Surface topographical studies of glass fiber reinforced epoxy-ZnO nanocomposites

Sridhar Thipperudrappa, Achutha Ullal Kini, Anupama Hiremath and Karani Dileep Kumar

Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education (MAHE), Manipal 576104, Karnataka, India

E-mail: achutha.kini@manipal.edu

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Abstract

The objective of present research work is to investigate the surface morphology and surface microhardness of unidirectional E-glass fiber epoxy composites filled with varying amount of ZnO nanofiller content such as 1, 2, 3, 4 and 5 wt% respectively. ZnO nanofiller was added to the epoxy resin matrix in varying amount (wt%) using mechanical stirrer and followed by ultrasonication process. The laminate composites were fabricated using a compression molding press technique. Further, laminate composites were subjected to individual characterization and testing according to ASTM standards. The crystalline nature of ZnO nanofiller was studied using x-ray diffraction analysis (XRD) and surface morphology of ZnO nanofiller on the resin surface was examined by using a scanning electron microscope (SEM). The experimental test results revealed that addition of nanofiller content by 1, 2 and 3 wt% resulted in a gradual reduction of void fraction and thereafter increase in void fraction was observed with 4 and 5 wt% of ZnO loading. The surface microhardness results indicated a linear increment with increase in ZnO nanofiller loading from 1 to 5 wt%. Further, surface topography was studied with the help of atomic force microscopy (AFM), to obtain the surface roughness values. The surface roughness values increased with increase in ZnO wt% within the epoxy resin matrix. The results of the surface analysis of the fabricated composites indicate that at higher loading of ZnO nanofiller, there is formation of clusters and agglomerates of the nanofiller which reduces the nano-scale effects of the filler and nanofillers tend to behave as micro-fillers.

1. Introduction

Glass fiber epoxy composites are a classic variety of engineering materials and are extensively used in marine, aerospace, automotive, sports and construction as structural composites [1]. These composites are well known for low creep, good thermal and dimensional stabilities [2]. But, due to irregular cross-link chain structures (three dimensional) present in the matrix, these composites have low impact and toughness strength. Such chain structures cause composites to shrink at elevated temperature and lose its dimensional stability. At heavy mechanical loads, induced stresses cause to break down the chain structure and results in micro-cracks initiation in the matrix as shown in figure 1(a) [3]. During the curing process and fabrication route, voids (empty spaces) are formed in the interface layers and develop some modes of failure in the composites such as de-bonding and de-lamination as shown in figure 1(b) which reduces the effective service life of such materials.

To avoid the composite from failures, suitable reinforcing agents should be applied to the matrix, which gives the additional properties that, the composite need [4]. Matrix modification is one of the processes to strengthen the matrix phase and improve the composite’s properties [5]. This matrix modification process can be done by reinforcement of the second phase mainly (Nanotubes, Nano-wires, Nano-particles, etc) to the matrix, which can alter mechanical, physical and chemical properties [6]. Reinforcing the matrix with the secondary phase, alter its multifunctional properties due to the physical interaction between them [7]. Since the
Fillers are in nano-level, they occupy the large surface area to given surface volume, so the amount required (wt%) to obtain the mechanical properties are lesser than that of traditional fillers [8].

The loading content of nanofillers considered as an important factor for composites fabrication [9–14]. The specific weight fraction of nanofiller content mainly depends on the type of composite material, filler size, and resin content [15]. Research works found out that, as a weight fraction of nanofiller content increases in the matrix beyond specific weight fraction level (wt%), there is a sharp decline in mechanical properties of composites, this is due to the formation of irregular clusters which results in uneven distribution of stresses in the matrix [16]. However, nanosize fillers are hard to disperse uniformly into the resin manually (hand stirring) [17]. Recent advances show that ultrasonication is one of the dispersion methods used to obtain uniform filler dispersion [18, 19].

In the present work, ZnO (20–40 nm) was selected as reinforcement to the matrix, because of its excellent properties such as thermal, chemical and photo-stability and can be used as multi-functional material. ZnO is one of the promising materials used in a wide range of applications [20]. The aim of the present research work is to develop the composites with varying load content of nano ZnO as reinforcement into the epoxy matrix with E-glass fiber produced by compression molding press technique and to investigate the surface morphology and surface hardness of the composites.

