A COMPREHENSIVE REVIEW ON CFRP LAMINATES ADDED WITH NANO FILLERS

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Abstract

Fibre-reinforced polymers (FRPs) are prime choice materials in various structural and high-performance applications. Their unique properties make them superior to their metallic counterparts. The present review paper gives the precise review on influence of reinforcement and functional fillers on machining of polymer matrix composites in terms of its mechanism and machining responses. This includes the effect of fiber orientation and fiber/filler loading on machining response of polymer composites. This review article It will also provide summary of the emerging new aspects of nanotechnology for development of hybrid composites for the sustainable and greener environment. The review on CFRP laminates added with nano fillers provides valuable insights into the enhanced mechanical properties and performance of these composites. It highlights the improved strength, stiffness, and durability achieved through the incorporation of nano fillers, making them promising materials for various applications in industries such as aerospace and automotive.

Keywords: *Nano-composites, Laminates, CFRP,*

1. INTRODUCTION

Composite materials are consisting two or more dissimilar materials and have properties that cannot be attained by a single material. In the composite materials one material performs as the matrix and another one material acts as reinforcement. The matrix of composites protects the reinforcement and distribute the stress among the reinforcement to achieve the required strength of the composite part. The reinforcement achieves the strength of the composite in particular directions and confirms the excellent mechanical properties composite parts. Polymer matrix composites have substituted several conventional materials in different applications including marine, automotive, and aerospace applications [1]. Polymer matrix composites consist of thermoset/thermoplastic as matrix materials and fibers/particulates are reinforcements. The properties of polymer composites are determined by the type of matrix and reinforcements, the geometry of reinforcements (short/long fibres or fabric, particles), the amount of reinforcement and matrix used in composites. Polymer matrix composites reinforced with fibers and fillers exhibits improved strength-to-weight ratio [2, 3]. Addition of fillers in the polymer matrix composites plays key role in improvement of the mechanical properties of composites. The strong interface between constituents causes the effective load transfer [4]. Along with mechanical properties thermal and electrical properties are inherent with the filler for biomedical application, structural application, aerospace application, etc [5].

2. Composites and its applications

Composite materials and their types Composite materials are synthetic materials created by combining two or more component materials that possess distinct physical or chemical characteristics [6]. The use of these resources enables the production of a resultant product with improved and customized characteristics. The following are a few prevalent categories of composite materials: Carbon Fiber Reinforced Polymer (CFRP) is a composite material where carbon fibers are incorporated into a polymer matrix, often epoxy, resulting in a material that is both lightweight and very strong. Carbon fiber reinforced polymer (CFRP) finds extensive use in the aerospace, automotive, and sports equipment industries [7]. Glass fibers are often used as a means of reinforcement in polymer matrices. GFRP is renowned for its affordability, exceptional durability, and remarkable corrosion resistance. It is used in the construction, maritime, and automotive sectors [8]. Aramid Fiber Reinforced Polymer (AFRP) refers to the use of aramid fibers, such as Kevlar, as a means of strengthening polymer matrices. AFRP has exceptional strength and resilience, making it a popular choice for applications requiring ballistic protection and aeronautical engineering. Metal Matrix Composites (MMC) refer to the combination of metal matrices, such as aluminum, with reinforced ceramic particles or fibers. Metal matrix composites (MMCs) provide enhanced tensile strength, rigidity, and durability against abrasion. Frequently used in aerospace and automotive industries [9]. Polymer Matrix Composites (PMC) are polymers that are strengthened by the addition of particle fillers such as glass beads or carbon black. PMCs are used throughout many sectors, including automotive and construction [10]. Fiber-reinforced laminates are composite materials consisting of alternating layers of polymer matrix and fibers, such as glass or carbon. This structure offers multidirectional strength. Frequently used in aeronautical and structural contexts [11]. Metal Matrix Laminates are laminates that consist of metal matrices, similar to fiber-reinforced laminates. These composites possess exceptional strength and thermal conductivity [12]. Fiber-reinforced composites as an instance, are made up of fibers with high strength and stiffness embedded in the matrix which holds fibers and prevents fibers exposure from destructive environmental conditions such as humidity and moisture. Numerous developing applications of composite materials have been found in recent years as a result of utilizing boron, aramid and carbon fibers along with the ceramic and metal matrixes[11-12]. In comparison with isotropic materials, composites have a wider range of parameters influencing the structural behavior. Ply orientations, fiber volume fraction, number of layers, stacking sequence, the material of fibers and matrix and the thickness of layers are examples of these effective parameters which can act as design variables in optimization problems. Most studies have considered fiber orientation angles and the thickness of layers as design variables[14-17]. Moreover, objective functions vary tremendously among different optimization studies. The most frequent objective functions include buckling load, fundamental frequency, weight, load carrying capacity, deflection and stresses. In terms of mechanical perspective, composite structures are globally classified into three types of beams, plates and shells.

