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The Influence of Dimensional parameters on Mechanical Behavior of Fiber Reinforced Polymer Matrix Composites: A Review

Harsha H M [*1]
[*1] Department of Mechanical Engineering,
GMIT, Davangere, Karnataka, India

Dr. K G Satish [2]
[2] Department of Studies in Mechanical Engineering,
UBDTCE, Davangere, Karnataka, India

Abstract: **Over the last four decades, conventional materials have been replaced by composites as they have reasonably superior properties and characteristics. These composites are abundantly used in the fabrication of structural and non-structural components under various engineering applications. The various dimensional parameters such as major fiber and matrix factors, the volume/weight fraction of both fibers and matrix influence the mechanical behavior of fiber reinforced composites. Types of fibers include synthetic, natural, long, short and particulate type. Unidirectional and bi-directional fabrics can also be used. Furthermore, exposure to different environments, operating temperatures, chemical treatment of fibers, and fillers influences the mechanical behavior of fiber reinforced composites. This paper includes a brief review of the influence of dimensional parameters on the mechanical behavior of fiber reinforced polymer matrix composites.**

Keywords: Fibre & Matrix factors, Moisture, Chemical treatment, Fillers, Mechanical properties & tests, SEM.

I. INTRODUCTION

The Monolithic metals and their alloys cannot meet the requirements of the latest Technology as they have high density and their cost of fabrication is high. Hence they have been replaced with the advent of Composites since they have relatively low cost, low density, high specific strength, high specific modulus, low specific gravity, high stiffness, resistance to fracture, fatigue, impact, and creep. In recent years, Fiber Reinforced Polymer Matrix Composites are being used for various primary and secondary components of aerospace, transport, automotive and domestic applications. Fiber reinforcements and matrices have a major influence over the mechanical behavior of composites. The material of fiber directly influences the mechanical properties of composite like elastic moduli and strengths [1, 3]. Fiber oriented in one direction (unidirectional composite) gives high stiffness and strength, in that direction. If the fibers are oriented in more than one direction (multidirectional composite), such as in a mat, there will high stiffness and strength in fiber orientations. However, for the same for the same volume of fibers per unit volume of the composite, it cannot match the stiffness and strength of the unidirectional composite [1, 4]. The fibers are available as short and long based on the length. The fiber orientation is quite difficult in case of short fibers whereas it is easy in case of continuous and long fibers. The long fibers have good impact resistance, less shrinkage, better surface finish and dimensional stability compared to short fibers. On the other hand short fibers contribute reasonable cost, flexible to handle, and have lesser fabrication cycle duration. Short fibers exhibit higher strength as they have few flaws in them [1, 5]. The fiber mat arrangement or stacking sequence of fiber mats affects the mechanical performance of hybrid fiber reinforced composites [1, 6]. The most common shape of fiber is circular because handling and manufacturing are easy. Hexagonal and square shaped fibers are also available which have advantages like high strength and high facing factors but they have drawbacks like difficulty in handling and processing. Fibers with thin diameter are always preferred as the smaller diameter fibers reduce the chances of an inherent flaw in that material. For same volume fraction, the fiber-matrix interface area is inversely proportional to the fiber diameter. Composites with a larger surface area of fiber-matrix interface provide higher ductility and toughness [1]. Under different environmental conditions, the moisture absorption capacity of fiber reinforced polymer matrix composites, over a period of time, might increase with salt concentration, lower fiber content and in the fiber direction. This results in degradation of fiber-matrix bonding and affects the elastic properties which influence the mechanical behavior [7]. High operating temperature makes the matrix soft and affects the fiber-matrix bonding. This may reduce mechanical properties to a certain extent. Low operating temperatures improves the strength of composites but induces microcracks due to a mismatch in fiber and matrix thermal expansion [8]. Chemical treatment of fibers modifies their surface quality and improves the bonding capacity with the matrix. Thus treated fiber reinforced polymer matrix composites yield better mechanical properties when compared to that of untreated composites [9]. The addition of fillers increases the reinforcement of fibers and may improve the tensile strength of the composites. The filler-matrix interface results in increased viscosity of matrix mix. This may improve tensile, compressive strengths and Impact energy of composites [10]. The aim of this review article is to brief out the influence of fiber material, length, orientation, volume fraction of fiber and matrix, exposure to different environments, operating temperatures, fiber treatment and fillers on the mechanical properties such as tensile, flexural and impact strengths of fiber reinforced composites.

