Effect of Nanoparticles on The Improvement of Mechanical Properties of Epoxy Based Fiber – Reinforced Composites - A Review

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Abstract- *Recent years have witnessed a substantial increase in the use of Fiber-Reinforced Polymer (FRP) Composites in place of conventional construction materials.For the last eras, nanocomposites have been extensively studied in the scientific literature as they afford significant properties enrichments, even at low nanoparticles content. In this review, the research results obtained with commercial nanoparticles published in the last decade are studied, results are compared with a focus on mechanical / thermal properties and the mechanisms responsible for the property improvements are discussed.*

Keywords- Polymer , Nanocomposite , Fiber, Mechanical Properties.

I. INTRODUCTION

In engineering applications the reinforcing fiber are nonwoven and their orientation towards the force along the part are of utmost importance. However, the choice of resin and hardener is important as well – to match performance as well as production cycle needs. Of course any improvement of the resin performance is welcome to help to improve the performance of the composite parts.

Epoxy resins are widely used in fibre-reinforced composites due to their superior thermal, mechanical, and electrical properties. Depending on the chemical compositions and curing kinetics, it is possible to vary their mechanical properties ranging from extreme flexibility to high strength and hardness, and physical properties such as adhesive strength, chemical resistance, heat resistance and electrical resistance. The extensive usage of the epoxy thermosets, nevertheless, is restricted in many high-performance applications because of their intrinsic brittleness, delamination and fracture toughness margins. The progress of enhanced high performance composites based on thermosetting polymers can only be accomplished by concurrently refining resin, fibre and interface properties. Substantial property improvements are presently made possible by the incorporation of dispersed elastomeric and thermoplastic phases into the resin matrix, which results in a multiphase polymeric system.[1–2].

Mineral fillers like calcium carbonate or quartz powder can enhance the mechanical properties of epoxy resins like strength, stiffness and modulus. Still, they do rise the viscosity of the resin considerably. Owing to their size, naturally microns, they cannot be usedin injection manufacturing methods since they are filtered out by the fabric upon injection. In prepreg manufacturing they tend to sediment in the process. Thus in most composites applications no mineral fillers are used.

A recently developed method proposing encouraging outcomes and an exclusive level of mechanical properties enrichment and/or control comprises the use of nano-sized organic and inorganic particles. Nano-particles are currently considered to be high potential filler materials for the enhancement of mechanical and physical properties of polymer and its composites. The nanometric size, leading to massive specific surface areas of up to more than 1000 m^2/g, and their sole properties (of at least some of these nano-particles) have produce drigorous research accomplishments in the fields of natural and engineering sciences.

This review includes a survey of the past research already available involving the issues of interest. It presents the research works on the fiber reinforced composites dispersed with nano particles on the mechanical / thermalproperties of composites deliberated by various investigators.

II. EFFECT OF NANOPARTICLES ON MECHANICAL PROPERTIES OF FIBER REINFORCED COMPOSITES

Wu et al (2001)[3] were prepared carbon fiber and glass fiber reinforced polyamide-6 and polyamide-6/nanocomposites. Results showed that the mechanical and thermal properties of the polyamide-6 / clay nanocomposites are superior to those polyamide-6 composite in terms of the heat distortion temperature, tensile, flexural strength and modulus without sacrificing their impact strength.

Timmerman et al (2002) [4] modified carbon/epoxy composites with Closite 25 and alumina particles to determine the effect of particle reinforcement and response of modified materials to cryogenic cycling. Closite 25 was incorporated into the base resin at a concentration of 2, 5 and 8 parts per hundred resin and alumina particles were added at a concentration of 5 parts per hundred resins (phr). The interlaminar shear strength was found to improved at 2 and 5% nano.But flexural properties were found to decrease with the addition on nano.The average crack density detected using optical micrographs diminished with incorporation of nano when compared with unmodified laminate whereas incorporation of alumina particles brought no change in microcrackdensity when compared with the unmodified system.

Haque et al (2003)[5] prepared S2-glass/epoxy-clay nanocomposites through an affordable vacuum assisted resin infusion method (VARIM) and observed the effects of nano clay particles on improving mechanical and thermal properties of fiber reinforced polymer matrix composite materials. Basic correlations between polymer morphology, strength, modulus, toughness, and thermal stability of thermoset nanocomposites were also examined as a function of layered silicate content. They found that by dispersing 1% by weight nano silicate,S2-glass/epoxy-clay nanocomposites attributed to almost 44, 24 and 23% improvement in interlaminar shear strength, flexural strength and fracture toughness in comparison to conventional S2-glass/epoxy composites.

