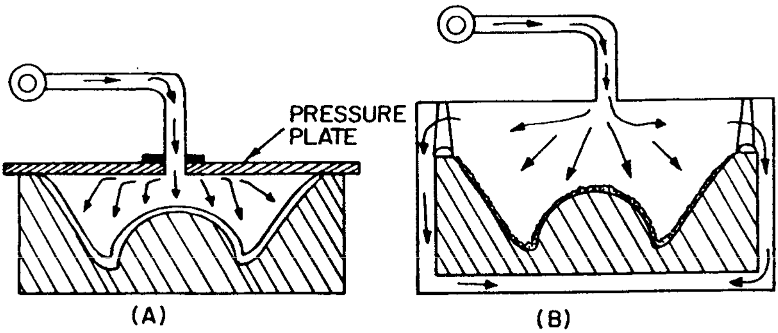


Figure 1–5: (A) Pressure bag molding; B) Autoclave.

A modification of the pressure bag molding method is shown in Figure 1–5b, in which the entire unit is placed in a steam autoclave. Here, applied pressures rang from 50–100 psi. The latter of the two approaches is preferred as it allows maximum loading with glass and produces the greatest product density.

Flexible Plunger Molder

This employs a cavity mold with a plug unit. In this method, fiber–glass and resin are deposited in a heated cavity. The plug unit, usually made of hard rubber, is fashioned in the approximate shape of the piece to be molded. The plug or plunger literally stamps out the mixture into the mold. The plunger or rubber plug provides uniform high pressures; however, the method is not practiced for large moldings because of pressure and mechanical limitations of the flexible plunger.

Vacuum Injection Molding

This method employs two molds. The layup is made between the two molds, and resin is poured into a moat around the bottom. A vacuum is applied whereby resin is drawn up through the reinforcement material. Glass contents are normally low with this operation; however, it tends to eliminate many air pockets.

Matched Dye Molding

Matched dye molding usually employs two metal molds having closefitting tolerances. The molds are heated either electrically or by steam. The molds have close–fitting, telescoping areas to seal in resin and trim the glass reinforcement. This method is employed only on a large – scale production basis.

Compression Molding

This procedure consists basically of two molds having close–fitting tolerances. The molds are designed to provide sufficient loading space above the cavity or mold detail so that the unmolded thermosetting material can be contained. Closing the mold forces the charge into the cavity. These molds are designed for minimum material loss resulting from a portion of the charge being pushed out of the cavity as overflow during closing. Figure 1–6 illustrates the technique. Compression molding is most often done on hydraulic presses operated by water, oil or air pressure. In these large units, the molding compound is compressed and transformed to a fluid state in the mold cavity.

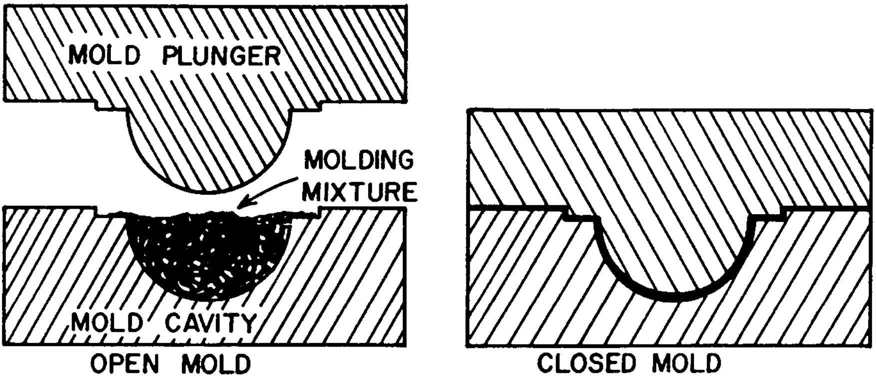


Figure 1–6: Illustrates the compression molding method.

Transfer Molding

Transfer molding is often done in compression presses with integral–type molds. The molding material is charged to the mold cavity in a fluid state. As the name implies, a transfer plunger forces the plasticized compound into the cavities. The design is equipped with a transfer tube, which accepts the preheated charge before the plunger is lowered into the tube.

Injection Molding

These techniques introduce the molding compound to the mold cavity in a fluid state. The material solidifies in the cavity and is removed after curing. The method can be practiced either by hand, by which one charge at a time can be melted in a furnace or oven, or be performed automatically on specially designed machines. Material quantities to be injected into the mold per cycle are measured on a volume or a weight basis. Machines are equipped with separate feed systems and various adjustments to compensate for variables in each cycle. The key step in this operation is the loading. The feed system must be designed properly and adjusted very carefully during startup. If insufficient plasticizing material is charged, unfilled regions will develop in the mold cavities producing a low–density product with poor characteristics. Too much charge will cause the mold to open slightly and cause overflow and flashing of material. Overfill can also cause pieces to adhere to the mold and break during the ejection step. There is a variety of feed systems available.

CHAPTER 2

RESINS AND PROPERTIES

FRP RESINS

Some of the properties of fiberglass reinforced plastics (FRP) have been discussed already. The use of a specific resin will determine which properties are the strongest and the range of conditions over which the final product can be used.

Some of the resins used in FRP combinations were listed in Chapter 1. They are commercially available in a variety of forms, as powders, flakes, granules, water solutions, water emulsions and latexes, solutions in organic solvents and in liquid form covering a wide range of viscosities.

Properties of resins vary greatly and determine the conditions under which fabricating or molding a particular mixture can be done. For example, many resins generate volatiles during curing. As such, high molding pressures are necessary to prevent by–products from forming gas pockets in the product. Similarly, high–viscosity resins also require high pressures for molding to ensure thorough filling of the mold cavity. Low–viscosity resins can often be molded at room temperature and pressure and provide no by–product formation.

Resins that can be used at low pressures are most often preferred for FRP molding. Molding equipment at low pres–sure is less costly and simpler in design. In addition, high molding pressure operations tend to reduce FRP product properties and high pressures tend to crush the fiberglass. A brief description of resins follows.

Epoxy Resins

Epoxy resins traditionally are made by reacting epichlorohydrin with bis-phenol A, which are linear polymers that cross-link, forming thermosetting resins basically by the reaction with amine-type compounds. They have low polymerization shrinkages, excellent mechanical strength, good electrical properties and are chemical resistant.

The primary disadvantages of the epoxy resins is that they require long curing times and, in general, their mold release characteristics are poor. However, they are superior to polyester resins in three areas:

1. They have excellent resistance to chemical attack.
2. They have very low water absorption characteristics.
3. They have low cure shrinkage.

The epoxies are relatively viscous liquids in their thermoplastic state. When cured, these resins are up to seven times more durable and tougher than cured phenolic resins. The relative toughness of the epoxies is attributed to the distance between cross-linking locations and the presence of integral aliphatic chains.

The epoxy resins are characterized by their high adhesive strengths. This property is attributed to the polarity of aliphatic hydroxyl groups and ether groups that exist in both the initial thermoplastic resin and cured system. The polarity associated with these groups promotes electromagnetic bonding forces between epoxy molecules and the substrate.

Epoxy resins are cured by means of a curing agent. No volatile by-products are generated during the curing process. Curing agents are referred to as catalysts, hardeners or activators, and although the terms are often used interchangeably, there are differences. In general, some ring agents will facilitate curing via catalytic action, whereas others will participate in a reaction with the resin an become absorbed into the resin chain. The curing process can take place at conditions of room temperature, with the addition of heat or under the influence of an exothermic reaction, depending on the specific agent employed.

The pure epoxy resins (without agents) have an almost indefinite shelf life. They are chemically stable up to about 400°F. During curing, epoxy resins can undergo three basic reactions:

1. Epoxy groups are rearranged and form direct linkages between themselves.
2. Aromatic and aliphatic hydroxyls link up to the epoxy groups.
3. Cross-linking takes place with the curing agent through various radical groups.

In reaction 1, curing is affected by the polymerization of the epoxy groups. For commercial-grade epoxy resins, the reactivity is promoted by an ether linkage. Available ions, active hydrogens and/or tertiary amines may be responsible for opening the epoxy groups. With tertiary amine cures, the ideal epoxy-epoxy polymerization occurs as illustrated in Figure 2-1.

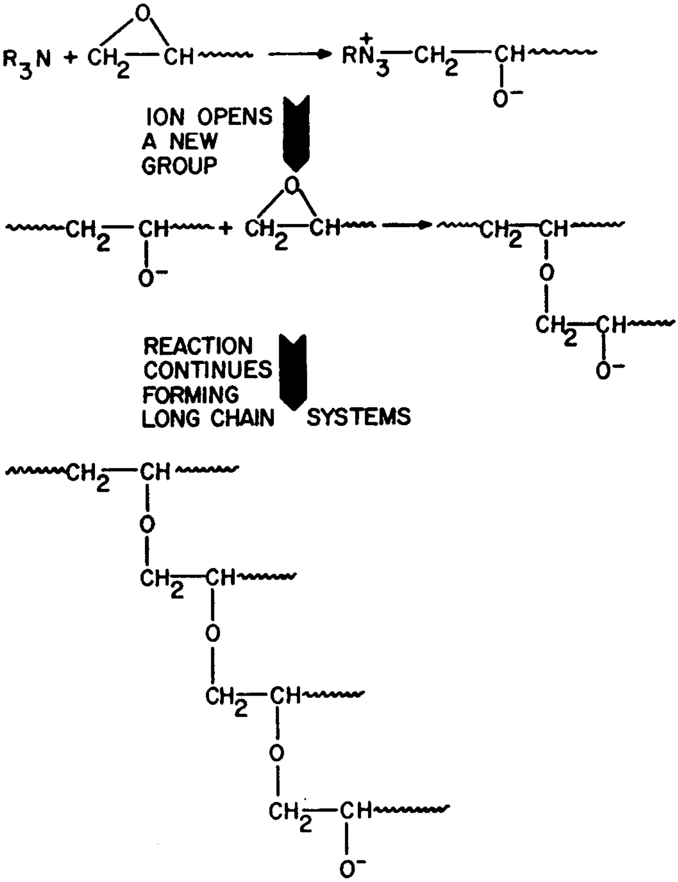


Figure 2-1: Illustrates the basic scheme behind epoxy-epoxy polymerization. In an actual system, the curing reaction occurs between a large number of molecules, resulting in a cross-linking, complex three-dimensional network.

Epoxy groups will also cure in the presence of hydroxyl groups that are mixed into the resin with the curing agent. This also is a cross-linking reaction which is generally promoted in the presence of an acid or base catalyst. For epoxy–hydroxyl reactions, the inorganic bases (for example sodium hydroxide or the tertiary amines) are used. This is essentially an ionic reaction.

Reactive intermediates (cross–linking agents) that combine with the resin chains are also used in curing. Primary cross–linking agents for the epoxies are polyfunctional primary amines (RNH_2), secondary amines (R_2NH), dibasic acids and acid anhydrides. Polyfunctional phenols (examples are bisphenol A and resorcinol) are also used as cross–linking agents but more often in conjunction with other curing agents.

Organic acids are primarily employed in the esterification of higher – molecular–weight resins in surface–coating formulations; however, the anhydrides of organic acids are used as curing agents for liquid epoxies.

High–temperature cured epoxies show much better performance than the room–temperature–cured epoxies. They are somewhat less resistant than the polyesters to the wide range of corrosive, chemicals but show better resistance on the alkaline side. Various epoxy resins provide outstanding service in chemical process equipment under severe conditions.

Resins of this type generally require elevated–temperature post–cures. This is common practice in manufacturing of piping, tanks and structures made from epoxy resins. This type of resin is more costly, and the manufacturing process is considerably slower. The epoxies are usually combined with filament winding to produce extremely strong products. Reinforced epoxies are generally used in piping systems and tanks.

Piping systems in reinforced epoxy are widely used.

Melamine Resins

These are condensation thermosetting resins produced by a condensation reaction between formaldehyde and melamine. Handling characteristics are not unlike many of the phenolics. High pressures are required for molding as they generate volatile by–products during curing. Their primary application with FRP combinations is as electrical insulators. In general, they are more expensive than polyesters and phenolic resins. An additional disadvantage is that they must be preloaded for use. Besides having excellent electrical properties, they are good thermal insulators and are fire retardant. They have good colorability properties and are among the leading resins in hardness and abrasion resistance. In addition, they can withstand high impact strength.

The name melamines refers to the melamine–formaldehyde resins, belonging to the amino resins family. Melamine itself [$C_3N_3(NH_2)_3$] is a white crystalline material. This group of resins is cured with various acid catalysts or by heat alone, depending on the specific composition of formaldehyde and melamine present. Because of the excellent properties of these resins, they are employed in numerous industrial laminates, primarily for electrical applications. The laminating resins are normally available in the form of spray-dried powders.

Phenolic Resins

Among the most widely used thermosetting resins, these are produced from the reaction of phenol and formaldehyde. The phenol–formaldehyde resins comprise the most important single subgroup of the phenolics. Other resins classified as phenolics are phenol–furfural and resorcinol–formaldehyde. The phenol resins are commercially available as a water solution, as a solution in an organic solvent or in powder form. Alcohol solutions of the powder or granular resin are known as varnishes. Their color properties are limited, ranging from dark amber to black.

Traditionally, the phenols were derived from coal tar. They are manufactured either by the sulfonation process, chlorobenzene process via liquid phase or by the regenerative process (catalytic vapor phase).

Formaldehyde (HCHO), a colorless gas, is soluble in water, alcohol and ether. When phenol and formaldehyde are combined in the presence of a catalyst, phenolic resins are produced by a condensation reaction. (A condensation reaction is a reaction in which two or more molecules combine with the separation of water or other substance. For plastic resins in general, condensation reaction refers to the formation of a synthetic resin via the elimination of water, ammonia or hydrogen chloride to combine molecules into a macromolecular structure of high molecular weight.)

As discussed earlier, curing is carried out in three phases. The first step is referred to as the A–stage or resole stage; the second is the B–stage or resitol stage; and the third is the C–stage or resite stage. During the first stage, the resin becomes fusible and soluble. Heat must generally be supplied to initiate the second step, in which the resin is transformed into a fusible solid having low solubility. The reaction that takes place is a condensation polymerization that generates by–products. Further heat drives the curing operation to the third stage in which the resin hardens and becomes insoluble. At this point, the resin takes on the chemical resistant properties and becomes infusible. Molding operations usually require very high pressures to suppress volatiles. Resin properties are modified by the kettle cycle time, type catalyst used, concentrations, the use of plasticizers, pigments, lubricants and filler quantity.

Their properties include good resistance to chemicals and, in particular, many acids, good electrical properties, excellent thermal resistance and good mechanical strength. The general purpose phenolics are less expensive than the polyesters. In addition, they have higher temperature endpoints than the polyesters so that they retain a higher fraction of their original strength after long-term exposure to high temperatures. When properly formulated, their flame resistance surpasses the polyesters. Phenolics can be cured via heat and pressure, without the use of catalysts or curing agents.

Disadvantages of these resins include high curing pressures, longer curing times than polyesters, and short shelf life (shelf life is roughly 90 days in liquid state). In addition, they have the property of extreme brittleness and the use of plasticizers usually results in a degradation of cured properties. Their limited color range is another major drawback.

Polyesters and Vinyl Esters

General Purpose Polyester Resins The upper temperature limit is generally considered to be 50°C (120°F) and then only to a very limited amount of corrosive media, although the general purpose resins perform well in water and seawater.

Isophthalic Polyester Resins have an upper temperature limitation of about 70°C (150°F) and are useful in a much wider area than the general purpose resins, and water mildly corrosive conditions. They can usually be used with salts, mild acids, waters of various kinds, gasoline, and petroleum distillates.

High-Performance Polyester Resins are generally of the bisphenol type or chlorinated polyesters. They have an upper wet limit of 120°C (250°F) and a dry limitation of 150°C (300°F) and are resistant to a wide range of oxidizing acids (up to 70% H_2SO_4 salts) and have shown a wide application in the chemical industry. The polyesters are generally resistant to attack from saturated hydrocarbon molecules but are much less resistant to unsaturated hydrocarbons and are particularly vulnerable to solvents such as carbon disulfide.

Vinyl Esters in general, are only slightly less corrosion resistant than the bisphenol resins, but with bleaching compounds such as chlorine, sodium hypochlorite, hypochlorous acid, and chlorine dioxide they offer better resistance than the bisphenol polyesters or chlorinated polyesters. Modifications of the vinyl ester molecule have produced higher temperature performance resin systems which will go up to 140°C (280°F) in continuous service.

General Purpose Polyester resins are normally not recommended for use in chemical process equipment. Their use in the finished fabrication represents a potential savings of 10 to 20%. Only users can make the ultimate decision regarding the premium they are willing to pay for chemical resistance. These resins are generally adequate for use with nonoxidizing mineral acids and corrosives that are relatively mild. This resin predominates in boat building, its resistance to water of all types, including seawater, being excellent. Test work has indicated satisfactory uses up to 52°C (125°F) with the following materials:

Acids

- 10% Acetic acid
- Citric acid
- Fatty acids
- 1% Lactic acid
- Oleic acid
- Benzoic acid
- Boric acid

Salts

- Aluminum sulfate
- Ammonium chloride
- 10% ammonium sulfate
- Calcium chloride (saturated)
- Calcium sulfate
- Copper sulfate (saturated)
- Ferric chloride
- Ferric nitrate
- Ferric sulfate
- Ferrous chloride
- Magnesium chloride
- Magnesium sulfate
- Nickel chloride
- Nickel nitrate
- Nickel sulfate
- Potassium chloride
- Potassium sulfate
- 10% Sodium chloride

General purpose resins have been found to be unsatisfactory in the following:

Oxidizing acids
Alkaline solutions, such as calcium hydroxide, sodium hydroxide, and sodium carbonate
Bleach solutions, such as 5% sodium hypochlorite
Solvents, including carbon disulfide, carbon tetrachloride, gasoline, and distilled water

Where the use of general purpose resin is contemplated, an environmental test program should be inaugurated to determine if the resin will be satisfactory. All contemplated applications above 52°C (125°F) should receive rigorous testing.

Isophthalic Polyesters

Isophthalic polyesters offer better chemical resistance than the general purpose resins in certain application areas, at a slightly higher cost. They show much better resistance to attack to solvents, and are used extensively in the manufacture of underground gasoline tanks, where a satisfactory service life in the storage of gasoline and under the varied conditions of ground–soil corrosion are successfully met. The following general usage of the isophthalic resins is given as a guide in applications up to 54°C (150°F).

Acids
- 10% acetic acid
- Benzoic acid
- Boric acid
- Citric acid
- Fatty acids
- Oleic acid
- 25% Phosphoric acid
- Tartaric acid
- 10% Sulfuric acid
- 25% Sulfuric acid

Salts
- Aluminum sulfate
- 10% Ammonium carbonate
- Ammonium chloride
- Ammonium nitrate
- Ammonium sulfate
- Barium chloride
- Calcium chloride (saturated)
- Copper chloride
- Copper sulfate
- Iron salts
- 5% Hydrogen peroxide
- Magnesium salts
- Nickel salts
- Sodium and potassium salts that do not have a strong alkaline reaction
- Dilute bleach solutions

Solvents
- Amyl alcohol
- Ethylene glycol
- Formaldehyde
- Gasoline
- Kerosene
- Naphtha

Isophthalic resins are unsatisfactory for:

- Acetone
- Amyl acetate
- Benzene
- Carbon disulfide
- Solutions of alkaline salts of potassium and sodium
- Hot distilled water
- Higher concentrations of oxidizing acids

High–Performance Polyester Resins

Furane and polyester composites are another group. Furanes will not support combustion and have a tunnel test rating of less than 20; and are rated as nonflammable. These materials weigh approximately one–fifth that of conventional iron or steel fitting and thermal conductivity is slightly higher than for the polyesters.

Furane–lined piping, tanks, and reinforced–plastic (RP) structures are widely available from fabricators. An advantage of furanes is their resistance to solvents, including acetone, ethyl alcohol, benzene, carbon tetrachloride, carbon disulfide, chloroform, the fatty acids, methyl ethyl ketone, toluene, and xylene, many of which cannot be used with polyester or epoxy resins.

The furanes excel in solvent resistance. With some areas they are not as good as the high–chemical–resistance polyesters. These include wet and dry chlorine gas; chromic acid plating solutions; hypochlorous acid; some of the nitrate solutions, such as lead, nickel, and zinc; and brine solutions saturated with chlorine, sodium hypochlorite solutions, or trichloracetic acid.

Furane–lined RP structures have a very broad spectrum of corrosion resistance in both acids and alkalis. The furanes themselves do not possess the rugged physical strength of a glass–reinforced structure, although corrosion–resistant piping in low–pressure supply and drain line work may be purchased built completely from a furane resin. Using the furane as the inner lining of a composite structure, with the fibrous glass polyester overlay either laid up by hand or filament wound, effectively combines the best qualities of both systems in many applications.

Furane tanks up to 30,000 gal, duct work to 24 in., piping, and equipment are available to meet difficult corrosive conditions involving organic solvents coupled with oxidizing chemicals. Flame spread ratings meet the fire retardant classification and low smoke evolvement competes with the best polyesters (about 400). Furane costs run 15 to 35% higher than those for the best polyesters. Accelerated heat–curing techniques for the furanes reduce curing times considerably, but they are still longer than the polyesters. High–temperature performance [92°C (200°F)] with the furanes is favorable, with case histories showing 10 years of service in 5% H_2SO_4.

Vinyl Ester Resins

Vinyl ester resins possess good resistance to corrosion by a wide range of different chemicals, both acid and alkali, at room and elevated temperatures. Some commercial vinyl esters possess two double bonds and others possess three double bonds. With minor additions of elastomers their percent elongation can be altered and may vary in elongation range 2 to 8%. This is critical in the field of cyclic temperature and pressure operation and with additions of various abrasion-enhancing additives becomes important in increasing the abrasion resistance of laminated structures. Depending on the formulation, these may or may not interfere with the chemical resistance of the laminate. These resin systems use catalyst and promoter systems similar to those used with the polyesters. They show excellent resistance to severe oxidizing environments and generally exhibit better resistance than polyester and epoxies in applications such as bleach, chlorine, chlorine dioxide, chlorine-caustic systems, and calcium and sodium hypochlorite. In some areas they also show better solvent resistance, but not as good as that of the furanes. Physical properties are in general very similar to those of the polyesters. Formulations varieties of the vinyl esters have been developed so that these are capable of operating at relatively high temperatures and available in addition to fire-retardant grades.

Carbon-to-carbon double-bond linkages occur both in vinyl ester and polyester molecules. Unreactive double bonds are subject to chemical attack through oxidation and halogenation. In vinyl esters the double bonds are generally at the end of the molecule and give a more chemically resistant structure. For solvent attack the closer the double bond is to the carbon atoms, the greater the attack. The vinyl ester molecule furthers reactions with hydroxyl groups on the surface of glass fibers and gives excellent wet out and good adhesion, which is shown high strengths obtainable with vinyl ester resins.

Furanes

Furanes are much more difficult to fabricate, for example, than the polyesters because their setting depends on a condensation reaction rather than the rapid polymerization that occurs with polyesters. The curing of furanes, with the liberation of water, is a self-limiting reaction which if pushed too rapidly generally results in severe internal stress and ultimate cracking of the plastic structure. However, furanes do show remarkable solvent resistance that are better than the polyesters. They have an upside temperature limitation of 205°C (400°F) in continuous operation, which makes them useful in specific applications. With the furane molecule it is possible to fabricate difficult systems that will meet the National Fire Protection Association (NFPA) standards, with a fire spread rating of 25 or less and a smoke rating of 50 or less. They typically carry about a 30% premium in price over polyesters.

Polyester Resins

The development of the unsaturated polyester resins and their use with fiberglass came about the 1940s. Shortly before World War II, maleic anhydride became commercially available. During the war, mass production of inexpensive styrene became available. Glass fibers in woven cloth form appeared at this time. The combination of these materials producing the first FRP product resulted from the need for a strong plastic material to serve as windows for radar vanes. Hence, in 1944 unsaturated polyester resins and glass reinforcement opened up a new field in the plastics industry.

Polyesters traditionally have been the most widely used resins for FRP combinations. The chemistry of polyesters is rather complex. Basically, when an organic acid and an alcohol are reacted, they produce an ester. When the alcohol is polyhydric and the acid is polybasic, complex esters known as alkyds are formed. Alkyds have long been used in surface coating chemistry because of their toughness and chemical resistance. If either the alcohol or acid has an unsaturated carbon bond, the alkyds or polyesters formed will react with other unsaturated compounds (such as styrene). This further reaction causes the different polyester molecules to interconnect, forming three–dimensional cross–linked units, which is the basic structure of the thermosetting resins. (To review, an alcohol containing more than one hydroxyl group is a polyhydric alcohol; dihydric alcohols are those having two hydroxyl groups. A dibasic acid is an acid having two hydrogen atoms that can be replaced with hydroxyl groups. A polybasic acid has two such hydrogen atoms.)

The most common dihydric acids employed in the production of polyesters are the glycols of ethylene (glycols are synthetic compounds intermediate between glycerins and alcohols), propylene, butylene, diethylene and dipropylene. Common dibasic acids used include maleic anhydride or fumaric acid.

A two–stage reaction occurs in the manufacture of polyester resins from the dibasic acids. The first stage in the reaction of dihydric alcohol with a dibasic acid forms a polymerizable monomer, which is usually styrene, vinyl toluene, ethyl methacrylate, etc. The second–stage is a copolymerization reaction between this monomer and the unsaturated polyester base, usually with heat and in the presence of a catalyst. Curing occurs as an exothermic reaction.

Catalysts used are usually from the organic peroxide group. The particular catalyst used will determine the curing time. Curing times can vary from as little as 15 seconds to one month or more and can range from room temperature cures up to 300°F. Once the polyester has cured, it is a hard, transparent solid with a light color. The polyester has good mechanical and electrical properties and can be either rigid or flexible. They are water and chemical resistant and have good weatherability characteristics.

Polyesters can be readily mixed with pigments and dyes. It should be noted, however, that some pigments tend to inhibit resin cure. When polyesters are mixed with halogenated acids and anhydrides, with antimony trioxide, a flame–resistant resin is formulated. Some types are light stabilized. In general, the flame–resistant formulations have good heat resistance and strength properties.

The general–purpose polyesters are usually in liquid form and, hence, are completely reactive when mixed with the proper amount of catalyst. A key advantage with these resins is that they can be handled easily. They can be brushed, poured or sprayed onto the reinforcement. Additionally, no high–pressure requirements are necessary for molding.

The polyesters exhibit good mechanical and electrical properties. Curing conditions vary greatly; however, most applications can be done under room temperature conditions.

The major drawback with these resins is that they shrink during curing making it difficult to obtain smooth surfaces. Excessive shrinkage can cause poor weathering resistance.

Polycarbonates

The polycarbonate resin system has extremely high impact resistance and good clarity, it is widely used for sight windows in chemical equipment. Polycarbonate is used extensively in the lighting market for lenses on shipboard, in aircraft, etc. Polycarbonate foam has found increased application for machine housings. The use of 10% glass fiber reinforcing results in use as a replacement for sheet metal, with better corrosion resistance.

Silicone Resins

These are the most heat–resistant resins employed in FRP combinations. They are usually available in the form of solutions in organic solvents. Among their advantages are good mechanical and electrical properties and excellent thermal resistance. They retain their properties over wide temperature ranges (up to 100°F+). They do require preloading and give off volatile by-products during curing. High pressures are recommended for molding; however, there are a number of commercial grades available for molding at low pressures.

Silicone resins have been referred to as semiorganic polymers and have been described as a group of compounds halfway between carbon-based plastics and silicon-based stone. The technical term for these resins is organopolysiloxanes (originally called organosilicons). Silicon is quadrivalent, as is carbon, and capable of forming long-chain molecules similar to the carbon-based compounds. With the organic compounds, carbon-carbon bonds form in repetitious patterns whereas the silicone atoms in silicones cross-link to oxygen atoms in an alternating pattern of silicon-oxygensilicon-oxygen atoms. The result of this complex network provides extreme resistance to low and high temperature, resistance to weathering and oxidation, water resistance and superior adhesive properties.

Silicone resins are primarily manufactured by the hydrolysis and condensation of organosilicon halide intermediates by a variety of methods. The most common method is called the direct alkylation process which involves the reaction of CH_2Cl (methyl chloride) with a metallic silicon.

$$2CH_3Cl + Si \rightarrow (CH_3)_2SiCl_2 + CH_3SiCl_3 + (CH_3)_3\,SiCl \qquad (1)$$

The products of Equation 1 are called methychlorosilanes, which are then hydrolyzed via aqueous sodium bicarbonate to form hydroxylmethylsilanes, in accordance with Equation 2:

$$\begin{aligned} \text{Methylchlorosilicanes} \quad & + NaHCO_3(aq.) \rightarrow CH_3Si(OH)_3 \\ & + (CH_3)_2Si(OH)_2 + (CH_3)_3SiOH \qquad (2) \\ & + NaCl + CO_2 \end{aligned}$$

The hydroxylmethylsilicanes are then polymerized at 390°-430°F to form the cured silicone resin.

The silicones are also produced by the Wurtz process and the silicon hydride-hydrocarbon method in which the major products of these reactions are called organochlorosilanes. Table 2-1 summarizes some of the properties of the resins described.

The Barcol Hardness Test is employed as a standard industrial test for indicating the extent of cure. Barcol readings will vary with the resin system. The more resilient resins, for example, will usually produce lower readings. The SPI Department of Commerce Product Standards PS15-69 and ASTM D–3299 recommend that readings of 90% of a manufacturer's recommendation for a particular cast resin should be specified.

Table 2–1: Properties of FR Resins

	Epoxies	Phenolics	Polyesters	Melamines	Silicones
Specific Gravity	1.2	1.2	1.2	1.4	1.3
Colorability	G[a]	P[a]	G+	G+	G
Mechanical Properties	VG[a]	VG	VG	VG	F-G[a]
Electrical Properties	E[a]	G	E	E	E
Thermal Resistance	F	E	G	E	E
Water Resistance	E	VG	VG	F	G+
Flammability	S[a]	X[a]	S	X	N[a]
Molding Pressure	L-M[a]	L-H[a]	L-M	M-H	L-H
By-Product Formation	N	Y[a]	N	Y	Y

[a] E = excellent; F = fair; G = good; H = high; L = low; M = medium; N = none; P = poor; S = slow burning; VG = very good; X = self-extinguishing; Y = yes.

Laminates composed of thixotropic materials generally have readings three to five units higher. When paraffin, synthetic fiber overlays or separate unreinforced gel coats are used (as in tank construction), Barcol units are lowered by three to ten units.

In general, the Barcol test cannot be used to detect air–inhibited surfaces in final layups or laminated articles. In these cases, the Acetone Sensitivity Test should be used. This method involves the application of a trace amount of resin over the cured resin surface. The surface should be wetted slightly with a swab or finger and rubbed until the acetone is completely evaporated. If the surface softens or appears tacky, the resin has not properly cured.

Thermoplastic Resins

Thermoplastic resins are not extensively used with FRP combinations; however, their importance is expected to increase because of their corrosion–resistance properties. This group includes the polycarbonates, nylons, polyethylenes, polypropylenes and polystyrenes. The thermoplastics are basically straight–chain polymers. As such, they have a lower level of heat and solvent resistance than do the thermosetting resins, which have a cross–linked, three–dimensional gel structure. During molding, they do not undergo chemical curing as do the resins described above. Fabrication basically consists of applying heat until the substance is soft and formable and can be molded into the desired shape. After cooling, the substance hardens to the final product. Table 2–2 lists some of the chemical resistant properties of the thermoplastic resins.

Table 2–2: Chemical Resistance Properties of the Thermoplastic Resins

Material	Chemical Resistance To: Weak Acids	Strong Acids	Weak Alkalis	Strong Alkalis	Organic Solvents
Nylon	G[a]	N[a]	E[a]	F[a]	G
Polycarbonate	E	G	G	F	N
Polyethylene	E	G	E	E	G
Polyproplyene	E	G	E	E	G
Polystyrene	E	G	G	G	N
Thermoplastic Polyester	F	N	N	N	E

[a] E = excellent; F = fair; G = good; N = not recommended.

Polyethylene (PE)—One of the most widely used thermoplastics is polyethylene. Molecular weights of 120,000 to 220,000 are common. High-density polyethylene (HDPE) has a wide range of chemical resistance to oxidizing chemicals and salts and finds application in continuous service up to 82°C (180°F). Ultraviolet stabilizers are widely used typically carbon black. Polyethylene has good lubricity and has found use in bearings and heavy machinery. The fact the number and variety of different polyethylene compounds offered commercially indicates wide acceptability. As much as one third of the total annual consumption of all plastics is polyethylene. Polyethylene has exceptional abrasion resistance and is used as liners. A higher grade is ultrahigh molecular weight polyethylene, commonly called UHMWPE.

Polyphenylene Sulfide—Polyphenylene sulfide is an economical thermoplastic. It is useful up to temperatures as high; as 230°C (450°F) and as temperature increases, the is a corresponding increase in toughness. Polyphenylene sulfide provides outstanding performance in aqueous inorganic salts and bases, and it is inert to many organic solvents. Use of a glass filler improves physical properties. Use under highly oxidizing conditions, and coatings exhibit good hardness and chemical inertness or resistance.

Polypropylene—Polypropylene is unique in that it is used in all primary fabrication processes molding, extrusion, fibers, and film and competes with metals and natural fibers. It can be reinforced with fiberglass to enhance physical properties, and polypropylene fibers can be used to reinforce polyesters. It has been used as an alternate to rubber in the chemical industry. Use as a composite with a fiberglass overlay for ductwork is another use. Exposed to sunlight, an ultraviolet (UV) absorber should be used to protect the resin from degradation. Thermal oxidation degradation is also a major problem. Polypropylene is not affected by most inorganic chemicals except halogens and severe oxidizing chemicals. Chlorinated hydrocarbons can cause swelling and softening at elevated temperatures. With a fiberglass overlay, resistance up to 150°C (300°F) is possible. Fillers can be used to improve impact resistance and increase stiffness.

Polyvinyl Polymers

PVC is the largest family in this group and can be found in many products, from rigid pipe to film and relatively heavy sheets. Generally, high molecular weight PVC has better physical properties. Like other plastics, additives are used to further specific end uses, such as thermal stabilizers, lubricity, impact modifiers, and pigmentation. PVC can be either rigid or flexible. Both plastisols and organosols can be produced with PVC. Hard films can be produced as thin as 1 mil. PVC is used extensively in chemical piping with a service range of –18° to 60°C (0° to 140°F). The use of PVC above 60°C is not recommended. Polyvinyl dichloride (PVDC) is used extensively in chemical piping systems up to a temperature of 82°C (180°F). One of the problems with PVC is that in fluctuating temperatures there is a tendency for the material to "grow" and not return to its original length when the temperature subsides. This produced growth in pipelines which can be troublesome. Another disadvantage is that under sudden shock the resistance to impact is limited. It has found extensive use in venting systems and gravity lines in corrosive chemicals. It has a wide range of chemical stability and has been successfully overlaid with fiberglass to provide external reinforcing. In prolonged high-temperature use, thermal degradation takes place. Even with a fiberglass backing, PVC, PVDC, and chlorinated PVC (CPVC) are subject to checking, crazing, and cracking which ultimately destroys the structure. In terms of use, it is a very important plastic and is widely used in the building and allied industries, including household appliances.

The alloying of thermoplastic resins often produces better physical qualities than any single system can produce by itself. These include impact resistance, flame retardency, and thermal stability. Alloying is generally done with intensive mixing or screw extruders. ABS and PVC are frequently blended to provide rigidity, toughness, flame retardency, and chemical resistance.

Polycarbonate can be blended with ABS to provide better heat resistance and toughness. Polyurethane improves the abrasion resistance and toughness of ABS, while retaining the advantage of reduced cost. The impact strength of polypropylene is increased by alloying with polyisobutylene. Alloying is generally done on a relatively small scale, varying from as low as 0.01% up to as high as 9%.

FLAME-RETARDANT MATERIALS

In general, for plastics requiring flame or fire resistance, there are a multitude of additives that can be blended physically with the substrate to acquire these properties, such as organic phosphate esters and halogenated hydrocarbons (which includes chlorinated waxes, antimony oxide and various inorganic salts). Modifiers can also provide these qualities. These include HET acid (chlorendic acid), phosphorus and halogen-containing polyols, and halogenated phenols, which are allowed to react and combine chemically with the plastic material.

HET acid is the principal ingredient used for making polyester, flame-retardant resins. The disadvantage of using flame-retardant modifiers (especially forms of HET) is that they tend to promote poor weathering properties. Additional additives such as various ultraviolet light stabilizers must be added to counteract the adverse properties associated with flame-resistant modifiers.

Examples of other flame-retardants are chlorinated phenols, halogenated organic phosphates and the unsaturated organic phosphates. The unsaturated organic phosphates are primarily employed as coatings for plastic articles, paper, specialty wood and in cable lacquers.

The phenolic resins have a relatively high ignition point and, as such, require only small quantities of flame retardants. For many applications, uncontaminated phenolic resins are sufficiently flame retardant.

The epoxies can be made flame retardant by additives, such as tetrabromo-*bis*-phenol A or tetrachlor-*bis*-phenol A, HET anhydride or tetrachlorophthalic anhydride. These additives usually will not alter the resin's electrical or strength properties.

Resin fire retardance is tested by the manufacturer in accordance with ASTM standard methods for testing surface burning characteristics of building materials. Tests evaluate the comparative burning characteristics of the resin by examination of the flame spread over its surface when exposed to fire. The method establishes a basis for which surface burning characteristics of various materials may be compared with that of asbestos–cement board and select–grade red flooring oak. These two cases have been arbitrarily assigned units of 0 and 100, respectively.

FILLERS

Various types of fillers were discussed in Chapter 1. Frequently, these are incorporated (primarily the mineral fillers) with the glass reinforcement. Calcium carbonate and aluminum silicate are often used with polyester–FRP combinations.

Fillers have a tendency to increase resin viscosity. They are generally mixed into the resin with any pigments or catalysts. As a rule of thumb, no more than 40 of the entire mixture should be filler, or properties will be reduced.

The main justification for using fillers is that they reduce materials costs. However, if proper amounts are used, they can reduce curing shrinkage and improve surface appearance. Reducing shrinkage with the aid of fillers can also improve water resistance and weathering properties.

FIBERGLASS ARRANGEMENT AND FORMS

Fibers are prepared from molten glass and transformed into a variety of forms for different uses. Chopped strands are one common form of glass reinforcement. The strands range in length from 1.3–5.1 cm.

Rovings are among the least expensive forms of glass reinforcement. They are groups of continuous strands that have been wound into thread or rope. The number of strands varies; however, 60 `end´ rovings are most common. They can be transformed readily into chopped strand mats.

Woven rovings are fabricated by weaving rovings into a coarse, heavy duty, drapeable fabric. They find greatest use in making thick laminates and are available in a range of weaves and weights.

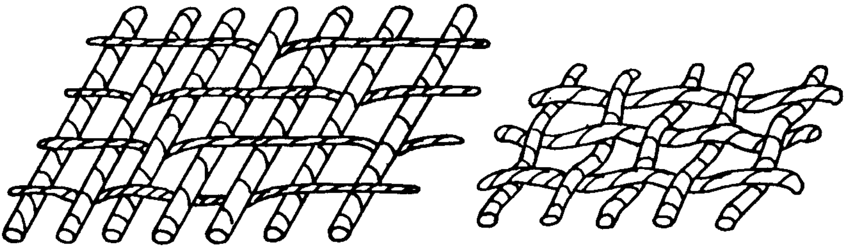
Reinforcing mats are nonwoven mattings that are generally made from randomly arranged chopped strands. Resinous binders are often used to bind strands together into mat form. Other forms are held together by stitching. These forms are available in a wide range of weights. Stitched mats are usually soft and drapeable while the bonded form is stiffer.

Milled fibers are continuous strands that have been hammermilled into nodules of filamentized glass. Fiber lengths range from 0.08–0.10 centimeters.

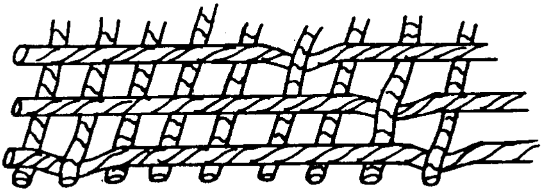
Yarns are another form of fiberglass reinforcement that are used extensively. Yarns usually must go through a surface finishing step, which cleans them and ensures maximum resin–to–glass adhesion.

Overlaying mats are employed when smooth surfaces are required on a molding. Usually, thin mats of staple monofilaments are placed over the main reinforcing media. Mats can range in thickness from 0.25 to 0.76 millimeters. They are usually impregnated with a binder and are given water–repellent qualities.

There are a variety of woven cloths, as shown in Figure 2–2. Woven cloths are available in a wide range of thicknesses, weight, type of weave, filament diameter and type of yarn. The most common are square weaves (plain) and satin weaves. Continuous and staple yarns are employed, with the former preferred because of better strength. There are a number of advantages and disadvantages associated with each type of woven cloth reinforcement. The ultimate choice of a specific fabric will dictate the nature of the surface finish, the economics and ease of fabrication, and the directional strength characteristics of the final product.



UNIDIRECTIONAL WEAVE PLAIN WEAVE



SATIN WEAVE (LONG SHAFT)

Figure 2–2: Different types of fiberglass woven cloth.

As pointed out earlier, the use of glass fibers tends to improve the material's mechanical properties in much the same way that steel rods reinforce concrete. The maximum mechanical properties that can be achieved with fiberglass reinforcement are outlined in Table 2–3.

Table 2–3: Mechanical Properties of Fiberglass

Tensile Strength (psi)	100,000
Young's Modulus (psi)	3,000
Elastic Recovery (%)	10
Specific Strength (km)	76
Coefficient of Expansion ($^{\circ}F^{-1}$)	40- 60 x 10^{-7}
Thermal Conductivity (cal/sec/cm^{2}/$^{\circ}$C)	8 x 10^{-5}
Specific Heat	0.16–0.2
Specific Gravity	2.5+

CHARACTERISTICS AND PROPERTIES OF FRP

FRP has many attractive qualities that make it adaptable to numerous applications. Table 2–4 lists some of the general advantages of FRP products.

Table 2–4: General Advantages of FRP

Corrosion Resistant
High Strength-to-Weight Ratio
Low Thermal Conductivity
Longevity
Adequate Optical Properties
Low Transportation Costs
Low Installation Costs
Low Resistance to Flow
Low Electrical Conductivity
Dimensional Stability
Ease of Installation
Good Energy Savings
Light in Weight

Many of the physical and chemical properties of fiberglass are not unlike those of bulk glass. The mechanical properties are, however, quite different. High mechanical strengths associated with fibrous glass put FRP in the class of structural materials. If comparisons are made on an equal weight basis, fiberglass is one of the strongest structural materials available. Strength properties are proportional to the rate of loading; that is, the faster the loading, the greater the strength.

Table 2–5 shows a comparison between various FRP combinations and steel. An examination of this table reveals that FRP have properties that are competitive with steel.

One of the major concerns in the evaluation of the mechanical properties of a material is whether it displays creeping and fatigue and under what conditions they will occur. Glass fibers do not display creep at room temperature. Fatigue, however, as the term applies to glass, differs from the fatigue that takes place in metals. For metals, the loss in strength takes place because of an internal adjustment to applied loads. This is described as cold working. Fatigue in glass occurs by a loss in strength caused by surface attack from the environment. By providing proper protection to the surface, reduction of strength with time can be reduced. In addition, strength tends to increase at lower temperatures.

In terms of hardness, on the Moh scale, glass lies between 6 and 7. For perspective, talc is rated at 1 and diamonds at about 10.

The modulus of resiliency of glass fibers is roughly 103 times that of bulk glass. (Resilience is defined as the energy stored per unit volume without permanent set.)

Among the various properties listed in Table 2–4, probably one of the most important for structural materials is corrosion resistance or weather–ability. The steel industry alone devotes roughly 40 of its production towards the replacement of corroded materials. If FRP components are properly prepared, fewer replacements are necessary, which has a significant impact on energy savings and manufacturing costs. Weathering resistances of the glass–reinforced polyesters are better than average. During the first several months of exposure to the outdoors, these materials tend to increase in strength due to additional curing of the resin. Ultraviolet light and heat from the sun also promote curing. After prolonged exposure, strength properties gradually diminish as illustrated in Figure 2–3.

Mechanical properties also depend on the materials resistance to heat and chemical attack. Chemical resistance depends largely on the specific resin employed. However, note that fiberglass can be attacked by very strong alkalis and a number of the weaker acids. Water tends to play a large role in FRP strength properties. The glass–reinforced polyesters tend to decrease in strength after prolonged exposure to water. Usually, an asymptotic value of strength is approached when one plots strength vs. immersion time. This value normally occurs around 30 days. Exposure to seawater generally has a smaller strength–diminishing effect.

Table 2–5: Comparison of FRP Mechanical Properties to Steel

	Filament-Wound Epoxy	Rod-Stock Polyester	Molding Compound Phenolic	Spray-Up Polyester	Cold Press Molding Polyester	Preform/Mat (Compression molded)	Low Carbon Steel (Cold rolled)	Stainless Steel
Percent Glass Fiber by Weight	30-80	40-80	5-25	30-50	20-30	25-50	–	–
Flexural Strength, psi x 10^3	100-270	100-180	18-24	16-28	22-37	10-40	28	30-35
Flexural Modulus, psi x 10^6	50-70	40-60	30	10-12	13-19	13-18	300	280
Tensile Strength at Yield, psi x 10^3	80-250	60-180	7-17	9-18	12-20	25-30	29-33	30-35
Compressive Strength, psi x 10^3	45-70	30-70	14-35	15-25	–	15-30	28	30
Ultimate Tensile Elongation, %	1.6-2.8	1.6-2.5	0.25-0.6	1.0-1.2	1-2	1-2	38-39	50-60
Heat Distortion at 264 psi, °F	350-400	325-375	400-500	350-400	350-400	350-400	–	–
Continuous Heat Resistance, °F	500	150-500	325-350	150-350	150-400	150-400	–	–
Thermal Coefficient of Expansion, in./in./°F x 10^6	2-6	3-8	4.5-9.0	12-20	10-18	10-18	6-8	9-10

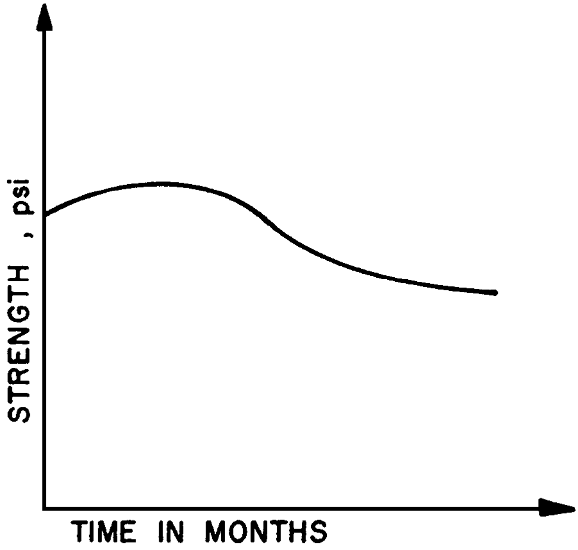


Figure 2–3: Outdoor weathering effects on strength properties.

These general trends will vary depending on the specific resin basis and, as such, FRP manufacturers should be consulted prior to selecting a specific combination.

At low temperatures, FRP becomes stronger and less brittle than at room temperature. The effect of cooling on mechanical properties is due to the characteristics of the glass reinforcement rather than the resins as the latter tend to become brittle. After heating, strength properties decrease as illustrated in Figure 2–4. The thermal properties of FRP are primarily a function of the glass content and orientation in the resin. Thermal coefficients of expansion (Table 2–5) are similar to those of metals. In general, they make good thermal insulators.

The use of various types of fillers can affect mechanical properties. In general, inorganic fillers are not recommended for use with fabric reinforcements; however, they can be used with chopped strand reinforcements such as mats, producing favorable strength properties.

Physical properties and moldability are important factors in determining the optimum filler concentrations that can be used. As a rule of thumb, the maximum filler content that can be employed before strength deteriorates is roughly 40 under normal molding conditions.

For sheets, generally much higher filler contents are acceptable. Concentrations as high as 80b are often acceptable; again, this depends on the specific resin.

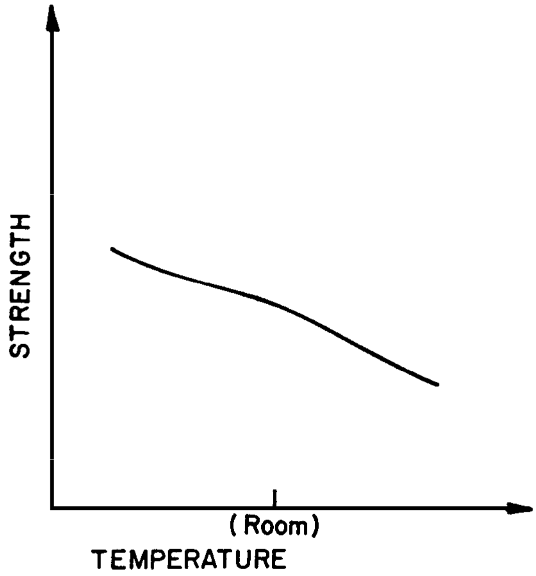


Figure 2-4: Strength varies with temperature.

It should be noted, however, that filler addition significantly raises the viscosity of the resin, which, during fabrication, can tear the reinforcement producing a product with poor mechanical properties Other parameters that determine strength properties in FRP are: reinforcement content, reinforcement orientation and reinforcement fiber lengths.

As stated earlier, the more reinforcement used, the greater the material's strength.

The direction in which the material will exhibit its greatest strength will be determined from the orientation of the fibers. That is, the directional characteristics of a material are derived from the amount of reinforcement arranged in a given direction. Randomly composed chopped strand mats, for example, are nondirectional. For reinforcements arranged in parallel, the material's greatest strength lies in the direction of the glass.

The highest strengths are generally achieved with fiber lengths no less than 1 cm. Shorter strands usually produce lower-strength products.

There are a number of other factors that can determine or affect the mechanical properties of FRP. Many of these are related to fabrication. Table 2-6 summarizes some of these controlling factors.

Table 2-6: Parameters Affecting the Mechanical Properties of FRP

Type Resin
Type Filler
Type Pigment or Dye
Time for Impregnation
Cure Time
Cure Pressure
Glass Content
Resin Content
Nature of Molding Operation
Form of Reinforcement
Type Catalyst System
Orientation of Reinforcement
Fiber Length
Humidity during Impregnation
Cure Temperature
Heat Applied
Filler Content
Mold Cavity Properties
Form of Final Product

INDUSTRIAL APPLICATIONS

FRP materials are attractive for numerous applications because of their design flexibility, high performance characteristics and potential cost- and energy-saving advantages. Figure 2-5 shows a breakdown of industries that utilize reinforced plastics.

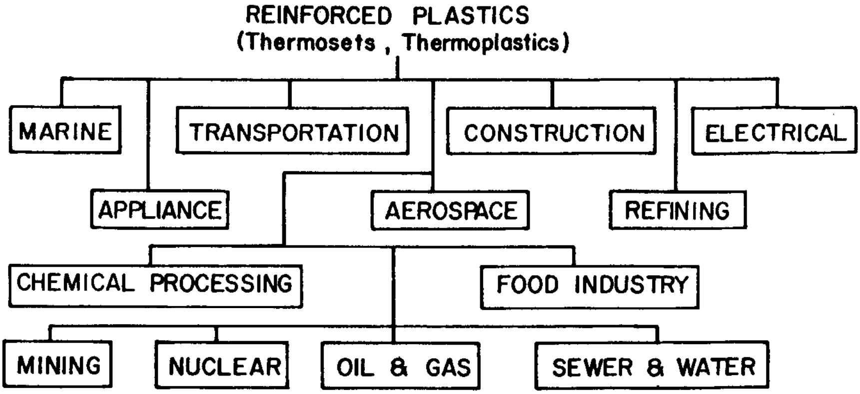


Figure 2–5: Breakdown of industries utilizing reinforced plastics.