II. INFLUENCE OF DIMENSIONAL PARAMETERS ON FIBER REINFORCED PMC'S FROM LITERATURES

The synthetic fibers are costlier, presumed to have high elastic moduli and strengths. This anticipation in properties and production cost has been the major factors in graphite, aramid, kevlar and glass fibers. Many researchers focused towards fabrication of mono fiber reinforced composites and hybrid composites. The hybrid composites may exhibit better mechanical properties over mono fiber reinforced composites. The mechanical properties such as tensile, compressive, flexural and impact strength were improved through combining jute fiber with glass fiber reinforced with epoxy resin by C Velmurugan et al. [11]. They compared the mechanical properties of jute/glass fiber reinforced epoxy hybrid composites with that of jute reinforced epoxy composites. The authors showed that hybrid composites had better mechanical properties than jute epoxy composites. S Nallusamy and Gautam Majumdar [12] developed jute fibre and jute/glass fiber based composites. Two types of hybrid composites, Hybrid 1 and Hybrid 2, were prepared with different layer of fibre orientation jute and synthetic glass for all stacking sequences. The mechanical properties of the composites were obtained experimentally and compared them with that of jute reinforced composites. The authors concluded that in hybrid 1 and hybrid 2 composites, different fiber layup and stacking sequence had major influence on the tensile, hardness, impact and flexural strengths compared to that of jute reinforced composite. P D Mangalgiri [13] briefly described and reviewed the developments of polymer-matrix composites for high temperature applications such as military fighters, transport aircraft, satellites and space vehicles. He fabricated carbon fiber reinforced with PMR-15 matrix. The mechanical properties were evaluated at room temperature and high temperature of 288°C. The author compared tensile and compressive strength. Also he observed significant matrix cracking, steep increase in weight loss at high temperature. A series of low velocity impact tests were performed on jute fiber reinforced with unsaturated polyester composites by H N Dhakal et al. [14]. They conducted experiments using an instrumented falling weight test system at three different temperatures and two impact velocities. They found that the composites had higher impact loads at low temperature. Also they subsequently conducted three-point bending test on impact tested composite specimens and determined flexural strength after impact. The authors concluded that the flexural strength decreased significantly with increase in temperature. Libo Yan et al. [15] fabricated untreated and treated flax, linen and bamboo fabric reinforced epoxy resin bio-composites. They investigated and compared the mechanical properties of composites. Treated composites showed higher tensile and flexural strengths than that of untreated composites. The authors also investigated the influence of 5 wt% NaOH treated flax, linen and bamboo single-strand yarns. They concluded that the alkali treatment had negative impact on tensile strength. Also the surface morphology was studied which revealed fiber breakage and slippage under tension. Untreated and treated fiber composites based on unsaturated polyester resin reinforced with alfa short fiber were fabricated by A Benyahia et al. [16]. The alfa fibers were treated with various concentrations of NaOH before composite fabrication. The composites prepared with treated fibers were subjected to mechanical tests and showed better tensile and flexural strengths compared to that of untreated fiber reinforced composite. The authors analyzed the SEM photographs which indicated the modified fiber morphology after alkali treatment. The polymer matrix composites with synthetic fibers such as glass, carbon, boron, kevlar, graphite, and aramid fibers as reinforcements are used in primary and secondary structural components in military, commercial and passenger aircrafts, space vehicles, satellites, and automobiles. Irrespective of their high cost, they are also used in golf club and tennis rackets [2]. Nowadays, the natural fibers such as jute, flax, kenaf, hemp, sisal, banana, and palm are also being used in place of synthetic fibers by many scientists, engineers and researchers as they are environment friendly, carbon free, have good physical properties, elastic moduli and strengths. The natural fiber composites are less costlier, abundantly available and environment green materials. Hence they are being used by builders, construction and packaging industries (production of panels, false ceilings, partition boards etc.), interior parts of automobile & railway coach, storage containers and equipments [17].