Kornmann et al (2005)[6] successfully synthesized glass fiber reinforced epoxy layered silicates nanocomposites using hand lay-up, vacuum bagging, and hot pressing techniques. Scanning electron micrographs of the laminate with a nanocomposite matrix showed that nanolayers stacked at the surface of the glass fiber, improving possibly in this manner the interfacial properties of the fibers. Flexural testing of the laminates showed that the nano layers improved the modulus and the strength, respectively, by 6% and 27%.

Lin et al (2006)[7] were prepared the nano clay/glass fiber/epoxy hybrid composite using a vacuum-assisted resin transfer molding process. The results indicated that introducing a small amount of organoclay to the glass fiber/epoxy composites enhanced their mechanical and thermal properties. Wichmann et al (2006)[8] have produced glass-fiber – reinforced composites with nanoparticle modified epoxy matrix with a resin-transfer-mouldingprocess.They found that the interlaminar shear strength of the nanoparticle modified composites were significantly improved by adding only 0.3wt% of CNTs also the laminates containing CNT exhibited a relatively high electrical conductivity at very low filler contents.Chowdhury et al (2006)[9] carried out a study to investigate the effects of nano clay particles (Nanomer 1.28E) dispersed in SC-15 epoxy/weave carbon fiber composite on flexural and thermal properties. Maximum improvements in flexural strength and modulus were found for 2wt% nano clay reinforced composites.DMA also showed an enhancement in thermomechanical properties.

Bozkurt et al (2007)[9] investigated the mechanical and thermal properties of non-crimp glass fiber reinforced clay/epoxy nanocomposites. The tensile test indicated that clay loading has a minor effect on the tensile properties, flexural properties of laminates were improved by clay addition. DSC results showed that the modified clay particles affected the glass transition temperature of the nanocomposites. Incorporation of surface treated clay particles increased the dynamic mechanical properties of nanocomposite laminates also the flame resistance of composites was improved significantly by the clay addition into the epoxy matrix.

Tsai & Wu (2007)[10] prepared the glass/epoxy nanocomposite dispersed with 2.5,5 and 7.5wt% organoclay by hand lay process. the tests revealed that tensile strength decreases as organoclay loading increases, tensile modulus increases upto 5wt% organoclayinplane shear strength and flexural strength increases with increase in organoclay content. Furthermore, the interlaminarModeI fracture toughness also decreases with increase in organocaly content.Cho et al (2007)[11] were modified the carbon fiber / epoxy composites with graphite nanoplatelets to improve their mechanical properties. The composite reinforced with nanoparticles showed enhanced compressive strength and in-plane shear properties.Siddiqui et al. (2007)[12] investigated the mechanical properties and fracture behavior of nanocomposites and carbon fiber composites (CFRPs) containing organoclay in the epoxy matrix.. Morphological studies revealed that the clay particles within the epoxy resin were intercalated or orderly exfoliated. The organoclay brought about a significant improvement in flexural modulus, especially in the first few wt% of loading, and the improvement of flexural modulus was at the expense of a reduction in flexural strength. The quasi-static fracture toughness increased, whereas the impact fracture toughness dropped sharply with increasing the clay content. Flexural properties of CFRPs containing organoclay modified epoxy matrix generally followed the trend similar to the epoxy nanocomposite although the variation was much smaller for the CFRPs. Both the initiation and propagation values of mode interlaminar fracture toughness of CFRP composites increased with increasing clay concentration. Mridha et al (2007) [13] used oil palm wood flour (OPWF) particles as a filler material in the woven-glass-fiber reinforced epoxy composite , it was observed that impact strength was reduced upto 5pph OPWF and then increased.

