Opportunities for Thermoset Resins in the Composites Industry

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Types of Thermoset Resins and Its Applications for the Composites Industry

The composites industry uses significant amount of thermoset resins to fabricate parts and products for the automotive, aerospace, construction, sporting goods, electrical/electronics, wind energy and other markets. The end product market for the composites industry is about $60 billion. Polyester, epoxy, vinyl ester, polyurethane, phenolic and a variety of other resins are used with reinforcements such as glass, carbon and aramid to make these parts. While, exploring the usages of thermoset resins in the composite industry, it can broadly be categorized into six resin types:

- Polyester resin
- Epoxy resin
- Vinyl ester resin
- Phenolic
- Polyurethane
- High temperature resins such as Cyanate Ester and BMI

Polyester resin dominates the thermoset resin market, with 66 percent market share. Epoxies hold the second position with 23% thermoset resin market share. Rest 11% of the share is held by other thermoset resins.

Global Thermoset Resin market share in composites industry 2007

![Pie chart showing market share distribution]

Fig. 1 Global thermoset resin market share distribution in composite industry (million lbs).

Polyester resins are 'unsaturated polyesters' which are widely used in the composite industry holding 66% share. Construction is the largest market for the polyester resin followed by pipe and tank and transportation in 2007.

There are two principle types of polyester resin used as standard laminating systems in the composites industry. Orthophthalic polyester resin is the standard economic resin used by many whereas Isophthalic polyester resin is the preferred material in industries such as marine where its superior water resistance is desirable.

Because of their premium variety of mechanical attributes, corrosion resistance and low weight, polyester resins are frequently used in a host of applications where it proves to be advantageous. While building of the polymer chains, polyesters can easily be customized or modified. The
foremost advantage of these resins is a balance of properties (including mechanical, chemical and electrical) dimensional stability, low cost, easy processing and handling.

For manufacturing polyester concrete, clear casting resins, coatings, body fillers, buttons etc. unreinforced versions of polyester resins are most commonly used. However, for building and sanitary (bath tub, pipe, tank, cooling tower, ladder, door, window), automotive parts (deck lid, doors, hoods), electrical parts (housing, fuse box etc.), boat parts (boat hulls, decks, etc.) polyester resins with glass fibers are used (composite materials). The construction industry is the largest user of polyester resin materials with almost 1/3rd of total polyester resin shipments in the year 2007. The pipe and tank industry is the second largest user of polyester resin materials in the world followed by marine, transportation, and E&E.

**Vinylester resins** contribute around 5% of the share of total resins used in the composites industry. Vinylester resins are similar in their molecular structure to polyesters, but differ primarily in the location of their reactive sites, these being positioned only at the ends of the molecular chains. As the whole length of the molecular chain is available to absorb shock loadings, this makes vinylester resins tougher and more resilient than polyesters. The vinylester molecule also features fewer ester groups. These ester groups are susceptible to water degradation by hydrolysis which means that vinylesters exhibit better resistance to water and many other chemicals than their polyester counterparts, and are frequently found in applications such as in piping and chemical storage tanks. With the reduced number of ester groups in a vinylester when compared to polyester, the resin is less prone to damage by hydrolysis.

Applications: Main markets for vinyl ester resins are in corrosion market such as in fiberglass tank for chemical industry, grating, and FRP pipes, and in boat applications.

**Epoxy resins** contribute 23% of the share of total resins used in the composites industry. Like polyester resin, epoxy resins are used in FRP and non-FRP applications. The term 'epoxy' refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. The simplest epoxy is a three-member ring structure known by the term 'alpha-epoxy' or '1,2-epoxy'. Epoxies differ from polyester resins in that they are cured by a 'hardener' rather than a catalyst. The hardener, often an amine, is used to cure the epoxy by an 'addition reaction' where both materials take place in the chemical reaction.

The applications for epoxy resin are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiberglass reinforcements. Epoxies are notably being used in many applications. For heavy duty service on metal substrates (rapid dry protective coating applications), two part waterborne epoxy coatings are used which are energy economic. The coating dries swiftly providing a strong, UV resistant, protective coating with good mar and abrasion resistance. It is also used in corrosion protection of steel pipes and fittings used in the oil and gas industry. Although, they are more expensive than polyester resins and vinyl ester resins, yet generally produce stronger and more temperature-resistant composite parts. Major applications of epoxy resin for the composites industry are: electronics market such as in PCB (printed circuit board) for computers, wind energy, pipes, tanks, aircraft parts, sporting goods and industrial applications.

