International Journal of Composite Materials and Matrices
Vol. 3: Issue 1
www.journalspub.com

Market Assessment of Polymer Matrix Composites

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ABSTRACT
Polymeric composition compound with a plasticizer or very low proportion of pigment or processing aids are nonordinary consider as a composition the goal is to improve strength stiffness or toughness or dimensional stability by embedding particles in matrix or binding phase. Polymer-matrix composites are valued in the aerospace industry for their stiffness, lightness, and heat resistance. They are fabricated materials in which carbon or hydrocarbon fibres (and sometimes metallic strands, filaments, or particles) are bonded together by polymer resins in either sheet or fibre-wound form. Chief among the advantages of PMCs is their light weight coupled with high stiffness and strength along the direction of the reinforcement. This combination is the basis of their usefulness in aircraft, automobiles, and other moving structures. Other desirable properties include superior corrosion and fatigue resistance compared to metals. Because the matrix decomposes at high temperatures, however, current PMCs are limited to service temperatures below about 600°F (316°C).

Keywords: aramid fibre reinforced polymer composites, carbon fibre reinforced polymer composites, fibre-reinforcedpolymer, glass fibre reinforced polymer composites, polymer matrix composites

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INTRODUCTION

A composite is any material made of more than one component. There are a lot of composites around you. Concrete is a composite. Obviously, we mean composites made from polymers, or from polymers along with other kinds of materials. Polymer-matrix composites are valued in the aerospace industry for their stiffness, lightness, and heat resistance. They are fabricated materials in which carbon or hydrocarbon fibres (and sometimes metallic strands, filaments, or particles) are bonded together by polymer resins in either sheet or fibre-wound form. A Composite material (also called a composition material or shortened to composite, which is the common name) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual [1].

Polymer matrix composites (PMCs) are comprised of a variety of short or continuous fibres bound together by an organic polymer matrix. Unlike a ceramic matrix composite (CMC), in which the reinforcement is used primarily to improve the fracture toughness, the reinforcement in a PMC provides high strength and stiffness. The PMC is designed so that the mechanical loads to which the structure is subjected in service are supported by the reinforcement. The function of the matrix is to bond the fibres together and to transfer loads between them [2].

Reinforcements

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibres used in composites have different properties and so affect the properties of the composite in different ways. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement. The first modern composite material was fibre glass. A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. Ceramic matrix composites (CMCs) are a subgroup of composite materials as well as a subgroup of ceramics. They consist of ceramic fibres embedded in a ceramic matrix, thus forming a ceramic fibre reinforced ceramic (CFRC) material [3].

Fibre-Reinforced Polymer (FRP)

Fibre-reinforced polymer (FRP), also Fibre-reinforced plastic, is a composite material made of a polymer matrix reinforced with fibres.

The fibres are usually glass, carbon, or aramid, although other fibres such as paper or wood or asbestos have been sometimes used. A fibre-reinforced composite (FRC) is a high-performance composite material made up of three components – the fibres as the discontinuous or dispersed phase, the matrix acts as the continuous phase, and the fine interphase region or the interface. The matrix is basically a homogeneous and monolithic material in which a fibre system of a composite is embedded. It is completely continuous. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, colour, durability and functionality [4].

Fibre reinforced polymer composites are subdivided into:

- Carbon fibre reinforced polymer composites (CFRPs
- Glass fibre reinforced polymer composites (GFRPs)
- Aramid fibre reinforced polymer composites (AFRPs)

In each case the fibre is encased in a resin matrix (the continuous phase). These matrices are usually acrylicepoxyphenolic or polyester resins.

Manufacturing of Fibre-Reinforced Composite

Manufacturing a fibre-reinforced composite involves several steps in which the filler (fibre) is produced and then, if required, aligned prior to the introduction of the matrix. Fibres produced from polymers (for example, the aramids, see below), glass and metals can be produced from the molten state by drawing them. Most carbon fibres are first drawn from a polymer, for example poly(propenonitrile) (polyacrylonitrile), which is then oxidized, followed by pyrolysis. If the fibres are unaligned (random orientation) with each other, the filler and matrix can be blended together as powders or slurries, shaped or moulded, and the matrix hardened and bonded to the filler by heat or by chemical reaction. The shaping may be accomplished by injection moulding or casting of the composite. If required, additional machining is done before any further treatment to harden the composite.

