Influence of Nano Materials on the Mechanical Properties of Epoxy Matrix Composite - A Review

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***Abstract*— This paper reviews on the addition of nanomaterial with matrix material epoxy, which is widely used in the manufacturing of fiber reinforced polymer composite (FRP) materials due the good adhesion, chemical resistance and mechanical properties. However, it possesses inherent brittleness, which limits its performance in more stress conditions. To overcome this, several researchers investigated with the incorporation of nanomaterilas on different weight percentages such as nanosilica, titania, aluminium oxide, carbon nanotube, silicon carbide, multiwall carbonnanotube, zinc oxide, zirconium dioxide, titanium carbide with epoxy material on mechanical properties. The results shows that, with addition of nanmaterilas, the mechanical properties enhanced due to uniform dispersion of nanoparticles within the matrix, leading to improved stress distribution and crack resistance.**

Keywords*— *epoxy, nanomaterial, nanosilica, mechanical, stress

I. Introduction

Matrix material mixes reinforcement materials with high bond strength, protecting them from external impacts. The main function of the matrix is to transfer external loads into the reinforced phase. Matrix materials should have the requirements such as low weight, low viscosity, low shrinkage, and strong corrosion resistance. Matrix material has less strength and more plasticity in comparison to the reinforcing phase.

The polymer matrix can be separated into thermosetting and thermoplastic polymer matrix. Thermosets are densely cross linked polymers. Thermosetting polymer resins are easy to work with and generally more durable than thermoplastic resins. They are ideal for high-temperature applications and are also less expensive. But they are more brittle than thermoplastics. Epoxy resin, vinyl ester resin and polyester resin, are the thermoset polymer matrix commonly used to fabrication of polymer composite The most commonly used thermosetting polymer matrix in the fabrication of fiber reinforced polymer composites is epoxy resin, which has low shrinkage, light weight, low toxicity, high adhesion to substrate, high stiffness, high strength, high electrical insulation, high amenability to various methods of composite fabrication, ease of fabrication, dimensional stability and having good water and chemical resistance characteristics also excellent heat and moisture resistance. A lot of research has been done on nanoparticle epoxy-based nanocomposites, many researchers are working to analyze the epoxy composite behavior by adding different nanofillers. Nanomaterials having particles of nanoscale dimensions ranging from 1 to 100 nanometre. Nanomaterials may be in the form of zero dimensional, one dimensional and two dimensional. The most commonly zero dimensional nanomaterial are nanoparticles, one dimensional material includes nanorods, nanotubes, and nanowires, two dimensional materials include nanofilms, nanolayers, and nanocoatings. Some of the commercially available nanomaterials are nanosilica, aluminium oxide, titanium oxide, silicon carbide, graphene, carbon nanofibers, and multiwall carbon nanotubes and many more. Presently nanomaterials are extensively used in manufacturing the nanocomposite components for automotive, aerospace, space crafts and marine applications [1-7].

The objective of this review is to provide a comprehensive overview of the developmental trends in epoxy composites. Mechanical properties with addition of nanfillers.

II. Effect of Nanomaterial on Mechanical Properties in Epoxy Composites

K. Bharadwaja et al. [8] In this paper researchers focused on the effect of epoxy matrix with nanomaterilas. Epoxy resin mixed with Al_2O_3 and SiO_2 nanoparticles in varying 1 and 3 weight percentage. The different tests were performed in order to investigate the mechanical properties of composite. The mixing of nanomaterials carried out using an ultrasound process where the nanoparticles are mixed with the resin for a homogeneous diffusion. The strengths observed for the nanocomposite were higher for bending and impact strength because of the Al_2O_3 and SiO_2 nanoparticle incorporation. This characteristic has a significant benefit of using Al_2O_3 and SiO_2 nanoparticles for loading conditions.

Gagi Tauhidur Rahman et al. [9] reported the impact of incorporation of TiO_2 and SiO_2 on epoxy resin nanocomposites for properties such as tensile and hardness. Nano TiO_2 and SiO_2 were added into the epoxy in varied wt.% of 1, 3, 5, and 10. The test results shows that, modulus and hardness values were enhanced in nano fillers added composites when compared to unfilled one. Nano SiO_2 exhibited comparable and better contribution in magnifying the young's modulus and hardness values than TiO_2 nanocomposites.