At present, approximately 40% of all FRP uses are related to automated, high-volume, closed-mold processes. Roughly half the remainder is tied up in boat construction and structures of larger sizes (generally customized products). Widespread acceptance of FRP sheet molding compound and glass fiber-reinforced thermoplastics by the automobile and equipment manufacturing industries has generated rapid growth in FRP production.

FRP growth is expected to rise sharply over the next decade for two reasons. First, corrosion resistance properties and high strength–to–weight ratios that are achievable in products make FRP competitive with a number of structural materials such as steel, cast iron and aluminum. Second, and most important, FRP products offer significant energy savings. Cumulative energy requirements to manufacture and use FRP materials is significantly less than for steel and aluminum.

Energy costs for a product includes all the energy consumed in manufacturing, transportation, installation, operation, maintenance and fuel value of the product itself. Figure 2–6 compares various energy requirements for different metals and plastics.

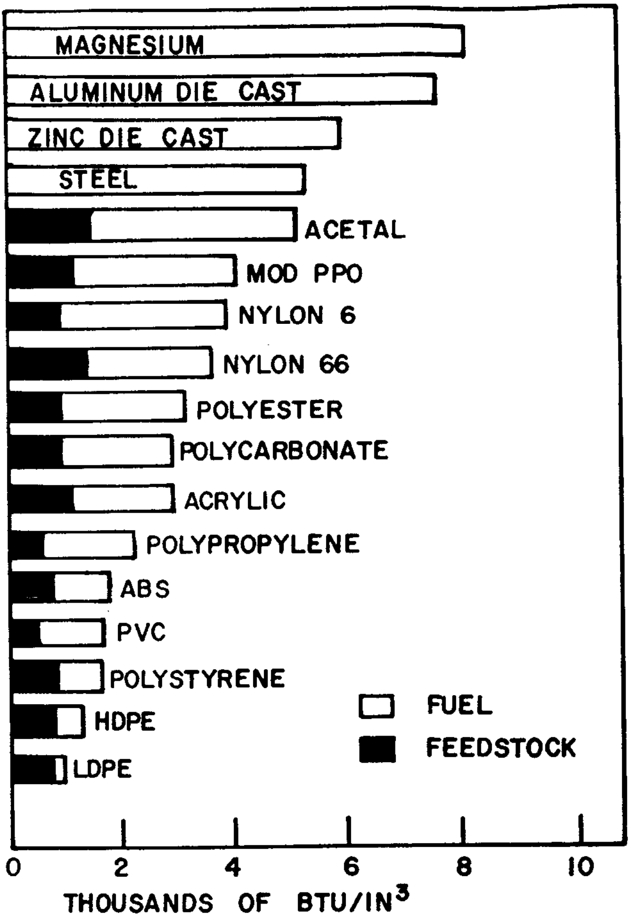


Figure 2–6: Comparison of the energy requirements per unit volume between metals and plastics.

It should be noted that because of the lower densities of FRP compared to metals, considerable savings can be met in transportation costs as well as the energy required to transport materials.

FRP applications in energy–related industries (i.e., oil, gas and nuclear industries) will probably share a good portion of this rising market. At present, these industries have minimal uses. The oil and gas industries primarily employ FRP materials in the areas of transportation, production, distribution and enhanced recovery systems. Specifically, the gas industry employs FRP in low–pressure gas collection lines and in gas distribution and transmission lines. The oil industry uses FRP to a limited extent in applications such as oil field flow lines, in equipment for separating water and heavy crude oil, for underwater fuel storage and transfer.seawater clarification in offshore oil production, petrochemical plant waste treatment systems, and petrochemical plant cooling water systems. The nuclear industry employs FRP in tailing lines from uranium ore milling operations to tailing ponds and for circulating water diffuser discharge pipes, blowdown lines and makeup water lines.

Another area that will play an important role in the FRP market will be the greater use of corrosion–resistant tanks, pipes, structures and various water treatment equipment. FRP are superior to many metals such as steel in implementing modifications during installation and operation. FRP can be cut and fitted much easier than metals. Piping made from FRP for example, has smoother inside wall surfaces than steel or cast iron pipe, which leads to lower friction coefficients and lower pumping energy expenditure.

Because of the numerous properties and advantages that FRP have over many metals, there are a number of potential applications that may readily implement these materials. Table 2–7 lists some of these areas for the oil and gas industries.

Table 2–7: Potential Uses of FRP in Oil and Gas Industries

Drill Sites – Mud Handling Equipment
Offshore Oil Platforms
Brine and Saltwater Lines
Saline/Brine Discharge Lines
Undersea Gathering Lines
Railway Tank Cars
Injection Wells
Field Liquid Storage Vessels
Pipe Linings
Casing Linings
New Gas Pipelines
New Oil Pipelines
Synthetic Fuel Plants
Pipelines for Coal/Oil Slurries

CHAPTER 3

PIPE PRODUCTS AND APPLICATIONS

GENERAL DEFINITIONS

This chapter will serve as a guide to the selection of FRP pipe products for different applications. Wherever possible, data and recommendations supplied by various manufacturers have been included. Guidelines for pipe installation are discussed in a subsequent chapter. Some traditional plastics fabricating techniques have already been discussed. Several other methods and definitions must be introduced before proceeding.

Filament Winding

This FRP fabrication technique is done with continuous lengths of fiberglass yarn or tape, which are wound onto the outside of a steel mandrel. The reinforcement may be saturated either with resin or preimpregnated with partially cured resin. Specially designed machines wind the fiberglass at any specified pitch about mandrels of various cylindrical shapes. Winding is continued until the desired wall thickness is achieved and then additional resin is applied. The resin polymerizes either by an endothermic or an exothermic reaction. By varying the pitch angle and the tension applied to the reinforcement, the mechanical properties of the end product can be changed. Filament winding is used in making high-pressure pipes and small vessels and tanks.

Centrifugal Casting

In this method, chopped glass fibers are mixed in with resin and applied to the inside of a rotating cylindrical mold. As the resin cures, it forms a cylindrically symmetrical pipe. The reinforcing fibers are arranged randomly throughout the wall, and strength properties are isotropic. Centrifugal casting is used in the manufacture of large–diameter pipes, tanks and vessels.

Contact Molding

This method has been described previously. By way of review, fiberglass and resin are applied to the surface of a mold and polymerized. Application may be done by hand, spraying or with an automated system. The method is employed in the manufacture of low–cost, large diameter pipes, vessels and tanks.

Piling Pipe

This is round–welded or seamless pipe that is employed as foundation pipe. The pipe cylinder behaves as a permanent load–carrying unit and is usually filled with concrete to form coast–in–place concrete piles. This type of pipe is employed in buried installations for foundation work by the construction industry for buildings, highways, bridges and docks.

Line Pipe

This is pipe employed in the transportation of gas, oil and water. Pipe diameters range from 118 to 4 in [outside diameter (o.d.)] inclusive. This pipe is fabricated to meet American Petroleum Institute (API) and American Water Works Association (AWWA) specifications whereas piling pipe must meet ASTM specifications.

Mechanical Tubing

This includes welded or seamless tubing fabricated in large sizes ranging from 3/16 to 10¾ in o.d. inclusive for carbon and alloys. Specifications are not tight and only exact outside diameter and decimal wall thickness must be met.

Pressure Tubing

This is employed in conveying fluids at elevated temperatures and/or pressures. It is suitable for head applications and is fabricated to meet exact o.d. and decimal wall thicknesses (sizes range from 0.5 to 6 in o.d. inclusive, at ASTM specifications). Examples of pressure tubing include air heater tubes, boiler tubes, header tubes, heat exchanger and condenser tubes, oil–still tubes, superheater tubes and pressure tubing couplings and coupling stock.

Standard Pipe

This type of piping is employed in low-pressure operations such as transporting air, steam, gas, water, oil, etc. Applications are in machinery, buildings, sprinkling systems, irrigation systems and water wells. This type pipe is capable of transporting fluids at elevated temperatures and pressures that are not subjected to external heat conditions. Diameters and wall thicknesses must meet ASTM specifications (diameters range from 1/8 to 42 in o.d.). Specific examples include ice machine piping, conduit pipe, distributor's pipe, driven well pipe, drive pipe, pressure piping, pump pipe, signal pipe, standard pipe doupling stock, turbine pump pipe, and water and gas service pipe, nipple pipe and pipe for plating or enameling.

Structural Pipe and Tubing

This includes welded or seamless pipe and tubing that is usually employed in structural or aboveground load-bearing operations. The construction industry finds the greatest use in this type of pipe; however, ships, trucks, trailers and farm equipment also use it extensively. It is manufactured in nominal wall thicknesses and sizes according to ASTM specifications in round, square, rectangular and odd cross-sectional shapes.

Pipes manufactured from FRP are available in a wide range of diameters and lengths. In the U.S., inside diameters (i.d.) range from less than 1 in to more than 12 ft FRP pipe diameters from 60 to more than 100 ft have been proposed for ocean thermal energy applications in which excessive volumes of water must be circulated between the surface and the ocean floor. FRP piping is being used for numerous underwater installations.

The most extensively used FRP pipes are fabricated from polyesters, vinyl esters and epyotics for the resin and fiberglass. Maximum operating temperatures are as high as 300°F, depending on the resin used. Operating pressures vary with pipe diameter, wall thickness and the nature of fabrication.

FILAMENT-WOUND PIPE AND MOUNTINGS

Filament-wound pipe is commercially available in a wide range of diameters and wall thicknesses. Table 3-1 lists some of the general properties of large-diameter, filament-wound pipe.

Table 3-1: Nominal Properties of Vinyl Ester, Filament-Wound Pipe (Pipe Diameter = 14 to 62 in; Specific Gravity = 1.86; Coefficient Thermal Expansion = 10.5 x 10^{-6} in/in/°F)

Temperature	Hoop Stress on Reinforced Thickness (psi)	Axial Stress (psi)	Axial Tensile (psi)	Coefficient of Elasticity	Beam Bending Modulus of Elasticity (psi x 10^6)	Beam Bending (psi)	Pipe-Fitting LayUp Joint Shear (psi)
77	50,000	25,000	9,000	2.0	1.0	9,000	600-1,000
150	50,000	25,000	7,000	1.5	0.4	7,000	600-1,000
180	50,000	25,000	5,000	1.2	0.15	5,000	600-1,000
200	40,000	20,000	4,000	0.8	0.04	2,000	600-1,000

Filament–wound pipe and ductwork can be employed in a wide number of high–pressure applications. They are used extensively in chemical processing plant, pulp and paper mills, auto manufacturing plants, food processing facilities, bulk storage and loading complexes, and various conventional and nuclear power generating plants.

FRP is well–suited for many fluid flow applications. Its weight is roughly one–sixth that of steel and one–twelfth that of concrete. It does, however, have the strength of steel with additional beneficial properties. Specifically, these properties include inertness (i.e., FRP pipe will not support combustion, decay or corrode), dimensional stability and flexibility.

FRP piping can be made corrosion resistant to almost every kind of chemical or compound which explains why it received early acceptance in the Chemical Process Industry.

Structurally, FRP piping has exceptional strength–to–weight ratio. Pound for pound fiberglass is stronger than steel; hence, materials have high tensile strength as well as shock and impact resistance.

Pipe and fittings are capable of absorbing more than 40% diametrical deflection without undergoing structural damage, and they will return to their original configuration once the overload has been removed.

In terms of stability, filament–reinforced piping can be used at working temperatures up to around 300°F with a projected service life of 100 years.

Filament–wound fiberglass–reinforced pipe has excellent flow properties. The interior surfaces of piping and components are generally smooth and glass–like. This smooth finish greatly reduces and, in many cases, eliminates material build–up. This, in turn, significantly reduces pumping costs. Figure 3–1 is a flowchart that can be used for rough estimates for large–diameter pipes.

The filament–winding technique provides great strength properties to the pipe. The method employs a high resin–to–glass ratio, usually on the order of 70–85% in the interior surface, which gives the inner pipe wall its glassy–smooth finish with excellent flow characteristics. During manufacturing, a resin–rich glass surfacing mat or veil is first applied to the steel mandrel. Depending on specific corrosion–resistant requirements, the veil is further reinforced with either one or more plies of chopped strand fiberglass mat. The thickness of the inner liner is controlled carefully. Continuous fiberglass filaments are then wound over the cured liner until the desired structural wall thickness is obtained. The outer filament–wound wall generally has a much lower resin content (glass content in the range of 55–65%). The higher glass content provides a much stiffer wall with high strength. Figure 3–2 shows a cutaway view of a filament–wound pipe.

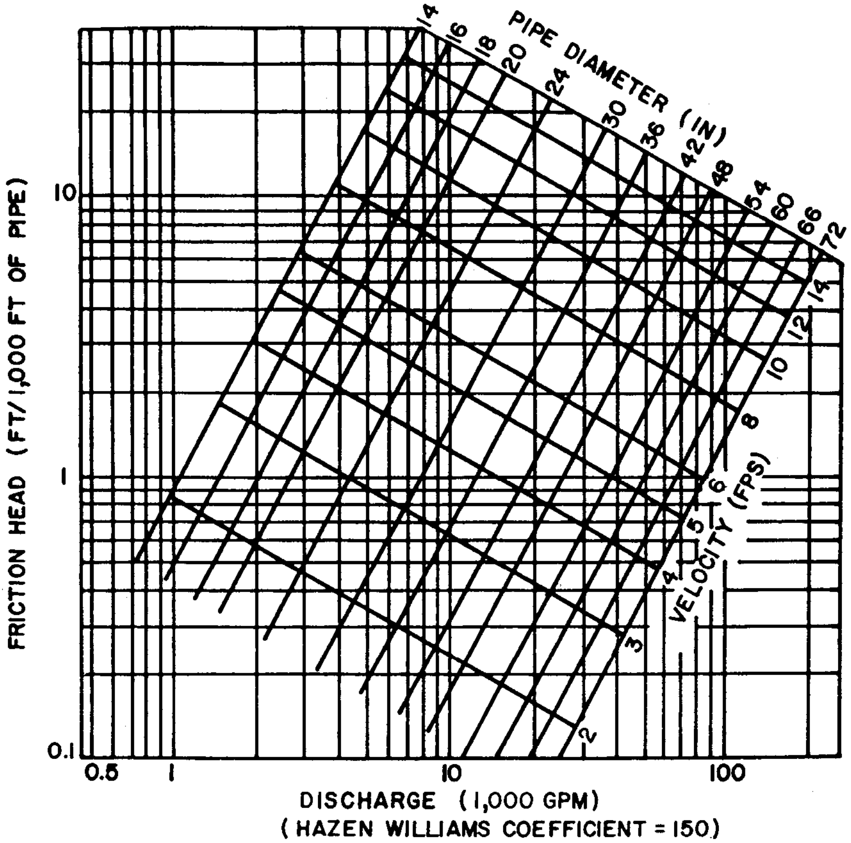


Figure 3–1: Flowchart for large–diameter, filament–wound pipe.

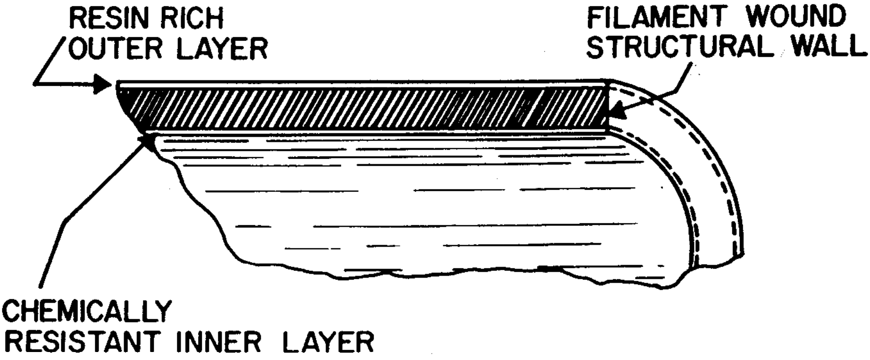


Figure 3–2: Cross section of filament–wound pipe wall.

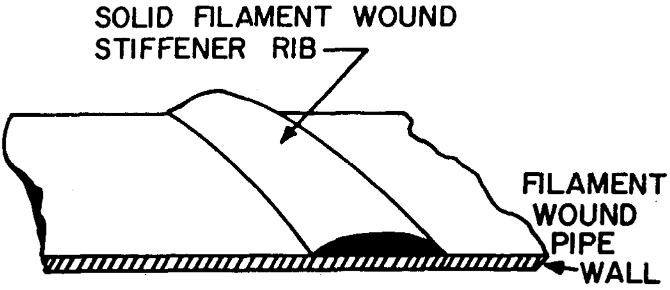
There are several types of wall construction that are used. The standard FRP filament-wound pipe is of the type described above with no circumferential reinforcement ribs. These pipes are designed in this manner to meet the pressure/bending stress criteria of various applications. This design is suitable for buried pipe installations, or for aboveground or hanger-suspended pipe systems. Standard wall designs are also often used as tunnel liners.

Rib-wall construction is used on large-diameter pipes to provide additional strength for buried and subaqueous installations. Usually, soil compaction is difficult to achieve in these situations or higher than normal burial loads are anticipated. Prestressed ribs are circumferentially wound over cured pipe after the specified overall wall thickness has been reached. The rib reinforcement must be positioned based on closely calculated spacing requirements. This addition greatly increases the pipe wall stiffness. This design reduces the nominal pipe wall thickness while maintaining the same strength-to-weight ratio. Two basic types of rib reinforcement are the half-elliptical and the trapezoidal designs.

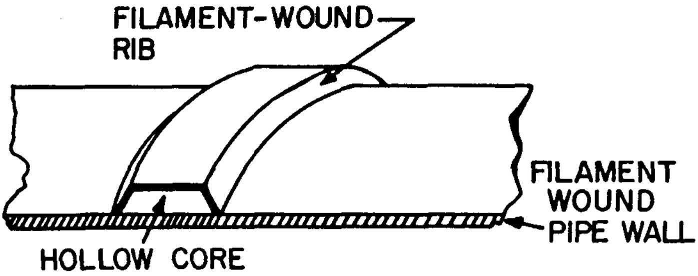
In the former design, a solid filament-wound, half-elliptical rib is provided to give additional pipe wall stiffness (Figure 3-3). These are usually employed in substandard burial conditions or excessive burial depths. The half-elliptical rib is constructed from continuous strands of tensioned high-strength glass reinforcement, which are helically wrapped at high helix angles over the completed outer wall. The rib generally has a shape that is wider than it is high. Sometimes a foamed structure is used under the rib although this is not normally recommended.

The trapezoidal rib design (Figure 3-3) is employed under conditions in which the ultimate degree of pipe stiffness is necessary. The rib is also constructed from highly tensioned continuous strands of impregnated fiberglass. A helix angle is employed that gives a much thicker rib profile. This type of rib configuration enables pipe to withstand excessive burial loads and extremely high impact strengths. As such, this arrangement provides the most rugged construction, capable of withstanding shock and treatment that would normally crumble or damage concrete or steel piping.

There are a variety of procedures for connecting FRP filament-wound pipe in addition to the numerous structural components often encountered in large, complex construction jobs. If the pipe is to pass through a wall, for example, it is recommended to use a filament-wound thrust ring, which is wound onto the pipe during fabrication. The thrust ring ensures anchoring and serves as a medium to transfer hydrodynamic and thermal stresses to the wall.



HALF-ELLIPTICAL RIB-WALL
CONSTRUCTION



TRAPEZOIDAL RIB-WALL
CONSTRUCTION

Figure 3–3: Two types of rib reinforcements used on filament–wound pipe.

When subsidence is expected, the pipe can be adapted to accommodate the anticipated settlement. Usually, a neoprene rubber compression wrap can be employed at the pipe–to–concrete termination encasement to dampen or minimize shear possibilities at this termination point.

When expansion joints are required, a flex–coupling can be employed for such connections. Expansion joints are usually used less frequently in filament–wound FRP piping networks than with other systems such as steel. They are important, however, when severe expansion thrusts at connection points are anticipated or for adjusting misalignment at equipment connections, or where provisions for value replacements are necessary (Figure 3–4).

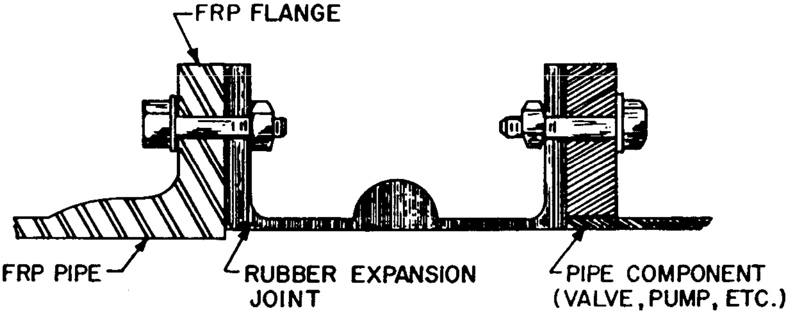


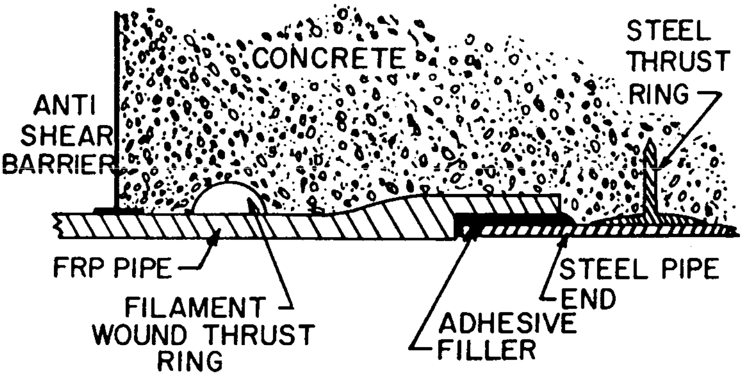
Figure 3–4: Typical expansion joint tie–in.

Because of the great versatility of FRP pipe, it can be readily incorporated into existing systems constructed from other materials. The proper connection must, however, be used. For making connections to concrete pipe, there are two methods generally employed. One method encloses the mated sections of pipe in a concrete encasement. The other approach is to employ a specially designed spigot joint to fit a concrete bell.

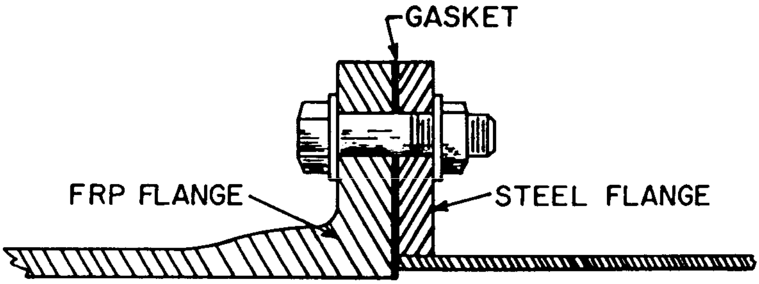
Mating FRP pipe with steel pipe can be done in a number of different ways. One way is to use a concrete–encased adhesive joint connection as shown in Figure 3–5A. Here, the steel pipe is adhesively sealed within the end of the plastic pipe and the entire joint is encased in concrete. A second method, shown in Figure 3–5B employs flange ends on both pieces of pipe. An appropriate size flange must be fabricated onto the end of the FRP pipe and drilled to prespecified orientation. FRP pipe may also be joined to steel by means of a flexcoupling, similar to that shown in Figure 3–4.

Support Systems

FRP pipe can be supported on hangers or saddles, which may be constructed from either FRP or steel. FRP saddles can be cut from actual portions of the pipe to be supported. Recommended saddle lengths should be at least one–half the pipe diameter. Note that the pipe and saddle will not have exactly the same radius; therefore, the gap must be filled with a suitable filler material to provide full bearing support. Clamps and "U" bolts should be used to provide snug, but not excess, clamp pressure on the pipe. Some typical support designs are shown in Figures 3–6 and 3–7.



(A) FRP PIPE TO STEEL PIPE CONNECTION.



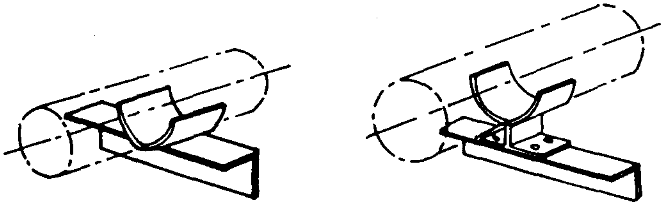
(B) FRP FLANGE TO STEEL FLANGE.

Figure 3–5: Two methods for connecting FRP pipe to steel pipe.

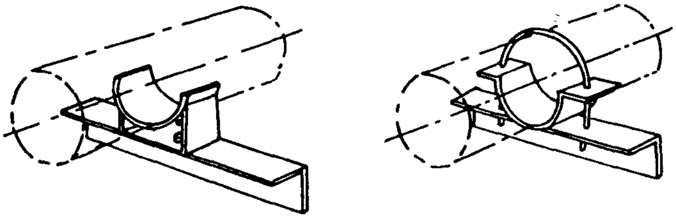
The recommended saddle angle should be 180° for any one of the following conditions:

1. when pipe diameters exceed 18 in,
2. when the pipe wall is rated less than 50 psig, and
3. when the pipe is designed for vacuum.

Valves, flow meters or other flow equipment that cause weight concentrations to occur in the line should be supported rigidly. This additional support should be independent from the remainder of the piping system.

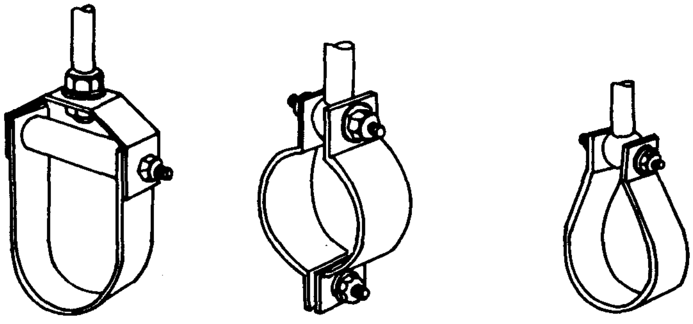


(A) SADDLE SUPPORT (B) SADDLE SUPPORT



(C) SADDLE SUPPORT (D) FLANGE SADDLE PLATE WITH U BOLT GUIDE

Figure 3–6: Typical support arrangements.



(A) CLEVIS (B) 360° CLAMP (C) 180° SLING

Figure 3–7: Typical hanger support arrangements.

Support spacings should provide for maximum tolerable deflection as well as maximum stress at the points of maximum deflection and maximum stress at the hangers. Table 3–2 lists recommended support spacings by one manufacturer. (Note that when complete line drainage requirements exist, lines should be sloped at a minimum of 0.5 in for every 10 ft of pipe length. The system should be provided with periodic low spots with flanged drain connections for positive drainage during a shutdown or cleanout.)

Table 3–2: Recommended Support Spacing Span (ft) for Fluids with Specific Gravity 1.2

Inside Diameter (in.)	Internal Pressure Rating (psig) 25	50	75	100	125	150
2	8.0	8.0	8.0	8.0	8.0	8.0
4	10.0	10.0	10.0	10.5	10.5	10.5
6	10.5	10.5	11.5	11.5	12.0	12.5
8	11.5	12.5	13.0	13.0	13.5	14.0
10	12.0	13.0	14.0	14.5	15.0	15.5
12	12.5	14.0	15.0	15.5	16.0	17.0
14	14.5	15.0	15.5	16.5	17.5	18.5
16	15.0	15.5	16.5	17.5	18.5	
18	15.5	17.0	18.0	19.0	20.0	
20	15.5	17.5	18.5	20.0		
24	12.5	19.0	20.5	22.0		

The most effective way to restrain pipe movement by applied forces is through the use of an anchor. Figure 3–8 illustrates the anchor arrangement. The design can be used to restrain thermal expansion; as such, it must meet maximum anticipated end forces. It must also prevent the pipe from sliding within the arrangement.

In situations in which a full anchor is not necessary but movement must be restricted, a tie–down can be used. Tie–downs can be employed in situations in which a long run of pipe is left to expand. It is generally recommended that the pipe be tied down in the middle, which will ensure an equal expansion in both directions. The expansion may be directed to one end by placing the tie–down away from the center. Another situation in which tie–downs can be used is when the velocity and surge forces promote pipe movement.

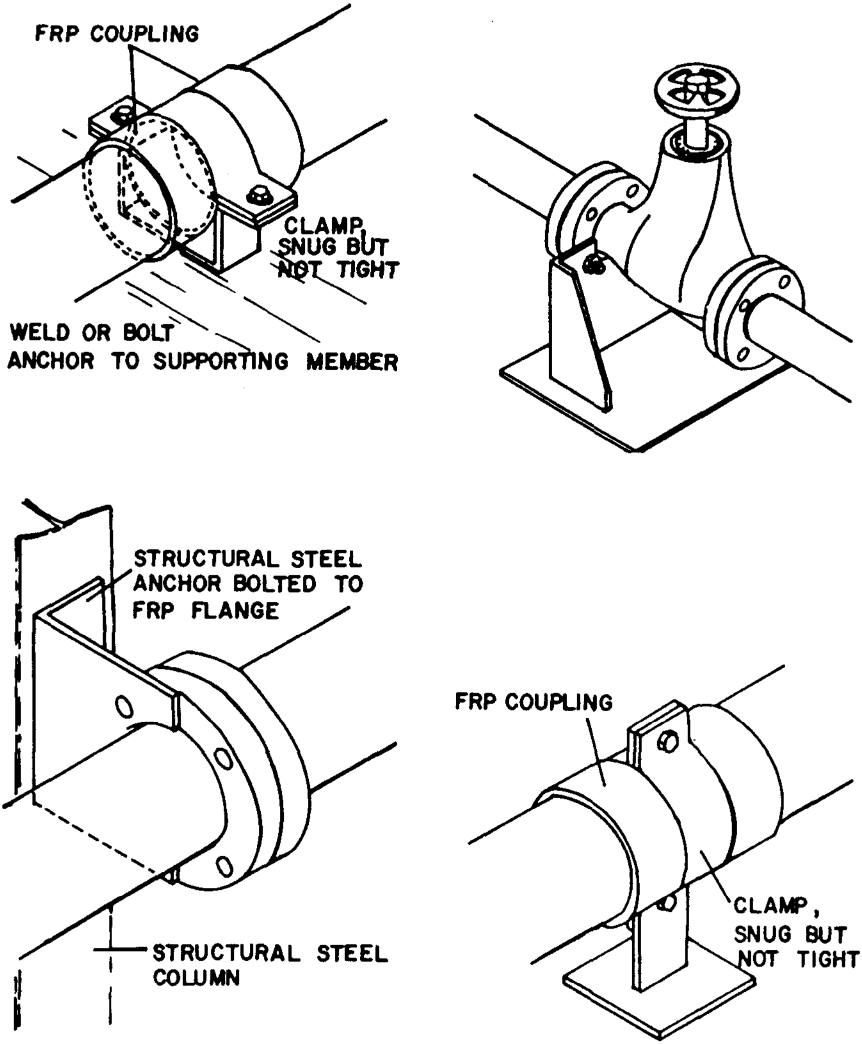
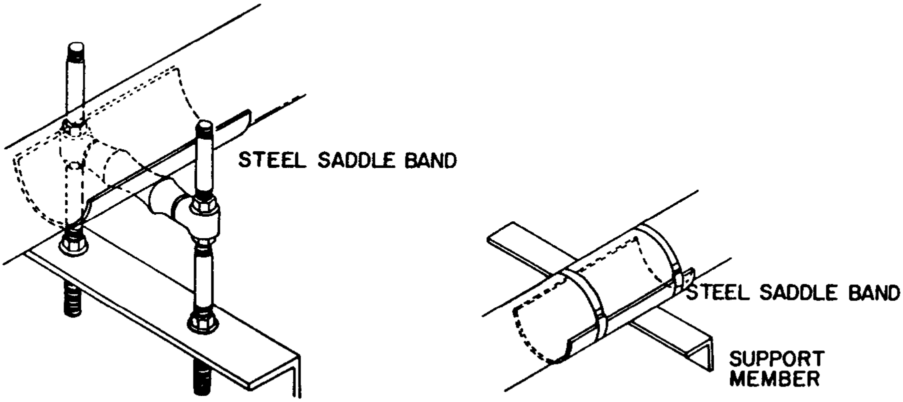


Figure 3–8: Various anchor arrangements that restrain pipe movements in all directions.

When expansion must be directed away from equipment to prevent the expanding line from overstressing a tank shell or vessel nozzle, tie–downs can be used. Tie–downs basically consist of a snug "U"–bolt and a 6–in wide strap joint, which is placed over the U–bolt to maintain the pipe in a fixed condition. The support must be fastened securely to a rigid foundation. This arrangement should not be used for supporting vertical runs. The other methods described above are acceptable.

Guides should be used to minimize snaking when the pipe has been restrained from expanding. A guide is essentially any type of device or support that prevents the pipe from transverse movement (but not axial movement). Under conditions in which axial movement is excessive, sliding guides should be employed. These will protect the pipe from abrasion. Figure 3–9 illustrates this type of guide.



(A) ADJUSTABLE PIPE SUPPORT (PIPE CAN ROLL OR MOVE AXIALLY)

(B) PIPE SUPPORT (PIPE CAN MOVE SIDEWAYS OR AXIALLY)

Figure 3–9: Typical sliding guide arrangements.

Most FRP piping systems can be designed without expansion joints, the reason for this being that although plastic piping systems have roughly two times the rate of thermal expansion of steel, they have a comparatively low modulus of elasticity. Usually, a slip–type joint or a bellows–type expansion joint is recommended for added protection. Anchors and supporting structures must be designed properly for the endforce from operating line pressures when expansion joints are employed. Between any two anchors, only one expansion joint should be installed. The pipe should be guided close to the expansion joint to prevent shear and bending loads and to eliminate any misalignment during axial movement. Guides should be positioned on both sides of the expansion joint at 4 and 12 pipe diameters away from the joint. Expansion joint manufacturers should be consulted for further recommendations and details.

Standard Sizes

Filament–wound FRP pipe is commercially available in a wide range of diameters, wall thicknesses and pressure ratings. Wall thickness specifications for a particular application are based on an allowable strain, which can yield structural safety factors in some cases in excess of 20:1. The strain level is defined as the maximum strain that can be tolerated to ensure long–term integrity of the inner liner. Note that when considering FRP pipe vs concrete pipe, corrugated metal or other types for buried installations, the user should base the decision on the safety factor. Standard construction in concrete and corrugated metal usually incorporates much higher safety factors than FRP pipe (on the order of 1 safety margins for FRP pipes).

Because of the high strength properties and good flexibility of FRP pipe, it can be delivered to job sites in lengths well over 100 ft. Rail cars are capable of handling up to 60–ft lengths without special permits.

Table 3–3 gives wall thicknesses of filament–wound FRP pipe at various pressures.

In addition to having high pressure ratings, filament–wound pipe can be fabricated with the proper resins to be highly resistant to corrosion and chemical attack. Filament–wound FRP pipe can be used to transport both acids and volumes. It has been used by chlorine manufacturers in transporting hot chlorinated acid brine. This type of pipe has also been employed in the paper industry in handling corrosive wastes at high temperatures. Specifically, it has been used in transporting caustic, chlorine and sodium hypochlorite from a bleach plant to waste treatment facilities. It has also found wide use in the food processing industry in handling both acetic and citrus acids in addition to process treatment chemicals.

Unlike most metals which undergo electrochemical attack, plastic pipe in general will be affected by chemical reaction or by solvation, which is the penetration of the plastic by a corrosive element. This causes softening, swelling in the walls and, eventually, failure. Because of the fundamental differences between electrochemical and solvation reactions, conventional corrosion rates should not be used in evaluating or comparing the chemical resistance of FRP pipe to other materials. Chemical resistance for FRP is usually determined by immersing the laminates in a bath of the corrosive media. Testing must be done under simulated operating conditions. Tests of strength retention, surface hardness and visual inspection for chemical attack provide detailed qualitative information on FRP pipe characteristics. Table 3–4 lists the chemical resistance of filament–wound pipe to various fluids and the range of maximum operating temperatures for which FRP pipe is commercially available.

Table 3-3: Recommended Wall Thickness for Filamount-Wound FRP Pipe at Various Pressures

	Internal Pressure Rating (psi)											
	25		50		75		100		125		150	
Inside Diameter (in.)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)
2	0.188	0.945	0.188	0.945	0.188	0.945	0.188	0.945	0.188	0.945	0.188	0.945
2.5	0.188	1.18	0.188	1.18	0.188	1.18	0.188	1.18	0.188	1.18	0.188	1.18
3	0.188	1.42	0.188	1.42	0.188	1.42	0.188	1.42	0.188	1.42	0.188	1.42
4	0.188	1.89	0.188	1.89	0.188	1.89	0.188	1.89	0.188	1.89	0.188	1.89
5	0.188	2.36	0.188	2.36	0.188	2.36	0.188	2.36	0.188	2.36	0.188	2.36
6	0.188	2.63	0.188	2.83	0.188	2.83	0.188	2.83	0.188	2.83	0.188	2.83
8	0.188	3.78	0.188	3.78	0.188	3.78	0.188	3.78	0.188	3.78	0.188	3.78
10	0.188	4.72	0.188	4.72	0.188	4.72	0.188	4.72	0.188	4.72	0.188	4.72
12	0.188	5.67	0.188	5.67	0.188	5.67	0.188	5.67	0.188	5.67	0.214	6.45
14	0.188	6.61	0.188	6.61	0.188	6.61	0.188	6.61	0.208	7.32	0.250	8.80
16	0.188	7.56	0.188	7.56	0.188	7.56	0.190	7.64	0.238	9.57	0.286	11.5
18	0.188	8.50	0.188	8.50	0.188	8.50	0.214	9.68	0.268	12.1	0.321	14.5
20	0.188	9.45	0.188	9.45	0.188	9.45	0.238	12.0	0.298	15.0	0.357	17.9
24	0.188	11.3	0.188	11.3	0.214	12.9	0.286	17.3	0.357	21.5	0.429	25.9
30	0.188	14.2	0.188	14.2	0.268	20.2	0.357	27.0	0.446	33.6	0.536	40.4
36	0.188	17.0	0.214	19.4	0.321	29.0	0.429	38.8	0.536	48.5	0.643	58.2
42	0.188	19.8	0.250	26.4	0.375	39.6	0.500	52.8	0.625	66.0	0.750	79.2
48	0.188	22.7	0.286	34.5	0.429	51.8	0.571	68.9	0.714	86.1	0.857	103.4
54	0.188	25.5	0.321	43.6	0.482	65.4	0.643	87.3	0.804	109.1	0.964	130.8
60	0.188	28.3	0.357	53.8	0.536	80.8	0.714	107.7	0.893	134.7	1.07	161.4
72	0.214	38.7	0.429	77.6	0.643	116.4	0.857	155.1	1.07	193.6	1.29	233.4
84	0.250	52.8	0.500	108.1	0.750	158.3	1.00	211.1	1.25	263.9	1.50	316.7
96	0.286	69.0	0.571	137.8	0.857	206.8	1.14	275.1	1.43	345.0	1.71	412.6
108	0.321	87.1	0.642	174.3	0.964	261.7	1.29	350.0	1.61	437.0	1.93	524.0
120	0.357	107.7	0.714	215.3	1.07	322.7	1.43	431.0	1.79	540.0	2.14	645.0
144	0.429	155.3	0.857	310.2	1.29	467.0	1.71	619.0	2.14	775.0	2.57	930.0

Table 3–4: Chemical Resistance of Filamount–Wound FRP Pipe (Polyester Resin Systems)

Chemical	Strength (%)	Maximum Operating Temperature of	Chemical	Strength (%)	Maximum Operating Temperature of
Acetic Acid	0-10	100-150	Ammonium Hydroxide	10-20	150
	10-50	100		20-30	100
Acetic Acid, Glacial	–	100	Ammonium Nitrate	–	200-250
Aceto	0-5	150	Ammonium Persulfate	–	200
Acrylic Acid	–	75	Ammonium Phosphate	–	150
Adipic Acid Air	Solution	200-250	Ammonium Sulfate	–	200-250
	–	300	Amyl Acetate	–	75
Alcohol, Ethyl	0-10	150	Amyl Chloride	–	75
Alcohol, Isopropyl	10	150	Aniline	–	75
Alcohol, Methyl	10	150	Antimony Trichloride	–	150-200
Alcohol, Methyl Isobutyl	10	150	Barium Carbonate	–	200-250
Alcohol, Secondary Butyl	10	150	Barium Chloride	–	200-250
Allyl Chloride	–	100	Barium Hydroxide	0-10	150-200
Aluminum Chloride	–	100-300	Barium Sulfate	–	200-250
Aluminum Fluoride	–	150	Barium Sulfide	–	150-300
Aluminum Hydroxide	–	150	Beer	–	200
Aluminum Nitrate	–	150-250	Benzene	–	100
Aluminum Sulfate	–	200-300	Benzen Sulfonic Acid	–	200
Alums	–	200-300	Benzoic Acid	–	200
Ammonia Gas, Dry	–	150	Black Liquor	–	200
Ammonia, Wet	–	100	Borax	–	200-250
Ammonium Carbonate	–	100-200	Boric Acid	–	200
Ammonium Chloride	–	200	Bromic Acid	–	150
Ammonium Fluoride	25	150-200	Bromine, Liquid	–	NR[b]
Ammonium Hydroxide	0-10	150-200	Bromine Water	–	100

(continued)

Table 3–4: (continued)

Chemical	Strength (%)	Maximum Operating Temperature of	Chemical	Strength (%)	Maximum Operating Temperature of
Butadiene	–	100	Copper Chloride	–	200-250
Butane	–	100	Copper Fluoride	–	200-250
Butyl Acetate	–	75	Copper Nitrate	–	200-250
Butyl Cellusolve	–	150	Copper Sulfate	–	200
Butyric Acid	0-15	150-200	Crude Oil, Sour	–	200-300
	25-50	150	Crude Oil, Sweet	–	200-300
Calcium Bisulfide	–	200	Deionized Water	–	200-300
Calcium Carbonate	–	150-300	Diacetone Alcohol	–	150
Calcium Chlorate	–	200	Dichlorobenzene	100	150
Calcium Chloride	–	200-300	Dichloroethylene	100	75
Calcium Hydroxide	0-50	150-200	Diethylene Triamine	100	NR
Calcium Hypochlorite	0-20	200	Dimenthylamine	–	NR
Calcium Nitrate	–	200-250	Ethyl Acetate	–	150
Calcium Sulfate	–	200-250	Ethyl Ether	–	75
Carbon Dioxide	–	200-250	Ethylene Chlorohydrin	–	NR
Carbon Disulfide	–	NR	Ethylene Diamine	–	NR
Carbon Tetrachloride	–	100	Ethylene Glycol	–	200
Carbonic Acid	–	150	Ethylene Oxide	–	NR
Chloroacetic Acid	0-25	100-150	Fatty Acids	–	200
Chlorine, Dry	–	200	Ferric Chloride	–	200-300
Chlorine, Wet	–	200	Ferric Nitrate	–	200-250
Chlorine Dioxide	15	150	Ferric Sulfate	–	200
Chlorine Water	–	200	Ferrous Chloride	–	200-250

(continued)

Table 3–4: (continued)

Chemical	Strength (%)	Maximum Operating Temperature of
Chlorobenzene	100	100
Chloroform	100	100
Chromic Acid	5	150
	10	150
	20	75-150
	100	NR
Chromic Fluoride	–	75
Citric Acid	–	200-250
Gasoline, Sour	–	200-300
Gasoline, 108 Octane	–	150
Glucose	–	200-300
Glycerine	–	150-300
Glycol, Ethylene	–	200
Glycol, Propylene	–	200-250
Heptane	–	150
Hexane	–	75
Hydraulic Fluid	–	150-200
Hydrobromic Acid	50	150-200
Hydrochloric Acid	0-37	200
Hydrocyanic Acid	10	150
Hydrofluoric Acid	10	150
Ferrous Sulfate	–	200
Fluorine Gas, Wet	–	75
Fluorosilicic Acid	10	200
Fluoroboric Acid	–	200
Formaldehyde	40	150-200
Formic Acid	25	100
Freon®	–	150
Gas, Natural	–	200
Magnesium Carbonate	–	200-250
Magnesium Chloride	–	200-300
Magnesium Hydroxide	–	150-250
Magnesium Nitrate	–	200-250
Magnesium Sulfate	–	200-250
Maleic Acid	100	150-200
Mercury	–	200-300
Mineral Oils	–	200-300
Naphtha	–	200
Naphthalene	–	100-150
Nickel Chloride	–	200-300
Nickel Nitrate	–	200
Nitric Acid	0-15	100

(continued)

Table 3–4: (continued)

Chemical	Strength (%)	Maximum Operating Temperature of	Chemical	Strength (%)	Maximum Operating Temperature of
Hydrogen	–	150		20	75
Hydrogen Peroxide	10	150	Oleic Acid	–	200
	20-30	75-150	Perchloric Acid	70	75
Hydrogen Sulfide			Phenol	1	150
Aqueous	–	200-250	Phosphoric Acid	0-75	200-250
Dry	–	200-250		75-85	200
Hypochlorous Acid	–	200		85-110	200
Kerosene	–	200-250	Phosphorus Pentoxide	0-54	200
Lactic Acid	–	200	Picric Acid	–	75
Lauric Acid	–	200	Potassium Bicarbonate	–	150-250
Lead Acetate	–	200-250	Potassium Bromide	–	200
Levulinic Acid	25	200-250	Potassium Carbonate	–	150-250
Potassium Chloride	–	200-300	Sulfite Liquors	–	200
Potassium Dichromate	–	200-250	Sulfur Dioxide, (Wet and Dry)	–	200
Potassium Hydroxide	–	150-200	Sulfuric Acid	10	200-250
Potassium Permanganate	10-25	150		25	150-200
Potassium Sulfate	–	150-200		50	100-200
Propane	–	100		60	75-200
Silver Nitrate	–	200-250		70	75
Soaps	–	200-250	Sulfurous Acid	0-7	200
Sodium Acetate	–	150	Tartaric Acid	–	200-250
Sodium Bicarbonate	–	150-250	Tetraethyl Lead	–	100

(continued)

Table 3–4: (continued)

Chemical	Strength (%)	Maximum Operating Temperature of	Chemical	Strength (%)	Maximum Operating Temperature of
Sodium Bromide	–	200	Toluol	100	150
Sodium Carbonate	–	100-250	Trichloroacetic Acid	–	200
Sodium Chlorate	–	150	Trichloroethylene	–	150
Sodium Chloride	–	200-300	Triethylamine	–	75
Sodium Cyanide	–	200-250	Tung Oil	–	200
Sodium Fluoride	–	200-250	Turpentine	–	75
Sodium Hydroxide	0-5	150-200	Urea	–	150
	>5	150-200	Vinegar	–	150
Sodium Hypochlorite	0-10	75-100	Vinyl Acetate	–	150
Sodium Methoxide	40	150	Water, Deionized	–	200-250
Sodium Nitrate	–	200-300	Water, Distilled	–	200-300
Sodium Peroxide	–	75	Water, Fresh	–	200-300
Sodium Sulfate	–	200-300	Water, Salt	–	200-300
Sodium Sulfite	–	200	Xylene	–	150
Sodium Thiosulfate	–	150-200	Zinc Chloride	–	200-250
Stearic Acid	–	150	Zinc Sulfate	–	200-250
Sulfamic Acid	25	200			

[a] Souce: Fibercast Co./Div. of Youngstown Sheet and Tube Co.

[b] NR = not recommended.

The specific corrosion-resistant service for a reinforced plastic pipe is determined from the resin-to-glass ratio used in the laminate construction. The nature of the resin plays the dominant role in corrosion resistance to specific chemicals. The interior layer of the pipe generally has a low glass content (on the order of 20–30% glass content by weight). This ratio provides high corrosion resistance. To meet desired wall thicknesses and strengths, a higher glass content is used in fabricating laminates for the remaining thickness. A typical overall ratio is roughly 70% resin to 30 glass reinforcement by weight. The outer wall is often covered with a glass surfacing mat that is resin rich. Such a surface provides excellent resistance to weathering (sunlight, heat, cold and other weathering conditions), fumes and spillage.

As indicated, the choice of the resin determines the specific corrosion resistance of the pipe. A general breakdown of those resins most often used is as follows:

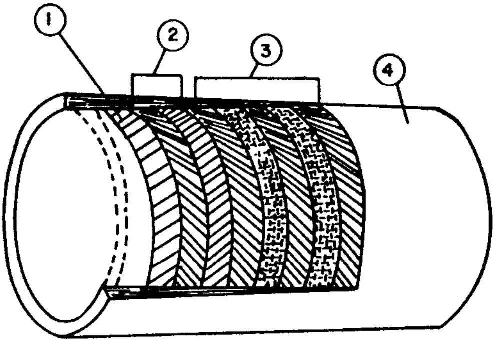
1. For transporting mild corrosives at moderate temperatures, a high quality isophthalic resin system is employed. This can provide adequate protection from general use in acid wastes.
2. For handling mild to severe corrosive fluids often encountered in industrial processes and waste treatment, a fumarated bisphenol A–type polyester can be used. This provides excellent protection against many alkalies and acids.
3. For maximum chemical resistance to acids, alkalies and solvents, a fire-retardant polyester system is often employed.
4. For a high degree of chemical resistance to specific chemicals, selection must be made among the various thermosetting resins.
5. For extremely high resistance to strong caustic solutions, a high – quality epoxy resin system is used.
6. For materials that can operate in excess of 350°F and/or have extremely high resistance to organic acids, oxidizing acids, alkalis and specific solvents, the manufacturer should be consulted for proprietary systems that have been developed for specific applications.

CENTRIFUGALLY CAST AND CONTACT-MOLDED PIPES

Contact-molded or hand layup piping is often used where maximum chemical resistance is required throughout a laminate and where pressure requirements are not severe. For many applications, however, filament wound FRP pipe is preferred over contact-molded because of the former's much higher structural properties. These properties in turn possess economic advantages since thinner laminate thicknesses can be employed to meet physical requirements. Table 3-5 gives recommended wall thicknesses of contact-molded pipe at various pressures.

Recall that contact molding is a process in which layers of resin impregnated fabrics are built up, one layer at a time, on a mold forming the pipe. Little or no pressure is applied in forming the resulting laminate during curing. The structural wall of the pipe usually consists of chopped glass strand mat and/or woven roving. Normally, a 60% resin, 40% glass content by weight is used. A very high resin content inner wall is made for protection against chemical attack and corrosion. The resin content at the inner wall is on the order of 80–90%, and the reinforcement consists of chopped strand mat (roughly 0.10-in thick mat). An intermediate layer is usually formed with resin contents in the range of 70–80%. Figure 3-10 illustrates a cutaway view of contact-molded FRP pipe.

The physical properties of contact-molded pipe depend on the wall thickness, laminate construction and type of resin. Typical properties of one leading manufacturer's contact-molded FRP pipe with various wall thicknesses are given in Table 3-6. Table 3-7 lists other average properties.



1. SMOOTH INNER SURACE (RESIN RICH INTERIOR REINFORCED WITH SURFACING VEIL, 90% RESIN / 10% GLASS)
2. NEXT INTERIOR LAYER (REINFORCED WITH CHOPPED STRAND MAT, 25-30% GLASS)
3. REMAINING THICKNESS (70% RESIN/30% GLASS)
4. EXTERIOR SURFACE (RESIN RICH SURFACING VEIL / PROTECTS AGAINST WEATHERING, SPILLAGE, FUMES, ETC.)

Figure 3-10: Cutaway view of contact-molded pipe.

