Influence of Nanofiller addition on Tensile Properties in Fiber Reinforced Polymer Composites

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ABSTRACT

Fiber reinforced polymer composites play an important role during material selection in various engineering application due to their weight to strength ratio. The tensile property is the important property to be investigate in fiber reinforced polymer composites in according to ASTM D3039. The commonly used synthetic fibers during fabrication of FRP composites are E-glass, Carbon and Kevlar and matrix material epoxy. The tensile property can be enhanced with addition of nanofiller to fiber reinforced polymer composite during fabrication process with matrix materials. The research results show that, the addition of nanofiller had an effective impact in enhancing tensile property in fiber reinforced polymer composites.

Keywords: Polymer, Composite, Matrix, Strength, tensile, flexural, interlaminar shear strength, Nanofiller.

I. INTRODUCTION

Composite materials are materials that are made up of at least two different materials and have distinct properties at the microscopic level. The composite material is composed primarily the base material as matrix and constituent which is added to the matrix is known as reinforcement material. Composites comprised of a polymer matrix and fibers are known as fiber reinforced polymer (FRP) composites. Carbon, E-glass, Kevlar, and thermosetting polymer matrix namely, epoxy, polyester and vinyl ester are commonly used in the fabrication of these composites. In the last few years, FRP composites played a vital role in selecting the materials for the components manufacturing in the various sectors such as automobile, sports, space, aeronautical, marine, construction, defence, because of their superior weight to strength ratio, non-corrosive, high modulus can be easily fabricated [1-3].

Hybridisation in polymer composite play an important role to meet the current needs and design requirements in the industry in a more economical manner, when compare to single fiber composites used in the engineering industries. These polymer composites contain minimum two various kind of fibers, that are reinforced with a single matrix material to offer synergistic effect such as improved physical, mechanical, tribological, and electrical properties. These composites provide better mechanical characteristics including high modulus, strength, corrosion and fatigue resistance, also reduced weight, impact resistance in comparison to single fiber composites [4-6].

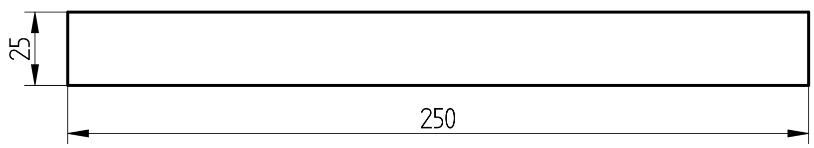
Nanomaterials having particles of nanoscale dimensions ranging from 1 to 100 nanometer. Nanomaterials may be in the form of zero dimensional, one dimensional and two dimensional. Many research work carried out by incorporation of nano materials like silica (SiO_2) [7], MWCNT [8], Tungsten carbide [9], aluminum oxide (Al_2O_3) [10], SiC [11], nanoclay, TiO_2 [12], $CaCO_3$ [13], halloysite [14], carbon nano tube [15], graphene [16], in varying weight percentages with thermoset polymer epoxy matrix, to find the influence on the mechanical and tribological characterisation in FRP composites.

The nanomaterials presence in the polymer composites reduces the porosity, resistance to moisture absorption, improves in physical, mechanical, thermal, and tribological. The nanoparticles offer a strong bonding ability and also stop crack growth, which improves the material characteristics.

To further extend these properties, the hybrid polymer nanocomposites received more attention from researchers. Hybrid polymer nanocomposites have hybrid polymers with nanomaterials added to matrix materials during the fabrication. The inorganic nano materials are more oftenly used during the fabrication of hybrid polymer nanocomposites. Improvements in damage tolerance are anticipated with the incorporation of nanoparticles from more energy absorbing mechanisms in the polymer hybrid nanocomposites.

II. TENSILE PROPERTY

The tensile properties such as tensile strength and tensile modulus are play a very vital role during selection of materials for engineering applications. Tensile testing is one of most widely used mechanical characterization technique, which is a destructive type of material testing. In this type of testing tensile load is applied to the test specimens until it fails. This test helps in investigating how a material will behave under tensile load and the maximum load it can take before fracture. Also, to investigate the materials yield strength, ultimate tensile strength, modulus, elongation at break, strain hardening, peak load. The ASTM D 3039 standard is used for the preparation and testing of the tensile test samples. Figure 1 shows the dimension of the tensile test specimen according to ASTM D 3039.



