Compressive and Impact Behavior of Nanoscale Hybrid Composite Materials

Mohd. Minhajuddin Saif, Dasari V. Ravi Shankar, and Mohd. Manzoor Husain

Abstract The use of polymer matrix composites has been increased exponentially for the past. Marine, aeronautical, automobile, and space structures are the areas were fiber-reinforced composites are very widely used for their specific properties like high tensile strength, high strength to weight, inert to the environment, etc. These conventional fiber-reinforced polymers (FRP) fall shortage of both compressive strength and impact strength. To overcome these challenges, an attempt is being made to develop the properties of FRP composites (glass/epoxy) by adding nanofiller. Three different types of nanoparticles are used: (i) multi-wall carbon nanotube (MWCNT), (ii) Nanosilica (NS), (iii) Nano-Iron oxide (NI) with four different weight percentages 0.1, 0.2, 0.5, and 1.0%. The experiments reveal a significant enhancement in the compression and impact behavior for Glass/Epoxy FRP when modified with nanofillers.

Keywords GFRP · MWCNT · Compressive strength

1 Introduction

The fiber-reinforced polymer materials are very considerably used in automobile, aeronautic, marine, civil sector, and defense industries for replacing the conventional metals like steel, aluminum, and their alloys [1]. This replacement of metals and there alloys with composites is because of high specific stiffness and strength

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which leads to the overall improvement in material properties. Composite materials face critical issues like high brittleness, low compressive strength, high cost, manufacturing repeatability, etc. Subsequently, there is a need to overcome these issues for mainstream acceptance of composite materials in conventional engineering applications.

Various methods such as modifying fiber/matrix interface, matrix modification, and fiber hybridization are reported to increase the resistance to impact and providing a great amount of tolerance to damage in FRP [2–4]. Though the fiber hybridization is a cost-effective method to improve the impact properties of the FRP components [5, 6], matrix modification by us of nanofillers could be an alternate. And this would be more optimal methodology which would enhance the resistance toward impact and improved tolerance toward damage. By improving the polymer matrix properties, composite materials properties can in improved and the above-mentioned issues can be resolved. One way of enhancing the properties of the polymer matrix is by modifying it by nanofiller. If the reinforcement additives of composite materials have one or more dimensions in nanoscale, these are referred to as nanoscale composites [7, 8]. Carbon nanotubes (CNTs) were used by most of the researchers for fabricating nanoscale composite materials, as this material has a high potential with combined benefits of high hardness and higher absorption capabilities. Other than that, it also exhibits a high strength and stiffness, improved hardness, and low density with high length to diameter ratio. These high aspect ratios of CNTs leads to high surface area and a suitable interface, for transfer of stress in composites, is obtained through high surface areas of CNT. It is found that multi-wall carbon nanotubes [MWCNTs] are more capable in the transfer of stress from the polymer to CNTs than single-wall carbon nanotube [9]. Gojny et al. contradicted that high surface area leads to high surface energy and undesirable attractive force that would lead to excessive agglomeration [10]. To overcome this specific problem of agglomeration, various methods such as regression shear stirring and sonication were reported [11–13].

Santos et al. [14] used two different fillers; (a) cork powder and (b) nanoclay investigated the resistance toward impact and the tolerance toward damage of Kevlar/epoxy composite. An increase in impact load-bearing capacity was observed and was also reported that the quantity of increment would be influenced by the type of filler. The damaged area of laminate with nanoclay as filler was increased by 29%. Athanasios et al. [15] examined the resistance toward the impact of carbon fiber-reinforced polymer (CFRP) with MWCNT as fillers under different weight percentages. Maximum improvement was observed for 0.5 wt% CNT-doped specimens.

