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A REVIEW ON PROCESSING OF POLYMER MATRIX COMPOSITES: CHALLENGES AND OPPORTUNITIES

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ABSTRACT

The polymer matrix composites (PMCs) are gaining popularity among automobile, aircraft and medical sector due to their promising role in manufacturing of light weight and high strength components. The wide varieties of polymers are used as matrix materials in combination with ceramics, carbon and synthetic fibers to fabricate polymer matrix composites. This paper makes an attempt to discuss the various polymeric materials used that can be used as matrix in PMCs and also focuses on their processing techniques in respect to the area of their use. The processing environment of the polymer based composites plays significant in deciding the mechanical and physical properties of the composites. The addition of certain additives like fillers, plasticizers, colorants and flame retardants during the processing can improve tensile and compressive strength, abrasion resistance and dimensional stability. Later the challenges in manufacturing of PMCs have been discussed with scope of opportunities available in the global market.

KEYWORDS: *Polymer; Matrix; Composite; Fiber; Reinforcement.*

1. INTRODUCTION

Polymer composites are composed up of variety of short and continuous fibers bonded with organic polymers matrix materials like thermosetting and thermoplastics. These composites are designed for high strength, fatigue, fracture toughness and environment resistance properties. The main advantages of polymeric composites are their light weight and strength along the direction of reinforcements. These composites are known for their wide applications in marine, automobile and aircraft components. These composites are having tendency to provide work under water and high corrosive environment due to their enhanced mechanical and chemical properties. The polymer matrix composites (PMCs) can be classified on the basis of matrix materials. Two polymeric materials like thermosetting and thermoplastics are used to fabricate the composites. These composites are derived from various forms of fibers like glass, carbon and Aramid (Kevlar). These fibers are impregnated into the matrix by various processing techniques. These composites are also suitable for military aircraft structural applications [1-2]. Due to the stainless and strength of the PMCs these are widely used in manufacture of medical and surgical equipments. These are also used in the fabrication of cover and frames for the X-Ray and other radiation equipments. The continuous developments in their fabrication techniques are responsible for their versatile use in various high end applications. The processing cost of these composites is the main decisive factor for their implementation in manufacturing industries.

2. PROCESSING OF POLYMER MATRIX COMPOSITES

Polymeric composites are formed by different techniques depending upon the material like thermolplast or thermoset, processing temperature, ambient stability and shape or profile of component. The polymers are often processed under high temperature and pressure. The thermoplastics are processed above trasition temperature and the pressure is applied to retain the final shape of product. The advantage of thermoplastics over thermosets is that there is no chemical reactions involved which generate gases and heat during processing [3]. Whereas thermosets are processed in two consecutive stages in which first semi-liquid or liquid state polymers are produced and then they are poured in mould along or over the fibers laminates to produce composites.

2.1 Processing techniques for polymeric materials

There are many processing methods for polymeric composites with thermoset matrix materials like epoxy, unsaturated polyesters and vinyl esters. In this section some most versatile processing techniques are discussed. Table. 1 shows the brief view of polymer matrix composite processing techniques with their characteristics and applications.

a) **Hand layup and spray technique:** These are the one of the simplest polymer processing techniques in which fibers are laid into mold by hand and resin is sprayed or rolled on it. Resin and chopped fibers are sprayed combined on the mold surface. Then resin and fiber layers are densified with hand rollers. The curing of charge in mold is done at higher temperature in furnace or at room temperature. The curing of an charge in die is carried out to complete polymeric reactions to attain the required shape. In some cases it is carried to reduce thermal stresses from the composites.

b) **Filament winding Technique:** This processing technique is used to fabricate large cylindrical pipes and spherical vessels used for chemical storage. This technique uses glass, carbon and aramid fibers with epoxy, polyester and vinyl ester resins to develop filament wound components. Two types of winding pattern can be made on component i.e polar and helical winding. In polar winding fiber rows do not cross over to each other whereas in helical winding they cross each other. The set up is composed up of mandrel having rotating facility with carriage to move roving of fibers parallel to the axis of mandrel.

c) Pultrusion: During this process continuous parts of composites with axially placed fibers are produced. The fiber reels are used to provide continuous row of fibers during the process. These fiber rows are then passed through the resin bath with catalyst. Resin impregnated fibers are then passed through a narrow passage called collimator before moving to heated die. In the later stage mat type fabric is added to provide longitudinal strength to the part. Through this process more than 60% volume fraction of fiber can be introduced into the polymer matrix [4].

d) Resin Transfer molding (RTM): RTM is a closed mold and low pressure process in which liquid resin such as epoxy or polyester is injected into the mold by low pressure pump. This low liquid pressure resin is allowed to pass over the preheated preform of desired fiber. The RTM mold has built-in heating source to accelerate the process of curing. The large complex profiles can be obtained by this process. The process is simple and speedier than the previous processes due to scope of high level automation.

e) Injection molding: In this process reinforcement fiber and thermoplastic matrix are mixed to produce a blended yarn. This yarn is subjected to external heat and pressure to wet the reinforcements with matrix material to obtain the desired composite. The items processed through injection molding are automotive bumpers, fenders and air spoiller.