2. Experimental methods

2.1. Materials

The primary fiber reinforcement used in the present work is in the form of unidirectional E-glass fiber mat (450 GSM) having a thickness and density of 0.5 mm and 2.55 g cm$^{-3}$ as shown in figure 2. E-glass fiber material is commercially procured from Jushi Pvt. Ltd, India. In the present fabrication work matrix material such as LY 556 Epoxy (Diglycidyl ether of bisphenol-A) with densities of 1.15 and 0.97 g cm$^{-3}$ and HY 951 Hardener (Triethylene tetramine) were selected. Matrix materials were procured from Huntsman Pvt. Ltd, India. The Secondary reinforcement material such as nano Zinc-Oxide (ZnO) with particle size and density of 30–50 nm and 6.0 g cm$^{-3}$ was supplied by Nano Labs Pvt. Ltd, India.
2.2. Fabrication of laminate composites

Initially, continuous E-glass fiber mat is cut into the dimensions of 300 mm × 300 mm (length × width). This is done to obtain 6 fiber mats of equal dimensions for each composite. The stoichiometric weight ratio of epoxy and hardener is taken as 10:1 ratio as per the manufacturer’s specification. The composite designation and its chemical composition is mentioned in Table 1.

The required quantity of epoxy is weighed and is then heated at 65 °C for 1 h at to lower the viscosity of liquid and then the resin is degassed in a vacuum oven at 65 °C for 20 min to remove entrapped air and volatilites. Further on, varying wt% of ZnO nano-filler is measured by using an electronic weighing machine. This weighed ZnO content is then mixed into the epoxy by using mechanical stirrer at 500 rpm for 30 min and subsequently followed by ultrasonication process for 20 min with a sonication frequency of 20 kHz. Ultrasonication process time is increased with increasing of ZnO content for better uniform dispersion [21]. The hardener quantity (wt%) is slowly and steadily added into the epoxy and mixed for 2 min by manual stirring using a wooden stick. This mixture of liquid matrix with varying wt% of ZnO is then applied on the glass fiber layers.

Compression molding press is one of the fabrication techniques adopted for producing laminated composites. In this technique, the liquid matrix was uniformly applied on one side of the fiber surface mat by using a roller brush. The second layer of fiber mat is then placed on the first layer of mat and compressed with mild pressure using a roller brush to remove the excess matrix in the interface zone. This technique is repeated for 6 layers with 0° fiber orientation for each composite. Then the stacked mat layers are placed on the mold die and compressed with uniform pressure of 5 MPa at a temperature of 100 °C for 15 min [22]. The composite fabrication is schematically illustrated in Figure 3. Figure 4 depicts the composite laminates fabricated in the present research work. The entire fabrication work is carried out in the laboratory having a room temperature of 32 °C, humidity 76% and an ambient pressure of 1 atm.

3. Characterization techniques of laminate composites

3.1. X-ray diffraction analysis (XRD)

ZnO nanofiller was characterized by using Rigaku MiniFlex 600 desktop XRD. Cu Kα x-ray source wavelength was operated at a voltage of 40 kV and a current 20 mA. The continuous scanning mode 2θ was selected with a scan speed rate of 2° min⁻¹. ZnO nanofiller mean crystallites size at peak diffractions were calculated from the Debye–Scherrer method by using the following equation (1) [23].

![Figure 3. Schematic illustration of the fabrication technique process for laminate composites.](image-url)

![Table 1. Composites designation and its chemical composition.](table-url)

| Composite ID | Chemical composition (wt%) |
|--------------|----------------------------|
| C₀           | E-glass Fiber mat 50 + Matrix 50 |
| C₁           | E-glass Fiber mat 50 + Matrix 49 + ZnO 1 |
| C₂           | E-glass Fiber mat 50 + Matrix 48 + ZnO 2 |
| C₃           | E-glass Fiber mat 50 + Matrix 47 + ZnO 3 |
| C₄           | E-glass Fiber mat 50 + Matrix 46 + ZnO 4 |
| C₅           | E-glass Fiber mat 50 + Matrix 45 + ZnO 5 |
Where $D$ is the mean crystallites size (nm), $k$ is the dimensionless shape factor ($k = 0.94$ for FWHM of spherical crystals with cubic symmetry), $\lambda$ is the x-ray source wavelength of $1.54 \text{ Å}$, $\beta$ is the Full Width at Half Maximum (FWHM) and $\theta$ is the Bragg’s diffraction angle.