Waas and Lee [16] conducted a study on the micro mechanism of composite failure of FRP laminate in compression loading, where it was observed for a laminate with a low volume fraction of fiber a splitting failure mode, whereas with a high volume fraction of fiber, a splitting/kink banding failure mode was observed. Harris and Piggott [17] conducted studies under compression loading on composites structures made with three reinforcements: (i) glass, (ii) carbon, and (iii) aromatic polyamide fibres. Later, it was reported that the 'Rule of Mixtures' in an FRP composite (glass–polyester) with an apparent fibre strength existence in a range of 1.3–1.6 GPa, the tensile, and compression moduli were equal with respect to two different limiting fiber volume fractions (V_f), 0.31 and 0.46. Matrix yield strength and composite strength are directly proportional to each other at a higher fraction of volume, whereas a composite with epoxy resin matrix was having more strength than polyester-based composites at the same matrix yield strength. When volume fraction is maintained at 0.30, they observe a slight decrease in the stiffness of carbon fiber and also they appear to be weaker in compression than they are found to be when in tension.

In the present study, three different nanoparticles, MWCNT, NS, and NI with four different weight percentages (a) 0.1%, (b) 0.2%, (c) 0.5%, and (d) 1.0% wts, are used as fillers in glass/epoxy composite(GFRE). The suspension of nanoparticles in the matrix system is done with the help of mechanical stirring followed by bath sonication. Two types of tests were performed one compression and other impacts.

2 Materials and Methods

The nanofilled polymer composite was prepared by using a mat comprising of 66% unidirectional glass fiber and 34% chopped stand making a total 600 GSM mat. A commercial-grade epoxy with a trade name of Lapox L12 was used as a matrix with appropriate hardener. The fillers (i) MWCNT, (ii) NS, and (iii) NI were used in present works were supplied by Intelligent Materials Pvt. Ltd, India.

The quality of the nanofiller was determined using SEM and TEM and the following were found. For MWCNT, the outer diameter was 30–50 nm, inner wall was 15–20 nm, and length was 10–15 μm with an apparent density being 0.21 g/cm^3 and the specific area of 110 m^2/g with a purity of 99.8%. A 50 nm spherical nanosilica was used which has a specific external available area of 110–120 m^2/g, the apparent density of 2.4 g/cm^3, and a purity of 99.9%. A similar size specification was found for the iron oxide with a purity of 99.9%; however, the specific surface was of 30 m^2/g and the bulk density was 5.242 g/cm^3.

A Hand Layup method was used for the fabrication of required samples in a mold of 325 mm × 300 mm. Initially, the two halves of the mold are coated with wax on the inner sides which would play as a releasing agent. Later, E-glassfiber (four plies) as per the required dimensions are stacked in the mold after applying the modified resin. The modification in the resin was done by adding the required weight percentage of a particular nanoparticle in the resin. To produce a sound laminate, good dispersion of nanoparticles in resin is needed. This was done with the help of mechanical stirring followed by sonication (bath sonicator). The time duration for mechanical stirring was maintained for half an hour followed by one hour for sonication for all the weight percentage of nanoparticles. The required samples as per the standards were cut from a single laminate of a particular weight percentage and type of nanoparticles.