Sushil Kumar Singh et al. [10] focused in their research work with the inclusion of nano SiO_2 with the epoxy in different wt.% such as 2, 4, 6 and 8 for tensile and flexural characteristics. The test result shows that, these properties were increases with the increasing nano SiO_2 content in the epoxy matrix up to 4 weight percentage and deterioration observed above the 4 wt.%. This could be related to the aggregation of nano SiO_2 particles during the curing process.

Aidah Jumahat et al. [11] during their research, they studied the impact of nanosilica inclusion in epoxy on tensile characteristics. In varied wt.% of 0, 5, 13 and 25, the nanosilica incorporated with the epoxy. The test results demonstrate that, in comparison to an unfilled sample (0 wt.%) in all weight percentages, adding nanosilica to epoxy improves its tensile properties. The peak values of tensile strength and modulus found at 25 weight percentage of nanosilica addition, increased by 24 % and 38 % respectively in comparison with unfilled one, without sacrificing the failure strain.

Asmaa S. Khalil et al. [12] reported the impact of adding SiO2 nanofiller on tensile, flexural and hardness in epoxy/MWCNT composites. Nano SiO_2 added to epoxy/MWCNT with distinct wt.% such as 1, 2, 3, 4 and 5. The weight percentage of MWCNT were kept with a constant of 3 wt.% while preparing the composite laminates. The test findings show that, the incorporation of two and four weight percentage of SiO_2 nanofiller increases the tensile modulus to 3.36 and 4.06 GPa respectively when compared to the pure epoxy with 1.59 GPa. Flexural strength increased to 111 GPa with a maximum value for 2 weight percentage of nano SiO_2 and the maximum value of hardness for the composite with 5 wt. % SiO_2 nanoparticles observed as 88 when compared to pure epoxy and weight percentages of nano SiO_2.

Halil Burak Kaybal et al. [13] studied the tensile, flexural characteristics by adding nano SiO_2 to the epoxy in weight percentages of 0, 1, 2, 3, 4 and 5. The mixing of nano SiO_2 to the epoxy were carried out with ultrasonicator for 30 minutes. The test result shows that, best tensile and bending properties in the epoxy were found, when 3 wt.% of SiO_2 nanofiller was added, but increasing beyond three weight percentage, causes in reducing the tensile and flexural characteristics due to agglomeration, this causes nanosilica to be unevenly dispersed throughout the epoxy.

Krishan Kumar Patel et al. [14] reported in their research work on the characterisation of tensile, flexural strength, impact stress and hardness in nano SiO_2 added epoxy polymer composites. The inclusion of nano SiO_2 to the epoxy in various wt.% such as 1, 2, 3 and 4. When compared to other weight percentages, the peak value of tensile, flexural strength, impact stress, and hardness of composites was found at the addition of 3 weight percentage of nano SiO_2, and adding more than 3 wt. %, the tensile, flexural strength, impact stress and hardness starts decreased, which may be due agglomeration.

Gemi L et al.[15] reported carbon nanotube (CNT) and ceramic nanoparticles have different effects on the mechanical properties in epoxy nanocomposites. In this study, multi-walled CNT and three different ceramic nanoparticles (Fe_2O_3, SiO_2 and Al_2O_3) reinforcements on epoxy were examined. The weight percent of these additions were kept to be 0.5 wt% in all the tests. Tensile tests were carried out in order to characterize the mechanical properties. The additions of nanomaterilas enhanced tensile strength with the largest increase obtained with SiO_2 and Fe_2O_3 nanoparticles

Ismail Salih Mohammed et al. [16] reported the influence of nanofiller content on the mechanical properties of epoxy nanocomposites. Epoxy is used as the matrix material. A varying weight percentage of 0.1, 0.3, 0.5 and 0.7 ZnO nanofiller was used. The samples were tested for bending strength, flexural modulus and stiffness. The test results shows that, with increasing the percentage of nanofiller material, the values of bending strength, flexural modulus, and stiffness increased. The values were before adding the nanofillers 1.05 MPa, 0.164 GPa, 79 N/mm^2 respectively, and after the reinforcement, they increased than they were to become 6.15 MPa, 1.636 GPa, 81 N/mm^2 respectively.