The production of aligned fibre (Figure 1) composites is more complicated. The fibres may be used as monofilaments, or they may be twisted into yarns of up to 10 000 filaments. The yarns are then woven or knitted into two or three-dimensional fabrics and can be then formed into tapes by weaving or braiding. Filaments can also be processed into non-woven mats of fibres, randomly orientated in two dimensions. The mats, tapes and fabrics may be impregnated with matrix material (or materials from which the matrix is made) before final assembly and processing, and are then referred to as a prepreg (pre-impregnated). Thus, there is no need to handle the individual chemicals. It is simply rolled out and used as a laminate. Curing is accomplished by heating. The fabrics and mats are placed in moulds, sometimes by hand, and impregnated with matrix material and processed. They can be compressed mechanically or by pressure or vacuum forming techniques. Filaments or tapes can also be wound, passing through a bath of matrix before being processed into a solid shape. A simple example of a prepreg is the bandage that is used to set broken limbs. The bandage is made of a polyester and it is impregnated with a linear polyurethane, the matrix. The bandage, the prepreg, is flexible and is wound around the broken limb. On soaking, the polyurethane molecules react with water to form cross linkages between the molecules, producing a strong but light cast [5].

Carbon Fibre Reinforced Polymer Composites (CFRPs)

Carbon fibres are generally made by heating filaments of poly(propenonitrile) (polyacrylonitrile, PAN) at *ca* 500 K, under an atmosphere of air to form oxidized PAN. The oxidized PAN is then placed into a furnace with an inert atmosphere of a gas such as argon, and heated to *ca* 2000 K, a process known as pyrolysis, the heating of a substance in the absence of air. The product, carbon fibre, contains chains of carbon atoms which are bonded side-to-side (ladder polymers), forming narrow sheets of carbon atoms, one atom thick, known as graphene. One can imagine it as a piece of chicken-wire on a very small (atomic) scale. Graphene is also the basic structure of graphite and of carbon nanotubes. In the case of a carbon fibre, the sheets merge to form a single circular filament. Carbon fibres are used as a filler in a continuous matrix of a polymer, often an epoxy resin. Layers of carbon fibre cloth are laid down in the shape required, usually in a mould which is then filled with epoxy resin and heated [6].

Glass Fibre Reinforced Polymer Composites (GFRPs)

Glass fibre is made from silica (sand), sodium carbonate and calcium carbonate together with other compounds to give the specific properties required. The materials are heated to ca 1700 K in a furnace and then extruded directly from the furnace through metal (a platinum/rhodium alloy) orifices of various diameters (4 - 34 urn) to produce filaments. A high-speed winder revolving faster than the exiting molten glass draws them under tension into very fine filaments. The number of orifices varies from 200 - 8000. The filaments are coated with a lubricant to protect them and bundled together on a drum, looking like a spool of a thread. In fibreglass, in which glass fibres are the filler (dispersed phase), the matrix is usually a polyester resin although epoxy and acrylic polymers are also used [7].

Aramid Reinforced Polymer Composites (ARPCs)

An *aramid* is a polymeric aromatic amide. Kevlar® is a particularly widely used aramid.

It is very difficult to handle as the only effective solvent is concentrated sulfuric acid. Kevlar® is made from lightweight atoms but is very strong and flexible, weight for weight five times as strong as steel. Its strength comes from the way the polymer chains are aligned, the flat molecules being held together by hydrogen bonds. These sheets of molecules can stack up along the fibre axis. These fibres, already strong, are used as the filler in ARPCs with a phenolic resin or epoxy resin as a matrix. They are particularly useful where energy has to be absorbed and dissipated, and they are also able to resist abrasion [8].

