Review of Composite Materials and Applications

M.K.S.Sai
Department of Mechanical Engineering
VBIT, Hyderabad, Telangana, India

Abstract- This study demonstrates the need of composite materials over common materials. Using different molding 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

I INTRODUCTION

Most of human needs lead to inventions. At first, he used only the materials which surrounded him in nature. Wood and stone are used as tools and animal skin for clothing. Then he learnt to weave natural fibers, like cotton and silk to make cloth. Later he discovered the use of iron and copper to make different hunting implements. Man's scientific understanding has greatly increased in the last two centuries, which have witnessed a revolution in technology. Scientists have discovered how to make special synthetic materials like plastics. Plastic can be inorganic or organic, natural or synthetic. But increasingly, the word has come to denote synthetic organic plastics, essentially ***polymers [9]***. *P*olymers, means many parts are composed of giant molecules or units called monomers[9]. Each monomer is composed essentially of carbon and hydrogen. Sometimes, they may contain other elements like oxygen, nitrogen, chlorine, silicon, etc. Most polymers are immensely *long c*hains; sometimes linear, sometimes branched. This is possible because carbon atoms can combine very easily with one another and with many other kinds of atoms. They have the ability to form strong bonds in long chains.

A composite can define as "Two inherently different materials that when combine together produce a material with properties that exceed the constituent materials". In other words Composite material can be defined as a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. The reinforcement fibers can be cut, aligned, placed in different ways to affect the properties of the resulting composite. The matrix, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical and environmental attack, and it bonds the reinforcement so that applied loads can be effectively transferred.

II. NEED OF COMPOSITES & BENEFITS

In comparison to common materials used today such as metal and wood, composites can provide a distinct advantage. The primary advantage in composites is the light weight, relative stiffness and strength properties. In transportation, less weight equates to more fuel savings and improved acceleration. In sporting equipment, lightweight composites allow for longer drives in golf, faster swings in tennis, and straighter shots in archery. While in wind energy, the less a blade weighs the more power the turbine can produce. Rubber tiers replacing wooden wheels; bright nylon or polyester dress materials becoming more popular than cotton; tennis rackets made of lighter materials being preferred over the old, heavy wooden one. Composite materials are generally costlier as compared to conventional materials, but still their use is becoming increasingly popular because of their significant properties.

- Non-conductive
- Non-corrosive

- Flexible, will not dent
- Low maintenance
- Long life
- Design flexibility

For example, carbon-fiber reinforced composite can be five times stronger than 1020 grade steel at one fifth of the weight. Though Aluminum (6061 grade) is much nearer in weight to carbon-fiber composite, but the composite can have twice the modulus and up to seven times the strength. Materials are classified into different categories like Metals, Polymers, Ceramics and inorganic glasses and composites. At high temperature metals lose their strength. High-Polymeric materials in general can withstand still lower temperatures. Ceramics and polymers are able to withstand at high temperatures, good strength and thermal expansion properties, but due to brittleness they are not as structural materials. Basically composites are grouped into the following categories -

Fiber Composites: The fibers reinforce along the line of the length.

Particle Composites: P Particles used to strengthen a matrix. Spread at random throughout a matrix, particles tend to reinforce in all directions equally. Ex cement and plastics.

Flake Composites: Flakes, because of their shape usually reinforced in two dimensions. Common flake materials are glass and mica.

Laminar Composites (layered): laminar composites involve two or more layers of same or different materials. The layers can be arranged in different directions to give strength.

Combined Composites: It is possible to combine several different materials into a single composite. It is also possible to combine several different composites into single product.

III. FABRICATION METHODS

With their relatively short history, Composite materials are succeeded remarkably. Ceramics must overcome certain obstacles, especially in structural uses. Concern to cost several changes takes place in composite industry. Molding Operations: Using molding operations large number of composite product are manufactured. Different molding methods are:

- Hand lay-up
- Spray up
- Vacuumed-bag molding
- Pressure-bag molding
- Thermal expansion molding
- Autoclave molding
- Centrifugal Casting
- Continuous pultrusion and pulforming.
- Other types of fabrication include press moulding, transfer moulding, pultrusion moulding, filament winding, casting, centrifugal casting, continuous casting and slip forming. There are also forming capabilities including CNC filament winding, vacuum infusion, wet lay-up, compression moulding, and thermoplastic[10] moulding.

IV. APPLICATION OF COMPOSITES

As composite materials possess a unique combination of properties such as

- High strength to weight ratio, i.e., lightness in weight
- Better toughness, fatigue and stiffness
- Functional superiority, i.e., better corrosion,
- weathering and fire resistance, electrical insulation and anti-friction properties
- Ease of fabrication or versatility of fabrication methods
- Better durability **and** low maintenance cost

Great Importance is given to the composites as raw material for various Industries.

Fig.1 Sector wise Composite Materials

A) 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
- 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 fibers 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.