All dimensions are in mm

Figure 1: Dimensions of the test specimen according to ASTM D 3039

The tesing is carried out using universal testing machine as shown in Figure 2, with a cross head speed of 2 mm/min. Five test specimens tobe tested for the tensile properies and the load is applied upto failure, the mean results tobe considered to calculate the final test result [17].

Figure 2: Universal Testing Machine

III. MATERIALS AND FABRICATION METHODS

The materials used for the fabrication of FRP composites are synthetic fibers such as E-glass, carbon, Kevlar and the matrix materials are epoxy, vinyl ester and polyester resin.

A. **Synthetic Fiber**

Synthetic fibers are man-made or artificial fibers that are created through various chemical processes by transforming raw materials into thread-like structures. They are distinct from natural fibers, such as cotton, wool, or silk, which come from plants or animals. Synthetic fibers are designed to possess specific properties like strength, durability, moisture resistance, and elasticity, making them suitable for various engineering applications.

(a) (b) (c)

Figure 3: Synthetic Fiber (a) E-glass woven fiber (b) Carbon Woven fiber (c) Kevlar woven fiber

E-glass fiber is an important reinforcing material, particularly for polymer composites. It is a lightweight and long-lasting material that is employed in a variety of industries. E-glass fiber has excellent mechanical qualities, is highly compatible with epoxy, is widely available, and is inexpensive [18].

Table 1: Physical and mechanical properties of synthetic fibers

Reinforcement	Diameter (μm)	Thickness (mm)	Density (g/cc)	Tensile Strength (MPa)	Tensile Modulus (GPa)
E-glass woven ($0/90^o$) fiber	14.7	0.598	2.59	1770	72
Carbon woven ($0/90^o$) fiber	7	0.197	1.76	3530	230
Kevlar woven ($0/90^o$) fiber	12	0.207	1.44	3000	124

Carbon fibers are made from precursors such as 90 % polyacrylonitrile and 10 % rayon. These fibers become a vital in the reinforcing material of advanced polymer composites due to, their extremely high tensile strength, stiffness, chemical resistance, fatigue strength, and excellent thermal properties, good vibration damping, non-corrosive properties [19].

Kevlar is an organic fiber in the aromatic polyamide group and it is based on poly para-phenylene terephthalamide. It is developed by DuPont and Kevlar is the trade name of DuPont's para-aramide fiber. It has high strength, modulus, kinetic energy absorption, toughness, thermal stability, strength to weight ratio and low elongation to brake, thermal shrinkage with good ballistic impact resistance [20].

Figure 3 shows the synthetic fiber such as E-glass, carbon, Kevlar and the properties of these fibers are tabulated in Table 1.

B. **Matrix Material**

The thermoset matrix material used in the fabrication of polymer composite are epoxy, vinyl ester and polyester resin. Among these matrix materials, the epoxy resin is more widely used during the fabrication of polymer composites. Epoxy resin is having high strength, stiffness, dimensional stability with low shrinkage and exhibit very strong bond to woven synthetic fibers namely, glass, carbon and Kevlar.

C. **Nanofiller**

Nanofillers such as nanosilica, MWCNT, Tungsten carbide, aluminum oxide, SiC, nanoclay, TiO_2, $CaCO_3$, halloysite, , carbon nano tube, graphene are used as a nanofiller during fabrication of the polymer composites.

The nanofiller are added with matrix material and for better dispersion the different methods such as simple mechanical mixing, ultra-sonication, high shear and slurry-compounding. Widely used methods to blend the epoxy-nanomaterial is shear mixing and ultra-sonication.

D. **Fabrication Method**

The mechanical properties of FRP composite depends on, the type of fibers, matrix material and fabrication method. The FRP composites were fabricated in divergent methods such as hand lay-up, vacuum bagging, liquid composite molding (LCM) and autoclave.

E. **Hand lay-up Method**

The traditional and widely used method for fabricating polymer composite materials is Hand layup. It involves manually layering reinforcement fibers such as glass fiber, carbon fiber, or aramid onto a mold and then saturating them with a polymer resin matrix (such as epoxy, polyester, or vinylester) to create a composite part. Here's an overview of the process. Figure 4 shows the hand lay-up method for fabricating the polymer composite.