3 Methodology

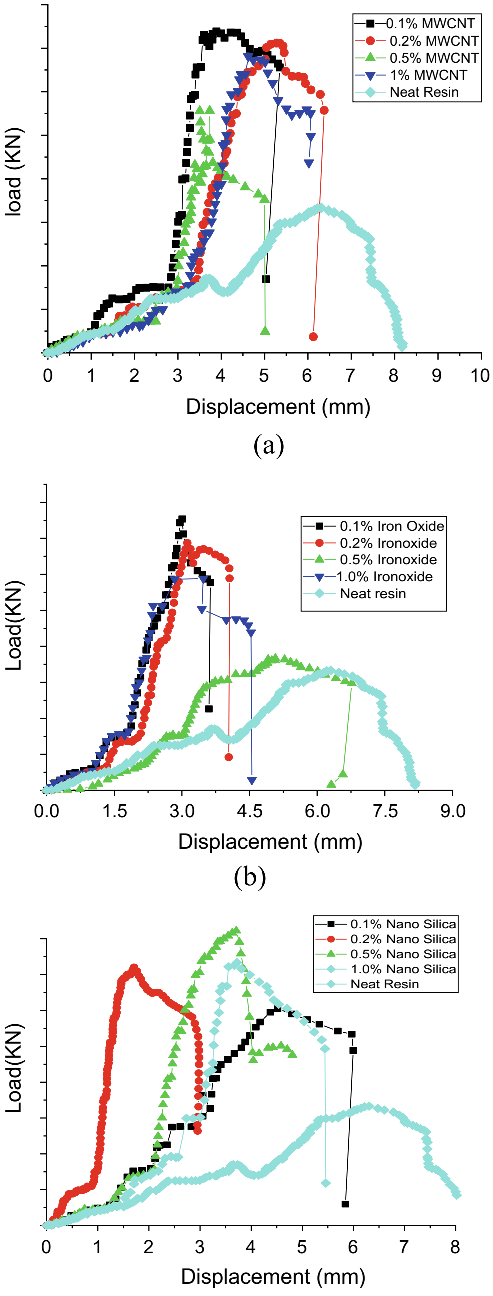
The compressing test was carried out as per ASTM D695, where the specimen is of the size of 25 mm × 25 mm. Such small size specimen is used to avoid buckling and premature failure of sharp corners. The small cross section of the specimen will also reduce friction. The speed of the movable jaw was maintained at 2 mm/min. The resistance offered by the specimen gives the force induced by the hydraulic systems into the specimen. The movement of the jaw gives the displacement specimen.

The impact testing was carried out as per ASTM D3763. A V notch is first prepared in sample of size 12.6 cm × 1.27 cm × 0.3 cm. The V notch was made at the centre of the specimen, which was placed between the fixtures such that the pendulum strikes the cracked side. Energy absorbed per meter was given as scale reading by sample thickness.

4 Results and Discussion

The compression test was performed as discussed in Sect. 3 and Fig. 1a–c represents the deviation of compressive load with a displacement of various set of nanoscale composites. For MWCNT set nanoscale composites, an increased ultimate compressive strength with an increased weight percentage of MWCNT is observed. It is increased to a percentage of 84% for 0.2% MWCNT from 74% for 0.1% of MWCNT. For 0.5% MWCNT sample, percentage increase is 65% when compared with neat composite. From 1.0%, the increase in strength is almost the same as 0.5%. The increase of ultimate compressive strength for the first two samples that is 0.1 and 0.2% is due to an increase in properties of the matrix due to the addition of MWCNT. As the quantity of MWCNT added is very less in these samples, even distribution of nanoparticles is very much possible. But for the samples of 0.5 and 1.0%, the quantity is high and this may lead to the increase in the van der Waals forces between nanoparticles resulting in a decrease in the dispersion of nanoparticles in the resin system. From Fig. 1b, an 89% increase in ultimate compressive strength is observed for 0.5% weight percentage. The minimum ultimate compressive strength is observed for 1.0% weight of nano-iron oxide sample which is 68% more than conventional composite. The difference in the behavior of the sample is due to the high density of nano-iron oxide when compared to MWCNT. This high density leads to a low quantity of nano-iron oxide particles when compared to that of MWCNT for same weight. So, a shift from 0.2 to 0.5% is absorbed for maximum strength in nano-iron oxide samples when compared to MWCNT samples. Figure 1c is for silica type of nanoparticles. In this, the ultimate compressive strength is going on increasing with the addition of nanoparticles. An increase of 140% is observed in 1.0% weight of nanosilica sample when compared to conventional composite. For 0.1% weight sample, the increase in ultimate compressive strength is increase by 81%. This variation of behavior when compared to other nanoparticles is due to the same molecular

Fig. 1 Load vs displacement under compression for composite modified with **a** MWCNT **b** NI **c** NS



(a)

(b)

(c)

