

CHAPTER II

THEORY

During World War II, new plastic compounds and improved molding methods, together with the use of glass fiber, produced a new field of structural products. Yarns, strands, mats, and cloths made from glass fiber were united with various resins to give a material with characteristics of very high strength and impact resistance, light weight, and dimensional stability. Resins with FRP contribute mechanical strength, determine electrical, chemical and thermal performance, and prevent abrasion of fibers by keeping them separated. By varying resin ingredients and their treatment, many different materials are produced for a wide range of applications.

Two main classes of resins are used in reinforced plastic products. Thermosetting resin systems become hard when cured or heated, and further heating will not soften them - the hardening is irreversible. Thermoplastic resins become soft when heated and hard when cooled - this cycle is repeatable. At present, thermoplastic resins are used in reinforced plastic industries in small quantity because they require more complex equipment and procedure than thermosetting resins.

2.1 Unsaturated Polyester Resins

Polyester, the workhorse of the industry, accounts for about three-fourths of the thermosetting resins used in industry

and about 90% or more of the resins used in the reinforced plastic products (16-18). Because of the versatility of polyesters and their capability to be modified or tailored during their chemical construction, they have almost unlimited range of uses in nearly every type of applications which require good mechanical property, chemical and electrical, as well as dimensional stability, low cost and ease of handling.

Initially one can classify polyester resins into two major types :

1. The general purpose resin is a low-cost polyester, with good electrical, mechanical properties and reasonable good corrosion resistance. These resins also find wide use in reinforced plastic luggage, trays, boxes, furniture, automotive components, and boat hulls - all applications which do not require outstanding corrosion resistance. 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.

2. Special purpose polyesters are those resins which have been specially formulated to meet some particular end-use requirement with respect to performance. Generally, these polyesters can be divided into five major classes as follows (19) :

- 2.1 Flexible resins and semi-rigid resins : These resins are tough resins, good impact resistance, high flexural strength and low flexural modulus, which find wide use in machine covers and guards, safety helmets, boats, etc.

- 2.2 Light-stable and weather-resistant resins : These resins also find wide use in structural panels, skylighting and glazing - all applications which do require resistant to

weather and ultraviolet degradation.

2.3 Chemical-resistant resins : These resins have highest chemical resistance, excellent acid resistance and fair in alkalies. These resins also find wide use in corrosion resistant applications such as pipe, tanks, ducts and fume stacks.

2.4 Flame-resistant resins : These resins are rigid, self-extinguishing and also find wide use in building panels (interior), electrical components and fuel tanks.

2.5 Resins with high heat deflection temperature : These resins are rigid and can service up to 500°C, so major work is to be used in aircraft parts.

2.2 Other Materials Used in the Unsaturated Polyester Resins

1. Fillers

Fillers and pigments are added to molding resins to reduce shrinkage, minimize crazing, lower material costs, impart color or opacity, and improve surface finishing. Calcium carbonate, diatomaceous earths, and clays are commonly used as fillers. Noncompact materials such as colloidal silica, bentonite, mica platelets, or short-length fibers of asbestos or glass can be used with polyester resins to produce a flow characteristics known as thixotropy. The practical application of thixotropic agents is to permit the use of resin systems on vertical surfaces without excessive drain or run off.

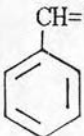
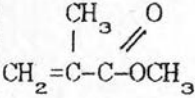
2. Crosslinking Agents

Styrene is the ideal monomer and the most commonly used monomer in polyester resin systems because it is abundantly available, low in cost, has good solvent characteristics and reacts readily with unsaturated polyester during the curing

reaction. The addition of styrene also has some disadvantages such as: fiber pattern is more difficult to hide. Adding styrene also tends to increase the exothermic temperature, thus the possibility of crazing in resin rich sections is increased. It has been proposed that the styrene-styrene linkage in the crosslinked polyester system is subjected to breakdown in much the same fashion as straight polystyrene. Higher concentration of styrene will adversely affect the strength properties (19-21).

Use of some methyl methacrylate (MMA) results in considerable improvement in the weathering characteristics of polyesters. However, when used by itself as the crosslinking agent, it has poor reactivity with unsaturated acids in the polyester chain leading to slow cure. MMA can also be used to improved the transparency characteristics of the finished laminate (22-24). Optimum glass retention is also obtained at a resin : styrene : MMA of ratio 60 : 20 : 20. Specifications of styrene and MMA were shown in Table 2.1.