**Phenolics** meet FAA and JAR requirements for low smoke and toxicity. They are used for aircraft interiors, stow bins and galley walls as well as in other commercial markets that require low-cost, flame resistant and low smoke products. Their cure characteristics are different than other thermosetting resins such as epoxies due to the fact that it generates water during cure reaction. The phenolic products are usually red, blue, brown or black. To get light color products, urea formaldehyde and melamine formaldehyde are used.

Electrical circuits and systems, passenger rail market, aerospace market, and fire retardant beams and shapes are few major applications of phenolics. Phenolic products have
demonstrated their capabilities, where high temperature resistance, electrical properties, wear resistance, chemical resistance and dimensional stability are essential.

Phenolics are used for various composite manufacturing processes such as filament winding, RTM, injection molding and compression molding. Phenolics provide easy process ability, tight tolerances, reduced machining and high strength. Because of their high temperature resistance, phenolics are used in exhaust components, missile parts, manifold spacers, commutators, and disc brakes.

**Polyurethane** can be a thermosetting or thermoplastic resin depending upon the functionality of the selected polyols. The thermoplastic based polyurethane contains linear molecules whereas thermoset based resin contains cross-linked molecules. A wide range of stiffness, hardness, and densities is covered by Polyurethane formulations. In automobiles industry, polyurethanes are widely used for the manufacture of seats, headrests, armrests, headliners, dashboards and instrument panels. In construction industry, polyurethanes are used in utility poles, FRP doors and other applications. Because of its advantageous water resistance, Polyurethane is also used as a good adhesive, especially as woodworking glue.

Thousands of product manufacturers use composite materials to make their products and there are hundreds of material suppliers in the composites industry to meet various application needs. In the marine industry alone, there are more than 1,000 boat builders in the world who utilize thermoset resins for making boats. There are many types of thermoset resins used in the composites industry to meet various application needs as discussed earlier. Below mentioned table describes major market players US thermoset resin industry with their application type.

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**Price and Performance Analysis**

The price of a resin depends upon several factors such as volume, quality, customer service, and more. Even though there is a wide variation in formulations, and thus prices, the changes in resin prices closely follow behavioral trends in some base resin prices. For example, if ortho polyester resin prices jumped 50% in the last 2 years then most of the formulated resin prices in ortho resin category have also increased approximately 50% in last 2 years. In the last 2 years, prices of many resins and metals increased significantly due to increase in energy cost as well as oil cost.

The overall attribute analysis of the thermoset resins shows that epoxies have largest price variations. The mechanical properties of epoxies are also highest followed by vinyl ester and polyester resins. Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which has lead to their almost exclusive use in aircraft components. Epoxy resin provides highest toughness and strain to failure as shown in following figure.
In the year 2007, the prices for medium volume quantities of above mentioned thermoset resins varied between $1.00 / lb to $3.00 /lb for base resins. Formulated resins cost more than base resins. Formulated resins are made using base resin and then adding various types of additives in the base resin to increase various processing and performance characteristics such as UV resistance, toughness, viscosity, etc. Formulated epoxy resin ranges in price from $2.20 / lb to $4.00 / lb for marine and wind energy applications whereas for aerospace applications, it is generally in the range of $4 - $15 / lb. Similar to epoxy resin, polyurethane (PU) resin comes in both base and formulated form. The base PU resin comes at $1.50 - $2.00/ lb depending on UL
rating, UV stability and other performance and physical property characteristics. Because of the relationship between competing materials and composites, where one material can be used as a replacement for another should the price become attractive enough, few competing raw materials are compared in following figure.

Fig. 4 Cost comparison for metals and composites based on weight and strength

Following observations can be made based on price analysis on raw material costs (not end product costs, which includes labor, energy and other variable costs) as reported in Lucintel 2007 report titled “Composites Materials Price Trends, Forecast and Analysis”.

1. Based on raw materials cost of metals and composites on weight basis, cold rolled steel is least expensive followed by glass / polyester material. Based on weight basis, stainless steel is 214% more expensive than glass / polyester composites. Aluminum is about 173% more expensive than glass / polyester composites. If aluminum extrusions are compared with pultruded bars, then prices are comparable.