### 3.2. Scanning electron microscope (SEM)

In order to study the surface morphology of variable wt% of ZnO on the resin surface, laminate composites are cut into the required dimension of $10 \text{ mm} \times 10 \text{ mm}$ (length $\times$ width). Later, prepared specimens are examined by using scanning electron microscope (ZEISS EVO 18). The specimens are mounted on the aluminum multi-pin stubs using carbon tape. The instrument is operated with an accelerating voltage of 15.00 kV.

### 3.3. Density and void fraction

Void fraction is one of the important characterizations done on polymer composites, which determines the composite quality and span [24]. The void fraction of composite is obtained by using the following equations. Theoretical density (without voids) of fabricated composite is obtained from equation (2) [25].

$$\rho_{\text{theoretical}} = \frac{1}{\left( \frac{W_{\text{fib}}}{\rho_{\text{fib}}} + \frac{W_{\text{mat}}}{\rho_{\text{mat}}} + \frac{W_{\text{fill}}}{\rho_{\text{fill}}} \right)}$$

(2)

Where $W_{\text{fib}}$, $W_{\text{mat}}$, and $W_{\text{fill}}$ are the weight fraction of fiber, matrix, and nano filler, $\rho_{\text{fib}}$, $\rho_{\text{mat}}$, and $\rho_{\text{fill}}$ are the density of fiber, matrix, and nano filler respectively. Experimental density (with voids) of fabricated composites is obtained from equation (3) [26].

$$\rho_{\text{Experimental}} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (cm}^3\text{)}}$$

(3)

The void fraction in composites was obtained from using equation (4) [27].

$$\text{Void fraction (\%)} = \frac{\rho_{\text{theoretical}} - \rho_{\text{Experimental}}}{\rho_{\text{theoretical}}} \times 100$$

(4)

### 3.4. Microhardness

Vickers microhardness test was performed on samples of $10 \text{ mm} \times 10 \text{ mm}$ (length x width). To conduct Vickers microhardness test, specimens were prepared into the required dimensions later indentations were performed at 10 different locations on specimen surface for obtaining mean microhardness with an applied indentation load of 100 gf and dwell time of 15 s in accordance to ASTM D785 testing standards [28].

### 3.5. Surface topography

Contact mode atomic force microscopy (AFM) technique is used to study the effect of Zinc oxide nanoparticles on the morphology and topography of the glass fiber reinforced epoxy composites. AFM is an advanced form of stylus profilometry wherein the sharp probe tip is made to scan the surface to produce topographical images.
The specimens of dimension 2 mm × 2 mm (length x width) are cut from the composite laminate with the help of a diamond cutter and these are used for AFM.

4. Results and discussion

4.1. X-ray diffraction analysis of ZnO nanofiller

4.1.1. ZnO peak indexing

X-ray diffraction analysis is conducted on the ZnO nanofiller to characterize the crystalline nature. Figure 5 explains the diffraction peaks of nanofiller at various scanning angles in the XRD pattern.

The XRD pattern of ZnO nanofiller (Figure 4) illustrates that all the characteristic diffraction peaks obtained were consistent with the patterns observed with that of hexagonal wurtzite structure with ZnO space group of P63mc (186) or C46v and space lattice constants (lattice parameters) of \( a = b = 3.249 \text{ Å} \), \( c = 5.207 \text{ Å} \) and \( c/a = 1.602 \text{ Å} \). The obtained XRD pattern which was in good agreement with JCPDS data (card no. 01-089-0510), and confirmed the hexagonal wurtzite phase of ZnO [29]. In figure 5, seven strong diffraction peaks of ZnO were observed at 2\( \theta \) values of 31.391°, 34.075°, 35.878°, 47.178°, 56.191°, 62.465° and 67.573° corresponding to the space lattice planes (hkl) of (100), (002), (101), (102), (110), (103) and (112) respectively. It is also observed that sharp and narrow broad varying diffraction peaks in the XRD pattern were attributed to good crystalline nature of ZnO. Hence, there was no evidence for remnant micro and foreign particles in as bought ZnO. Mean crystallites size of ZnO at strong peak diffractions were calculated by using the Debye–Scherrer equation. Mean crystallites size, d-spacing and space lattice plane at strong diffraction peaks of ZnO are mentioned in Table 2.