Table 2.1 Specifications of styrene and methyl methacrylate

Crosslinking agent	Formula	MW (g/mole)	bp. (°C)	Primary characteristics
styrene	$\text{CH}=\text{CH}_2$ 	104	146	low cost, strength properties, good reactivity and compatibility with polyester resin
MMA	$\text{CH}_2=\text{C}-\text{C}-\text{OCH}_3$ 	100	101	weathering

3. Catalysts

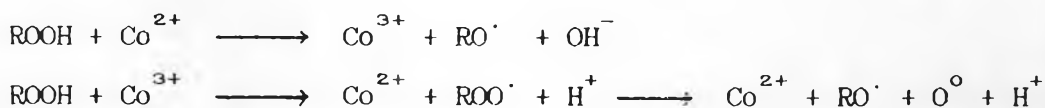
Organic peroxides are widely used to catalyze polyester resin system and to initiate the copolymerization reaction. Because most organic peroxides exhibit good solubility in styrene and do not release gaseous by-products on cure and some can be induced to decompose to release free radicals at lower temperature, they are preferred over the azo initiators (25). In addition, the use of organic peroxides facilitates control of the reaction (time of gelation and cure). The most common catalysts used are methyl ethyl ketone peroxide, benzoyl peroxide and cumene hydroperoxide.

4. Inhibitors

Inhibitors are added in polyester resins to enhance their storage stability. Hydroquinone is commonly used as inhibitor for preventing polymerization until it is consumed by some of the free radicals from the catalyst.

5. Accelerators or promoters

Accelerators are usually added to polyester resin to initiate or speed the gelling at room temperature by accelerating the decomposition of the catalyst to free radicals (24). Commonly used accelerators are cobalt naphthenate, diethyl aniline and dimethyl aniline. Ketone peroxides and several hydroperoxides react readily in the presence of several metal salts, especially those of cobalt, by an oxidation-reduction reaction (25-27) :



An excess of the cobalt compound often results in a reduction in the reactivity. However, if a resin is cured in the presence of air, an excess of cobalt compound may prevent the cure inhibition caused by the oxygen in the air (24).

6. Mold release

Zinc stearate or paraffin wax are added to the resin mix in order to facilitate the removal of the part from the mold after completion of the curing cycle.

7. Other additives

Other materials may be added to the resin mix either by the resin supplier or the molder to impart special performance. Examples of these substances are ultraviolet absorbers which are added to resin mixes subjected to exposure to ultraviolet rays in natural sunlight or fluorescent light. Flameproofing substances, such as antimony trioxide or chlorinated waxes, are added to achieve a fire-retardant property.

2.3 Crosslinking Mechanism

After addition of the vinyl monomer, crosslinking begins on introducing a catalyst. The curing process starts as soon as the catalyst breaks down into active free radicals. This is most frequently accomplished by heating the system to the temperature at which the catalyst decomposes at a fairly rapid rate. It can also be accomplished at lower temperature by the use of accelerators or promoters which serve to decompose the catalyst to free radicals more rapidly than thermal decomposition. Crosslinking occurs via free radical polymerization (3,16,17). In the common styrenated polyester, three types of radicals are

formed : those of fumarate, of styrene, and of the catalyst as shown in Figure 2.1. In order to obtain a high-quality product, it is desirable that the styrene and fumarate radicals react either alternatively or in the proportion existing before crosslinking occurs (24). This so-called "gelation time" is defined as the period between the addition of the accelerator to the liquid resin and the appearance of a soft intractable gel, where 1-2% of the polymer has been crosslinked. The gelation time should be controlled by varying the accelerator content and not be altering the amount of catalyst. Crosslinking proceeds rapidly and establishes the structure of the three dimensional network in which polymers and monomer are immobile. As crosslinking and copolymer formation accelerate, heat is generated (exothermic reaction) and a rigid plastic forms. This so-called "curing time (hardening time)" is defined as the time from the setting of the resin to the point when the resin is hard enough to allow the molding or laminate to be withdrawn from the mold. As the mass begins to heat up, the hardness increases rapidly and other physical characteristics develop quickly as well. The crosslinkage network is 95% complete after the heat dissipates from the mass ; further heating (postcure) at higher temperature drives the reaction to completion. This so-called "maturing time" ; it may be hours, several days or even weeks depending on the resin and curing system, and is the time taken for the molding or laminate to postcure to acquire its full hardness, chemical resistance and stability. Maturing will take place at room temperature or it can be accelerated by postcure (28). Without postcure, the plastic exhibits a distinct styrene odor, which may persist for weeks.