3. Nanofillers

In order to define nano meter scale items (10−9 m) the term nano is used. A nano meter is, therefore, equivalent to the billionth of a meter, or 80,000 times thinner than a human hair. The nanometer range covers sizes smaller than the wavelength range of visible light but bigger than several atoms [13]. Nanomaterials are categorized into three groups; nanotubes, nanoparticles, and nanolayers, depending on the number of measurements of the dispersed particles that are in the nanometer range [14]. Nano-particles regarded as the important potential filler materials for the enhancement of physical and mechanical properties of polymer matrix [15]. The unique nanometric size, capable of producing huge and vast specific surface areas, even more than 1000 m^2 /g, along with their other distinctive properties currently shows exhaustive research activities in the fields of engineering and natural sciences [16]. Nanofillers possess tendency to improve or adjust the altered or variable properties of the materials into which they are incorporated, such as fire-retardant properties, optical or electrical properties, mechanical and thermal properties, significantly, sometimes in synergy with conventional or traditional fillers. Nanofillers are incorporated in polymer matrices at rates from 1% to 10% (in mass) [17]. The diverse nanofillers that are used in nano composites are nano clays, nano-oxides, carbon nanotubes, and organic nanofillers

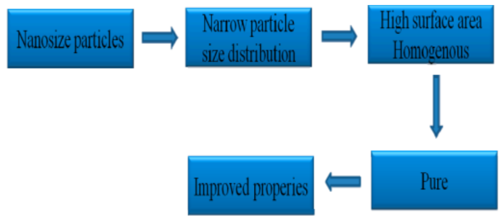

Figure 1: Changes due to incorporation of nanoparticles in composites.

3.1 Natural Filler Reinforced Polymer Nanocomposites

Nanocomposites considered to belong the groups called nanomaterials, where a nano-object (particle) is distributed into a matrix [18]. Generally, nanocomposite is a multiphase dense material in which at least one of its phase has either one, two or three measurements lower than 100 nm The nanocomposites exhibit unique characteristics and comparably better properties than conventional or traditional composites such as glass fiber reinforced composites [19]. Nowadays, a great deal of research and study are in progress towards various fillers to form a huge variety of nanocomposites. The nanofiller in nanocomposite material are the main components and can be constituted of inorganic/inorganic, inorganic/organic, or organic/organic sources. Polymer nanocomposites are polymers (thermoplastics, thermosets, or elastomers) that have been reinforced with small quantities (less than 5% by weight) of nano-sized particles having high aspect ratios (L/h > 300) [20]. The reinforcement of polymeric matrix materials (thermoplastics or thermosets) with nano-sized, such as nano-sized particles, carbon nano-tubes or intercalated layers to forms nanocomposites are considered as an attractive and active area of research. Polymer/layered nanocomposites, in general, can be classified into three different types, namely (i) Intercalated nanocomposites, (ii) flocculated nanocomposites, and (iii) exfoliated nanocomposites [21]. Considerably larger interfacial matrix material surface (interphase) are presented by nanocomposites, depicting properties quite dissimilar from the bulk polymer caused by high specific surface area of the nanofiller.

3.2 Nanofiller-Enhanced Mechanical Properties

The influence of filler size, shape, orientation and volume content of conventional composite materials on the properties of the composite can be described by the boundary concept and the model concept [22]. Carbon nanotubes (CNTs) with different aspect ratios (length/diameter) as a function of the diameter are shown here, and the same ratios are shown for spherical nanoparticles such as fumed silica (FS) and carbon black (CB). For comparison, conventional reinforcements like glass balls (GB), glass fibres (GFs) and CFs are also given. It can be seen that a small volume content of nanofillers provides huge surface areas, thereby enhancing the nucleation of polymer crystals in thermoplastic materials or the cross-linking density in thermosets, resulting in increased mechanical properties by changing the polymer morphology [22]. The advantage of nanofiller reinforcement may thus be a synergistic effect of introducing the reinforcing phase with desirable mechanical properties and enhancing the polymer morphology.