III. FABRICATION AND ASTM STANDARDS

The fiber reinforced polymer matrix composites are most commonly fabricated by using hand layup technique [1]. The different test standards such as ASTM D3039, D790 and D256 standards were used to evaluate the mechanical properties like tension, flexural and impact strengths respectively [18-21]. M. Ramesh et al. [22], fabricated sisal-glass epoxy and jute-glass epoxy composite samples by hand layup process. The authors evaluated mechanical properties such as tensile and flexural properties of sisal/glass and jute/glass reinforced epoxy hybrid composites. Results revealed that the sisal/glass composite specimens had higher tensile strength and the jute/glass fiber composite specimen had flexural load which considerably more than that of sisal/glass fiber composite specimen. The results indicated that the mixing of sisal and glass fibers yielded better properties than the jute/glass composites in tensile properties and jute/glass fiber composites exhibited good flexural strengths. Scanning Electron Microscope (SEM) images showed Fiber fracture, pull out, and dislocation of fibers due to application of tensile load. Flexural load resulted in fiber separation from resin. The jute/glass reinforced polyester resin composites with different weight fraction ratios were fabricated using hand layup process by Sanjay M R et al. [23]. They evaluated mechanical properties like tensile, impact and flexural strength of Jute - glass fiber reinforced polyester. The results revealed that 50/50 jute/glass fiber reinforced polyester composites have the high tensile strength and impact energy. Further, 60/40 jute/glass fiber reinforced polyester composites exhibited high flexural strength. They concluded that the tensile, flexural, and impact strengths of the composites were greatly influenced by the fiber composition. Ajith Gopinath et al. [24], developed separate composite specimens of epoxy and polyester resin reinforced with NaOH treated short jute fibers. As per standards, the prepared composites were subjected to mechanical tests to obtain tensile strength, flexural strength, impact strength and hardness experimentally. The jute fibers were had a length of 5-6 mm. The polyester and epoxy resins were used as matrix. The fiber to matrix weight fraction was 18:82 during composite fabrication. Test results showed that the 5% NaOH treated jute fiber reinforced composites exhibited higher tensile and flexural strength than 10% NaOH treated fiber reinforced epoxy composite. Compared to jute epoxy composite, the jute epoxy composite exhibited good impact energy. The polyester based jute reinforced composite showed better impact energy than epoxy based jute reinforced composites. Fiber stacking and fiber less matrix, pulled fibers at the fractured portion, lack of matrix near surface of fiber, poor adhesion between pulled out fibers, fiber distribution, and orientation was observed in the morphology of fractured surfaces. The composite specimens with sodium hydroxide (NaOH) treated jute fibers reinforced with polyester resin with and without nano clay fillers were developed by compression molding process K. Deepak et al. [25]. The author also conducted tensile and impact tests as per standards and studied the influence of composite processing techniques, moisture content, fiber type and content on their mechanical properties. Jute fiber reinforced with polyester resin composite specimens with nano clay fillers showed higher tensile strength and impact energy absorbed values when compared to that of the composite specimen without filler. They concluded that the addition of nano-clay to the jute fiber reinforced composites exhibited significant improvement in the mechanical properties. Arun Kumar Chaudhary et al. [26] fabricated banana/bagasse fiber reinforced epoxy composites filled with silica and subjected them to different mechanical tests. The authors studied the improvement in the mechanical properties like tensile, flexural, compressive, impact and fracture strengths, when the fibers are mixed with different volume fractions. The epoxy reinforced with inter- and intra- silk/flax fiber hybrid composites were developed by Change Wu et al. [27]. The authors tested these composites and evaluated the effect of hybridization on tensile, flexural and impact properties. Camila Cruz da Silva et al. [28] fabricated the polyester reinforced with glass/sisal fiber hybrid composites. They studied and assessed the hybridization effect on the tensile, flexural properties and water absorption capacity.