| Material | Peak/2\( \theta \) (deg) | FWHM (deg) | Space lattice (hkl) | d-spacing (Å) | Mean crystallites (nm) |
|----------|----------------------|------------|---------------------|--------------|----------------------|
| ZnO      | 31.391               | 0.353      | (100)               | 2.846        | 24.43                |
|          | 34.075               | 0.282      | (002)               | 2.622        | 30.77                |
|          | 35.878               | 0.364      | (101)               | 2.500        | 23.96                |
|          | 47.178               | 0.340      | (102)               | 1.924        | 26.63                |
|          | 56.191               | 0.387      | (110)               | 1.635        | 24.29                |
|          | 62.465               | 0.343      | (103)               | 1.485        | 28.28                |
|          | 67.573               | 0.375      | (112)               | 1.384        | 26.62                |

The specimens of dimension 2 mm × 2 mm (length x width) are cut from the composite laminate with the help of a diamond cutter and these are used for AFM.

4.1.2. Estimation of lattice-strain (induced-strain) by Williamson-Hall (W-H) analysis

In this Williamson-Hall analysis approach, the induced-strain from the peak broadening of ZnO crystallites can be evaluated by considering the Uniform Deformation Model (UDM) [29]. According to the W-H approach, narrow broad varying peaks of ZnO crystallites, as seen in the XRD pattern, are caused due to varying crystallites size and induced-strain. However, from the uniform deformation model proposed by Williamson-Hall, the induced strain (\( \varepsilon \)) in the narrow broadening peaks are mainly due to lattice plane structure distortion and dislocation which arises from the imperfection of ZnO crystallites and this can be calculated by using equation (5) [29].
From equations (1) and (5), it is identified that the peak width of ZnO crystallites size \( D \) is a function of \( 1 / \cos \theta \) and the strain \( \varepsilon \) varies with respect to \( \tan \theta \). Total narrow peak broadening \( (\beta_{hkl}) \) of the individual Cauchy profile is indexed by the sum of the crystallites size \( (\beta_D) \) and induced-strain \( (\beta_\varepsilon) \) and this can be represented as equation (6) [30].

\[
\beta_{hkl} = \beta_D + \beta_\varepsilon
\]

(6)

It was assumed that the crystallites size and induced-strain contributions are independent to each other in the formation of the strong narrow peaks in the XRD pattern, also perceived that both are forming an overlap Cauchy like profile, so the observed Cauchy profile line breadth is the sum of equations (1) and (5) and given as equation (7) [29].

\[
\beta_{hkl} = \frac{k \lambda}{D \cos \theta} + 4 \varepsilon \tan \theta
\]

(7)

By rearranging the above equation (7) we get the equation (8)

\[
\beta_{hkl} \cos \theta = \frac{k \lambda}{D} + 4 \varepsilon \sin \theta
\]

(8)

The above equation (8) is the Williamson-Hall equation from which it is assumed that induced-strain is uniform in the entire crystallographic directions and known as uniform deformation model. In this model, crystallites are considered to have isotropic behavior and it is assumed that properties of crystallites are independent along the direction of measurement. The values \( \beta_{hkl} \cos \theta \) on the \( y \)-axis and forms the linear fit with respect to the given experimental data. The induced-strain \( (\varepsilon) \) in the strong diffraction peaks are estimated from the negative slope of the linear fit as shown in figure 6. Overall, it was observed that there is an induced-strain of \(-3.1125 \times 10^{-4}\) in the strong peaks of ZnO crystallites and also that negative linear fit indicates the lattice shrinkage in the crystallites and can be evaluated by the calculation of lattice parameters [29].