2. Based on strength basis, glass / polyester as well as carbon / epoxy composites are highly competitive and provide significant savings as compared to aluminum and stainless steel. Aluminum costs $23 per unit strength as compared to glass / polyester composites, which costs only $1.20 per unit strength. Stainless steel costs $48 per unit strength and carbon / epoxy costs $8.34 per unit strength. Pultruded bars cost $3.20 per strength. This parameter is most critical in applications where primary concerns are for high strength and low weight.

3. Based on cost per unit modulus, stainless steel, aluminum and carbon/epoxy prices are comparable. Based on cost per unit modulus, glass / polyester composites provide 40% - 50% raw material cost savings as compared to aluminum and steel. When glass/polyester pultruded bars are compared with aluminum extrusions then, aluminum is 50% more cost effective.

In above analysis, price and property comparisons are made based on raw material costs. In fact, cost competitiveness of end products should be performed to create better business case. If end products are bars / tubes, then pultruded products should be compared above with steel and aluminum bars / tubes.

Fiberglass composites offer high specific stiffness (stiffness to density ratio) and strength, enabling these parts to be lighter than their counterparts, typically in the range of a 3 to 5 time improvement over that of steel and aluminum alloys. Due to this, automobiles move faster with better fuel efficiency. FRP composites offer high corrosion resistance. Iron and Aluminum corrode
in the presence of water and air, requiring special coatings and alloys. Since the outer surface of glass fiber composite materials is formed by plastics, corrosion and chemical resistance is very high. This is one of the major reasons for their use in marine and offshore industries.

**Market Opportunities**

In the global composites industry, thermoset composites dominate the market with 76.5% share (11,622 Million lbs) of total volumes while, thermoplastic composites holds the smaller chunk being at 23.5% (3577 Million lbs).

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Fig. 5 Amount of thermoset and thermoplastic composites shipment (million lbs) in 2007.

Continent-wise analysis of the global thermoset resin industry shows that Asia and rest of the world tops the list holding 40% of the total market share, followed by North America (36%) and Europe (24%) according to recent Lucintel report titled “Trends and Forecasts in Global Thermoset Resin Market 2008-2013”.

**Thermoset resin shipment ($ mil) by region in 2007 for the composites industry**

![Thermoset resin shipment by region in 2007](image)

Fig. 6 Thermoset resin shipment ($ mil) by region in 2007 for composites.

Depending on the application, thermoset resins for the composites market can be divided into the following categories: transportation, construction, pipe and tank, marine, recreation/consumer goods (sports, leisure and other), electrical/electronic, wind energy, aerospace and other. Based on Lucintel global thermoset resin market analysis, market breakdown based on $ shipment is shown below. Construction (26%) market is the largest user of thermoset resin followed by pipe and tank (20%), E&E (16%) and transportation (12%) and marine (8%). These five markets represent 84% of the market. Detailed description is given in the figure below.
Thermoset resin market distribution ($ mil) by segments for global composites industry in 2007

Wind Energy 2%
Aerospace

Consumer goods
7%

Electrical/Electronic
16%

Construction
26%

Pipe & Tank
20%

Marine
8%

Transportation FRP
12%

Others
7%

Fig. 7 Thermoset resin market distribution ($ mil) by segments for global composites industry in 2007.

Brief descriptions of these markets are listed below.

**Construction:**
The construction market can be divided into two major segments: residential and commercial as follows.
- Residential:
  Bathtubs, bathroom components and fixtures, decks, swimming pools, premanufactured homes, etc.
- Commercial / Infrastructure:
  Utility poles, bridges and bridge components, structural framing systems, pilings, gratings, railings, catwalks, and similar items.

**Pipe and Tank:**
Tanks (underground, above ground, and wrapping), fittings, pipes for sewer, and chemical plants, stacks, ducts and hoods. Strong sub-segments of this market are those geared toward oil and gas recovery.

**Electrical and Electronic (E & E) Segment:**
The electrical / electronic segment includes printed circuit boards (PCB), rods, tubes, molded parts, electrical housings, pole line hardware, substation equipment, electronic microwave antennas, electronic connections, and lighting.