Table 3–5: Recommended Wall Thickness for Contact–Molded FRP Pipe at Various Pressures

	Internal Pressure Rating (psi)											
	25		50		75		100		125		150	
Inside Diameter (in.)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)	Wall (Nominal) (in.)	wt/ft (lb/ft)
2	0.187	0.863	0.187	0.863	0.187	0.863	0.187	0.863	0.187	0.863	0.187	0.863
2.5	0.187	1.08	0.187	1.08	0.187	1.08	0.187	1.08	0.187	1.08	0.250	1.44
3	0.187	1.30	0.187	1.30	0.187	1.30	0.187	1.29	0.250	1.73	0.250	1.73
4	0.187	1.73	0.187	1.73	0.187	1.73	0.250	2.30	0.250	2.30	0.250	2.30
5	0.187	2.17	0.187	2.17	0.250	2.89	0.250	2.89	0.312	3.61	0.375	4.33
6	0.187	2.59	0.187	2.59	0.250	3.45	0.250	3.45	0.312	4.32	0.375	5.18
8	0.187	3.45	0.250	4.60	0.250	4.60	0.312	5.76	0.375	6.91	0.437	8.06
10	0.187	4.32	0.250	5.76	0.312	7.20	0.375	8.64	0.437	10.07	0.500	11.9
12	0.187	5.18	0.250	6.91	0.375	10.4	0.437	12.1	0.500	13.82	0.625	17.3
14	0.250	8.05	0.312	10.7	0.375	12.1	0.500	16.1	0.625	20.15	0.750	24.2
16	0.250	9.21	0.312	11.5	0.437	16.1	0.562	20.7	0.687	25.3	0.812	30.0
18	0.250	10.36	0.375	15.5	0.500	20.7	0.625	25.9	0.750	31.1	0.937	38.9
20	0.250	11.51	0.375	17.3	0.500	23.0	0.687	31.7	0.875	40.3	1.00	46.1
24	0.250	13.82	0.437	24.2	0.625	34.5	0.812	44.9	1.00	55.3	1.12	62.2
30	0.312	21.59	0.500	34.5	0.750	51.8	1.00	69.1	1.25	86.4	1.50	103.6
36	0.375	31.08	0.625	51.8	0.937	77.7	1.25	103.6	1.50	124.4	1.81	150.3
42	0.375	36.3	0.750	72.5	1.06	102.8	1.44	139.0	1.75	169.3	2.12	205.9
48	0.437	48.4	0.812	89.8	1.25	138.2	1.62	179.6	2.00	221.1	2.44	269.4
54	0.500	62.2	0.937	116.6	1.37	171.0	1.81	225.4	2.25	279.8	2.75	342.6
60	0.500	69.1	10.00	138.2	1.50	207.3	2.00	276.3	2.50	345.4	3.00	415.0
72	0.625	103.6	1.25	207.3	1.81	300.5	2.44	404.0	3.00	497.0	3.62	601.8
84	0.750	145.1	1.44	278.1	2.12	411.0	2.81	545.0	3.50	677.0	4.25	820.8
96	0.812	179.6	1.62	359.2	2.44	540.0	3.25	720.0	4.00	885.0	4.81	1065.0

Table 3–6: Physical Properties of Contact–Molded FRP Pipe

Wall Thickness (in.)	Ultimate Tensile Strength (psi)	Flexural Strength (psi)	Flexural Modulus of Elasticity (psi)	Compressive Strength (psi)
0.187	9,000	16,000	700,000	18,000
0.250	12,000	19,000	800,000	20,000
0.312	13,500	20,000	900,000	21,000
0.375	15,000	22,000	1,000,000	22,000

Table 3–7: General Properties of Contact–Molded FRP Pipe

Specific Gravity	1.3-1.7
Impact Strength, ft-lb	30-40
Barcol Hardness	35-45
Thermal Conductivity @ 212°F, Btu/ft^2-hr-°F/in.	1.5
Linear Coefficient of Thermal Expansion (32-212°F), in./in.-°F	15×10^{-6}
Heat Distortion Temperature at 264 psi, °F	250-350
Electrical Resistivity, ohm-cm	10^{14}
Dielectric Constant	3.16
Machinability	Good
Light Transmission	Translucent

Reinforced plastic properties, particularly those of layup pipe, vary with temperature. Consequently, the operating temperature must be considered in design and materials selection. For example, tensile strength will tend to increase at elevated temperatures whereas flexural properties (i.e., flexural modulus, flexural strength) decrease as temperature goes up. This must be taken into consideration when the modulus is used in computing deflections, vacuum capability and any elastic stability conditions.

Fiberglass–reinforced pipe can also be manufactured by centrifugal casting and pressure molding. Wall thicknesses vary, and the use of fillers in both methods is optional. The manufacturing processes produce pipe that is greatly different in construction and physical properties; however, the general benefits each has to offer are approximately the same. Table 3–8 compares various physical properties of the three principal manufacturing techniques.

As with filament–wound pipe, a variety of resins can be used; the specific resin will determine the corrosive resistance properties of the pipe. Polyester resins are most often used for applications that require protection against strong acids and/or oxidizing chemicals.

Table 3–8: Average Properties of Various Types of FRP Pipe

	Filament-Wound, Epoxy or Polyester Resins	Centrifugally Cast Epoxy or Polyester Resin	Contact-Molded Polyester Resin
Modulus of Elasticity in Axial Tension @ 77°F, psi	$1.0\text{-}2.7 \times 10^6$	$1.3\text{-}1.5 \times 10^6$	$0.8\text{-}1.8 \times 10^6$
Ultimate Axial Tensile Strength @ 77°F, psi	8,000-10,000	25,000	9,000-18,000
Ultimate Hoop Tensile Strength @ 77°F, psi	24,000-50,000	35,000	9,000-10,000
Modulus of Elasticity in Beam Flexure @ 77°F, psi	$1\text{-}2 \times 10^6$	$1.3\text{-}1.5 \times 10^6$	1.0-1.2 x 10
Coefficient of Thermal Expansion, in./in./°F	$8.5\text{-}12.7 \times 10^{-6}$	13×10^{-6}	15×10^{-6}
Heat Deflection Temperature @ 264 psi, °F	200-300	200-300	200-250
Thermal Conductivity Btu/ft^2-hr-°F/in.	1.3-2.0	0.9	1.5
Specific Gravity	1.8-1.9	1.58	1.3-1.7
Corrosive Resistance	E[a]	E	NR[a]

[a] E = excellent, will resist most corrosive chemicals;
NR = not recommended for highly alkaline or solvent applications

Normally, a premium–grade polyester resin is used that is especially formulated to provide specific chemical resistance. The most common among this group are the corrosion resistant vinyl esters, bisphenol A furmate–based polyester resins and the chlorinated hetanhydride–based resins.

The best, overall chemical resistance is usually obtained with an epoxy resin (normally with an aromatic, amine–cure). Pipe that is produced with an epoxy resin system has extremely good resistance to alkalis, solvents and moderate concentrations of nonoxidizing acids. It is often used for steam–condensate or hot water heating systems because it has superior resistance at elevated temperatures when compared to other resin systems.

Epoxy resin pipe is most often manufactured either by centrifugal casting or by the filament winding method. It is used as an alternative to steel, stainless steel and rubber–lined steel pipe in literally hundreds of different applications. Installations can be below and above the ground, underwater or aboard ships. As with most FRP pipe, they are noncontam–

inating, that is, they can prevent contamination by metallic ions wherever high–purity chemicals are employed. This type of pipe has been installed to handle high–purity water employed in nuclear reactors. Thermal conductivity of FRP epoxy–based pipe is around 2.3 Btu/ft^2–hr–°F/in[20]. Because of the low thermal conductivity, less heat input is required to control process temperatures. This is an important consideration in designing steam condensate return or hot water heating systems in which the heat transfer medium must be transported over considerable distances. For applications in which additional insulation may be necessary, factory insulated piping is most often available.

In addition to having excellent thermal properties, epoxy resin FRP pipe displays excellent corrosion resistance both inside and out. Insulated fiberglass pipe is widely employed in various underground heating arrangements. This type of pipe is nonconductive and, as such, may be buried in corrosive soils without additional protection. As pointed out earlier, steel piping will undergo galvanic corrosion in such an environment and, therefore, require additional exterior protection before being used for this application.

Abrasion resistance is an important consideration in the design of piping networks for various slurry–handling operations such as sand lines, fly and bottom ash lines and mine tailings. Not all FRP pipe has this property and, as such, the manufacturer should be consulted for specific details.

CHAPTER 4

PIPE SYSTEM DESIGN AND INSTALLATION

GENERAL DESIGN

FRP pipe has been shown to have outstanding chemical and corrosion resistance, temperature capabilities and mechanical strength. Recognition of these properties has led to its widespread use in numerous industrial applications.

As with any piping material, proper fabrication and good system design and installation techniques must be practiced to ensure reliable and long service life. The purpose of this chapter is to discuss some of the specific properties of FRP pipe and common design problems facing the piping designer or project engineer.

A flow capacity curve permits the determination of head loss vs flowrate as well as flow velocity in feet per second. The Hazen–Williams C factor for the plot is 150. To estimate the head loss in various fittings for polyester resin or epoxy resin base, refer to Table 4.1.

Table 4–1: Head Loss (ft) for Filament–Wound Fittings

Nominal Diameter (in.)	90° Elbow (Long Radius) (ft)	45° Elbow (ft)	Tee (Run) (ft)	Tee (Branch) (ft)
2	3.5	2.5	3.5	11
3	5	4	5	16.5
4	7	5	7	22
6	10.5	7.5	11	34
8	15	10	15	45
10	17	12.5	17	60
12	21	15	21	70

In selecting materials for a piping system, head losses in pipelines should be compared for different systems. The head loss can be translated into pumping costs. Figures 4–1 and 4–2 are flow capacity comparisons between typical FRP pipe having Hazen Williams coefficient C = 150 and ductile iron pipe for inside diameters 4, 6 and 12 in. The shaded area of the plot represents the pumping cost savings that can be realized in selecting FRP over ductile iron pipe. Table 4.2 is the accompanying data to Figure 4–1.

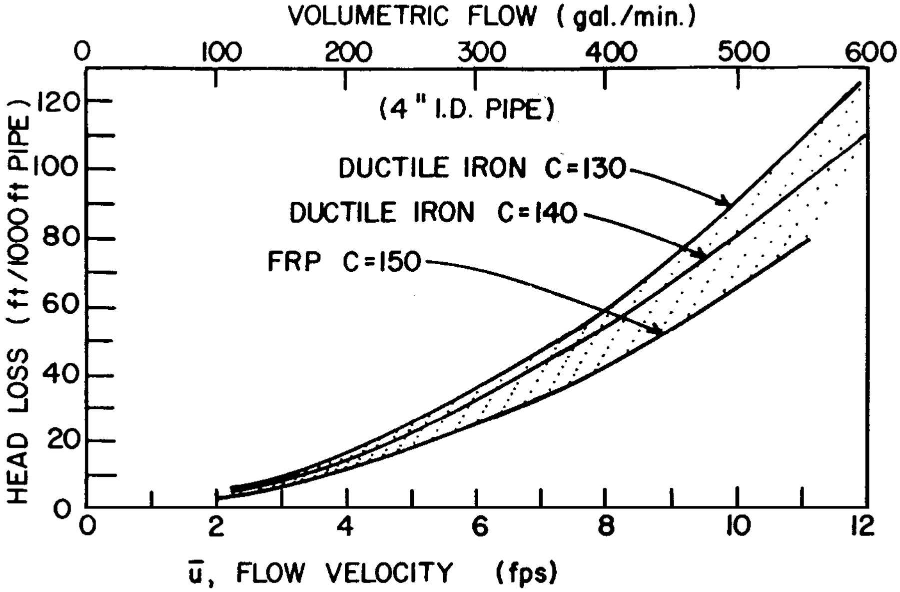
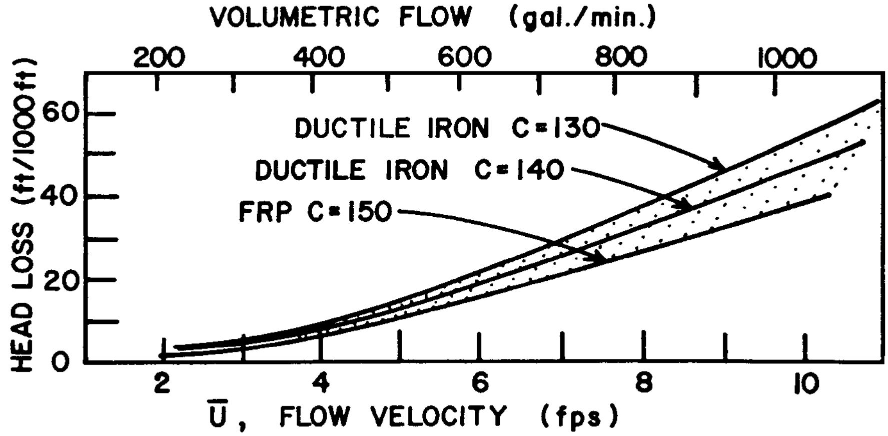


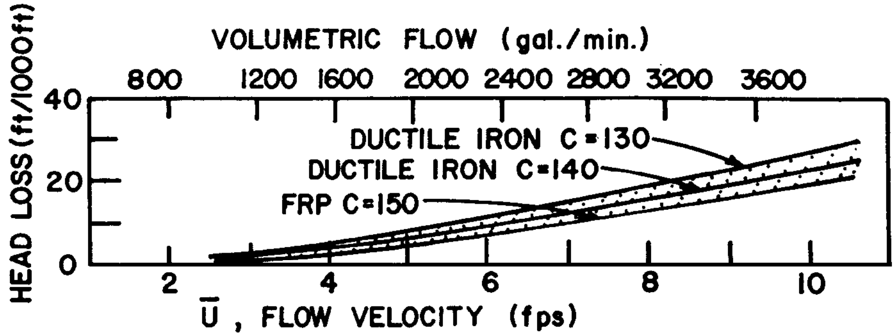
Figure 4–1: Flow capacity comparison between 4–in i.d. FRP pipe with C = 150 and ductile iron pipe having Hazen Williams coefficients 130 and 140. The shaded region represents the pumping cost savings of FRP over ductile iron.

As an example, the following values were interpolated from Table 4–2 for a linear velocity of 10 ft/sec of fluid flowing through a 4–in i.d. line (the fluid is assumed to be water at ambient conditions).

FRP–Head Loss (ft/1,000 ft)	FRP (gpm)	Ductile Iron (gpm)
63.0	495.5	422.1



(A.) 6" I.D. PIPE.



(B.) 12" I.D. PIPE.

Figure 4–2: Flow capacity comparison curves for FRP and ductile iron pipes for 6– and 12–in i.d. lines. The shaded region represents the pumping cost savings of FRP over ductile iron.

Table 4–2: Flow Capacity and Head Loss Data for Figure 4–1 (4 in i.d.)

	Data For FRP Pipe				
Volume Flow (Gpm)	Linear Velocity (ft/sec)	Loss of Head (ft/1,000-ft pipe) (C = 150)	Linear Velocity (ft/sec)	Loss of Head (ft/1,000-ft pipe) (C = 140)	(C = 130)
100	2.02	3.27	2.37	5.48	6.28
120	2.42	4.56	2.84	7.66	8.78
140	2.82	6.06	3.32	10.22	11.72
160	3.23	7.79	3.79	13.06	14.98
180	3.63	9.66	4.26	16.21	18.59
200	4.03	11.73	4.74	19.75	22.65
220	4.44	14.03	5.21	23.53	26.98
240	4.84	16.46	6.16	27.60	31.66
260	5.24	19.06	6.16	32.07	36.78
280	5.65	21.92	6.63	36.74	42.14
300	6.05	24.86	7.11	41.82	47.96
320	6.46	28.07	7.58	47.07	53.99
340	6.86	31.37	8.05	52.62	60.35
360	7.26	34.84	8.53	58.57	67.17
380	7.67	38.57	9.00	64.68	74.18
400	8.07	42.37	9.47	71.06	81.50
420	8.47	46.34	9.95	77.87	89.31
440	8.88	50.57	10.42	84.81	97.27
460	9.28	54.87	10.90	92.18	105.72
480	9.68	59.32	11.37	99.67	114.31
500	10.09	64.05	11.84	107.42	123.21

[a] The inside diameter reported for the ductile iron pipe is based on the average outside diameter less twice the wall thickness and twice the minimum cement lining and bituminous coating.

In terms of volumetric flowrate, this represents a 17.4% increase in *throughput* for FRP over ductile iron pipe. For C = 140, the ductile iron has a head loss of 78.6 ft/1,000 ft of pipe, which means a 19.8% to reduction in head loss in selecting FRP. Similarly, from Table 4–2 for C = 130 the head loss is 90.14 ft/1,000 ft, which means 30% less head loss. This reduction means significantly lower pumping costs can be realized in selecting FRP over ductile iron or similar pipe materials.

Some useful formulas for computing the pressure drop in a line are given below:

$$\mathrm{Re} = \frac{DU\rho}{\mu} = \frac{DU}{\nu} \qquad (1)$$

where

Re = Reynolds number
D = pipe diameter, ft
$\overline{U}$ = average fluid velocity ft/sec
ρ = density, lb/ft^3
μ = viscosity, lb/ft–sec
ν = kinematic viscosity = μ/ρ, ft^2/sec

The Reynolds number is used to compute the Fanning friction factor.

For laminar flow, i.e., Re < 2,100:

$$f = \frac{16}{Re} = \frac{16\mu}{DU\rho} \tag{2}$$

For full pipe turbulent flow, *i.e.,* Re > 2,100, either Equation 3 or 4 can be used:

$$f = \frac{0.046}{(Re)^{0.2}} \tag{3}$$

$$f = 0.0014 + \frac{0.125}{(Re)^{0.32}} \tag{4}$$

Equation 3 can be used for completely smooth tubes or small-diameter pipes. The latter of the two expressions should be preferred.

The friction factor can be used to compute the skin friction per pound of fluid conveyed by:

$$H_{fs} = \frac{2fL\overline{U}^2}{D_{g_c}} \tag{5}$$

where

L = length of straight pipe line, ft
g_c = conversion factor = 32.174 ftlb$_m$/lb$_f$sec^2
H_{fs} = skin friction, ft–lb$_f$/lb$_m$

The frictional pressure loss in the line is computed from:

$$\Delta P = H_{fs}\rho \tag{6}$$

where ΔP is in lb_f/in^2.

The following example illustrates the use of these expressions.

Illustrative Example 4.1

Kerosene is to be transported at a rate of 300,000 Ib/hr in a 6–in. i.d. pipeline, 400 ft straight length. The pipe is constructed from epoxy resin FRP so that the walls can be assumed to be hydrodynamically smooth. Conditions are at 68°F. Compute the frictional pressure drop per foot of pipe. Elevation changes and back pressure considerations are assumed negligible.

Table 4–3: Physical Properties of Fluid

Density (lb/ft^3)	Viscosity (lb/hr-ft)	Kinematic Viscosity (ft^2/hr)	Surface Tension (lb/hr)
51.2	4.35	0.085	22

Step 1. Calculate the average vluid velocity, $\bar{u}$:

$$A = \text{cross–sectional area of pipe} = 1/4\pi(6/12)^2 = 0.20\ ft^2$$

$$\bar{u} = \frac{300{,}000\ \text{lb}}{\text{hr}}\bigg|\frac{\text{ft}^3}{51.2\ \text{lb}}\bigg|\frac{}{0.20\ \text{ft}^2}\bigg|\frac{\text{hr}}{3600\ \text{sec}} = 8.14\ \text{ft/sec}$$

Step 2. Compute the Reynolds number from Equation 1:

$$Re = \frac{0.5\ \text{ft}}{}\bigg|\frac{8.14\ \text{ft}}{\text{s}}\bigg|\frac{\text{hr}}{0.085\ \text{ft}^2}\bigg|\frac{3600\ \text{sec}}{\text{hr}} = 1.724 \times 10^5$$

Since Re> 2,100 the flow is turbulent.

Step 3. Comute the friction factor from Equation 4:

$$f = 0.0014 + \frac{0.125}{(1.724 \times 10^5)^{0.32}}$$

Step 4. Compute the friction head from Equation 5:

$$H_{fs} = \frac{2 \quad 0.00404 \quad 400\ \text{ft}\ (8.14\ \text{fps})^2 \quad \text{lb}_f\text{-sec}^2}{0.5\ \text{ft} \quad 32.174\ \text{ft-lb}_m}$$

$$H_{fs} = 13.30\ \text{ft-lb}_f/\text{lb}_m$$

Step 5. Compute the pressure drop per foot of pipe using Equation 6:

$$\Delta P/L = \frac{13.31\ \text{ft-lb}_f \qquad 51.2\ \text{lb} \qquad \text{ft}^2}{\text{lb}_m \qquad \text{ft}^3 \qquad 400\ \text{ft} \quad 144\ \text{in}^2}$$

$$\Delta P/L = 0.012\ \text{lb}_f/\text{in}^2/\text{ft of pipe}$$

Pressure Rise from Water Hammer

Disturbances or changes in a flowline can cause excessive or instantaneous rises in line pressure. This is most often caused by closing a valve or by sharp expansions or contractions in the line or other constrictions such as sharp bends, tees, etc. Water hammer can occur in any size pipeline, and it is important to note that the normal working pressure does not play a role in the intensity of the hammer. The impact of the flow stoppage is proportional to the mass of liquid holdup being stopped and the square of the flow velocity.

Air chambers are recommended for cushioning the shock; however, frequent maintenance and spot checking is required as they often become inoperable due to waterlogging.

Water hammer does not always create a noise problem. It is most often detected by violent vibration of the pipeline. Furthermore, the point of region where water hammer is detected may not be the source. Shock waves can travel over a considerable distance through the line and be the cause of damage or noise problems far from the wave source. Under certain conditions shock forces caused by water hammer can reach levels of sufficient magnitude to rupture the piping system. The buildup of shock waves is illustrated in Figure 4–3.

Proper design practices can eliminate or at least minimize water hammer. Check valves on pumps should be designed to close as quickly as possible to maintain the liquid velocity flowing back through the check valve at a minimum. Quick closing valves are most difficult to eliminate in short lines. Reliable estimates of the impact of water hammer on pressure rise should be made to ensure that the system will function properly.

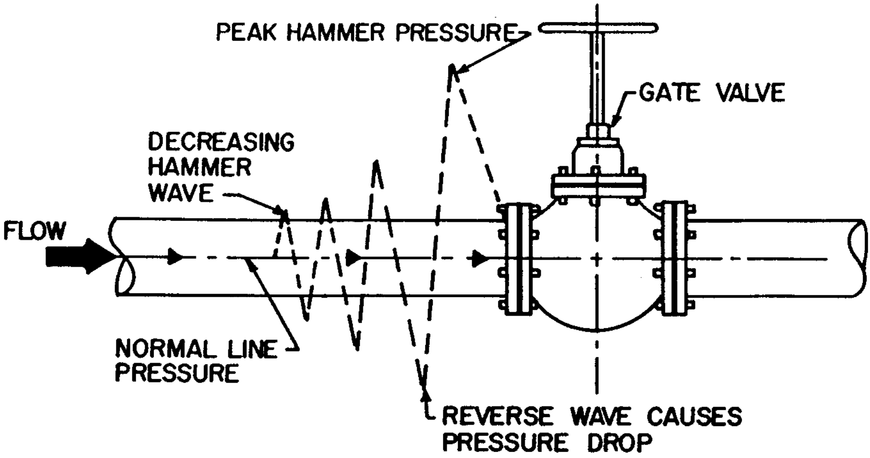


Figure 4–3: The buildup of shock waves by quickly closing a valve at the end of a line.

The velocity of the shock wave through the line can be estimated from the following expression 25:

$$\omega = \frac{12}{\left[\frac{\rho}{g_c}\left(\frac{1}{k} + \frac{D}{\epsilon\chi}\right)\right]^{1/2}} \tag{7}$$

where

ω = shock wave velocity, fps
k = bulk modulus of compressibility of the fluid, psi
ρ = fluid density, lb/ft^3
D = pipe inside diameter, ft
ε = modulus of elasticity of the pipe, psi
χ = reinforced wall thickness of the pipe, ft

For an estimate of the instantaneous rise in pressure that would be experienced from a fast valve closure at the end of a line, the following expression can be used:

$$\Delta P' = \frac{\rho\omega U}{144\ g_c} \tag{8}$$

where $\Delta P'$ is the pressure rise above normal (psi). Equation 8 is subject to the constraint:

$$t < \frac{2L}{\omega} \tag{9}$$

where

t = elapsed time for closing the valve completely,
L = length of straight pipe into the valve, ft

For a situation in which the valve is closed slowly, the following set of expressions are recommended for use along with Figure 4–4:

$$K = \frac{\omega U}{2gh_o} \tag{10}$$

$$N = \frac{\omega t}{2L} \tag{11}$$

where

g = acceleration due to gravity, 32.2 ft/sec^2
K = top axis of plot in Figure 4–4
N = left axis of plot in Figure 4–4
h_o = normal head for steady flow, ft

Equations 10 and 11 are subject to the condition:

$$t > \frac{2L}{\omega} \tag{12}$$

Once parameters k and N are known, Figure 4–4 can be used to estimate the fractional rise in pressure, F, defined by:

$$F = \frac{h_o + \Delta P'}{h_o} \tag{13}$$

The following example problem illustrates the use of Equations 7–13 and Figure 4–4.

Illustrative Example 4.2

A 5–in i.d. FRP pipeline, 2,000 ft long, is to be used to transport oil at near ambient conditions. The system is to be designed for a normal operating head of 70 ft and a full pipe flow velocity of 8 ft/sec.

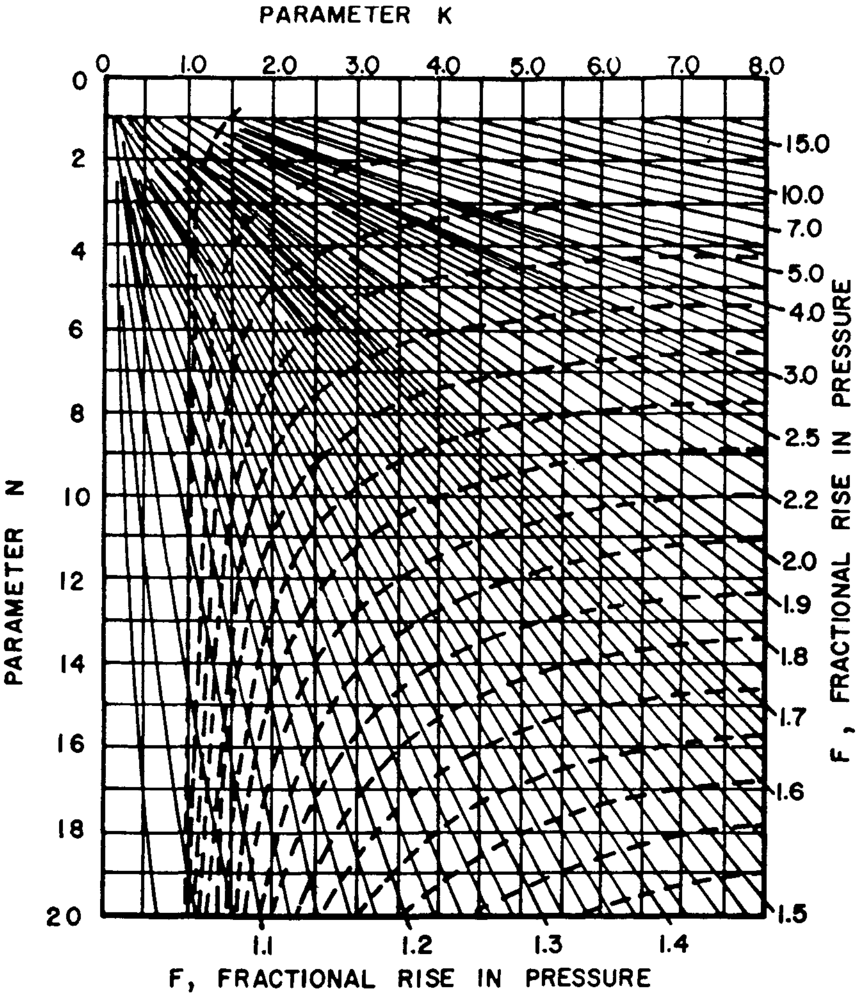


Figure 4–4: Pressure rise prediction plot for slow valve closure.

The pipe selected is rated at 170 psi. The density of oil under the system's conditions is 49.9 lb/ft^3, and the bulk modulus of compressibility of the oil is approximately 2 × 10^5 psi. The pipe wall thickness is 1/8 in, and the modulus of elasticity is 4.2 x 10^6 psi.

1. Compute the rise in pressure for an instantaneous valve closure at the end of the line and determine whether the pipe chosen will meet the expected increase.
2. Compute the pressure rise if a valve closure time of 15 sec is used and determine whether the chosen pipe will meet the expected increase.

Solution a:

Step 1. Compute the shock wave velocity from Equation 7:

$$\omega = 12 \quad \frac{49.9}{32.174} \quad \frac{1}{2 \times 10^5} + \frac{5}{(4.2 \times 10^6)\ (0.125)} \quad ^{-1/2}$$

$$\omega = 2528.4 \text{ ft/sec}$$

Step 2. Compute the pressure rise from Equation 8:

$$\Delta P' = \frac{(49.9)\ (2528.4)\ (8)}{(144)\ (32.174)}$$

$\Delta P'$ = 217.8 psi, the increase in pressure due to water hammer

Step 3. Compute the resultant line pressure and compare to the pressure rating of the pipe. The resultant line pressure from an instantaneous valve closure is the sum of the pressure rise and normal head, h_o:

$$h_o = (70 \text{ ft } H_2O)\ (0.433) = 30.3 \text{ psi}$$

therefore

$$\text{line pressure} = 217.8 + 30.3 = 248.1 \text{ psi}$$

This is above the recommended operating pressure of the pipe selected.

Solution b:

Step 1. Check which boundary condition, t, matches Equations 9 and 12:

$$\frac{2L}{\omega} = \frac{2(2.000)}{2528.4} = 1.6 \text{ sec}$$

Since t > 1.6 sec, Equations 10 and 11 are applicable.

Step 2. Compute parameters k and N from Equations 10 and 11, respectively:

$$K = \frac{(2528.4)\ (8)}{(2)(32.2)(70)} = 4.49$$

$$N = \frac{(2528.4)(15)}{2(2000)} = 9.48$$

Step 3. Locate the point designated by the values for K and N on the plot in Figure 4–4 and interpolate between diagonal lines to the F axis to obtain F = 1.6.

Step 4. Compute the total line pressure at the peak:

$$F = \frac{h_o + \Delta P'}{h_o} = 1.6$$

$$h_o + \Delta P' = (1.6)(70) = 112 \text{ ft}$$

or the total line pressure in psi would be

$$(112)(0.433) = 48.5 \text{ psi}$$

which gives a 71% safety margin over the recommended operating pressure of the pipe.

Whenever possible, the piping system should be hydrostatically tested before initiating service. As in actual operation, care should be taken to avoid water hammer. As a further precaution against damage from water hammer as well as external vibrations or shock loads, connections to pumps and other equipment should consist of flexible connections. Flexible connections compensate for vibrations by absorbing shock and thus eliminate the placing of undue strain on pipe and fittings. Expansion joints like the bellows design shown in Figure 4–5 are recommended. These are often constructed from Teflon; however, a wire reinforced rubber hose can serve the purpose in many low to moderate pressure applications. Note that the latter requires much higher forces to compress and elongate and, as such, is not considered the better of the two options.

Raised–face flanges are often used to mate with butterfly or check valves that have partial liner facings, Van Stone flange hubs and various other components that do not have full, flat–flange faces. Some of these raised–faced flanges are equipped with a ring spacer between the gasket and the flange or component having the raised face. The spacer serves the purpose of filling the gap outside the raised face to prevent bolt loads from cracking the FRP flange or breaking it away from the pipe.

Gasket sealing can be achieved without the use of a spacer ring if proper connection procedures are practiced. Flanges and components should be bolted together. Flange bolts should be tightened to only 15–20 ft–lb torque. This will produce a good gasket seal in most applications as usually only a small ring of the gasket need be compressed.

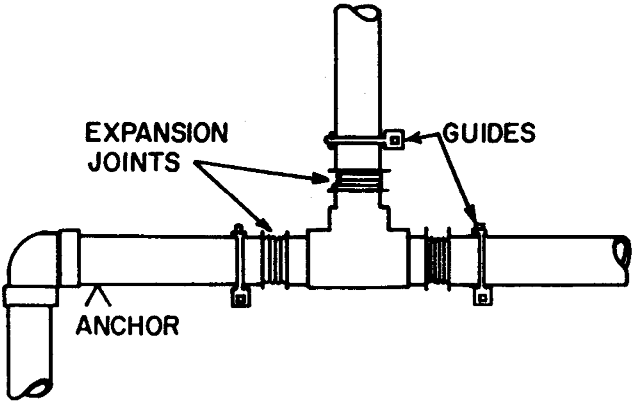


Figure 4–5: A bellows expansion joint is recommended for reducing shock loads and vibrations.

Fluid pressure should then be supplied to the line; if leaks are detected, the bolts should be retightened. Care should be taken to ensure equal torque on all bolts. The use of a torque wrench is advisable.

Thermal Expansion and Contraction

Physical properties of FRP pipe were discussed in an earlier chapter. Physical properties and strengths vary with the resin system and fabrication *(i.e.,* centrifugally cast or filament wound). The coefficient of thermal expansion is approximately 10.5×10^{-6} in./in./°F for centrifugally cast pipe and 13×10^{-6} in./in./°F for filament–wound pipe. Figure 4–6 is a plot of one FRP pipe manufacturer's data on the total expansion per 100 ft of pipe for increments of temperature.

This type of information must be incorporated into the design of a piping system. Such information is critical when metal to FRP combinations are used. In general, FRP are good thermal insulators, that is, they conduct heat more slowly than metal, which expands and contracts more rapidly. This must be considered carefully to prevent any excess stress on FRP pipe or components when connections are made to metal piping systems. Tanks, steel piping and other structures can transmit significant stresses to FRP pipe; hence, these deflections created by the non–FRP system must be compensated for by independent means. In a piping system, non–FRP lines should be anchored immediately before the FRP connection to ensure that any thermal strain is not transmitted to the FRP system.

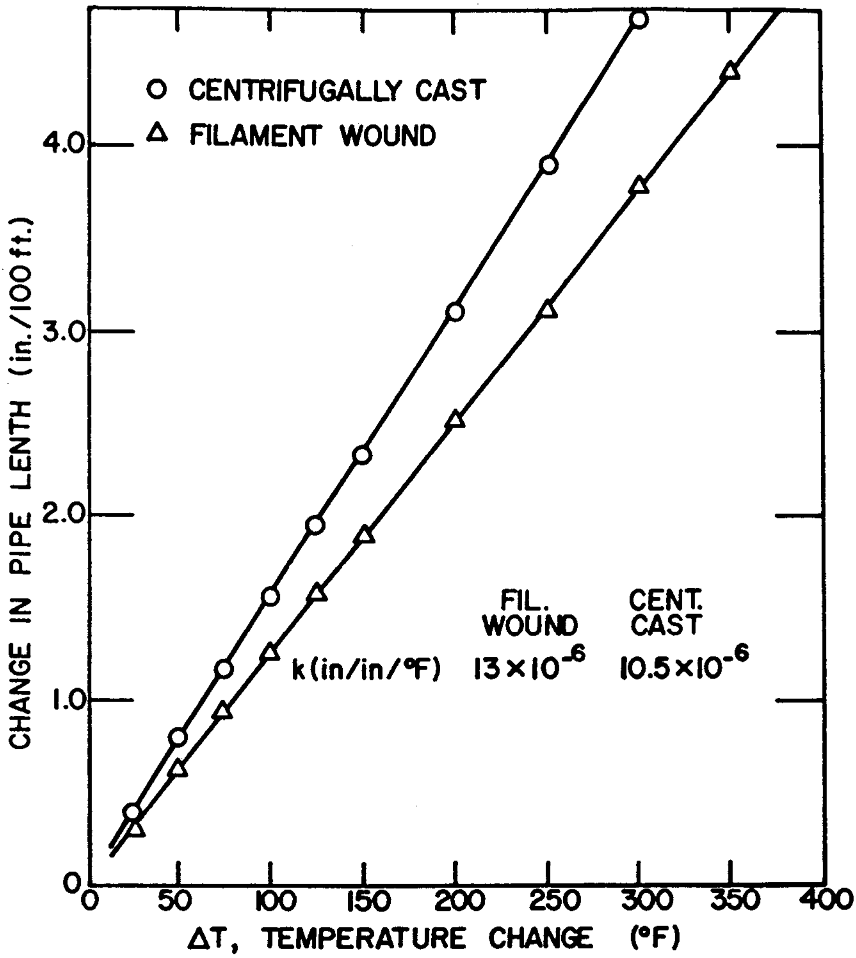


Figure 4–6: Expansion as a function of temperature change.

Usually, directional changes in piping systems can compensate for small expansions due to temperature changes (the same is often true for contractions due to drop in temperatures). Expansion joints or expansion loops should be designed into the system wherever possible to prevent overstressing.

When expansion joints are used, they should be preset to properly allow for both expansion and contraction. The amount of precompression necessary for an expansion joint can be computed from the following expression:

$$C_p = \frac{R_M\,(T_i - T_m)}{\Delta T} \qquad (13)$$

where:

C_p = amount of precompression, in.
R_M = expansion joint rated movement, in.
T_i = temperature at which system was installed, at °F
T_m = minimum operational temperature anticipated, °F
ΔT = operational temperature difference anticipated, °F

If expansion joints are not employed in a system, then the piping arrangement must be designed to absorb the expansion or contraction. End loads are caused when the pipe is restrained and no proper means of expansion is provided. Such situations require guiding to keep the pipe straight. Guides direct forces in the axial direction and prevent buckling.

When the piping system is allowed to move freely with temperature change, care must be taken to ensure that all fixed points, anchors, laterals, elbows, etc. are within the recommended safe stress level. High stress levels can be minimized by employing one or more 90° bends with adequate pipe leg between anchors or rigid mounting stations, as shown in Figure 4–7.

The amount of expansion that can be handled by right angle pipe legs can be estimated from the plot shown in Figure 4–8, which is a plot of the allowable deflection vs pipe length with pipe diameter as a parameter. For pure thermal stress, the amount of expansion at the point of leg attachment is expressed by:

$$\Delta x = kL\Delta T \qquad (14)$$

where:

Δx = expansion, in.
k = coefficient of thermal expansion, in./in./°F
L = pipe length, in.
ΔT = temperature change, °F

From Equation 14 and Figure 4–8, the necessary pipe leg length can be obtained to take up the anticipated expansion.

Another approach to this problem is to anchor the pipe at some intermediate point and direct the expansion to another portion of the system. To eliminate expansion completely, long straight runs can be anchored at both ends. If the latter arrangement is selected, anchors must be designed to meet the end force, which is the total force resulting from both the internal operating pressure and the thermal expansion stress.

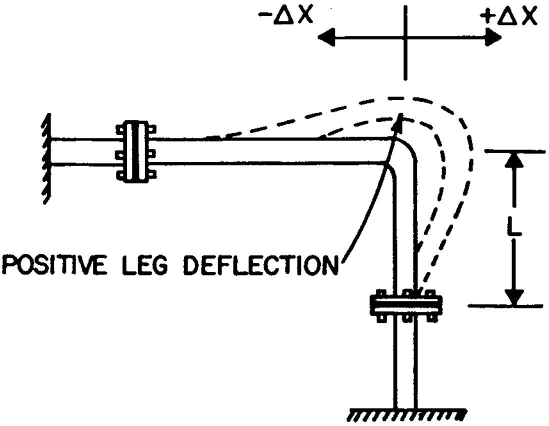


Figure 4–7: High stress levels can be minimized by using at least one 90° bend with sufficient pipe length, L, between anchors.

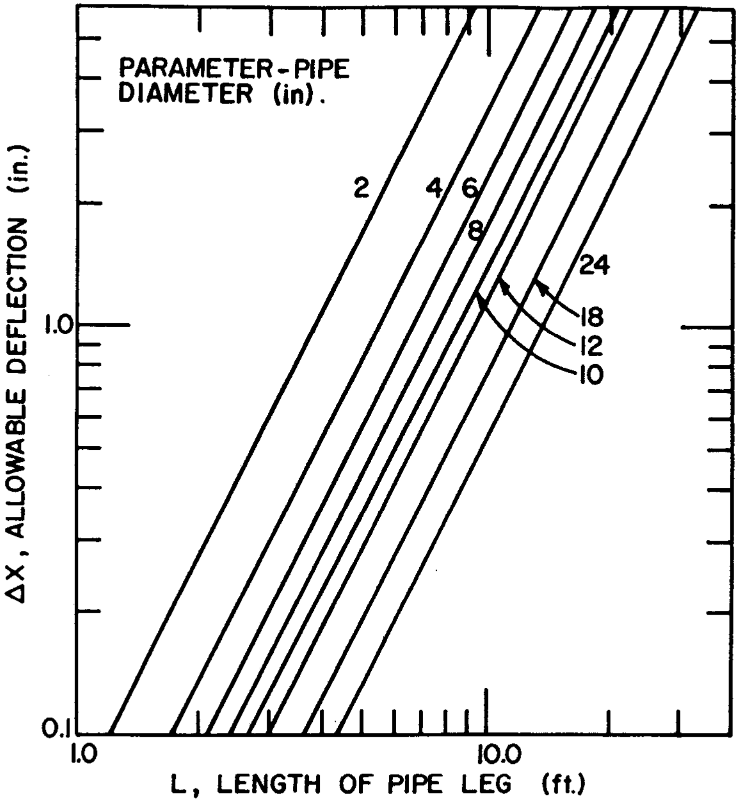


Figure 4–8: The allowable deflection for right angle pipe legs.

The end force resulting from the internal operating pressure of the system can be estimated from the plot shown in Figure 4–9. Figure 4–9 is a plot of end force, F, vs operating pressure, P, with pipe diameter as a parameter. The amount of end force exerted on anchors due to thermal stress from expansion and contraction can be estimated from the plots shown in Figures 4–10 and 4–11, respectively.

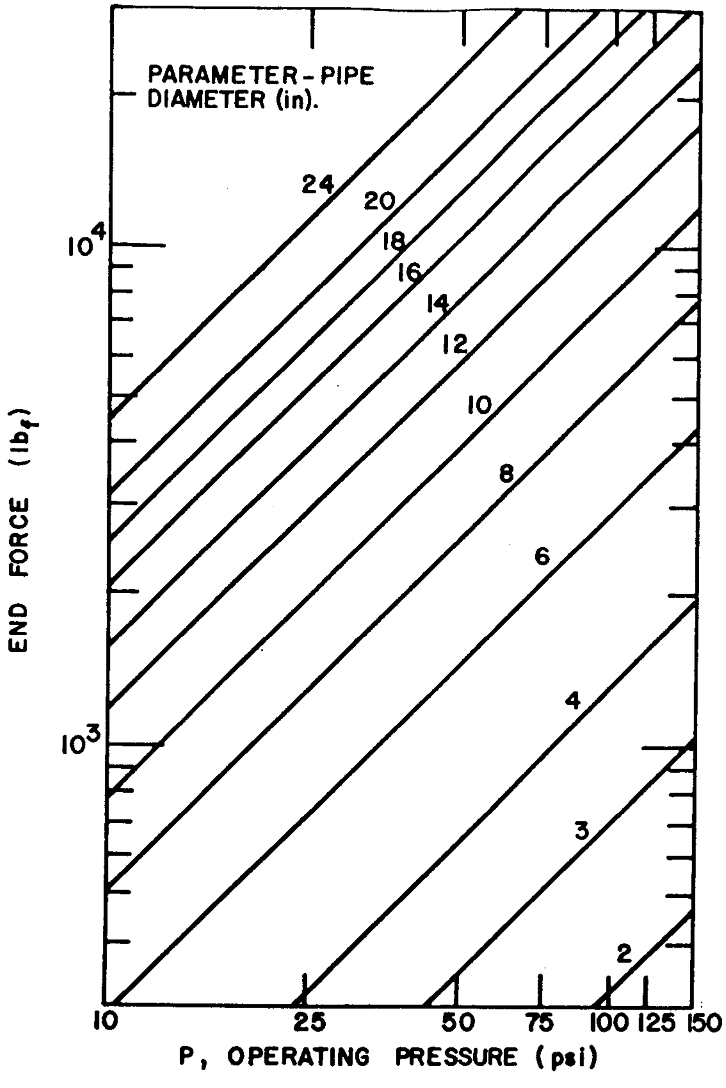


Figure 4–9: End force exerted on anchors due to internal pressure.

When employing guides with expansion joints, care must be taken in their selection and spacing throughout the system. They must be rigidly fixed to the supporting structure and permit pipe movement only in the axial direction. The guiding mechanism should be loose enough to permit free axial movement. The most common types of guides are U bolts that are double nutted (shown in Chapter 3).

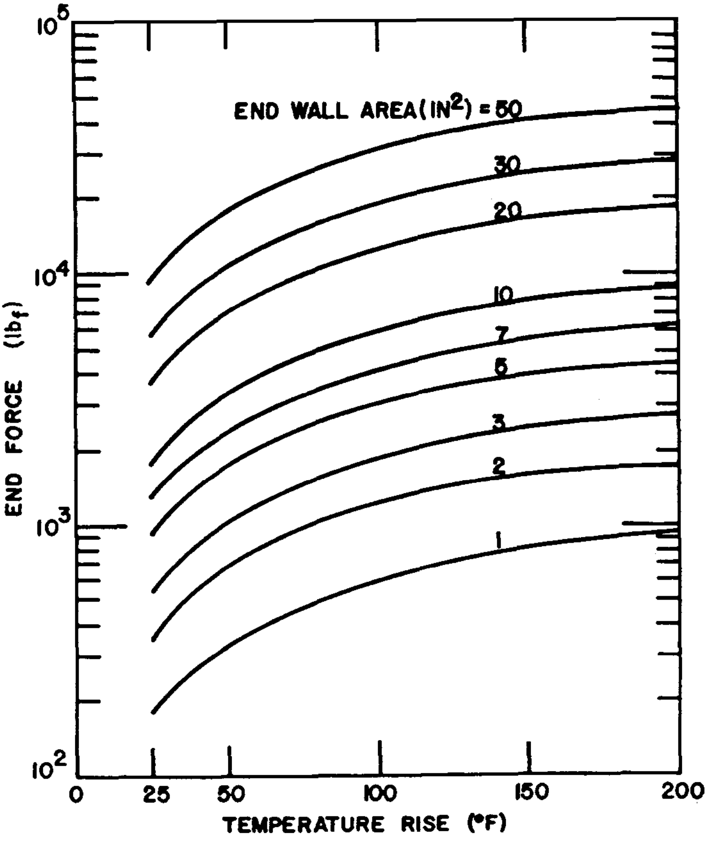


Figure 4–10: End force exerted on anchors due to expansion.

Guides immediately adjacent to expansion joints are referred to as primary guides. A secondary guide is one that is adjacent to a primary.

These are usually more closely spaced than intermediate units. Manufacturers should be consulted for recommendations on guide spacings. Table 4–4 can serve as a rough guide to primary and secondary guide spacings.

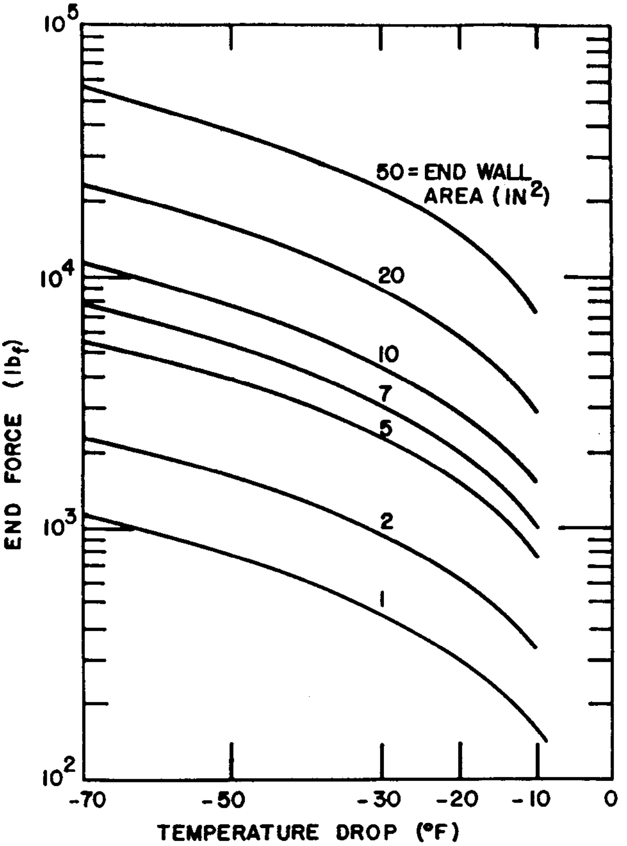


Figure 4–11: End force exerted on anchors due to contraction.

Table 4–4: Distance from Expansion Joints to Primary and Secondary Guides

Nominal Pipe Size (in.)	Distance to Primary Guide (ft)	Distance to Secondary Guide (ft)
1.5	0.67	2.50
2	0.83	3.00
2.5	0.92	3.25
3	1.00	3.50
4	1.33	4.67
6	2.00	7.00
8	2.67	9.33
10	3.33	11.67
12	4.00	14.00

Note that when U bolts are used as anchoring devices, pipe should be protected from excessive pressure. In general, supports that make only a point contact or have narrow supporting areas should not be used unless additional protection is supplied *(i.e.,* some means for increasing the supporting area should be employed).

If fabricated adhesive joints are to be employed in outdoor installations in cold weather, certain precautions must be taken. First, it is important that the ends of the pipe and the inside walls of the sockets be thoroughly dry. It is often advisable to preheat the end of the pipe and the sockets of the fitting prior to applying the adhesive. The adhesive's temperature should also be raised prior to mixing and application. Adhesives can be warmed by allowing the temperature of the adhesive container to gradually increase in a warm room, an oven or by placing sealed containers in a bucket of warm water until the desired temperature is reached (usually 100°F). The purpose of warming the adhesive is to provide heat inside the socket of the connection to facilitate curing. External heat can be applied around the outside of the connection to ensure full curing. Heat can be supplied from electric heat guns, electric heat bands or blankets, heat lamps or propane torches. If propane torches are used, care must be taken to avoid the open flame from coming into direct contact with pipe, connections and adhesives. Aluminum foil can be placed over the joint surfaces to provide protection from flames.

In colder regions, especially where a large number of joints require heat application, heat chambers or hot rooms that employ gas burners with blowers can be employed. Other possible sources include exhausts from engines and electrical room heaters. FRP pipe and fittings that are to be employed in cold weather installations should be fabricated into subassemblies on the inside of a shop when allowable. Warmer conditions in enclosed areas facilitate curing of adhesive joints, which can lead to savings of installation labor and time.

Sanded surfaces should be kept moisture free so that the adhesive can produce an effective bond and prevent improper curing. This will also aid in a more even application of adhesive.

The minimum recommended cure temperature is approximately 60°F. Cure temperatures as high as 200°F greatly accelerate cure time and make a stronger joint. If adhesives are allowed to cure below 60°F, inadequate joint strengths may result. Manufacturers should be consulted for curing time–temperature charts for commercial adhesives, such as the one shown in Figure 4–12.

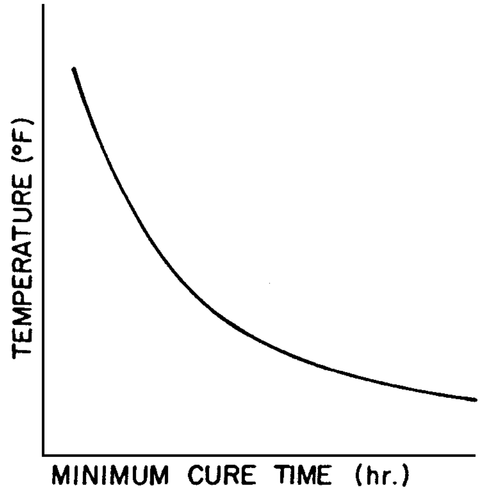


Figure 4–12: Typical adhesive cure time–temperature chart.

