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A Comparative Study on the Effect of HNT and Nano-Alumina Particles on the Mechanical Properties of Vacuum Bag Moulded Glass-Epoxy Nanocomposites

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ABSTRACT

In the present work, the mechanical properties of the Halloysite nanotube (HNT) and Nano-Alumina particle additions in glass-epoxy nanocomposites are investigated experimentally. The composite specimens for tensile, flexural, interlaminar shear strength (ILSS) and impact tests are prepared by vacuum bag moulding process and tested in accordance with the ASTM standards. HNT/Nano-Alumina particle contents are varied from 0 to 4 wt. %, while the weight fraction of glass fiber is kept constant at 60%. The strength values of the respective tests are obtained and compared graphically to study the effect of nanoparticle type and content on the mechanical properties. From the experimentation and subsequent result analysis, considerable improvements in the mechanical properties are observed with the addition of nanoparticles as compared to neat composites. The 3 wt.% addition of HNT in the nanocomposites resulted in increase in tensile strength, elastic modulus, flexural strength, flexural modulus, ILSS and impact energy values by 12.7%, 6.96%, 5.46%, 4.49%, 7.44% and 119.3% respectively in comparison with the same weight percentage of Nano-Alumina. HNT modified composites reveal an improvement in mechanical properties, hence qualifying it as a most promising cost-effective reinforcing filler for glass-epoxy composites. Further, the SEM micrographs of fractured surfaces are analyzed to study the failure mechanisms and fracture morphologies of higher loaded composites (4 wt.%) and understand the reason for decline in mechanical properties.

1. Introduction

Polymer based composites are increasingly used in aircraft, marine, construction and automotive industries due to their superior mechanical properties, high adhesion strength and good chemical/thermal resistance [1–2]. Despite these superior properties, polymer matrix composites especially Glass-Epoxy composites is limited to some application areas due to low glass transition temperature, brittleness and high density. In this regard, it is necessary to improve the properties of Glass-Epoxy composites with the reduction of weight. In the literature, the Glass-Epoxy composites have been modified by adding natural, synthetic and inorganic particles in order to enhance the mechanical properties [3-8]. In recent years, the researchers and scientists have carefully addressed the issue of incorporation of nanoparticles in composite systems to enhance their mechanical properties. Further, some of the researcher's works on the effect of shapes, sizes and types of nanoparticles on the structure-property relationships of composites are identified as a preamble for framing the research methodology for the present work. Also, the research framework and objectives formulated for the present work distinctly identifies itself, especially with regard to the comparative evaluation of the effect of Nano HNT filler and Nano Al_2O_3 filler on the mechanical properties of vacuum bag moulded glass epoxy Nano

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composites, as not much of literature is available on comparative evaluation of two Nano fillers and most of the research is confined to study on a single Nano filler and not multiple Nano fillers.

1.1. Literature background of HNT reinforced nanocomposites

HNT's are less expensive as compared to other nano-particles and even, it has the morphology of carbon nanotubes with the kaolinite chemistry. Nowadays, HNT's have become a subject of attention for researchers as a new class of nano-filler, which has been enhancing mechanical performance of nanocomposites particularly for strengthening and toughening epoxy base composite systems [9-13]. Ye et al. [14] investigated the ILSS and Charpy impact strength of carbon fiber reinforced epoxy composites with HNT loading at different wt. %. They reported that the incorporation of 2.3 wt. % of HNT in the epoxy has increased the ILSS and Charpy impact strength up to 40 and 46% respectively. M.S. Saharudin et.al [15] studied the effect of Halloysite nanotubes (HNTs) on the mechanical properties of epoxy nanocomposites. They reported that the addition of 0.5 wt. % HNTs has significantly increased the tensile strength, tensile modulus, flexural strength, flexural modulus, fracture toughness, critical strain energy release rate and micro-hardness of the nanocomposites by 45, 49, 46, 17, 125, 134 and 11% respectively. From, the literature background of HNT reinforced nanocomposites, it is noted that the criteria for selection of HNT as Nano filler is majorly based on its bonding strength and its ability to impart strengthening and toughening effect on the epoxy-reinforcement systems.

1.2. Literature background of Nano-Alumina filler based nanocomposites

Nano-Alumina has been widely used in composites due to its high strength, excellent thermal stability, good insulation, high corrosion resistance and low costs [16–20]. Zhao and Li [21] have studied the mechanical properties of Alumina nanoparticles reinforced epoxy composites. The experimental results reveals that the tensile strength and their modulus values are increased by 4.9 and 15.4% respectively in comparison to neat composites. Ghadami et al. [22] investigated the mechanical properties of Nano-Alumina reinforced epoxy nanocomposites and found that the tensile strength value enhanced upto 46.5 % at 1.5 wt. % reinforcement ratio compared to other weight percentages (3 and 5 wt. %). Zhao et al. [23] conducted the mechanical properties study on epoxy nanocomposites at loading of 5, 10, 15 and 20 wt. % of Nano-Alumina. They concluded that 20 wt. % reinforced ratio enhances the Ultimate tensile strength and their moduli values to 5.7 and 18 % respectively. Guo et al. [24] experimentally investigated the mechanical properties of functionalized and non-functionalized Nano-Alumina reinforced polymer matrix nanocomposites at loading ratios of 0.5, 1 and 3 wt. %. They reported that higher loading condition of nanoparticles leads to better improvement in the strength and stiffness values of the functionalized Nano-Alumina addition nanocomposites. The review of the literature on Nano-Alumina filler-based nanocomposites has explicitly given the rationale to select Nano-Alumina as filler, which is majorly due to its ability to take up higher loading conditions and transfer the load from matrix to fiber and bond the fiber – matrix in a strong manner to impart better stiffness.