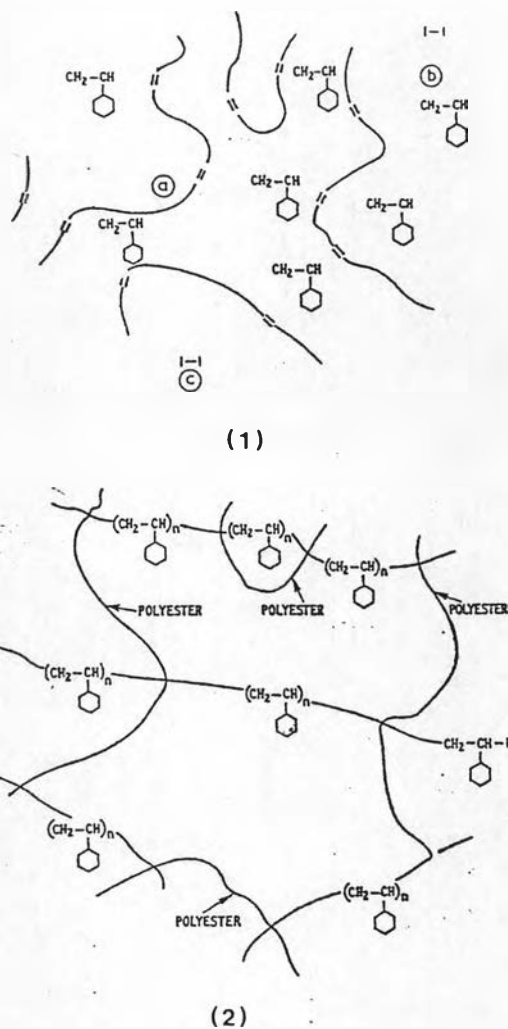


Figure 2.1 The nature of cured polyester resins.

- (1) Structures present in polyester resin ready for laminating :
 - (a) low molecular weight unsaturated polyester molecules
 - (b) reactive diluent (styrene) molecules
 - (c) initiator (catalyst) molecules
- (2) Structures present in cured polyester resin. Crosslinking via an addition copolymerization reaction. The value of $n \sim 2-3$ on average in general purpose resins.

2.4 Glass Fiber

Glass has been one of man's most useful materials. Its use dates back as far as 2500 B.C. in its most familiar forms such as windows, dishes, etc. It is usually used by not regard to structural which brittleness and easy fracture. Although it is strong in compression, its tensile strength in bulk form is only on the order 10,000 to 20,000 psi while glass in fiber form has a virgin tensile strength of 100,000 to 800,000 psi. Because of their high strength, high performance capabilities, glass fibers are currently used as reinforcing agents in structure composites such as rocket, motor cases and aircraft parts. Today glass fibers are produced in a variety of forms by several major corporations.

2.4.1 Glass Compositions

Glass is an amorphous material that is neither solid nor liquids ; it does not posses either the crystalline structure of solids or the flow characteristics of liquids. Chemically, glass is composed primarily of a silica (SiO_2) backbone in the form of an $(-\text{SiO}_4-)_n$ polymer. The three dimensional network of silica tetrahedra is the basis of the various and unusual properties of glass. By addition of modifying ingredients such as metallic oxides which may become part of the silica network or disrupt it. The properties of the glass can be varied and adjusted to various levels of performance (20) as shown in Table 2.2.

Table 2.2 Typical properties of E, S, and D glass

Property	E Glass	S Glass	D Glass
Physical Properties*			
Specific gravity	2.54	2.49	2.16
Mechanical Properties*			
Virgin tensile strength at 72°F	500,000 psi	665,000 psi	350,000 psi
Yield strength at 1000°F	120,000 psi	275,000 psi	
Ultimate strength at 1000°F	250,000 psi	350,000 psi	
Modulus of elasticity at 72°F	10,500,000 psi	12,400,000 psi	7,500,000 psi
Modulus of elasticity at 72°F (after heat compaction)	12,400,000 psi	13,500,000 psi	
Modulus of elasticity at 1000°F (after heat compaction)	11,800,000 psi	12,900,000 psi	
Elastic elongation at 72°F	4.8%	5.4%	4.7%
Thermal Properties**			
Coefficient of thermal expansion	2.8 in/in/°F × 10 ⁻⁶	1.6 in/in/°F × 10 ⁻⁶	1.7 in/in/°F × 10 ⁻⁶
Specific heat at 75°F	0.192	0.176	0.175
Softening point	1,555°F	1,778°F	1,420
Strain point	1,140°F	1,400°F	890
Annealing point	1,215°F	1,490°F	970
Electrical Properties**			
Dielectric constant at 72°F, 10 ⁶ Hz	5.80	4.53	3.56
Dielectric constant at 72°F, 10 ¹⁰ Hz	6.13	5.21	4.00
Loss tangent at 72°F, 10 ⁶ Hz	0.001	0.002	0.0005
Loss tangent at 72°F, 10 ¹⁰ Hz	0.0039	0.0068	0.0026
Acoustical Properties*			
Velocity of sound (calculated)	17,500 ft/sec	19,200 ft/sec	16,000 ft/sec
Velocity of sound (measured)	18,000 ft/sec		
Optical Properties**			
Index of refraction	1.547	1.523	1.47

* Properties measured on glass fibers.

