Mechanical Properties of Particulate Reinforced Epoxy Composites – A Review

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Abstract-
Composite materials are new alternatives to steel and aluminium across various industries, from aerospace, automobile, civil, defence, railway and marine. The unique properties of composite materials like high strength, high stiffness, less weight, low cost, and high resistance to wear/corrosion are the main advantages of using composites as a replacement for traditional materials. Depending on the main goal to be achieved in different industries, epoxy-based composites, due its outstanding properties like low cost, low density, high strength, etc., can be tuned to fulfil the needs of the end-user. Recent research work indicates that particle-reinforced epoxy composites have many applications in different areas. This paper is a review on the effect of inclusion of particulates on the mechanical performance of epoxy composites. The attributes such as hardness, fracture toughness, tensile, flexural, impact strength have been discussed for various types of particulate reinforced composites.

Keyword: *Epoxy, particulate composites, Mechanical properties.*

I. INTRODUCTION

Every area of technology relies heavily on materials, and new materials with enhanced qualities are constantly needed to meet the demand for improvement [1]. The invention of composite materials is one of the most significant advances in the history of materials. [2]. They are the important materials which are now used widely and continue to replace traditional materials like steel and aluminium across various industries from aerospace, automobile, civil, defence, railway to marine [3]. High strength, low density, great wear resistance, and a low coefficient of thermal expansion are common characteristics of composites, which are useful figures of merit for many potential applications [4]. Epoxy resin composites are one of the most extensively used materials due to their good bonding strength with other materials and excellent structural properties, high impact resistance, and chemical resistance. But they also have several disadvantages, for example low toughness, strength, stiffness, etc. [5]. To cope with the above limitations, the matrix material, i.e., epoxy resin, is reinforced with different particulate fillers. A very wide variety of micro or nano particulate fillers are added to process the composites and modify their properties, merging the benefits of both original components, i.e., the matrix and reinforcement [6]. The commonly used particulates are shown in figure 1. The selection of composites depends on the performance of the material to enhance the properties. The incorporation of particulate fillers in matrices improved the chemical, thermal, electrical properties along with maintaining the mechanical properties of the epoxy composites [7-8].

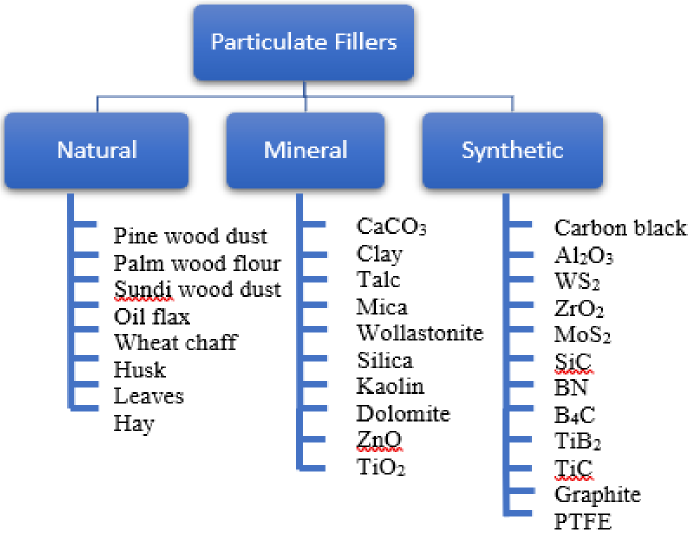

Fig. 1. Particulate fillers

A. Micro/nano particles

A large variety of micro/nano particles are believed to enhance the mechanical characteristics of composites as evidenced by their properties like specific gravity, hardness, tensile, flexural, impact strength, etc [9]. Fillers have been incorporated into all types of matrices for the development of composites from the very beginning, and they still continue to play a vital role [10]. One of the most important advantages of adding fillers was the reduction of cost, but now the concern has been shifted to the functional properties achieved by the incorporation of particulate fillers [11]. As there is no ideal filler, the skill for the selection of particulate filler depends on several key properties like cost, specific gravity, hardness, morphology, etc. There are a number of properties that can be modified by the inclusion of particulate fillers. The particles used and the properties altered due to inclusion of particles along with its findings are summarized below. (Table 1)

Table 1. Summary of Reinforcements, Characterization of composites and its findings