Important requirement s for designing an aero plane structure are listed in table 1.In order to meet the requirements listed in the table.1 it is necessary to have a material posse the properties. Composite offer several of properties like:

Requirement	Applicability	Effect
Light – weight	All Aerospace programmes	Semi monocoque construction *Thin walled-box or stiffened structure. *Use of low density material: *Wood *Al-alloys *Composites High strength / weight, high stiffness/weight
High reliability	All space programmes	Strict quality control Extensive testing for reliable data Certification proof of design

Passenger safety	Passenger vehicles	Use of fire retardant materials Extensive testing: Crashworthiness
Durability-Fatigue and corrosion degradation: Vacuum Radiation thermal	Aircraft Spacecraft	Extensive fatigue analysis/testing *Al-alloys do not have a fatigue limit Corrosion prevention schemes Issues of damage and safe- life, life extension Extensive testing for required environment Thin materials with high integrity
Aerodynamic performance	Aircraft Reusable spacecraft	Highly complex loading Thin flexible wings and control surface *Deformed shape-Aero elasticity *Dynamics Complex contoured shapes *Manufracturability N/C machining, moulding.
Multi-role and functionality	All Aerospace programmes	Efficient design Use: Composites with functional properties
Fly-by-wire	Aircrafts, mostly for fighters but also some in passenger a/c	Structure control interactions *Aero servo elasticity Extensive use of computers and electronics *EMI Shielding
Stealth	Specific military aerospace applications	Specific surface and shape of aircraft *Stealth coatings
All weather operation	Aircraft	Lightning protection, erosion resistance

Table 1 Feature of Aircraft Structure.

Significantly the advantages are overcome the weakness and most of the aerospace programs use large amount of composites as highlighted in the figure below.

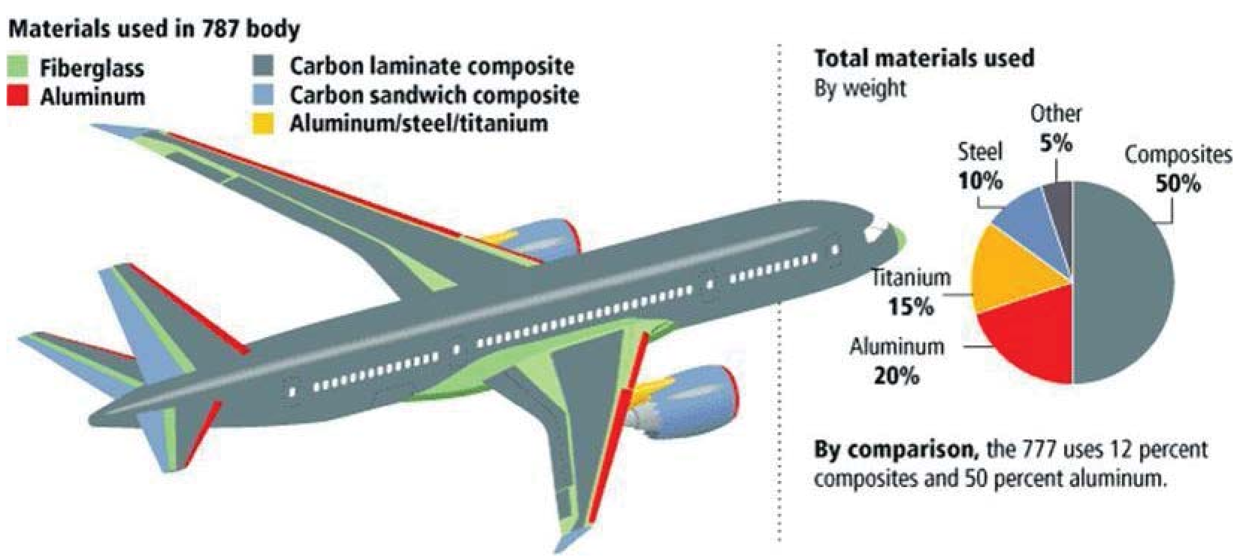

Fig.2 Materials used in 787 Body

Based on reinforced fibers and matrix resins given in table 2 and table 3 are used as material for aerospace sector. Using autoclave as manufacture method most of the aerospace sector used composites as raw material. For low speed aircraft, glass fiber composites are used. Whereas for large number of components , metallic conventional tooling is preferred. For special products such as radomes, Resign injection moulding is used. Radome is a protective covering capable of transmitting electromagnetic signals with less distortion and loss. The most important requirements for a radome are uniform electrical thickness and wavelength identical to the radar equipment with which it is to be used.