4. Effect of nanofiller on interlaminar and interfacial bonding performance

Being chemically inert, CF shows poor ballistic impact resistance due to weak adhesion and compatibility between the fibre matrix in FRPs. To overcome this challenge, many researchers worked on modifying the CF surface Thus, using CNTs as reinforcement was considered novel and became an effective method to enhance the mechanical properties of fibre-reinforced composite laminates [23,]. Also, CF hybridisation with CNTs gained popularity as it improved the binding of fibres with the matrix, leading to better mechanical properties. However, this method has limitations as the maximum bonding strength is restricted to the chemical bonding strength at the interface [24]. It is known that the enhancement in the mechanical properties and efficient load transfer from the fibres to the matrix is determined by interfacial adhesion between the components of the polymer composite. Thus, predicting the acceptable performance of CNT-reinforced polymer composites is critical. Zhang *et al.* [25] reported a 36% decrease in IFSS when MWCNTs were grown on CFs due to poor wettability with the matrix leading to stress concentrations at the end of MWCNTs, Cai *et al.* [26] showed an increase of 45.2% in interlaminar shear strength (ILSS) when CF was reinforced with functionalised graphene oxide (GO). Li *et al.* [27] found that the deposition of carboxylic acid-functionalised CNTs (COOH-CNT) on

T700SC and T300B resulted in 43 and 12% enhancements in IFSS, respectively. The findings show that interfacial friction, chemical bonding, and resin toughening account for the improved interfacial properties. Baek *et al.* [28] evaluated the properties of CF/polycarbonate composites reinforced with CNTs and determined that IFSS was 25% higher when CNTs were added to the thermoplastic polycarbonate resin. Patnaik *et al.* [29] examined the effect of graphene-based nanofillers on the interlaminar behaviour of CFRP composites. GO and graphene hydroxyl (GOH) nanofillers were applied *via* EPD. Modified CFRP laminates improved ILSS by 15.6 and 11.42% for CFRP with GO and GOH, respectively.

4.1 Dispersion procedures preparation of laminates

Dispersion agents were used for dispersion of non-treated and treated multiwall CNTs in the epoxy as shown in Figure Treated (MWCNTs-COOH) and non-treated (MWCNTs) were prepared and drawn into a beaker to mixed with the epoxy. The epoxy was heated at 60 C for 30 min to reduce viscosity before adding the multiwall CNTs The non-modified MWCNTs and epoxy subjected to over head stirrer with the rotational speed of 2000 rpm for 24,48, 72 and 96 h. Similarly, the modified MWCNT sand epoxy were subjected to overhead stirrer at a rotational speed of 2000 rpm for 24, 48, 72 and 96 h.Later, the dispersed material was degassed for about30 min to remove the entrapped air from the inside of the mixtures.

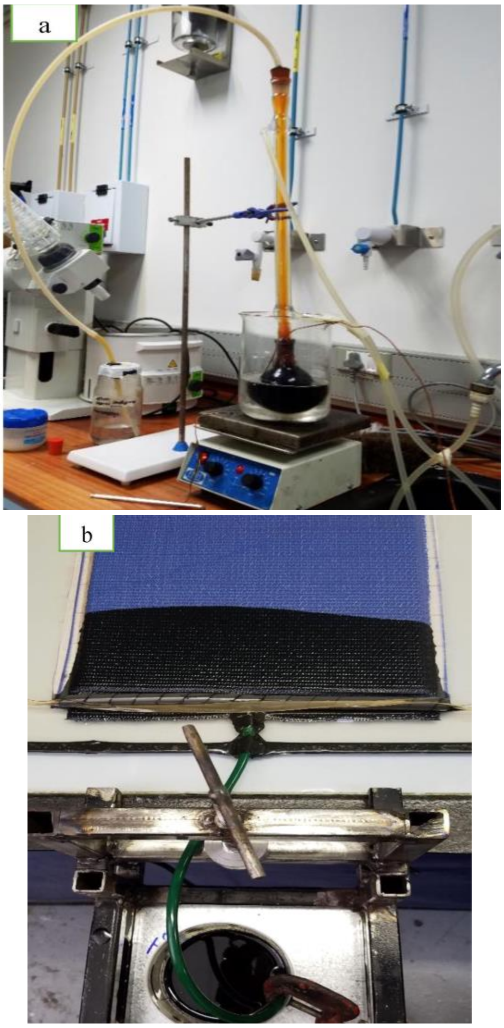

Figure 2. Refluxing process for acid treatment of multiwall CNTs using nitric acid (a) and CFRP-MWCNTs laminate production (b)

The hardener and the epoxy were mixed using an overhead stirrer with a rotational speed of 500 rpm for about 15 min, then degassed for 10 min CFRP laminates were prepared using resin trans-fer molding (RTM) method. Fourteen layers of uni-directional carbon fabric were laid up in the unidirectional orientation considering testing standards The epoxy material to hardener ratio was10:2.8. The MWCNTs/epoxy mixtures were infused.