Table. 1 Polymer matrix composite processing techniques

Processing Technique	Characteristics	Applications
Hand lay & spray	Large parts, low pressure, low density	Frames, structures, covers
Filament winding	Intricate geometries, large tubular parts, medium speed	Pipes, shafts, pressure vessels
Pultrusion	Continuous system, uniform cross-sectional parts	I-Section Beams, columns
Resin Transfer Molding	Control over fiber placement, faster, complex profile parts	Car body panels, structural
Injection molding	High production, short fibers, thermoplastics	Exhaust fan blades, gears & sprockets
Compression molding	High density, high fiber, high production, high accuracy	Aircraft, rudder, elevator, gear box doors

3. LATEST OPPORTUNITIES IN MANUFACTURING OF PMCS

The polymer composites are gaining vast interest among automobile, aircraft, marine and biomedical manufacturing companies. This is due to the availability of better processing techniques and multifunctional fibers and matrix materials. The choice of various alternatives for material processing and variety in materials has increased the possibility of PMCs in various sectors. These composites are suitable for production of various car body panels and structures. PMCs are also for manufacturing of bottom of marine boats (boar hull) due to their resistance toward moisture environment. These composites are also finding applications in fabrication of aircraft rudders, elevators and take off gears doors. The researchers are also trying to enhance the thermal capacity of polymer composites. The organic polymers can maximum work under temperature upto 400^{0}C whereas ceramic matrix can sustain upto 316 ^{0}C. The thermal capacity of the composites can be enhanced by selection of thermally stable matrices with reinforcements.

Thermoplastics are having the advantage of easy processing and molding and on other hand thermosets are capable of performing under corrosive environment and also provide dimensional accuracy. The possibility of PMCs for space applications can be improved by enhancing structural integrity and defect free service at high temperature near to 800^0C. The properties such as high strength, specific stiffness, low thermal expansion and better resistance toward corrosion and fatigue have increased the possibility of these composites in defense sector. The metal matrix and ceramic based composites are finding lot of applications in defense machinery. The trend of using natural fibers like jute, rapeseed, husk, flex, hemp etc. is increasing in fabrication of bio polymer composites for medical applications [5].

4. CHALLENGES IN MANUFACTURING OF POLYMER MATRIX COMPOSITES

To develop more reliable PMC structures to cope up the engineering requirements of given applications, it is necessary to understand and model the various aspects of PMCs systems. This section highlights the areas which require special attention for the researchers in reference to the challenges involved in development of PMCs composites.

The objective of processing of PMCs is to ensure proper control on resin/matrix content, placement of fibers and desired curing time. Through the modeling influence of various parameters can be determined to apply temperature and pressure in a controlled manner. The purpose is to ensure the control over properties of PMC systems. The ongoing developments in the field of polymeric materials have posed many challenges to use the low cost fabrication techniques. The requirement of impact resistance in aircraft and marine applications poses critical effect on the reliable functioning of polymer composites. There is still need to explore the mechanism of damage and its relation with properties of the matrix, fiber and strength of interfacial bonding between reinforcement and matrix. The chemical stability and effective bonding between reinforcement and matrix at interface yield maximum strength and resistance toward environmental degradation [6-7]. There is a strong need to develop knowledge base about the coating materials and surface treatments which can enhance the bonding strength between the fiber and matrix. There is also a difficulty in understanding the mechanical behavior of composites due to heterogeneity which arises complexity in failure modes of composites. Apart from strength there is dire need to study the fatigue behavior of these composites. Due to hidden strains in fibers and stresses in matrix base under various loading conditions it is difficult to understand mechanism of fatigue failure in polymer matrix composite materials. The development of cracks in matrix base, debonding/separation and bridging in the composites are difficult to predict under various loading conditions. There is still lack of knowledge available for use some composite systems in specific environments. The environments that are affecting the properties of composites are high temperature, moisture, loading conditions, corrosive chemical agents and ultraviolet radiations. A thorough understanding of these environments can help in develop robust design of composite systems.

5. SUMMARY

In this article the design of polymer matrix composites is outlined. The processing techniques for PMCs have been discussed. This article also highlights the issues and challenges in fabrication of PMCs. The thorough knowledge of processing techniques and field environment can help to improve the performance characteristics of PMCs in relevant applications. In the later sections latest applications of PMCs have been discussed. The choice of appropriate processing technique, fibers, matrix and their proportion is the key factor for the development of polymeric composite for the required application.

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