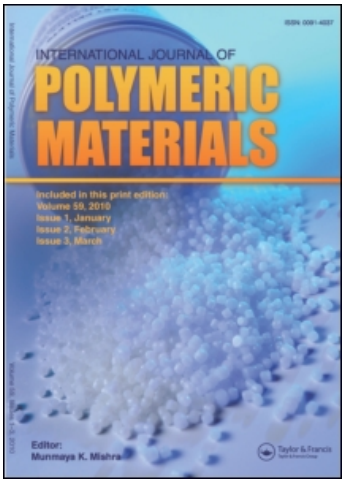

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

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M. Ashok Kumar[a]; K. Hemachandra Reddy[b]; Y. V. Mohana Reddy[c]; G. Ramachandra Reddy[d]; S. Venkata Naidu[d]
[a] Department of Mechanical Engineering, Sri Krishnadevaraya University College of Engineering & Technology, Anantapur, Andhra Pradesh, India [b] Department of Mechanical Engineering, JNTU College of Engineering, Pulivendula, Kadapa, Andhra Pradesh, India [c] Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India [d] Department of Polymer Science & Technology, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India

Online publication date: 21 September 2010

To cite this Article Kumar, M. Ashok , Reddy, K. Hemachandra , Reddy, Y. V. Mohana , Reddy, G. Ramachandra and Naidu, S. Venkata(2010) 'Improvement of Tensile and Flexural Properties in Epoxy/Clay Nanocomposites Reinforced with Weave Glass Fiber Reel', International Journal of Polymeric Materials, 59: 11, 854 — 862
To link to this Article: DOI: 10.1080/00914037.2010.504144
URL: http://dx.doi.org/10.1080/00914037.2010.504144

International Journal of Polymeric Materials, 59:854–862, 2010

ISSN: 0091-4037 print/1563-535X online
DOI: 10.1080/00914037.2010.504144

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M. Ashok Kumar,[1] K. Hemachandra Reddy,[2] Y. V. Mohana Reddy,[3] G. Ramachandra Reddy,[4] and S. Venkata Naidu[4]

[1]Department of Mechanical Engineering, Sri Krishnadevaraya University College of Engineering & Technology, Anantapur, Andhra Pradesh, India
[2]Department of Mechanical Engineering, JNTU College of Engineering, Pulivendula, Kadapa, Andhra Pradesh, India
[3]Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India
[4]Department of Polymer Science & Technology, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India

The tensile strength, tensile modulus, flexural strength and flexural modulus properties were investigated on epoxy/clay nanocomposites to assess the influence of nanoclay. Mechanical properties were significantly increased due to an increase in clay content up to 5 wt%, and decreased with a further increase in clay content. Optimal improvement of properties was observed with increased clay content up to 5 wt%. Duo properties of the glass fiber were improved by clay addition due to the improved interface between the glass fiber and epoxy. SEM analysis was conducted on different fractured surfaces to study the mechanical behavior.

Received 4 February 2010; accepted 8 April 2010.
The authors would like to thank the Department of Pharmacy and the Department of Polymer Science and Technology at S. K. University, Anantapur, AP, India for instrumental assistance.
Address correspondence to S. Venkata Naidu, Department of Polymer Science & Technology, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India. E-mail: challaninaidu@yahoo.com

Keywords mechanical properties, montmorillonite clay, nanocomposite, weave glass fiber reel

