

## Review Article

# Embryonic Phases of Hard Composites: A Review

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## Abstract

The incremental advancement in composites revolutionized the whole world in the 20<sup>th</sup> century. Fundamental features of composite materials are high strength, light weight, fatigue resistance, high stiffness, fire resistance, flexibility and thermal resistance. Four generations of composites are the backbone in the development of composites i.e. Glass Fibers Reinforced Polymers (GFRP'S), high performance composites, synergy of properties of materials, hybrids and Nano composites. Bio-composites, shape memory composites, soft magnetic composites and flexible composites initially grasped the main focus of the whole world. Different manufacturing techniques i.e. hand lay-up, forming, vacuum bad molding and pultrusion method are utilized for composite fabrication. Composite materials utilized everywhere i.e. aerospace; wind power generation, offshore applications, telecommunication and industrial fields etc. huge flexibility, light weight and high strength make composite materials most suitable materials for aerospace applications. In this review paper, possible combinations, classifications and important development phases have been discussed. In addition, detailed features and characteristics of matrix and reinforcement materials and their categorization as composites have been listed.

**Keywords:** Composite; Glass fiber reinforced polymers; Nanocomposites; Reinforcement; Matrix

## Abbreviations

GFRP: Glass fiber reinforced polymers; MPa: Mega Pascal; MP: Melting point; DOE: Design of experiment; PLA: Poly lactic acid; GPa: Giga Pascal; PDMS: Polydimethylsiloxane; UV: Ultraviolet; PVA: Polyvinyl alcohol; MMC: Metal matrix composite; PVC: Polyvinyl chloride; FRC: Fiber reinforced composite; PHB: Polyhydroxy butyrate; SiC: Silicon carbon

## Introduction

Since the beginning of civilization, human being are learning and applying the natural rules and phenomenon for their innovations. Composites have been developed by clearly examining the natural phenomena of bones. Bone is the biological material lighter in weight but having good strength, which is achieved by combination of collagen with appatite. Composites are formed by the combinations of suitable materials for getting desired properties like thermal resistance, heat resistance, high strength, lower co-efficient of thermal expansion, electrical, acoustical and optical properties [1-3]. Usage of composite materials and its development started in 1940 through two main resources/driving forces. The driving forces are firstly, high strength and light weight in military and secondly the growth in market of plastics. There was a need of for more stiffer and lighter weight composites for getting the required benefits. Combination of two or more materials gave the best results. So it covers vast engineering materials. The concrete is another example of composites.

Composites can be regarded as a mixture or combination of two or more than two materials which differ in composition having different chemical and physical properties but the new mixture formed achieve different appearance and properties than individual component. Carbon fiber reinforced polymer composites can provide cutting

force i.e. tool life, machine dynamics, heat generation, machine induced damage etc. this factor is utilized in the aerospace industry to minimize the processing cost and enhance the tool/equipment life [3-4].

Four generations of composites are regarded as four important phases of in the history of composites. They are shown in (Table 1). Glass materials have high strength. Initially working was done to make vehicle's parts with glass fibers but there were some limitations. The limitations of micro-crack on the surface, brittleness and fracture etc., so sensitive parts of vehicles made from these fibers were causing the problem. This problem was solved by immersing fibers in light weight and low strength matrix [5-6]. Initially, the limitation was to know "how to add fibers in the matrix to ensure evenly distribution". This limitation raised the concept of high pressure but it damaged. In 1940, development of Pittsburgh plate glass solved this problem. So initially glass fibers were utilized in marine industry. In 1940s the wooden or metallic boats was replaced with glass fibers. In 1944, the allied forces used these metallic boards and arrived at Normandy. US navy replaced all the electric boards with glass fibers in 1942. So the primary commercialized composites were glass fiber reinforced composites and greatly utilized as 90% all over the world [7-8].

