A Mini-Review on Properties and Application of Composite Materials

*Sujata Warambhe**
Savitri Phule, Pune University, Pune, Maharashtra, India

ABSTRACT

This study demonstrates the need of composite materials over common materials. Using different moulding methods, composite components are manufactured in different sectors. The primary advantage of composite is lightweight, relative stiffness and strength properties. The key concepts of composites are its physical properties, material properties, tooling, design, inspection and repair. Military vehicles, such as airplanes, helicopters, and rockets, placed a premium on high-strength, light-weight materials. While the metallic components that had been used up to that point certainly did the job in terms of mechanical properties, the heavy weight of such components was prohibitive. Polymer industries were quickly growing and tried to expand the market of plastics to a variety of applications. The emergence of new, light-weight polymers from development laboratories offered a possible solution for a variety of uses, provided something could be done to increase the mechanical properties of plastics.

Keywords: ceramics, fatigue, monomers, polymers

***Corresponding Author**
E-mail: warambhesujata78@gmail.com

INTRODUCTION

Composite is a combination of two or more chemically distinct and insoluble phases. Constituent materials or phases must have significantly different properties for it to combine them: thus, metals and plastics are not considered as composites although they have a lot of fillers and impurities. The properties and performance of composites are far superior to those of the constituents. Composites consist of one or more discontinuous phases (reinforcement) embedded in a continuous phase (matrix). Examples: – Cemented carbides (WC with Co binder) – Rubber mixed with carbon black – Wood (a natural composite as distinguished from a synthesized composite) [1]. 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. Using composites rather than conventional materials such as steel usually provides major weight savings [2]. This is partly due to the specific properties and low weight of the individual components, and partly because it is possible to manufacture composites for very particular purposes. 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. Composites are engineered products made from two or more different materials. A composite product provides a designed solution that surpasses the performance of the starting materials. While there are many variations of composites, the most common engineered composite materials are fibre reinforced polymers (FRP). Concrete containing such rods or wires is called reinforced concrete. 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. Composite structure diagram in the Unified Modelling Language (UML) is a type of static structure diagram, that shows the internal structure of a class and the collaborations that this structure makes possible. A composite structure is a set of interconnected elements that collaborate at runtime to achieve some purpose [3].

Engineering Composites
Mechanical Properties

Composite materials include some of the most advanced engineering materials today. The addition of high strength fibres to a polymer matrix can greatly improve mechanical properties such as ultimate tensile strength, flexural modulus, and temperature resistance.

Typical engineered composite materials include:

- Mortars, concrete.
- Reinforced plastics, such as fibre-reinforced polymer.
- Metal composites.
- Ceramic composites (composite ceramic and metal matrices)

Merits of Composite Materials

Composites can be very strong and stiff, yet very light in weight, so ratios of strength-to-weight and stiffness-to-weight are several times greater than steel or aluminium ΨHigh specific strength and ΨHigh specific stiffness Long fatigue life ΨHigh creep resistance ΨLow coefficient of thermal expansion ΨLow density ΨLow thermal conductivity ΨBetter wear resistance ΨImproved corrosion resistance ΨBetter temperature dependent behaviour.

Advantages of Composite Materials

Design Flexibility

Thermoset Composites give designers nearly unlimited flexibility in designing shapes and forms. They be moulded into the most intricate components and can be made a wide range of densities and chemical formulations to have precise performance properties.

Low Cost Per Cubic Inch

When comparing costs based on volume, thermoset composites have lower material costs than traditional materials such as wood, engineered thermoplastics and metals. In addition, because thermoset composites have a low petroleum-based content, they are not subjected to the price fluctuations experienced in petroleum-based products.

Lower Material Costs

Because thermoset composites can be precisely moulded, there is little waste and therefore significantly lower overall material costs than metals products.

Improved Productivity

Industrial designers and engineers are able to reduce assembly costs by combining several previously assembles parts into a single component. Also, inserts can be moulded directly into the part during the moulding process thereby eliminating the need for a post-process. In addition, composites do not usually require additional machining, thereby reducing work-in-process and time to market.

Other key advantages include:

- As moulded dimensional accuracy
  - Tight tolerance, repeatable mouldings
  - Low-post mould shrinkage
- Chemical resistance

- Consolidated parts and function
- Corrosion resistance
- Design flexibility
- Durable
- High flexural modulus to carry demanding loads
- High impact strength
- High performance at elevated temperatures
- Heat resistance
- Naturally flame retardant
- Creep resistance
- Mechanical property retention
- Superior thermal stability
- Lighter weight than metal
- Lower costs vs. die cast
- Low petrochemical content
- Better cost stability than commodities
- Lower cost per cubic inch as compared to thermoplastics
- Moulded-in colour
- Moulded in inserts
- Outstanding electrical insulation
- Arc and track resistance
- Ability to quench [4]

Disadvantages and Limitations of Composite Materials

- Properties of many important composites are anisotropic – the properties differ depending on the direction in which they are measured – this may be an advantage or a disadvantage
- Many of the polymer-based composites are subject to attack by chemicals or solvents, just as the polymers themselves are susceptible to attack
- Composite materials are generally expensive
- Manufacturing methods for shaping composite materials are often slow and costly [5].