IV. RESULTS AND DISCUSSIONS

The natural fibre (sisal, kenaf, hemp, jute, and coir) reinforced polypropylene composites were fabricated through compression moulding with the help of film stacking method by Paul Wambua et al. [29]. The mechanical properties of the different natural fibre composites were tested and compared with different natural fibers such as sisal hemp, jute etc. The author observed that the tensile and flexural strengths of hemp fibre composite were highest and that of coir fibre composite was least. The ultimate tensile stress of kenaf reinforced polypropylene composites were found to increase with increasing fibre weight fraction. Coir fibre composites displayed the lowest mechanical properties, but their impact strength was higher than that of jute and kenaf composites. K.G.Satish et al. [30] experimentally determined the tensile, compressive, and shear strengths of hand layup processed steel/nylon fiber reinforced polyester hybrid composite specimens with various fiber volume fractions, and orientations. The main objective of the work was to investigate the effect of fiber volume fraction and its loading direction on the major mechanical properties. The investigations revealed that, the specimens with higher volume fraction of steel exhibited higher loads & also the specimens with fibers oriented in $0/90^0$ direction exhibited superior strengths. The author observed that the difference in compressive strength was considerable from 30-45% of steel content due to poor interfacial bonding which resulted in the delamination failure of the laminates. They also established a relationship between the tensile/compressive strength, fiber content and orientation by subjecting the hybrid composite specimens to in-plane tensile and compressive loading. B. Vijaya Ramanath et al. [31], fabricated a jute/flax/glass fiber reinforced epoxy composite and jute/glass fiber epoxy composite. They compared experimental results by conducting mechanical tests. The vertical flax fiber was introduced between horizontal jute fiber, with glass fiber laminates on both sides which resulted in good surface finish and hardness. The matrix material used was epoxy resin with HY951 hardener. The volume fraction of jute and flax fibers was 33.33% of total volume fraction. The tensile and flexural tests were conducted on jute/flax/glass, jute/glass fiber composite specimens by using universal testing machine. They concluded that the jute/flax/glass fiber composite specimen had higher ultimate tensile and flexural strengths compared to that of the jute/glass fiber composite specimen. The authors found that the the jute/flax/glass, jute/glass fiber composite had higher flexural stiffness compared to that of the jute/glass fiber composite. Further, they suggested future work that the mechanical properties can be compared by developing composites with treated fibers reinforced in different type of resin. Further, from SEM image analysis of fractured surfaces, they observed adhesion between fibers, grouped breakage of fiber and the resin, defects like air bubbles, the perpendicular arrangement of fibers, completely broken fibers and improper breakage of fibers.

V. CONCLUSION

Many authors have done research work from which they have experimentally studied the influence of various parameters on mechanical behavior of fiber reinforced polymer matrix composites. With the literature review of the technical papers, the conclusions are listed as follows:

- The composite specimens were fabricated using synthetic and natural fibers reinforced with polymer matrix by hand layup technique.
- The mechanical tensile, flexural and impact tests were conducted as per ASTM standards
- The effect of fiber type, volume fraction, hybridization of fibers and fillers on tensile, flexural and impact strengths were discussed experimentally.

- The mechanical properties can be successfully enhanced by hybridizing different types of natural/synthetic fibers and varying volume fraction of fibers.
- The chemical treatment of fibers increases the bonding strength between matrix and fibers which results in improving the mechanical properties.
- When the fillers are added to matrix, they disperse through it and the interface bonding/adhesion between them affects the mechanical properties.
- The fractured surface morphology of the tested composite specimens was studied in depth through Scanning Electron Microscope photographs.

VI. FUTURE PROSPECTS

Many authors and researchers have successfully carried out the mechanical experimentations and studied and analyzed effect of various parameters which affect the mechanical behavior of polymer matrix composites (PMCs). These parameters are dimensional, that is, fiber length, fiber orientation, hybridization of fibers with different volume/weight fraction, chemical treatment of fibers, different environment, operating/service temperatures, and addition of fillers into the matrix. The natural fibers are being replaced in place of synthetic fibers as they have many advantages with respect to availability, cost, feasibility and environment. Thus the research is getting a broad and wide scope in these days. Further, the research can be extended in studying the effect of above listed dimensional parameters on the tribological behavior, wear properties, fatigue and fracture behavior of PMCs.

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