A new industry of Saint-Gobain was setup in France. They were manufacturing the blades of helicopter. There was felt a need of new high modulus composites for military purposes. Scientist focused on the manufacturing of metal matrix composites. The elementary key was addition of fiber or particulate in metal for giving heat resistant property to light weight metals and to lower the thermal expansion co-efficient. Next in 1969, an attempt was made to produce stronger starting material as reinforcement fiber than rayon. Aramid compound was developed in 1964 by Stephen Kwolek. She discovered

**Table 1:** Four generations of composites in embryonic stages.

| Years             | Generation      | Composites                                |
|-------------------|-----------------|---|
| 1940's            | 1 <sup>st</sup> | Glass fibers reinforced polymers (GFRP'S) |
| 1960's            | 2 <sup>nd</sup> | High performance composites               |
| 1970's and 1980's | 3 <sup>rd</sup> | Synergy of properties of materials        |
| 1990's            | 4 <sup>th</sup> | Hybrids and Nano composites               |

**Figure 1:** High performance composites to increase durability and reduce weight for maximum space utilization [6].

5 times stronger material than steel and used them as bulletproof fibers. The high modulus fibers were required by space and aircraft in 1960. These expensive fibers had been used for civil applications in 1970's i.e. in the space station and space shuttle etc. After high modulus fibers, Metal Matrix Composites (MMC) were made and examined. The requirements of composite materials for aerospace applications were light weight, low thermal co-efficient of expansion and high temperature resistant. For this purpose the liable additives for matrices were introduced in 1970's which were "SiC" with carbon and boron coatings. In 1976, Yajima presented SiC fibers for high performance applications. After that, high temperature reinforced composites had practiced at the decade. Graphite fibers were added in carbon matrix to achieve the features of heat resistance and high toughness, which eventually introduced a class "carbon-carbon composites CMCs". Ceramic engines development for automobile industry was the aim of ceramic engineers in that era.

Composites started to use in smaller and smaller level after 1990, with the help of industrial and academic researches e.g. in hybrid materials and Nano-composites. In this generation the new design strategy emerged called as biomimetism. It was the study which made the scientists to focus on hybrid configuration. The hybrid materials are basically formed from the mixture of organic and inorganic components e.g. wood, shells of sea animals, and bones etc. The structure of such biological parts had been studied to develop the hybrid material. When the structure of bones was studied, scientist realized that it was made up of collagen in which hydroxyapatite was embedded. This gave the idea to scientists of reinforcing in matrix. Hence after that SiC was embedded in alumina to achieve the specialized properties [9-10]. As shown in (Figure 1), High performance composites and hybrid composites are highly utilized for aerospace applications owing to low density and durability.

**Figure 2:** AL/SiC metal matrix composites fabricated by Stir Casting method [12].

### Classification of composites

Composites can be classified as structural and functional composites on the basis of their usage in industry and their properties etc. Composites are generally classified on matrix and reinforcement basis.

#### Matrix based classification

Matrix based classifications are four types, Metal matrix composites, Ceramic matrix composites, Carbon matrix composites and Polymer matrix composites [1]. In metal matrix composites, metal is used as matrix due to certain characteristics as high temperature ranges, higher toughness, moisture effects, high thermal and electrical conductivities, better fatigue resistance etc. Although these composites have many advantages, there are also some limitations as metals may be heavy, encounter degradation and fabrication cost etc.

Besides high strength, abrasion resistance and stiffness, metal matrix composites have enhanced oxidation resistance. Metal matrix composites can be fabricated or manufactured by different techniques i.e. compo casting, squeeze casting, hot pressing, high pressure infiltration casting, pressure less infiltration, physical vapor deposition, self-propagation synthesis etc.

Nowadays aluminum silicon carbide composites have been practiced that have specialized properties i.e. compatible bonding between matrix interface and segregation of silicon carbide particulates according to different weight contents. Wear resistance improved upto a greater extent by AL/SiC composites [11-12]. Figure 2 shows AL/SiC metal matrix composites fabricated by Stir Casting method.

In addition, metal matrix composites are utilized for laboratory manufacturing of automotive components i.e. gears, brakes, pumps, shafts, connecting rods, engines and pistons etc. Enhanced wear resistance and cutting capability can be achieved by manufacturing of tough MMCs (Metal Matrix Composites). Ceramics are used as matrix material in ceramic matrix composites. Generally ceramics are made up of metallic and non-metallic elements. The chief advantages of usage of these composites are temperature range of >2000 degree centigrade, low densities, high elastic modulus values etc. The main limitations are lack of uniformity, brittleness, low mechanical shock and thermal resistances.