Pressure Service and Vacuum Considerations

The wall thickness for FRP pipe that is to be fabricated for pressure service can be computed from Barlow's formula:

$$x = \frac{PD}{2\gamma} \tag{15}$$

where

x = laminate wall thickness required, in.
P = operating pressure, psi
D = inside diameter of pipe, in.
γ = design stress, psi

After the system has been installed, it should be tested for leaks by filling the lines with water and pressurizing to one and a half times the rated pressure of the pipe. Testing with compressed air or gases is dangerous and is not recommended.

Consideration should be given to protection against the occurrence of high vacuums during operation as reinforced plastics have relatively low moduli of elasticity. Adequate vacuum protection can be accomplished by employing vacuum release valves or stand pipes. Vacuum lines should be supported by 180° saddles and should not be exposed to any external loads. Whenever flow velocity is suddenly disrupted (e.g., pump shutoff or valve closure), vacuum conditions may arise.

Pipe Components and Joining Methods

The proper selection of valves for a piping system is a key issue. Select valves that have linings that are corrosion resistant to the liquid environment. They must have a full face flange that will prevent over–stressing adjoining FRP flanges and should have a gear operator or an equivalent to prevent water hammer from occurring due to instantaneous shutoff.

If throttling is desired, only gate/valves or orifice plates should be employed. Butterfly valves or disc valves are not recommended as they may cause nonuniform flow pressure leading to cavitation in FRP pipe. This disruption in flow caused by these types of valves is illustrated in Figure 4–13.

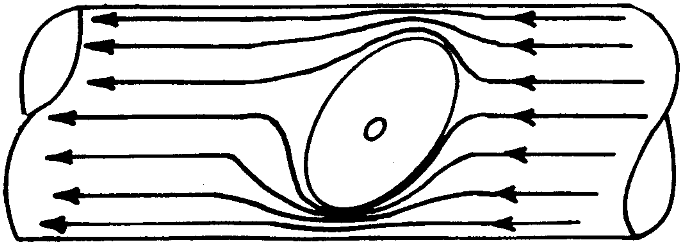


Figure 4–13: Butterfly or disc valves can cause nonuniform flow pres–sure which may lead to cavitation in FRP pipe.

The selection of the proper joining method is also an important con–sideration particularly from the standpoints of service requirements and total installation costs. There are a variety of joining techniques that can be used. One of the most common techniques used to join FRP pipe is the butt and strap arrangement illustrated in Figure 4–14. The method gives a strong joint and can be made readily in the field. Connections are made by butting two sections of pipe together and overwrapping the joint with successive layers of fiberglass reinforcement. The reinforcement should be saturated with the appropriate resin. Layers of reinforcement should be applied until the thickness is at least that of the pipe wall. Pipe, elbows, tees, reducers and various other fittings can be joined by this method. The joint must first be prepared by sanding and cleaning the pieces to be joined. They are then butted together and overwrapped with the composite of fiberglass reinforcement saturated with catalyzed resin. The overlapping hardens quickly, giving a permanently bonded butted section.

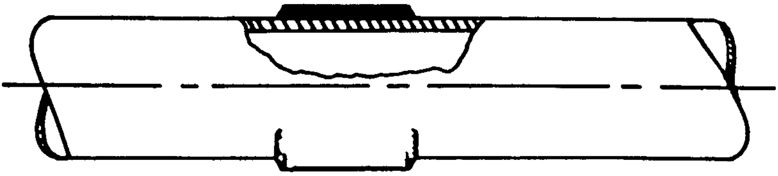


Figure 4–14: The butt and strap pipe joining arrangements.

Threaded connections are often preferred because they require no adhesives. Usually, an elastromeric gasket can be used to provide the seal. With this joint, only the coupling need be turned to join the pipe. This joining method is designed for rapid field assembly of long runs and is often used for temporary installations. It is also useful in wet or cold environments for permanent installations.

Threaded and bonded joints improve the reliability of bell and spigot joints. This reduces the opportunity for installation errors under all temperature conditions. This joining method combines both threads and adhesive on bonding surfaces. The threads promote a mechanical locking action that gives positive makeup and eliminates backout during adhesive curing. Standard bell systems can be used with this system (Figure 4–15). Note that the pipe should be inspected carefully for damage to the bell or spigot prior to installation, as transportation, storing and handling often incur rough treatment. Impaired or damaged portions should be cut away or repaired.

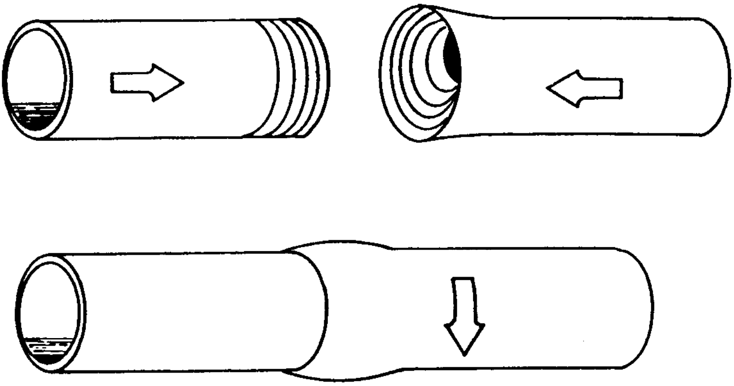


Figure 4–15: Threaded and bonded joints improve bell and spigot joints.

Wherever possible, prior to installation, lay out individual pipe lengths along the planned route. Make sure all spigot ends are pointing in the same direction; there is, however, no difference which direction the spigots point relative to the direction of flow. For easier assembly, pipe can be laid over skids. Portable bench setups for tapering and bonding are recommended for shorter and more complicated installations.

For long runs, the minimum recommended crew size is three. As pipe diameter increases, so should crew size. One man should be assigned the task of joint cleaning and pipe alignment. Other members should spread the adhesive and make up the joints. Additional manpower may be necessary for mixing adhesives or to provide additional heat to assist curing.

For complex assemblies, the size of the crew will depend on the amount of tapering and prefabrication required. The crew should be organized so that adhesive is spread onto the bonding surface in as little time as possible, especially in hot or humid weather.

Pipe can be cut by circular saws with reinforced abrasive blades, hacksaws or sabersaws with fine teeth. For square cuts, a line should be scribed around the pipe as a cutting guide. There are a variety of tapering tools available; the specific choice depends on the required tolerances. Any matched taper will have minor variations in tolerance. As in the bell and spigot joint, this will affect the insertion depth. If the final length of makeup is not critical, variations are not important. For close tolerances, compensation must be made.

By carefully marking and adjusting tapering tools, a standard reproducible taper can be achieved in the field. The nature of the adjustment differs with the tool used. As a guide, always check the tapering tool blade setting by inserting the tool into a factory taper. The blade must fit the taper snugly and evenly over the entire length. The location of the pipe end should be marked on the mandrel or cutting head. This provides a reference point and stop (i.e., all future tapers can then be made such that the pipe end terminates at the mark). If the pipe is not square cut, position the pipe in a vise so that the long side is always on top. In this way, the taper will be based on the long side, which will provide the deepest insertion into the fitting.

The insertion length (Figure 4–16) should be obtained by inserting a taper, fashioned from the tool being used, into a fitting and measuring after removal. Usually a short nipple can be made to serve as the standard insertion gauge. A makeup dimension should be added to this measurement as adhesive will tend to act as a lubricant and cause greater penetration than when surfaces are dry. As a rough guide to makeup dimensions, refer to Table 4–5.

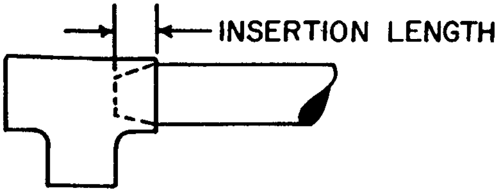


Figure 4–16: Insertion length can be determined by inserting a taper into a fitting and measuring.

Table 4–5: Recommended Make–up Dimensions

Inside Diameter (in.)	Approximate Make-up Diameter (in.)
1	1/8
1 1/2	1/8
2	1/4
3	1/4
4	1/4
6	1/4
8	3/8
10	5/8
12	5/8
14	3/4
16	1

Before installation, be sure bonding surfaces have a factory–fresh appearance. If pipe has been stored outside it will weather, causing a loss in bond strength. If weathered surfaces are detected, spigots should be re–tapered and bells sanded.

Surfaces should be cleaned thoroughly with solvent and paper towels. Methylene chloride, acetone or methyl ethyl ketone are all good joint cleaners. Cleaning should be thorough to remove all oil, grease, mud, fingerprints, etc. After cleaning, the joint surface should not be handled to prevent recontamination.

Adhesives should be mixed thoroughly and packaged instructions should be followed carefully. As pointed out earlier, if adhesives have been stored in temperatures below 60°F, they should be prewarmed prior to mixing with catalysts. Mixing should be continued until the adhesive has a consistent flow off the mixing stick.

Suppliers of adhesive kits will generally warn the user about the working life or pot life of the adhesive. Pot life is the time taken for the adhesive to harden in the mixing container, as measured from the time the hardener and adhesive are mixed. At high temperatures, usually above 80°F, pot life shortens; as temperature drops, pot life increases. The pot life is also affected by the amount of adhesive. The working life can be extended slightly in hot weather by spreading the mixture out into a thin film. This can be done by spreading it out onto a clean sheet of foil.

When using the bell and spigot joining arrangement, the spigot must be aligned and locked in the bell. If the joint is misaligned or cocked, the bond eventually will fail. After cleaning, the surface should be prewarmed if temperatures are significantly below that of the adhesive. A clean–burning heat source such as a propane torch can be used. The torch should have a spreader–type tip so that the heat may be applied uniformly to the bell and spigot. The temperature can be checked by touching the outside of the bell and the inside of the spigot to avoid contacting the bonding surfaces. The surfaces should not be hot to touch, only warm. Before the flame is allowed to contact surfaces, allow all the joint cleaner to evaporate or a smude deposit will develop. If electric heating collars or blankets are used for prewarming, the joint should be connected dry and the heater wrapped about the outside of the bell to prevent contamination of the spigot.

Adhesive should be applied to both surfaces by brush as a thin uniform layer. The adhesive should coat deep into the bell, past the insertion depth. All machined–tapered surfaces on the spigot and the cut end of the pipe should be coated uniformly. Too much adhesive makes it difficult to lock the joint and may result in a flow restriction.

To make the final connection, insert the spigot into the bell until the surfaces are in contact, then push while turning simultaneously until the joint is locked. Usually a half to a full turn is required. For large–diameter pipes, turning may not be practical. Additional driving force can be supplied to achieve the locked joint with "come–alongs" or a piece of wood and a mallet.

For come–alongs, use 5/8 in or larger manila rope. A series of half hitches should be fashioned to grip the pipe. Hitches should be positioned 1.5–2 ft from the joint, allowing sufficient room to operate. Takeup should proceed slowly, and the joint should be worked together with care to avoid misalignment. The come–along will have a cocking tendency that can be counteracted by rapping on a board held against the joint with a hammer. The joint should be forced together until no further movement can be seen in the joint when the free end of the pipe is moved about (Figure 4–17).

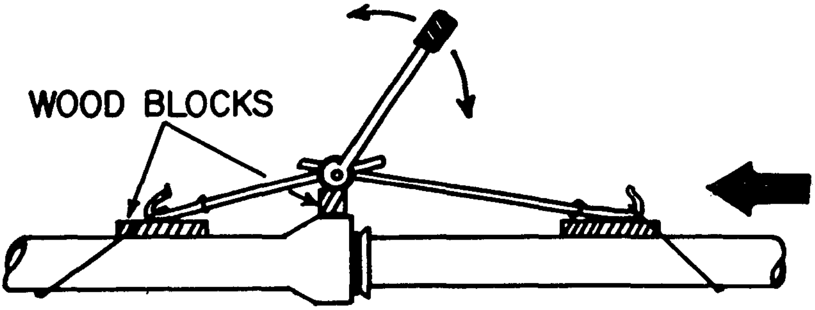


Figure 4–17: Come–alongs can be used on large–diameter pipes.

For smaller–diameter pipe, driving force can be supplied by placing a strong board flat across the bell and rapping it squarely with a hammer. The first series of raps should be light to avoid any backing out tendencies. –Stronger blows can be used once adhesive begins squeezing out of the joint. Back pressure should be applied to previously assembled joints to prevent them from loosening up. When engagement has stopped, the joint is locked into place.

One of the easiest joints to make is shown in Figure 4–18. The female has a rubber gasket about it and an outer coupling tightens the male over the spigot, forcing the gasket to compress, thus effecting a seal. Before assembly, the gasket should be checked to ensure that it is properly seated over the female. The unit should be assembled with the male thread pointing in the direction of assembly. Care must be taken to prevent misalignment, which can cause a false lock of the threads.

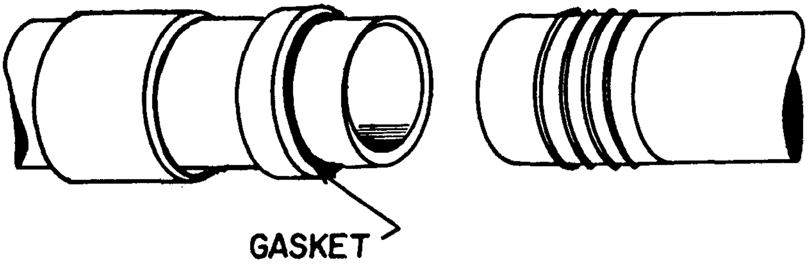


Figure 4–18: Threaded pipe joint for temporary installations.

In Chapter 3, several methods were illustrated for connecting FRP pipe to components made of materials other than reinforced plastic. For connections to process equipment, valves, meters, pumps, etc., flanges must be used. Flanged connections should also be used where disassembly is anticipated. Flanges should be bolted to full-face flanges. As Iq earlier, if full-face flanges are not used, proper spaces (Figure 4-19) should be employed to build up the flange to a flat surface. This will prevent overstressing the FRP flange. If existing flanges cannot be modified to give full-face flange contact, then "Van Stone"-type flanges can be used (Figure 4-20).

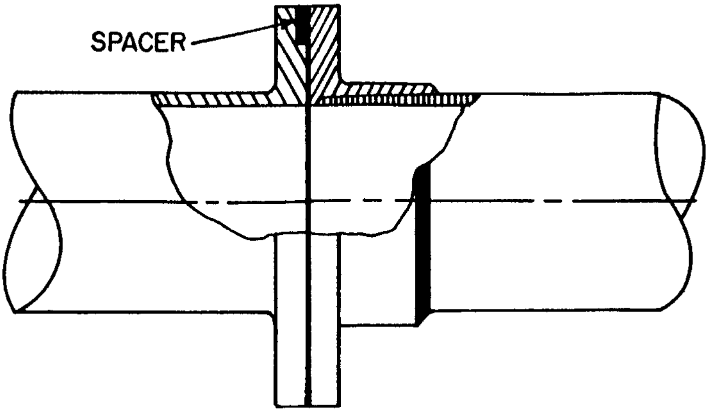


Figure 4-19: Spacers should be used to build up flange surfaces to a flat face.

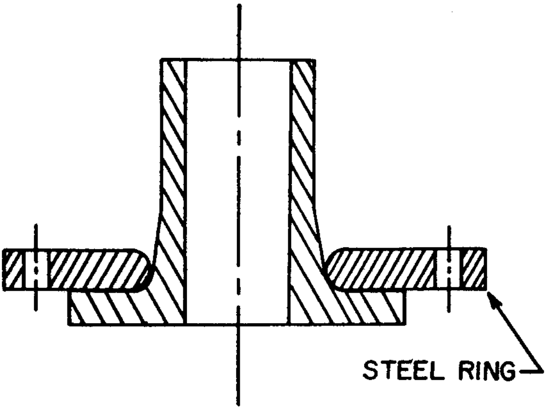


Figure 4-20: Van Stone-type flange.

Flanges are available in standard straight socket style and in tapered socket. The latter design provides a fast and accurate joining method that can be done in the field or in the shop. To make a tapered joint, a cut must be taken on the pipe end (tapered to 1-1/2°+) with a pipe-tapering tool. An adhesive is applied to the flange socket and the tapered end of the pipe and the two components are then fitted together. A 1-1/2° taper on the pipe end minimizes variations in wall thickness normal to the pipe and matches the angle of the socket interior. Matching angles ensure that the adhesive volume decreases as the pipe is inserted. The excess adhesive is extruded back between the pipe and socket, forming a radius which completes the gluing operation. A close fit is obtained by this method, which provides a uniform, thin glue line and minimizes voids in the adhesive layer.

Contact–molded flanges can be used for moderate–to–high–pressure systems and large diameters. They are fabricated by essentially the same technique as that of making contact–molded pipe, whereby successive layers of fiberglass reinforcement saturated with the appropriately catalyzed resin are laid over individual, precision–made molds to a specified thickness. The technique provides a smooth interior surface and these types of flanges have excellent strength characteristics and chemical resistance.

Full–face gasketing materials should be selected on the basis of their chemical resistance to the liquid environment. Red sheet rubber or Neoprene are employed in most applications. Other gasketing materials suitable for use with FRP flanges include Teflon R, PVC and asbestos. FRP pipe manufacturers should be consulted when making gasket material selection.

In addition to flanges, grooved and threaded–end adapters can be used for connecting FRP pipe to other systems. Grooved adaptors should not be employed with plastic– or cement–lined steel couplings. These can cause leaks because of differences in groove dimensions. A standard high pressure coupling or equivalent is recommended.

Threaded adapters should be threaded into the other system before they are bonded to FRP pipe because unless a union is employed it may not be possible to turn the adapter into the mating thread.

BURIED INSTALLATIONS

The depth, grade and general layout or contour of a trench will depend on the project specifications. However, general guidelines have been established.

The width of the trench floor should be roughly one to two foot wider than the diameter of the pipe to be installed. This will allow sufficient clearance for working crews and is optimum for compacting the backfill. If unstable soil conditions exist, the trench width should be widened to remove unwanted matter adjacent to the pipe. Stable backfill material should be used to replace the additional removal. As standard safety practice, trenches should be shored and drained.

Bell and spigot joints allow the pipe to be deflected at each point for alignment adjustments and for curves, as shown in Figure 4–21. Table 4–6 gives rough estimates of the amount of joint deflection possible and the resulting radius of curve for two different lengths of pressure and non pressure pipe. The table should be used in conjunction with Figure 4–21.

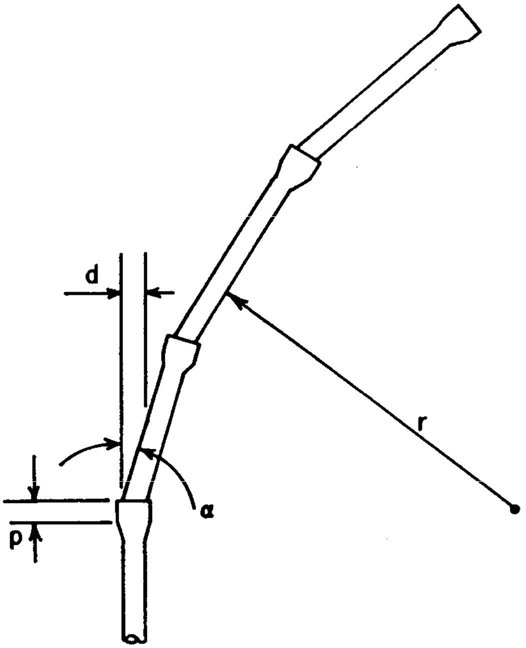


Figure 4–21: Illustrates the important dimensions in bending lines in a trench: α = maximum angular deflection per joint; p = maximum pull per joint; d = maximum linear deflection per joint; and r = minimum curve radius.

If the design calls for curves of shorter radius than can be obtained with deflected joints, then fittings will be necessary. Extra trench space is then required for working.

The trench bedding should be uniform and continuous. The floor should be free of rocks greater than 1 in., lumps or debris. It is often recommended that excavation be at least 1 in. below grade and then the bottom can be built backup with rock–free granular soil. For rougher terrain, where the soil is saturated, full of stones, or the trench is rock base, over–excavation is recommended to at least 6 in. below the grade. This can then be replaced with granular soil or crushed stone.

Table 4–6: Permissible Curve Radius and Joint Deflection for Pressure and Nonpressure Pipe

				Length = 10 ft		Length = 20 ft	
Inside Diameter (in.)	a, Maximum Angular Deflection Per Joint (°)		p, Maximum Pull Per Joint (in.)	d, Maximum Linear Deflection Per Joint (in.)	r, Minimum Curve Radius (ft)	d, Maximum Linear Deflection Per Joint (in.)	r, Minimum Curve Radius (ft)
8	5	0	3/4	10 1/2	115	21	230
10	5	0	1	10 1/2	115	21	230
12	5	0	1 1/4	10 1/2	115	21	230
14	5	0	1 3/8	10 1/2	115	21	230
15	5	0	1 3/8	10 1/2	115	21	230
16	4	0	1 1/4	8 3/8	145	16 3/4	290
18	4	0	1 3/8	8 3/8	145	16 3/4	290
20	4	0	1 1/2	8 3/8	145	16 3/4	290
21	4	0	1 5/8	8 3/8	145	16 3/4	290
24	4	0	2	8 3/8	145	16 3/4	290
27	4	0	2	8 3/8	145	16 3/4	290
30	3	50	2 1/8	7 5/16	177	14 5/8	354
33	2	45	1 3/4	5 3/	250	11 1/2	500
36	2	35	1 3/4	5 7/16	266	10 7/8	532
39	2	35	1 3/4	5	286	10	572
42	2	15	1 3/4	4 11/16	308	9 3/8	616
45	2	0	1 3/4	4 1/4	344	8 1/2	688
48	2	0	1 3/4	4 1/4	344	8	688
54	2	0	1 7/8	4 1/4	290	8 1/2	580
60	2	0	2	4 1/4	290	8 1/2	580

(continued)

Table 4–6: (continued)

				Length = 10 ft		Length = 20 ft	
Inside Diameter (in.)	a, Maximum Angular Deflection Per Joint (°)		p, Maximum Pull Per Joint (in.)	d, Maximum Linear Deflection Per Joint (in.)	r, Minimum Curve Radius (ft)	d, Maximum Linear Deflection Per Joint (in.)	r, Minimum Curve Radius (ft)
8	3	0	1/2	6 1/4	190	12 1/2	380
10	3	0	5/8	6 1/4	190	12 1/2	380
12	3	0	3/4	6 1/4	190	12 1/2	380
14	3	0	3/4	6 1/4	190	12 1/2	380
15	3	0	7/8	6 1/4	190	12 1/2	380
16	3	0	3/4	6 1/4	190	12 1/2	380
18	3	0	1	6 1/4	190	12 1/2	380
20	3	0	1 1/8	6 1/4	190	12 1/2	380
21	3	0	1 1/4	6 1/4	190	12 1/2	380
24	3	0	1 3/8	6 1/4	190	12 1/2	380
27	3	0	1 1/2	6 1/4	190	12 1/2	380
30	3	0	1 5/8	6 1/4	190	12 1/2	380
33	2	0	1 1/4	4 3/16	285	8 3/8	570
36	1	50	1 1/4	3 3/4	310	7 1/2	620
39	1	40	1 1/4	3 1/2	345	7	690
42	1	36	1 1/4	3 11/32	356	6 11/16	712
45	1	30	1 1/4	3 1/8	380	6 1/4	760
48	1	24	1 1/4	2 15/16	410	5 7/8	820
54	2	0	1 7/8	4 1/4	290	8 1/2	580
60	2	0	2	4 1/4	290	8 1/2	580

High spots in the trench floor promote uneven bearing on the pipe and may cause damage due to stress from backfill. They may also cause excessive wear, particularly when pulsation occurs in lines due to pumping.

Bells should be provided with depressions on the trench bottom to provide clearance and provide the proper support along the pipe length. Figure 4–22 illustrates the recommended manner in which pipe should be laid in a trench.

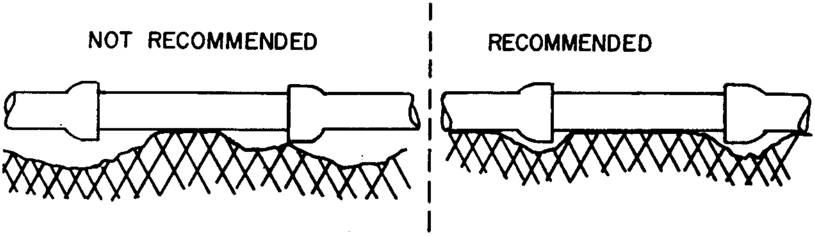


Figure 4–22: Illustrates the proper way to support pipelines in a trench.

For assembly, pipe should be strung along the top of the trench with the bells faced in the direction in which they are to be installed. For small–diameter pipes, the following procedure is recommended:

1. If the trench wall is straight, having firm edges, lower the pipe by hand (Figure 4–23).
2. If the trench is not too deep, a crew can be stationed on the bottom to reach the pipe as it is lowered.

For larger–diameter pipes or for relatively deep trenches that do not fit the criteria in steps 1 and 2 above, the following is recommended:

1. Wooden skids should be placed along the side of the trench. (This prevents dirt and rocks from entering the bell and protects against any damage from rocks extending out of the trench wall.)
2. Using the arrangement shown in Figure 4–23, slowly lower the pipe by hand. Each man should stand firmly on the other rope end.
3. Stop–knots should be used on the ropes under the workmen's feet to prevent heavy pipe lengths from slipping. For very large pipe, cranes or other types of heavy duty hoists may be necessary.

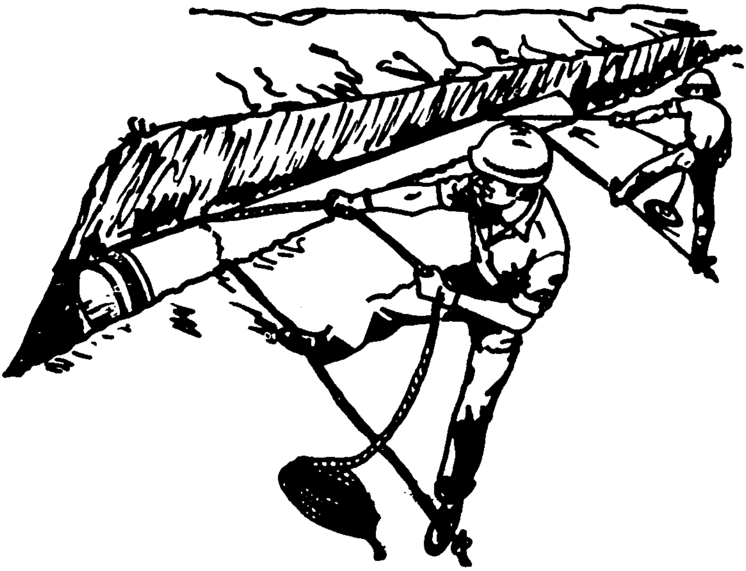


Figure 4–23: Lower the pipe into the trench by hoist.

Once the pipe has been positioned on the trench floor, the joints can be cleaned. The bell inside surface, spigot groove and rubber gasket should be cleaned thoroughly and the solvent given sufficient time to evaporate. The bell sealing surface and the gasket should be lubricated. The gasket should be stretched over the spigot and snapped into the groove, making sure that it is stretched evenly around the groove and not twisted. Care should be taken not to recontaminate cleaned surfaces.

There are a number of techniques used for making the final connections. For pipe diameters up to 18 in., one or more leverage bars and a block of wood an be used as shown in Figure 4–24(A). The wood block protects the pipe from point loads. The block should be positioned horizontally against the bell, and the bar should be embedded firmly in the trench floor behind the block. The spigot should be pushed firmly into the mouth of the bell until it reaches the shoulder.

Another technique is shown in Figure 4–24(B), in which a choker cable can be attached to a crane boom. This requires an adequate downward load onto the bell ends of the pipe. Care must be taken to ensure that the cable angle is low to prevent buckling or misalignment. Choker cables and come–a–long jacks, as described previously, may also be used.

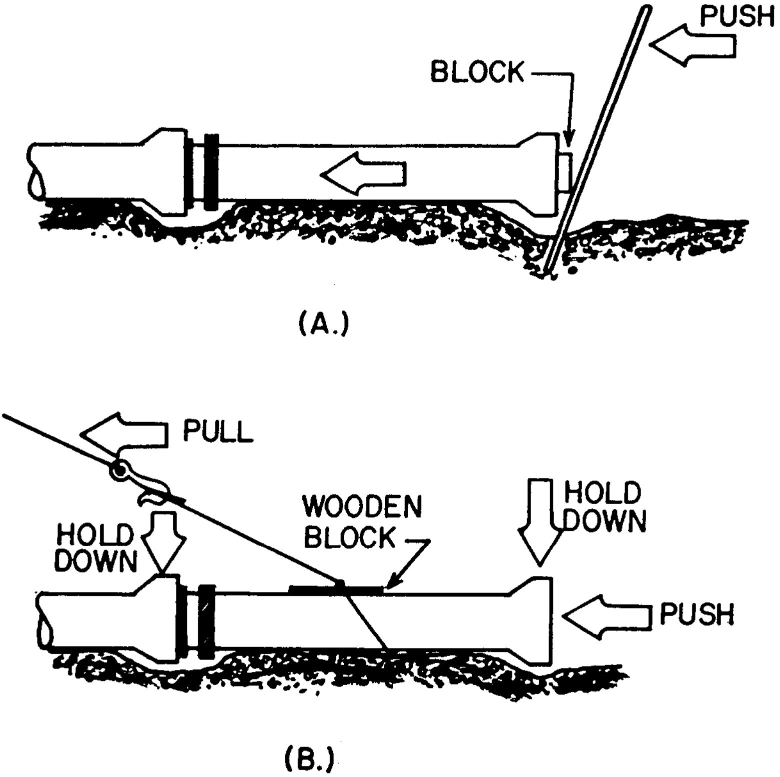


Figure 4–24: Two methods of making joints in buried installations.

THRUST BLOCKING AND CLOSURES

If fittings are used to make changes in direction, thrust blocking must be provided against solid trench walls. These fitting areas should not be machine dug as it is likely that the excavator will dig too deep and may damage the bearing surface of the trench wall.

The primary function of thrust blocking is to prevent movement of the piping component; that is, it serves as an anchor. A major part of the system design is to determine where thrust blocks are needed and how large they should be. Figure 4–25 shows some typical cases in which concrete thrust blocks can be employed. As a general rule when pouring concrete, the widest practical support should be provided without covering piping components.

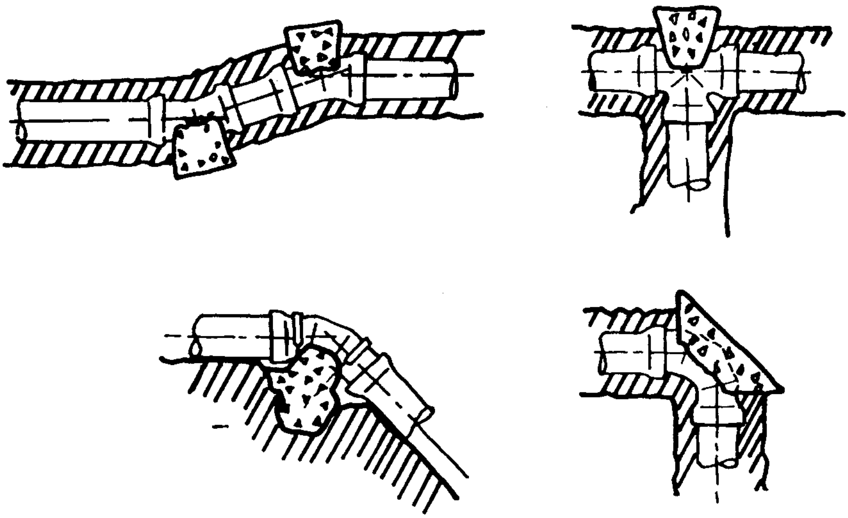


Figure 4–25: Typical examples of the use of thrust blocks.

Closures are also a significant part of the system design Closures are the arrangement at the last length of pipe that closes the line. The assembly usually requires a special length of pipe with a coupling. The most common way this is done is to use a long bell–shaped pipe. Another approach is to use a flexible coupling that is to be installed over the pipe. The latter method requires a pipe with either a resin outer wall, smooth outside diameter or some specially prepared standard pipe from the supplier. A third type of closure makes use of a plain end section of pipe where a full circle repair clamp can be employed as the coupling.

Road Crossings

If pipe is to be laid under road crossings, it is advisable to use conduits through which the pipe can pass [Figure 4–26(A)]. This will protect pipe from damage due to excessive loads or burial depths. Care should be used to ensure that the pipe is properly bedded at the entrance and exit points of the conduit so that stress or wear do not occur to the pipe. Conduits are also useful in preventing pipe movement caused by pressure surges or flotation.

When installing pipe through casings or conduit, skids must be used The use of skids prevents the pipe from snagging on the inside wall of the casing during installation [Figure 4–26(BB)]. It also prevents the pipe from resting on the bells. Skids should be 2 to 2–1/2 in. long or continuous and should be sufficiently high to provide clearance between the pipe bells and the casing. The leading ends of the skids should be rounded so that the pipe may be readily pushed through the casing. Skids must be tightly strapped to the pipe by metal strapping.

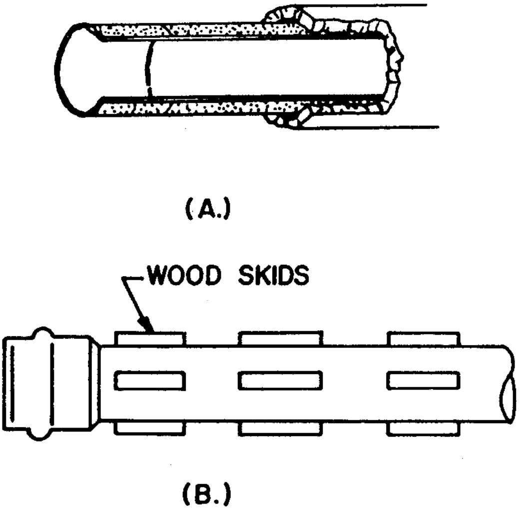


Figure 4–26: Pass pipe through conduits for road crossings.

Care should be taken to install bottom skids parallel to the centerline of the pipe. This will prevent the pipe from rolling in the casing. Normally, six skids are recommended, mounted at 60° intervals about the periphery of the pipe and at selected axial intervals.

Pressure grouting may also be used to restrict pipe movement in the conduit; however, it may be necessary to reposition skids to accommodate the grouting hose. The recommended grout mix ratio is four parts sand to one part cement. Sufficient water should be added to obtain a pea soup consistency. The grouting machine should b equipped with a pressure gauge at its discharge. Once the delivery pressure has built up, the grout will discharge from the hose and fill the void between the pipe and conduit. Delivery pressure should be monitored carefully as just a 2–3 psi excess over the initial required delivery pressure might be enough to collapse the pipe.

Backfill

Once the pipe has been laid out and final connections are made, the installation should be backfilled with sufficient fill to hold the line in place All fittings and joints should be left open for inspection during a test period.

Primary backfill serves the function of a continuous and firm support for the line. Primary backfill, sometimes called the pipe zone, must be placed and compacted so that it provides sufficient and even support about the periphery of the pipe.

Note that most FRP pipe cannot be considered rigid, such as concrete. When soil settles about rigid pipe, the line retains its shape and transfers the load of the overburden to the bedding. Flexible pipe on the other hand, deflects loads vertically and, as such, the soil beside the pipe takes the responsibility of absorbing most of the load of the overburden. Furthermore, as FRP pipe compresses vertically it will expand horizontally. The horizontal expansion of the pipe is opposed by the horizontal soil pressure and this, in turn, opposes contraction of the pipe vertically. After backfilling, the pipe's vertical deflections must not exceed 57% of the pipe diameter. As such, the soil for the primary backfill region should be well compacted so that the soil can support these loads without excessive settling. If deflections are observed to be in excess of 5%, the line must be uncovered and the pipe allowed to regain its original shape. The backfill zone can then be recompacted. By limiting the vertical deflection to 5%, the strain is minimized. It is important to note that severe local loads can generate excessive loads without exceeding the allowable deflection. Pipe manufacturers should be consulted for specific guidelines.

Damp, stone–free, nonlumpy soil should be used for primary backfill. The soil or filler material should be relatively clean of vegetation, debris and stones over 1 in. in size. Filler materials that can be used in place of soil include sand, graded gravel or crushed rock.

Compaction may be carried out by shovelling the backfill thoroughly under the pipe. Care must be taken not to shovel excessive amounts as this will create voids under the pipe. Backfill should be placed in 6– to 8–in. lifts uniformly on both sides of the pipe. When backfilling with gravel or crushed stone, shovel slice the material under the haunches of the pipe.

Water jetting or flooding can be used as a method for compaction provided there is adequate drainage. If the pipe is laid close to or below the groundwater table, water compaction must be used cautiously to avoid floating the pipe.

When installations are placed under streets, the backfill compaction must match the compaction of the roadbed. A relative compaction of 85–90% is required. Mechanical compactors should not be used directly over the pipe if there is less than 6 in. of cover. For heavy–duty compaction equipment, a minimum of 1 ft of coverage is required.

In general, when installing underground installations, only a portion of the line should be covered so that checks can be made for deflections against the 5% limit. A good installation should average around 2% with maximum vertical deflections peaking at 3%.

Once primary backfilling is completed, the entire trench may be filled in with secondary backfill material. Secondary backfill is most often the native soil. It should be graded adequately so that vegetation and large stones are removed. In situations where live loads will exist, the secondary backfill should be placed and compacted in short lifts. Figure 4–27 illustrates the recommended trench configurations and composition. Note that bed depth and recommended compaction densities will vary with the specific pipe used. Manufacturers should be consulted for this information.

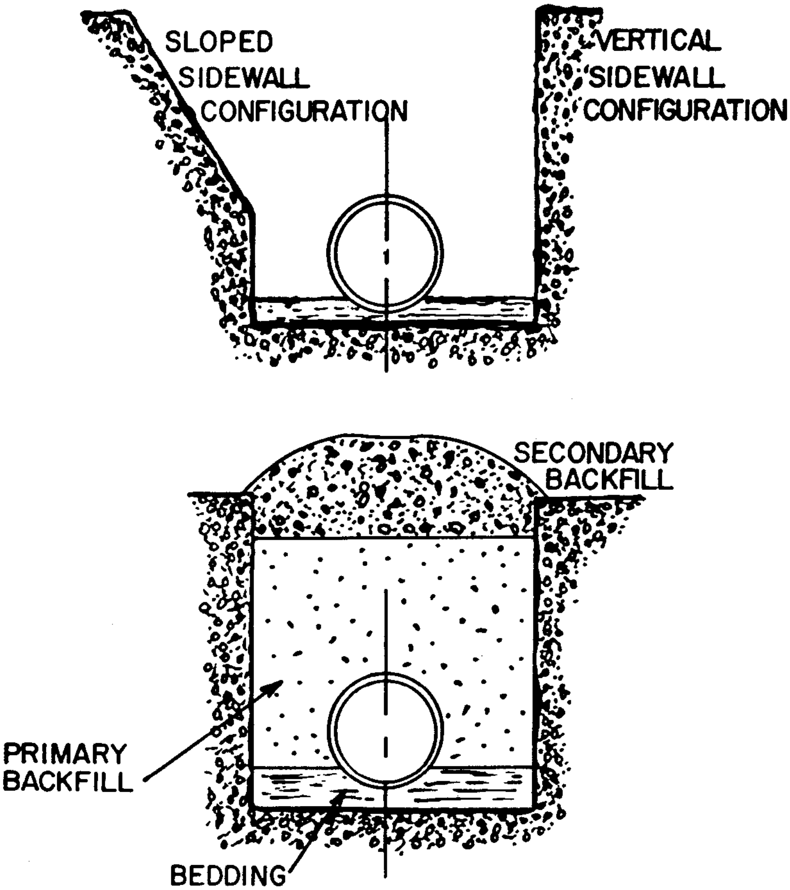


Figure 4–27: Recommended trench configurations and compositions.

Line Testing

During installation it is often advisable to pressure test segments of the assembly before it is completed. Portions to be tested should be backfilled and compacted to prevent movement under pressure. Factors that should be considered for testing include the following:

1. Sufficient backfill must be provided to restrict all movement under test pressures.
2. Thrust blocks at fittings must be permanent and capable of withstanding test pressures.
3. Test ends must be capped and anchored to withstand thrusts generated under test pressures.

As pointed out earlier, lines can be tested with either air or water, although the latter is preferred. When the line is being filled with water, air becomes entrapped in the water. The air will begin to escape and becomes entrapped in the line once the flowing has stopped and the water settles down. An air vent or air relief valve should be supplied at the highest point in the line so that entrapped air can be forced out of the pipe; that is, water should displace the air so that the entire length of pipe undergoing testing is filled. This must be done before pressure is applied to the system.

It is generally recommended to fill the line 24 hours in advance at a nominal pressure prior to initiating tests. Once the line air has been expelled, the water can be pumped at the specified test pressure, with a pressure gauge located at a low point in the line, where pressures are usually highest. Possible sources of leakage are in joints at saddles, transition fittings, valves and adaptors. Pipe joints are normally not trouble areas.

The project engineer should establish allowable leakage standards. As a general rule, a pipeline is acceptable if water losses are less than 100 gallons per inch of diameter per mile of pipe per day for tests conducted on nonpressure lines with up to 8.7 psi of head. Usually pressure lines are not tested in excess of 1.5 times the pipe's rated pressure. Pressure lines are considered acceptable if the water needed to maintain pressure is less than 30 gallons per inch of diameter per mile per day. Pressure tests at 1.5 times the maximum operating pressure should be conducted for a minimum of 2 hours. As a rough guide, Table 4–7 can be used for allowable leakage criteria at different test pressures.

Table 4–7: Allowable Leakage Guide (gal/1,000 ft/hr)

Pipe Inside Diameter (in.)	Test Pressure (psi)				
	50	100	150	200	250
4	0.38	0.54	0.66	0.77	0.85
6	0.57	0.81	0.99	1.15	1.28
8	0.76	1.08	1.32	1.53	1.71
10	0.96	1.35	1.66	1.91	2.14
12	1.15	1.62	1.99	2.30	2.56

For critical operations, a more severe cyclic test is recommended. This involves subjecting the system to 5 to 10 pressurization cycles at one and a half times the maximum rating of the lowest–rated component in the arrangement. Sudden pressure surges or water hammer should be avoided during testing. Water hammer can cause pressures several times higher than the system's rating.

Testing the system with gas or air is not recommended because of the safety hazards created. The characteristics of FRP pipe (light weight, flexibility and elasticity) establish different conditions than are present in steel pipe during gas testing. If failure occurs during testing, the line will undergo whipping and other conditions induced by shock caused by the sudden release of stored energy. If gas testing is necessary, the manufacturer should be consulted for proper test procedures and safety precautions for work crews.

REPAIRING DAMAGED PIPE

Most damage that occurs to FRP pipe happens through improper handling. Pipe walls can be punctured by sharp impact loads, such as dropping pipe onto rocks or rough handling by operating machines. Usually the damage is localized, and most of the pipe can be saved.

If a bruise occurs on the outer pipe wall, and has not punctured all the way through, the wall may have been weakened sufficiently to require repair. One should look carefully down the inside of the pipe to check for cracks, crazing, breaks or bulges that may have resulted.

For aboveground installations, a conventional repair clamp is often satisfactory for temporary repairs. Buried installations, however, should have more permanent repair done before backfilling.

For localized damage, patching should not be done with the line under pressure. The bruised area must be completely dry during repairs. The patch should consist of a length of good pipe, whose length has been cut to adequately cover the damaged region by extending 3–4 in. on both sides of the bruise. The patch should be slit lengthwise twice, discarding the cutaway length. The slit patch should have roughly 75% of the circumference left for pipe diameters 1–4 in. and roughly 50% of the circumference for pipe diameters greater than 6 in. [Figure 4–28(A)].

The inner surfaces of the patch should be sanded thoroughly; also, the area about the damaged portion of the pipe should be sanded with coarse sandpaper. Joint cleaner should be used to clean both surfaces. Adhesive should then be applied to both surfaces and the patch snapped over the damaged area. Hose clamps or banding tools can be used to force the patch tightly around the pipe as shown in Figure 4–28 (B).

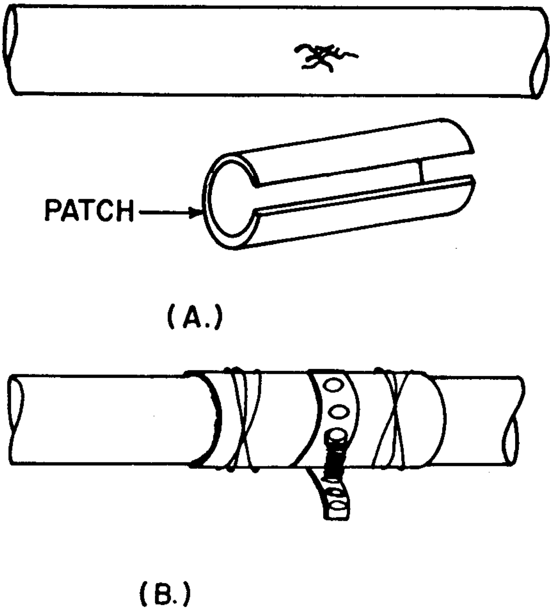


Figure 4–28: Recommended procedure for repairing localized damage to pipe.

If the damage is extensive, that is if the bruised area is too long to patch or extends about the entire circumference of the pipe, the section may have to be replaced. If the pipe has sufficient slack, the damaged section can be cut away. The cut ends can be tapered and a sleeve coupling can be bonded between the tapered ends. Figure 4–29 illustrates the procedure. Care must be taken to ensure that all tapered ends are securely locked into position once adhesive has been applied.

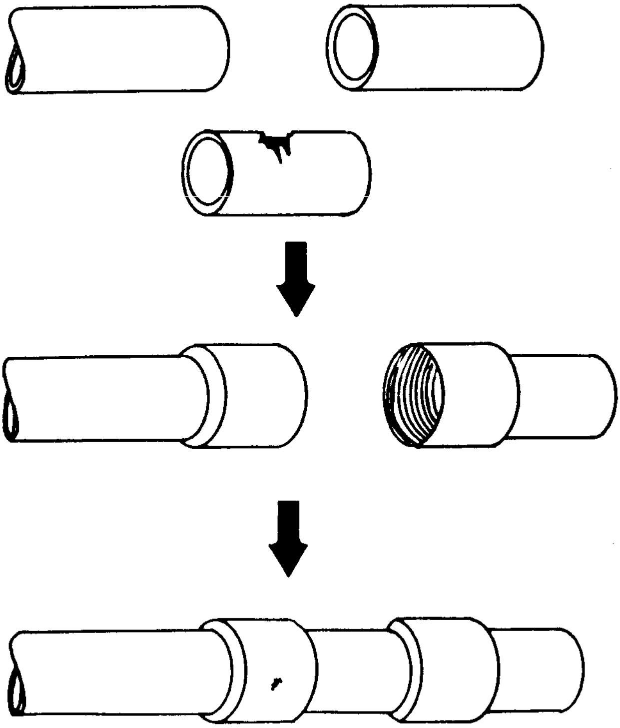


Figure 4–29: Recommended repairs for extensive damages.

As an alternate approach, if the line cannot be moved sufficiently to install a sleeved coupling, the damaged section can be removed, ends tapered and flanges installed. A flanged spool can be readily bolted into position.

Joints generally leak because they are not locked properly, as in the case of bell and spigot joints. Leaky joints can be repaired by overwrapping the joint with glass cloth impregnated with resin. A 7– to 10–oz cloth, 6 to 8 in. wide is generally recommended. The resin should be compatible with that of the pipe. Repairs should not be effected with the line under pressure and the area should be completely dry.

Before making repairs, the joint must be properly prepared. A grinder or coarse sandpaper should be used to remove all resin glass 5–6 in. on either side of the joint. The shoulder of the bell should be bevelled to blend in with the pipe wail. The joint should be cleaned thoroughly with solvent. The glass cloth should be cut into strips so that they will overlap the circumference by at least 2 in. Apply either adhesive or resin to the entire region that has been sanded and place a piece of the cloth over the joint. The cloth should be wetted down with more adhesive starting at one end of the cloth and working around the circumference. The cloth should be worked onto the joint away from the starting end and from the center of the sheet to the sides. The cloth must be worked down smooth so that there is no air trapped underneath it. If any areas are not saturated, they should be brushed in one direction until flat and fully wetted.

The next layer of glass cloth should be placed on the joint starting from a new point on the circumference. The ends should not be overlapped until the cloth has been wetted out. Care should be taken not to use more adhesive than is necessary to wet out the cloth. If repairs are to be effected on warm days, the overwrap should be protected from direct sunlight. If the overwrap begins to give off heat, application should be stopped and the section allowed to cure and cool down. The resin glass will have to be removed by light sanding and cleaned before continuing.

NOTATION

A = cross–sectional area of flow, ft^2
C = Hazen–Williams Coefficient
C_p = amount of precompression, in
D = pipe diameter, ft
d = maximum linear deflection per joint, in
F = fractional rise in pressure in Equation 13
f = friction factor
g = acceleration due to gravity, 32.2 ft/sec^2
g_c = conversion factor, 32.174 $ft–lbm/lbf–sec^2$
H_{fs} = skin friction, $ft–lb_f/lbm$
h_o = pressure head, ft
K = parameter in Equation 10
k = coefficient of thermal expansion, in/in/°F
L = length, ft
N = parameter defined by Equation 11
ΔP = pressure drop, psi
$\Delta P'$ = pressure rise, psi
p = maximum pull per joint, in
Re = Reynolds number
R_M = expansion joint rated movement, in
r = minimum curve radius, ft

T = temperature, °F
t_ = time, sec
Uu = average fluid velocity, ft/sec
x = wall thickness, ft

Greek Letters

α = maximum angular deflection per joint, °
γ = stress, psi
ε = modulus of elasticity, psi
μ = viscosity, lb_m/ft–sec
ν = kinematic veiscosity, ft^2/sec
ρ = density, lb_m/ft^3

Subscripts

i = refers to installation or initial
m = refers to minimum
o = refers to initial

CHAPTER 5

FIBERGLASS TANKS

TANK CONSTRUCTION

Filament-Wound

Laminate construction of standard vertical FRP tanks is done with automated equipment on a rotating mold called a mandrel. A resin-rich layer of chemically resistant polyester or vinylester is applied uniformly to a specified thickness on an inner surface mat. The mat is usually of a chemically resistant fiberglass reinforcement composition or an organic veil. After the initial layer is applied (approximately 20 mil thickness), a second layer of resin-rich, chemically resistant polyester or vinylester is applied uniformly, to roughly a four times greater thickness. The reinforcement usually consists of randomly oriented, chopped strand fiberglass. The next step involves the construction of a filament-wound layer impregnated with isophthalic polyester resin or other suitable resin. The layer thickness depends on the size requirements and the specific gravity design criteria. Generally, the layer composition is comprised of filament winding interspersed with chopped strand fiberglass. The purpose of this third layer is to provide the primary strength characteristics of the vessel. This layer serves to minimize the strain placed on the corrosion barrier to avoid cracking of this layer. The corrosion barrier can undergo cracking to loads considerably below the ultimate strength of the corrosive layer material, resulting in tank failure. As a fourth layer, a resin-rich outer surface mat is applied that is usually of the same thickness as the inner layer. This generally consists of a chemically resistant fiberglass reinforcement or an organic veil that is saturated by spraying with isophthalic polyester resin.

The responsibility of the first and second layers is to provide the tank with noncorroding, noncontaminating features. A cross–sectional view of the standard vertical tank wall laminate is illustrated in Figure 5–1.