Fiber	Density (g/cc)	Modulus (GPa)	Strength (GPa)	Application areas
Glass				
E-glass	2.55	65 – 75	2.2 – 2.6	Small passenger a/c parts, air-craft interiors, secondary parts, Radomes, rocket motor casting.
S-glass	2.47	85 – 95	4.4 – 4.8	Highly loaded parts in small passenger a/c
Aramid				
Low modulus	1.44	80 – 85	2.7 – 2.8	Fairings: Non load bearing parts.
Intermediate modulus	1.44	120- 128	2.7 - 2.8	Radomes, some structural parts,rocket motor castings.
High modulus	1.48	160 - 170	2.3 – 2.4	Highly loaded parts.
Carbon				
Standard modulus (high strength)	1.77-1.80	220-240	3.0-3.5	Widely used for almost all types of parts in a/c, satellites, antenna dishes, missiles, etc.
Intermediate modulus	1.77-1.81	270-300	5.4-5.7	
High modulus	1.77-1.80	390-450	2.8-3.0 4.0-4.5	Primary structural parts in high performance fighters. Space structures, control surfaces in a/c
Ultra-high strength	1.80-1.82	290-310	7.0-7.5	Primary structural parts in high performance fighters, spacecraft.

Table 2. Reinforcing fibers commonly use in aerospace applications

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

Absolute moisture (5-6%) causing selling and degradation of high temp properties. Also ultra violet degradation in long term.	Absorbs moisture but no significant effect of moisture in working service range	Less sensitive to moisture than epoxies.		No moisture absorption.

Table 3. Polymeric matrices commonly used in aerospace sector.

B) 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 like Japan are extensively using graphite dispersed aluminum 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-polyesterlepoxy 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.

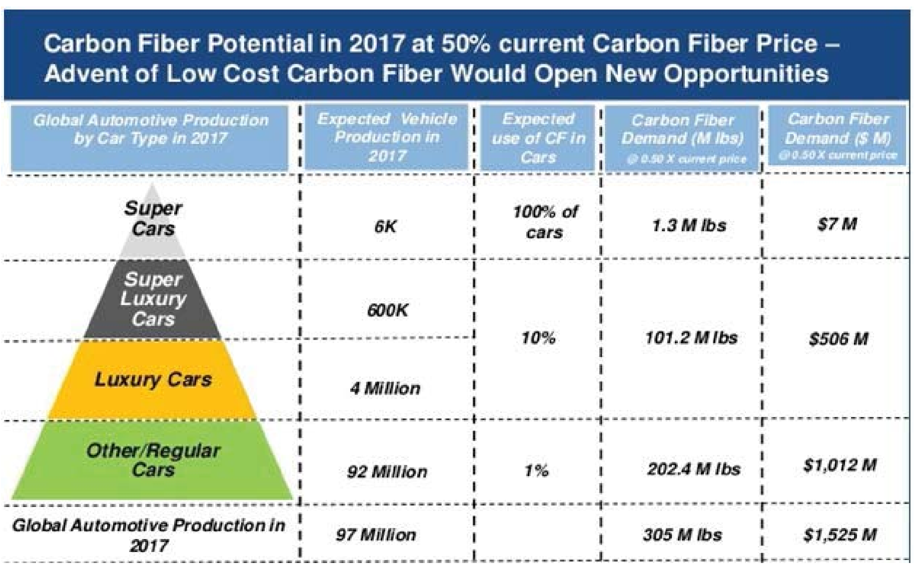

Fig.3 Carbon Fiber Potential in 2017

The other various industries are Marine Industry, Chemical Industry, Mechanical, Civil, Electrical and Electronics industries used very widely.

V. CONCLUSION:

Extant studies shows 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 aluminum) 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 aluminum, 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 make-up, 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 aluminum and steel, strength characteristics of many materials can be reproduced through research and development with reinforcements, eg. glass.
7. Innovative designs which were previously impractical can be achieved with composites with no loss in performance or strength.
8. Safety – fiber-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] Composite airframe structures by Michael C. Y. Niu.
[2] Designing with advanced fibrous composites by L. J. Hart Smith, Douglas A./C. company workshop on new materials and process for mechanical design 1988 Brisbane 11-13 Aug (1877).
[3] L.J. Hart Smith designing to minimize peel stresses in adhesive bonded joints in delamination and debonding of materials ASTM STP 876 (eds). W. S. Johnson ASTM (1985) 238-266.
[4] L. J. Hart Smith The design of repairable advanced composite structures soc. Automotive engineers trans., 851830 (1985).
[5] M. F. Earo& J. H. Stannes Current research in composite Structures at NASA‘S Lagleyresearch center intern. Conf, composite materials and structures India Jan 6-8 (1988).
[6] J. E. Mecarty, R. E. Harton, Damage tolerance of composites intern. Conf. aeronautical sciences 15th congress England (1986).
[7] Nikhil V Nayak, International Journal of Scientific and Research Publications.
[8] J. E. Mecarty, R. E. Harton, Damage tolerance of composites intern. Conf. aeronautical sciences 15th congress England (1986).
[9] http://www.materialsworldmodules.org/resources/polimarization/2-
[10] http://www.adhesiveandglue.com/thermoplastic.html