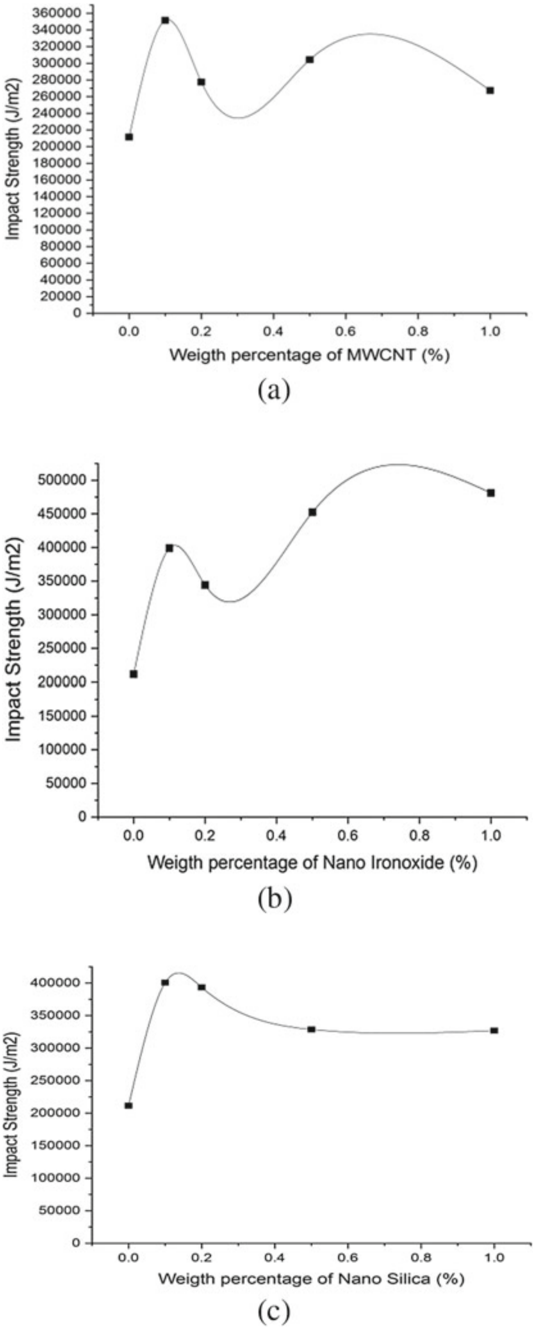
formula of nanosilica and glass fiber. This nanosilica acts as supporting reinforcement along with the glass fibers. Even agglomeration that takes place at high weight percentage will not act stress concentration point but are used to transfer the load.

The compression test was performed as discussed in Sect. 3 and Fig. 2a–c shows the impact strength with the variation of nanoparticles for MWCNT, NI, and NS set of nanoscale composites. For the MWCNT set of sample, the maximum impact strength is observed at 0.1% weight sample. The percentage increase in impact strength is 66% and the minimum increase is of 26% for 1.0%. In the case of nano-iron oxide set, it is observed to be an increase in impact strength by 127%. In the case of a set of silica nanoparticles, the maximum strength is 89% more when compared to conventional composite for 0.1% weight percentage silica set sample. The minimum increased in strength is 54% for 1.0% set of sample. Owing to the change of the morphological in resin during crystallization, this increase in impact strength is observed. For MWCNT and NS sets of samples, the impact strength reduces for 0.2 wt%, and thereafter, it remains constant. This decrease in impact strength is due the high quantity of MWCNT and NS compared to NI and this leads to the agglomeration of nanoparticles in a resin base.

5 Conclusion

In this study, compressive strength and impact strength of nanoscale hybrid composite under different weight percentages and different nanoparticles were observed. The maximum increase in compressive strength by 89% for a sample modified with a nano-iron oxide-modified resin at a weight percentage of 0.5% is observed. The breaking point in the entire sample is much early when compared to neat resin; this is due to the brittle nature of nanoscale composite when compared to conventional composite. The impact strength has also been improved due to the addition of nanoparticles with a maximum increase of 127% for a GFRE sample modified with nano-iron oxide.

