The Effect Of Nano SiO₂ On The Mechanical And Tribological Properties Of Hybrid Polymer Matrix Composites: A Review

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Abstract
Composite are exciting materials finding widespread applications because of their enhanced mechanical, dynamic and thermal properties over the conventional materials. Polymer Matrix Nano Composites (PMNCs) were developed by uniform dispersion of nano silica particles with different weight percent in epoxy matrix using hand lay-up and compression moulding technique were showing remarkable improvements in the mechanical properties like tensile strength, flexural strength, and impact strength. The nano particles show considerable improvement in properties when reinforced with carbon/Kevlar fabric/epoxy composites, because of their larger surface area to volume ratio, very high specific strength, hardness and stiffness. This performance indicates the good adhesion strength and chemical compatibility of the nano-silica particles with the polymer matrix. Being environment friendly, applications of nano composites offer new technology and business opportunities for several sectors, such as aerospace, automotive, defence, electronics and biotechnology industries. Hybrid composites that exploit the synergy between natural fibres in a nano-reinforced polymer can lead to improved properties along with maintaining environmental appeal. This review article involves the detailed study of polymer matrix composites and epoxy resin hybrid nano composites for engineering applications.

Key words: Polymer matrix nano composites, Hybrid composites, Nano particles, Kevlar fibre, Hardness, Impact strength.

1. Introduction
Composite materials are finding widespread applications in the commercial enterprises in light of their excellent properties like Ease of creation, environmentally benevolent nature, chemical and erosion resistance, high quality and solidness, and economically productive properties. Researchers mainly focus on the improvement of thermal and mechanical properties of the developed composite material. Epoxy is the most common matrix material used for the composite material development. This is because of the desirable properties of epoxy viz. chemical stability, good mechanical properties, high adhesive strength and excellent heat and moisture resistance. Because of the above properties of epoxy it is now widely used in mechanical engineering, electronics/electrical engineering applications, aerospace and aviation fields and also in chemical industries.

There are many reinforcements that can be added to polymers for the enhancement of properties like glass particles, ceramic particles, layered silicates, metal particles and thermoplastics. Sometimes ceramic nano particles, clay, graphene and CNT are also added to toughen the epoxy resin by plastic void growth, crack

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pinning etc., with a simultaneous increase in strength and modulus with no drastic effect on glass transition temperature. If fillers are added in larger weight percentage then a noticeable improvement in toughness of epoxy matrix will also be seen. Silica/Epoxy composites is one of the most widely used polymer matrix composites. Epoxy and its composites are widely used in coatings, pottery, adhesives, encapsulation of semiconductors, laminates etc. Adding silica to epoxy matrix enables lower shrinkage on curing, reduction in coefficient of thermal expansion, enhancement in thermal conductivity and other mechanical properties. Adding of silica particles prompts a change in mechanical electrical and warm properties.

The new trend of adding nano-material and polymeric alloying to epoxy is gaining popularity. This approach of adding nano particles to epoxy leads to enhancement in mechanical properties of epoxy without any change in the glass transition temperature. Common nano-fillers used as reinforcement in epoxy material are Aluminium Oxide (Al$_2$O$_3$), Silica (SiO$_2$) and Titania (TiO$_2$). Adding thermoplastic fillers, rubber agents etc. to the epoxy matrix have also shown an improvement in the properties of epoxy.

1.1 Hybrid Nano Composites

When two or more nano particles or micro particles are together employed as reinforcement then the composite developed is termed as Hybrid Nano Composites. Achievement of improved mechanical properties and also properties of crack resistance encouraged the use of hybrid nano composites in areas where improved strength is in demand that too with a low cost. Sometimes to achieve better properties the polymer matrix composites are reinforced with an additional reinforcement.

1.2 Nano particles:-

A Nano particle (Nano-powder or nanocrystal) is a microscopic particle with dimension less than 100 nm. The Nano particles structure a viable association between naturally visible (mass) materials and nuclear or atomic structures. This scaffold component, nano particle and nanotechnology have capacity to see and control singular particles and atoms. It is used in different fields, for example, biomedical, optical, sensor innovation and electronic fields.