4.2. Surface morphology of ZnO nanofiller on the resin surface

Surface morphology of ZnO nanofiller on the resin surface is examined by using ZEISS EVO 18 scanning electron microscope (SEM). Figure 7 shows the dispersion state of varying ZnO nanofiller on the resin surface. It is observed from the above SEM images of resin surface with 1 wt% and 2 wt% of ZnO nanofiller, they have almost homogenous dispersion and spherical shaped structure on the resin surface as shown in figures 7(a) and (b). The main reason for uniform dispersion on the resin surface is due to optimal ultrasonication method and also low nanofiller loading content (wt%). At such a low wt% of loading, nanofiller occupies sparse area of the given surface volume in the resin, hence there are negligible van der Waals interactive forces (physical force) between the nanofiller, so this helps in uniform dispersion thereby retaining the uniform shape and size (aspect ratio). Further, loading of ZnO nanofiller content to 3 wt%, it is observed from figure 7(c) that, there is a variation in the nanofiller shape and size due to interaction of nanofiller with each other and there is a visible formation of small cluster groups, and also that nanofiller diameter is slightly increased to micron level due to collision. It is also perceived from figure 7(c) that, the addition of 3 wt% of ZnO nanofiller to the resin results in good dispersion and reduces the possible formation of voids, thereby improving the interfacial bonding strength.
between each fiber laminate. Further loading of ZnO content to 4 wt%, it is observed from the figure 7(d) that, the nanofiller occupies short inter-particulate distances because of less surface area to volume ratio in the resin and they start to agglomerate and overlap with each other due to high van der Waals interactive forces between the nanofiller as shown in figure 7 [31–33]. This results in the formation of high aspect ratio particles and causes inhomogeneous distribution of clusters. Further loading to 5 wt%, inter-particulate distance becomes lesser than that of 4 wt% resulting in the formation of large and big uneven continuous clusters, these clusters will collide with other clusters and form voids in the collided interface area as shown in figure 7(e). Overall, it is observed from 4 and 5 wt% of nanofiller loading into the resin that there is difference in the size of the clusters and the reduction of inter-particulate distance between the nanofiller. Also, there are voids in interface area of collided clusters at 5 wt% loading on the resin surface.

### 4.3. Density and void fraction

Void fraction is an important consideration in composites and it has a strong influence on physical, mechanical, wear and creep resistance properties [34]. The measured theoretical density, experimental density and void fraction of fabricated composites with varying wt% of ZnO loading are shown in figures 8 and 9.

It is clearly observed from figure 8 that each composite has different theoretical and experimental density. This is mainly due to the presence of non-uniform voids and matrix pores in stacked interface layers. These defects are mainly responsible for the reduction of weight and density in composites [35]. Overall it is identified
from figure 8 that the experimental density of composite gradually increased from 0 to 5 wt% of ZnO loading which is because of the density differences between glass fiber (2.55 g cm$^{-3}$), ZnO nanofiller (5.606 g cm$^{-3}$) and matrix density (1.06 g cm$^{-3}$). While loading nanofiller content into composite resin matrix, ZnO content (wt%) is gradually increasing with a simultaneous decrease in the matrix content (in the required proportionate manner. Hence, ZnO imparts more density to composite and eventually there is an increasing density variation in composite with nanofiller loading. Overall from figure 8 it is observed that, neat resin composite showed the highest void fraction of 3.186% with no addition of nanofiller content. High void fraction in the neat resin composite is mainly attributed to entrapped air in manufacturing route (pressure, temperature variation) and presence of volatile organic compounds (alcohol, amine and ether groups) which become vapours or gases during curing stage in the matrix. These result in the formation of empty spaces (air pockets or voids) in the matrix [36]. Further increase in the loading of nanofiller content from 1 to 3 wt%, it is perceived that void fraction gradually reduced from 2.760 to 1.641% in composites. Therefore, decreased void fraction in composites was mainly due to ZnO nanofiller content, this nanofiller content in the matrix occupies the air gaps and also reduce the formation of voids in interface zones. Further increase in the loading of nanofiller content from 4 to 5 wt%, void fraction increased from 2.696 to 2.833% in composites. It is also observed that at 4 wt% ZnO loading, there may be a generation of micro-voids in interface layers due to the increased aspect ratio of particles and clusters [37]. Further loading of ZnO to 5 wt%, nanofiller turn in to micro-filler by collision and

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**Figure 8.** Theoretical and experimental density of composites.

**Figure 9.** Void fraction of composites.
thereby there is an increase in the formation of more uneven clusters in stacked zones as compared to such phenomenon at 4 wt% ZnO. These clusters in the interfacial layers create more air pockets. Hence, clusters are responsible for the increment of void content in composites.

4.4. Surface microhardness results and analysis

Surface microhardness test results of composites showed increment in the hardness with an increase of nanofiller loading as shown in figure 10. The hardness value is represented by Vicker’s pyramid number, given as ‘HV’.