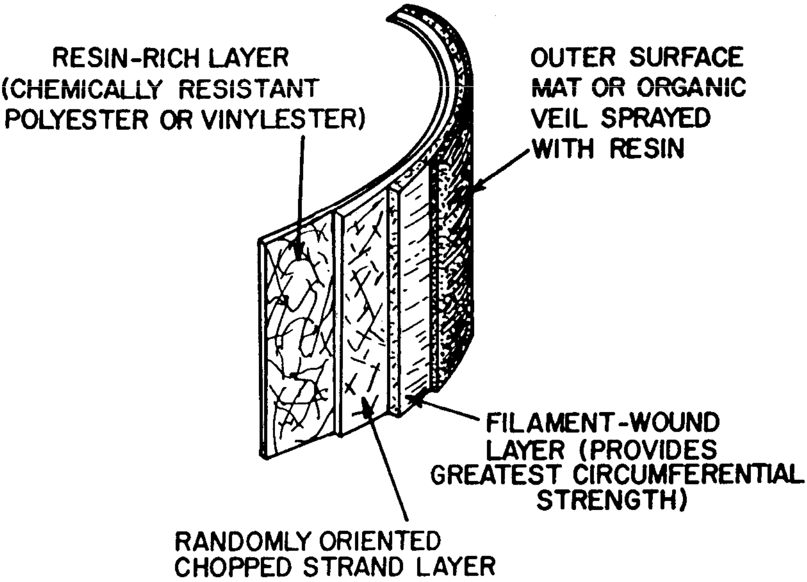


Figure 5–1: Cross–sectional view of standard vertical tank wall laminate.

Excessively large tanks (100,000 gallons and up) can be constructed m sections for shipping by conventional means. Special steel mandrels that are covered with a film, are used to wind sections of tanks to specified diameters with a bell joint at one end. Upon removal from the mold, each section is cut into segments. The sections are cut to fit exact dimensions of the specified circumference, so that when the tank is assembled, a true shape is achieved. One unique design consists of a press–molded fiberglass reinforced locking panel.

The locking panel has glass fibers oriented to provide a row of high performance tension elements. Mating slots are milled into the ends of each tank wall section, as shown in Figure 5–2. The slots receive the ends of the molded tension locking elements. During assembly, the locking panels are coated with resin and positioned into the slots from the inside and held in place by a layer of resin–impregnated mat or fabric that is applied on the outside.

Molded sections are of a similar resin construction, providing a very smooth tank wall. A final coat of glass veil is usually applied with the same resin as the tank.

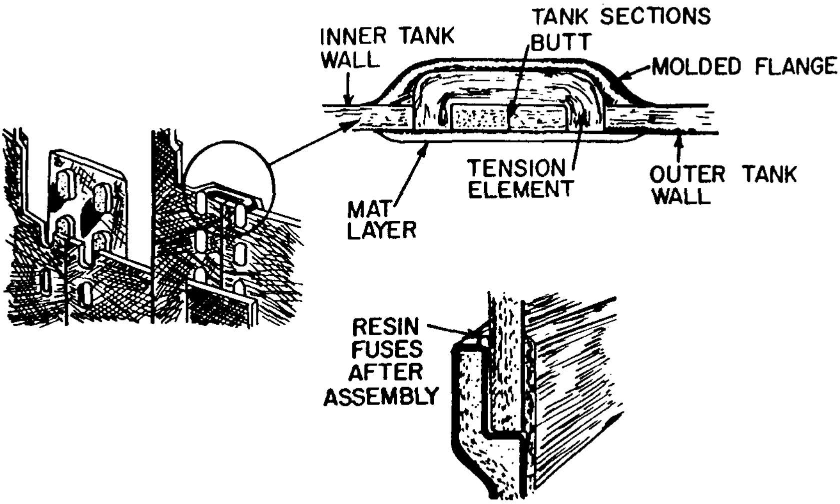


Figure 5–2: For large–diameter, vertical tanks, press–molded fiberglass reinforced locking panels are used.

Each horizontal joint between adjacent sections of the tank wall that is to be attached to the top head can be constructed as a bell and spigot joint. A seal is effected by a strip of resin–impregnated mat and veil applied over the inside. The seam is then fused by pouring resin into the joint from the outside. The bottom head seam is sealed from the inside by using a cove–forming rind which forms a specified radius and several layers of resin–impregnated fabric and mat.

When installing these types of tanks, the setup should proceed from top to bottom. A concrete pad is usually prepared in advance whereby the pad may be flat with a small cutout at the edge for the outlet of the tank. It is often advisable to provide an internal slope on the pad to allow for tank drainage. The specific design of the pad will depend on the tank bottom *(i.e.,* flat or sloping).

The side walls and top are installed first. The tank is then raised sufficiently to allow the bottom base sections to be inserted. The structure is then lowered to the pad. Base sections are joined smoothly and attached to the completed side wall with resin–impregnated mat. Outlet fittings, inlet and vents can then be installed.

The tank head is generally equipped with a manhole and vent. These are blocked up when assembling the outer top pie–shaped ribbed sections, as shown in Figure 5–3. In addition to inlets, outlets, vents and manholes, the tank can be equipped with ladders, heating or cooling coils and other accessories.

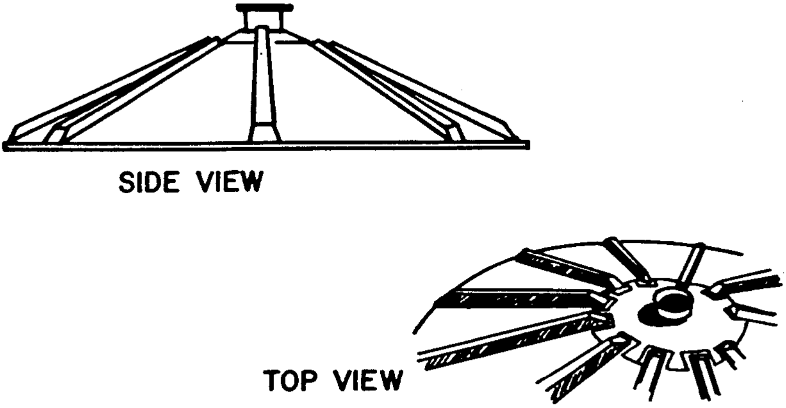


Figure 5–3: The tank head can be constructed with outer pie–shaped ribbed sections.

The reader should refer to ASTM Specifications, which covers filament–wound tanks. According to the ASTM standard, the allowable strain level is 0.001 in./in.

Contact Molded

Tanks are also fabricated by contact molding. There are no ASTM specifications on contact–molded tanks; however, the National Bureau of Standards (NBS) Voluntary Product Standard outlines a set of wall thicknesses based on three conditions, namely:

1. the material to be stored has a specific gravity of 1.2,
2. the modulus properties are given in the specification,
3. allowable strain level is not to exceed 0.001 in./in.

The NBS standards outline the requirements for each of the layers, which are not unlike those of the ASTM requirements for filament–wound pipe. Again, sufficient resin richness must be maintained throughout fabrication to obtain the desired corrosion resistance, at the same time providing adequate reinforcement to prevent cracking.

Both types of tanks require that the inner surface layer be of a resin–rich composition using fiberglass–surface mat or an organic veil. The layer thickness is usually between 10 and 20 mils and must include a maximum of 20% by weight of reinforcement.

Specifications for the hoop tensile modulus of the structural layer are different for contact–molded and filament–wound FRP tanks. For the latter, the hoop tensile modulus is a function of the angle at which fila–

ments are wound onto the vessel as measured from the tank axis. Values of the hoop tensile modulus range from 2.0 × 10^6 to 4.3 x 10^6 psi for filament–wound tanks. These tanks are designed to have axial strength that is at least equal to that of a helically wound vessel having a maximum wind angle of 80°. This strength will provide adequate strength for wind and top loads. The requirement is usually met by using fiberglass–chopped strand in the laminate.

For contact–molded tanks, the hoop tensile modulus of the structural layer is specified within the range of 1.0 × 10^6 to 1.2 × 10^6 psi. The laminate can be built up from alternate layers of fiberglass–chopped strand and woven–roving. Chopped strand layers are usually applied both on the inside and outside of the structural layer.

Basic Design—The vertical tanks described can be of four basic designs: sloped bottom, dished bottom, flat bottom or conical bottom. Figure 5–4 shows the basic designs. Sloped–bottom tanks are used when full drainage of slurries or fluids is necessary. These tanks are particularly useful when there is limited head clearance. Tank bottoms are normally sloped approximately half an inch per foot of tank diameter from the high side to the low side. Dished–bottom tanks are most often used when full drainage is required and a minimum amount of head space is available. They are available for nonpressure/nonvacuum applications and can be equipped for complete drainage with internally flush center drains. Drains are usually stainless steel threaded couplings or flanged and gusseted nozzles. These tanks are usually equipped with lift lugs for installation purposes.

The flat–bottom type of construction is employed when a full–bottom support on concrete or packed sand is provided. Vertical, flat–bottom tanks are employed in nonpressure/nonvacuum applications. They are capable of handling liquids with specific gravities up to 2.1 (higher depending on manufacturer) and service temperatures slightly above 200°F. These designs are fabricated with either open or closed tops. Cone bottom tanks provide open working space underneath the vessel. These designs are used when complete drainage is necessary. The included cone angle should not exceed 120°. They have the advantage of providing easy removal of precipitated solids through the center bottom drains making them well suited for use with slurries and suspensions.

There are several methods for supporting vertical tanks. Small–to–moderate–sized tanks are often supported on carbon steel legs with square footings. Four legs are normally attached 90° apart for up to 8–ft–diameter tanks and six legs spaced at 60° apart are used for tanks over 10 ft in diameter.

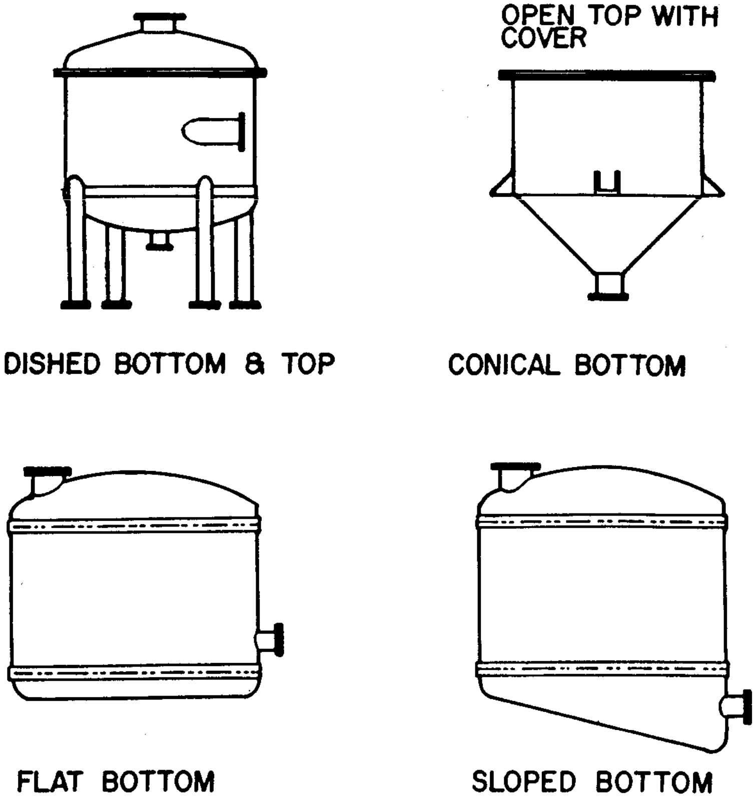


Figure 5–4: The basic vertical tank geometries.

Another common design has FRP pipe legs molded into the tank shell whereby they become an integral part of the sidewall. This has the added advantage of providing complete corrosion resistance. This type of construction distributes stresses over a large surface area, helping to support the tank bottom. FRP pads are provided on the base of all FRP legs.

Skirt supports, complete or partial, are also used for supporting tanks. These also have the advantage of providing accessibility to the drain nozzle.

Lugs are designed into the tank wall when space limitations or operating conditions require substantial working area underneath the vessel. When the lugs are mounted on a structural framework or where through the floor mounting is necessary, lugs can be designed to support the full weight of the vessel.

Tank diameters are measured internally. Tolerances on the inside di–

ameter, including out-of-roundness, are generally specified to within ± 1% by most manufacturers. Measurements are always made with the vessel in the vertical position. Any taper that exists should not exceed ½° per side. Manufacturers generally specify the overall height to within ± 0.5%, with an excess of ± ½ in. being unacceptable. Tolerances on flange construction is the same as for pipe flanges. Nozzle locations on tanks are generally held to within ± 1/8 in. Capacities for round, vertical tanks are given in Table 5-1.

Table 5-1: Round Vertical FRP Tank Capacities in Nominal U.S. Gallons

	Tank Diameter (ft)						
Tank Depth Height (ft)	6	7	8	9	10	11	12
5	1,000	1,400	1,800	2,300	2,900	3,500	4,200
6	1,200	1,700	2,200	2,800	3,500	4,200	5,700
7	1,500	2,000	2,600	3,300	4,100	4,900	5,900
8	1,600	2,300	3,000	3,800	4,700	5,600	6,700
9	1,900	2,600	3,300	4,200	5,300	6,400	7,600
10	2,100	2,800	3,700	4,700	5,900	7,100	8,400
11		3,100	4,100	5,200	6,400	7,800	9,300
12		3,400	4,500	5,700	7,000	8,500	10,000
13		3,700	4,900	6,100	7,600	9,200	11,000
14		4,200	5,200	6,600	8,200	10,000	11,800
15		4,300	5,600	7,100	8,800	10,600	12,700
16					10,500	12,700	13,500
17					11,000	13,500	14,000
18					11,750	14,000	15,000

For rectangular vessels, the optimum dimensions are determined by the capacity requirements, in addition to the hydrostatic pressure that is to be exerted on the tank walls. Most rectangular vessels are fabricated as one unit. Usually the heavy corner wall thickness is extended beyond the corner radius. This ensures greater strength and tends to minimize stress concentrations. Rectangular FRP tanks are also fabricated in modular sections for assembly in the field. The capacity for rectangular vessels of various dimensions, in U.S. gallons per foot of depth, is given in Table 5-2.

For underground cylindrical vessels and aboveground horizontal tanks, the optimal combination of strength and economic factors that satisfy structural requirements are met with chopped glass strand laminate construction. The third and fourth layers of these types of vessels are composed of chopped fiberglass strand and resin. For underground tanks, FRP ribs are incorporated into the design to provide added strength against buckling. Capacities for horizontal tanks are given in Table 5–3.

Table 5–2: Rectangular Tank Capacities in U.S. Gallons per Foot of Depth

	Tangential Length (ft)								
Width (ft)	3	3.5	4	4.5	5	5.5	6	7	8
2	45	52	60	67	75	82	90	105	120
2.5	56	65	65	84	94	103	112	131	150
3	67	79	90	101	112	123	135	257	180
3.5		92	105	118	131	144	157	183	209
4			120	135	149	165	180	210	224
4.5				152	168	185	202	236	269
5					187	206	225	262	299
5.5						226	247	288	329
6							269	314	359
7								367	419
8									479

Over the life of most facilities, FRP underground storage tanks are less costly than comparable steel tanks because of the superior corrosion resistance characteristics of FRP vessels. In addition, FRP tanks eliminate the cost and wasted space of diking aboveground storage tanks. FRP tanks need not be insulated or heated to prevent freezing when buried below the frost line.

TANK MODIFICATION AND ACCESSORIES

Internal, sloped–bottom tanks are used to aid in drainage in vertical flat–bottom–vessels (Figure 5–6). Internal bottoms are normally sloped 0.25–0.5 in/ft. A sump is usually located at the bottom of the slope which can be drained with a side bottom drain. These designs can be used to store liquids with specific gravity as high as 2.1 and temperatures slightly above 140°F. A side–flanged or quick–opening manaway is included in most designs.

With external, sloped–bottom tanks, inclined pads must be used for proper installation (Figure 5–6) are should be taken to ensure that the tank drain does not come into contact with the support pad.

Table 5-3: Horizontal Tank Capacities in U.S. Gallons per Foot of Depth

Diameter	Tangential Length (ft)												
(ft)	5	6	7	8	9	10	11	12	13	14	15	16	17
2	168	200	232	268									
2½	198	234	271	308	344	381							
3	289	341	394	447	500	553	608	658					
3½	398	470	548	614	686	758	830	902					
4	524	618	712	806	900	994	1,088	1,182	1,276	1,370			
4½	672	791	910	1,029	1,148	1,267	1,386	1,504	1,624	1,743			
5	840	987	1,134	1,281	1,428	1,575	1,722	1,869	2,016	2,162	2,309	2,456	
5½	1,029	1,206	1,384	1,562	1,740	1,917	2,095	2,273	2,450	2,628	2,806	2,984	
6	1,248	1,459	1,671	1,882	2,094	2,305	2,517	2,728	2,940	3,151	3,363	3,574	3,780
7	1,736	2,023	2,311	2,599	2,887	3,175	3,463	3,751	4,038	4,326	4,614	4,902	5,190
8	2,302	2,698	3,054	3,430	3,806	4,182	4,558	4,934	5,310	5,688	6.062	6,438	6,810

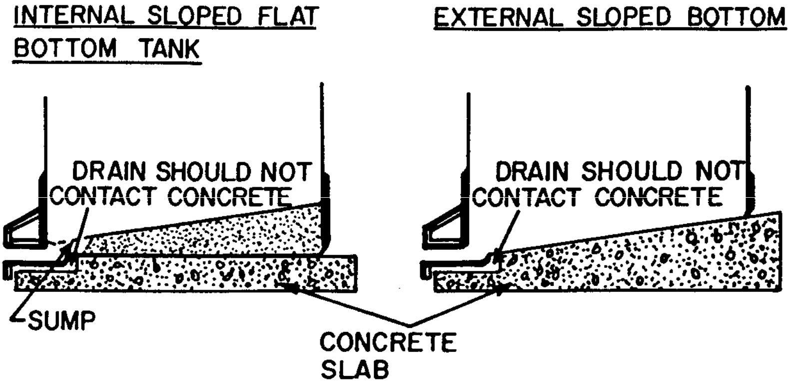


Figure 5–6: Internal sloped, flat–bottom tank.

Standard FRP vertical, closed flat–top and dished–bottom vessels are equipped with fixed–dome tops. These units are also designed with fixed flat–ribbed tops as shown in Figure 5–7. Removable tops are normally provided with a vertical side to lift over the open–top tank edge.

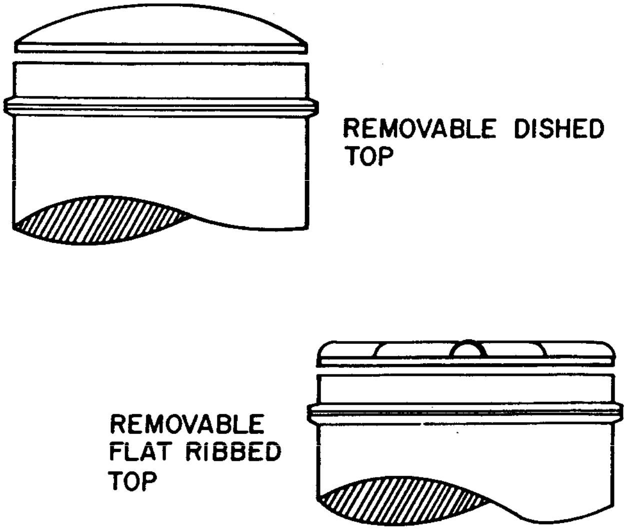


Figure 5–7: Different types of tops for vertical, closed top flat– and dished–bottom vessels.

There is a variety of custom–fabricated FRP tanks for numerous applications. One unique design currently on the market is a composite FRP pressure vessel. This design comprises fiberglass and resin wound over a polyethylene liner. Temperature capabilities of these tanks go as high as 200°F and they are recommended for use with liquids up to 100 psi and 120°F.

Tanks for atmospheric storage are available in a wide range of capacities. Systems are available in both vertical and horizontal geometries. Recommended minimum wall and bottom thicknesses for vertical tanks fabricated by one FRP tank manufacturer are given in Table 5–4.

It should be noted that wall thickness design is dictated by a number of factors including tangential length, tank diameter, specific gravity of fluid handled, service conditions and the method of support. For tanks to be used in service conditions where temperatures are in excess of 180°F, special design considerations must be given to the physical properties of the fluid at operating temperatures. In addition, vessels with physical loadings, such as agitation, also require special design consideration.

Special Designs–One unique FRP tank design manufactured consisted of helically wound steel cable. The cable can be either double galvanized steel, steel with extruded vinyl covering, type 316 stainless or other specified alloy. The FRP employs polyester, vinyl ester or furane resin systems. Figures 5–8 and 5–9 illustrate the principle behind this particular design. The arrangement provides superior strength properties due to the difference between the Young's Modulus of the fiberglass reinforced resin and the metal cable. When the tank is filled with fluid, pressure is distributed over the laminate. Side walls transmit this load over the entire length of a single–piece cable, which is hand–stressed about the shell. Chemically resistant plastic contacts with the fluid being handled while hoop stresses are distributed through the cable. These designs are highly resistant to chemical attack and corrosion from acids and weathering. Standard sizes range up to 12 ft in diameter and are custom manufactured up to 100 ft in diameter.

Insulation–Aboveground tank installations normally can be supplied with a layer of insulation such as polyurethane foam. Insulated tanks with a 2–in layer of polyurethane foam insulation, providing an overall heat transfer coefficient for the wall and top of 0.086 Btu/hr/ft^2/°F. Figure 5–10 shows such design. As shown, the insulation is guarded by a spill– and weather–resistant layer of resin and chopped fiberglass strand coated with an exterior pigmented gel coat. The gel liner is available in a range of colors. Usually, insulated vessels are equipped with expansion joints, installed horizontally to compensate for thermal expansion.

Another method for insulating aboveground vessels involves the use of polyester– or Teflon–insulated heat tracing tape. This is a useful method of insulation particularly when materials must be maintained at steady temperatures.

# Table 5-4: Recommended Minimum Wall and Bottom Thickness for Vertical Tanks
0 = Tank Capacity (U.S. Gallons), + = Filament-Wound Wall Thickness (feet),
* = Hand Lay-Up Wall and Bottom Thickness (feet)

	+ *												
2	1/8 3/16 (47)	1/8 3/16 (73)	1/8 3/16 (105)	1/8 3/16 (143)	1/8 3/16 (188)	1/8 3/16 (238)	1/8 3/16 (293)	1/8 3/16 (355)	1/8 3/16 (423)	1/8 3/16 (575)	1/8 3/16 (752)	1/8 3/16 (1175)	1/8 3/16 (1692
4	1/8 3/16 (94)	1/8 3/16 (140)	1/8 3/16 (211)	1/8 3/16 (287)	1/8 3/16 (376)	1/8 3/16 (476)	1/8 3/16 (587)	1/8 3/16 (710)	1/8 3/16 (846)	1/8 3/16 (1151)	1/8 3/16 (1504)	1/8 3/16 (2350)	1/8 3/16 (3389)
6	1/8 3/16 (141)	1/8 3/16 (220)	1/8 3/16 (317)	1/8 3/16 (431)	1/8 3/16 (564)	1/8 3/16 (714)	1/8 3/16 (881)	3/16 3/16 (1066)	3/16 3/16 (1269)	3/16 3/16 (1727)	3/16 3/16 (2256)	3/16 1/4 (3525)	3/16 1/4 (5076)
8	1/8 3/16 (188)	1/8 3/16 (293)	1/8 3/16 (423)	3/16 3/16 (575)	3/16 3/16 (752)	3/16 3/16 (951)	3/16 3/16 (1175)	3/16 3/16 (1421)	3/16 3/16 (1692)	3/16 1/4 (2303)	3/16 1/4 (3008)	3/16 1/4 (4700)	1/4 5/16 (6768)
10	1/8 3/16 (235)	1/8 3/16 (367)	1/8 3/16 (528)	3/16 3/16 (719)	3/16 3/16 (940)	3/16 3/16 (1189)	3/16 3/16 (1468)	3/16 1/4 (1777)	3/16 1/4 (2115)	3/16 1/4 (2879)	3/16 1/4 (3760)	1/4 5/16 (5875)	1/4 5/16 (8460)
12	1/8 3/16 (282)	1/8 3/16 (440)	1/8 3/16 (634)	3/16 3/16 (863)	3/16 3/16 (1128)	3/16 3/16 (1427)	3/16 1/4 (1762)	3/16 1/4 (2132)	3/16 1/4 (2538)	3/16 1/4 (3454)	3/16 1/4 (4512)	1/4 5/16 (7050)	1/4 3/8 (10153)
14	1/8 3/16 (329)	1/8 3/16 (514)	1/8 3/16 (740)	3/16 3/16 (1007)	3/16 1/4 (1316)	3/16 1/4 (1665)	3/16 1/4 (2056)	3/16 1/4 (2488)	3/16 1/4 (2961)	3/16 5/16 (4030)	1/4 5/16 (5264)	1/4 5/16 (8225)	5/16 3/8 (11845)
16	1/8 3/16 (376)	1/8 3/16 (587)	1/8 3/16 (846)	3/16 1/4 (1151)	3/16 1/4 (1504)	3/16 1/4 (1903)	3/16 1/4 (2350)	3/16 1/4 (2843)	3/16 1/4 (3384)	1/4 5/16 (4606)	1/4 5/16 (6016)	5/16 3/8 (9400)	5/16 7/16 (13537)
18	1/8 3/16 (423)	1/8 3/16 (661)	3/16 3/16 (951)	3/16 1/4 (1295)	3/16 1/4 (1692)	3/16 1/4 (2141)	3/16 1/4 (2644)	3/16 5/16 (3199)	3/16 5/16 (3807)	1/4 5/16 (5182)	1/4 3/8 (6768)	5/16 3/8 (10576)	5/16 1/2 (15229)
20	1/8 3/16 (470)	3/16 3/16 (734)	3/16 1/4 (1057)	3/16 1/4 (1439).	3/16 1/4 (1880)	3/16 1/4 (2379)	3/16 5/16 (2931)	1/4 5/16 (3554)	1/4 5/16 (4230)	1/4 3/8 (5758)	5/16 3/8 (7520)	5/16 7/16 (11751)	3/8 1/2 (16921)
22	3/16 3/16 (517)	3/16 1/4 (807)	3/16 1/4 (1163)	3/16 1/4 (1583)	3/16 1/4 (2068)	3/16 5/16 (2617)	1/4 5/16 (3231)	1/4 5/16 (3910)	1/4 5/16 (4653)	1/4 3/8 (6333)	5/16 3/8 (8272)	5/16 1/2 (12926)	3/8 9/16 (18613)
	3/16 3/16 (564)	3/16 1/4 (881)	3/16 1/4 (1269)	3/16 1/4 (1727)	3/16 1/4 (2256)	3/16 5/16 (2855)	1/4 5/16 (3525)	1/4 5/16 (4265)	1/4 3/8 (5076)	5/16 3/8 (6909)	5/16 7/16 (9024)	3/8 1/2 (14100)	7/16 5/8 (20306)
Diameter (ft)	2	2½	3	3½	4	4½	5	5½	6	7	8	10	12

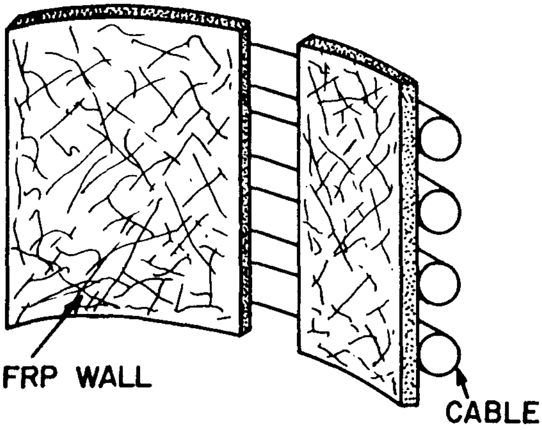


Figure 5–8: Tank wall construction with steel reinforcing cable.

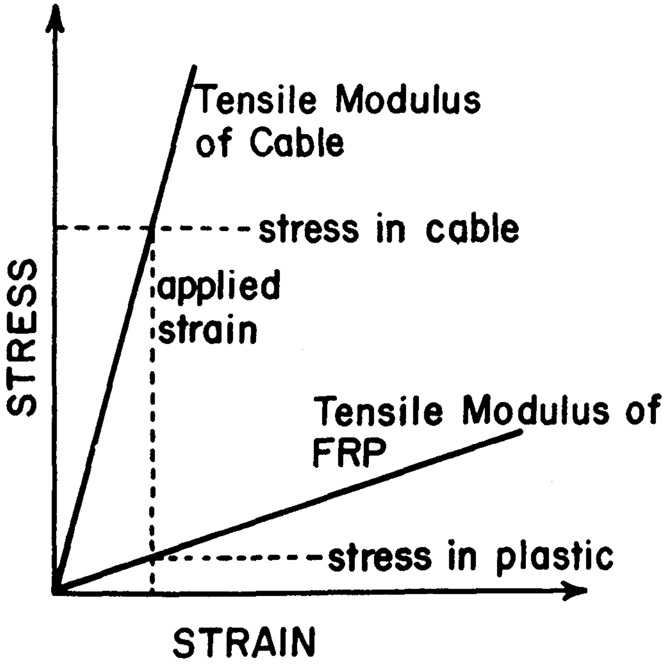


Figure 5–9: Illustrates the differences between the tensile modulus of the reinforcing cable and the FRP.

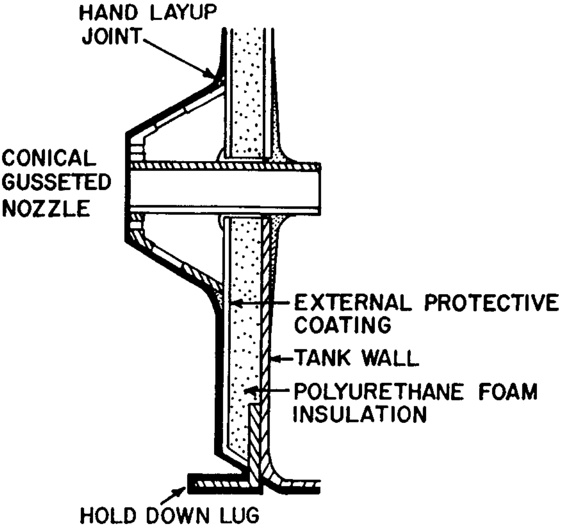


Figure 5–10: Owens–Corning arrangement for insulated tank walls.

Heat tracing tape systems normally use a continuous flat–strip heating element, which can be bonded helically to the vessel's wall. The tank is then insulated with a layer of polyurethane foam, a layer of resin and chopped fiberglass strand and sometimes an exterior pigmented gel coat. Agitation or recirculation is recommended to increase local heat transfer. Thermostat and power connection arrangements for temperature control are illustrated in Figure 5–11. The stored product's temperature should also be monitored independently, usually by installing one or more thermocouples in the vessel. Tank manufacturers should be consulted for specific information on the amount of heat tracing tape, tank coverage and specific temperatures to be maintained for given applications and temperature differentials expected.

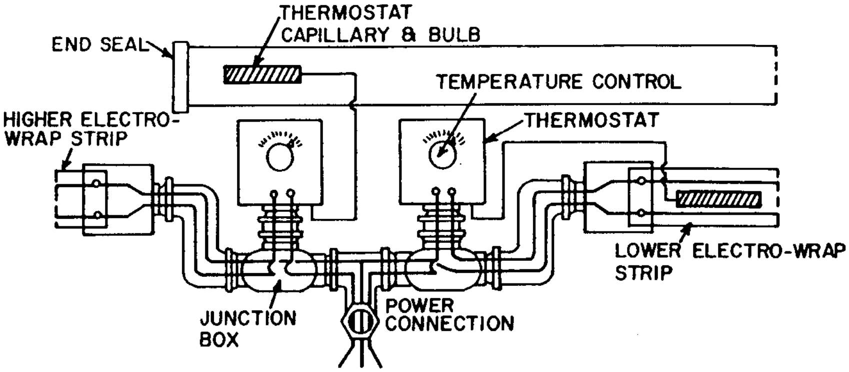
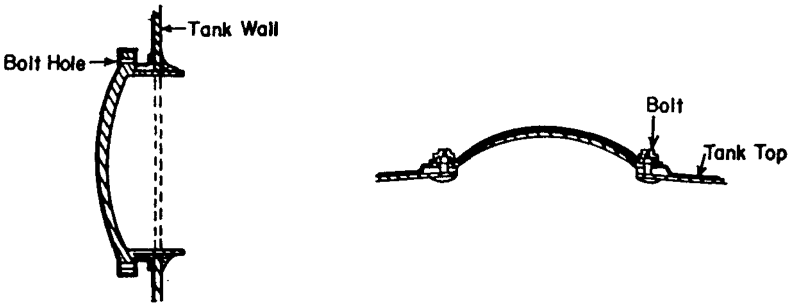


Figure 5–11: Details of the thermostat control and heater strips.

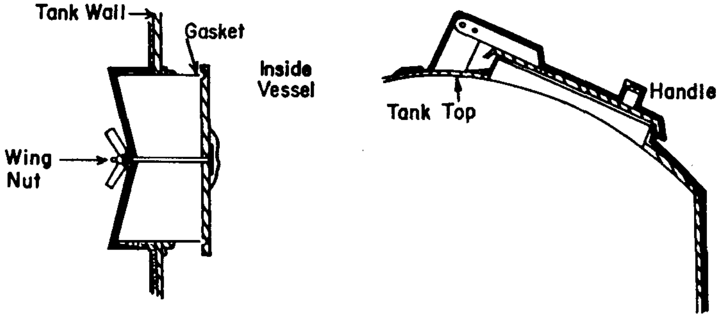
Access Manaways (Manholes)–Flanged manaways are used to obtain an air– and watertight seal. They are provided on the top and/or side of the tank. Side–mounted manaways are recommended for all tanks as they provide easy access for inspection and cleaning. Heavy–duty designs are used on vessels operating over 10 psig of hydrostatic head pressure. Zinc or stainless steel bolts are used and neoprene gaskets are common.

Manaways are required on all closed–top vertical, horizontal and underground vessels [Figure 5–12(A)]. Figure 5–12(B) illustrates a top access manaway. Usually these manaways are not intended to serve as air– or watertight seals and should not be specified on insulated vessels.

An oval–shaped manaway is shown in Figure 5–12(C). These are used as side–entry ports and are usually equipped with a stainless steel handle, rod and crossbar and neoprene gasket material. A hinged manaway for access through the top of aboveground vessels is shown in Figure 5–12(D). If no gasket is supplied with the unit, it cannot be used for an airtight seal.



(A) FLANGED DESIGN (B) TOP ACCESS



(C) QUICK OPENING DESIGN (D) HINGED DESIGN

Figure 5–12: Various access manaway designs.

Supports and Anchoring–Important to the proper design of horizontal vessels are the size and location of support saddles. The tank must be properly supported by saddles so that bending and deformation of the shell are minimized. Standard saddles normally provide about a 150° angle of support, which is generally adequate in deterring areas of high stress concentration from developing.

Wear plates are generally fabricated as an integral part of the shell of horizontal tanks so that stresses on saddle supports can be reduced. Wear plates are designed to extend a minimum of 180° about the tank. A standard tank support saddle and method of connection to the foundation is shown in Figure 5–13. The design shown is a hollow fiberglass saddle, which is laminated to the tank shell. The particular design shown can be filled with concrete or an appropriate hardenable fluid mix (for example, a high–density polyurethane foam). The advantage of this design is that it provides a noncompressible support over a specified area that can consist of an irregular rib surface. Furthermore, the saddles can be filled in the field, thus reducing costs for shipping weight and handling.

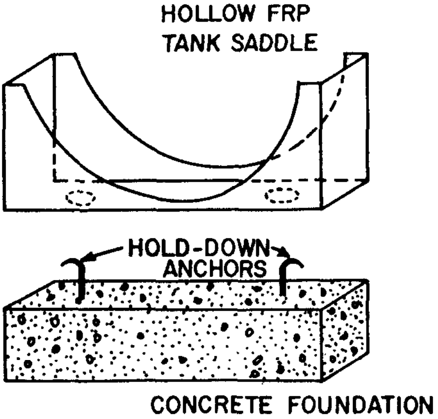


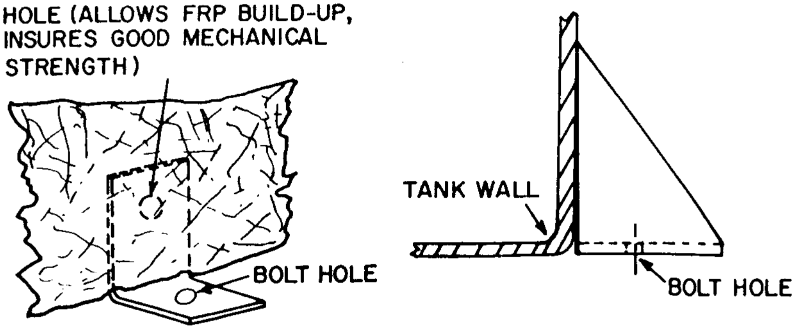
Figure 5–13: Fiberglass support saddles—hollow design.

The saddle base has openings for anchor bars to pass through and secure the units in place when filled. The tank should not be filled until the filler material has hardened completely.

A minimum of two support cradles should be provided for horizontal tanks. Cradles should be a minimum of 6 in. wide and capable of supporting at least 120° of the tank circumference. Tanks that exceed 24 ft in length require special design support considerations.

For vertical tanks, steel tie–down lugs can be used for outdoor installations. Steel tie–down lugs are normally employed in sets of three or four. They are considered the best method for securing flat–bottom, vertical vessels. Damage to bolt holes is eliminated by the use of steel, and adequate holding strength is provided under high wind loads. As shown in Figure 5–14(A), the lugs are installed on the outside tank wall by an encapsulating laminate. Lugs are also available as Type 304 and 316 stainless steel for corrosive environments.

FRP tie down lugs are also employed [Figure 5–14(B)] that have the advantage of providing the same corrosion resistance as the tank itself. They are installed in sets of three or four on each vessel. Each lug is hand laid–up with a gusset and a tie–down plate that is manufactured as one component. Lugs are installed onto the tank wall with a laminate that covers the gussets and tie down plates on both sides.



(A) STEEL TIE DOWN LUG

(B) FRP TIE DOWN LUG

Figure 5–14: Steel tie–down lugs are used on flat–bottom, vertical tanks.

GUIDELINES TO TANK SELECTION

FRP tanks are fabricated for use in applications involving more than 2,000 corrosive chemicals. Manufacturers should always be consulted for recommendations on tank selection to meet process requirements. Most manufacturers will provide testing services that will ascertain which specific laminate will work best with the fluid being handled.

Tank laminate samples can be tested independently by the potential customer by submersion in the proposed environment. Physical– and corrosion–resistant properties should be compared to rigid standards.

When contacting tank manufacturers, all available information on the fluid to be handled should be provided. Operating conditions such as concentrations, storage and handling temperatures, maximum input tem–

perature and the fluid's specific gravity should be provided for proper evaluation. Information on trace chemicals and reaction liquids or vapors should be included.

If the material to be handled has been approved for storage, the specifier should outline the requirements for the vessel. The following items should be evaluated carefully:

1. Determine whether the application is for atmospheric pressure. FRP tanks are designed specifically for atmospheric applications.
2. Determine the capacity of the vessel required.
3. Determine which tank configuration is best suited for the application based on space requirements–vertical flat bottom, vertical dished bottom, cone bottom, sloped bottom, open top, closed top, horizontal or vertical aboveground installation, or underground installation.
4. Determine whether there are any width, height or weight limitations. If the vessel is to be installed indoors, doorway size and room dimensions must be considered.
5. Determine the type of fittings best suited and their sizes. Also lay out where fittings should be installed on the vessel.
6. Evaluate the need for other tank accessories, e.g., baffles, agitators, agitator mounts, manholes, ladders, downpipes, level gauges, anchor bolts, etc.
7. Evaluate anticipated temperature differentials to determine whether insulation is necessary.
8. Establish priorities on delivery date and number of vessels required.
9. Establish tolerances and strength requirements. Evaluation of the proposed site should be made to determine whether special requirements as to wind load or snow load limits are necessary.

Table 5–5 can serve as a rough guide for specifying and selecting FRP tanks. When tanks are delivered, they should be examined for any damage and should be handled carefully during installation. Vessels should be installed on sites where the soil has good load–bearing characteristics and drainage. Foundations provided for tank support should allow for an even distribution of weight when the vessel is full. Foundations must provide smooth, continuous, full–bottom support.

Table 5–5: Guide to Tank Specifications and Selection

Specifications for Loading Conditions

1. Wind load limit when anchored, mph__________
2. Concentrated top load limit, lb_f at rated pressure, psi__________
3. Snow load limit, psf__________

Specifications for Handling Conditions

1. Pressure - atmospheric ( ) Yes ( ) No
   Pressure, psi__________
2. Chemicals__________
3. Trace chemicals__________
4. Concentration, wt %__________
5. Specific gravity__________
6. Maximum temperature__________

Dimensional Requirements

1. Minimum capacity as measured to top of straight shell or wall height, gal__________
2. Outside diameter, ft__________
3. Wall height, ft__________
4. Height to tank top, ft__________

Construction Requirements

1. Specify type construction
   ( ) Filament-Wound ( ) Contact Molded
2. Specify
   ( ) Open top with reinforcing rib
   ( ) Open top with reinforcing rib and removable cover
   ( ) Closed top; specify type closed top, (*i.e.*, dished or flat top)__________
3. Specify bottom construction, *i.e.*, flat, sloped, cone, etc.__________
4. Specify any additional requirements__________
   Indicate schedule as follows (supply drawings)

Connection	Size	No. Required
Vent	__________	__________
Inlet	__________	__________
Outlet	__________	__________
Drain	__________	__________
Manhole	__________	__________

5. Cover requirements:
   Specify style:
   ( ) dished or ( ) flat
   Specify whether lifting rings are needed (should be provided at center of cover)__________

(continued)

Table 5-5: (continued)

6. Specify number of tie-down lugs____________________
7. Specify number____________________and spacings (degrees apart) of lifting lugs at top portion of straight shell.
8. Indicate additional accessories required, *e.g.*, ladders, catwalk, etc.____________________

Specify Tank Accessories Required

---

1. Flanged nozzles
   Conically gusseted with specified strength requirements, *i.e.*, ft-lb$_f$ bending____________________and torque, ft-lb$_f$____________________
   Flanged diameter and drilling requirements____________________
   Specify whether standard orientation will have bolt holes straddling principal centerline of tank and a radial line on vessel top____________________
   Specify thickness, in., of full-face gaskets____________________
2. Venting
   Specify size (must be greater than or equal to largest size inlet or outlet port)
   ____
   Indicate nature of loading, *i.e.*, if fluid is to be air loaded into vessel, tank must be vented with a minimum size manhole/consult tank codes and manufacturer's literature____________________
3. Manaway requirements
   Specify from following:
      top access manaway and size, in.____________________
      top flanged manaway and size, in.____________________
      top hinged manaway and size, in.____________________
      side flanged manaway and size, in.____________________
   Specify flanged diameter and drilling requirements____________________
   Specify thickness, in., of full-faced gaskets, if necessary____________________

Once the vessel has been installed and prior to making connections to the piping system, all outlets should be blocked and the tank tested hydrostatically. The straight shell portion should be filled with a chemically compatible fluid for testing. When the system has been tested and all piping connections made, the tank, nozzles and connections should be scoured clean. Cleaning can be done with a mild soap solution and rinsed with hot water.

CHAPTER 6

STEEL AND FIBERGLASS CONSTRUCTION FOR BELOW GROUND STORAGE TANKS

INTRODUCTION

The principal use for underground storage tanks for the past fifty years has been petroleum, petroleum products and chemical storage. Underground storage of fuel oil developed as coal furnaces were replaced by oil furnaces in the United States after World War II. Gasoline and diesel motor fuel storage increased with the widespread use of automobiles and trucks. Chemical storage has grown with the ever-expanding chemical industry. The storage of petroleum and chemical products is now a commonplace practice in both above and below ground tanks.

Underground storage tanks are widely used for a number of reasons. Fire hazards are greatly reduced by surrounding tanks with an inert soil. By placing tanks underground, more effective use of aboveground spaces can be made. Below ground storage also eliminates the aesthetic concerns associated with aboveground storage tanks. Although an "out of sight, out of mind" philosophy had been applied for years, such thinking is no longer acceptable in an environmentally conscious society.

With the realization that underground storage tanks can leak, the underground storage tank industry underwent an overhaul. Traditionally tanks had been constructed of steel. In the 1960's fiberglass reinforced plastic tanks were introduced. Although they did not become widely accepted until the 1980's, fiberglass tanks have become the popular choice in part to regulatory programs and problems associated with corrosion. This chapter compares steel and fiberglass tanks for underground storage.

REGULATORY REQUIREMENTS

The federal regulations regarding underground storage tanks are contained within the Code of Federal Regulations (CFR) Title 40 (Environmental Protection Agency), Part 280—"Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST)." A copy of 40 CFR, Part 280 is provided in Appendix A.

The regulations were initially issued on November 8, 1984, pursuant to the Resource Conservation and Recovery Act (RCRA). The regulations do not mandate the use of fiberglass tanks over steel tanks; however, they do require corrosion resistant construction and/or installation. Section 280.20, "Performance Standards for New UST Systems," contained under Subpart B—"UST Systems: Design, Construction, Installation, and Notification," requires that new USTs be constructed of fiberglass-reinforced plastic, cathodically protected steel, or steel-fiberglass-reinforced-plastic composite. In addition, underground storage tanks may be constructed of unprotected metal if the site of installation is deemed to be non-corrosive for the design life of the tank by a corrosion expert. A corrosion expert must be either a certified corrosion expert by the National Association of Corrosion Engineers (NACE) or a licensed professional engineer.

The local UST enforcement agency may approve other below ground tank installations provided they meet the design criteria of the industry standards for steel and fiberglass USTs. The following industry standards are cited as acceptable criteria for fiberglass tanks:

- Underwriters' Laboratories (UL) Standard 1316, "Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products"
- Underwriters' Laboratories of Canada (ULC) CAN4-S615-M83, "Standard for Reinforced Plastic Underground Storage Tanks For Petroleum Products"
- American Society of Testing and Materials (ASTM) Standard D4021-86, "Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks"

The following standards are also relevant to fiberglass tanks:

- National Fire Protection Association (NFPA) 30, "Flammable and Combustible Liquids Code"
- NFPA 30A, "Automotive and Marine Service Station Code"
- NFPA 31, "Installation of Oil-Burning Equipment"
- National Sanitation Foundation, Standard 14
- Factory Mutual Systems Approval J.I.1G4AO.AF

- Military Specification No. MIL–T–52777, "Tanks, Storage, Underground, Glass Fiber Reinforced Plastic"
- General Services Administration, Public Building Service Guide, PBS:1568
- City of New York Department of Buildings M.E.A. Division #124–83–M
- Los Angeles Fire Department

The following industry standards are cited as acceptable for cathodically protected steel tanks:

- Steel Tank Institute "Specification for sti–P_3 System of External Corrosion Protection of Underground Storage Tanks"
- UL Standard 1746, "Corrosion Protection Systems for Underground Storage Tanks"
- ULC CAN4–S603–M85, "Standard for Galvanic Corrosion Protection Systems for Underground Tanks for Flammable and Combustible Liquids"
- ULC CAN–S631–M84, "Isolating Bushings for Steel Underground Tanks Protected with Coatings and Galvanic Systems"
- National Association of Corrosion Engineers (NACE) Standard RP–02–85, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems"
- UL Standard 58, "Standard for Steel Underground Tanks for Flammable and Combustible Liquids"

The following standard is also relevant to cathodically protected steel tanks:

- API Publication 1632, "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems"

The following industry standards are cited as acceptable for steel–fiberglass–reinforced–plastic composite tanks:

- UL Standard 1746, "Corrosion Protection Systems for Underground Storage Tanks"
- Association for Composite Tanks ACT–100, "Specifications for the Fabrication of FRP Clad Underground Storage Tanks"

The federal regulations also mandate that new below ground tank systems be installed in accordance with nationally recognized codes of practice and manufacturers' installation guidelines. The following industry standards are cited as acceptable criteria for UST installation:

- American Petroleum Institute (API) Publication 1615, "Installation of Underground Petroleum Storage Systems"
- Petroleum Equipment Institute (PEI) Publication RP100, "Recommended Practices for Installation of Underground Liquid Storage Systems"
- American National Standards Institute (ANSI) Standard B31.3, "Petroleum Refinery Piping"
- ANSI Standard B31.4, "Liquid Petroleum Transportation Piping System"

Cathodically protected steel underground tank systems must be coated with dielectric material to ensure electrical isolation. Cathodic protection systems must be operated and maintained continuously. Cathodic protection systems must also be inspected by a qualified cathodic protection tester within 6 months of installation and every three years thereafter. Records must be maintained of the prior two inspections. In addition, the operation of impressed current cathodic protection systems must be inspected every 60 days with records maintained for the prior three inspections.

UST interiors must be compatible with the substance being stored. The following industry standards are cited as acceptable criteria for compatibility of alternative fuels:

- API Publication 1626, "Storing and Handling Ethanol and Gasoline–Ethanol Blends at Distribution Terminals and Service Stations"
- API Publication 1627, "Storage and Handling of Gasoline–Methanol/Cosolvent Blends at Distribution Terminals and Service Stations"

In addition to the tank construction requirements, the federal regulations also require that UST systems be equipped with spill prevention and overfill protection devices. Monitoring systems are required for petroleum substances stored below ground and may consist of inventory reconciliation, manual tank gauging, tank tightness testing, automatic in–tank gauging, vapor monitoring, ground water monitoring, and interstitial monitoring. As secondary containment is required for USTs storing hazardous substances, interstitial monitoring is the minimum required method of discharge monitoring. Although secondary containment is not required by the federal regulations for petroleum substances, it is preferred.

Tank owners must provide financial responsibility assurance for their tanks. Depending upon the type of owner, one of the following means of financial responsibility assurance may be deemed acceptable: a financial test of self–insurance, a guarantee, an insurance and risk retention group coverage, a surety bond, a letter of credit, a state–required mechanism, a state fund or other state assurance, a trust fund, a standby trust fund, a local government bond rating test, a local government financial test, a local government guarantee, or a local government fund.

CFR Title 40, Part 281—"Approval of State Underground Storage Tank Programs" deals with the implementation and administration of the individual state UST programs. A copy of 40 CFR, Part 281 is provided in Appendix A. The state UST programs must require, at a minimum, mechanisms for the implementation of the federal UST regulations as per Subpart C—"Criteria for No–Less–Stringent." All 50 states have a UST program of some sort. Many of the state requirements are more stringent than the federal regulations. For instance, non–residential heating oil tanks for on–site consumption are regulated in New Jersey, whereas all heating oil tanks for on–site consumption are excluded from the federal regulations.

ENGINEERING

With respect to the design and construction of USTs, the main thrust of 40 CFR Part 280 is that they be fabricated of either cathodically protected steel or fiberglass. The two industrial standards which apply to these two types of tanks are UL Standard 58, "Standard for Steel Underground Tanks for Flammable and Combustible Liquids," and UL Standard 1316, "Standard for Glass–Fiber–Reinforced Plastic Underground Storage Tanks for Petroleum Products." Therefore, UL Standards 58 and 1316 forms a basis of the comparisons between steel and fiberglass tanks.

CORROSION

Corrosion of underground storage tanks can be either external or internal. External corrosion can be caused by high water table conditions in which the tank is in direct contact with ground water. Moisture contained within soil backfill, which may tend to be acidic, can also be corrosive to UST exteriors. Stray currents may also cause external corrosion as the underground storage tank acts as an anode.