Functions of the Matrix Material

- Provides the bulk form of the part or product made of the composite material.
- Holds the imbedded phase in place, usually enclosing and often concealing it.
- When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent.
- Cermets – Ceramic (up to 90%) contained in a metallic matrix – cemented carbides (tungsten, titanium, chromium) – cutting tools, dies, indenters.

Classification based on the type of matrix material (Figure 1):

- Polymer matrix composites (PMCs)
- Metal matrix composites (MMCs)
- Ceramic matrix composites (CMCs)
- Carbon/carbon composites (C/Cs) based on the geometry of reinforcement
- Particulate reinforced composites
- Whisker/flakes reinforced composites

Fibre Reinforced Composites Hybrid

A composite laminate comprising of laminae of two or more composite material systems or a combination of two or more different fibres such as C and glass or C and aramid into a structure [6].

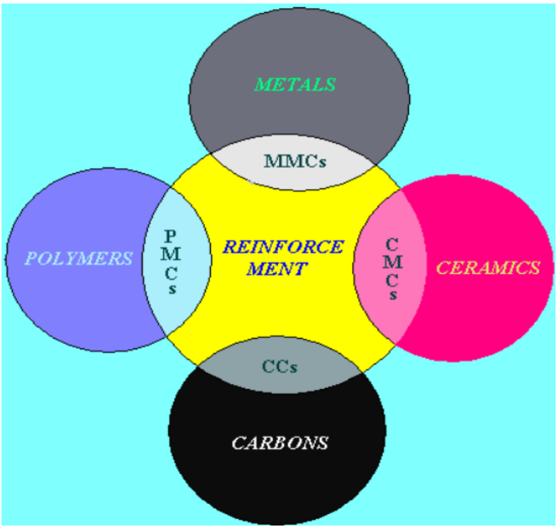


***Fig. 1.** Based on the type of matrix.*

PROPERTIES OF COMPOSITES MATERIALS

Composites are extremely versatile products - their benefits being:

High Strength to Weight Ratio

Fibre composites are extremely strong for their weight. By refining the laminate many characteristics can be enhanced. A common laminate of say 3mm Chopped strand mat, is quite flexible compared to say a 3 mm ply. However, it will bend a long way more than the ply before yielding. Stiffness should not be confused with Strength. A carbon fibre laminate on the other hand, will have a stiffness of many times that of mild steel of the same thickness, increased ultimate strength, yet only be less than 1/4 of its weight.

Lightweight

A standard fibre glass laminate has a specific gravity in the region of 1.5, compared to alloy of 2.7 or steel of 7.8. When you then start looking at carbon laminates, strengths can be many times that of steel, but only a fraction of the weight. A DVD case lid was produced using carbon fibre to reduce the case's overall weight so that it could be carried as cabin baggage whilst traveling, and for improved security. It was used by support crew for the All Blacks during their 1999 Rugby World Cup campaign.

Fire Resistance

The ability for composites to withstand fire has been steadily improving over the years. There are two types of systems to be considered:

Fire Retardant

Are self-extinguishing laminates, usually made with chlorinated resins and additives such as Antimony trioxide. These release CO_2 when burning so when the flame source is removed, the self-extinguish.

Fire Resistant

More difficult and made with the likes of phenolic resins. These are difficult to use, are cured with formaldehyde, and require a hi degree of post curing to achieve true fire resistance.

Other materials are also becoming more readily available to be used as in tumescent layers, which expand and blanket the surface, preventing spread of flame. There is a paint on coating usually applied to the back of the product laminate, plus a thin fibre film to go under the Gelcoat giving the outer surface a blanketing coat as well.

Fibreglass Developments Ltd produces a Fire Door as part of our Steridor TM range. Use of special Phenolic resin has allowed us to create the only fully tested Composite door in Australasia. Fire rated by BRANZ to 4 hours, this door is also approved by MAF as meeting all their Hygiene requirements.

Electrical Properties

Fibreglass Developments Ltd produced the Insulator Support straps for the Tranz Rail main trunk electrification. The straps, although only 4mm thick, meet the required loads of 22kN, as well as easily meeting insulation requirements.