In carbon matrix composites, carbon is used as matrix material. The carbon-carbon composites (c/c) give good strength in elevated temperature up to 2200 degree centigrade. These composites are used for structural and non-structural applications due to high fatigue resistant, high dimensional stabilities, high strength to weight ratio

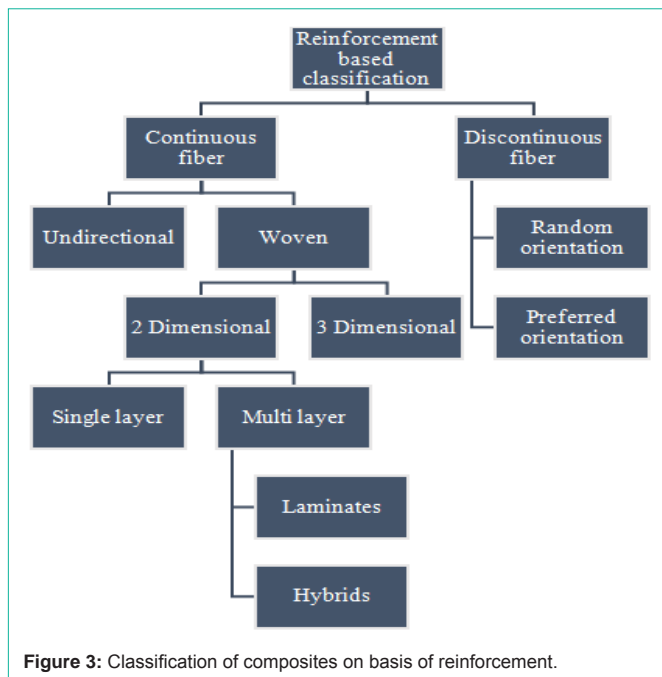


Figure 3: Classification of composites on basis of reinforcement.

etc. The main disadvantage of *c/c* composites is cost materials and cost of fabrication.

Polymer matrix composites are highly developed composite materials. Such materials used in specified areas to get the unique properties. In these types of composites, polymers are used as matrix. Polymers are usually organic compounds comprising of hydrogen, carbon and non-metallic elements. Thermoplastic and thermosetting Polymers used as Matrix in PMC Composites.

Now a-days main concern is to improve the overall performance of matrix materials by modifying the impact resistance, thermal and hydro degradation. Toughness is the main factor that has direct impact on impact resistance. Compression strength can be enhanced by transmitting the tension from fiber to resin and resin to fiber. Strain failure and shear modulus of matrix help in transmission of load. Shear modulus of 5GPa can be achieved by using polymeric materials. Thermoplastic materials like PEEK (Polyether Ether Ketone) and their combinations can be utilized. The main limitation is the high temperature of up to and more than 350 degree centigrade. So, to overcome these limitations polymeric materials are now the main area of concern in the composite industry [13-15].

## Reinforcement based Classification

Reinforcement phase exist normally in 10% fraction or more Fiber Reinforced Composite (FRC) and Particulate Reinforced Composite. Fiber phase is in dispersed form in such composites. Matrix evenly distributes the weight while fiber bears the main load [10]. Fiber reinforcement could be carried out in continuous form. There should be proper adhesion between matrix and fibers to ensure evenly load distribution from one fiber to another fiber. FRC provides high strength and high stiffness, which is the main objective of FRC. Particles used as reinforcement have different functions and vast impacts on the matrix material. E.g. if particle is ductile and matrix is brittle, then high toughness can be achieved. Conversely if matrix is

ductile and particle is brittle then high strength and stiffness is achieved [15]. Fiber reinforced composites can be continuous or discontinuous and can be random or preferred oriented. Continuous fibers can be multilayer to form laminates and hybrids (high performance fibers). Figure 3 show a classification on basis of reinforcement.