Applications and Market Status of Polymer Matrix Composites

PMCs areas more mature technology than structural ceramics. With the experience gained in military applications such as fighter aircraft and rocket motor casings beginning in the 1970s, advanced composites now have a good record of performance and reliability. They are rapidly becoming the baseline structural material of the defence/aerospace industry. Because of their high cost, diffusion of advanced composites into the civilian economy is likely to be a top-down process, progressing from relatively high value-added applications such as aircraft to automobiles and then to the relatively low-technology applications such as construction, which generally requires standardized shapes such as tubes, bars, beams, etc. On the other hand, there is also a bottom-up process at work in which savings in manufacturing costs permit unreinforced engineering plastics and short fibre reinforced PMCs to replace metals in applications in which high strength and stiffness are not required, such as use of SMC for automobile body panels. Applications and markets for PMCs are discussed according to end-user industry below.

1. Aramid reinforced polymer composites have been used widely in aviation, for helicopter rotor blades, in sport, to make tennis, badminton and squash racquets, and in boats such as kayaks and dinghies.
2. GFRPs are used widely in the manufacture of boats for reasons of cost and maintenance. While large ships are usually constructed in steel, over 80% of marine hulls, less than about 40 m in length, are made of glass fibre reinforced polymer. This is a much cheaper process and the hull is easier to maintain.
3. Additionally, there are certain applications in which the magnetic, electrical or thermal properties of GFRPs are advantageous, an example being minesweepers which need to be non-magnetic in order to avoid activation of mines.
4. Glass-phenolic resin prepregs are also used to improve protection for armoured vehicles.
5. Carbon fibre composites are relatively expensive construction materials and therefore used when their properties of lightness and strength are of paramount importance. Examples of use include high quality sports equipment, such as tennis racquet frames, golf clubs and fishing rods, and in laptops and cameras.
6. CFRP are also used extensively in the construction of aircraft. The fuselages of the newest commercial aeroplanes are constructed mostly from CFRP for its superior lightness and strength.
7. Another property of CFRPs is exploited in aircraft brakes. These are required to absorb considerable quantities of energy rapidly without mechanical failure or seizure. The usual construction is based on multiple rotating and stationary discs, which can reach surface temperatures of up to 3000 K. The disc material must therefore have excellent thermal and shock resistances and high-temperature strength, together with good thermal conductivity.
8. Carbon is an ideal material and the discs are made from a carbon composite where the filler is carbon fibre and the matrix is carbon produced from the pyrolysis of

methane. Additionally, weighing some 30% less than steel discs, they save a considerable amount of fuel.

9. CFRPs have also been used for many years to construct the body of F1 racing cars, giving drivers greater protection even in crashes at over 300 km h^{-1}. They are now being used in luxury cars (part of the Mercedes Benz range, and for the roof of the GM Corvette ZR1) and as protective gear for motor cyclists.
10. CFRPs are increasingly used to 'retrofit' existing large structures such as bridges made of reinforced concrete. The carbon fibre fabric is wrapped around the parts that need strengthening.
11. Aerospace – The primary matrix materials used in aerospace applications are epoxies, and the most common reinforcements are carbon/graphite, aramid (e.g., Du Pont's Kevlar), and high-stiffness glass fibres. However, high-temperature thermoplastics such as PEEK are considered by many to be the matrices of choice for future aerospace applications.
12. Military Aircraft – Advanced composites have become essential to the superior performance of a large number of fighter and attack aircraft. Because the performance advantages of advanced composites in military aircraft more than compensate for their high cost, this is likely to be the fastest growing market for advanced composites over the next decade. Indications are that composites may account for up to 40 percent of the structural weight of the Advanced Tactical Fighter (ATF), which is still in the design phase.
13. Medical Devices – PMC materials are currently being developed for medical prostheses and implants. The impact of PMCs on orthopaedic devices is expected to be especially significant. Although medical devices are not likely to provide a large volume market for PMCs, their social and economic values are likely to be high.
14. Construction – A potentially high-volume market for PMCs lies in construction applications, especially in construction of buildings, bridges, and housing. Additional applications include lampposts, smokestacks, and highway culverts. Construction equipment, including cranes, booms, and outdoor drive systems, could also benefit from use of PMCs. Because of the many inexpensive alternative building materials currently being used, the cost of PMC materials will be the key to their use in this sector.
15. Naval Application – Future applications for PMCs on surface ships include antenna masts and stacks (due to reduced weight and radar cross section), and valves, pipes, and ducts (due to lower weight and corrosion resistance). PMCs could also be used for an advanced technology submarine hull, providing weight savings and thus speed advantages over metal hulls currently in use.
16. Automotive Industry – The next major opportunity for PMCs in automobiles is in structural components. Two structural components currently in service are the advanced composite drive shaft and leaf spring. Some 3,000 drive shafts, manufactured by filament winding of graphite and E-glass fibres in a polyester resin, were used annually in the Ford Econoline van. Meanwhile, glass FRP springs in the Corvette and several other models are in production at the rate of approximately 600,000 per year. Leaf springs are regarded as a very promising application of PMCs, and