UL 1316 applies to glass–fiber–reinforced plastic underground storage tanks intended for the storage of petroleum–based flammable and combustible liquids, alcohols, and alcohol–blended fuels. The advantage of fiberglass construction in underground storage tanks is that fiberglass does not rust. Steel can rust. Internal and external linings or coatings are not necessary. The operation, maintenance, and inspection of cathodic protection systems are not required. Dielectric isolation is not an issue as fiberglass is not electrically conductive, although the isolation and protection of any steel pipes or fittings must be addressed.

UL 58 applies to horizontal atmospheric–type steel underground tanks for the storage of flammable and combustible liquids. Corrosion control of underground storage tanks is not covered in UL 58; it is covered by UL Standard 1746, "Corrosion Protection Systems for Underground Storage Tanks." UL 58 is primarily concerned with the fabrication and construction of steel below ground tanks. Since steel tanks are constructed from steel plates, a great deal of UL 58 focuses on the joining of the steel plates by welds. Seams in tanks are not an issue in the construction of fiberglass as they are fabricated by the continuous winding of glass filaments. Therefore, with the exception of fittings and accessories, no assembly is required for fiberglass tanks as they are fabricated directly into their final shapes or assembled as discussed in Chapter 5.

The corrosion of steel is an electrical process in which corrosion occurs where an electrical current leaves one metal structure and flows to another metal structure. The corroding metal from which the current leaves is known as the anode. The metal receiving current is known as the cathode. The goal of a cathodic protection system is to make the steel tank the cathode. Electrolytic corrosion results from the flow of direct current from an outside source through a metal object via an electrolyte. In the case of underground storage tanks, soil is the electrolyte.

Galvanic corrosion results from differences in electrical potential which develop when metal objects are placed in an electrolyte. Potential difference can result from variations in the surface of the same metal object. Potential difference can also result between two different metals when they are placed in the electrolyte (Figure 6–1).

Corrosion of steel tanks can occur as general or localized corrosion. General corrosion is a uniform deterioration of the entire steel surface. Localized corrosion may occur in one of four different ways in which only small areas deteriorate. Localized pitting is corrosion in the form of small pits or cavities which penetrate the surface and can eventually become holes.

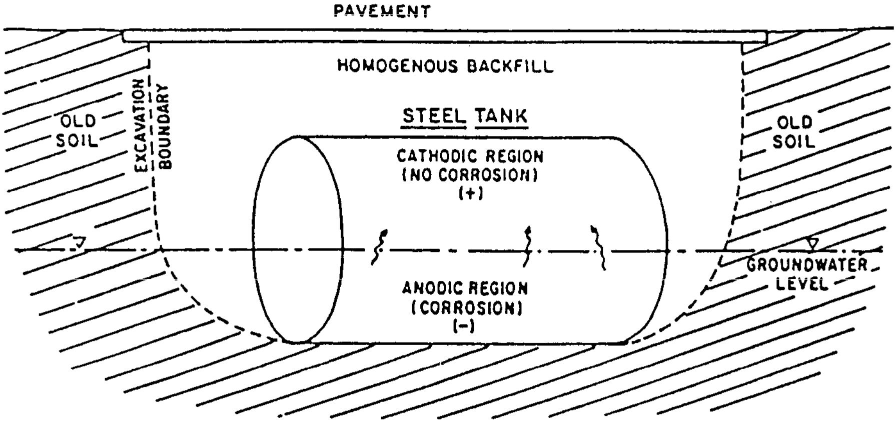


Figure 6–1: The presence of moisture can cause differences in electric potential which result in corrosion.

Stress cracking is local corrosion resulting from residual stresses from fabrication or uneven heating. Contact or crevice corrosion occurs at the specific point of contact or crevice between the steel tank and another object. Intergranular corrosion occurs at grain boundaries of the steel.

Corrosion may be influenced and accelerated by several conditions. The acidic condition of the soil or electrolyte generally enhances the corrosion of most metals, although zinc and aluminum require an alkaline condition. Corrosive action increases with rising temperature. Microbial action can enhance or hinder corrosion. Microorganisms can produce corrosive environments, create electrolytic concentration cells, effect surface films, effect the metal's environment, or effect the rate of anodic and cathodic reactions.

Soil resistivity is the resistance of the soil to the flow of an electric current. Low soil resistivity allows more corrosion. The presence of water can reduce soil resistivity and promote corrosion. Varying soil types will have differing properties which can effect the rates of corrosion. It is important to conduct a site soil survey in order to evaluate the soil suitability for pre–engineered cathodically protected steel tanks prior to their installation.

Newer steel corrodes in lieu of older steel; therefore, underground metal structures which exist prior to the installation of a steel tank may promote the corrosion of the new tank. Stray DC current can enhance corrosion by increasing the electrolytic activity. Stray electric current sources include electric rail transit systems, industry, and power lines.

Although external corrosion is more common, various studies indicate that approximately 10% of the leaks in steel below ground tanks are caused by internal corrosion. Conventional means of cathodic protection can be employed to prevent external corrosion, but it has no effect on internal corrosion. Internal corrosion is most often caused by water or aqueous salt solution which may be picked up by the stored fuel during transport and delivery. Fuels themselves are generally not corrosive to steel. Oxygen and bacteria can also be corrosive to steel tank interiors.

Internal corrosion of steel underground storage tanks may be prevented through the installation of internal linings or internal cathodic protection. Internal linings can take the form of fiberglass or zinc coating. Cathodic protection may utilize magnesium or zinc sacrificial anodes. A frequent inspection program should be employed in order to remove water and sediments on an annual basis. Inspection of the interior lining and testing of the sacrificial anodes is also necessary for the prolonged operation of the tank.

Corrosion protection of steel below ground tanks may be accomplished through the use of cathodic protection, protective coatings, and electrical isolation which should be designed as interdependent complimentary units in order to maximize protection.

In order to further discuss corrosion protection in steel tank systems, a basic understanding of cathodic protection is necessary. Cathodic protection is the application of a very low electrical current to a steel structure in order to prevent the corrosion of the steel structure. Therefore, in order to maintain a steel tank below ground, a small amount of energy must be expended over a long period of time.

Cathodic protection may take the form of a sacrificial anodes or impressed current. Sacrificial anodes are made from metals which will corrode and supply a direct electrical current in the presence of an electrolyte. Magnesium, zinc, and aluminum will corrode before iron; therefore, these metals are used for sacrificial anodes. Magnesium and zinc are commonly used in conjunction with steel underground storage tanks in soil and water. Aluminum is used for high chloride water such as seawater.

Impressed current cathodic protection uses a rectifier to convert alternating current to direct current for introduction into the electrolyte via graphite, iron, metal oxide, or platinum anodes. The direct current flows to the steel structure which is wired to the rectifier in order to complete the circuit. Protective coatings and linings help to protect steel tanks from the corrosive nature of the soil environment. Protective coatings may take the form of rubber, epoxy, silicone, and fiberglass reinforced plastic.

Electrical isolation requires the use of non–conductive materials in order for the connections to electrically isolate the steel tank from other metal objects. This helps to prevent the generation of an electrical current due to potential differences between dissimilar metals. Although the steel structures being protected must be electrically isolated, they must also be electrically continuous in order to ensure the protection of all portions of the objects being protected.

STRENGTH

One of the major advantages of steel underground storage tanks is that they are stronger than fiberglass tanks. However, when properly installed in the recommended backfill material, fiberglass tanks can perform satisfactorily. Fiberglass underground storage tanks are subjected to a rigorous series of tests under UL 1316, whereas steel underground storage tanks are subjected to only one pressure test under UL 58. Therefore, certain aspects of the fiberglass UST may be considered as strong as that of the steel UST.

UL 58 places certain construction requirements on underground storage tanks by specifying minimum gage thicknesses and types of welded connections. The minimum gage thickness permitted for steel tanks up to 285 gallons in capacity is 14 gage (0.075" uncoated). Steel underground storage tanks over 20,000 gallons in capacity require a thickness of 3/8".

Eight types of shell seams are specified as acceptable in UL 58 for steel underground storage tanks. Shell seams are seams which join the pieces of sheet steel forming the sides of the UST. Continuous welds and continuous full fillet welds are the primary welds specified for shell seams with combinations involving lock welds and tack welds.

The head, or end, of a steel tank may be formed by up to four pieces of sheet steel joined by shell seams for tank diameters up 12'; three pieces may be used for tanks up to 8' in diameter; two pieces may be used for tanks up to 4' in diameter. The head of the tank may be flat, dished, or conical.

Fifteen types of joints are specified for securing the head of the tank to the shell walls of the tank. Continuous welds and continuous full fillet welds are specified as acceptable. Unflanged flat heads of tanks must also be supported by interior bracing. Such bracing may consist of angled strut bracing from the head to the shell or support channels on the head for stiffening. Flanged flat heads do not require bracing. Dished and conical heads do not require bracing.

The height of a conical head shall be less than one-twelfth (1/12) of the diameter. The minimum height of a dished head is 1.5" for tanks under 5' in diameter.

UL 58 requires that pipe connections be provided on the top of steel underground storage tanks by welding one of eight standard-type pipe fittings. Manholes shall be affixed by continuous full fillets and equipped with bolted covers with 1/8" gaskets. An opening must be provided for a vent pipe and all openings shall be plugged during storage and transport.

The manufacturer shall perform a leakage test on steel underground storage tanks prior to painting in order to prove their tightness and integrity. An internal air pressure of 5 to 7 psig shall be applied to the tank while soap, linseed oil, or other such material is applied to the exterior to detect leaks. Alternatively, the tank may be placed in its intended installation position, filled completely with water, and subjected to an additional 5 psig. If leaks are noted during the leakage test, they shall be repaired to make the tank tight and the tank shall be retested. The individual compartments of compartmentalized tanks shall be tested separately.

UL 1316 for fiberglass below ground tanks does not specify material thicknesses or joint mechanisms. UL 1316 does place the same basic requirements on pipe connections and manholes as UL 58 does. UL 1316 requires that pipe connections be provided on the top of fiberglass underground storage tanks by bonding standard-type pipe fittings. Manholes shall be equipped with bolted covers equipped with 1/8" gaskets. An opening must be provided for a vent pipe and all openings shall be plugged during storage and transport.

Deflection plates must be provided on the bottom of fiberglass underground storage tanks beneath each tank opening. Deflection plates shall be at least one square foot and shall be constructed of 0.053" steel or 1/8" aluminum.

UL 1316 requires that only one sample of a line of fiberglass tanks need be subjected to the series of performance tests. For tank diameters less than 10 feet in diameter, an internal air pressure of 10 psig shall be applied to the tank while soap, linseed oil, or other such material is applied to the exterior for the detection of leaks. For tank diameters greater than 10 feet in diameter, an internal air pressure of 5 psig shall be applied to the tank while soap, linseed oil, or other such material is applied to the exterior for the detection of leaks.

By UL 1316, threaded pipe fittings must be subjected to torques ranging from 2,000 pound-inches for 3/4" pipe fittings to 4,600 pound-inches for 8" pipe fittings. Threaded pipe fittings shall be incrementally subjected to a bending moment of 2,000 pound-feet with a 4' length of Schedule 40 steel pipe. The bending moment shall first be applied along the tank axis, and then perpendicular to the tank axis. The test may be stopped if the pipe bends prior to reaching the 2,000 pound-feet bending moment. The leakage test shall be re-performed after the torque and bending moment tests.

Under UL 1316, fittings which are to be used for lifting must collectively be subjected to a load test equivalent to twice the load of the empty fiberglass tank. The leakage test shall be re-performed after the lifting load test.

UL 1316 requires that fiberglass underground storage tanks be subjected to a water load test. A tank shall be buried to one 1/8 of its diameter in sand and filled with water for one hour.

UL 1316 also requires that fiberglass tanks be subjected to an external pressure test. A tank is to be properly installed, anchored, and backfilled in a test pit which is then filled with water for 24 hours. A one minute internal vacuum shall be applied to the empty tank so that internal pressure is 5.3" of Mercury less than the external hydrostatic pressure.

In addition, UL 1316 requires the application of an internal pressure test. Tanks less than 10' in diameter must be subjected to 25 psig. Tanks greater than 10' in diameter must be subjected to 15 psig.

UL 1316 requires an earth load test. An empty tank shall be properly installed and backfilled to a 3' burial depth. The tank must remain buried for one hour. The leakage test shall be re-performed after the earth load test.

UL 1316 requires that coupons of fiberglass tanks be taken, conditioned, and subjected to a series of physical property tests. The coupons are representative samples of the fiberglass cut directly from a tank wall laminate. The coupons are to be 7.5" wide by 9" long with minimal curvature. Each coupon is cut into a 5" wide piece and 2.5" wide piece. The smaller coupon piece is used for "as is" testing while the larger coupon piece is used for testing after conditioning.

The coupons are subjected to flexural modulus and fiber strength tests as per "Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials," ANSI/ASTM D790-84a. Coupons are also subjected to the Izod impact-strength test as per "Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials, ASTM D256-84."

Large coupons are conditioned by air-oven aging at 70°C for periods of 30, 90, and 180 days. Coupons conditioned by air–oven aging must achieve at least 80% of the flexural properties and impact strength of unconditioned coupons.

Large coupons are subjected to conditioning by immersion in liquids maintained at 38°C for periods of 30, 90, and 180 days. Immersion liquids are classified into two categories: Type A liquids and Type B liquids. Type A immersion liquids are those used to simulate actual conditions while Type B immersion liquids represent conditions more severe than actual conditions. For tanks produced for the storage of petroleum products, Type A liquids include: premium leaded gasoline, regular unleaded gasoline, No. 2 fuel oil, ASTM Reference Fuel C, sulfuric acid, saturated sodium chloride, No. 6 fuel oil. For tanks produced for the storage of alcohol and alcohol–petroleum blend products, Type A liquids include: 100% ethanol, 10% ethanol–90% Reference Fuel C, 30% ethanol–70% Reference Fuel C, 50% ethanol–50% Reference Fuel C, 85% ethanol–15% Reference Fuel C, methanol, 50% methanol–50% Reference Fuel C, and 85% methanol–15% Reference Fuel C. For tanks produced for the storage of alcohol–petroleum blend products only, Type A liquids include: 10% ethanol–90% Reference Fuel C and 30% ethanol–70% Reference Fuel C. Type B immersion liquids for all tanks include: toluene, distilled or deionized water, hydrochloric acid, nitric acid, sodium carbonate–sodium bicarbonate solution, sodium hydroxide solution, and sodium hydroxide.

Coupons conditioned by immersion in Type A liquids for 180 days must achieve at least 50% of the flexural properties and impact strength of unconditioned coupons. Coupons conditioned by immersion in Type A liquids for 180 days must achieve at least 30% of the flexural properties and impact strength of unconditioned coupons. Coupons must achieve at least 50% of the flexural properties and impact strength of unconditioned coupons for the 270 day values. The 270 day value may be obtained by extrapolation of the 30, 90, and 180 day values or testing after 270 day immersion period.

Large coupons are also conditioned by cold exposure for a period of 16 hours in a cold box maintained at -29°C. After the cold exposure, the coupons are clamped between two steel rings and subjected the impact of a 1.18 pound steel ball dropped from a height of 6'. The coupon shall not crack or rupture.

In addition, large coupons are conditioned by light and water exposure for periods of 180 and 360 hours as per "Method I of the Standard Operating Light–Exposure Apparatus (Carbon–Arc Type) With or Without Water for Exposure of Nonmetallic Materials, ASTM G23–

81." Coupons conditioned by light and water exposure must achieve at least 80% of the flexural properties and impact strength of unconditioned coupons.

UL 1316 also requires that all tanks be subjected to the leakage test, the internal vacuum test, and the surface cure test. The internal vacuum test consists of the application of an internal partial vacuum equal to the sum of the radius of the tank and the maximum burial depth times 0.88" Mercury/foot. The surface cure test shall be the barcol hardness test as per the "Test Method for Indentation Hardness Of Rigid Plastics by Means of a Barcol Impresser, ASTM D2583-81."

CHEMICAL COMPATIBILITY

The chemical compatibility of a tank with the substance being stored is an important design consideration. Non-compatibility of a steel tank and the substance being stored would result in corrosion, which has already been discussed. However, the non-compatibility of a fiberglass tank may result in the softening, cracking, or swelling of the plastic.

The immersion testing protocols of UL 1316 for fiberglass tanks which were discussed in the previous section establish the criteria for chemical compatibility with petroleum products, alcohols, and alcohol-petroleum blends. Fiberglass tank manufacturers warranty the chemical compatibility of their tanks with the following petroleum products: gasoline, jet fuel, aviation gas, kerosene, diesel fuel, motor oil, used motor oil, and fuel oil. Fuel oil must not exceed a temperature of 150°F. Manufacturers warranty their fiberglass tanks for the storage of the following alcohol-petroleum blends: gasohol (10% methanol-90% gasoline), Arco Oxinol-50 Waiver (90.5% gasoline-4.75% methanol-4.75% GTBA), and DuPont EPA Waiver (gasoline-methanol-cosolvent blend). The storage of oxygenated motor fuel (gasoline with up to 20% MTBE) is also warrantied. The storage of potable water is warrantied at ambient underground temperatures. The storage of additional liquids must be assessed on an individual basis.

Chemical compatibility is the most important engineering feature of below ground tanks which must be addressed in the chemical industry. Both steel and fiberglass underground storage tanks have been developed for the petroleum industry. Steel is generally incompatible with mineral acids such as nitric acid, hydrochloric acid, and dilute sulfuric acid. Fiberglass is generally incompatible with sulfuric acid, nitric acid, hydroflouric acid, aromatic solvents, and chlorinated solvents.

Internal linings of steel tanks can be fiberglass and, therefore, they must be evaluated for chemical compatibility with products other than petroleum and alcohol blends. Alternate lining materials may be used to resist chemical action by the stored substance. Alkyds, poly–vinyl–chloride (PVC), chlorinated rubbers, epoxies, coal tar epoxy, polyesters, or silicones may be used for tank linings to provide chemical compatibility with substances other than petroleum products. Various resins may be used with fiberglass tanks to increase their resistance to certain chemicals. (See Chapter 2.)

Equally important as the factory construction and evaluation of tanks is the proper installation in accordance with manufacturers guidelines. After installation, proper maintenance of a system is crucial to ensure the prolonged performance of the system.

INSTALLATION

UL 58 does not include any installation guidelines for steel underground storage tanks. UL 1316 requires that the manufacturer's installation instructions specify lifting techniques and backfill material. UL 1316 also requires that lifting techniques shall include the load distribution between the fittings used for lifting. The type of backfill for fiberglass tanks may be pea gravel or clean, dry, compacted sand (Figure 6–2).

The installation guidelines for steel and fiberglass tanks have been established by industrial manufacturers. Installation techniques are actually quite similar for both types of tanks. Unless properly installed, the manufacturers' warranties are null and void.

For a steel UST installation, the excavation shall be prepared by removing large or sharp materials from the native soil that may potentially damage the tank coating. The bedding and backfill shall extend a minimum of 1' around the installed tank. If the steel tank is to be anchored to a concrete pad, a minimum of 6" of bedding material shall be placed between the concrete anchor mat and the steel tank. Bedding and backfill shall be homogenous material consisting of clean, inert sand, pea gravel or No. 8 crushed stone as per ASTM 448. Backfill on top of the steel shall be 18" with either 8" asphalt pavement or 6" reinforced concrete. Alternatively, 36" of backfill may be used without pavement cover. When installing backfill material it is important to ensure that the tank is properly supported around the lower quadrant of the tank. The use of a tamping rod is recommended.

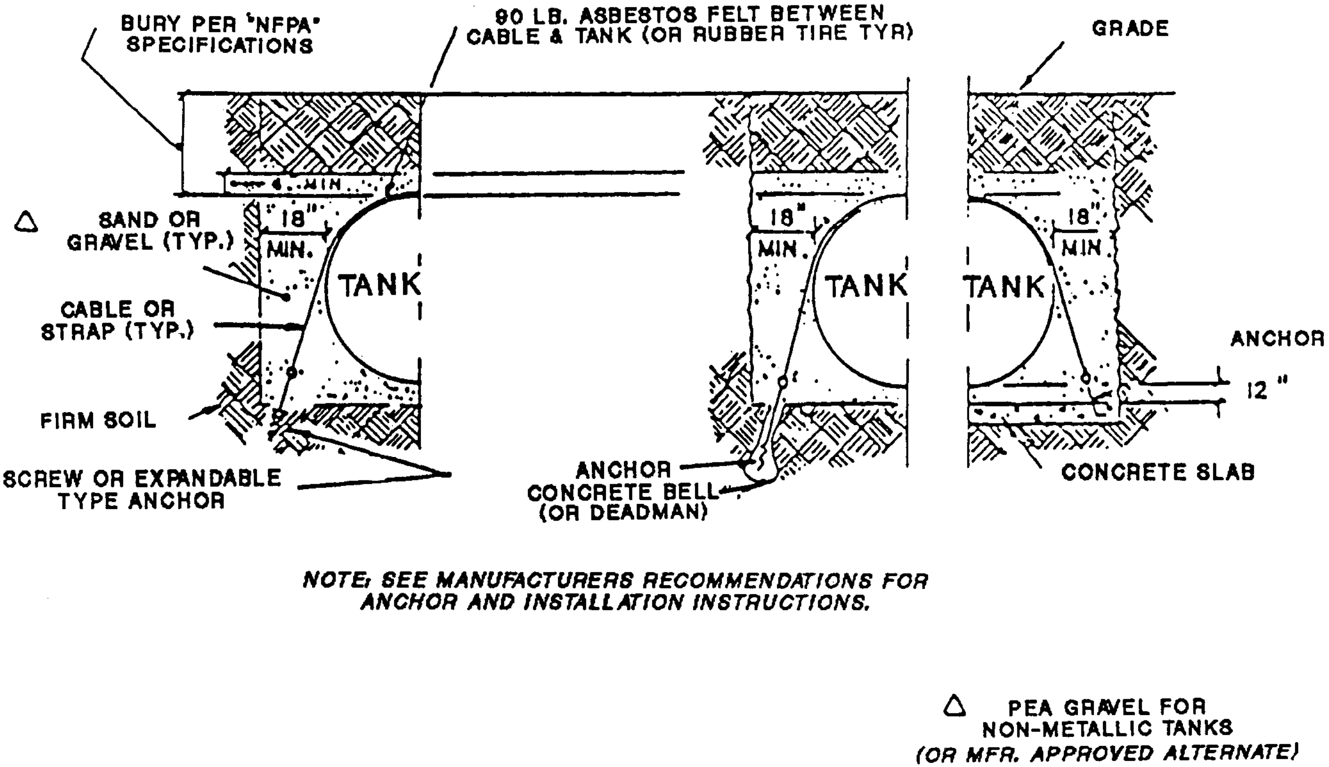


Figure 6–2: Anchoring of tanks installed in high groundwater tables.

Steel tanks may be stored aboveground using sandbags or tires as chocks. Prior to installation, steel tanks are subjected to an aboveground air pressure test of 5 psig. A soap solution must applied to the tank exterior at all weld seams and fittings for the detection of leaks. All foreign matter shall be removed from the tank exterior. Damaged areas of the coating material shall be repaired with the field touch–up coating supplied with the tank. After installation of appurtenant piping, the steel tank and piping system is subjected to a 5 psig air pressure test or hydrostatic test.

Steel tanks shall be lifted and lowered only through the use of chains or cable attached to the lifting lugs. The use of chains or slings around the tank shell may damage the tank coating. If necessary, steel tanks may be secured to concrete anchor mats or deadmen with hold straps which must be separated from the tank by an inert insulating dielectric pad. The distance of the end anchor straps to the end of the tank must not be more than 1/10th of the length of the tank. Steel cable and round bar may not be used for anchor straps.

Steel tanks equipped with factory installed anodes, shall be carefully inspected to ensure the integrity and proper connection of the anode. The operation of the anode is instantly tested by dowsing it with water. Dielectric isolation is a requirement to ensure the integrity of the steel tank. Prior to completely backfilling, the tank openings shall be inspected to assure that all dielectric bushings are in place. Electrical isolation may be checked with a continuity tester. The steel tank must not be in contact with any other structures such as piping, pumps, valves, or other equipment which will nullify the cathodic protection. After backfilling, continuity can be tested by connecting a high impedance voltmeter to these steel structures and to a copper/copper sulfate reference cell in the soil. The potential differences between the tank to soil and the other steel to soil must exceed 10 millivolts for acceptable electrical isolation. The tank to soil potential difference must be higher than –850 millivolts in order to verify activation of the factory installed anodes.

Cathodic protection of sti–P_3 steel tanks must be monitored at installation and every three years thereafter.

The bedding and backfill for fiberglass tank installations shall consist of pea gravel with rounded particles between 1/8" and 3/4" or crushed stone with angled particles between 1/8" and 1/2" as per ASTM C–33. Twelve inches of bedding material shall be placed beneath the tank. Eighteen inches of backfill material shall surround the sides and ends of the tanks up to 10' in diameter. Adjacent tanks shall be spaced 18" apart for tanks up to 10' in diameter. Twenty–four inches of backfill material shall surround the sides and ends of 12' diameter tanks. Adjacent tanks shall be spaced 24" apart for tanks up to 12' in diameter. If the cohesion of the native soil is less than 750 lb/sq ft or if the ultimate bearing capacity of the native soil is less than 3,500 pcf, then the surrounding backfill material must extend at least half the diameter of the tank around the sides and ends of the tank.

For fiberglass tanks up to 10' in diameter subject to traffic loads, tank cover shall consist of 18" of backfill with either 6" of reinforced concrete or 9" of asphalt pavement. Alternatively, tanks up to 10' in diameter subject to traffic loads may be covered with 36" of backfill. Tanks over 12' in diameter require either 36" of backfill with pavement or 48" of backfill without pavement. For fiberglass tanks up to 10 feet in diameter which are not subject to traffic loads, tank cover may consist of either 12" of backfill with 4" of reinforced concrete or 24" of backfill. The maximum tank burial depth is 7 feet.

Fiberglass tanks may be secured to concrete anchor mats or deadmen. Fiberglass anchor straps must be used in conjunction with such. Fiberglass tanks may be partially ballasted with water in order to assist in sinking the tank into the wet tankhole conditions; however, the level of ballast shall never exceed the level of the water in the tankhole. Under dry tankhole conditions the tank may be ballasted to prevent floating after it has been backfilled. The use of a non-metal tamping rod is recommended for ensuring that the lower quadrant is properly supported when backfilling. The bottom two feet of backfill shall be placed in 12" lifts and tamped accordingly.

Fiberglass underground storage tanks may be stored on cleared grade free of debris prior to installation if chocked with sandbags or tires. If high winds are prevalent, the tanks may be tied down as well. Chains or cables should not be placed around the tank. Fiberglass tanks should not be dropped or rolled. All lifting lugs should be used to lift the tank. Prior to installation, fiberglass tanks are subjected to 5 psig air pressure test. A soap solution must be applied to the entire tank exterior in order to detect leaks. After installation and backfill, fiberglass tanks are checked for vertical deflection. The backfilled tank is subjected to another 5 psig air test for a period of one hour.

MAINTENANCE

After the proper installation and start-up of a well-designed below ground tank system, certain tasks must be executed in order to ensure that the system remains in proper condition. The installation of a state–of–the–art system does not guarantee that leakage will not occur. The system must be properly monitored and maintained in order to preserve its tightness and integrity.

All petroleum tanks are regulated by the USEPA are now to be equipped with monitoring systems in order to be in compliance with the federal regulations. The operation of discharge monitoring systems and leak detection systems is the same for both steel and fiberglass tanks. All electronic monitoring systems must be regularly tested to ensure their proper operation for the prevention of leakage.

Tank monitoring systems may take the form of interstitial monitoring, excavation monitoring, or inventory control. The interstitial monitoring systems employed with double–wall underground storage tanks monitor the interstitial space between the inner and outer tank walls with electronic sensors. Leakage through either wall is detected by either liquid sensors or pressure sensors. The excavation monitoring systems used with single wall tanks monitor the tank backfill material for the presence of petroleum in observation wells or U–tubes. Electronic inventory control systems consist of an in–tank gauge which can detect product losses.

Inventory reconciliation may be accomplished by the compilation of daily stick readings, which is also a simple way of verifying the operation and results of the more sophisticated electronic monitoring systems which may be in place. Despite the presence of deflection plates, which is mandatory in fiberglass underground storage tanks and frequent in steel underground storage tanks, care must be taken when obtaining stick readings so that the bottom of the tank is not punctured. Tank gauge sticks should never be dropped into a UST, rather they should be gently lowered until reaching the bottom.

Overfill protection and spill containment technologies are also now required on all federally regulated underground storage tanks. Overfill protection may be accomplished through the use of electronic tank gauges and/or automatic shut–off valves. Spill containment employs the use of basins around fillports to contain spillage from delivery transfers. Both of these technologies are well enhanced through careful and diligent delivery processes which help to prevent the release of product to the environment.

Steel underground storage tanks are subjected to the operation of cathodic protection systems. Cathodic protection systems require periodic testing to ensure their continued operation and the integrity of the UST. Impressed current cathodic protection systems must also be tested every 2 months for proper operation. Sacrificial anodes and sti–P_3 underground storage tanks must be monitored every 3 years when electrical potential readings between the tank and soil are taken with a high impedance voltmeter and copper/copper sulfate reference electrode.

Good housekeeping practices will also aid in prolonging the life of all tanks. Common sense practices for cleanliness and orderliness will help to prolong the life of the system.

SECONDARY CONTAINMENT

Although it is not specifically required, secondary containment is the preferred installation for petroleum underground storage tanks by the federal regulations. The regulations require that by 1998 underground storage tanks containing non–petroleum hazardous substances be equipped with secondary containment. Secondary containment may take the form of a single–wall UST installed within a lined excavation, double–wall underground storage tanks, or composite double–wall underground storage tanks. Monitoring of the interstitial, or annular, space is necessary for effective use of such techniques. Concrete vaulted tanks usually create a "room" for the tank thereby forming an aboveground storage tank installation, which is a very different method of storage subject to different codes and standards. (Figures 6–3 and 6–4.)

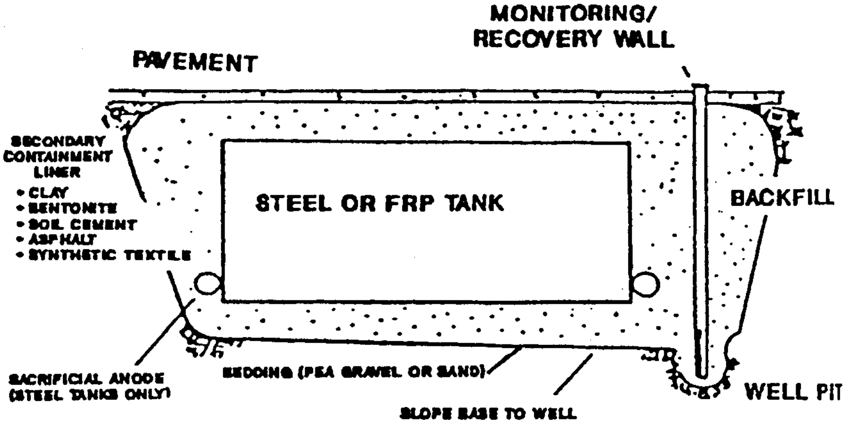


Figure 6–3: Secondary containment using liner technology–dry installation–not to be used in high groundwater.

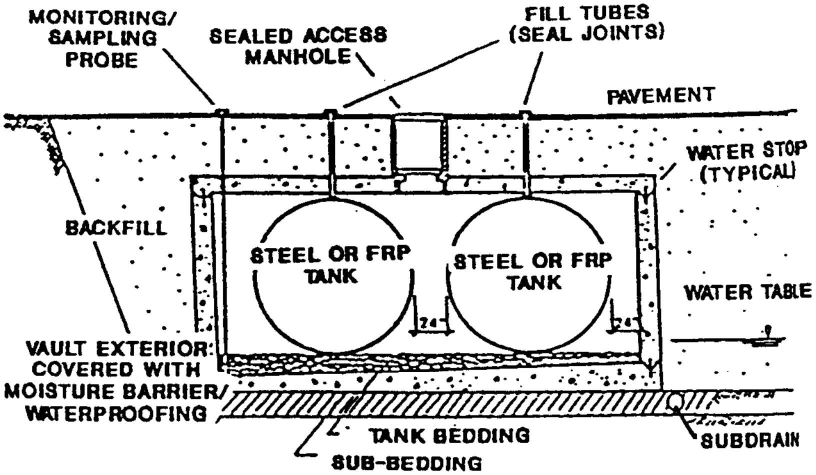


Figure 6–4: Secondary containment vault. Note: tanks must be designed to withstand internal forces without backfill support.

DOUBLE–WALL

Double–wall underground storage tanks are essentially a tank within a tank. An interstitial, or annular, space is created between the two layers of steel or fiberglass. Electronic sensors between the inner and outer tank walls detect the presence of leakage through either tank. After pressure–testing in the field and proper installation, double–wall underground storage tanks may be equipped with an appropriate interstitial monitoring system.

Double–wall steel underground storage tanks are provided with a vacuum pressure of 13" to 14" of Mercury within the interstitial space. The vacuum pressure gauge should be checked at delivery, upon placement in the open excavation, and after backfilling in order to ensure that the vacuum pressure has been maintained and that no damage has occurred to the UST. As a test of the UST, the primary (inner) tank is pressurized to 5 psig while a soapy solution is applied to the outer tank seams. The pressure is maintained for 12 hours for tanks less than 10,000 gallons in capacity or for 24 hours greater than 10,000 gallons in capacity. The entire UST is tight if no signs of leakage are evidenced and the interstitial pressure drop is less than 5" of Mercury. Aside from a maximum burial depth of 6', the remainder of the installation requirements for double–wall steel underground storage tanks are the same as for single–wall steel underground storage tanks.

Double-wall fiberglass underground storage tanks cannot structurally withstand shipment with pressurized interstitial spaces. In order to test the UST, the inner and outer walls must be separately pressure tested. First, the inner tank is pressurized to 5 psig for one hour while all accessible fittings are soaped and inspected for leaks. If the interstitial space is not equipped with a monitoring fluid, the inner tank pressure is then relieved to the interstitial space and both are pressurized to 5 psig for one hour while the external tank wall is soaped and then inspected for leakage. If the interstitial space is equipped with a monitoring fluid, the inner tank pressure is then relieved to the interstitial space and the external tank wall is inspected for fluid leakage.

COMPOSITE CONSTRUCTION

Because of the strength of steel and the corrosion resistance of fiberglass, the use of both materials in a composite form has emerged. Double-wall steel covered with fiberglass laminate provides the most protective UST available.

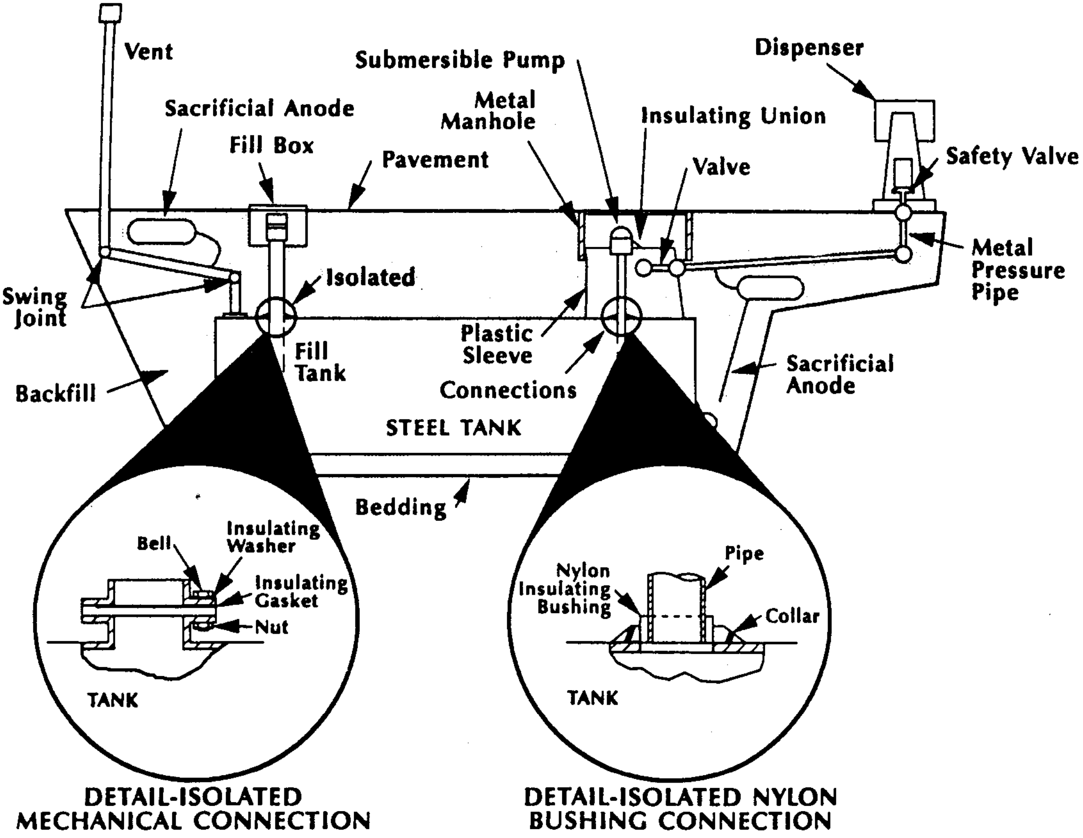
The installation of such composite underground storage tanks expectedly combines the techniques of both steel and fiberglass installations. The storage tank is subjected to a 5 psig air pressure test while fittings are soaped. The fiberglass laminate (typically 100 mil thick) is visually inspected for flaws which are then touched up in the field.

Dielectric insulating material must separate anchor straps from the UST shell. Continuity tests are conducted at all tank to pipe connections for electrical isolation. Lifting lugs must be covered with a dielectric cap or coated with field applied laminate touch up. (Figure 6-5.)

Cathodic protection is not necessary with composite underground storage tanks although protective fiberglass coating and electrical isolation are utilized. The elimination of cathodic protection simplifies the operation and maintenance of the UST system.

COST CONSIDERATIONS

The bottom line for many UST users is cost. However, there are many factors which influence the overall cost of a UST system aside from the actual tank purchase price from the manufacturer. In addition to the UST, all piping, monitoring systems, and accessories must be purchased and installed.



DETAIL-ISOLATED MECHANICAL CONNECTION

DETAIL-ISOLATED NYLON BUSHING CONNECTION

Figure 6–5: Underground tank and piping system.

Site preparation and safety precautions are required for installation. Operation and maintenance of the UST system includes all monitoring systems and controls. Steel underground storage tanks also require the operation and maintenance of cathodic protection systems.

Costs extraneous to the actual field installation and daily operation of the UST system include permit and registration fees imposed by municipal, county, and state governing bodies. The costs of insurance and/or financial responsibility have become very expensive as underground storage tanks are considered such an environmental liability. Manufacturers of underground storage tanks are presently offering 30-year warranties on both steel and fiberglass underground storage tanks.

The material and installation costs of steel and fiberglass UST systems are quite competitive, but fiberglass USTs are generally more economical. Composite underground storage tanks are obviously the most expensive to initially purchase. However, simplified maintenance and the extra-protection offered by composite construction will pay for itself over the life of the system.

CONCLUSIONS

The expansion of the petroleum and chemical industries over the past half-century has seen the advancement of underground storage tank technologies. Although steel had been the predominant UST construction material for many years, fiberglass construction has become very popular.

A majority of below grade tanks now being installed by the major oil companies are fiberglass. The advantage of fiberglass is its resistance to corrosion. The advantage of steel is its strength and broad chemical compatibility. Steel tank manufacturers have addressed the problem of corrosion with cathodic protection, protective coatings, and electrical isolation. However, cathodic protection systems require additional maintenance which is not necessary with fiberglass. The strength of fiberglass equals that of steel if installed properly. The installation requirements for steel are now very similar to those of fiberglass. Resin and other linings allow increased chemical compatibility for both steel and fiberglass.

CHAPTER 7

FRP AIR HANDLING EQUIPMENT

FRP FANS FOR CORROSIVE AIR HANDLING

FRP blower fans are fabricated from a variety of corrosion–resistant resin formulations to provide protection against corrosive fumes, gases and mists. In general, FRP fans provide efficient operation at reduced operating costs. They have received widespread acceptance in a variety of industrial applications, such as exhaust systems handling corrosives, because of their reliability, economy and high corrosion resistance.

Fan housings and impellers are normally fabricated from solid, fiberglass reinforced, polyester–based resins. A steel hub is usually encapsulated within the impeller to provide a secure connection with the drive shaft (Figure 7–1). There is a variety of resin systems employed to meet specific corrosion resistance requirements.

One of the major advantages of FRP fans is their light weight, which permits greater freedom in installation and location of units. They can be readily mounted on platforms or roofs without the need for excessive structural reinforcement. (Because of the weight of metal fans, additional structural reinforcement is required.) Furthermore, impact–resistant FRP housings are electrically nonconductive and fire retardant.

FRP fans display good mechanical features. Oversized shafts are capable of operating significantly below their critical speed. Selfaligning sealed pillow block bearings are often provided. Impellers must be balanced statically and dynamically before units are assembled. Fan performance tests are conducted in accordance with the Standard Test Code for Air Moving Devices.

Systems are designed to operate at relatively high levels of mechanical efficiency. Lower operating costs are generally realized as FRP blowers will deliver air loads at slightly lower horsepower levels than competitive metal fans under similar operating conditions.

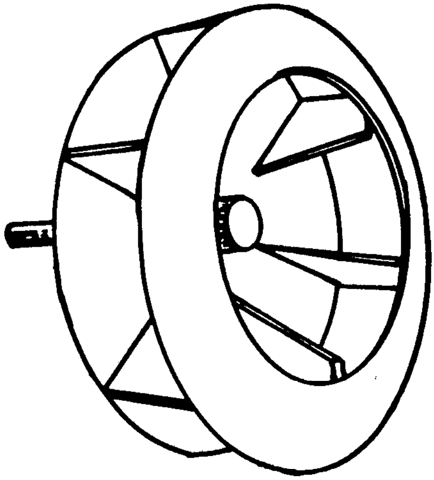


Figure 7–1: A one–piece solid FRP wheel. A steel hub and shaft through the shaft seal are encapsulated with FRP.

Service life can be correlated with impeller speed of rotation. In general, lower rotational speed provides less wear and leads to longer service life. Usually, plastic blowers are designed to operate at lower tip speeds than competitive metal fans for similar applications. Lower tip speeds tend to reduce impeller wear and extend the service life of bearings and mechanical drive components.

Axial fans are employed in horizontal or vertical installations in interior duct–work. These are one of the simplest designs and are available in capacities ranging from 2,000–100,000 CFM or more with static pressures to 3 in. There are a variety of configurations. The axial fan can be located on the entering air side or from the discharge air side. Vane axials are equipped with molded FRP curved discharge vanes, which are bonded between the inner cylinder and outer casing. This provides maximum fan efficiency rugged construction and maintains noise to acceptable levels.

For most designs, housing are generally of solid FRP construction with integrally bonded FRP flanges. Bearing cylinders are provided with neoprenegasketed, removable–end (FRP) covers held in place with metal bolts and nuts. This allows easy access for adjustments to fan sheaves or bearing replacements.

Fan shafts, usually type 304 or 316 stainless steel, are fitted with a wheel end treaded for a stainless steel castle nut and cotter pin which holds the wheel in position. To prevent the wheel from turning free, a keyway is provided with the key and wheel. Castle nuts can be protected further by a molded epoxy acorn nut threaded on shaft and sealed in place to the wheel hub by resin.

Bearings are normally enclosed within an inner cylinder with grease lines that extend to grease fittings located outside the outer casing. Grease lines are protected within plastic enclosures from corrosive fumes passing through the fan.

Centrifugal Fans

Air flow in a centrifugal fan is perpendicular to the shaft on which the impeller wheel is mounted. Impeller wheels are mounted in a scroll–type housing, which develops the system's rated pressures. There are several types of centrifugal fans; efficiency and operation of each type depend on the impeller wheel blade position in reference to the direction of rotation. In general, as the static pressure increases, the volumetric discharge (cfm) decreases.

Standard designs have fan housings and impellers constructed of solid fiberglass for maximum resistance to chemicals. Fan losses are minimized by close tolerances between wheel and housing, providing minimum clearance.

The various types of blade designs are shown in Figure 7–2. Forward inclined blades [Figure 7–2(A)] are designed such that the tips of the blades are inclined in the direction of rotation. These systems provide maximum air delivery at relatively low noise levels. They are employed in applications where static pressure requirements are under 2½ in. and can be used in air streams with moderate solids loadings.

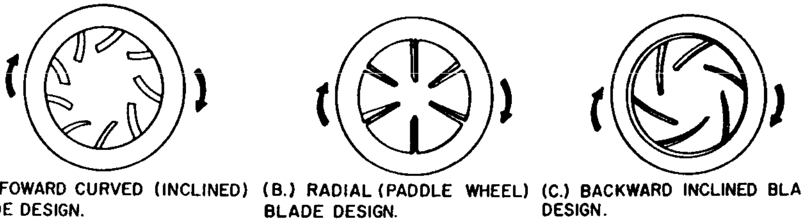

(A.) FOWARD CURVED (INCLINED) BLADE DESIGN.
(B.) RADIAL (PADDLE WHEEL) BLADE DESIGN.
(C.) BACKWARD INCLINED BLADE DESIGN.

Figure 7–2: Three types of centrifugal blade configurations.

Radial blade fans [Figure 7–2(B)] consist of straight, paddle wheel–type blades. For the most part, these systems are considered self–cleaning. The impeller wheels have narrow blades and are of relatively simple construction. They are capable of high speeds, which are required at higher system static pressures. These systems can operate under static pressures as high as 10 in. or more and can be employed for air streams with high solids loadings. Their major disadvantage is the high noise levels associated with their operation.

Backward curved impellers, shown in Figure 7–2(C), offer the highest fan efficiency of the three. Blade tips are inclined away from the direction of rotation. These designs are employed in applications where static head requirements range up to 4 in. They are not recommended for use in air streams containing particulates. They provide high volumes at relatively low static pressures and, as such, are competitive with many axial fans. Noise levels are considered moderate, although they may be considerably higher than backward-inclined blades, depending on the particular application and speed.

Several types of industrial exhausters are illustrated in Figures 7–3, 7–4 and 7–5. Whenever possible, exhaust fans should be mounted on the roof. This will maintain the ducting leading to the fan inlet under negative static pressure. When units are installed inside the building, ducting connected to the fan outlet will be under positive static pressure. This can cause hazardous situations should leaks develop in that portion of the duct contained in the building as toxic fumes can be forced out of the duct into the working area When installing these systems, exhaust fan stackhead discharge recommendations should be followed.

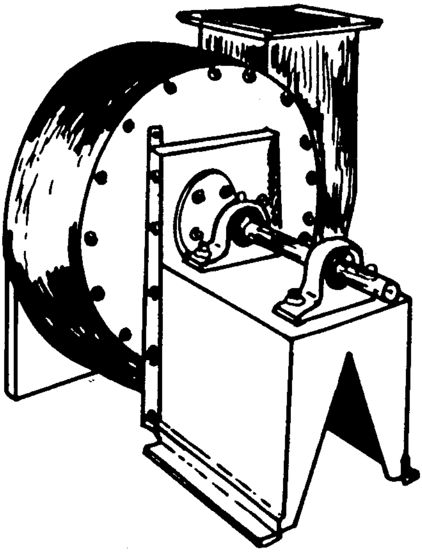


Figure 7–3: Typical industrial FRP exhauster. Exit flanges and inlet collar and flanges are solid FRP fabrications. System is designed for belt drive via a flexible coupling. Interior surfaces are FRP and exposed areas are usually sandblasted, primed and multicoated with a vinyl coating.

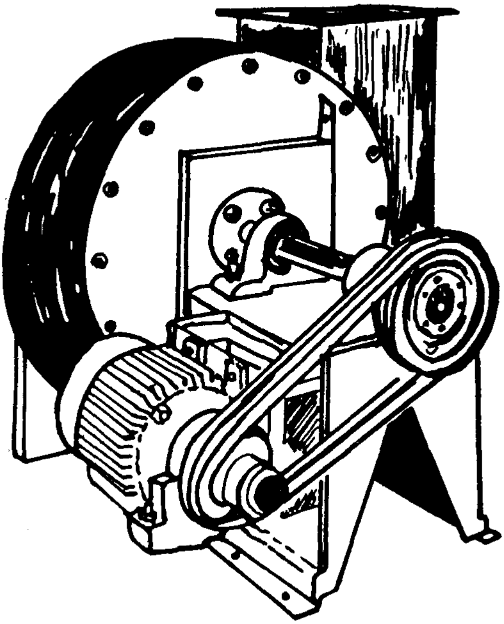


Figure 7-4: Typical industrial FRP exhauster equipped with an adjustable motor mount.

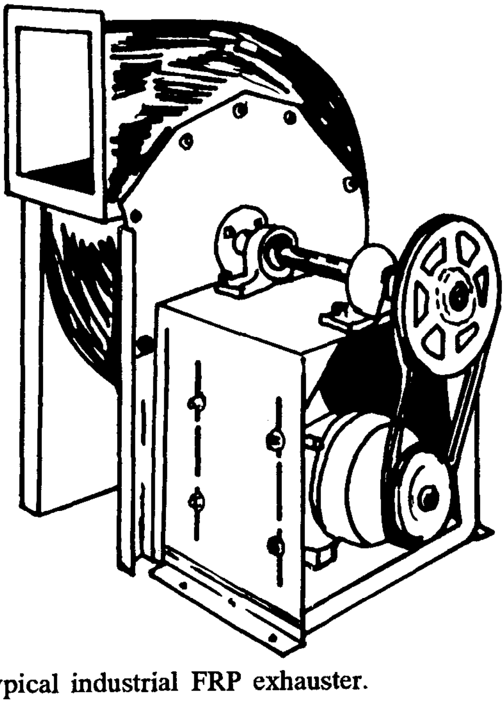


Figure 7-5: Typical industrial FRP exhauster.

For most exhaust fan applications, V–belt–type fans are recommended. These designs have adjustable pitch motor sheaves, which allow the fan impeller wheel rpm to be raised to provide greater exhaust capacity (cfm) and/or higher static pressure. Similarly, the fan impeller wheel rpm can be lowered, which would reduce both the cfm and static pressure One should choose a fan having middle range capabilities that match the cfm and static pressure required for a particular application so that adjustments can be made for optimum operation and efficiency.

The orientation of discharge required should always be specified when ordering an exhaust fan. The most common arrangement is the vertical upblast discharge. When sizing and/or selecting a fan, care must be taken in specifying the proper fan rating. It is important to specify operating requirements, taking into account altitude and temperature effects. Table 7–1 gives commended altitude and temperature correction factors.

Table 7–1 can be used to correct for static pressure requirements at various altitudes and/or design operating temperatures, as follows:

$$P = KP_d \tag{1}$$

where

P = operating static pressure
P_d = rated or design static pressure
K = correction factor

This information should be used in conjunction with performance charts provided by manufacturers.

Noise level criteria should also be considered when sizing and selecting exhaust system fans. To maintain the lowest practical noise levels, the following criteria should be applied where possible:

1. Exhaust fans should be mounted outside of the room. Ideally, they should be mounted on the building's roof close to their termination of the exhaust duct.
2. Vibration isolators should be used for mountings.
3. Select an exhaust fan that will provide the required cfm and static pressure at the lowest practical impeller wheel rpm.
4. If possible, use duct sizes sufficiently large to limit air duct velocities to under 1,200 fpm.
5. Flexible connections should be employed at the fan inlet. These will isolate mechanical transmission of noise through the ducting between the hood and exhaust fan.