2. Fabrication Processes for PMC:

The various types of techniques are used for Fabrication of Polymer matrix composites such as hand lay-up technique, Autoclave Processing, Spray lay-up, Liquid Composite Moulding, and Compression Moulding. The simplest technique available for polymer matrix composite processing is hand lay-up method; it has minimum requirement of equipments and set up. Firstly a mould release agent is applied on the lower surface of the mould to enable easy removal of polymer from the mould after curing. Thermo-set polymer is mixed with hardener in suitable ratio and poured in the mould until a desired thickness of polymer layer is obtained and then reinforcement in the form of woven mats are cut in accordance with the mould dimensions and placed onto the polymer layer. Major drawback of this method is the rate of production is less and high volume fractions of reinforcement are difficult to achieve. Aircraft components, boat hulls, automotive parts are some areas where hand layup technique can be used. The present paper reviews the recent studies on the mechanical and thermal properties of the polymer-Nano SiO$_2$ composites and polymer hybrid composites.

3. Study of Mechanical Properties of the Polymer-SiO$_2$ Composites

Composites are very useful materials now days; various researchers investigated different mechanical properties with various types of reinforcement. There are many researches which have already conducted work on
Polymer Matrix Composites with Silica as reinforcement. The usual particle size of SiO$_2$ taken by the researchers varies from 100 to 300 nm. Polymer matrix composites are showing remarkable mechanical properties. Mechanical properties like tensile strength, flexural strength, impact strength and hardness has been measured and it was found that the mechanical properties of composites increases with the addition of the filler material. In this paper the effect of the Nano silica on the mechanical properties has been studied.

P.B. Ma et al. [2015] studied the impact compression including quasi-static and high strain rate compression properties of epoxy with various SiO$_2$ nano particles (0 wt.%, 5wt%, 10wt%, 15wt%) was investigated via Split Hopkinson Pressure Bar. The high strain rate stacking, the disappointment anxiety of epoxy composites with different SiO$_2$ nano particles substance is much bigger than that in semi static stacking. Compressive disappointment rate increments with the strain rate and SiO$_2$ content. Fracture and the morphology turned out to be steadier with the expansion of SiO$_2$ nano particles substance under high strain rate. It was watched that the composites with higher substance of SiO2 nano particles enhanced the vitality retention of composites since they could hoist the harshness of composites [1].

Y. Rostamiyan et al. [2015] developed a hybrid composite by using Epoxy, SiO$_2$ particulate and high impact polystyrene. Later analysis of damping properties was done on Laser Dropler Vibrometer and by considering the specimen as cantilevered beam calculated damping coefficients and natural frequency. They observe that the varying the percentage of SiO2 first is an increase in the modes of damping to a specific value and then it starts decreasing [2].

M.Shariati et al [2015] examined ductile properties, elastic modulus and particular vitality retention of nano particles filled epoxy grid. The qualities of nano composites can be assessed by pressure, flexural and Charpy or Izod sway testing. Tensile tests were done and Young’s Modulus was found to increment with the expansion in silica sticking to epoxy; yet no impact of molecule size was seen on tractable properties. Numerous different looks into their works have reported comparative results [3].

Table 1: Variation in Young’s Modulus and Strength of Epoxy matrix with different wt% of Nano SiO$_2$ [3]

<table>
<thead>
<tr>
<th>Sample</th>
<th>Young’s Modulus(MPa)</th>
<th>Strength(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat Epoxy</td>
<td>1521</td>
<td>20.3</td>
</tr>
<tr>
<td>1.5% wt of 17nm</td>
<td>1547</td>
<td>19.6</td>
</tr>
<tr>
<td>3% wt of 17nm</td>
<td>1589</td>
<td>19.8</td>
</tr>
<tr>
<td>4.5% wt of 17nm</td>
<td>1605</td>
<td>19.2</td>
</tr>
<tr>
<td>6% wt of 17nm</td>
<td>1712</td>
<td>19.7</td>
</tr>
<tr>
<td>1.5% wt of 65nm</td>
<td>1535</td>
<td>20.1</td>
</tr>
<tr>
<td>3% wt of 65nm</td>
<td>1572</td>
<td>19.5</td>
</tr>
<tr>
<td>4.5% wt of 65nm</td>
<td>1591</td>
<td>20.4</td>
</tr>
<tr>
<td>6% wt of 65nm</td>
<td>1684</td>
<td>20.2</td>
</tr>
</tbody>
</table>