** Properties measured on bulk glass.

As compared to the other glasses, E glass is found to be more satisfactory chemically and draws well into strong fibers. This glass was found adaptable and highly effective in a great variety of processes and products ranging from decorative to structural applications. E glass does not have a single composition but may vary in composition within the range given in Table 2.3. Changes within the indicated ranges do not significantly influence its electrical or mechanical properties. Each glass producer can therefore tailor the composition to his raw material economics and production processes.

Table 2.3 Compositions of E glass

Composition	Range (% by weight)
SiO ₂	52 - 56
Al ₂ O ₃	12 - 16
CaO	16 - 25
MgO	0 - 6
B ₂ O ₃	8 - 13
Na ₂ O and K ₂ O	0 - 3
TiO ₂	0 - 0.4
Fe ₂ O ₃	0.05 - 0.4
F ₂	0 - 0.5

2.4.2 Glass Fiber Forms

Glass fibers are supplied in several basic forms. These forms allow for flexibility in cost, strength and choice of process (20).

1. Roving

Roving is a collection of parallel, continuous strands or filaments. Conventional rovings are produced by winding together the number of single strands necessary to achieve the required yield. Single-strand roving, as the name implies, consists of a single strand of glass fiber filaments.

2. Woven roving

Many rovings are woven into a heavy, coarse weave fabric for applications that require rapid thickness build-up over large areas. This characteristic is especially useful in the manufacture of various marine products and many types of tooling.

3. Mats

Mats are made from strands evenly distributed in a random pattern. Their basic application is to insure maximum uniformity in the finished laminate. Strands are held together by soluble or insoluble adhesive resinous binders or mechanically held in place by "needling". They have lower cost than wovens. They can be divided into three types :

a. chopped strand mat is a nonwoven material where the glassfiber strands are chopped into 1-2 inch, evenly distributed at random onto a horizontal plane and bound together with an appropriate chemical binder.

b. Continuous strand mat consists of multiple layers of unchopped continuous strands of glass fibers deposited and interlocked in a spiral fashion. This mat is open and springy, but due to its mechanical interlocking does not require much binder for adequate handling strength.

c. Surfacing Mat is a thin highly porous mat from monofilaments of C glass, arranged in a veil-like pattern. It has little reinforcing strength but serves to cover irregularities by drawing a slight excess of resin to the surface next to mold.

4. Chopped strand

Chopped strands are produced by cutting continuous-filament strands or spun strands. Chopped continuous-filament strands are used when uniform standard lengths are desired from 1/4 inch to over 3 inch, while chopped strands made from roving are not uniform in length and lengths will range from 1/4 to 1/2 inch.

5. Milled fibers

Continuous glass fiber strands can be hammer-milled into very short fiber length, generally 1/64 to 1/4 inch. They are used as inert fillers or flow control agents for a variety of thermoplastic and thermosetting resins. A variety of sizing agent on its surface to provide compatibility with polymer. They are generally used to provide anticrazing, body and dimensional stability to adhesives and patching compounds.

6. Yarns

A yarn is an assemblage of fibers or strands which is suitable for use in weaving into textile materials. The continuous, individual strand as it comes from the bushing represents the simplest form of the textile fiberglass yarn and is referred to as a "simple yarn". In order for this yarn to be properly and efficiently utilized in a weaving operation, additional strand integrity is introduced by twisting it slightly to usually less than 1 turn/inch (40 turns/m). However, heavier yarn can be produced by combining single strands via twisting and plying operations. Typically, this simply involves twisting two or more single strands together and subsequently plying. The twisting and plying operations permit the yarn strength, diameter and flexibility may be varied, and are

important step in producing a variety of fabrics which composite fabricators require.

7. Woven fabrics

A fabric is a material constructed or interlaced yarns, fibers or filaments ; usually of planar structure, and they are manufactured by interlacing lengthwise and crosswise by yarns on conventional weaving looms.