## Matrix Materials

Matrix is also termed as binder. The function of matrix is to hold the fibers and protect it from environment. Matrix materials are divided as polymers Matrix, metals matrix, ceramics matrix and carbon matrix. Polymers are mostly organic compounds having wide range of applications. Polymer matrix composites are the most developed composite materials that can be easily fabricated into large and complex shape. These are further divided into two categories, Thermoplastic and Thermosetting Polymers [1,6].

Thermoplastic polymers soften upon heating and can be reshaped with heat and pressure. The most commonly used thermoplastic polymers include polypropylene, polyurethane, Polyvinyl Chloride (PVC) and nylon [1,12].

Thermosetting polymers cross linked during fabrication and curing process and cannot be reshaped with heat and pressure. Thermosetting polymers include polyesters, epoxies and polyimides. Thermosetting polymers are mostly used in composites industries.

Polyester resin is used mostly in body filler and decorative casting. It is sensitive to ultraviolet rays and can tend to degrade over time, and thus coating is required to preserve it [12]. It has good mechanical strength, low viscosity and versatility, good heat resistances, good electrical properties and its curing temperature is 120°C. It is used in making surfboards and for marine applications. Its hardener is peroxide and Methyl Ethyl Ketone Peroxide (MEKP).

Epoxy resin is almost totally transparent when cured. It is used as structural matrix material in aerospace industry. Its properties are Low shrinkage during curing, high strength and flexibility, better adhesion between fiber and matrix, better electrical properties, resistant to chemicals and solvents.

Polyimides matrices are mostly used in premium high performance composite applications as they are specialty polymers. Their tensile and flexural strengths are commonly around 110MPa and 220MPa, respectively [1,12].

It has properties like excellent mechanical strength, excellent electrical properties, fire resistance and low smoke emission, hot molding under pressure, curing temperature is 175°C and 315°C [1,12,13].

## Reinforcement

Reinforcing agents are either particulates or fibrous in shape depending upon the aspect ratios. Particulate reinforcing agents are the most common and the cheapest materials. They give the specialized isotropic properties to composites. They could be organic or inorganic. Powdered cellulose and powdered rubber are the examples of organic particulate reinforcing agents while silica and metal oxides are the examples of inorganic particulate reinforcing agents. Fiber reinforcing agent can be either organic or inorganic. Main types of fiber reinforcement used in composites industry are

**Table 2:** Reinforcement materials for composites [9,15-19].

| Fiber name    | Density (g/cm <sup>3</sup> ) | Melting Point (°C)  | Properties  |
|---------------|------------------------------|---|---|
| Nylon         | 1.15                         | 190–350°c   | Lustrous, Durability, High elongation, Moisture regain(M.R) 4.5                         |
| Polyester     | 1.22-1.38                    | 248-258°c   | M.R.0.4 %   |
| PVC           | 0-0.94                       | 250°c   | M.R 0-0.1   |
| polyethylene  | 0.9-0.91                     | 110-120°c   | M.R practically nil. Hence no effect of moisture to the mechanical properties of fibers |
| polypropylene | 0.9-0.92                     | 165°c   | Lightest of all commercial fibers M.R 0.05  |
| Acetate       | 1.32                         | 175°c   | Poor resistant of conc. acids and alkalis<br>M.R 6.5                                    |
| Acrylic       | 1.17                         | 232°c   | Resistant to acids , excellent resistance for UV<br>M.R 1-1.5                           |
| Spandex       | 1.2                          | 230°c   | M.R 1.3   |
| Rayon         | 1.51                         | Does not melt. It starts to decompose at around 210°C   | M.R 11-16   |
| Glass         | 2.50-2.55                    | 733-849°c   | M.R 0   |
| Lyocell       | 1.56                         | Does not melt.<br>Maximum decomposition temp is 375°c   | Moisture regain 11.5  |
| Wool          | 1.30                         | Does not melt decompose at 155-177°c  | M.R 13-16   |
| Cotton        | 1.54                         | Non melting<br>Decomposes at 149°c  | M.R 8.5   |
| Silk          | 1.25-1.34                    | Non-melting<br>Decomposes at 165°c  | M.R 11  |
| Jute          | 1.48                         | Non-melting. On heating to high temperature, fibers chars and burns. Ignition temp is about 193°c | M.R 13  |

glass fiber, carbon fiber and poly-aramid fiber.