M.M. Alavi Nikje et al. [2012] Prepared the ground surface with the help of epoxy/siO2 nano composites by in –situ polymerization technique and investigating the rigidity, hardness and scraped area resistance, Dynamic Mechanical Analysis (DMA) and SEM. Conclusion of the study is the Hardness and Abrasion resistance increments with expansion in wt% of SiO2. Dynamic Mechanical Analysis uncovered that Glass Transition Temperature increments with the expansion in SiO2 wt%. Epoxy and nanoparticles giving a more grounded interface. High surface range/particles size proportion of nanoparticles is showing the amazing physical properties of polymer grid composites [4].

M.Zamanian et al. [2013] have developed the epoxy gum by including nano silica particles of different sizes of 12nm, 20nm and 40nm and particular territory of 200, 90 and 50 m2/g separately and were homogeneously circulated by ultrasonic shower. Glass transition temperature was ascertained by DMTA (Dynamic
Mechanical Thermal Analysis) while the Young's Modulus was found by Universal Testing Machine. They observe that the Young's Modulus increments with the expansion in weight rate. Fracture strength of epoxy silica content increments with the wt.% [5]. Peerapan Dittanet [2011] has done the exploration work by building up an epoxy composite fortified with SiO2 particles by sol-gel process. The nano silica particles had a normal molecule size of 170nm, 74nm, 23nm. Volume rate fluctuated from 0-30% nano SiO2 particles. Yield Stress and Young's Modulus increments with the expansion in SiO2 particles. Coefficient of warm development (CTE) was found to diminish with the expansion in SiO2 content [6]. F.N Ahmad et al [2008] investigated the effect of addition of different volume percentage (0 vol. %, 15 vol. %, 30 vol. %, 45 vol. %) of silica content to epoxy and different filler shapes (angular, cubical, and elongated) on the properties of epoxy composites. The properties of composite were compared on the basis of SEM, TGA, Tensile and Flexural property tests. Morphology of Silica mineral particles was done under SEM and results showed, the fused silica particles are irregular hexagonal structures. Elongated silica fiber showed greater strength because elongated fiber shows high aspect ratio. Flexural modulus was found to increase with the increase in filler loading in the epoxy matrix. Highest flexural modulus was obtained by short fiber because of high aspect ratio. Mechanical properties of silica mineral were better due to agglomerations, filler matrix compatibility, bonding at interface and aspect ratio [7].

<table>
<thead>
<tr>
<th>Shape of particles</th>
<th>Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular</td>
<td>0.84</td>
</tr>
<tr>
<td>Elongated</td>
<td>1.122</td>
</tr>
<tr>
<td>Cubical</td>
<td>2.954</td>
</tr>
<tr>
<td>Fused silica: Irregular Shape</td>
<td>1.362</td>
</tr>
</tbody>
</table>

Table 3: Values of Tensile properties [7]

<table>
<thead>
<tr>
<th>Sample</th>
<th>Strength(MPa)</th>
<th>Modulus(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>43.3</td>
<td>1695</td>
</tr>
<tr>
<td>Epoxy (Angular Silica mineral 15 vol %)</td>
<td>41.9</td>
<td>2242</td>
</tr>
<tr>
<td>Epoxy (Angular Silica mineral 45 vol %)</td>
<td>33.3</td>
<td>4910</td>
</tr>
<tr>
<td>Epoxy (Cubical Silica mineral 15 vol %)</td>
<td>40.9</td>
<td>2412</td>
</tr>
<tr>
<td>Epoxy (Cubical Silica mineral 45 vol %)</td>
<td>34.9</td>
<td>4987</td>
</tr>
<tr>
<td>Epoxy (Elongated Silica mineral 15 vol %)</td>
<td>47.5</td>
<td>3482</td>
</tr>
<tr>
<td>Epoxy (Elongated Silica mineral 45 vol %)</td>
<td>61.2</td>
<td>5204</td>
</tr>
</tbody>
</table>