2.4.3 Surface Treatments

An important requirement of glass fiber reinforced plastic is good adhesion between the glass and the plastic matrix. If adhesion is weak, stresses will not be effectively transferred from fiber to fiber, and complete reinforcing action of the fibers will not be realized. Good adhesion is obtained by the application of coupling agents which react with or bond strongly to the glass surface and to the plastic matrix. Coupling agents are applied to the fibers as a chemical surface treatment in the form of a "size" or a "finish".

There are two general types of sizes: compatible sizes used for roving, mat and chopped strand, and temporary sizes which are used for production yarns and fabrics. A compatible size typically contains a coupling agent, a lubricant and a film former. Temporary sizes typically contain such ingredients as dextrinized starch gum, hydrogenated vegetable oil, nonionic emulsifying agent, cationic lubricant gelatin and poly(vinyl alcohol). They are commonly called starch-oil sizes and they serve to protect fibers and hold strands together during handling and weaving.

The presence of a starch-oil size on fabric is satisfactory for some applications but it is not compatible with some resins, does not wet-out well, and gives poor laminate wet strength retention. Consequently, it is usually removed and a finish is then applied. Removal is accomplished by burning-off. The burning-off process is known as heat cleaning (29,30). It may be batch or continuous. The batch-heat process is a carefully controlled heat cycle reaching a temperature of about 600-700°C. This slowly burns off the organic material and produces a clean glass fabric with a slightly alkaline surface. It usually retains only about 40-60% of its original strength which is its major disadvantage to easily damaged, but the heat process is simple, inexpensive and uniformity can be maintained from batch to batch. A continuous desizing process involves passing fabric through a muffle furnace at about 1200°F (650°C) with a treatment time ranging from 2-20 sec. Desizing by heat treatment also relieves internal stresses and induces crimp or weave set. Immediately upon cleaning, the fiber-fabric should always be given a finish to protect the surface. Sometimes starch-oil sized fabric is heated only enough to burn off part of the sizing and the remainder is caramelized. This fabric has a tan color and is specially suited for melamine resins.

Chemical cleaning to remove the size, although it is used very little in the industry, can involve using detergents, enzymes or sequestering agents. Depending on the nature of the cleaning bath, temperatures up to 100°C, are employed. The chemically cleaned fabric usually retains as much as 0.10% organic material which is considered an acceptable level. This process is expensive and does not heat the fabric, but strength losses are much less. Combinations of these two

cleaning processes may be found; for example, a trichloroethylene bath followed by a mild heat cleaning treatment, or a pretreatment with KNO_3 , RbNO_3 , or CsNO_3 followed by heating at 1000-1200°F for 1 hr appears very promising.

2.4.4 Sizing Agents Compositions

The sizing agent was composed of six compositions as follows :

1. Film-forming agents

The film-forming agents used in sizing agents are members of a large group of polymeric substances that may have a natural origin or may have been produced synthetically. The polymers used as sizes are either water-soluble or may be easily solubilized by the addition of a mild alkali, such as ammonia or sodium bicarbonate. They possess only moderate viscosity to enable some penetration of glass fibers to take place (31-32) :

- Poly(vinyl acetate) : used for general purpose
- Epoxy and/or Polyester resins : used for high performance
- Polyurethane : used for thermoplastics

The function of the film-forming agents are to hold the filaments together in the strand, not only that when the silane forms a monolayer on the glass, but a portion of the film-forming reacts with the organic segments of the silane and the remainder of the film-former reacts with the resin used in preparing the final composite (29).

2. Coupling agents

The coupling agents, generally used, consist of an inorganic component reacting with the glass surface and an organic component reacting or at least having good compatibility with the polymers matrix. The coupling agents between the silicates or silica, containing the silanol (Si-OH) groups, and the polymers to be reinforced can be roughly subdivided as follows (33,34,38,39) :