Glass is one of the strongest and ideal reinforcing fibers for plastics. It is non-combustible and also chemically resistant. Its constituents are readily available. It is produced by drawing and rapidly cooling molten glass. It is available in variety of types and formats [1,13]. Carbon fibers have high strength, high modulus, low density and high electrical conductivity. Composites made by using high modulus, unidirectional carbon fiber can exceed the modulus of steel. Carbon fibers have applications in defense and aerospace industry [14]. Poly-aramid fibers are organic, man-made fibers having properties like flame resistant, chemical resistant and corrosion resistant. Their specific strength and specific modulus are superior to all glass fibers and some carbon fibers. These fibers are of two main grades, lower modulus material and higher modulus material. Higher modulus material is most widely used in composite industry. These fibers are used to produce light-weight and incredible strong composites [1,10,13].

### Suitable Combination of Materials as Matrix and Reinforcement

Different fibers can be chosen as matrix or reinforcement materials depending upon their properties and end application. Many fibers are used for composition of composites. Following is the list of some most commonly used composites materials in (Table 2).

In glass reinforced polyester composites, glass is used as reinforcement material while polyester is used as matrix material. Polyester is used as matrix material owing to its special features i.e. dimensional stability, electrical properties, economical then all resins available, chemical resistance, quite good mechanical properties, low viscosity [9,18]. Glass is used as reinforcement material because it is less brittle, light weight material, thermal insulator and has high elongation before break. Glass reinforced polyester

composites are simple molded shapes are formed that results by reduction and combining the components. These composites have improved aerodynamics and good surface quality, 60 % weight reduction. Clutch pedals are made from this composite and they are used to increase the strength of slabs, beams and columns of bridges and buildings [9,15-25].

In glass reinforced nylon composites, nylon is used as resin material while glass is used as reinforcement materials. The properties of nylon are durability, good specific strength, higher elongation, abrasion resistance, resistance for many chemicals, rots, molds, animals, fungi and insects, resilient, low rigidity, toughest engineering plastic (nylon 6/6).

The combination of these two materials (glass and nylon) in composites results in properties like high strength, rigidity, toughness, stability at elevated temperature, chemical resistance, used in many engineering components like under-bonnet, wind surfers and automobile parts are made from this composite [16].

Spandex fiber reinforced shape memory epoxy resin composites use spandex as reinforcement while epoxy is used as matrix material in above mentioned composite. Spandex fiber has superior stretch ability, high elastic recovery, light weight, soft, high strength and better quality than rubber. Shape memory Epoxy fiber possessing special properties i.e. Good shape memory effect, Poor stiffness and strength, Small recovery force, dual shape capability, low reliability, unique mechanical and thermal properties. The properties of spandex reinforced shape memory epoxy resin composites are improved mechanical performance of pure shape memory polymers, recoverable strain can be increased to 5 %, reliability increased.

Cotton fabric reinforced polypropylene composites use cotton fabric as reinforcement material while polypropylene fiber is used as matrix material [21]. Cotton fiber has good drape ability, strength,

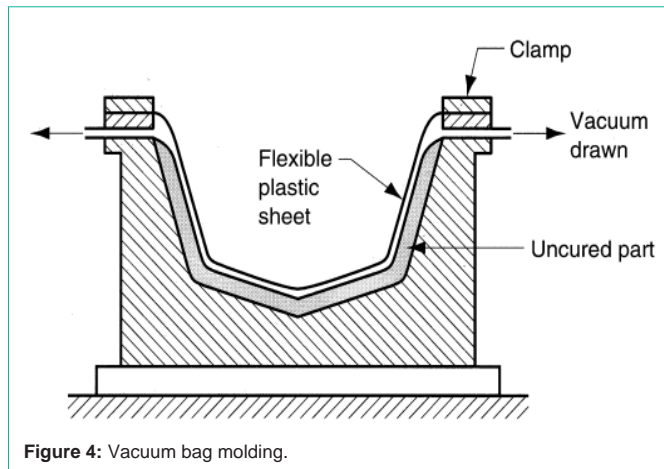


Figure 4: Vacuum bag molding.

high absorbency, good color retention, well printing, washable at machine, dry cleanable. Polypropylene is flexible, tough, degradable due to contact with UV radiation and heat, practically economical, isotactic, 20 % lighter than nylon, low specific gravity and lightest of all fibers. The cotton fabric reinforced polypropylene composites have high flexural strength, tensile strength and tensile modulus, tensile elongation decreases, increase in damping co-efficient, environmental advantages, low cost product.