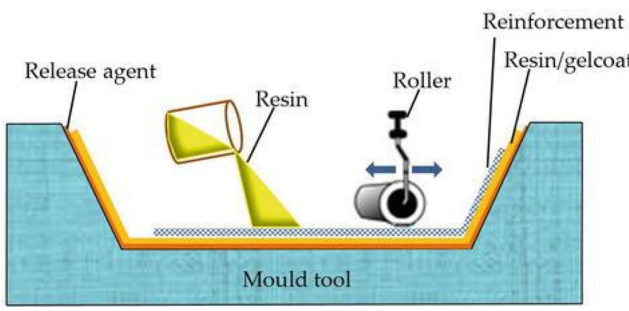


Figure 4: Hand lay-up [21]

(i) Preparation: The mold or tooling is prepared by applying a release agent to ensure that the cured composite part can be easily removed from the mold after fabrication. This prevents the composite from sticking to the mold surface.

(ii) Fabric Cutting and Arrangement: Reinforcement fibers are cut into the desired shapes and sizes based on the design and structural requirements of the composite part. These cut fibers, often in the form of woven or non-woven fabrics, mats, or rovings, are then manually placed onto the mold in layers.

(iii) Layer Building: The layers of reinforcement are built up according to the required orientation and thickness. This step involves arranging the fibers in the desired pattern to achieve the desired mechanical properties and structural integrity.

(iv) Resin Application: After placing each layer of reinforcement, a liquid polymer resin is applied over the fibers using brushes, rollers, or other applicators. The resin wets out the fibers, impregnating them thoroughly to create a strong bond between the fibers and the resin matrix. The resin also fills any voids or gaps between the fibers.

(v) Air Removal: It's crucial to eliminate air bubbles and ensure proper resin impregnation. Techniques such as rolling, squeegeeing, and using specialized tools can help in removing trapped air and excess resin.

(vi) Curing: Once the layers of reinforcement are saturated with resin and any air bubbles are removed, the composite part is left to cure. The curing process typically involves the resin undergoing a chemical reaction, often catalyzed by heat or ambient conditions, to harden and solidify.

(vii) Demolding and Trimming: After the curing process is complete, the composite part is carefully removed from the mold. Excess material around the edges is trimmed off, and the part may undergo further finishing processes such as sanding or machining to achieve the desired final shape and surface finish.

F. **Vacuum Assisted Resin Infusion Method**

The VARIM technique is one of the polymer composite fabrication method and Figure 4.7 shows the pictorial representation of it. During fabrication the vacuum pressure was employed to force the resin into the composite laminate. This process removes superfluous resin from the laminate, resulting in a stronger and lighter polymer hybrid nanocomposite product. Figure 5 shows the VARIM technique during the fabrication of polymer hybrid nanocomposite.

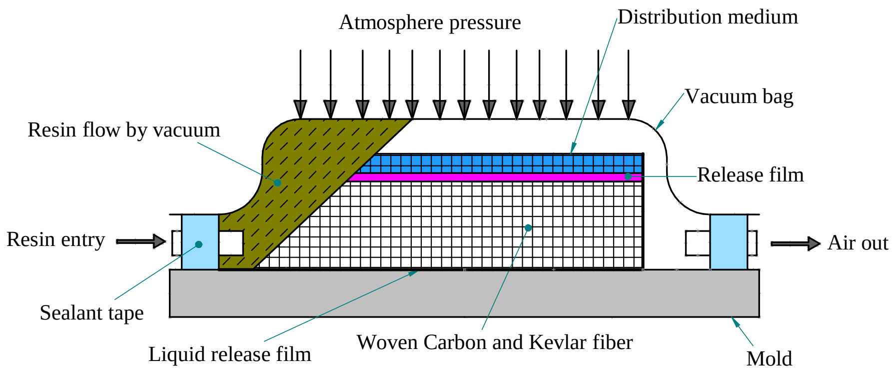


Figure 5: VARIM method

The procedure followed in VARIM technique

i) Prepare the mold as per the required dimension.
ii) Place the peel ply on the mold for roughness and bonding process.
iii) Place the synthetic fibers, as per the layering order of the fibers.
iv) Again place the peel ply over the woven fibers.
v) Place the release film and mesh over the fibers for resin flow.
vi) Place the resin feed lines and vacuum lines.
vii) Carryout the vacuum bagging process.
viii) Adjust the proper pressure from the pump of about 914 mili bar.
ix) Prepare the epoxy resin along with hardener
x) Degassing process to be carried out to remove air bubbles and any air trapped in the matrix mixture.
xi) Carryout the resin infusion process, which begins through the placed tubing, then the resin slowly sucked into the fibers.
xii) Once the resin infusion process completes, the laminates were cured for 24 hours at room temperature, followed by a 5 hours post cure in oven at 80ºC.
xiii) Demolding the laminates and edge trimming.