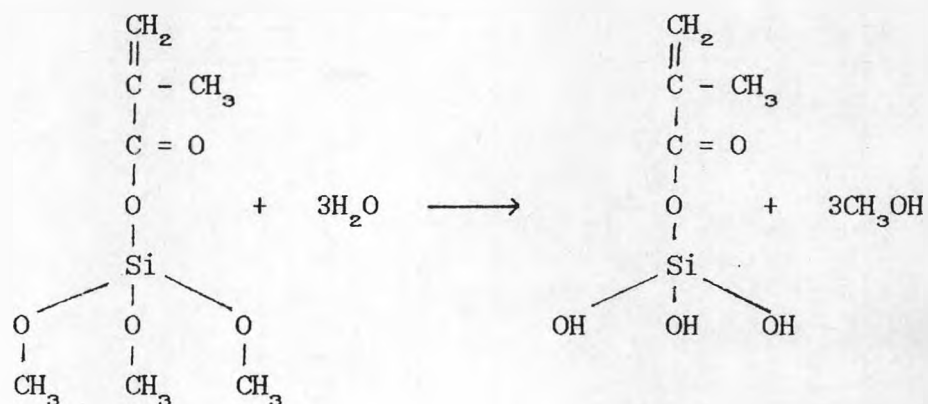
2.1 Chrome complexes

Chrome complexes, such as Cavco and Volan, were the first among the coupling agents but today they are been largely replaced by silanes.

2.2 Silanes

The silanes normally used are tetrafunctional molecules with a general formula $YR-Si(OR)_3$. They usually contain three methoxy or ethoxy groups at the central silicon atom, which are converted by hydrolysis into $Si-(OH)_3$ groups. These $Si-(OH)_3$ groups can bond with the silicate or silica surfaces by chemisorption to form Si-O-Si ; siloxane linkage. The fourth group Y, such as vinyl, epoxy, amine, etc., bound to the Si atom can form a primary valence bond to heat-curable plastics and increases thereby the adhesion between plastics matrix and reinforcement ; in the case of thermoplastics, this generally takes place by purely physical forces (adhesion) (1). As can be seen in Figure 2.2.

step 1 - Preparation of the hydrolyzed silane.



(γ -methacryloxypropyl)trimethoxysilane

silanol group

Step 2 - Application of the hydrolyzed silane to a glass fibre.

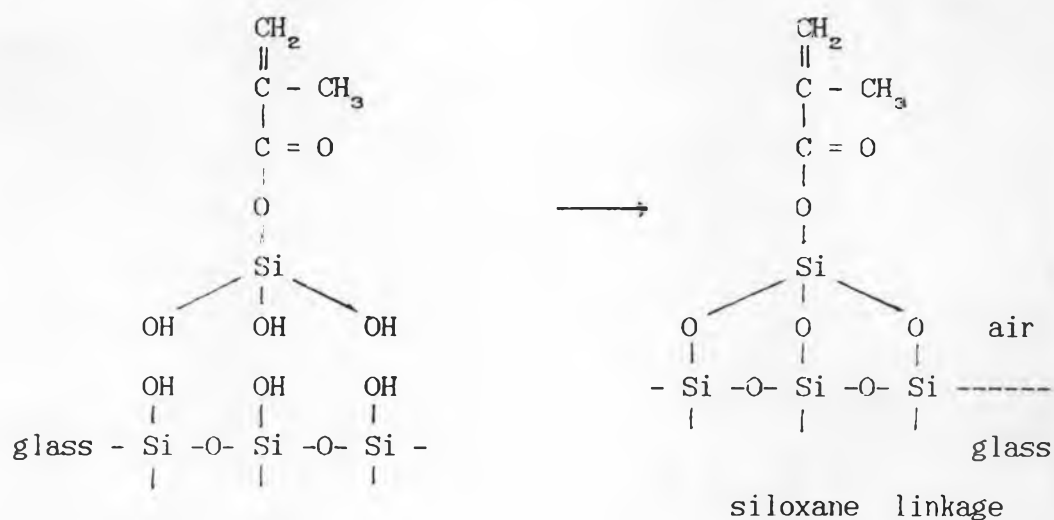


Figure 2.2 Proposed reaction of coupling agent with glass surface

The methacryloxy group represented in Figure 2.2 crosslinked with unsaturated polyesters by a copolymerization reaction between the double bond in the

methacryloxy group and double bond in unsaturated polyesters by styrene and/or methyl methacrylate (3E) to form fiberglass products as seen from Figure 2.3.

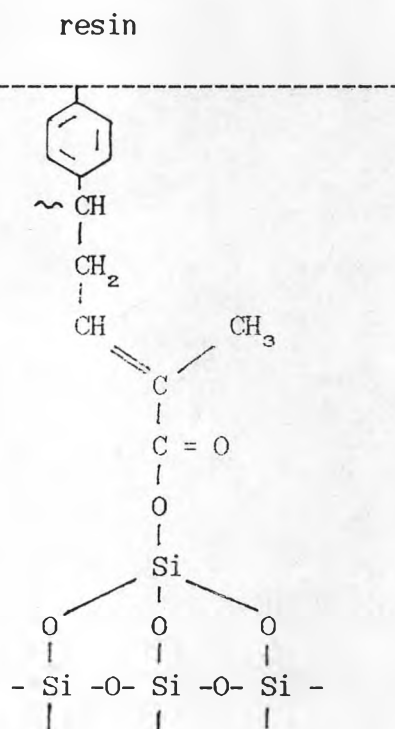


Figure 2.3 Chemical bonding to polyester resin of glass fiber treated with silane

2.3 Titanates

Like silanes, titanates are tetrafunctional compounds. Their mode of action is similar to that of the silanes. Titanates have not yet been able to compete commercially with the silanes.