Chemical and Weathering Resistance

Composite products have good weathering properties and resist the attack of a wide range of chemicals. This depends almost entirely on the resin used in manufacture, but by careful selection resistance to all but the most extreme conditions can be achieved. Because of this, composites are used in the manufacture of chemical storage tanks, pipes, chimneys and ducts, boat hulls and vehicle bodies.

FDL manufactured architectural panels for the construction of the Auckland Marine Rescue Centre. Composite panels were chosen because of their ability to withstand salty sea side conditions without corrosion.

Colour

Almost any shade of any colour can be incorporated into the product during manufacture by pigmenting the gelcoat used. Costs are therefore reduced by no further finishing or painting. Soluble dyes can be used if a translucent product is desired.

We do not however, recommend dark colours. These produce excessive heat on the surface which can lead to the surface deteriorating and showing print through, where the Resin matrix cures more and shrinks, bringing the fibres to the surface. In extreme cases delamination can occur.

Translucency
Polyester resins are widely used to manufacture translucent mouldings and sheets. Light transmission of up to 85% can be achieved.

Design Flexibility
Because of the versatility of composites, product design is only limited by your imagination.

Low Thermal Conductivity
Fibreglass developments have been involved in the development and production of specialized meat containers which maintain prime cuts of chilled meat at the correct temperature for Export markets. They are manufactured using the RTM process, with special reinforcing and foam inserts.

Manufacturing Economy
Fibreglass Developments produces several models of fuel pump covers for fuel quip. Fibreglass is an ideal material for producing items of this type for many reasons, including being very economical. Because of its versatile properties, fibreglass can be used in many varied applications [7].

APPLICATION OF COMPOSITES MATERIALS
As composite materials possess a unique combination of properties such as x high strength to weight ratio, i.e., lightness in weight x Better toughness, fatigue and stiffness x Functional superiority, i.e., better corrosion, x weathering and fire resistance, electrical insulation and anti-friction properties x Ease of fabrication or versatility of fabrication methods x Better durability and low maintenance cost Great Importance is given to the composites as raw material for various Industries [8].

Use of Composites in Aerospace Structure
Composite materials are used in aircraft for primarily – radomes and dielectric panels and secondary - doors, ring tips, ducts and fairings structures. The materials used for wall construction are E-glass roving’s and epoxy resin because of their good electrical as well as mechanical properties. The technique adopted is polar winding.

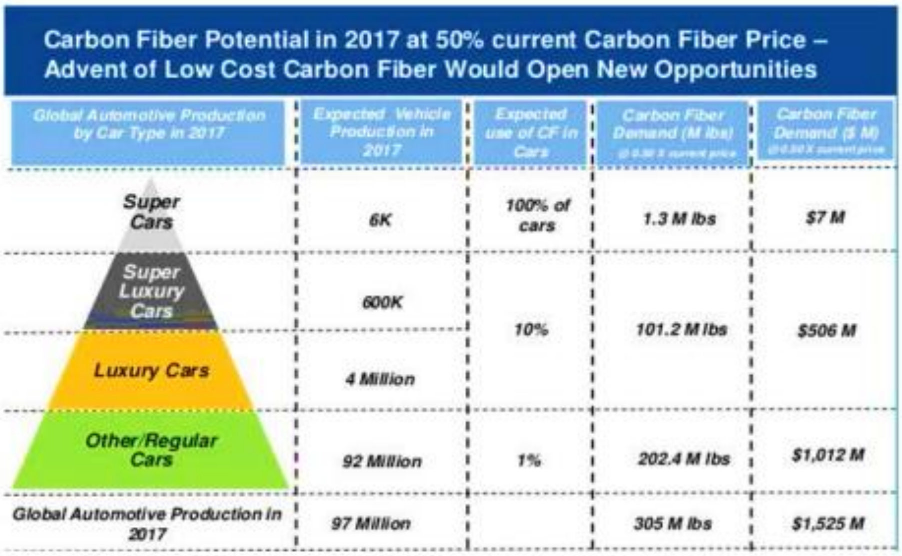
- Light weight
- Corrosion resistance
- Fatigue resistance
- Capability of mould large complex shapes
- Capability to maintain dimensional and alignment stability
- Possibility of low dielectric loss x capability of high degree of optimization

Along with the above advantages, some of the limitations are:
Shock, impact, or repeated cyclic stresses can cause the laminate to separate at the interface between two layers, a condition known as de-lamination. Individual fibres can separate from the matrix

- Moisture absorption
- Weak interference of laminated structure
- High possibility of manufacturing defects
- Compared to metals, composites have relatively poor bearing strength

Automobile and Transportation Industry

The potential for increasing fuel economy by reducing the vehicle's weight has stimulated tremendous interest for composite materials in automobile and transportation industry. As a result, industrially developed countries are extensively using graphite dispersed aluminium composites for automobile parts where friction is involved. The applications of composite materials in railways and road transports are well established all over the world. Glass fibre-polyesterl epoxy composites are the usual materials for the production of three-wheeled vehicles for invalids, commercial vehicles (cabs and trucks), car bodies, sporting cars, buses, ambulances, caravans, mobile shops, etc. in foreign countries. GRP is also used in motor cycle and scooter industry mainly due to weight saving and the need to obtain an inexpensive weather-resistant streamlined fairings. The other various industries are Marine Industry, Chemical Industry, Mechanical, Civil, Electrical and Electronics industries used very widely (Figure 1) [9, 10].