INTRODUCTION

Epoxy resins have played a vital role in polymer matrix materials because of their superior mechanical and adhesive properties. They have been used widely as a matrix to hold the high-performance fiber reinforcement together in composite materials, as well as structural adhesives [1–9]. Nanocomposites are named when the dispersed phase particle size is less then 100 nm, and the reinforcement of polymeric resin with nanoclay as fillers has resulted in light-weight materials with increased modulus and strength, decreased permeability, less shrinkage and increased heat resistance even at low friction loading. But in recent times epoxy resin added with modified MMT clay as filler finds major applications. In Mohan et al. [10], studied tensile modulus was significantly increased from 1.10 Gpa to 3.59 Gpa at 3wt% nanoclay. The introduction of nanoclay particles increases the mechanical (tensile strength and modulus), physical (permeability and barrier resistance), and thermal (decomposition and mass loss) properties of the polymer composites [11–15]. Recent researchers have found that commercial organoclay could be used to make aerospace epoxy nanocomposites, which possess excellent mechanical strength and low co-efficient of thermal expansion with relatively low cost and ease of fabrication [16,17]. Significant amount of work can be found in the literature on the effect of addition of clay on the mechanical properties of pure epoxy resin systems. However there has not been much work done on the effect of glass/epoxy short fiber composite materials. This is probably due to the significant increase in viscosity of the resin upon addition of the nanoparticles. This increase in viscosity makes it difficult to incorporate the modified epoxy with the short fiber. The objective of the present study is to fabricate nanocomposite that contain reinforcing short weave glass fiber reel in the epoxy matrix and to evaluate their mechanical properties as a function of clay concentration. This research presents the work done on the effect of adding nanoclay on tensile properties and flexural properties of (a) Epoxy + nanoclay, and (b) Epoxy + glass fiber + nanoclay nanocomposites as a function of nanoclay respectively are studied.

MATERIALS AND EXPERIMENTAL STUDIES

Materials

Commercially available epoxy resin (LY-556) and hardener (HY-951) obtained by Huntsman. The weave glass fiber reel (density: 350 g/m^2) obtained

from Saint Gobain Industries Ltd., Bangalore. In addition, montmorillonite clay (1.28E) surface modified with 25–30% trimethyl stearyl ammonium obtained from Nanocor® Inc., Aldrich.

Nanocomposite Preparation

The quantity of nanoclay dispersed in to the epoxy the systems, in weight, is 0, 2, 3, 5, and 12 wt.%. A glass mould was prepared with ASTM standards to fabricate samples, further it was coated with mould releasing agent for easy removal of casting. A 9 vol. % of the glass fiber was cut with sharp scissors into 20 mm length were used to prepare composites. The resin and hardener was taken in the ratio of 10:1 parts by weight respectively. Clay was mixed with stipulated quantity of resin based on the aforementioned ratio mixed thoroughly with mechanical shear mixing for about 1 h at ambient temperature conditions. Then a pre-calculated amount of hardener was mixed and stirred for 20 min before pouring into the mold. Hand-lay up technique was used to impregnate the composite structures. In this technique the glass fiber was wetted by a thin layer of clay/epoxy suspension in a mold. Stacking of glass fiber was arranged side by side all over the mold [18]. Stacking of the glass fiber was carefully arranged after pouring some amount of the resin against the mold to keep poor impregnation at bay. The remaining quantity of mixture was poured over the glass fiber. Brush and roller were used to impregnate fiber. The closed mold was kept under pressure for 24 h at room temperature. To ensure complete curing, the composite samples were post-cured at 80°C for 1 h and the test specimens of the required size were cut out from the sheet.

Tensile Load Measurement

Tensile strength was studied using an Instron Universal Testing Machine supplied by Instron Corporation; a series-9 automated testing machine was used with a crosshead speed of 5 mm/min. Testing samples were prepared in dumb-bell shapes and these dimensions are $100 \times 20 \times 3\,mm^3$ based on the ASTM D 638 standards. In each case, five samples were tested and the average value tabulated.

Flexural Load Measurements

Flexural strength and modulus were tested using an Instron Universal Testing Machine with a crosshead speed of 2 mm/min. The three-point bending test system was used for all samples. In each case, five samples were tested and the average value tabulated. Authors used 50 KN load cell for testing further the sample sizes and $100 \times 20 \times 3\,mm^3$ was cut in accordance with ASTM D 618.