2.4 Other coupling agents

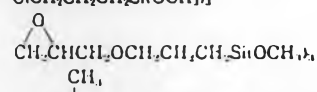
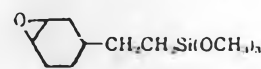
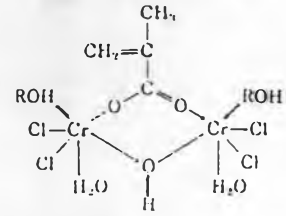
Many of the coupling agents mentioned in the patent literature are based on esters. Their mode of action lies solely in better dispersion or wetting of fillers or reinforcements with the polymer matrix resulting in the



improvement of the mechanical properties.

The various unsaturated compounds of silicon and other elements (36) were first tested as coupling agents as shown in Table 2.4.

Table 2.4 Representative commercial coupling agents

Functional group	Chemical structure	Name
vinyl	$\text{CH}_2=\text{CHSi}(\text{OCH}_3)_3$	vinyltrimethoxysilane
chloropropyl	$\text{ClCH}_2\text{CH}_2\text{CH}_2\text{Si}(\text{OCH}_3)_3$	chloropropyltrimethoxysilane
epoxy		3-glycidoxypropyltrimethoxysilane
methacrylate	$\text{CH}_2=\text{C}(\text{CH}_3)\text{COOCH}_2\text{CH}_2\text{CH}_2\text{Si}(\text{OCH}_3)_3$	3-methacryloxypropyltrimethoxysilane
primary amine	$\text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{Si}(\text{OCH}_3)_3$	3-aminopropyltriethoxysilane
diamine	$\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{CH}_2\text{Si}(\text{OCH}_3)_3$	N-2-aminoethyl-3-aminopropyltrimethoxysilane
mercapto	$\text{HSCH}_2\text{CH}_2\text{CH}_2\text{Si}(\text{OCH}_3)_3$	3-mercaptopropyltrimethoxysilane
cationic styryl	$\text{CH}_2=\text{CHC}_6\text{H}_4\text{CH}_2\text{NH}(\text{CH}_2)_2\text{NH}(\text{CH}_2)_2\text{Si}(\text{OCH}_3)_3 \cdot \text{HCl}$	3-(N-styrylmethyl-2-aminoethylamino)propyltriethoxysilane hydrochloride
cycloaliphatic epoxide		β -(3,4-epoxycyclohexyl)ethyltrimethoxysilane
chrome complex		Vulan
titanate	$(\text{CH}_2=\text{C}(\text{CH}_3)\text{COO})_3\text{TiOCH}(\text{CH}_3)_2$	tris(methacryloisopropyl) titanate

3. Lubricants

The main function of the lubricant is to protect fibers from glass-against-glass abrasion. Furthermore it promotes rapid wetting of the strand of glass fibers by the resin to make glass fibers attach with plastic, so that quantity of air bubbles trapped in products decreases.

4. Antistatic Agents

Because glass fibers tend to be statically charged, it is frequently desirable, and is indispensable in some cases, to use an antistatic agent during the manufacturing or cutting steps. Antistatic agents can function either by reducing the charge generation or by increasing the rate of charge dissipation or by both mechanisms. The mechanism on the charge reduction or generation is not completely understood, however, it seems likely that the presence of the antistatic agent at the interface will reduce the intimacy of contact between surfaces and therefore the net charge transfer. Evidently most lubricants function this way and it is often desirable to combine antistatic action with lubrication (37). If an antistatic agent is employed, it is possible to distribute the glass fibers uniformly in the lamination or molding composition. However, if the antistatic agent is not correctly chosen, the fibers are caused to repel from one another by static charges and a non-uniform distribution of glass fibers occurs in the composition (6,7).