**Transportation:**
The transportation market segment includes materials used in automotive (exterior and interior parts), trucks and truck trailers, mass transits (buses, trains, and subways), farm equipment, motorcycles, racing cars, etc. Transportation is the fourth largest market segment for the thermoset resin.

**Marine:**
The marine segment includes composite materials used for making all types of boats. Typically composites are used in making of hulls, decks, bulkheads, railings, hatch covers, tools and other items.
Consumer Products:
The consumer and recreational sector includes composite materials used in making toys and
sport items such as golf clubs, bicycles and tricycles, fishing rods, skis, tennis rackets,
snowmobiles, bowling equipment, mobile campers, etc. Also included in this category are service
trays, lampshades, totes and boxes, counter tops, seating, furniture and household appliances.

Aerospace / Defense:
This sector includes materials usage in commercial and military aircrafts. It is one of the smallest
segments of the composites industry and mostly utilizes advanced composites.

Wind Energy:
The business of generating electricity from the wind - designing and making turbines, erecting
and operating them - is growing fast and is set to expand as Europe and the rest of the world look
for cleaner and more sustainable ways to generate electricity. Unlike conventional power plants,
wind plants emit no air pollutants or greenhouse gases. Use of wind energy safeguards the
world’s natural resources, lowers the extent of environmental pollution, and also reduces the cost
of electricity. Wind energy is, therefore, the fastest growing energy technology in the world. The
Wind energy market includes wind turbine blades, hubs, nacelles, and other turbine components.

Other:
Other (Non-classifiable) includes all other applications such as medical equipment, industrial
machine housings and bases, tooling, safety hats, and other products that do not fit any of the
previous categories.

Market Trends
A brief comparison between CFRP and GFRP composites attributes and performance in
following figures:
In the last 15 years, Glass fiber reinforced plastics (GFRP) grew by 50%, however, the market for
Carbon fiber reinforced plastics (CFRP) grew at five times the rate of GFRP. In reinforcement
usages, Carbon fiber reinforced plastics are outpacing Glass fiber reinforced plastics (GFRP)
because of their superior attributes. On all the parameters, such as tensile strength, tensile
modulus, compressive strength, compressive modulus, flexural strength, flexural modulus,
fatigue resistance, thermal expansion CFRP comes up as better alternative than GFRP.
However, at few parameters such as low cost, fire resistance, thermal and electrical insulation
GFRP performs better.
Based on Lucintel industry analysis, some of the future growth opportunities for thermoset resins in the composites industry are (Lucintel 2008):
- FRP (fiber reinforced plastic) window in North America
- FRP door in North America
- FRP pipes in China, India, and other developing nations
- FRP tanks in China, India, and other developing nations
- Wind energy
- Aerospace applications

**Asia, the future of composites**
Asian players in the field of composites are growing in double digits, or faster than any other global player. The composites market in Asia and rest of the world accounts for 40% of the global thermoset resin market. Most composites application sectors (marine, transportation, consumer goods, aerospace, wind energy, pipes & tanks, construction, electronic equipment, etc.) are growing much faster in Asia-Pacific than anywhere else in the world. In the year 2007, China and India demonstrated the highest regional growth, along with the abovementioned global market segments.

China’s GDP has been growing at 9.8% per annum. Its industry output has been advancing at 15% per annum and will continue to sustain a strong growth into the next decade. Due to the rapid growth in the Chinese composites industry in the last 5 years, China has become the second largest market for composites in the world.

India is the fourth largest economy of the world and second biggest market place of the Asian region. The overall development of economy has come in handy for the Indian Composites Industry. Recently, India has signed a $100-million deal to sell composite materials to Israel for its future generation of mini Unmanned Aerial Vehicles (UAVs). The deal underlines that India is emerging as a leader as far as composite materials are concerned.

For a sustainable growth, the composites industry, looks for a holistic development for which technologies advancement, improved mechanised processes, processing machinery, support services like design, rapid product development, quality assurance, market research etc. are
needed. Over the years, composites industry has matured and its production process has been able to highly customize as per the application needs. Reinforced thermosets are replacing traditional materials from many end-user markets due to their numerous advantages of high strength, light weight, flexibility in design, parts consolidation, high dielectric strength, dimensional stability, corrosion resistance, and low tooling costs and the trend would continue in future.

References:
Lucintel (2007) report on “Composites Materials Price Trends, Forecast and Analysis”