Scanning Electron Microscopy Analysis

A JEOL JSM 840A JAPAN scanning electron microscope (SEM) was used to study the morphology of fractured surfaces of nanocomposite samples at uniform magnifications. The fractured surfaces were gold-coated initially subjecting it to SEM analysis. The scanning electron micrograms of different cross-sections with uniform magnification (i.e., 300 X) of the nanocomposite samples of pure epoxy, without reinforcement as well as with reinforcement, are studied.

RESULTS AND DISCUSSION

Tensile Test

The authors synthesized two different systems, namely (a) epoxy filled with clay and (b) past nanocomposites reinforced with WGFR as a function of clay, respectively. Table 1 shows the experimental measurements of tensile strength and modulus of nanocomposites as a function of nanoclay contents. For neat epoxy tensile strength and modulus, measurements are 18.0 Mpa and 897.6 Mpa, respectively. It was observed that tensile strength and modulus properties increase when clay content is increased up to 5 wt% and decreases with further increase in clay content. Tensile strength and modulus were improved by 133 and 58.0% improvement at 5 wt% clay content compared with neat epoxy, further the duo properties were optimum at 5 wt% clay content, respectively.

Similarly for the second system, experimental measurements of tensile strength and modulus properties of the glass fiber-reinforced nanocomposites as a function of nanoclay are shown in Table 2. For the glass fiber-reinforced composite (0 wt% clay content) duo properties were 25.0 Mpa and 1189.3 Mpa, respectively. Duo properties are increased up to 5 wt% clay content, then decreases as clay quantity increased up to 12 wt% as shown in Figure 1(a and b). Mittal [19] studied a linear increase in tensile modulus observed with the filler volume fractions owing to partial exfoliation of the clay up to 4 wt%. Yuanging Xiang et al. [20] observed significant improvement in tensile mechanical properties as a function of clay loadings. According to Reynaud et al. [13]

Table 1: Tensile properties of epoxy/nanocomposites as function of clay.

Name of the sample	Tensile strength (Mpa)	Tensile modulus (Mpa)
Epoxy	18.015	897.669
Epoxy + 2 wt% nanoclay	36.834	1137.676
Epoxy + 3 wt% nanoclay	38.429	1313.198
Epoxy + 5 wt% nanoclay	42.066	1418.844
Epoxy + 12 wt% nanoclay	20.873	916.451

Table 2: Tensile properties of epoxy/WGFR/nanocomposites as a function of clay.

Name of the sample	Tensile strength (Mpa)	Tensile modulus (Mpa)
Epoxy + WGFR	25.817	1189.333
Epoxy + WGFR + 2 wt% nanoclay	37.817	1372.306
Epoxy + WGFR + 3 wt% nanoclay	40.803	1402.083
Epoxy + WGFR + 5 wt% nanoclay	42.429	1565.790
Epoxy + WGFR + 12 wt% nanoclay	28.119	1104.824

an interface 1 nm thick represents roughly 0.3% of the total volume of the polymer in microparticle-filled composites, where it can reach 30% of the total volume in the case of nanocomposites. However, high surface area causes a strong tendency to agglomerate, which reduces the strength of nanocomposites by its stress concentration effect. Optimal loading of nanoclay in matrix is the key parameter to develop nanocomposites. Research revealed that true reduction in interfacial interactions lower the efficiency of the clay in strengthening of epoxy [21].