Table 4: Values of Thermal properties [7]

<table>
<thead>
<tr>
<th>Sample</th>
<th>CTE (ppm/°C)</th>
<th>T_a (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>20.72</td>
<td>83</td>
</tr>
<tr>
<td>Epoxy (Angular Silica mineral 45 vol %)</td>
<td>32.83</td>
<td>98</td>
</tr>
<tr>
<td>Epoxy (Cubical Silica mineral 45 vol %)</td>
<td>30.11</td>
<td>95</td>
</tr>
<tr>
<td>Epoxy (Elongated Silica mineral 45 vol %)</td>
<td>92.91</td>
<td>95</td>
</tr>
<tr>
<td>Epoxy (Fused Silica 45 vol %)</td>
<td>20.72</td>
<td>83</td>
</tr>
</tbody>
</table>

C. Chen et al [2008] created epoxy/SiO2 nano composites of which TEM pictures demonstrated negligible agglomerations of SiO2 particles in epoxy framework at 25 wt% stacking. Mechanical properties were found that pliable modulus increments up to 20 wt% stacking however it gets to be weak with lesser quality at high loadings of silica filler [8].

R. B. Nath and D. N. Fenner and C. Galiotis [2010] investigate the failure of Kevlar 49 fibre embedded in an epoxy matrix subjected to tensile loading by using finite element analysis. The geometry of the fibre end has been modelled employing an analytical fibre end fibrillation model (FEFM). The competing failure mechanisms are dependent on fibre geometry and material property differentials between fibre and matrix. Carbon reinforced composites have a much higher elastic modulus differential than Kevlar composites, and are more significant [9].
Aswani Kumar Bandaru [2015] investigated the ballistic impact response of thermoplastic-based composite armors made from Kevlar® fabric and polypropylene (PP) matrix. The Interfacial property between PP and Kevlar® was improved by adding a coupling agent called maleic anhydride grafted polypropylene and samples are made by compression moulding technology. Hydro code simulations were carried out using ANSYS AUTODYN v. 14.0 to obtain an estimate for the ballistic limit velocity and simulate failure modes. The observation of the test is showing the best result of ballistic impact is depending on the fabric architecture. The fabric architecture increase in the ballistic limit from 2D plain woven armour to 3D orthogonal and 3D angle interlock armours was 16.44% and 20%, respectively. The density of Kevlar® thermo plastic based composites reduce 16–29% over conventional thermo-set based laminates [10].

Zhang et al. [2006] reported that there was around 30% improvement in the tensile strength and flexural modulus when silica was added as reinforcement in the epoxy matrix [11].

P. Rosso et al. [2006] prepared polymer matrix composite material by adding 11 wt% silica nano particles to the epoxy matrix and reported an increase in fracture
toughness and tensile strength of the composites [12].

XF. Yao et al [2008] prepared polymer matrix composite material by adding SiO2 in 1, 3, 5 and 7 wt% to the epoxy matrix using magnetic stirrer. Fracture analysis was done by evaluating load –displacement relation and fracture surface were analyzed under SEM. With increase in load it showed a non linear deformation behavior and improvement in toughness character was observed. With 3 wt% content the fracture toughness increased by 15.4% when compared to pure epoxy. Fractured surface of 1wt% nano composite showed a wing peel stratum, whereas in 3 wt% composite ladder pattern was observed because of uniform distribution [13].