IV. RESULT AND DISCUSSION

Tensile Properties

Tensile properties of FRP composites can be tested in accordance with ASTM D3039 using universal testing machine. The Table 2 shows the research findings on the influence of nanofiller on tensile properties such as tensile strength and modulus. The percentage of change in tensile strength and modulus depends on the type nanofiller used and the type of fabrication process employed during the fabrication of FRP composite.

Table 2: The influence of nanofiller on tensile properties

FRP	Matrix material	Wt. % of Nanofiller	Fabrication method	Tensile strength % of change compared to neat epoxy	Tensile modulus % of change compared to neat epoxy	Reference
Carbon fiber	Epoxy	0.1 wt.% MWCNT 0.5 wt.% MWCNT 0.9 wt.% MWCNT 0.1 wt.% nanosilica 0.5 wt.% nanosilica 0.9 wt.% nanosilica	vacuum-assisted resin infusion molding	+15.4 +22.3 +4.5 +14.0 +15.3 +12.1	+8.5 +27.9 +3.7 +6.3 +12.8 + 5.7	[22]
Kevlar fiber	Epoxy	2 vol. % Titanium Oxide 4 vol. % Titanium Oxide 6 vol. % Titanium Oxide 2 vol. % Calcium Carbonate 4 vol. % Calcium Carbonate 6 vol. % Calcium Carbonate 2 vol. % Graphite 4 vol. % Graphite 6 vol. % Graphite	Hand lay-up method	+0.31 +0.71 +3.38 +0.92 +4.04 +5.89 +3.95 +5.26 +6.53	+0.31 +0.71 +3.38 +0.92 +4.04 +5.94 +3.94 +5.26 +6.53	[23]
Glass fiber	Epoxy	0.1 wt.% of graphene nanoplatelets 0.25 wt.% of graphene nanoplatelets 0.5 wt.% of graphene nanoplatelets	Vacuum-assisted hand lay-up method	+8.03 +2.44 +1.74	+10.64 +3.71 +0.21	[24]
Glass and Carbon fiber	Epoxy	0.1 wt.% of graphene nanoplatelets 0.25 wt.% of graphene nanoplatelets 0.5 wt.% of graphene nanoplatelets	Vacuum-assisted hand lay-up method	+0.22 +1.04 +1.51	+0.08 +3.59 -0.43	[24]
Carbon and Kevlar fiber	Epoxy	0.5 wt.% nanosilica 1.0 wt.% nanosilica 1.5 wt.% nanosilica 2.0 wt.% nanosilica	vacuum-assisted resin infusion molding	+43.78 +22.69 +21.39 +19.00	+144.10 +120.44 +134.74 +1.13	[17]
Twill 2/2 woven carbon/Kevlar fabric	Epoxy	0.5 wt.% nanosilica 1.0 wt.% nanosilica 1.5 wt.% nanosilica 2.5 wt.% nanosilica 3.0 wt.% nanosilica	Hand lay-up method	+5.55 +5.94 +8.32 +12.99 +16.46	+23.94 +10.61 -5.14 -14.06 -19.54	[25]

The tensile strength of nanofiller filled composites have higher tensile strength as compared to without nanofiller filled composite. The increase in tensile strength may be due to good dispersion of nanofiller within the epoxy and the inclusion of nanofiller in the epoxy led to increase the interfacial bonding strength in between nanofiller particles-fibers-epoxy interactions, which results in the enhancing load transfer between the nanofiller particles and epoxy interaction.

It was observed that the tensile strength starts decreasing in more weight content of nanofiller were added in the composites, which may be due to wide agglomeration of nanofiller in the composites, which leading in reducing the load transfer capacity between nano particles and matrix.

The increase in tensile modulus observed in the composite, which may be due to the modulus of nanofiller and also due to strong interaction between the nanofiller and epoxy resin.

V. CONCLUSION

In this chapter, the influence of nanofiller on tensile properties such as tensile strength and tensile modulus in fiber reinforced polymer composites were studied. The addition of nanofiller with matrix during fabrication enhances the tensile properties. It may be due the better adhesion between the matrix, fibers and nanofiller and which leads to increase in load carrying capacity of the composite. Addition of small weight percentage of nanofiller enhances the tensile properties, whereas increase in weight percentage of nanofiller reduces the tensile properties due to agglomeration.

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