Table 7–1: Altitude and Temperature Correction Factors

Air Temperature (°F)	Altitude (Feet Above Sea Level)													
	0	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	45,000	5,000	6,000	7,000	8,000
0	0.87	0.89	0.91	0.92	0.94	0.96	0.98	0.99	1.01	1.03	1.05	1.09	1.13	1.17
40	0.94	0.96	0.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.19	1.23	1.28
70	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.25	1.30	1.35
80	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.19	1.21	1.23	1.28	1.33	1.38
100	1.06	1.08	1.10	1.12	1.14	1.16	1.19	1.21	1.23	1.25	1.28	1.33	1.38	1.43
120	1.09	1.12	1.14	1.16	1.18	1.20	1.23	1.25	1.28	1.30	1.32	1.38	1.43	1.48
140	1.13	1.15	1.18	1.20	1.22	1.25	1.27	1.29	1.32	1.34	1.37	1.42	1.48	1.54
160	1.17	1.19	1.22	1.24	1.26	1.29	1.31	1.34	1.36	1.39	1.42	1.47	1.53	1.59
180	1.21	1.23	1.26	1.28	1.30	1.33	1.36	1.38	1.41	1.43	1.46	1.52	1.58	1.64
200	1.25	1.27	1.29	1.32	1.34	1.37	1.40	1.42	1.45	1.48	1.51	1.57	1.63	1.69

6. Exhaust systems should be designed with a minimum number of elbows, tees, etc. Radius type elbows should be preferred over square elbows, unless turn vanes are provided. Where transitions are necessary, use gradual, tapered designs to avoid abrupt changes in configuration or cross–sectional flow area.
7. For static pressure requirements under 2.5 in., use forward–inclined blade fans. For static pressure requirements in the range of 2.54 in., use backward–inclined blades. High pressure, radial blade–type fans will be necessary if system static pressure requirements exceed 4 in.

Hoods

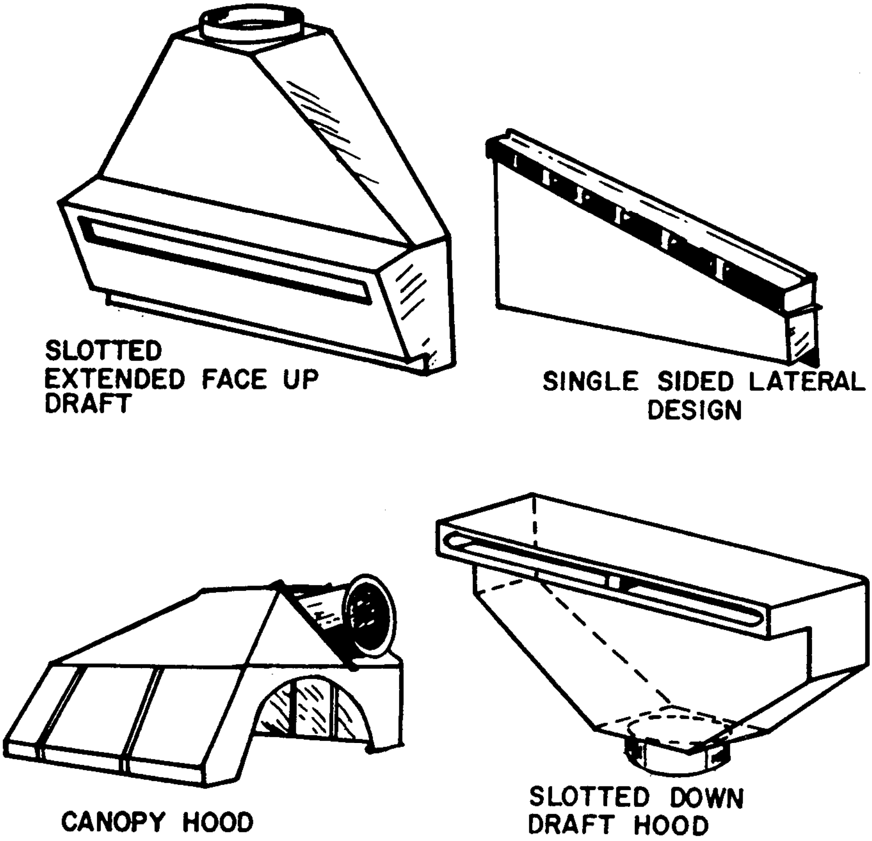
There is a wide range of styles and sizes of FRP exhaust hoods. Hoods provide the most efficient means of collecting corrosive fumes at their source. When properly designed, their slot velocities and plenum capacities ensure safe removal of contaminated fumes from their source with only minimum disturbance of the surrounding noncontaminated air mass. Figure 7–6 shows several types of hood configurations. FRP hoods feature smooth interior surfaces, which are achieved in fabrication by sprayup layup over a male mold. Exterior surfaces are usually finished with a pigmented exterior gel coat. The FRP construction not only guards them against corrosive fumes, but from splashes and spills of chemicals in tanks over which they can be used.

DUCTWORK AND STACKS

FRP fume stacks complete the ventilating system design. They are employed when exhaust stacks are required for the disposal of corrosive or noncorrosive fumes. The major advantages of FRP stacks over steel stacks are: (1) superior corrosion resistance, and (2) ease of installation, both of which lead to significant cost savings.

Because of the high corrosion resistance qualities of FRP stacks, considerably less maintenance is required; this is particularly true for wet scrubbing and condensation elimination processes.

Erection costs, manpower required and installation time are less for FRP stacks than with steel stacks. FRP stacks are more expensive than steel on a basis of cost per linear foot; however, savings in installation offset the difference in costs.



SLOTTED EXTENDED FACE UP DRAFT

SINGLE SIDED LATERAL DESIGN

CANOPY HOOD

SLOTTED DOWN DRAFT HOOD

Figure 7–6: Various FRP hood configurations.

FRP fume stacks are made by hand layup laminating techniques. Fabrication methods are similar to those employed in cylindrical ductwork except for wall thickness. For safety purposes, fire–retardant resin grades usually employed.

Stack accessories include rain caps, round and rectangular inlets and various types of nozzles. Guy wire attachments or guy wires with shackles and turnbuckles may be necessary (Figure 7–7). When specifying guy wires, care should be taken to ensure that the proper tension requirements are met.

FRP stacks have been constructed up to heights of 300 ft with diameters in excess of 10 ft. They are usually shipped to the consumer in sections of about 50–60 ft in length. The chemical process (CPI), pulp and paper, and phosphate industries are the major users of FRP stacks. In the oil and gas industry, petrochemical companies use relatively small–diameter FRP stacks.

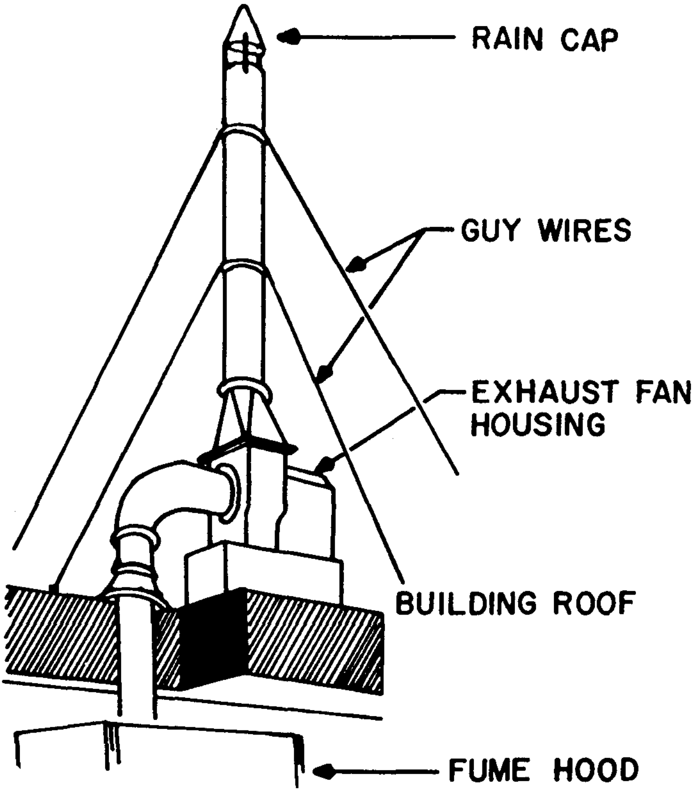


Figure 7-7: FRP stack and guy wires.

FRP stacks have been employed as small vents in the power industry. In general, they have not been accepted by the nuclear industries; however, because of the low cost of installation and high corrosion resistance, there is a potentially viable market for FRP stacks as vents and liners.

Ductwork

FRP ductwork has been used extensively in the CPI (chemical process industries) for conveying corrosive chemical fumes and as ventilating lines in corrosive environments. As with stacks, no exterior painting is required, resulting in low maintenance costs.

Relatively light-duty laminates are required for normal operating conditions. FRP ductwork is constructed by land layup laminating methods and in accordance with the Voluntary Product Standards. Ductwork is fabricated to a minimum wall thickness specified by

Voluntary Product Standards; however, heavier thicknesses are available for specialized applications. FRP ductwork has a smooth, resin–rich inner surface that is reinforced with glass or some synthetic surfacing veil. The remainder of the laminate is usually constructed from chopped strand fiberglass reinforcement. The exterior generally consists of a resin–rich surface coating.

A variety of corrosion–resistant grades of polyester resin are employed. In addition, ductwork is available with various fire–retardant grade resins. FRP ductwork is available in both cylindrical and rectangular configurations, and is available with either plain ends, flanged ends or bell shaped.

FUME SCRUBBERS

FRP fume scrubbers are available in a wide range of capacities in both vertical and horizontal designs that include rectangular–, cylindrical– or tower–type configurations. Figure 7–8 illustrates the principles behind wet scrubbing. As shown, contaminated air is collected by an exhaust system and drawn through the air inlet of the scrubber. The contaminated air stream's velocity decreases as it expands inside the scrubber shell. For particulate removal, this results in large particles settling out into a sump. This action is further accented by the changing air stream direction (the gas stream enters horizontally and then turns upward through the unit towards the outlet).

The air stream channels through the packed bed section, changing directions as it travels through packing voids. Fumes impinge on the large surface of the wetted packing and are washed into the sump.

Scrubbing liquor is introduced by a set of fine mist sprayer nozzles. Contaminated gas is diluted as it comes in continuous contact with scrubbing liquor. An air–mist extractor or demister removes residual moisture from the air stream via impingement.

Standard scrubber designs are capable of fume and particulate removal up to 99%, depending on the application. Typical scrubber removal efficiencies of various corrosive fumes are given in Table 7–2. Mist eliminators under most circumstances have the capability of up to 99% efficiency of moisture–laden air streams. Systems like this are applied to such applications as cooling and absorbing gases as well as particulate cleaning for industrial air pollution control.

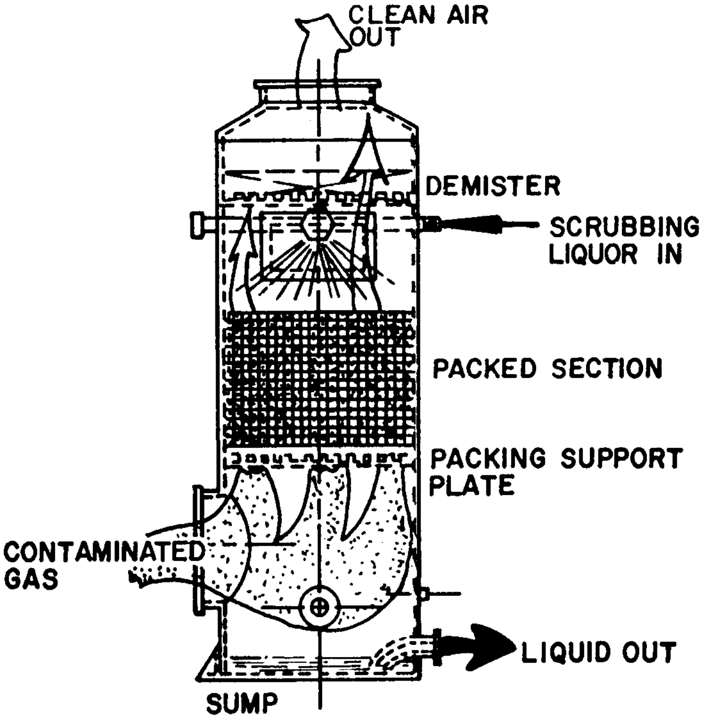


Figure 7–8: Counterflow scrubber operation.

Table 7–2: Scrubber Removal Efficiencies for Various Corrosive Fumes

Fume	Removal Efficiency (%)	Scrubbing Liquor	Liquor Loading (gpm/1,000 cfm)
Chromic Acid	98-99	Water	2-10
Chlorine or HC1	75-85	Caustic	2-10
H_2SO_4	95-98	Caustic	2-10
HNO_3	80-90	Caustic	2-10
NO_x	65-85	Caustic	2-10
Acetic Acid	80-90	Water	2-10
Phosphoric Acid	97-99	Caustic	2-10
NaOH	95-99	Water	2-10
Cyanide Solution	85-90	Water	2-10
SO_x	90-95	Caustic	2-10

[a] Inlet gas concentration = 250-1,000 ppm; Temperature = 70°F; Average particle s size $\geq 10\mu$; Water pressure = 20 psi at nozzles. Note, that efficiencies are on a weight basis.

Scrubber systems can be fabricated entirely from FRP with the exception of recirculating pumps and spray nozzles which are normally PVC. Units are generally equipped with inspection doors, often with Plexiglass covers that permit visual inspection of the system.

When headroom is limited, horizontal scrubbers can be employed. These units are readily mounted on steel channel support structures which are designed to accommodate the exhaust fan and connections; as such, complete systems are available as integral units.

CHAPTER 8

MISCELLANEOUS INDUSTRIAL APPLICATIONS AND PRODUCTS

FRP VALVES AND PUMPS

Filament–wound FRP valves can be employed in corrosive environments. They have advantages over both PVC and stainless steel. FRP valves are competitively priced with stainless steel and are roughly one–third the weight of steel valves. In addition, they are four times stronger than comparable molded PVC valves.

One manufacturer makes a filament–wound, fiberglass, wall–ball valve in sizes ranging from 2–10. It can be employed in both high– and low–pressure applications and has found wide acceptance in the CPI, petrochemical, marine and pulp and paper industries. The valve has a temperature service range from -40°–250°F. It is constructed from continuous glass windings impregnated with a thermoset vinyl ester resin. The exterior has a thick resin coating that provides good resistance to chemicals and attack from ultraviolet light. The valve is also available with fire–resistant resin coatings. Figure 8–1 provides pressure drop information in various sizes of FRP ball valves.

FRP pumps are available that are used in general industrial, chemical and petroleum products applications. Such a pump is fabricated from 30% fiberglass filled polyester via injection molding. Pump gaskets are constructed from Viton, capable of withstanding attack from a wide variety of chemicals. Fasteners in the design are stainless steel. Pedestal–mounted units and close coupled, electric motor–driven and hydraulic–driven pumps are equipped with– stainless steel shaft sleeves for added shaft protection. These pumps can be used in a wide range of applications including handling water, brine solutions, acids and many organic solvents having a pH less than 10. Advantages are good rugged construction, light weight and resistance to a large number of chemicals to an upper operating temperature of 130°F. Table 8-1 lists the corrosion resistance ratings of pump components to various industrial chemicals. Comparison to PVC pump components is also made.

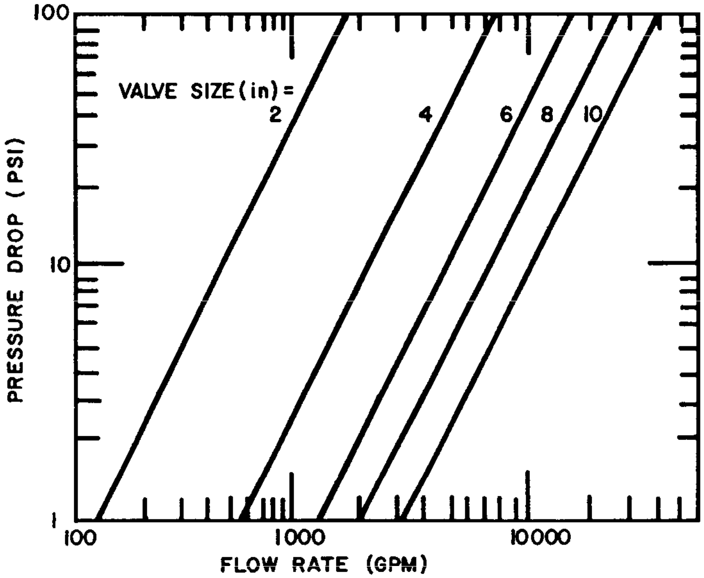


Figure 8-1: Pressure drop vs volumetric flowrate with valve entry size as a parameter (correlations based on water flow).

Mechanical shaft seal assemblies are also available in carbon and ceramic, depending on the application and nature of the chemical handled. Pumps are available in a range of configurations and for a variety of applications.

FRP GRATING

FRP structural products are used in a wide range of industrial construction applications. They have the advantages of high strength, light weight, ease of installation, corrosion resistance, are nonconductive, nonsparking, fire retardant, have a long service life, and, in the case of fiberglass-reinforced grating, are slip resistant.

Fiberglass-reinforced grating has been widely accepted for use in corrosive environments for such applications as flooring, bridges, trench covers, stairs, tower packing supports, walkways, ramps and grilles.

Table 8–1: Chemical Resistance of Pump Components to Various Industrial Chemicals

		Primary Pump Components			
Chemical	Concentration (%)	Polyester/ 30% Fiberglass	PVC	Viton Gaskets	316 Stainless Hardware
Acetaldehyde	–	R[a]	NR[a]	NR	R
Acetic Acid	20	R	R	R	R
	50 50	NR	NR	NR	R
Acetic Acid, Glacial	–	NR	R	R*[a]	R
Acetic Anhydride	–	NR	NR	NR	R
Acetone	–	R	NR	NR	R
Aluminum Chloride	–	NR	R	R	NR
Aluminum Fluoride	–	NR	R	R	R*
Aluminum Sulfate	–	R	R	R	R
Ammonia, Cold	30	R	R	R	R
Ammonium Chloride	–	R	R	R	R
Ammonium Nitrate	–	R	R	R	
Ammonium Persulfate	–	R	R	R	R*
Ammonium Phosphate	–	R	R	R	R
Ammonium Sulfate	–	R	R	R	R*
Amyl Acetate	–	R	NR	NR	R
Amyl Alcohol	–	R*	R	R	R*
Amyl Chloride	–	R	NR	R	R
Aniline	–	NR	NR	R	R
Aqua Regia	–	NR	NR	R*	NR
Arsenic Acid	–	R	R	R	R*
Barium Chloride	–	R	R	R	R*
Barium Sulfate	–	R	R	R	R

(continued)

Table 8–1: (continued)

		Primary Pump Components			
Chemical	Concentration (%)	Polyester/ 30% Fiberglass	PVC	Viton Gaskets	316 Stainless Hardware
Benzene	–	R	NR	R	R
Benzoic Acid	–	R	R	R	R
Boric Acid	–	R	R	R	R
Bromine Water	–	NR	R*	R	NR
Butyl Acetate	–	R	NR	NR	R
Butyric Acid	–	NR	R	R	R
Calcium Bisulfite	–	NR	R	R	R
Calcium Chloride	–	R	R	R	R*
Calcium Hypochlorite	20	R	R	R	R*
Calcium Sulfate	–	R	R*	R	R
Carbon Tetrachloride	–	R	R*	R	R
Carbonic Acid	–	R	R	R	R
Chloroacetic Acid	–	NR	R	R	NR
Chlorine Water	–	NR	R	R	NR
Chlorobenzene	–	NR	NR	R	R
Chloroform	–	R	NR	R	R
Chromic Acid	10	NR	R	R	R
	50	NR	R	R	R
	80	NR	NR	R	NR
Citric Acid	–	R	R	R	R
Copper Chloride	–	R	R	R	R
Copper Nitrate	–	R	R	R	R

(continued)

Table 8–1: (continued)

Chemical	Concentration (%)	Primary Pump Components		Viton Gaskets	316 Stainless Hardware
		Polyester/ 30% Fiberglass	PVC		
Copper Sulfate	–	R	R	R	R
Ethyl Acetate	–	R	NR	NR	R
Ethyl Chloride	–	R	NR	R	R
Ethylene Glycol	–	R	R	R	R
Fatty Acids	–	R	R	R	R
Ferric Chloride	–	R	R	R	NR
Ferric Nitrate	–	R*	R	R	R
Ferric Sulfate	–	R*	R	R	R
Ferrous Chloride	–	R	R	R	NR
Ferrous Sulfate	–	R	R	R	R
Formaldehyde	40	R	R	R	R
Formic Acid	–	NR	R	NR	R
Fuel Oils	–	R	R	R	R
Furfural	–	R	NR	NR	R
Gasoline	–	R	R*	R	R
Glycerine	–	R	R	R	R
Heptane	–	R	R*	R	R
Hexane	–	R	R*	R	R
Hydrobromic Acid	50	NR	R	R	NR
Hydrochloric Acid	0-15	R	R	R	NR
	15-37	R	R	R	NR

(continued)

Table 8-1: (continued)

		Primary Pump Components			
Chemical	Concentration (%)	Polyester/ 30% Fiberglass	PVC	Viton Gaskets	316 Stainless Hardware
Hydroflouric Acid	10	NR	R*	R	NR
	30	NR	R*	R	NR
	60	NR	R*	R	NR
Hydrofluorosilicic Acid	20	NI	R	R	R
Hydrogen Peroxide	30	R	R	R	R*
	50	RE	R*	R	R*
	90	R	NR	R*	R*
Hydrogen Sulfide (Ag. Sol.)	–	R	R*	NR	R
Kerosene	–	R	R	R	R
Ketones	–	R	NR	NR	R
Lactic Acid	–	R*	R	R	R
Laquer Thinners	–	R	R	NR	R
Lead Acetate	–	R	R	R	R
Lubricating Oil	–	R	R*	R	R
Magnesium Chloride	–	R	R	R	R*
Magnesium Nitrate	–	R	R	R	R
Magnesium Sulfate	–	R	R	R	R
Maleic Acid	–	R	R	R	R
Methyl Alcohol	–	R	R*	R	R
Methyl Chloride	–	NI	NR	R	R
Methyl Ethyl Ketone	–	R	NR	NR	R
Methyl Isobutyl Ketone	–	R	NR	NR	R
Methyl Chloride	–	NR	NR	R	R

(continued)

Table 8–1: (continued)

		Primary Pump Components			
Chemical	Concentration (%)	Polyester/ 30% Fiberglass	PVC	Viton Gaskets	316 Stainless Hardware
Naphtha	–	R	R	R	R
Naphthalene	–	R	NR	R	R
Nickel Chloride	–	R	R	R	R
Nickel Sulfate	–	R	R	R	R
Nitric Acid	10	R	R	R	R
	20	R	R	R	R
	50	R	R	R	R
Nitric Acid (Anhydride)	–	NR	NR	R	R*
Nitro Benzene	–	R	NR	R	R
Oil and Fats	–	R	R	R	R
Oleic Acid	–	R	R	R*	R
Oleum	25	NR	NR	R	NI
Oxalic Acid	–	NR	R	R	R*
Phenol	–	NR	R*	R	R
Phosphoric Acid	0-50	R*	R	R	R
	50-100	R*	R	R	R
Potassium Bicarbonate	–	R	R	R	R
Potassium Bromide	–	R	R	R	R
Potassium Carbonate	–	R	R	R	R
Potassium Chlorate	–	R	R	R	R
Potassium Chloride	–	R	R	R	R

(continued)

Table 8–1: (continued)

Chemical	Concentration (%)	Primary Pump Components		Viton Gaskets	316 Stainless Hardware
		Polyester/ 30% Fiberglass	PVC		
Potassium Cyanide	–	R	R	R	R
Potassium Dichromate	–	NR	R	R	R
Potassium Hydroxide	–	NR	R	R	R
Potassium Nitrate	–	R	R	R	R
Potassium Permanganate	–	NR	R	R	R
Potassium Sulfate	–	R	R	R	R
Propyl Alcohol	–	R	R	R	R
Soaps	–	R	R	R	R
Sodium Acetate	–	R	R	NR	R
Sodium Bicarbonate	–	R	R	R	R
Sodium Bisulfate	–	R	R	R	R
Sodium Bisulfite	–	R	R	R	R
Sodium Carbonate	10	R	R	R	R
Sodium Chlorate	–	R	R	R	R
Sodium Chloride	–	R	R	R	R
Sodium Cyanide	–	R	R	R	R
Sodium Hydroxide	20	NR	R	NR	R
Sodium Hypochlorite	50	NR	R	NR	R
Sodium Nitrate	–	R	R	R	NR
Sodium Silicate	–	R	R	R	R

(continued)

Table 8–1: (continued)

Chemical	Concentration (%)	Primary Pump Components		Viton Gaskets	316 Stainless Hardware
		Polyester/ 30% Fiberglass	PVC		
Sodium Sulfate	–	R	R	R	R
Sodium Sulfide	–	R	R	R	R
Stannic Chloride	–	NR	R	R	NR
Stearic Acid	–	R*	R	R	R
Sulfuric Acid	0-40	R*	R	R	R
Toluene	–	R	NR	R	R
Trichloroethylene	–	NR	NR	R	R
Turpentine	–	R	R	R	R
Urea	–[a]	NI	R	NR	R
Xylene	–	R	NR	R	R
Zinc Chloride	–	NR	R	R	R
Zinc Sulfate	–	R	R	R	R

[a] R = recommended for service up to 130°F; NR = not recommended; NI = no information or insufficient data; – = over all concentrations; * = recommended use only if service temperature does not exceed 80°F.

It is employed as a fire-retardant grate on tank car and truck loading catwalks in the oil refinery industry and as antiskid trench cover installations in paper mills. In the metal refining industry, it is used for aisles between cells. In food processing operations where acid conditions exist, FRP grating is employed as floor mats. It has also found use in fencing off high-voltage transformers. FRP grating has approximately one-fourth the specific gravity of steel and roughly two-thirds that of aluminum. In general, fiberglass grating has many of the qualities of metal plus several superior advantages. Table 8-2 lists the corrosion resistance properties of one leading manufacturer of fiberglass polyester gratings.

Gratings can be fabricated from a variety of resins on the market. The particular resin used will depend on the specific corrosion environment for which it is intended. Manufacturers will supply samples of grating for immersion tests or test sections can be installed on the site.

Fiberglass grating is available in a plain top surface or a surface that has deeply imbedded grit particles. The latter design is employed in applications where maximum nonskid features are required. Particles are fabricated into the structure and, as such, are not worn away after constant exposure to corrosive environment and continuous wear. The material is imbedded with angular silica particles during the laying up process. The product is essentially a matrix of polyester resin. Resin wears faster than the silica grit so the grit profile always protrudes above the resin base. This results in very high friction coefficients, even after many years of service.

Friction coefficients are a quantitative measures of antiskid. Tests performed by the inclined plane method (Figure 8-2) provide information on the static function coefficient. The technique involves tipping a grating until a test block begins sliding down the incline. The static of friction between the two materials being tested is defined as the tangent of the angle of inclination. The coefficient is a function of both the material of the plane (grating) and the sliding block. The test block consists of neoprene, as this simulates a person's shoe. Incline plane tests with neoprene blocks have shown the friction coefficients of FRP gratings to be more than twice that of standard metal grating.

A comparison of the friction coefficients between the grit top grating, plain top FRP grating and bare steel grating is shown in Figure 8-3 for different sliding block materials. The figure illustrates the superior antiskid qualities of the grit top as well as the effect of different test block materials on the friction coefficient.

Table 8–2: Chemical Resistance of Polyester–Grade FRP Grating

Chemical	Concentration (%)	Maximum Service Temperature (°F)	Chemical	Concentration (%)	Maximum Service Temperature (°F)
Acetic Acid	10	200	Citric Acid	–	150
	25	150	Copper Chloride	–	200
	75	160*[a]	Copper Cyanide	–	200
Alum	–	200	Copper Sulfate	–	200
Aluminum Sulfate	100	100	Copper Nitrate	–	200
Ammonium Hydroxide	10	75	Diethylene Glycol	–	200
	29	100*	Dimethyl Phthalate	100	77*
Ammonium Carbonate	100	75	Dipropylene Glycol	–	200
Ammonium Nitrate	–	200	Ethyl Alcohol	–	77*
Ammonium Sulfate	–	175	Ethyl Chloride	100	200
Benzoic Acid	100	150	Ethylene Glycol	100	200
Calcium Chloride	–	175	Fatty Acids	–[a]	200
Calcium Hydroxide	25	160	Ferric Acetate	–	200
Calcium Hypochlorite	20	75	Ferric Chloride	–	200
	20	200*	Ferric Nitrate	–	200
Carbon Tetrachloride	100	77	Ferric Sulfite	–	200
Chlorine Dioxide	Saturated	150	Ferrous Acetate	–	200
	15	220*	Ferrous Chloride	–	200
Chlorine Gas	100	75	Ferrous Nitrate	–	200
Chlorine Water	Saturated	75	Ferrous Sulfate	–	200
Chloroacetic Acid	50	140*	Fluoboric Acid	–	220*
Chromic Acid	10	150	Formaldehyde	44	150
	20	100*	Formic Acid	25	75
Chromium Sulfate	–	200	Gasoline	–	175

(continued)

Table 8–2: (continued)

Chemical	Concentration (%)	Maximum Service Temperature (°F)	Chemical	Concentration (%)	Maximum Service Temperature (°F)
Glycerine	–	200	Nickel Nitrate	–	200
Hydrobromic Acid	50	100*	Nickel Sulfate	–	200
Hydrochloric Acid	10	200	Nitric Acid	5	150
	37	150		60	77*
Hydrocyanic Acid	10	160*	Oleic Acid	100	200
Hydrofluoric Acid	10	180*	Oxalic Acid	100	200
Hydrogen Perioxide	30	140*	Perchloric Acid	10	75
Hydrogen Sulfide	–	200		30	77*
Hypochlorous Acid	50	175	Phosphoric Acid	10	200
Kerosene	–	175		80	220*
Lactic Acid	100	Boil	Potassium Chloride	–	200
Lead Acetate	–	200	Potassium Cyanide	–	200
Lead Chloride	–	200	Potassium Nitrate	–	200
Lead Nitrate	–	200	Potassium Sulfate	–	200
Lime Slurry	–	200	Potassium Dichromate	–	200
Linseed Oil	100	220*	Potassium Hydroxide	25	160*
Magnesium Chloride	–	200	Propylene Glycol	–	200
Magnesium Nitrate	–	200	Refinery Crudes	–	200
Magnesium Sulfate	–	200	Silver Nitrate	–	200
Maleic Acid	40	75	Sodium Acetate	–	200
Mercuric Chloride	–	200	Sodium Bisulfate	–	200
Methyl Alcoho	100	140	Sodium Bisulfite	–	200
Methyl Ethyl Ketone	20	75	Sodium Bromide	–	200
Naphthalene	100	100	Sodium Carbonate	32	160*
Nickel Chloride	–	200	Sodium Chloride	–	200

(continued)

Table 8-2: (continued)

Chemical	Concentration (%)	Maximum Service Temperature (°F)	Chemical	Concentration (%)	Maximum Service Temperature (°F)
Sodium Citrate	–	200	Sulfite Liquors	100	175
Sodium Ferrocyanide	–	200	Sulfonated Detergents	100	160*
Sodium Hydroxide	25	160*	Sulfur Dioxide	100	75
	50	77*	Sulfuric Acid	50	175
Sodium Nitrate	–	200	Tannic Acid	–	200
Sodium Nitrite	–	200	Tartaric Acid	–	200
Sodium Sulfate	–	200	Toluene	–	170
Sodium Thiocyanate	–	200	Urea	–	100*
Sodium Hypochlorite	10	150	Water, Distilled	–	200*
Stannic Chloride	–	260*	Zinc Chloride	–	200
Stearic Acid	100	200			

[a] – = all concentrations, * = that one grade of polyester resin has better service in this application.

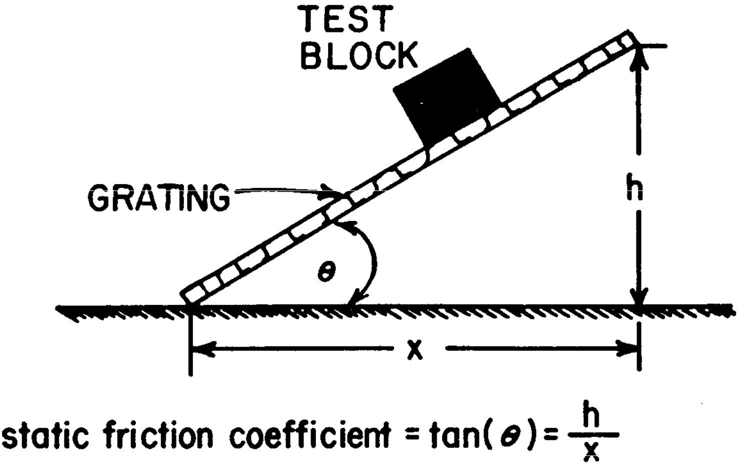


Figure 8–2: The inclined plane method of measuring friction coefficients.

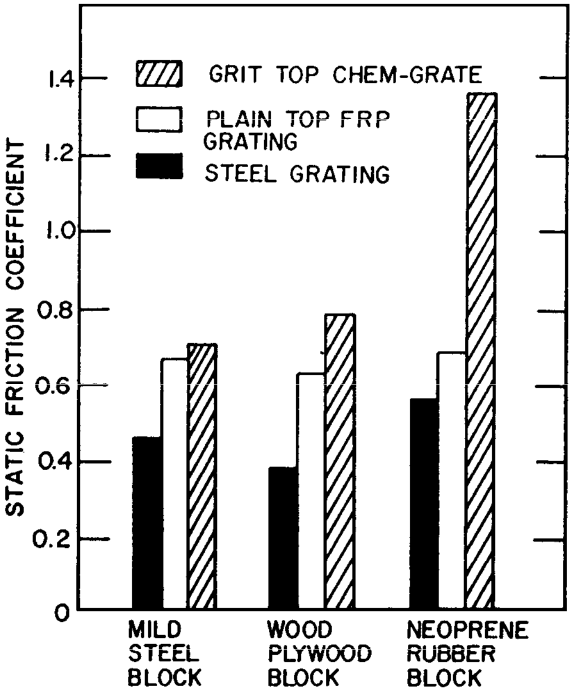


Figure 8–3: Comparison of grit top FRP grating to other grating materials using different block materials.

In general, FRP gratings differ from metal gratings in that the flexural modulus of the reinforced plastic bars is less than that of equivalent size metal bars. This means that although FRP grating is capable of supporting heavy loads, grating deflection caused by the load will be greater than for comparable metal grating. This is an advantage in the sense that it permits visual determination of any overload to the FRP grating in advance of any failure loads. Consequently, the desired deflection is the determining factor that establishes the span in FRP grating, rather than the specific strength.

Mesh designs are available in square or rectangular configurations. The following is recommended:

- For ordinary pedestrian traffic, short–span deflections not to exceed ¼ in. are acceptable.
- For applications involving walkways, 3/8 long span deflections, not to exceed ½ in. are acceptable.

From information on the design load and acceptable deflection criteria, the required span can be obtained from appropriate deflection tables or charts supplied by the manufacturer. Once the span has been determined, the maximum safe load at the span can be evaluated to determine whether the design load has been exceeded. For normal pedestrian traffic, a safe design load is approximately 65 lb/ft^2.

Deflection charts are based on the type of load, i.e., concentrated or uniformly distributed loads (Figure 8–4).

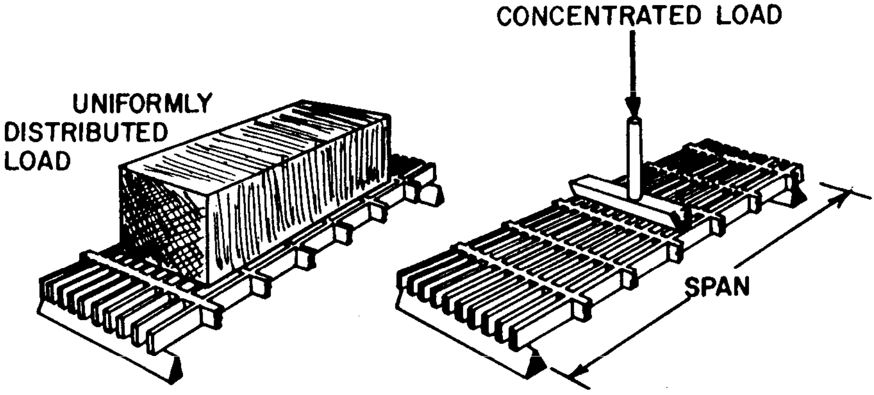


Figure 8–4: Types of loads encountered.

FRP grating can be cut to size in the field with an abrasive cutoff wheel (masonry type saw) or a hack saw. Exposed edges from cutting should be sealed with appropriate resin. When fastening sections together, FRP thermoset nuts and threaded rod should be used to provide maximum corrosion resistance to the structure. FRP fasteners eliminate cathodic corrosion problems associated with fastening dissimilar metals. This also assures insulation in electrical applications and provides weight savings over metallic fastening arrangements.

Data on physical and strength properties of one manufacturer's fiberglass reinforced line of fasteners is given in Table 8–3.

Table 8–3: Physical and Strength Properties of Polyester FRP Fasteners

	Diameter (in.) **No. Threads Per In.**	**3/8** **16**	**1/2** **13**	**5/8** **11**	**3/4** **10**
Ultimate Tensile Strength, lb_f/in. thread engaged		2,560	3,775	5,040	7,300
Ultimate Torque Strength, ft-lb_f with well-lubricated ME full nut		12	27	45	65
Stud Weight, Threaded (lb_f/ft), Axial Compressive Strength-ASTM-D 695 (psi)		0.070	0.116	0.191	0.282
Dielectric Strength-ASTM-D 149, kV/in.		90	90	90	90
Specific Gravity-ASTM-D792 Maximum Service Temperature °F–with 50% Ultimate Tensile Strength Retained		212	212	212	212

CHAPTER 9

INDUSTRIAL LININGS

TYPES OF FRP LININGS AND METHODS OF APPLICATION

FRP industrial linings are applied to prevent corrosion of vessels, to prevent leakage, prevent product contamination or to provide structural reinforcement. FRP linings can be applied to existing and new equipment, either at the plant site or at the manufacturer's facilities. FRP linings can be sprayed, rolled or troweled onto the surface of almost any type of industrial equipment. Common applications where FRP resin linings are used include tanks, vats, ductwork, breachings, pump pads, concrete trenches, stacks, fans, floors, etc.

The most common application technique involves spraying resin onto the surface with the glass–reinforcing media laid down by hand. This is followed by further spraying with resin. Resin and glass reinforcement are usually handworked with a brush. Grooved and mohair rollers are employed to remove entrapped air and to saturate the fiberglass with resin. Desired lining thickness is achieved by building up layers of fiberglass and resin. An outer layer of surfacing veil is normally added for additional corrosion resistance. This also ensures a smooth, resin–rich surface.

Spray–up lining techniques involve a considerable amount of hand labor and detailed quality control inspections during application. In general, the method produces thicker and often more durable linings. This type of bonded lining has one main disadvantage in that operating temperatures generally should not go above 60°C due to the differential expansion between the substrate and lining caused by elevated temperatures.

For applications at elevated temperatures, flake glass linings are used. Trowels are usually employed to apply the glass–resin mix although spray guns can be used. Mohair rollers are often used to orient glass crystals. For immersion service, flake glass–polyester resin and flake glass–epoxy resin linings display good corrosion resistance up to approximately 83°C. For fume or vapor service, both are serviceable up to about 180°C. Epoxy resin–based linings are to be preferred over polyester for high–temperature service provided the resin's corrosion resistance is capable of withstanding the environment.

For higher temperature service (up to 100°C) in immersion applications, a self–supporting inner liner can be used. That is, a tank within a tank can be constructed. An existing vessel can be used as a mold for an FRP inner liner. Liners made in this fashion will not bond to the mold tank. As such, differential expansion caused by elevated temperatures and/or decontamination caused by vapor penetration at high temperature will not facilitate liner failure. After fabrication, the original vessel can be removed if the liner has been constructed to sufficient thickness.

Mechanically anchored liners employ stainless steel studs to hold the liner to the walls of the tank. The studs can be coated or capped with FRP to prevent contact between the metal and environment inside the vessel. The shell or metal vessel's primary function is to provide structural support to the inner liner.

In addition to providing added corrosion resistance to an existing vessel, FRP linings can be used to repair damaged or corroded ductwork. Damaged fan casings, air washers and ductwork can be repaired by encapsulating the units with FRP. Ductwork that has been encapsulated with FRP is entirely self–supporting. Encapsulation is generally done in accordance with the NBS (National Bureau of Standards) codes for molded fiberglass duct. Once the system has been coated entirely, the original metal ducting can be removed or allowed to corrode away without affecting the FRP structure. Corroded steel equipment and ductwork can be almost completely restored by sandblasting the unit and applying a sprayup fiberglass–resin mix over the surface.

Bonded Linings

Chemically bonded linings are usually studded to concrete with stainless steel anchors at specified intervals. This provides insurance against any decontamination that may develop. The studs will hold the unit in place if, for example, the concrete is sheared and the bond weakens or breaks. Chemically bonded linings can be applied to almost any type of surface, provided it has been properly prepared, and the resin will adhere. The most common substrates are steel and concrete.

When applying a sprayup FRP lining or a flake glass overcoat lining, the resin and glass are built up to layers by hand. The first layer is allowed to air dry to tack free and then multiple layers are built up to the specified thickness.

There are five other types of bonded linings, namely (1) chopper gun linings, (2) troweled silica–filled resin linings, (3) sprayed flake glass, (4) troweled flake glass linings, and (5) troweled silica–filled resin with sprayed or troweled flake glass linings.

Chopper gun linings offer the poorest corrosion resistance. These types of linings generally have the highest failure rate of all FRP linings. Fabrication has little or no control over the resin–to–glass ratio and linings produced are of uneven thickness. Furthermore, they have been known to generate "hot spots" from puddling, which is caused by overheating from exotherm of the resin. The method of application tends to entrap more air, generating voids. It also produces a highly uneven surface usually with a large portion of glass exposed.

Troweled silica–filled resin linings are used successfully at lower temperatures. They are most often applied over spalling concrete having irregularly shaped surfaces and voids. They are also used on steel vessels with deep pit marks that require filling.

Flake glass linings can be applied as a mixture by either spraying or troweling onto the surface. The disadvantage with this method of application is that the lining is subject to air entrapment, voids and damage from sharp edges on the substrate much more readily than the other methods described. Considerable care must be taken during application. In general, flake glass–resin linings offer superior corrosion resistance and are capable of a relatively high–temperature service range when glass crystals are oriented in the same direction as the substrate. Considerable care and expertise is required in obtaining the proper crystal orientation. These types of linings have been reported not to be capable of functioning under continuous exposure corrosive environments much above 80°C for extended periods of time. Manufacturers generally recommend smaller, more finely divided glass flakes to cut down on high labor costs.

The last type of bonded lining, troweled silica–filled resin with a sprayed flake glass overcoat is essentially the same as except that an overcoat is applied. The flake glass overcoat protects against gas permeation at high temperatures. Uses for this type of lining include rebuilt concrete sumps and pits in the pulp and paper industry.

If a lining is to be effective, it must be free of any entrapped air and should not have exposed glass strands on the surface. It should be of sufficient thickness so that it can withstand abrasion and mechanical shock. A lining's quality can be related directly to the amount of materials used and the quality of labor that went into its fabrication. These factors, in turn, are proportional to the cost of application.

CORROSION RESISTANCE AND SELECTION CRITERIA

The ultimate selection of a specific lining will depend on the properties of the environment to which the lining is to be subjected. Temperature service range, nature of the application (immersion, fume or vapor application) and the chemical makeup of the material to be handled must be specified. Requirements such as resistance to abrasion, thermal cycling and/or physical stresses should be determined.

Properties of the materials to be handled must be carefully noted and lining manufacturers consulted in the selection of a specific resin that will meet the necessary chemical resistance. Table 9–1 lists some of the physical properties of various materials that can be used as a guide.

A grade of polyester resin can be found suitable for many lining applications. For alkaline environments at elevated temperatures (as a general rule if the pH of a liquid being handled exceeds 5.0), epoxy resin–based linings are most often employed. Fiberglass mat, cloth or roving can be used with epoxy resins, especially when high–strength properties are desired. These lining systems are limited to 70°–80°C for continuous–immersion applications. Epoxy resin glass–flake systems can extend service temperature ranges; however, strength properties usually take a penalty. In general, flake glass linings do not provide good structural reinforcement. High structural strength is normally obtained with the sprayup systems; however, there are temperature considerations that interact here. Table 9–2 provides ratings of the chemical resistance of epoxy resin coatings to various chemicals over a range of temperatures. The table provides information on immersion applications only. The chemical resistance over a particular temperature range can be considerably greater if the application involves occasional spillage, drainage, or fume or vapor contact.

Corrosive attack can occur not only from contact with a severe chemical environment such as strong acids, alkalies, etc., but also from the effects of weathering. A thorough knowledge of the causes and mechanisms controlling corrosion are necessary to properly select the right lining.