Analysis of the microhardness result indicate that, neat resin composite exhibits the lowest microhardness of 23.3 HV with no nanofiller addition. Further, microhardness in composites was substantially increased to 31.9, 32.7, 38.4, 39.1 and 40.6 HV with the incorporation of ZnO nanofiller content of 1, 2, 3, 4 and 5 wt% respectively.

This improvement of microhardness was mainly due to the gradual reduction of voids and pores with increment in loading of nanofiller into the matrix. Another fact which contribute to this increment in microhardness is that through the incorporation of hard ZnO nanoparticles into the epoxy resin, the matrix is rendered hard because these nano-particles in matrix restrict the movement of polymer molecules under the applied mechanical loads [38]. It is also evident that as a nanofiller concentration (wt%) gradually increases, load uptake capacity of the composites also increases this is due to the fact that more particles (ZnO) absorb applied energy and also inter-laminar distance between the particles in the matrix decreases, this results in composites exhibit more resistance to indentation by external loads [39].

4.5. AFM results and analysis

The AFM 3D images of glass fiber reinforced ZnO-epoxy nanocomposites are shown in figure 11. The surface roughness of the fabricated nanocomposites are calculated from the AFM data and are tabulated in table 3. The roughness average ($R_a$), root mean square ($R_q$) and the maximum height of the profile ($R_z$) are obtained through the application of equations (9)–(11) respectively [40].

\[
R_a = \frac{1}{L} \int_0^L |Z(x)| \, dx
\]  

(9)

\[
R_q = \sqrt{\frac{1}{L} \int_0^L |Z^2(x)| \, dx}
\]  

(10)

\[
R_z = \frac{\sum_{i=1}^{5} R_p + \sum_{i=1}^{5} R_v}{5}
\]  

(11)

Where, $L = \text{sampling length}$, $R_p = \text{Peak heights}$, $R_v = \text{Valley depths}$.

It is evident from table 3 that the surface roughness parameters are influenced by the ZnO loading and these parameters increase linearly with the increment in ZnO wt% in the epoxy matrix. The increased surface roughness at higher loading of ZnO nano-filler is attributed to the fact that at higher loading, particle clusters are

Figure 10. Composites surface microhardness.
formed due to a strong Vander walls forces. The increase in surface roughness results in the increase in surface microhardness of the fabricated composites. This is also evident from the SEM analysis illustrated in figure 7.

### Table 3. Surface roughness parameters and micro-hardness of ZEG nanocomposites.

| Parameters | $R_a$ (nm) | $R_q$ (nm) | $R_z$ (nm) | Microhardness |
|------------|------------|------------|------------|---------------|
| $C_0$      | 41.7       | 57.6       | 615        | 23.3          |
| $C_1$      | 47.4       | 67.1       | 874        | 31.9          |
| $C_2$      | 92.9       | 126        | 1517       | 32.7          |
| $C_3$      | 119        | 134        | 1726       | 38.4          |
| $C_4$      | 146        | 200        | 1800       | 39.1          |
| $C_5$      | 216        | 281        | 2125       | 40.6          |

**5. Conclusions**

The present research work was conducted to examine the influence of matrix modification with the addition of ZnO nanofiller to E-glass fiber epoxy composites. Experimental behavior of fabricated composites from surface morphology, physical and mechanical properties was evaluated. Based on composites behavior from experimental test results and analysis the following conclusions are drawn.

1. Surface morphological images of ZnO nanofiller on resin surface from SEM analysis showed that the presence of 1, 2 and 3 wt% ZnO loading, a better uniform dispersion was achieved via ultrasonication process. On further increase in ZnO loading to 4 and 5 wt%, uneven clusters are formed on the resin surface.
due to increased loading content which results in the increase in van der Waals interactive forces between the nanofiller particles.

2. The void fraction of composites gradually decreased from 2.760 to 1.641% for the ZnO loading from 1 to 3 wt% respectively. Further, void fraction increased to 2.696 and 2.833% with ZnO loading content of 4 and 5 wt%.

3. From surface microhardness test results, it was perceived that the surface hardness value increased with increase in ZnO wt% loading. Overall it is identified that, wt% of nanofiller and inter-particulate distance plays a vital role in controlling hardness in composites.

4. AFM results are in close agreement with the SEM analysis as the surface roughness values increases with increase in ZnO loading.