Thermosets				Thermoplastics
Forms cross-linked networks in polymerization curing by heating				No chemical change
Epoxies	Phenolics	Polyester	Polyimides	PPS, PEEK
Most popular 80% composite usage Moderately high temperature Comparatively expensive	Cheaper Lower viscosity Easy to use High temp usage Difficult to get good quality composites.	Cheap Easy to use Popular for general applications at room temp	High temperature application 300 °C Difficult to process Brittle	Good damage tolerance Difficult to process at high temp 300-400°C is required
Low shrinkage(2-3%) No release of volatile during curing	More shrinkage Release of during volatile during curing	High shrinkage(7-8%)		
Can be polymerized in several ways giving varieties of structures, morphology and wide range of properties.	Inherent stability for thermal oxidation. Good fire and flame retardance Brittle than epoxies	Good chemical resistance Wide range of properties but lower than epoxies Brittle Low Tz		
Good storage stability to make prepregs	Less storage stability – difficult to prepreg	Difficult to prepreg		Infinite storage life. But difficult to prepreg

CONCLUSION

Extant studies show the advantages like:

(1) Resistance to a wide range of chemical agents including acid rain and salt spray, conditions under which metal parts would suffer. This results in much reduced maintenance and repair costs.

(2) Resilience – the ability to deform and spring back to their original shape without major damage. Shape memory and impact tolerance are two of the biggest advantages of composites, particularly within the transport industry.

(3) Low weight – with substantial savings in weight over similar metal parts (25% the weight of steel, 30% lighter than aluminium) cost savings are noticeable with installation, handling and particularly fuel consumption, when in service. Even greater weight savings are achieved when two components, previously manufactured out of steel or aluminium, are combined in one composite structure. This also gives savings in the installation process.

(4) Adhesive and coating compatibility – since composites and adhesives/coatings share a similar polymeric makeup, they are widely compatible with one another.

(5) Thermal properties – composite structures act as very good insulators, whilst retaining their shape while not becoming brittle in cold temperatures.

(6) Strength – comparable to aluminium and steel, strength characteristics of many materials can be reproduced through research and development with reinforcements, e.g. glass.

(7) Innovative designs which were previously impractical can be achieved with composites with no loss in performance or strength.

(8) Safety – fibre-reinforced composites are low in electrical conductivity and are efficient fire retardants, which makes them a good choice for covering electrical parts.

(9) Reduced cost – effective techniques have been developed which produce a post-mould paint-finish type surface which requires no further processing, thus eliminating the need for time consuming and expensive finishing. For composites which have been designed to be painted, the part manufacture can include allowances for a surface finish suitable for the keying-in and adhesion of the finish. The above merits clearly indicate the necessity of the composites than common materials.

REFERENCES

[1] M.C.Y. Niu. *Composite Airframe Structures*.

[2] L.J. Hart Smith, A.C. Douglas. Designing with advanced fibrous composites, In: *Company Workshop on New Materials and Process for Mechanical Design*. 1988 Brisbane 11–13 Aug (1877).

[3] L.J. Hart Smith. In: *Designing to Minimize Peel Stresses in Adhesive Bonded Joints in Delamination and Debonding of Materials ASTM STP 876*. W.S. Johnson. (Eds). ASTM (1985) 238–66p.

[4] L.J. Hart Smith. The design of repairable advanced composite structures soc. *Autom Eng Trans*. 1985; 851830.

[5] M.F. Earo, J.H. Stannes. Current research in composite Structures at NASA‘S Lagleyresearch center intern, In: *Conf Composite Materials and Structures*. India, Jan 6–8, 1988.

[6] J.E. Mecarty, R.E. Harton. Damage tolerance of composites, In: *Intern. Conf. Aeronautical Sciences 15th Congress*. England, 1986.

[7] N.V. Nayak. *Int J Sci Res Publ*.

[8] J.E. Mecarty, R.E. Harton. Damage tolerance of composites, In: *Intern.*

Conf. Aeronautical Sciences 15th Congress. England, 1986.
[9] http://www.materialsworldmodules.org/resources/polimarization/2.
[10] http://www.adhesiveandglue.com/thermoplastic.html