they are expected to show strong growth, especially in light trucks. prototype primary body structures have been constructed with weight savings of 20 percent or more.

17. Helicopters – Materials such as graphite/epoxy are likely to be used in the airframe, bulkheads, tail booms, and vertical fins, while glass/epoxy PMCs of lesser stiffness could be used in the rotor systems. As with aircraft, there could be a long-term trend away from epoxy resins and toward thermoplastic resins.
18. Commercial Aircrafts – By the year 2000, PMCs could make up 65 percent of the structural weight of commercial transport aircraft. Estimating a structural weight of 75,000 pounds per aircraft and production of 500 aircraft per year, this application alone should account for 24 million pounds of advanced composites per year. Assuming a starting material value of $60 per pound, the market in the year 2000 is projected to be worth about $1.5 billion for the composite materials alone. A much more conservative estimate, which assumes that no new commercial aircraft will be built by 1995, has placed the U.S. composite commercial airframe production at only 1 million to 2 million pounds in that year [9].

HEALTH AND SAFETY

There are a number of unique health and safety issues associated with the manufacture of PMC materials. The health hazards associated with the manufacture of PMC materials stem from the fact that chemically active materials are used and workers handling them may breathe harmful fumes or come into contact with irritating chemicals. The chemical of greatest concern is the styrene monomer used in polyester resins. The problem is most severe when the resin is sprayed, and the monomer evaporates into the air. Inhalation of styrene monomer can cause headaches, dizziness, or sore throat. In fact, some people become sensitized to the vapours and they can no longer work in a reinforced plastics plant.

A new safety hazard was introduced with the advent of carbon fibres. They tend to float around the plant in which they are used. Because they are electrical conductors, they can get into unprotected electrical devices and cause short circuits. The fibre concentration in the air can be controlled by a negative pressure exhaust system in the area in which they are used, but all electrical devices in the area should be sealed to make them explosion proof. Because most factories using carbon fibres are generally involved with advanced composites and are more sophisticated than most reinforced plastics plants, they are able to handle this hazard without undue difficulty [10].

Recycling and Disposal

Most PMC materials in use today have thermosetting matrices; consequently, after they have been cured, they have no apparent scrap value. Although attempts have been made to grind them up and use them as fillers, this has not proven to be economically practical. The reuse of uncured PMCs offers little economic incentive; most scrap is simply discarded. By contrast, one of the potential advantages of PMCs with thermoplastic matrices is that the scrap can be recycled, Cured PMCs present no particular disposal problem; they are chemically inert and can be used for landfill. Incineration is generally avoided because it can generate toxic smoke. The principal problem associated with PMC disposal arises with uncured PMCs. Wet lay-ups, prepregs, SMC, etc. are still chemically active and pose both health and safety problems. If used in landfill, the active chemicals can leach out and cause contamination of the soil or water. A more serious problem is that the catalysed resins may go on to cure and generate an exotherm that causes spontaneous combustion or self-ignition. The safe way to dispose of uncured PMC material is to bake it until it is cured and then dispose of it [10].

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