5. pH Controller

Acid or base is added to the sizing agents to aid in the hydrolysis of the $\text{Si}(\text{OR})_3$ groups to $\text{Si}(\text{OH})_3$ groups. The surface is then dried, usually at temperature over 100°C , to promote the condensation reactions and to remove excess water (32). Yet a basic characteristic of glass structures is that this network in silicate glasses is irregular and aperiodic. From that, glass may be viewed as having interstices in it. These holes are filled with cations which have been relatively large ionic radii and small charges and these cations which

specifically modify the properties of the glass. The cations may be divided into two types : (1) those forming the network, such as silicon and boron and (2) those found in the interstices where they modify the final properties such as sodium, calcium and others. Some of the elements used in glass are amphoteric and may enter the network or be found in the interstices. For example, one thinks of -Si-O-Si- linkages in glass, but in multicomponent compositions containing sodium, -Si-O-Na is formed. The presence of such monovalent cations in silica glass causes a breakage of the solid structure increasing fusibility, decreasing viscosity, and reducing chemical and thermal stability (29). The pH near the fiber surface will be increased by sodium ion extraction. Furthermore, acetic acid may be used to promote these reactions. Since acetic acid can also extract calcium and aluminium from the fibre, therefore condensation reaction of silanol groups and glass proceeds better and faster (32).

6. Water

Because water is the main constituent of size formulations, it should be as free as possible from calcium, magnesium, and iron salts, as well as from organic matter. Hard water can be successfully softened by the well known technique of ion exchange. Soft water is the most satisfactory for use in the preparation of size solutions (31). The function of water is to hydrolyze silane compounds as mentioned above.

2.5 Fabrication Processes

Many processes are available to produce the desired combination of design performance and economic of glass fiber

composites. Each process has its own usefulness that can be considered broadly in two classes: open mold processes and close mold processes (18,20).

Open molds are single cavity molds, either male or female, used in processes which require little or no pressure. They include hand lay-up, spray-up, vaccum bag, pressure bag, autoclave, filament winding, centrifugal casting, and continuous pultrusion. The principal characteristics of the molded object are :

1. Low investment due to the need for only one mold and lack of other equipment. Mold materials can be plaster or reinforced plastics (absence of high pressure).
2. Relatively high labor cost.
3. Speedy mold production and easy design changing. Complex shapes and large objects may be formed.
4. Relatively slow production of parts.

Closed molds are two-piece male and female molds, usually made of metal. They are match-die molding, injection molding, and continuous laminating. The principal characteristics of the molded object are :

1. Controlled surface finishing (two side finishing).
2. Efficient use of raw materials.
3. Excellent reproduction of detail from part to part (highest production rate).
4. Highest equipment and mold cost.



2.6 Hand Lay-up

Hand lay-up or contact molding is the oldest and simplest glass fiber reinforced plastic forming process (19). A cavity or positive shaped mold is made of easily worked materials, such as wood, plaster or reinforced plastics. In fabrication the glass fibers and resin are placed in or on the mold and entrapped air is removed with rollers. Layers of glass and resin are added to build up to the desired thickness. If a high quality surface is desired, a gel coat (pigmented surfacing resin) is applied on the mold prior to lay-up. The lay-up normally cures at room temperature but heat may be used to accelerate cure. The exposed side is generally rough but it can be made smoother by wiping on cellophane or other suitable releasing films such as "Mylar" or poly(vinyl alcohol). Resins used in hand lay-up are usually polyesters or epoxies.

2.7 Glass Fiber Reinforced Plastics Engineering Features (38)

1. **High strength to weight ratio** : GRP have a higher strength to weight ratio than either mild steel or aluminum which are very widely used as materials of construction.

2. **Wide performance range** : It is possible, by the proper choice and proportion of the glass fiber reinforcements and matrix materials to obtain a wide range of performance characteristics.

3. **Low manufacturing cost** : Cost of making reinforced plastics is relatively lower than cost in fabricating out of other construction materials. By selecting the most suitable molding method, it is possible for a unit to produce its products economically in large or small numbers.

4. **Superior styling :** The ease with which double curvature could be introduced in molding gives the design greater freedom to incorporate superior styling. Other standard materials of construction do not easily lend themselves to this possibility, at an economical cost.

5. **High resistance to impact :** Impact loads which would nearly buckle or distort a metal component have little or no effect on glass fiber reinforced plastics. When there is rupture due to a high level of impact, the damage is localized and easily repairable.

6. **Resistance to corrosion :** By the proper choice of the resin material, it is possible to get a high corrosion resistance to a wide range of chemicals.

7. **Good electrical characteristics :** By the proper choice of the matrix materials, it is possible to obtain excellent electrical properties with glass fiber reinforced plastics.

8. **Heat and sound insulation :** Glass fiber reinforced plastics have a thermal conductivity and good sound deadening properties.