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ORCID iDs

Sridhar Thipperudrappa @ https://orcid.org/0000-0001-5277-2094
Achutha Ullal Kini @ https://orcid.org/0000-0001-9897-9197
Anupama Hiremath @ https://orcid.org/0000-0002-3558-8620

References

[1] Koniuszewska AG and Kaczmar J W 2016 Prog Rubber Plast Recy Technol. 32 1
[2] Colangelo F et al 2017 Compos Part B Eng. 126 100
[3] Rahul R and Kitey R 2016 Compos Part B Eng. 85 336
[4] Mittal G, Rhee K Y, Miličković-Stanković V and Hui D 2018 Compos Part B Eng. 138 122
[5] Liu F, Deng S and Zhang J 2017 J Nanomater. 2017 1
[6] Kumar A et al 2014 Rev Adv Mater Sci. 38 40 (http://www.ipme.ru/e-journals/RAMS/no_13814/05_13814_kumar.pdf)
[7] Saba N, Tahir P M and Jawaid M 2014 Polymers 6 2247
[8] Beigbeder A et al 2008 Adv Mater. 20 1003
[9] Khare H S and Burris D L 2010 Polymer 51 719
[10] Verma A et al 2019 Polym Compos. (https://doi.org/10.1002/pc.25373)
[11] Verma A, Negi P and Singh V K 2019 Polym Compos 40 2690
[12] Verma A, Parashar A and Packirisamy M 2018 Wiley Interdiscip Rev Comput. Mol Sci. 8 e1346
[13] Verma A, Parashar A and Packirisamy M 2019 Appl Surf Sci. 470 1085
[14] Verma A et al 2019 Polym Eng. Sci. 59 2941
[15] Arbaoui J et al 2016 Mater Res Innov. 20 145
[16] Prusty R K et al 2017 Compos Part A Appl Sci Manuf. 95 40
[17] Bensouda F et al 2011 J. Nanomater. 2011 1
[18] Jiang Y, Tohgo K and Shimamama Y 2011 J Compos Mater. 46 1159
[19] Alrekkabi S et al 2016 Int. J. Civil Environ Struct Constr Archit Eng. 111 268
[20] Wang J et al 2018 Ceram Int. 44 7357
[21] Ghaleb Z A, Mariatti M and Arief Z M 2014 Compos Part A Appl Sci Manuf. 58 77
[22] Gall N et al 2015 Mater Des. 67 313
[23] Dorofeev G A et al 2012 Colloid J. 74 675
[24] Xueshu L and Fei C H 2016 Eng Trans. 64 33 (http://entra.put.poznan.pl/index.php/et/article/view/280/247)
[25] Das G and Biswas S 2016 IOP Conf Ser: Mater Sci Eng 115 012012
[26] Agwa M A, Megahed M and Megahed A A 2017 Polym Adv Technol. 28 1115
[27] Kaundal R, Pattnaik A and Satapathy A 2012 Walisik J. Sci. Technol. 9 49 (http://wjst.wu.ac.th/index.php/wjst/article/view/206)
[28] ASTM A, ASTM D7758-08 2013 Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials. (West Conshohocken, PA Std.: ASTM International)
[29] Bindu P and Thomas S 2014 J. Theor Appl Phys. 8 123
[30] Prabhbu Y T et al 2014 World J Nano Sci Eng. 4 21
[31] Singh V K and Verma A 2018 J. Test Eval. 47 1193
[32] Jain N, Verma A and Singh V K 2019 Mater Res Expres. 6 103537
[33] Verma A, Negi P and Singh V K 2018 J. Mech Behav Mater. 27 1
[34] De Almeida S F and Neto Z D 1994 Compos Struct. 28 139
[35] Sarkar F, Modak N and Sahoo P 2018 Mater Today-Proc. 5 5496
[36] Mehdi Khani M et al 2018 J. Compos Mater 53 1579
[37] Hamidi Y K, Aktaš Land Alan M C 2008 J. Thermoplastics Compos Mater 21 141
[38] Prasad V, Joseph M A and Sekar K 2018 Compos Part A Appl Sci Manuf 115 360
[39] Pawar M J, Patnaik A and Nagar R 2015 Polym. Compos. 38 736
[40] Ramezanzadeh B, Attar M M and Farzam M 2010 J. Therm Anal. Calorim. 103 731