Jute fiber reinforced low density polyethylene has low density polyethylene as matrix while jute fiber is used as reinforcement material. At room temperature low polyethylene fiber is not reactive, flexible, rather tough but also breakable, excellent chemical resistance, corrosion resistant [23]. Jute fiber has properties like good dimensional stability, long fiber, soft vegetable fiber, average abrasion resistant, prevention abilities are better than cotton, easy to dyeing. Jute fiber reinforced low density polyethylene composites have high bending elongation, high bending strength and tensile strength and high mechanical strength.

Silk-epoxy resin composites use epoxy as the matrix material while silk is reinforcement material in silk-epoxy resin composites [15,24]. Silk fiber is smooth and soft, less slippery, strongest natural fibers, poor conductor of electricity, resistant to mineral acids. Flexural strength of composites increases up-to 33%, high toughness, tensile and impact achieved by silk-epoxy resin composites as compared with other synthetic fibers as Kevlar and carbon, increment in the volume of silk fiber results in high pressing pressure.

Lyocell fiber-reinforced cellulose acetate butyrate contains lyocell fiber as reinforcement material while cellulose acetate butyrate is used as reinforcement material. The properties of lyocell fibers are soft fibers, absorbent, very strong, resistant to wrinkles, drapes well and can be dyed in many colors.

Cellulose acetate butyrate is thermoplastic, flexible, can be stretched till 60% to its original length. Its molecular structure does not change, so can be melted and molded into different shapes. This material is susceptible to impairment from alcohols and ketones. The properties of above mentioned composite are easy processing, even alignment, void formation and high moisture absorption.

Glass fiber reinforced acrylic resins composites use glass fiber as

reinforcement material while acrylic is used as matrix material. Acrylic fibers feel like wool, high fastness to light and good heat retention, durability, easy to care, bulky, low water absorption, weather and light resistant [19]. Glass fiber reinforced acrylic resins composites are flexural strength increases, fracture resistance increases.

Polyester cotton reinforced polypropylene composites use polyester as reinforcement material while polypropylene is used as matrix material [17]. Polyester cotton composites are available in variety of weights and blends, pilling can be controlled due to presence of polyester. These composites possess the fair performance of cotton, high laundering temperature, less expensive, easy care, strong and soft product. The properties of polyester cotton reinforced polyethylene composites are high mechanical strength, chemically reactive, light weight, Pilling resistant, inert, easily available and low cost product and susceptible to environment [22,25].

## Composite Fabrication Techniques

Composites are manufactured by variety of techniques including vacuum bag molding, pressure bag molding, autoclave molding, resin transfer molding, hand layup, filament winding, pultrusion and forming [1,12]. Hand layup method is slow and time consuming but are of great importance in aerospace industry due to its flexibility and wide range of shape making characteristics. As this method comprises of many steps and thus its production rate is very low. Filament winding is mostly used for pressure vessels, rocket motor cases, tubes and other similar shapes. This technique has high production rate and suitable for making parts having rotational symmetry although odd shapes can also be made by using some special procedures. Pultrusion uses wetting station for pulling of fibers. After pulling of fibers heated die is used for the curing of resin. This method is cheaper, relatively productive and suitable for making materials having constant cross section. Fiber orientation is one of the limitations of this method. Resin transfer molding comprises of group of processes that involve injection of resin into a fiber. Heating may be required for resin reaction. Although, this method is not cost effective but it has high production rates and dimensional stability. In vacuum bag molding (Figure 4), mold is covered with flexible sheet so that it can be sealed from outside air. Vacuum is drawn after sealing the mold that creates pressure during curing. In order to accelerate curing, heat is applied. This method has limitation of pressure supplied that cannot exceed 98 KPa. Forming involves two types of forming, press forming and diaphragm forming. Press forming is the simplest process while diaphragm forming is difficult. Diaphragm forming has disadvantage of slow cycle time [26].