Xu& Ho (2008)[14] fabricated the carbon fiber /epoxy / clay nano composite with montmorillonite nano clay and found that interlaminar fracture toughness was increased by 85% with the introduction of 4% nano clay also 38% enhancement in the flexural strength by the 2% addition of nano clay.Uddin& Sun (2008)[15] has developed an attempt to improve the strength of unidirectional composites by enhancing the matrix properties through nanoparticles infusion. The silica nanoparticles in Nanopox were grown in situ via a sol–gel process resulting in a concentration of 40 wt% which was later diluted to 15 wt% particle loading.. Compression test revealed a substantial improvement (40%) in elastic modulus of the modified epoxy The inclusion of silica nanoparticles dramatically increased the longitudinal compressive strength and moderately increased the longitudinal and transverse tensile strengths. A micro buckling model was used to verify the compression testing results.
Asi (2009)[16] has experimentally study of mechanical properties of glass-fiber reinforced epoxy composite filled with different proportions of Al_2O_3 particles. The results showed that while ultimate tensile strength and shear strength of the composites decreased with increasing Al_2O_3 particles content, flexural strength increased with the Al_2O_3 particles content upto 10% beyond which it decreased.

Zulfli&Shyang (2010)[17] was manufactured the epoxy composite reinforced with glass fiber and OMMT with hand-layup technique and concluded that the flexural modulus and strength of E/GF composites were improved by the addition of silane treated OMMT.Kumar et al (2010)[18] assessed the influence of nano clay on tensile strength , tensile modulus , flexural strength and flexural modulus properties of epoxy/glass fiber /nano clay composites and found that optimal improvement of properties was increased with the clay content upto 5wt%.Singla (2010)[19]manufactured the glass fiber reinforced epoxy resin-fly ash composite and the found that With the addition of fly-ash in epoxy resin –fly-ash composite the compressive strength has been found to increase with increase in fly ash particles. This increase is attributed to the hollowness of fly-ash particles & strong interfacial energy between resin & fly-ash.

Rozman et al (2011)[20] has produced Kenaf/unsaturated polyester composites filled with MMT filler and concluded that the addition of MMT resulted in an overall increase in tensile strength of composites compared to those without MMT.

He et al (2011)[21] has prepared the composites of CF-reinforced modified epoxy matrix with different NR content. From the testing results it was concluded that by adding the different content of NR, 7-13% NR content in composite shows an obvious improvement in ILSS and impact strength, however with increase in NR content, the flexural strength and flexural modulus decreased.Kim et al (2011)[22] investigated the effect of carbon nanotube (CNT) modifications on the flexural and wear behaviors of multiscale carbon/CNT/epoxy composites. Carbon/epoxy woven composites and two types of multiscale carbon/CNT/epoxy composites were fabricated by incorporating woven-type carbon fibers into epoxy matrices modified with 2 wt% acid-treated and silane-treated multi-walled carbon nanotubes (MWCNTs). Three-point bending and ball-on-disk wear tests were performed on the three composites. The results showed that the flexural moduli and strengths of carbon/CNT/epoxy composites were greater than those of carbon/epoxy composites, regardless of CNT modification. Specifically, the flexural modulus and strength of the silane-treated specimens were 10% and 15% greater, respectively, than those of the acid-treated samples. The results also showed that the wear properties of carbon/epoxy composites are improved by the addition of CNTs. In addition, the wear properties of silane-treated samples were superior to those of acid-treated samples. Karippal et al (2011)[23] was dispersed Nanomer 1.30E nano clay (0-6wt%) and manufactured the epoxy/glass/nano clay hybrid composites using hand lay-up technique and found that mechanical properties such as ultimate tensile strength, Young’s modulus, flexural strength, flexural modulus, interlaminar shear strength and micro hardness of the hybrid composites increased with increase in nano clay loading up to 5wt%. Glass transition temperature increased marginally at 2wt% nano clay loading and decreased for further addition of the filler.Ye et al (2011)[24] prepared the hybrid composites with HNT and carbon fiber-woven fabrics. The interlaminar properties of the composites were investigated by a short-beam shear test, a double-cantilever-beam test and an end-notched flexure test. The results showed that the addition of HNTs to the composites improved the interlaminar shear strength and the fracture resistance under Mode I and Mode II loadings greatly. The morphological study of the hybrid composites revealed that HNTs were non-uniformly dispersed in the epoxy matrix, forming a unique microstructure with a large number of HNT-rich composite particles enveloped by a continuous epoxy-rich phase. A study of the fracture mechanism uncovered the important role of this special morphology during the fracturing of the hybrid composites.