5.Summary of Literature

Author	Year	Inference
R. Murugana, R. Ramesh b [30]	2014	Carbon laminate has higher mechanical strengths than glass laminate except for impact strength. The variation in tensile strength and impact strength among hybrid laminates is minimal and H2 (CF) hybrid arrangement has higher flexural strength than H1(GF) hybrid laminate. Storage modulus, loss modulus and loss factor of hybrid laminate H2 is greater than H1(GF) hybrid laminate. The glass transition temperature, Tg of H2 laminate was shifted through 5o C from dedicated glass laminate which facilitates the higher operating temperature.
Abdellatif selmi [31]	2014	Void Effect on Carbon fiber Epoxy Composites, the mechanical properties of carbon fiber reinforced polymers are impacted by the presence of voids because of the assembling of carbon fiber epoxy composite itself.
K. Lozano, E.V. Barrera.[32],	2015	Nanofiber-reinforced thermoplastic composites, Incorporation of carbon nanofibers raised the working temperature range of the thermoplastic by 100°C. The nanofiber additions led to an increase in the rate of polymer crystallization with no change in the nucleation mechanism. Although the tensile strength of the composite was unaltered with increasing nanofiber composition, the dynamic modulus increased by 350%

Anoop Anand and Makarandh joshi [33].	2015	Structural composites Hybridized with Nanofillers, Large numbers of polymers have been modified with nanofillers for either reinforcing them or for introducing multifunctionality. Use of such modified polymers for structural composites with fiber reinforcement has been a challenge considering their altered process characteristics.
IfeOlorun Olofin, Ronggui Liu [34]	2015	The Application of carbon fiber Reinforced Polymer (CFRP) cables in engineering, CFRP cables and examines the importance of such studies. Literature has confirmed that CFRP cables do not corrode nor suffer stress solution. They are easy to handle, exhibit outstanding fatigue behavior and have good
		efficiency in life cycle cost, even though the initial cost may be substantial.
Muhammad Shahid Nazir, Mohammad Haafiz [35]	2016	Clays have been one of the more important industrial minerals; and with the recent advent of nanotechnology, they have found multifarious applications and, in each application, nanoclays help to improve the quality of product, economize on the cost and saves environment. The chapter describes key characteristics of nanoclays and their classification on the basis of the arrangement of "sheets" in their basic structural unit "layer".
Shaoyun Fu*, Zheng Sun [36]	2019	Some basic aspects of polymer nanocomposites: A critical review, It has been clearly shown that incorporation of a low content of nanoscale fillers into polymers leads

		to enhancements in mechanical and physical properties. Introduction to various nanoscale fillers of two dimensional, one dimensional and zero dimensional morphologies used in polymer nanocomposites has been given in this review paper.

5. Conclusions

This review study it was found that addition of fillers into polymer matrix enhances the mechanical properties due to fillers are stiffer than matrix and addition of fillers improves the interfacial strength between matrix and fibers. The enhancement of mechanical properties depends on type, size, and shape of the fillers and dispersion and loading of fillers. The addition of nano fillers to CFRP laminates has been shown to significantly enhance their mechanical properties, such as improved strength, stiffness, and toughness. Additionally, the incorporation of nano fillers can also improve the resistance to various environmental factors, making CFRP laminates more durable and suitable for a wide range of applications. The scope of research on CFRP laminates added with nano fillers includes investigating the effects of different types and concentrations of nano fillers on the mechanical properties and durability of the composite material. Additionally, it aims to explore the potential applications of these enhanced CFRP laminates in various industries such as aerospace, automotive, and construction. Research on CFRP laminates added with nano fillers is essential to explore the potential benefits they can offer, such as improved mechanical properties, enhanced durability, and increased resistance to environmental factors. This research can pave the way for the development of advanced composite materials with superior performance characteristics.

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