Flexural Test

Flexural strength and modulus measurements for neat epoxy are 15.1 Mpa and 1089.3 Mpa, shown in Table 3. Flexural strength and modulus are improved by 62.7 and 51.1% respectively when 2 wt% clay content is dispersed in the matrix compared with neat epoxy. Flexural strength and modulus were improved by 170.1 and 148.4% respectively at 5 wt% clay content. It is observed that the flexural strength and flexural modulus properties increase

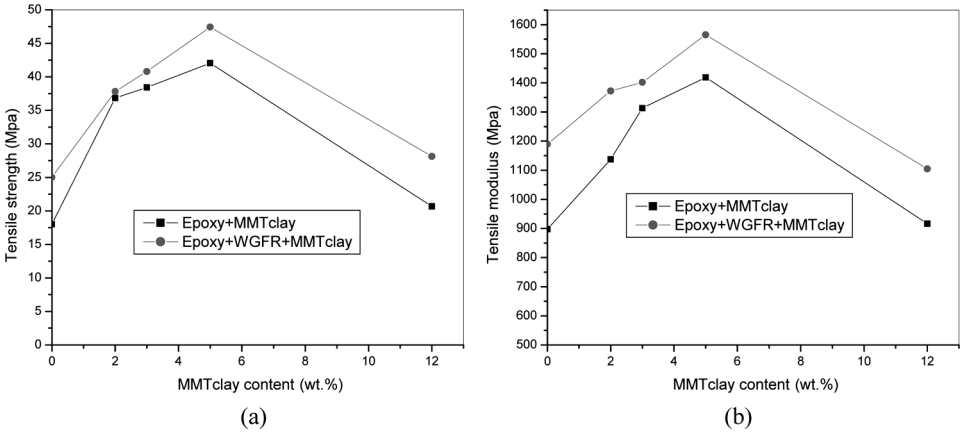

FIGURE 1: (a) Tensile strength and (b) tensile modulus of two different epoxy/clay nanocomposites as a function of nanoclay, respectively.

Table 3: Flexural properties of epoxy/nanocomposites as a function of clay.

Name of the sample	Flexural strength (Mpa)	Flexural modulus (Mpa)
Neat epoxy	15.122	1089.397
Epoxy + 2 wt% nanoclay	24.614	1648.183
Epoxy + 3 wt% nanoclay	28.321	1825.341
Epoxy + 5 wt% nanoclay	40.854	2706.729
Epoxy + 12 wt% nanoclay	14.023	1433.822

as the percent of clay content increases up to 5 wt%, but further increasing the clay contents causes duo properties to gradually decrease. Linearly increasing duo properties were observed up to 5 wt% of clay, then a sudden fall was observed at 12 wt% clay, seen clearly in Figure 2(a and b). Emrah Bozkurt et al. [15] studied mechanical and thermal behavior of non-crimp glass fiber-reinforced layered clay/epoxy nanocomposites in which they have shown improved flexural strength and modulus at 5 wt% clay due to the presence of clay layers located at the interface of the fiber and the matrix. The clay layers may enhance the interfacial properties up to some concentrations. For pure epoxy + WGFR composite, flexural strength and modulus are 22.6 Mpa and 1301.5 Mpa. It was observed that flexural strength and modulus results were improved by 36 and 47.5%, with 2 wt% clay content, respectively. Duo properties were increased up to 5 wt% clay content, then figures gradually decrease as clay quantity increased to 12 wt%. Optimal values were obtained at 5 wt.% clay content as shown in Table 4. Authors observed flexural strength and modulus values are 56.8, and 103.6% increased at 5 wt% clay. Figure 3 represents SEM images to confirm the hypothesis as to how morphology changes when clay content changes.