He et al (2013)[25] conducted a study on evaluating the effect of nano-CaCO3 particle contents (2-6 wt%) on thermal and mechanical properties of epoxy/carbon fiber composite . It was revealed that nano- CaCO3 /epoxy/carbon fiber represents higher thermal stability and mechanical strength. Shivamurthy et al (2013)[26] were made the multi-layered laminates of bi-directionally woven E-glass fabric/epoxy with different loading of graphite particles and determined the tensile , flexural behaviours , impact strength, hardness and density of these laminates also wear behaviour of these composites were investigated by pin-on-disc wear test apparatus. Specific wear rate of these composites strongly depend on their filler content and applied normal loads. The composite containing 3wt% of graphite exhibits the optimum mechanical and wear performance and a further increase in graphite content increases the specific wear rate and deteriorates the mechanical behaviour.Dhawan et al (2013)[27] studied the effect of natural fillers on the mechanical characteristics of FRPs. Rice husk, wheat husk and coconut coir have been used as natural fillers in glass fiber reinforced plastics (GFRPs).To study the effect of matrix on the properties of GFRPs polyester and epoxy resins have been used. It has been found that natural fillers provide better results in polyester based composites also amongst the natural fillers , in general, the composites with coconut coir have better mechanical properties as compared to the other fillers in glass/epoxy composites. Prabhu et al (2013)[28] were prepared the epoxy-nylon fabric composite containing 0.1 – 0.7 Phr clay reinforcements using hand lay-up method The testing results indicated that an increase in impact resistance, tensile strength, flexural strength and Young’s modulus to an extent and then a decreases as the clay content was increased. Wang et al (2013)[29] studied the effect of adding graphene in epoxy containing either an additive (MP) or reactive type (DOPO) flame retardant on thermal, mechanical and flammability properties of glass fiber-reinforced epoxy composites. It was found that the presence of grapheme increased the flexural and impact properties, but slightly decreased tensile performance.Zulfli et al (2013)[30]studied the influence of precipitated nano calcium carbonate (PNCC) on the mechanical and thermal properties of epoxy/glass fiber laminates.It was found that the flexural properties, impact strength and fracture toughness of epoxy/GF laminates were increased profoundly in the presence of PNCC, also the storage modulus and decomposition temperature of the epoxy/GF increased remarkably with the addition of PNCC.

Soliman et al (2014)[31] examined the role of carboxyl functionalized multi-walled CNT(COOH-MWCNT) with different content(0.5wt% , 1.0 wt% and 1.5wt% of epoxy) in the flexure and shear responses of thin carbon woven fabric composite plates and found significant increases in flexure strength, modulus and toughness of the specimens.

Ramamoorthi &Sampath (2015)[32] were made the Epoxy/Glasss fabric / HNT nanocomposite with different loading percentage of HNT and concluded that addition of HNT has significantly enhanced the mechanical properties of the resultant composite laminates.

Ustun et al (2016)[33] investigated the fatigue performance carbon fiber/epoxy filament wound composite pipes toughened by carbon nanotubes (CNTs) and boron nitride nanoplates (BNNPs) , and discussed the effectiveness of nanofillers with different morphologies on fatigue damage development and their micro/nano reinforcing mechanisms. And based on the fractographic investigations they revealed that the morphologies of nanofillers play a key role on improving mechanical performance by generating different nano- and micro-scale toughening mechanisms

Alsaadi et al (2017)[34] investigates the interlaminar shear strength of the woven carbon, glass, and Kevlar fiber reinforced epoxy (CFRE, GFRE, and KFRE) composites filled with SiC particles. The work covers the samples preparation, testing, and analyzing. The samples were fabricated using the regular addition of the SiC particles as 0, 5, 10, 15, and 20 wt% of the total weight of epoxy resin and stated that, SiC particles significantly enhanced the interlaminar shear strength of CFRE, GFRE, and KFRE composites as the comparison to the conventional ones.Jeyakumar et al (2017)[35] manufactured the glass fiber reinforced epoxy composites filled with various proportions of closite clay particles and tested their mechanical and morphological properties. They concluded that for 5% reinforced clay composites,the tensile strength/ modulus flexural strength/modulus and impact strength were increased as compared to unfilled composite, whereas for allthe other compositions it showed a decreasing trend.

III. CONCLUSIONS

From various experimentation done by research team it is clear that addition of nanoparticles are showing promising increase and enhancement in mechanical mproperties.

Significant improvements in strength, modulus and toughness were found for polymers modified with nanoparticles. When these resins are used as matrix for fiber reinforced composites significant improvements were found.

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