Reference no.	**Reinforcements**	**Characterization**	**Findings**
[12]	Glass fibers, Aluminium particles	Mechanical (tensile, flexural, hardness, impact) Tribological (wear) Morphological (SEM)	When compared to glass fibre reinforced epoxy, the produced composites shown improved mechanical properties. While greater weight fractions of nano-aluminium in the epoxy had caused minor agglomerations, increasing the weight percentage of aluminium particulates to 4 wt.% showed fair improvement for all specimens of aluminium loading.
[13]	Graphene oxide	Mechanical (tensile, flexural, hardness, impact) Thermal (TGA, DTA) Morphological (SEM, XRD, Optical microscopy)	PVA composites were created using a straightforward solution mixing procedure with varying RGO loading. Shore hardness tests, DTA tests, and TGA testing were completed. According to the findings of those tests, hardness and thermal stability of the sample increased.
[14]	PTW, Graphite	Mechanical (Density, tensile, flexural, hardness, impact) Tribological (wear) Morphological (SEM)	The glass and PTW reinforced epoxy composites showed superior properties with the inclusion of 2.5 wt% graphite. Epoxy/glass composites' strength qualities have declined when PTW has been added alone, but have significantly improved when Gr has been added.
[15]	Wood dust	Mechanical (tensile, flexural)	Up to a particular filler %, tensile and flexural behaviour increases, and after that, the characteristics steadily degrade.
[16]	CaSiO3, Alumina	Mechanical (flexural, impact) Thermal Tribological (wear) Morphological (SEM	With the addition of nanoparticles, the epoxy resin's impact energy, flexural strength, and thermal characteristics are all significantly improved. An increase in wear resistance and stiffness was found.

[17]	Al2O3	Mechanical (flexural, impact) Tribological (wear) Morphological (SEM)	The incorporation of Al_2O_3 nanoparticles into epoxy resin at low concentrations, significantly reduced the wear of composites along with improvement in bending and impact strength of developed composites.

In this review, the reinforcing influences of particle on the mechanical characteristics of epoxy-based composites is discussed.

II. MECHANICAL PROPERTIES OF PARTICLE REINFORCED EPOXY COMPOSITES

In epoxy polymer, the mechanical characteristics of several types of micro and nanoparticles were examined. For the comparison of various types of particle reinforced composites, mechanical properties were taken into consideration. The testing was carried out in accordance with ASTM standards. Epoxy resins incorporated with micro/nano particles have been the subject of numerous papers.

I. Ozsoy et al. [18] dealt with the influence of filler elements; clay, Al_2O_3, titanium dioxide (TiO_2) and fly ash on the mechanical behaviour of polymer composites. The particle sizes used for Al_2O_3 are 45μm and 40 nm, for TiO_2 are 50μm and 10 nm, and the fly-ash used has a size of 45μm whereas nano-clay is of 10μm. The properties evaluated are the hardness, tensile strength, bending strain, elastic modulus, bend strength and modulus, and elongation at break values. The results revealed as the percentage of micro and nano particles increased, except for tensile and flexural modulus all other attributes tested declined. Also, hardness was found to be improved with the addition of fillers, except in case of fly-ash and nano-clay. J. Abenojar et al. [19] studied composites added with nano and micro silicon carbide particles. The matrix was introduced with 6% and 12% SiC particles to improve its mechanical properties. The inclusion 10μm SiC particles showed better properties of composites when compared to nanoparticles (50 nm–150 nm) reinforced composites. The researchers concluded that the agglomeration of nanoparticles resulted in non-uniform mechanical properties.

M. Kameswara Reddy et al. [20] examined the result of inclusion of nano-particles; Tungsten Carbide (WC) in epoxy resin. The tensile, flexural tests were studied for different weight percentages (1wt.%, 2wt.%, 3wt.%, and 4wt.%) of particles. The outcomes showed, the inclusion of up to 2 wt.% WC improved the properties, after which a downward trend in mechanical properties has been observed. M. A. Martinez et al. [21] examined a work on mechanical properties of B_4C filled polymer composite. They concluded that the reinforced epoxy had excellent mechanical properties. The properties were found to be better for composites reinforced with 12 wt.% B_4C having 7μm particle size when compared to 6 wt.% B_4C with a particle size of 23μm.

M. Booplan et al. [22] fabricated zinc oxide reinforced epoxy composites. ZnO was dispersed in the matrix in the percentages of 1, 3, 5, and 7 %. Fracture, bend and impact strength were the attributes assessed of the developed composites. The outcomes of the tests show that the mixture with 1 % ZnO to 5 % ZnO show far better properties than pure epoxy composites, whereas the composites with 7 % ZnO showed a decrease in properties.