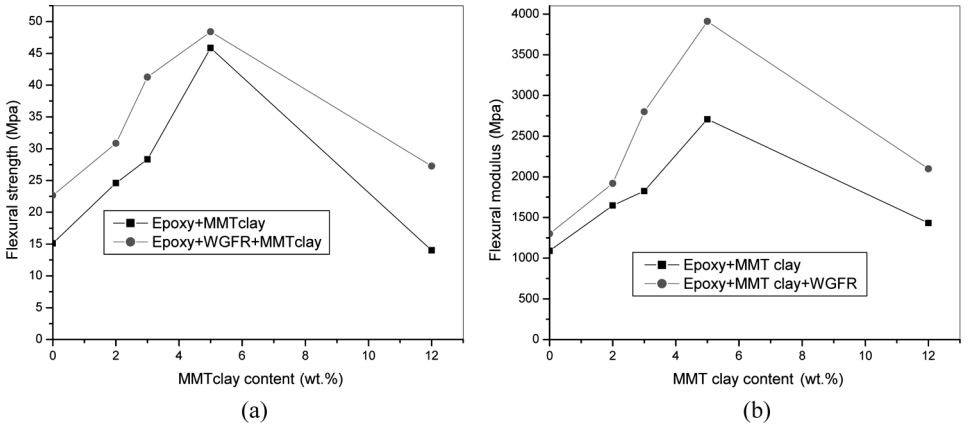

FIGURE 2: (a) Flexural strength and (b) flexural modulus of two different epoxy/clay nanocomposites as a function of nanoclay, respectively.

Table 4: Flexural properties of epoxy/WGFR/nanocomposites as a function of clay.

Name of the sample	Flexural strength (Mpa)	Flexural modulus (Mpa)
Epoxy + WGFR	22.655	1301.501
Epoxy + WGFR + 2 wt% MMT clay	30.811	1919.653
Epoxy + WGFR + 3 wt% MMT clay	41.272	2798.580
Epoxy + WGFR + 5 wt% MMT clay	48.404	3910.248
Epoxy + WGFR + 12 wt% MMT clay	14.023	1433.822