T. Mahrholz J. S et al. [2009] investigated the suitability as a new type Epoxy–silica nano composites matrix for fibre-reinforced polymers (FRP) using injection technology (LCM). The Photon Cross Correlation Spectroscopy (PCCS) and Scanning Electron Microscopy (SEM) analysis performed on the liquid and cured epoxy–silica nano composites indicate a nearly homogeneous distribution of the nano scale silica in the epoxy matrix. It was observed that the quantity of silica content in the composite increases the mechanical properties of the composites such as its stiffness, strength and Toughness. The resin shrinkage and the thermal expansion (CTE) can be significantly reduced and the thermal conductivity increased, with high weight percentages. The initial viscosity of the resin increases slightly depending on the nano particle content.[14]
Tensile properties of epoxy-silica composites

Flexure and impact properties of epoxy-silica composites

Stress–strain curve and absolute value of epoxy-silica composites

Fig. 4: Effect of Nano SiO$_2$ on the epoxy-silica composites.

Peerapan Dittanet et al [2013] studied the effect of addition of silica nanoparticles (23 nm, 74 nm, and 170 nm) to a lightly cross linked, model epoxy resin. The effect of silica nanoparticle content and particle size on glass transition temperature (Tg), coefficient of thermal expansion (CTE), Young’s modulus (E), yield stress (σ), fracture energy (GIC) and fracture toughness (KIC), were investigated. The toughening mechanisms were determined using scanning electron microscopy (SEM), transmission electron microscopy (TEM) and transmission optical microscopy (TOM). The Young’s modulus was also found to significantly improve with addition of silica nanoparticles and increase with increasing filler content and fracture toughness and fracture energy also showed significant improvements with the addition of silica nanoparticles, and increased with increasing filler content [15].

Comparison between the model prediction and experimental data for the CTE of different silica particle.

Experimental Data for the CTE of different silica particle.

Comparison between the model prediction and experimental data for the Young modulus of different silica particle.

Experimental Data for the Young modulus of different silica particle.
The fracture toughness for different size of silica nano particles.

The fracture energy for different size of silica nano particles.

Fig. 5: Comparison between the theoretical models and experimental data of epoxy filled with different silica nano particle sizes [15]

M. Conradi et al. [2013] prepared epoxy composites filled with a low, 0.5% volume fraction of 130-nm and 30-nm spherical silica particles and investigate the mechanical properties. Raman spectroscopy was employed to obtain additional information about the crack-propagation path. The mechanical properties, characterized by a three-point bending test. He observed that the modulus of elasticity is increased by 20% and fracture toughness is improved up to 30%. The impact energy of composites is strongly depending on the size of the silica. The impact energy is 30% increase for the 130-nm, and 60% increase for the 30-nm, silica/epoxy composites as compared to the pure epoxy.[16]

Stress strain curves of composites and neat epoxy Load deflection curves of composites and neat epoxy.

Fig. 6: Effect of the different particle size on the properties of composites. [16]

L.M. Bresciani et al [2016] develop a numerical model and investigate the ballistic impact behaviour of tungsten blunt projectiles on Kevlar® 29 plain woven fabrics with an epoxy matrix. He found that the numerical models have been showing the better result. Meso-heterogeneous model simulates the fabric in its specific architecture and adopts the individual mechanical properties [17].
Comparison of the residual velocities of the two Numerical model and experimental data. Numerical model and experimental data. Fig. 7: comparison of Numerical model and experimental data [17]

4. Conclusions
There are wide variety of research studies already conducted on polymer matrix composites with silica as reinforcement and investigation of different mechanical properties with silica as well as other types of reinforcement. The current study presents a detail review on the development and analysis of epoxy/nano SiO₂ polymer matrix composites utilizing much lesser particle size reinforcement and study of their mechanical properties like tensile strength, flexural strength, impact strength and hardness. The main focus in this study was on the polymer matrix composite with epoxy as the matrix material and reinforcement of nano silica particles with different weight percent and the hybrid composites incorporating Kevlar fiber bidirectional woven mat in the epoxy matrix with various weight percent of SiO₂. The comparisons of properties of both the composites was also reported and found the improvement in the mechanical properties.

References