## Applications

Composites materials have gained importance due to high stiffness, high strength, improved fatigue life, resistance to corrosion and light weight etc [27-30].

### Aerospace

Composites are mostly significant in aircraft applications. Aircraft designer deals with many features of safety and power, these features can be achieved by correct use of composites. For this purpose carbon and glass reinforced hybrid composites are used. Fiber-reinforced polymer composites have made significant contribution in designing and manufacturing area in the aerospace industry. They are used

**Table 3:** List of bio-composites and their properties [34-36].

| Matrix                    | Reinforcement  | Properties   |
|---------------------------|----------------|--|
| PLA(poly lactic acid)     | Jute fiber     | Highest elongation areas                                       |
| PLA                       | Flax fiber     | Lowest elongation area   |
| PLA                       | Sisal fiber    | Maximum flexural modulus(19)GPa                                |
| Polycaprolactone          | Flax fiber     | Low flexural modulus(1.9)GPa                                   |
| PLA(poly lactic acid)     | Hemp fiber     | Maximum tensile strength(73)MPa and flexural strength(102)MPa  |
| PHB(polyhydroxy butyrate) | Flax fiber     | Highest impact strength  |
| Soya resin                | Natural fibers | High strength to weight ratio, reducing wear and tear on roads |
| Soya based resin          | Recycled paper | High strength to bear load                                     |

**Table 4:** Flexible composites and their properties [37-39].

| Matrix                  | Reinforcement    | Properties                                    |
|-------------------------|------------------|---|
| Polyurethane            | Braided graphite | Flexible and mechanical load bearing capacity |
| (PVC)Polyvinyl chloride | Twisted yarns    | Large radius buckling                         |
| Rubber                  | Cord             | High fatigue resistance, flexibility          |
| 184 Silicon Elastomer   | Kevlar           | High stiffness and strength                   |

**Table 5:** Shape memory composites and their properties [40].

| Matrix       | Reinforcement              | Properties            |
|--------------|----------------------------|-----------------------|
| Polyurethane | Carbon powder              | Stress recovery       |
| Epoxy        | Silicon carbide            | Elastic modulus       |
| Polyurethane | Nano fillers(Nano carbons) | Excellent flexibility |

basically as starting materials for the aircrafts and space craft's construction [8].

### Industrial composites

Transportation, sports, marine, construction and further new infrastructure are the areas of industrial composites. High act continuous carbon fibers are used where high strength, high stiffness and light weight are the requirements but these composites are expensive one. The marine materials are vulnerable to attack from nature and enemy. So ship hulls are made up of carbon steel to cope with corrosion etc. Fiber Reinforced Plastic (FRP) hybrids are used in civil construction. These hybrids are used due to its nature of bearing heavily corrosive environment e.g. in bridge construction. Composites are light in weight, better resistance to chemicals and fire, which is highly desirable in chemical industry. Composites grips are widely used for alkaline and acidic environments e.g. in storage tanks, columns and blowers etc. Due to excellent fission gas retention properties, composites are used in nuclear industries. The ceramics fuels are used in steel matrix is recommended in fast reactors [31].

### Wind power composites

The aspects of composites like safety and resource savings are used in wind power generation, especially for fabrication of blades. In the future, structural modification in wind turbine i.e. size of blades is estimated to be enhancing to get unique functional features. Collapse can be avoided by identification of failure utilizing experimental and analytical techniques. Numerical simulations are becoming more popular as compared with analytical and experimental methods owing to the less processing cost [32].

### Telecommunication applications

Hybrid cables are used for data transmission in telecom industry. Nowadays hybrid aerial are used which is basically an underground cable and advanced cabling solution used for network equipment. The hybrid composite cable is used mainly for transmission of power. Composites are good antimagnetic agents; spark free and high quality electrical insulation. These are used in link boxes; profiles for distinguishing current carrying phase to stop short circuit. These composites have fillers on a nanometer scale. Nano composites are used mostly in industrial equipment, auto motives, and electronic parts etc [31].