Fig. 2 Variation of impact strength for composite modified with **a** MWCNT **b** NI **c** NS



(a)

(b)

(c)

References

1. R.C. Santiago, R.L. Azevedo, A.F. Avila, M.A. Alves, Mechanical characterization of glass/epoxy composite material with nanoclay. Proc. COBEM (2007)
2. J. Gustin, A. Joneson, M. MahinFalah, J. Stone, Low velocity impact of combination kevlar/carbon fiber sandwhich composites. Comp. Struct. **69**, 396–406 (2005)
3. G.L. Dai, S.L. Tae, S.C. Seong, Impact energy absorption characteristics of glass fiber hybrid composites. Comp. Struct. **46**, 267–278 (1999)
4. Y. Peter, J.B. Lawrence, The effect of glass/resin interface strengthen impact strength of fiber reinforced plastics. Polym. Eng. Sci. **18**, 062–072 (1978)
5. R. Ramasimha, N.K. Naik, H. Arya, N. ShamaRao, S. Prabhu, Impact response & damage tolerance characteristics of glass–carbon/epoxy hybrid composite plates. Composites B **032**, 565–574 (2001)
6. S. Jeelani, M. Hosur, M. Adbullah, Studies on the low-velocity impact response of woven hybrid composites. Comps. Struc. **067**, 253–262 (2005)
7. J.B. Donnet, Nano and Micro composites of polymers elastomers and their reinforcement. Comps. Sci. Tech. **063**, 1085–1088 (2003)
8. T.J. Pinavia, G.W. Beal, *Polymer-clay Nano-composites* (Wiley, New York, 2000)
9. P.M. Ajayan, L.S. Schadler, S.C. Giannaris, Load transfer in carbon nanotube epoxy composites. Appl. Phys. Lett. **73**, 3842–3844 (1998)
10. K. Schulte, F.H. Gojny, B. Fiedler, M. Wichmann, Influence of different carbon nanotubes on the mechanical properties of epoxy matrix composites—a comparative study. Comp. Sci. Tech. **65**, 2300–2313 (2005)
11. W. Ben, L. Yu-Hsuan, O.M. Tondin, L. Zhiyong, Z. Chuck, B. Wang, Investigation of the dispersion process of SWNTs/SC-15 epoxy resin nanocomposites. Mater. Sci. Eng. A **385**, 175–181 (2004)
12. M.M. Rahman, S. Zainuddin, M.V. Hosur, J.E. Malone, M.B.A. Salam, A. Kumar, S. Jeelani, Improvements in mechanical and thermo-mechanical properties of e-glass/epoxy composites using amino functionalized MWCNTs. Comp. Struc. **94**(8), 2397–2406 (2012)
13. S.S. Young, R.Y. Jae, Influence of dispersion states of carbon nanotubes on physical properties of epoxy nanocomposites. Carbon **43**(7), 1378–1385 (2005)
14. J.B. Santos, P.N.B. Reis, P. Santos, J.A.M. Fereira, M.O.W. Richardson, Impact response of Kevlar composites with filled epoxy matrix. Comp. Struc. **94**, 3520–3528 (2012)
15. B. Athanasios, V. Kostopoulos, P. Karapappas, I.V. Antonios, P. Alkis, Impact and after-impact properties of carbon fibre reinforced composites enhanced with MWCNTs. Comp. Sci. Tech. **70**, 553–563 (2010)
16. M.A. Waas, S.H. Lee, Compressive response and failure of fiber reinforced unidirectional composites. Int. J. Fract. **100**, 275–306 (1999)
17. B. Harris, M.R. Piggott, Compression strength of carbon, glass and Kevlar-49 fibre reinforced polyester. J. Mater. Sci. **15**, 2523–2538