Aldousari et al.[17] focused on, the influence of nanomaterials with epoxy resin with different types of nanofillers including SWCNT, DWCNT, MWCNT, SiC and Al_2O_3. The amount of CNTs (SWCNT, DWCNT and MWCNT) used for each type of CNTs were 0.1, 0.3 and 0.5 wt.-%. The amount used for SiC, and Al_2O_3 measured 0.5, 1 and 1.5 wt.-% for each type. Tensile test were conducted for each group to investigate the mechanical properties of epoxy based nanomaterials. The results show that CNTs of 0.3 wt.-% is optimal compared with other amounts. The tensile strength at 0.3 wt.-% SWCNT/E, DWCNT/E and MWCNT/E increased by 44 %, 37.4 % and 35.9 %, respectively compared to the neat epoxy. For SiC, and Al_2O_3, the results show that an amount of 1.5 wt.-% is optimal compared with other amounts. The tensile strength at 1.5 wt.-% for Sic/epoxy and Al_2O_3/epoxy nanocomposite increased by 25 %, and 43 %, respectively compared to the neat epoxy. Finally, the results show that the SWCNT is optimal compared to the other nanofillers.

Rahmah et al.[18]researchers conducted comparative experimental study on the impact of zinc oxide and zirconium dioxide nanomaterials on the mechanical properties of epoxy resin. Nanomaterials were incorporated into the epoxy resin at three different concentrations 4%, 6%, and 8% by weight. Results indicated enhanced properties of the epoxy resin, including tensile and compressive strengths. Notably, zirconium dioxide exhibited superior performance in enhancing tensile and compressive strengths by 67% and 50%, respectively. Zinc oxide, at the same concentrations, led to a 50% increase in tensile strength and a 40% increase in compressive strength. These outcomes were observed at the highest concentration of 8 %wt. of both nanomaterials and the pure epoxy resin. The presence of nanomaterials at this ratio promoted greater cohesion within the composite, as evidenced by SEM images of selected samples. SEM analysis highlighted the pivotal role of ZrO2 nanoparticles in improving epoxy integration, surface quality, crystallization, and imperfection removal, crucial factors for enhancing composite materials.

Nadia et al. [19] focused on mechanical properties of impact properties of epoxy with different weight percentage of SiO_2 and Al_2O_3 nano particles (0.5%, 1%, 1.5%, 2%, 2.5%, 3%). A combination of two different techniques high shear mixing followed by ultrasonication was used to prepare the nanocomposites. The impact energy properties were measured for EP/ Al_2O_3, EP/ SiO_2 nanocomposites. Approximately 80% increasing in values of impact energy were observed. An enhancement in whole measurement for all composites was observed, composites with 2.5%nano Al_2O_3 show in general better impact results.

Y. KrishnaBhargavi et al.[20] carried research work with Titanium carbide (TiC) nanoparticles added into epoxy resin composites to enhance their mechanical properties. Epoxy-TiC nanocomposites were produced using a solution mixing method, including different concentrations of TiC (0.5 weight percent, 1 weight percent, 2 weight percent, and 5 weight percent). The nanocomposites were then submitted to mechanical assessment. The results indicate that the addition of TiC nanoparticles enhanced the tensile strength from 50 MPa to 75 MPa, the flexural strength from 80 MPa to 110 MPa, and the impact strength from 10 kJ/m² to 15 kJ/m² at a TiC content of 2 weight percent. A little reduction in features occurred due to the agglomeration of TiC nanoparticles when the concentration was raised to five weight percent. This study demonstrated that the optimal concentration of titanium carbide (TiC) for enhancing mechanical performance in epoxy composites is 2 weight percent. This suggests that these composites possess the capability for use in sophisticated engineering applications.

Pinto, S. de S et al. [21] explored the development of epoxy resin nanocomposites with 0.1, 0.3%, and 1.0% by weight of aluminum nanoparticles. These nanocomposites were evaluated for mechanical properties such as tensile test and Izod strength test Adding even small amounts of aluminum nanoparticles led to notable improvements in the mechanical properties. Composites with 1.0 wt% of aluminum nanoparticles presented a 25% increase in the elastic modulus, This finding hold significant promise for advancing the field of polymer-metal nanocomposites.

III. CONCLUSION

Today in the composite material world, the researchers are focusing to enhance the mechanical properties of epoxy by adding a very small weight percentage of nanomaterial to it. In epoxy nanocomposites, the epoxy resin is supplemented with a nanoparticle that has a large surface area thereby allowing considerable interaction between epoxy and filler. The literature survey revealed that a desired quantity of nanomaterial enhance the mechanical properties of epoxy and on the other side by adding more percentage of nanomaterial the mechanical properties starts decreasing due to agglomeration.

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