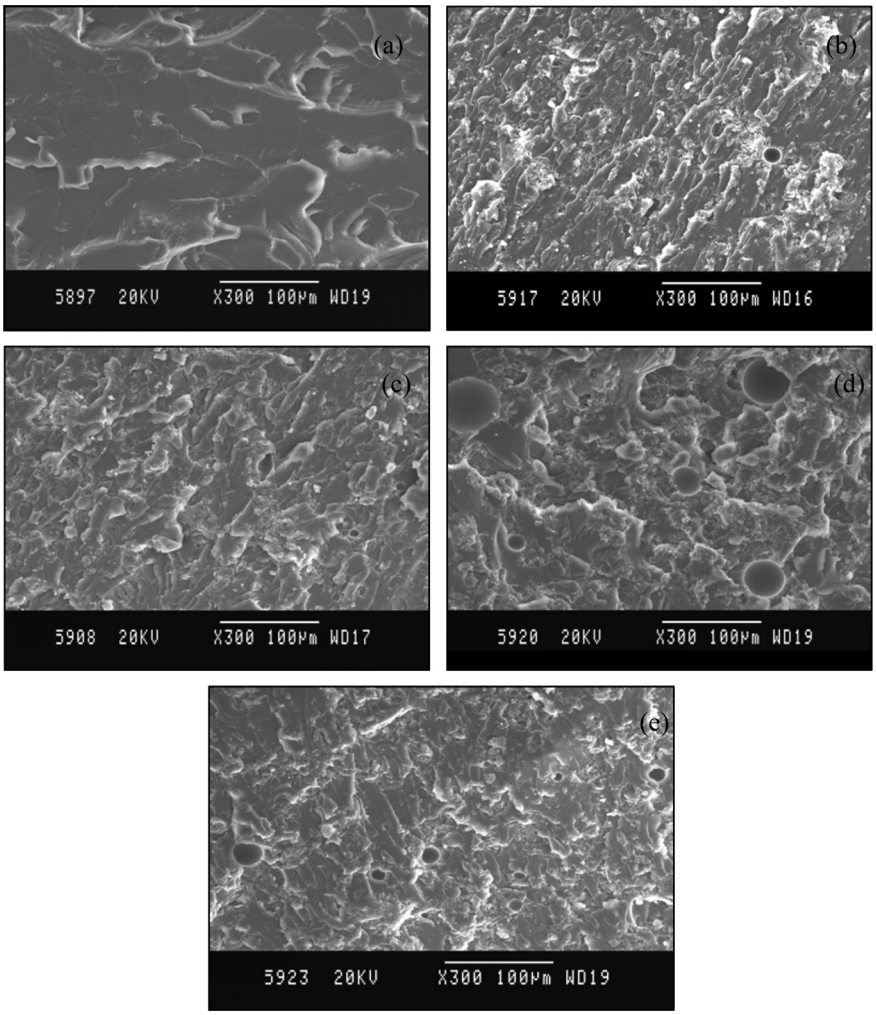

Figure 3: SEM micrographs as a function of nanoclay content of (a) neat epoxy, (b) epoxy +5 wt% nanoclay, (c) epoxy +5 wt% nanoclay, +WGFR, (d) epoxy +12 wt% nanoclay, and (e) epoxy +12 wt% nanoclay +WGFR nanocomposites.

Under the present processing conditions, it was observed that an increased viscosity is due to the addition of a high content of nanoclay and made resin degassing difficult. This allows the entrapment of small air voids within the blend and also causes a poor dispersion of the clays further high deformability, resulting in the formation of agglomerates in the epoxy matrix. Another possibility is that because the clay has a much greater modulus than the polymer, stress concentration may have existed at the interfaces of the clay and epoxy matrix. Therefore, under tensile loading, cracks can initiate at those weak points and cause the specimen to fail at relatively low strains. It appears that the variation of modulus with the degree of exfoliation of clay is small and the modulus is controlled primarily by the volume fraction of clay rather than by its exfoliation. Another possibility is, this might due to the fact that the viscosity of the room temperature cured resin would not be low enough to allow diffusion of the monomer into the planar structure of the nanoclay particles. Thus agglomeration may be caused during the curing process of composites.

SEM Analysis on Fractured Surfaces

Cross-sections of fractured surfaces of the nanocomposites (magnification size: 300X) of two systems namely without glass fiber reinforcement and with glass fiber reinforcement as a function of clay are shown in Figure 3, respectively. As depicted in Figure 3(a), smooth fractured surfaces were observed on pure epoxy indicating a relatively brittle fracture [21]. In Figure 3(b), the bright feature clay of microstructures indicates a significant increase in cross-linking between clay and matrix. Figure 3(c) shows a further increase in duo properties attributed to the good interface between the glass fiber and epoxy due to the addition of 5 wt.% clay contents. Figures 3(d) and (e), depicted high clay concentration resulting in agglomeration which led to high deformability, and another reason was higher fractions of clay resulting micro voids which act as stress concentration factors and facilitate shear yielding in the system, and therefore, reduces tensile and flexural strength in fractured cross-sections through SEM images.

CONCLUSIONS

Reinforced WGFR epoxy/clay nanocomposites were synthesized with different concentrations of nanoclay dispersion through *in situ* polymerization. Flexural strength, flexural modulus, tensile strength and modulus were increased correspondingly up to 5 wt% of clay for (epoxy + clay) and similarly for (epoxy + clay + WGFR) as a function of clay, respectively, and decreases with further addition of clay contents. Flexural strength, flexural modulus, tensile strength

and tensile modulus were increased by 170.1, 148.4, 133.0, and 58.0% at 5 wt% clay content, respectively. Thus it can be concluded that nanocomposites can be used for high strength, stiffness, and bending applications in aerospace, automobile, and marine and lightweight article applications. Overall studies indicate that the reinforced nanocomposites at 5 wt% clay loading are promising candidates for structural applications where high strength and stiffness is indispensable. The present study thus bears testimony to all of these findings. Hence the present study not only discloses that nanoclay overseen through the polymer with different surface treatment promotes the performance of composites, but that unique tailored properties are improved by changing the orientation of fiber on the matrix. This present work however needs further study to develop a comprehensive evaluation of electrical and thermal properties from exposure to nanoclays.

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