### Offshore applications

Composite materials can bear aggressive environment and high pressure conditions. These aspects of composites are highly utilized in offshore applications [31].

### Armor system

Impact resistance and light weight factors of composite materials are utilized in armed applications to achieve ballistic performance e.g. composite metal foams. These composite foams have the capability of absorbing K.E (kinetic energy) up to sixty to seventy percent [33].

### Smart memory hybrid composites

Smart memory hybrid composites are used in engineering practical applications due to growing requirements on carrying into action of materials. Thermoplastic composites has long lasting potential properties utilized for mass producing light weight structural parts [3,25].

### Comparison of Composites

Bio composites are compared in Table 3 with their properties have following constituent materials as matrix and reinforcement [34-36] followed by flexible composites [37-39] in Table 4, shape memory composites in (Table 5) [40] and soft magnetic composites in (Table 6) [41-43].

### Conclusions

Composite materials have many types, characteristics and manufacturing technologies. Composite materials captured the attraction of world due to special properties of high strength, high modulus, light weight, shape retention, stiffness, thermal resistance, unique functionalities etc. Unique and enhanced physical and mechanical characteristics of composite materials make them suitable for aerospace and automotive applications. Advance

**Table 6:** Soft magnetic composites and their properties [41-43].

| Matrix  | Reinforcement                               | Properties  |
|---|---|---|
| Resin   | Iron  | High electrical resistivity, good magnetic property, Good permeability. |
| Resin   | Iron powder                                 | Three dimensional isotropic ferromagnetic                               |
| Resin   | Nickel iron                                 | Highest permeability  |
| Silicon elastomers                              | Iron particles                              | Good magnetic properties  |
| Polydimethylsiloxane(PDMS) carbonyl             | Iron  | Control drug delivery   |
| Glutaraldehyde (PVA) polyvinyl alcohol hydrogel | Fe <sub>3</sub> O <sub>4</sub> nanoparticle | Bear stretching, bending deformation                                    |

manufacturing techniques and modern fibers are now developing for the composite materials to achieve higher temperature ranges and diverse fabrication methods. Ceramic metal composites are suitable for oxidation resistant, abrasion resistant and heat/thermal resistant applications. Polymer matrix composites have many applications in designing and wear tolerance areas like industrial systems and mining. Ceramic metal composites and metal matrix composites are utilized in light weight applications. Fiber reinforced composite materials are of great importance and most commonly utilized in aerospace and civil applications. Different types of fibrous materials have been utilized as preforms i.e. braided woven, two dimensional and three dimensional fibrous materials. High temperature resistance, fracture toughness, high strength, ductility and fire resistance are responsible for the tremendous growth of metal and ceramic matrix composites. Now advanced and high performance composites could be developed by using nanotechnology. Nanoclay, metal nanoparticles, nanofibers and carbon nanotubes are used to achieve new functionalities. Hybrid composites and multistate composites have been developed. These are the new applications of nanocomposites to achieve high mechanical properties, impact strength, thermal stability, fracture toughness and fatigue resistance. Carbon-carbon composites are the most suitable composites for rocket nozzles, turbine engine parts and heat shields. Self-sensing or self-monitoring composites are developed to detect the damage or any malfunctioning in the aerospace parts. Self-healing composites are another new advancement in the field of composites. Such kind of innovative composites can repair the damages automatically using agents like hollow fibers and vascular chains. Self-healing and self-monitoring composites are used to make aerospace parts more protective and safe by detecting and repairing the damages [44-49]. Besides innovations and tremendous growth in the field of composites, there are some limitations as well. Reliability and cost factor cannot be neglected while considering advanced composites i.e. self-healing, nanocomposites and self-sensing composites. There are great efforts to reduce the cost and repairing time. Flexibility along with high strength is the main aspect that makes composite materials superior than metals. In future, there is a possibility to replace all metals in the aerospace industry with composite materials.

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