Muhannad Mahdi et al. [23] prepared epoxy micro-composites and nano-composites by reinforcing the TiO_2 particles with a 50μm and 50nm sizes, respectively. They attributed the reinforcing effect of TiO_2 on fracture toughness, young's modulus and bend strength. The properties showed improvement as the volume fraction of filler goes on increasing, for both micro and nano composites, except for bend strength and fracture toughness, where these properties of epoxy micro-composites are seen to be decreasing. L. S. Schadler et al. [24] processed the TiO_2- Epoxy nano-composites at 5, 10, and 20 weight percent and investigated the mechanical behaviour of manufactured composites. The results of 10 wt.% percent loading were then compared with 10% TiO_2 reinforced epoxy micro-composites.

Madan Morle et al. [25] developed a set of epoxy composites modified by using hexagonal boron nitride (hBN), a micron size filler. The work shows enhancement in properties like hardness, tensile strength and compressive strength, density with the impregnation of filler. The attributes were evaluated for the composites with the filler content ranging from 0 to 40 wt.%. Joo-Eon Park et. al. [26] investigated two factors, tensile strength and flexural strength for particle reinforced epoxy composites. The single composite is either alumina or silica reinforced composite whereas a mixed composite is the composite reinforced with both alumina and silica particles. The study reported that mixed-particle reinforced composites showed enhanced mechanical properties as compared to alumina or silica-reinforced composites.

Sefiu A. Bello et al. [27] developed epoxy/aluminium composites and evaluated the results of mechanical tests like tensile strength, impact strength, and micro-hardness for the prepared composites. Aluminium micro-particles of size 56μm and Al nano-particles of the nano-size 55.5nm were incorporated into the polymer matrix. J. Cho et al. [28] dealt with the effect of the size of alumina particles (0.5 mm - 15 nm) on the young's modulus and fracture strength of polymeric composites. It was discovered that particles of size 0.5 mm have small impact on the composite's young's modulus as compared to the particles of 15 nm, i.e., composites with nano particles show higher young's modulus. It is also observed that composites exhibit superior fracture strength with the decreasing particle size, up to a 3 vol.% limit, after which a declining trend has been found.

Ahmed Fadhil Hamzah et al. [29] analysed the findings of wollastonite particles (0, 2, 4, 6, and 8 wt.%) added to epoxy composites. The particles were reinforced separately and together as functionally graded composites. The study reported that graded reinforced composites exhibit higher fracture toughness and hardness while the flexural modulus and tensile strength are found to be lower.

Tayfun Uygunoglu et al. [30] observed that the inclusion of boron from 0 to 66 wt.% in polymer composites increases the compressive strength. Also, it did, however, resulted into more brittle and one's with the lower bend strength composites. Wear resistance, water absorption, and density are found to increase with the addition of weight percentage of boron. An investigation of hybrid epoxy polymers, i.e., nano silica and micro CTBN rubber particles reinforced epoxy composite is also considered. It is reported that the hybrid composites showed a large increase in toughness compared to other fabricated composites.

S. Dinesh et al. [31] examined the jute-epoxy composites impregnated with different percentages of Rosewood and Padauk wood dust fillers for finding the best thermal and mechanical behavioural properties. The properties such as shore hardness, fracture, flexural, impact and compression strength were tested. The findings demonstrated a noteworthy enhancement in the mechanical characteristics of the resulting composites.

R. Bapatista et al. [32] described that the inclusion of 7.5, 10 and 11.5 wt.% graphite particles exhibited better mechanical properties. The addition of filler contents resulted in improved tensile modulus and ultimate stress value. Aleksandra Jelic et al. [33] incorporated silicate nanofillers into the polymer matrix. In this study, newly produced composites were examined using tensile test and a full-field non-contact 3D Digital Image Correlation (DIC) technique. Compared to pure epoxy, the results of the tests conducted revealed that the inclusion of 3% silicate nanofillers increased tensile strength up to 31.5% for dicalcium silicate/epoxy composites, 29.0% for magnesium silicate/epoxy composites, 27.5% for tricalcium silicate/epoxy composites and 23.5% for wollastonite/epoxy composites.

The influence of nano-carbon and orange peel particles, on the mechanical characteristics of epoxy-based composites was examined by D. Satish Kumar [34] and Prajapati Naik [35], respectively. It was concluded that the produced composites exposed improved mechanical characteristics.

III. CONCLUSION

The addition of micro or nano fillers in an epoxy matrix modifies the mechanical behaviour of neat polymers. The various particulates used in polymer composites were listed and their mechanical properties were reviewed alongside. The mechanical properties such as hardness, fracture toughness, tensile strength, flexural strength, impact strength, etc. have been studied for all composites in the present survey. The scope for the development of a new variety of particulate-filled epoxy composites is also deliberated. The desired properties of the composites can be obtained by varying the proportions of particles, the size of the particles used in the epoxy resin matrix, improving the interaction between the matrix and fillers, etc.

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