Table 9-1: Physical Properties of Various Compounds

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F		Explosive Limits Vol. %	
				Closed Cup	Open Cup	Lower	Upper
Acetaldehyde	CH_3CHO	44.05	0.821	-17	–	3.97	57
Acetic Acid	CH_3COOH	60.05	1.049	104	110	5.40	–
Acetic Anhydride	$(CH_3CO)_2O$	102.09	1.082	121	130	2.67	10.13
Acetone	CH_3COCH_3	58.08	0.792	0	15	2.55	12.80
Acrolein	$CH_2{:}CHCHO$	56.06	0.841	Gas		Unstable	
Acrylonitrile	$CH_2{:}CHCN$	53.06	0.806	–	32	3.05	17.0
Ammonia	NH_3	17.03	0.597	Gas		15.50	27.0
Amyl Acetate	$CH_3CO_2C_3H_{11}$	130.18	0.879	76	80	1.10	–
Iso-Amyl Alcohol	$(CH_3)_2CHCH_2CH_2OH$	88.15	0.812	109	115	1.20	–
Aniline	$C_6H_5NH_2$	93.12	1.022	168	–	–	–
Arsine	AsH_3	77.93	2.695	Gas		–	–
Benzene	C_6H_6	78.11	0.879	12	–	1.40	7.10
Bromine	Br_2	159.83	3.119	–	–	–	–
Butane	$CH_3(CH_2)_2CH_3$	58.12	2.085	Gas		1.86	8.41
1,3 Butadiene	$(CH_2{:}CH)_2$	54.09	0.621	Gas		2.00	11.50
n-Butanol	$C_2H_5CH_2CH_2OH$	74.12	0.810	84	110	1.45	11.25
2, Butanone (Methyl ethyl ketone)	$CH_3COC_2H_5$	72.10	0.805	30	–	1.81	9.50
n-Butyl Acetate	$CH_3CO_2C_4H_9$	116.16	0.882	72	90	1.39	7.55
Butyl "Cellosolve"	$C_4H_9OCH_2CH_2OH$	118.17	0.903	141	165	–	–
Carbon Dioxide	CO_2	44.01	1.53	–	–	–	–
Carbon Disulfide	CS_2	76.13	1.263	-22	–	1.25	50.0
Carbon Monoxide	CO	28.10	0.968	Gas		12.5	74.2
Carbon Tetrachloride	CCl_4	153.84	1.595	Nonflammable			

(continued)

Table 9–1: (continued)

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F		Explosive Limits Vol. %	
				Closed Cup	Open Cup	Lower	Upper
Cellosolve	$C_2H_5O(CH_2)_2OH$	90.12	0.931	104	120	2.6	15.7
Cellosolve Acetate	$CH_3CO_2C_4H_9O$	132.16	0.975	124	135	1.71	–
Chlorine	Cl_2	70.91	3.214	Gas		–	–
2-Chlorobutadiene	$CH_2{:}CClCHCH_2$	88.54	0.958	–	–	–	–
Chloroform	$CHCl_3$	119.39	1.478	Nonflammable			
1-Chloro-1-Nitropropane	$NO_3ClC_3H_6$	139.54	1.209	144	–	–	–
Cyclohexane	C_6H_{12}	84.16	0.779	1	–	1.26	7.75
Cyclohexanol	$CH_2(CH_2)_4CHOH$	100.16	0.962	154	–	–	–
Cyclohexanone	$CH_2(CH_2)_4CO$	98.14	0.948	147	–	–	–
Cyclohexene	$CH_2(CH_2)_3CH{:}CH$	82.14	0.810	–	–	–	–
Cyclopropane	$CH_2CH_2CH_2$	42.08	0.720	Gas		2.40	10.40
o-Dichlorobenzene	$Cl_2C_6H_4$	147.01	1.305	151	165	–	–
Dichlorodifluoromethane	CCl_2F_2	120.92	1.486	Nonflammable			
1,1 Dichloroethane	CH_3CHCl_2	98.97	1.175	–	–	–	–
1,2 Dichloroethane (Ethylene dichloride)	$ClCH_2CH_2Cl$	98.97	1.257	56	65	6.2	15.9
1,2 Dichloroethylene	$ClCHCHCl$	96.95	1.291	43	–	9.7	12.8
Dichloroethylether	$ClCH_2CHClOC_2H_5$	143.02	1.222	131	180	–	–
Dichloromethane	H_2CCl_2	84.94	1.336	–	–	–	–
Dichloromonofluoromethane	$HCCl_2F$	102.93	1.426	–	–	–	–
1,1 Dichloro-1-nitroethane	$H_3C_2Cl_2NO_3$	143.97	1.692	–	168	–	–
1,2 Dichloropropane	$CH_3CHClCH_2Cl$	112.99	1.159	59	65	3.4	14.5
Dichlorotetrafluoroethane	$CClF_2CClF_2$	170.93	1.433	Nonflammable			
Dimethylaniline	$(CH_3)_2NC_6H_5$	121.18	0.956	145	170	–	–
Dimethylsulfate	$(CH_3)_2SO_4$	126.13	1.332	182	240	–	–

(continued)

Table 9-1: (continued)

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F Closed Cup	Flash Point F Open Cup	Explosive Limits Vol. % Lower	Explosive Limits Vol. % Upper
Dioxane	$O(CH_2)_4O$	88.10	1.034	–	35	–	–
Ethyl Acetate	$CH_3CO_2C_2H_5$	88.10	0.901	24	30	2.18	11.4
Ethyl Alcohol	C_2H_5OH	46.07	0.789	55	–	3.28	18.95
Ethyl Benzene	$C_6H_5C_2H_5$	106.16	0.867	59	75	–	–
Ethyl Bromide	C_2H_5Br	109.98	1.430	–	–	6.75	11.25
Ethyl Chloride	C_2H_5Cl	64.52	0.921	-58	-45	3.6	14.80
Ethylene Chlorohydrin	$ClCH_2CH_2OH$	80.52	1.213	–	140	–	–
Ethylenediamine	$NH_2CH_2CH_2NH_2$	60.10	0.899	–	–	–	–
Ethylene Oxide	CH_2CH_2O	44.05	0.887	–	–	3.0	80.0
Ethyl Ether	$(C_2H_5)_2O$	74.12	0.713	–	–	–	–
Ethyl Formate	$HCO_2C_2H_5$	74.08	0.917	–	–	2.75	16.40
Ethyl Silicate	$(C_2H_5)_4SiO_4$	208.30	0.933	–	125	–	–
Formaldehyde	$HCHO$	30.03	0.815	Gas		7.0	73.0
Gasoline	$C_nH_{(2n+2)}$	86	0.660	-50	–	1.3	6.0
Heptane	$CH_3(CH_2)_5CH_3$	100.20	0.684	25	–	1.1	6.7
Hexane	$CH_3(CH_2)_4CH_3$	86.17	0.660	-7	–	1.18	7.4
Hydrogen Chloride	HCl	36.47	1.268	–	–	–	–
Hydrogen Cyanide	HCN	27.03	0.688	Gas		5.6	40.0
Hydrogen Fluoride	HF	20.01	0.987	Gas		–	–
Hydrogen Selenide	H_2Se	80.98	2.12	Gas		–	–
Hydrogen Sulfide	H_2S	34.08	1.189	Gas		4.3	45.5
Iodine	I_2	253.82	4.93	–	–	–	–
Isophorone	$(CH_3)_3C(CH_2)_2CCHCO$	138.20	0.923	–	205	–	–

(continued)

Table: 9–1 (continued)

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F		Explosive Limits Vol. %	
				Closed Cup	Open Cup	Lower	Upper
Mesityl Oxide	$(CH_3)_2{:}CHCOCH_3$	98.14	0.857	87	–	–	–
Methanol	CH_3OH	32.04	0.792	54	60	6.72	36.5
Methyl Acetate	$CH_3CO_2CH_3$	74.08	0.928	15	20	3.15	15.60
Methyl Bromide	CH_3Br	94.95	1.732	–	–	13.5	14.5
Methyl Butanone (Iso propyl butane)	$CH_3COCH(CH_3)_2$	86.13	0.803	–	–	–	–
Methyl Cellosolve	$HOCH_2CH_2OCH_3$	76.06	0.965	107	115	–	–
Methyl Cellosolve Acetate	$CH_3OCH_2CH_2OOCCH_3$	118.13	1.007	132	140	–	–
Methyl Chloride	CH_3Cl	50.49	1.785	Gas		8.25	18.70
Methyl Cyclohexane	$CH_3(CHC_5H_{10})$	98.18	0.769	25	–	1.15	–
Methyl Cyclohexanol	$CH_3(CHC_4H_8CHOH)$	114.18	0.934	154	–	–	–
Methyl Cyclohexanone	$CH_5C_5H_9CO$	122.17	0.925	118	–	–	–
Methyl Formate	HCO_2CH_3	60.05	0.974	-2	–	4.5	20
Methyl Isobutyl Ketone	$CH_3COC_4H_9$	100.16	0.801	73	–	–	–
Monochlorobenzene	C_6H_5Cl	112.56	1.107	90	–	–	–
Monofluorotrichloromethane	Cl_3CF	137.38	1.494	Nonflammable			
Mononitrotoluene	$CH_3C_6H_4NO_2$	137.13	1.163	223	–	–	–
Naphtha (Coal tar)	$C_6H_4(CH_3)_2$	106.16	0.85	100-110	–	–	–
Nickel Carbonyl	$Ni(CO)_4$	107.73	1.31	–	–	–	–
Nitrobenzene	$C_6H_5NO_2$	123.11	1.205	190	–	1.8 (200°F)	–
Nitroethane	$CH_3CH_2NO_2$	75.07	1.052	82	106	–	–

(continued)

Table 9–1: (continued)

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F		Explosive Limits Vol. %	
				Closed Cup	Open Cup	Lower	Upper
Nitrogen Oxides	NO	30.0	1.0367	–	–	–	–
	N_2O	44.02	1.53	–	–	–	–
	N_2O_3	76.02	1.447	–	–	–	–
	NO_2	46.01	1.448	–	–	–	–
	N_2O_3	108.02	1.642	–	–	–	–
Nitroglycerine	$C_3H_5(ONO_2)_3$	227.09	1.601	–	–	–	–
Nitromethane	CH_3NO_2	61.04	1.130	95	112	–	–
2-Nitropropane	$CH_3CHNO_2CH_3$	89.09	1.003	–	103	–	–
Octane	$CH_3(CH_2)_6CH_3$	114.22	0.703	56	–	.95	3.2
Ozone	O_3	48	1.658	–	–	–	–
Pentane	$CH_3(CH_2)_3CH_3$	72.15	0.626	-40	–	1.4	7.8
Pentanone (Methylpropanone)	$CH_3COCH_2C_2H_5$	86.13	0.816	45	60	1.55	8.15
Phosgene	$O:C:Cl_2$	98.92	1.392	–	–	–	–
Phosphine	PH_3	34.0	1.146	–	205	–	–
Phosphorus Trichloride	PCl_3	137.35	1.574	–	–	–	–
Iso-Propanol	$(CH_3)_2CHOH$	60.09	0.785	53	60	2.02	11.80
Propane	$CH_3CH_2CH_3$	44.09	1.554	Gas		2.12	9.35
Propyl Acetate	$CH_3CO_2CH_2C_2H_5$	102.13	0.886	43	60	1.77	8.0
Iso-Propyl Ether	$(CH_3)_4(CH)_2O$	102.17	0.725	-18	-15	–	–
Stibine	SbH_3	124.78	4.344	–	–	–	–
Styrene Monomer	$C_6H_5HC:CH_2$	104.14	0.903	90	–	1.1	6.1

(continued)

Table 9–1: (continued)

Material	Chemical Formula	Molecular Weight	Specific Gravity	Flash Point F Closed Cup	Open Cup	Explosive Limits Vol. % Lower	Upper
Sulfur Chloride, Mono	S_2Cl_2	135.03	1.678	245	None	–	–
Di	SCl_2	102.97	1.621	–	–	–	–
Tetra	SCl_4	173.89		–	–	–	–
Sulfur Dioxide	SO_2	64.07	2.264	Gas		–	–
1,1,2,2 Tetrachloroethane	$Cl_2CHCHCl_2$	167.86	1.588	–	–	–	–
Tetrachloroethylene	$Cl_2C{:}CCl_2$	105.85	1.624	Nonflammable			
Toluene	$C_6H_5CH_3$	92.13	0.866	40	45	1.27	6.75
Toluidine	$CH_3C_6H_4NH_2$	107.15	0.999	188	205	–	–
Trichloroethylene	$ClCHCCl_2$	131.40	1.466	Nonflammable			
Turpentine (Turpene)	$C_{10}H_{16}$	136.23		95	–	0.8	–
Vinyl Chloride (Chloroethane)	C_2H_5Cl	62.50	0.908	Gas		4	21.70
Xylene	$C_6H_4(CH_3)_2$	106.16	0.881	63	75	1.0	6.0

Table 9–2: Chemical Resistance of Epoxy Resin Coatings

Material	Concentration(%)	Temperature (°C) 5	15	27	38	49	60	71	82
Acetic Acid	1-5	G[a]	G	F[a]	F	F	F	F	P[a]
	5-10	F	F	P	P	P	NR[a]	NR	NR
	10-50	NR	NR	NR	NR	NR	NR	NR	NR
Acetone	1-5	G	G	G	F	F	F	P	P
	10-20	F	F	F	P	P	NR	NR	NR
Alcohols (Ethyl)	–[a]	X[a]	X	G	G	F	F	P	P
Alum Sulfate	–	X	X	X	X	X	X	X	X
Ammonium Chloride	–	X	X	X	X	X	X	X	X
Ammonium Fluoride	–	X	X	X	X	X	X	X	X
Aromatic Solvents	–	X	X	X	X	G	G	G	F
Beer	–	X	X	X	X	X	X	X	X
Black Liquor	–	X	X	X	X	X	X	X	X
Boric Acid	1-5	X	X	X	G	G	G	F	F
Calcium Chloride	1-50	X	X	X	X	X	X	G	G
Carbon Tetrachloride	–	X	X	G	G	G	G	F	F
Chromic Acid	1-5	F	F	NR	NR	NR	NR	NR	NR
Citric Acid	1-5	F	F	F	G	G	G	G	F
Cooking Oils	–	X	X	X	X	X	X	X	G
Copper Salts	–	X	X	X	X	X	X	X	X
Esters	–	X	X	X	X	X	X	X	X
Esters (Ethyl ether)	–	X	X	X	X	X	G	G	G
Formaldehyde	1-35	X	X	X	X	X	X	X	X
Ferric Chloride	–	X	X	X	X	G	G	G	F
Ferrous Salts	–	X	X	X	X	X	X	X	X
Gasoline	–	X	X	X	X	X	X	X	G
Glycerin	–	X	X	X	X	X	X	X	X
Hydrochloric Acid	1-5	X	X	X	G	G	F	F	F
Hydrofluoric Acid	1-5	G	G	G	P	P	NR	NR	NR
Kerosene	–	X	X	X	X	X	X	X	G
Lactic Acid	1-10	X	X	X	G	G	G	F	F
Lead Acetate	–	X	X	X	X	X	X	X	G
Manganese Salt	–	X	X	X	X	X	X	X	G
Methyl Ethyl Ketone	1-5	G	G	G	F	F	NR	NR	NR
Mineral Spirits	–	X	X	X	X	G	G	G	F
Naphtha	–	X	X	X	X	X	X	X	X
Nitric Acid	1-5	F	F	P	P	P	P	NR	NR
	10-20	P	P	P	NR	NR	NR	NR	NR
Oxalic Acid	saturated	G	G	G	F	F	NR	NR	NR
Pospheric Acid	20	F	F	P	P	NR	NR	NR	NR
Potassium Hydroxide	–	X	X	X	X	X	X	X	X
Salt Brine	–	X	X	X	X	X	X	X	G
Soaps	–	X	X	X	X	X	X	X	G
Detergents	–	X	X	X	X	X	X	X	G
Sodium Chromate	–	X	X	X	X	X	X	X	G
Sodium Dichromate	–	G	G	G	G	G	G	F	F
Sodium Fluoride	–	X	X	X	X	X	X	X	X

(continued)

Table 9–2: (continued)

Material	Concentration(%)[a]	5	15	27	38	49	60	71	82
		Temperature (°C)							
Sodium Hydroxide	1-10	X	X	X	X	X	X	X	G
	50	X	X	X	G	G	G	G	F
Sodium Hypochlorite	3	G	G	F	P	P	NR	NR	NR
Sodium Phosphate	–	X	X	X	X	X	X	X	X
Sodium Sulfate	–	X	X	X	X	X	X	X	X
Sodium Sulfite	–	X	X	X	X	X	X	X	X
Sodium Thiosulfate	–	X	X	X	X	X	X	X	X
Sulfite Liquor	–	X	X	X	X	X	X	X	X
Sulfuric Acid	1-5	X	X	X	G	G	F	F	P
	10-20	X	X	P	P	NR	NR	NR	NR
Vegetable Oils	–	X	X	X	X	X	X	X	X
Water (Fresh)	–	X	X	X	X	X	X	X	X
Water (Distilled)	–	X	X	X	X	X	G	G	G
White Liquor	–	X	X	X	X	X	X	X	G

[a] = all concentrations; X = excellent; F = fair; NR = not recommended for use; G = good; P = poor.

Examples of Corrosion Mechanisms

Figure 9–1 illustrates the process in which iron and steel surfaces undergo one form of corrosion–rust. Rusting results from an electro–chemical reaction in which minute regions on a metal surface function as microscopic storage values. Differences in crystalline structure, stress concentrations and work hardness in various portions of the metal's surface cause anodic properties to develop while at the same time cathodic properties arise in adjacent regions on the same surface.

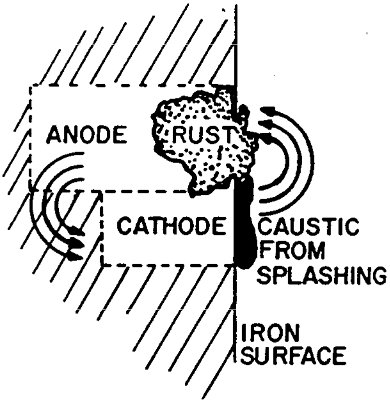


Figure 9–1: Illustrates the process of rust on steel or iron surfaces.

A natural electrolyte, in the form of moisture and ion–containing impurities from the environment, complete the circuit of the so–called battery and facilitate the flow of current between the anode and cathode through the metal. This action results in the development of rust–covered pits over the anodic regions of the metal surface causing the eventual disintegration of the entire metal surface.

Another example of the various mechanisms involved in different types of corrosion is shown in Figure 9–2. Corrosion problems can arise from the contact of two dissimilar metals. Generally, the more reactive metal tends to undergo corrosion.

A third type of corrosion can occur in an oxygen–starved environment. For example, a situation may arise as shown in Figure 9–3 where an oxygen–starved crevice develops between a rivet and a metal wall. The portion of the rivet exposed to oxygen tends to become a cathode. This forces the oxygen–starved region to act anodic, causing corrosion conditions to develop.

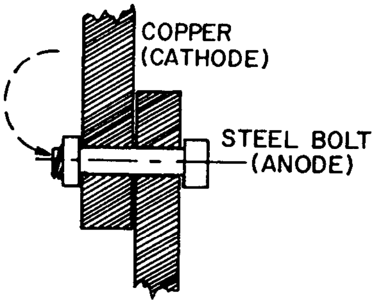


Figure 9–2: Illustrates how corrosions develop by the contact of two dissimilar metals.

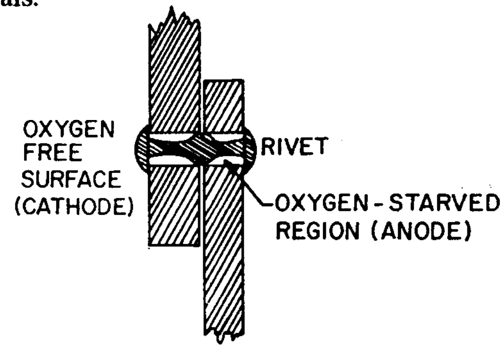


Figure 9–3: Preventing oxygen from reaching a metal's surface does not always hinder corrosion. Oxygen–starved conditions can also promote corrosion.

Other Properties and Special Resins

Once the nature of existing or potential corrosion problems has been evaluated, one should consult the lining manufacturers for specific information. Test kits can be obtained to test laminates under corrosive conditions in the field and/or in the laboratory. Sample laminates should be tested for exposure from three to ten months (longer, if necessary) in the actual environment. They should be returned to the manufacturer who can properly conduct corrosion inspections and evaluate strength–retention properties.

In addition to testing for corrosion resistance, studies or recommendations on the effects of solvents on the system, if any, should be made. Generally, the polyesters and epoxy–based linings offer the best chemical resistance to a wide variety of concentrated solvents.

Abrasion resistance should also be considered. There is a wide variety of abrasion–resistant additives that can be employed in FRP linings. These are usually incorporated into the fabricated lining by the supplier without detailed information from the customer. Abrasion–resistant additives are essential to the prevention of erosion on the surfaces of linings in agitated vessels or in handling abrasive slurries. Abrasion–resistant additives are also used widely in FRP–lined pipes and FRP pipelines handling slurries containing abrasive particles or liquids flowing at relatively high velocities.

Fire– and smoke–resistant resins are usually incorporated into standard FRP linings and in encapsulating coatings for fume exhaust equipment. Flame–spread ratings are available on the various types of fire–resistant resins from the manufacturer.

There are five basic pointers that can aid in selecting the proper lining system:

1. Determine the objective of a lining for repair, protection, safety, preventing contamination, etc.
2. Make a thorough environmental evaluation. Analyze for conditions of heat, moisture, impact, abrasion, atmospheric corrosion, chemical corrosion, fire potential, sparking, etc. The analysis should be the basis for selecting the optimum and type of lining along with the recommended surface preparation and application procedures.
3. Establish or advise the proper surface preparation of the substrate. Surface preparation sometimes can be the most expensive phase of fabricating or installing the lining system. There are a number of methods that can be used for cleaning and

preparing various metals, wood, wallboard, gypsum and concrete surfaces. The optimum method must be determined prior to lining selection.

4. Establish or advise the proper method of application. Lining quality and performance will depend heavily on the specific application technique employed. Lining thickness and surface finish should be specified as well.
5. Establish quality control inspections and procedures. Since most linings are fabricated by lengthy hand operations, quality control checks for thickness, adhesion, glass–reinforcement exposure, etc. should be made at specified intervals during application. Inspections should be conducted after completion as well so that any finish coat breakdown can be detected before putting the system into use.

SUBSTRATE SURFACE PREPARATION AND LINING FABRICATION

Bonded Linings

Because of the lengthy and tedious process of applying FRP–resin mixtures in fabricating linings, many potential problems can arise. The user should consult lining manufacturers for recommendations and solutions.

Contamination can become a major problem during layup by adversely effecting the adhesive properties of the resin. It can take the form of moisture, in which case the use of heaters or circulation of dry air over the working area will help alleviate the problem. One should always check for leaks and try to prevent condensation. Contamination of surfaces can occur from other sources. Substrate surfaces should be cleaned thoroughly prior to application either by sandblasting or by hand–cleaning with the use of solvents. To ensure good adhesion, surface preparation should also include the use of resilient wetting primers. The thickness of the primer coat can affect adhesion as well. If the prime coat thickness is too great, cracking and/or shrinkage can occur to the nonreinforced material. The manufacturer should prescribe the proper millage for a specific primer and substrate.

Resin shrinkage after curing can occur for a variety of reasons. The use of flexible additives or various plasticizers in resins reduces shrinkage. Fillers may also be used with some resins. Another approach is to employ inhibitors to regulate curing time and pot life.

Heat can usually be applied to assist curing of most polyesters. When heat is applied, the surface of the lining will tend to soften as the temperature increases. Once the recommended temperature for curing has been obtained, the lining should be kept at that temperature for a prescribed length of time. The lining should be cooled gradually during which surfaces will harden. The same type of curing process can be used on epoxy resin lining systems.

It is not good practice to apply resins under cold weather conditions. Below 50°F, it is almost impossible to obtain a complete resin cure unless external heat is applied. Lining steel located outside can present problems even if heat is applied inside the tank. Outer steel surfaces will remain cold, which can offset any advantages of heating from within the vessel. Tanks inside heated buildings generally do not present curing problems, provided there is sufficient downtime.

In general, exposed edges of linings will be attacked by chemicals, fumes or vapors. It is not good practice to only partially line a tank in which liquids are being processed or stored, unless some protection is provided to the exposed areas. For example, putties or flashings can be used. Similar problems could be experienced with unfinished floor coatings, trench linings, pump pads, etc. Manufacturers usually will provide recommendations for proper protection.

Surface Preparation (Steel and Concrete)

Inside steel surfaces should be sandblasted to white metal including flange facings and nozzles. For badly corroded areas, grinding can be done to clean surfaces. A thin coating of zinc–rich primer should then be applied. An epoxy–based or other suitable coating should then be applied over the zinc primer. Steel surfaces may also be hand–cleaned, in which case paint can be brushed or sprayed on to partially cleaned surfaces to prevent oxidation. The type of paint used will depend on the surface conditions of the substrate and the fluid to be handled by the vessel.

The surfaces of concrete chests or vessels should be scoured by steam cleaners. Surfaces should be thoroughly dried after cleaning before fabrication of the lining begins. Often downtime in existing systems prevents sufficient drying of surfaces. In such cases, polyethylene sheets can be used to cover surfaces to prevent moisture bleed–through. The liner can then be laid up over the polyethylene. Similar procedures can be used for concrete trenches, pits, sumps and reservoirs.

For fresh concrete, a minimum of 10–15 days set time should be allowed before applying a lining. Both old and new concrete will contain a certain amount of moisture. Therefore, it is advisable that such linings be mechanically anchored to prevent delamination during operation. Moisture can cause separation of the lining from the substrate or from shearing of the concrete because of resin shrinkage.

Concrete surfaces can also be sandblasted to remove all loose concrete. This also etches the surface for priming purposes. When sandblasting, the work area should be vented thoroughly and exhaust dust directed outside the building. Wet blast methods on concrete should be used if venting or exhausting are not possible. Primer can be applied with either rollers or brushes.

Once the lining has been applied, it should be anchored to the supporting walls with stainless steel anchors. The anchors should be capped with the same resin–glass buildup used in applying the lining to provide maximum corrosion resistance. The finished unit can usually be put into service within 24 hours after application. The use of heat can accelerate cure times.

For large concrete installations such as chill water tanks, pits and cooling towers, added protection may be necessary to prevent moisture accumulation. Mechanical anchoring of linings is generally recommended. Large concrete units present severe leakage problems. Many concrete tanks leak almost immediately after installation at various points while others tend to crack and develop slow leakage over the years. Concrete vessels lined with resilient resins and reinforced fiberglass generally have expansion joints or loops incorporated into the lining to prevent lining cracking due to flexing of the substrate.

Acid etching is sometimes preferred over sandblasting in preparing concrete surfaces, depending on the condition of the substrate. A roughened surface is desirable for good adhesion. Etching is normally done by mopping a suitable acid–water solution liberally over all surfaces. The inside should then be flushed with freshwater. A suitable neutralizing agent in water solution should then be applied to all etched surfaces and allowed to set for one or two hours before a final freshwater flushing is done. Once the lining has been applied, it should be spark tested for any defects such as pinholes.

If the unit is a below–ground installation, moisture will almost always seep back into the pit or tank from the surroundings. This can be avoided by digging down a foot or two below the lowest point of the unit and a sump pump used to direct accumulated water away.

Surface Preparation of Wooden Vessels

Wooden vessel linings can present a large number of difficulties both in fabrication and use. Good bonded linings are difficult to achieve. Dry rot and shrinking of woodwork after a lining has been applied occurs quite often, causing linings to crack.

There are many recommended procedures for cleaning wooden surfaces. Generally there are no hard and fast rules, but roughening of the woodwork should be avoided.

A mastic should be sprayed onto the backside of the woodwork to prevent wood rot. This will prevent melting and retard drying action caused by exposure to the environment. Both sides of the fiberglass reinforced resin should be saturated with oil; however, this procedure does not always prevent lining cracking. Tightening up the reinforcing bands around the vessel and then spraying the mastic or encapsulating the entire tank with FRP may be necessary.

Probably the most successful method of lining a wooden tank or trough is to install a nonbonded liner (i.e., a tank within a tank). In this situation only flange faces and nozzles that extend through the lining can exert stresses on it. The liner must be designed to have sufficient thickness, strength and flexibility to withstand these stress points.

RECONDITIONING INDUSTRIAL EQUIPMENT AND WORK AREAS

Exhaust Equipment

Metal fans can be readily protected by FRP encapsulation or linings composed of resilient resins. Old fans can be almost completely reconditioned in many cases. Surface preparation generally involves sand-blasting metal surfaces. It is not advisable to line cracked fan blades unless they can first be repaired or replaced. Many blades become so thinned from corrosion that blade replacement is necessary. New blades that are coated with FRP lining will display a significantly longer service life than bare metal.

Linings can be successfully applied to fan casings provided they are not too badly corroded. Pitted areas or large holes can be patched with thicker layers of fiberglass-reinforced resin mix. Rebuilt fan housings with FRP generally provide significant extensions in service life.

For single-width centrifugal fans, it is often necessary to pull the cone from the unit. A cutting torch may be used, if necessary, to cut off a small portion of the edge of the cone to provide clearance between the wheel and cone edge. The additional clearance is necessary as the wheel and cone. from rotation of the wheel would cut through the lining. It is often necessary to cut an opening in the side of the unit to gain access to the back side of the wheel for removal. Openings can be patched with either metal or FRP patches after the lining has been applied.

Bearing casings have to be unbolted from the bearing support beams when removing the wheel. Anywhere from three to four hours is required in removing the wheel from the housing. Vane axial fan wheels are rarely lined with FRP because of the relatively high operating rpm although it can be done with proper planning. With these units, the motor must be pulled if it is mounted inside the casing. The wheel, shaft and bearings must also be removed and replaced if badly worn. In fans, the clearance between the blades and casings may be no more than 1/8 in., in which case the blades must be trimmed carefully and rebalanced to account for the lining. If the RPM exceeds 1,000, suitable paint coatings are to be preferred over FRP linings. Baked phenolic coatings generally provide superior protection for vane axial wheels.

During sandblasting operations in preparing fan metal surfaces, care should be taken to prevent sand contamination. Duct work leading from the fan should be blanked off from the inside with a sheet of plywood tightly fitted to the inside of the duct. All other openings leading from the fan to the plant area should be sealed off similarly. Bearing casings should be encased in a heavy layer of grease and wrapped and sealed with rubber lining. Motors, controls, etc. should also be covered carefully to prevent sand contamination. Ventilating fans should be employed during the blasting operation and dust channeled outside the plant area.

Once the lining has been applied and cured, the wheel can be repositioned and balanced. When balancing, the belt drives should be off and the wheel rotated at a moderate speed. Crimped stainless steel weights should be used on the inside edges of the fan blades to balance the wheel. Dynamic wheel balancing is often preferred, however.

Supply and Exhaust Ductwork

The options available for repairing corroded or deteriorated metal ductwork are:

1. Replace the existing duct with molded FRP duct.
2. Apply an FRP lining to the inside surfaces of the duct.
3. Apply an FRP lining to the outside surfaces of the duct.
4. Encapsulate the existing unit with performed segments of FRP ducting.

If the ductwork is not badly pitted, an inside surface lining will be sufficient. Sufficient downtime must be available for fabricating the lining and the inside of the duct must have enough working area. Note that this method will not prevent corrosion from occurring on the outside of the duct.

For situations in which corrosion is a concern on the outside of the ductwork only, a coat of fiberglass–reinforced polyester resins can be wrapped about the structure. Both inside and outer surfaces can be prepared by sandblasting, or where this is not feasible, wire brush and solvent application may be necessary. Prepared surfaces should be primed with an appropriate primer paint. This can usually be applied with a spray gun; however, the coat should be rolled out with a mohair roller before setting up.

Structurally unsound duct should be encapsulated with FRP ducting. Duct segments are generally prefabricated to thicknesses specified by the manufacturer. The mold release side of the FRP duct is applied to the inside of the metal duct. Outside surfaces of the ductwork should be free of burs, pinholes, voids, etc. and should be rich in resin. The mold release side serves as a corrosion barrier and is generally composed of a resin–rich, smooth surface covered with a surfacing veil and several plies of fiberglass mat. Alternate layers of woven roving are usually applied to build up to specified thicknesses. If the outside of the duct is to be subjected to corrosive fumes or spillage, surfacing veil is employed over a roving mat.

Prefabricated duct must be designed to fit as snugly as possible over the existing unit. Metal banks or straps should be employed to hold half sections in place (Figure 9–4). Seams should be primed with resin and allowed to cure. A ply of surfacing veil should be applied over the seam and/or several layers of resin–rich mat. Glass and resin should be worked down with grooved rollers and/or brushes and all entrapped air pockets, voids, burrs, pinholes, etc. eliminated.

Floor Toppings

Epoxy systems are usually employed in floor applications. The epoxies have superior adhesion to many different types of surfaces and low shrinkage properties. In addition, they have good mechanical strength, abrasion resistance and chemical resistance to most alkalis and strong acids. The specific reinforced resin coating to be used will depend on the nature of the working environment. In areas where concentrated acids or chlorine spillage occur, polyester or vinyl ester resin systems are preferred over the epoxies.

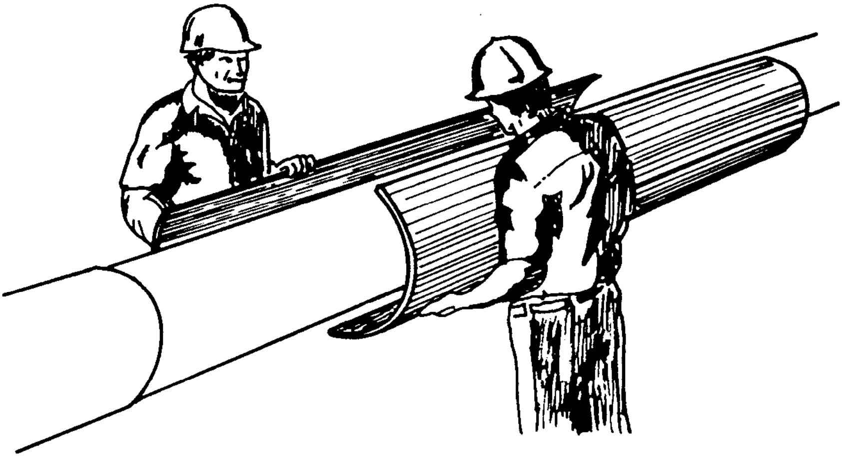


Figure 9–4: Illustrates application of prefabricated FRP duct over existing metal duct.

Chemical resistant floor toppings are usually applied by hand as shown in Figure 9–5. A sand finish is applied to the coating's surface to make it skid–proof. Concrete floors should first be coated with an epoxy primer and then polyester–type resins applied over the epoxy. The epoxy resins have good adhesion to concrete whereas the polyester and vinyl ester resins may separate from the substrate after curing.

Figure 9–5: Applying a floor coating by hand.

New and old concrete surfaces should be etched by sandblasting, scarified or acid etched. Note that exposed edges should be protected around walls, curbs or wherever the topping terminates or peeling may occur. This can be avoided by providing a groove along the terminating edges and forcing the glass and resin down into it.

During application, fiberglass and resin should be worked down with grooved rollers and brushes. The coating should be free from any defects. Coatings should be turned down into and bonded to all drains in the floor. Manufacturers should be consulted for specific information and tips in applying FRP floor linings.

GLOSSARY

PLASTICS AND ENGINEERING TERMS

A–stage	Initial or early stage in the reaction of some thermosetting resins, the material is still soluble in certain liquids and fusible; referred to as *resol*.
Acid–acceptor	Chemical that acts as a stabilizer by chemically combining with an acid that may be present initially in trace quantities in a plastic; may also be formed via decomposition of the resin.
Acrylic plastics	Group of plastics based on resins generated from the polymerization of acrylic monomers (e.g, ethyl acrylate and methyl methacrylate).
Activation	Process of inducing radioactivity in a material by bombardment with other types of radiation, such as neutrons.
Adherent	A component or body held to another body by an adhesive.
Adhesion	Condition in which two surfaces are bonded together by interfacial forces caused by valence forces or interlocking forces or both (see mechanical adhesion and specific adhesion).
Adhesion, mechanical	Bonding between two surfaces caused by interlocking action of molecules.

Adhesion, specific	Adhesion between surfaces whereby valence forces predominate that are similar to those promoting cohesion.
Adhesive	Material that holds parts together by surface attachment. Examples include glue, mucilage, paste and cement. Various forms of adhesives include liquid or tape adhesives (physical type) and silicate or resin adhesives (chemical type).
Adhesive, assembly	Adhesive for bonding materials together, *e.g.,* boat, airplane, furniture, etc.; term commonly used in wood chemistry to distinguish between 'joint glues' and veneer glues. Term applied to adhesives employed in fabricating finished goods and differs from adhesives used in fabricating sheet materials such as laminates or plywood.
Aging	The effect of exposure of plastics to the environment for a length of time. The specific effect and degree depend on the moisture in, temperature and composition of the environment in addition to the length of exposure.
Air vent	Small outlet for preventing gas entrapment.
Alkyd plastics	Group of plastics composed of resins based on saturated polymeric esters whereby the recurring ester groups are an integral part of the primary polymer chain and the ester groups exist in cross–links that are present between chains.
Allyl plastics	Group of plastics composed of resins formulated by addition polymerization of monomers containing allyl groups (*e.g.,* diallyl phthalate).
Amino plastics	Group of plastics generated by the condensation of amines (*e.g.,* urea and melamine with aldehydes).

Anneal	As applied to molded plastics, the process of heating material to a specified temperature and slowly cooling it to relieve stresses.
Assembly	The positioning or placing together in proper order layers of veneer or other materials, with adhesives, for purposes of pressing and bonding into a single sheet or unit.
Assembly time	Refers to the elapsed time after an adhesive is applied until applied pressure effects curing.
Autoclave	A closed vessel or reactor for chemical reaction to take place under pressure.
B–stage	Intermediate–stage reaction step for various thermosetting resins. During this stage the material swells when in contact with certain liquids and becomes soft when heat is applied. The material may not dissolve or fuse entirely. Resin in this stage is referred to as resitol.
Back–pressure–relief port	Opening from an extrusion die used for excess material to overflow.
Backing plate	Also called support plate, it serves to back up cavity blocks, guide pins, bushings, etc.
Binder	Part of adhesive composition responsible for adhesive forces.
Blanket	Veneers laid up on a flat table. Complete assembly is positioned in a mold at one time; used primarily on curved surfaces to be molded by the flexible bag process.
Blister	Elevation of the surface of a plastic caused by trapped air, moisture, solvent; can be caused by insufficient adhesive, inadequate curing time, excess temperature or pressure.

Blocking	Adhesion between layers of plastic sheets in contact; condition arises during storage or use when components are under pressure.
Bloom	Visible exudation or efflorescence on the surface of a plastic; caused by plasticizer, lubricant, etc.
Bolster	Spacer or filler material in a mold.
Bond	The attachment at the interface or exposed surfaces between an adhesive and an adherent; to attach materials together with adhesives.
Bulk density	Density of a molding material in loose form, such as granular, nodular, etc., with units g/cm^3 or lb/ft^3.
Bulk factor	Ratio of the volume of loose molding compound to the volume of the same amount in molded solid form; ratio of density of solid plastic component to apparent density of loose molding compound.
C–stage	Final reaction stage of various thermosetting resins. In this stage material is insoluble and infusible. Resin in fully cured thermosetting molding is in this stage and is referred to as resite.
Case harden	Process of hardening the surface of a piece of steel to a relatively shallow depth.
Cast film	Film generated by depositing a layer of liquid plastic onto surface and stabilizing by evaporating the solvent, by fusing after deposition or by cooling. Cast films generated from solutions or dispersions.
Catalyst	Material used to activate resins to promote hardening. For polyesters, organic peroxides are used primarily. For epoxies, amines and anhydrides are used.

Cavity	Portion of a mold that forms the outer surface of the molded product.
Cell	Single cavity caused by gaseous displacement in a plastic.
Cellular plastic	A plastic that suffers a density decrease by the presence of numerous cells dispersed throughout the material.
Cellular striation	Layering of cells within a cellular plastic.
Cellulosic plastics	Group of plastics composed of cellulose compounds, for example esters *(e.g.,* cellulose acetate) and ethers *(e.g.,* ethyl cellulose).
Centrifugal casting	Process in which tubular products are fabricated through the application of resin and glass strand reinforcement to the inside of a mold that is rotated and heated. The process polymerizes the resin system.
Chalking	Dry, chalk-like deposit on the surface of a plastic.
Chase	Main portion of the mold containing the molding cavity, mold pins, guide pins, etc.
Chemically foamed plastic	Cellular plastic whereby the material's structure is formed by gases generated from the chemical reaction between its constituents.
Clamping plate	Mold plate that matches the mold and is used to fasten the mold to the machine.
Closed-cell foam	Cellular plastic which is composed predominantly of noninterconnecting cells.
Cohesion	Forces binding or holding a single material together.

Cold flow	Creep: the dimensional change of a plastic under load with time followed by the instantaneous elastic or rapid deformation at room temperature; permanent deformation caused by prolonged application of stress below the elastic limit.
Cold molding	The fashioning of an unheated mixture in a mold under pressure. The article is then heated to effect curing.
Cold pressing	Bonding process whereby an assembly is subjected to pressure without applying heat.
Cold slug	Material to first enter an injection mold.
Cold–slug well	Section provides opposite sprue opening of the injection mold, used for trapping cold slug.
Condensation	Chemical reaction whereby two or more molecules combine and separate out water or other substance. When polymers are formed, it is referred to as polycondensation.
Contact molding	Process whereby layers of resin–impregnated fabrics are built up one layer at a time onto the mold surface forming the product. Little or no pressure is required for laminate curing.
Consistency	Resistance of a material to flow or undergo permanent deformation under applications of shearing stresses.
Copolymer	Formed from two or more monomers (see polymer).
Core	Portion of the mold that forms the inner surfaces of the molded product.
Core and separator	Center section of an extrusion die.
Core pin	Pin for molding a hole.

Core–pin plate	Plate that holds core pins.
Crazing	Tiny cracks that develop on a laminate's surface. Caused by mechanical or thermal stresses.
Creep	See 'cold flow.'
Cross–linking	Generation of chemical linkages between long–chain molecules; can be compared to two straight chains joined together by links. The rigidity of the material increases with the number of links. The function of a monomer is to provide these links.
Cull	Remaining material in the transfer vessel after the mold has been filled.
Cure	Process in which the addition of heat, catalyst or both, with or without pressure, causes the physical properties of the plastic to change through a chemical reaction. Reaction may be condensation, polymerization or addition reactions.
C–veil	Thin, nonwoven fabric composed of randomly oriented and adhered glass fibers of a chemically resistant glass mixture.
Degradation	Deleterious change in a plastic's chemical structure.
Delamination	Separation of a laminate's layers.
Deterioration	Permanent adverse change in the physical properties of a plastic.
Diaphragm gate	Gate employed in molding tubular or annular products.
Die–adaptor	Piece of an extrusion die that serves to hold die block.

Die block	Part of extrusion die that holds the core and forming bushing.
Die body	Part of an extrusion die that is used to separate and form material.
Dilatant	Property of a fluid whose apparent viscosity increases with increasing shear rate.
Dished	Displays a symmetrical distortion of a flat or curved section; as viewed, it appears concave.
Dispersant	In an organosol, the liquid constituent which displays solvating or peptizing action on the resin; subsequent action aids in dispersing and suspending resin.
Dispersion	Heterogeneous mixture in which finely divided material is distributed throughout the matrix of another material. Distribution of finely divided solids in a liquid or a solid (e.g., pigments, fillers).
Doctor bar	Device for regulating the amount of material on the rollers of a spreader.
Doping	Coating a mandrel or mold with a material that prevents the finished product from sticking to it.
Dowel	Pin that maintains alignment between the various sections of a mold.
Draft	Angle of clearance between the molded article and mold, allowing removal from the mold.
Dry spot	Incompleted area on laminated plastics; the region in which the interlayer and glass are not bonded.
Durometer hardness	A material's hardness as measured by the Shore Durometer.

Ejector pin	Pin or dowel used to eject molded articles from a mold.
Ejector–pin–retainer plate	Receptable into which ejector pins are assembled.
Elasticity	Property of materials whereby they tend to retain or recover original shape and size after undergoing deformation.
Elastomer	A material under ambient conditions which can be stretched and, upon release or the applied stress, returns with force to its approximate original size and shape.
Epoxy plastics	Group of plastics composed of resins produced by reactions of epoxides or oxiranes with compounds such as amines, phenols, alcohols, carboxylic acids, acid anhydrides and unsaturated compounds.
Ethylene plastics	Group of plastics formed by polymerization of ethylene or by the copolymerization of ethylene with various unsaturated compounds.
Evenomation	Softening, discoloration, mottling, crazing, etc. Process of deterioration of a plastic's surface.
Exotherm	Indicates that heat is given from a reaction between a catalyst and a resin.
Expandable plastics	Plastics that can be transformed to cellular structures by chemical, thermal or mechanical means.
Extender	A material which, when added to an adhesive, reduces the amount of primary binder necessary.
Extraction	Transfer of materials from plastics to liquids with which they are in contact.

Extrusion	Process in which heated or unheated plastic compound is forced through an orifice, forming a continuous article.
Filament winding	Process in which continuous strands of roving or roving tape are wound, at a specified pitch and tension, onto the outside surface of a mandrel. Roving is saturated with liquid resin or is pre-impregnated with partially cured resin. Application of heat may be required to promote polymerization.
Filler	Inert material that is added to a plastic to modify the finished product's strength, permanence and various other properties; an extender.
Fin	Portion of the 'flash' that adheres to the molded article.
Finishing	Removal of any defects from the surfaces of plastic products.
Fisheye	A clump or globular mass that does not blend completely into the surrounding plastic.
Flash	Excess material that builds up around the edges of a plastic article; usually trimmed off.
Foamed plastic	Cellular structured plastic.
Force plate	A plate used for holding plugs in place in compression molding.
Furane plastics	Group of plastics composed of resins in which the furane ring is an integral portion of the polymer chain; made from polymerization or polycondensation of furfural, furfural alcohol and other compounds containing furane rings; also formed by reaction of furane compounds with an equal weight or less of other compounds.

Fusion	As applied to vinyl dispersions, the heating of a dispersion, forming a homogeneous mixture.
Fusion temperature	Fluxing temperature; temperature at which fusion occurs in vinyl dispersions.
Gel	State at which resin exists before becoming a hard solid. Resin material has the consistency of a gelatin in this state; initial jelly-like solid phase which develops during the formation of a resin from a liquid.
Gel coat	Specially formulated polyester resin which is pigmented and contains fillers. Provides a smooth, pore-free surface for the plastic article.
Gel point	Stage at which liquid begins to show pseudo-elastic properties.
Gelation	Formation of a gel.
Glass	Inorganic product of a fusion reaction. Material forms upon cooling to a rigid state without undergoing crystallization. Glass is typically hard and brittle and will fracture conchoidally.
Glass transition	Transition region or state in which an amorphous polymer changed from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one. Transition occurs over a narrow temperature region; similar to solidification of a liquid to a glassy state. This transformation causes hardness, brittleness, thermal expansibility, specific heat and other properties to dramatically change.
Gum	Class of colloidal substances prepared from plants. Composed of complex carbohydrates and organic acids that swell in water. Also, a number of natural resins are gums.

Halocarbon plastics	Group of plastics composed of resins generated from the polymerization of monomers consisting of a carbon and a halogen or halogens.
Hardener	Compound or mixture that, when added to an adhesive, promotes curing.
Heat treat	Refers to annealing, hardening, tempering of metals.
Hot soils	Soils having a resistivity of less than 1,000 ohm–cm; generally very corrosive to base steel.
Hydrocarbon plastics	Plastics composed of resins consisting of carbon and hydrogen only.
Inhibitor	Material that retards chemical reaction or curing.
Isocyanate plastics	Group of plastics produced by the condensation of organic isocyanates with other plastics. Examples are the urethane plastics.
Isotactic	Type of polymeric molecular structure that contains sequences of regularly spaced asymmetric atoms that are arranged in similar configuration in the primary polymer chain. Materials having isotactic molecules are generally in a highly crystalline form.
Isotropic	Refers to materials whose properties are the same in all directions. Examples are metals and glass mats.
Laminate	Article fabricated by bonding together several layers of material or materials.
Laminated, cross	Laminate in which some of the layers of materials are oriented at right angles to the remaining layers. Orientation may be based on grain or strength direction considerations.

Laminated, parallel	Laminate in which all layers of materials are oriented parallel with respect to grain or strongest direction in tension.
Lignin plastics	Group of plastics composed of resins formulated from the treatment of lignin with heat or by reaction with chemicals.
Line pipe	Pipeline used for transportation of gas, oil or water; utility distribution pipeline system ranging in sizes 1/8–42 in. o.d. inclusive. Fabricated to American Petroleum Institute (API) and American Water Works Association (AWWA) specifications.
Lyophilic	Referring to vinyl dispersions, having affinity for the dispersing medium.
Lyophobic	Referring to vinyl dispersions, no affinity or attraction for dispersing medium.
Mechanical tubing	Welded or seamless tubing manufactured in large range of sizes of varied chemical composition (sizes range 3/16–10 3/4 in. o.d. inclusive for carbon and alloy material); usually not fabricated to meet any specification other than application requirements; fabricated to meet exact outside diameter and decimal wall thickness.
Mechanically foamed	Cellular plastic whose structure is fabricated plastic by physically incorporated gases.
Melamine plastics	Group of plastics whose resins are formed by the condensation of melamine and aldehydes.
Metastable	Unstable state of plastic as evidenced by changes in physical properties not caused by the surroundings. Example is the temporary flexible condition some plastics display after molding.
Mold base	Assembly of all parts making up an injection mold, excluding cavity, cores and pins.

Molding, bag	Process of molding or laminating in which fluid pressure is applied, usually by means of water, steam, air or vacuum, to a flexible film or bag which transmits the pressure to the material being molded.
Molding, blow	Method of forming plastic articles by inflating masses of plastic material with compressed gas.
Molding, compression	Process of shaping plastic articles by placing material in a confining mold cavity and applying pressure and usually heat.
Molding, contact pressure	Method of molding or laminating whereby pressure used is slightly greater than is necessary to bind materials together during molding stage (pressures generally less than 10 psi).
Molding, high pressure	Molding or laminating with pressures in excess of 200 psi.
Molding, injection	Process of making plastic articles from powdered or granular plastics by fusing the material in a chamber under pressure with heat and forcing part of the mass into a cooler cavity where it solidifies; used primarily on thermoplastics.
Molding, low pressure	Molding or laminating with pressures below 200 psi.
Molding, transfer	Process of molding plastic articles from powdered, granular or preformed plastics by fusing the material in a chamber with heat and forcing the mass into a hot chamber for solidification. Used primarily on thermosetting plastics.
Monomer	Reactive material that is compatible with the basic resin. Tends to lower the viscosity of the resin.

Nonrigid plastic	Plastic whose apparent modulus of elasticity is not greater than 10,000 psi at room temperature in accordance with the Standard Method of Test for Stiffness in Flexure of Plastics.
Novolak	Phenolic–aldehydic resin that remains permanently thermoplastic unless methylene groups are added.
Nylon plastics	Group of plastics comprised of resins that are primarily long–chain synthetic polymeric amides. These have recurring amide groups as an integral part of principal polymer chain.
Organosol	Suspension of finely divided resin in a volatile organic slurry.
Phenolic plastics	Group of plastics whose resins are derived from the condensation of phenols (e.g, phenol and cresol, with aldehydes).
Piling pipe	Round–welded or seamless pipe for use as foundation piles where pipe cylinder acts as a permanent load–carrying member; usually filled with concrete. Used below the ground in foundation work in the construction industry for piers, docks, highways, bridges and all types of buildings. Fabricated to ASTM piling specifications.
Plastic	According to ASTM, a material containing an organic substance of large molecular weight is sold in its finished state, and at some stage in its manufacture into finished goods, it can be shaped to flow.
Plastic, semirigid	Plastic having apparent modulus of elasticity in the range of 10,000–100,000 psi at 23°C, as determined by the Standard Method of Test for Stiffness in Flexure Plastics.

Plastic welding	Joining of finished plastic components by fusing materials either with or without the addition of plastic from another source.
Plasticate	Softening by heating or kneading.
Plasticity	Property of plastics which permits the material to undergo deformation permanently and continuously without rupture from a force that exceeds the yield value of the material.
Plasticize	Softening by adding a plasticizer.
Plasticizer	Material added to a plastic to increase its workability and flexibility. Plasticizers tend to lower the melt viscosity, the glass transition temperature and/or the elastic modulus.
Plastisol	Suspension of finely divided resin in a plasticizer.
Polyamide plastics	See nylon plastics.
Polyester plastics	Group of plastics composed of resins derived principally from polymeric esters which have recurring polyester groups in the main polymer chain. These polyester groups are cross-linked by carbon/carbon bonds.
Polyethylene	Plastic or resin made by the polymerization of ethylene as the sole monomer.
Polymer	Material produced by the reaction of relatively simple molecules with functional groups that allow their combination to proceed to high molecular weights under suitable conditions; formed by polymerization or polycondensation.
Polymerization	Chemical reaction that takes place when a resin is activated.

Polypropylene	Plastic or resin derived from the polymerization of propylene as the principal monomer.
Polystyrene	Plastic derived from a resin produced by the polymerization of styrene.
Polyvinyl acetate	Resin derived from the polymerization of vinyl acetate.
Polyvinyl alcohol	Polymer derived from the hydrolysis of polyvinyl esters.
Polyvinyl chloride	Resin derived from the polymerization of vinyl chloride.
Polyvinyl chloride-acetate	Copolymer of vinyl chloride and vinyl acetate.
Pot life	Time period beginning once the resin is catalyzed and terminating when material is no longer workable; working life.
Preform	Coherent block of granular plastic molding compound or of fibrous mixture with or without resin. Prepared by sufficiently compressing material, forming a block that can be handled readily.
Prepolymer	An intermediate chemical structure between that of a monomer and the final resin.
Pressure tubing	Tubing used to convey fluids at elevated temperatures and/or pressures. Suitable for head applications, it is fabricated to exact o.d. and decimal wall thickness in sizes ranging from 1/2–6 in. o.d. inclusive and to ASTM specifications.
Primer	Coating that is applied to a surface before application of an adhesive, enamel, etc. The purpose is to improve bonding.

Promoted resin	Resin with an accelerator added but not catalyst.
Reinforced plastic	Plastics having superior properties over those consisting of the base resin, due to the presence of high-strength fillers embedding in the composition. Reinforcing fillers are fibers, fabrics or mats made of fibers.
Resin	Highly reactive material which, in its initial stages, has fluid-like flow properties. When activation is initiated, material transforms into a solid state.
Roller	A serrated piece of aluminum used to work a plastic laminate. Purpose of device is to compact a laminate and to break up large air pockets to permit release of entrapped air.
Roving	Bundle of continuous, untwisted glass fibers. Glass fibers are wound onto a roll called a 'roving package.'
Saran plastics	Group of plastics whose resins are derived from the polymerization of vinylidene chloride or the copolymerization of vinylidene chloride and other unsaturated compounds.
Shelf life	Period of time over which a material will remain usable during storage under specified conditions such as temperature and humidity.
Silicone plastics	Group of plastics whose resins consist of a main polymer chain with alternating silicone and oxygen atoms and with carbon-containing side groups.
Softening range	Temperature range in which a plastic transforms from a rigid solid to a soft state.
Solvation	Process of swelling of a resin or plastic. Can be caused by interaction between a resin and a solvent or plasticizer.

Standard pipe	Pipe used for low-pressure applications such as transporting air, steam, gas, water, oil, etc. Employed in machinery, buildings, sprinkler and irrigation systems, and water wells but not in utility distribution systems; can transport fluids at elevated temperatures and pressures not subjected to external heat applications. Fabricated in standard diameters and wall thicknesses to ASTM specifications, its diameters range from 1/8–42 in. o.d.
Stress–crack	Internal or external defect in a plastic caused by tensile stresses below its short–time mechanical strength.
Structural pipe	Welded or seamless pipe used for structural or load–bearing applications in aboveground installations. Fabricated in nominal wall thicknesses and sizes to ASTM specifications in round, square, rectangular and other cross–sectional shapes.
Structural shapes	Rolled flanged sections, sections welded from plates and specialty sections with one or more dimensions of their cross section greater than 3 in. They include beams, channels and tees, if depth dimensions exceed 3 in.
Styrene plastics	Group of plastics whose resins are derived from the polymerization of styrene or the copolymerization of styrene with various unsaturated compounds.
Styrene–rubber plastics	Plastics that are composed of a minimum of 50% styrene plastic and the remainder rubber compounds.
Syneresis	Contraction of a gel, observed by the separation of a liquid from the gel.

Thermoelasticity	Rubber–like elasticity that a rigid plastic displays; caused by elevated temperatures.
Thermoforming	Forming or molding with heat.
Thermoplastic	Reverse of thermoset. Materials that can be reprocessed by applying heat.
Thermoset	Those plastics that harden upon application of heat and cannot be reliquefied, resin state being infusible.
Thixotropy	Describes those fluids whose apparent viscosity decreases with time to an assymptotic value under conditions of constant shear rate. Thixotropic fluids undergo a decrease in apparent viscosity by applying a shearing force such as stirring. If shear is removed, the material's apparent viscosity will increase back to or near its initial value at the onset of applying shear.
Tracer yarn	Strand of glass fiber colored differently from the remainder of the roving package. It allows a means of determining whether equipment used to chop and spray glass fibers are functioning properly and provides a check on quality and thickness control.
Urea plastics	Group of plastics whose resins are derived from the condensation of urea and aldehydes.
Urethane plastics	Group of plastics composed of resins derived from the condensation of organic isocyanates with compounds containing hydroxyl groups.
Vacuum forming	Fabrication process in which plastic sheets are transformed to desired shapes by inducing flow; accomplished by reducing the air pressure on one side of the sheet.

Vinyl acetate plastics	Group of plastics composed of resins derived from the polymerization of vinyl acetate with other saturated compounds.
Vinyl alcohol plastics	Group of plastics composed of resins derived from the hydrolysis of polyvinyl esters or co–polymers of vinyl esters.
Vinyl chloride plastics un–	Group of plastics whose resins are derived from the polymerization of vinyl chloride and other unsaturated compounds.
Vinyl plastics	Group of plastics composed of resins derived from vinyl monomers, excluding those that are covered by other classifications (*i.e.*, acrylics and styrene plastics). Examples include PVC, polyvinyl acetate, polyvinyl butyral, and various copolymers of vinyl monomers with unsaturated compounds.
Vinylidene plastics	Group known as saran plastics.
Weathering	Exposure of a plastic to outdoor conditions.
Yield value	Also called yield stress; force necessary to initiate flow in a plastic.

INDEX