In the present work, the effect of nanoparticles type (HNT or Nano-Alumina) and loading wt. % (0, 1, 2, 3 and 4 wt. %) on the mechanical properties of Glass-Epoxy nanocomposites are investigated comparatively, and also the optimum quantity of nanoparticles (HNT or Nano-Alumina) are effectively determined, which yields better mechanical strength. Finally, the morphologies of fractured surface and failure mechanism of the nanocomposites are characterized by scanning electron microscopy (SEM).

2. Experimental study

2.1. Materials

Lapox L-12 (Atul India Ltd., Gujarat, India) epoxy are effectively used as the resin. The K-6 (Tryethylene Tetramine (TETA)) and N, N-dimethyl benzyl amine (BDMA) are used as curing agent and accelerator. Woven fabric of E-glass mat (SunTech Fabrics Pvt. Ltd, Bengaluru, India) is effectively used as the reinforcement. Halloysite Nanotube (HNT) and Nano-Alumina particles are used as the fillers. Their features are as follows: The HNTs used in the present work are having an outer diameter in the range of 30–180 nm, inner diameters in the range of 10–30 nm, lengths in the range of 2–10 μm and specific surface area of 64 m^2/g, whereas, Nano-Alumina having diameter in the range of 10-200 nm and specific surface area in the range of 20 m^2/g are used. Transmission electron microscope (TEM) images are taken at the same magnifications (100 nm) to determine the shape and dimensions of HNT and Nano-Alumina particles as shown in Fig. 1.

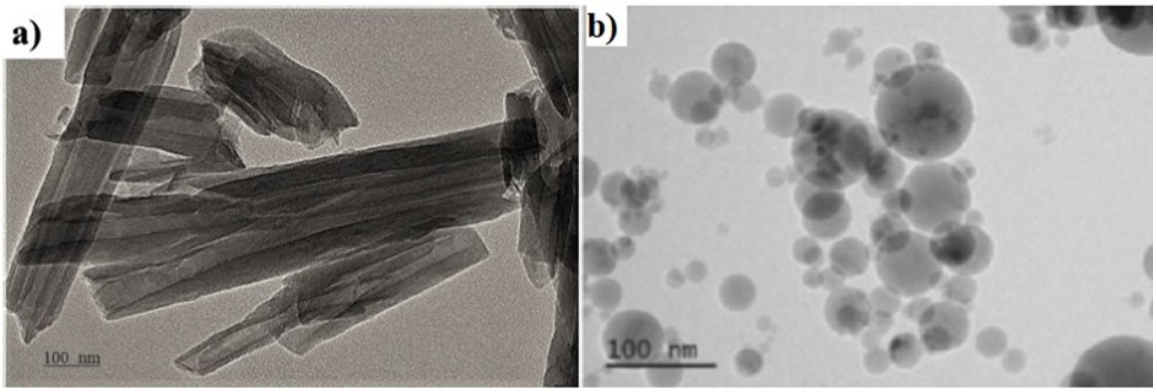

Fig. 1. TEM images: (a) HNT and (b) Nano-Alumina

The TEM images of the HNT and Nano-Alumina filler gives an ultrafine understanding of the structural morphologies of the filler used in the present work. The TEM image of HNT clearly depicts the tubular structure of the Nanotube and the longitudinal dimension of the HNT ranges from 250 nm to 700 nm, while the TEM image of Nano-Alumina clearly depicts spherical structure with globular peripheries, the diametrical dimension of the Nano alumina ranges from 30 nm to 350 nm. Thus, from the TEM images, the shape and size of the filler materials used are ascertained.

2.2. Nanocomposite laminates fabrication procedure

In the present study, the vacuum bag moulding technique is employed to prepare the nanocomposites. Initially, measured weight percentages (0, 1, 2, 3 and 4 wt. %) of the nanoparticles (HNT or Nano-Alumina) are mixed with Epoxy resin using ultra-sonicator to provide a homogeneous dispersion. Further, the prepared mixtures are kept in vacuum oven at 800 C for 30 minutes under the vacuum at 0.075 MPa for removal of the air bubbles present in the mixture by effective degassing. The complete removal of the air bubbles is ascertained by injecting a very small quantity (0.5 ml) of water so that the air if present in the mixture forms water bubbles which are sucked out immediately. Thereafter, the curing agent (K6) in proportion of 1:10 of epoxy resin is added to the mixture. The N, N-dimethyl benzyl amine (BDMA) accelerator is also added to the mixture to increase the rate of curing, the compatibility of the accelerator with the mixture is confirmed after initial trials before used the accelerator for the present work.

After the addition of hardener and accelerator, the resultant mixture is stirred again for 15 minutes at 1000 rpm using a mechanical stirrer for effective dissolution of nanoparticles.

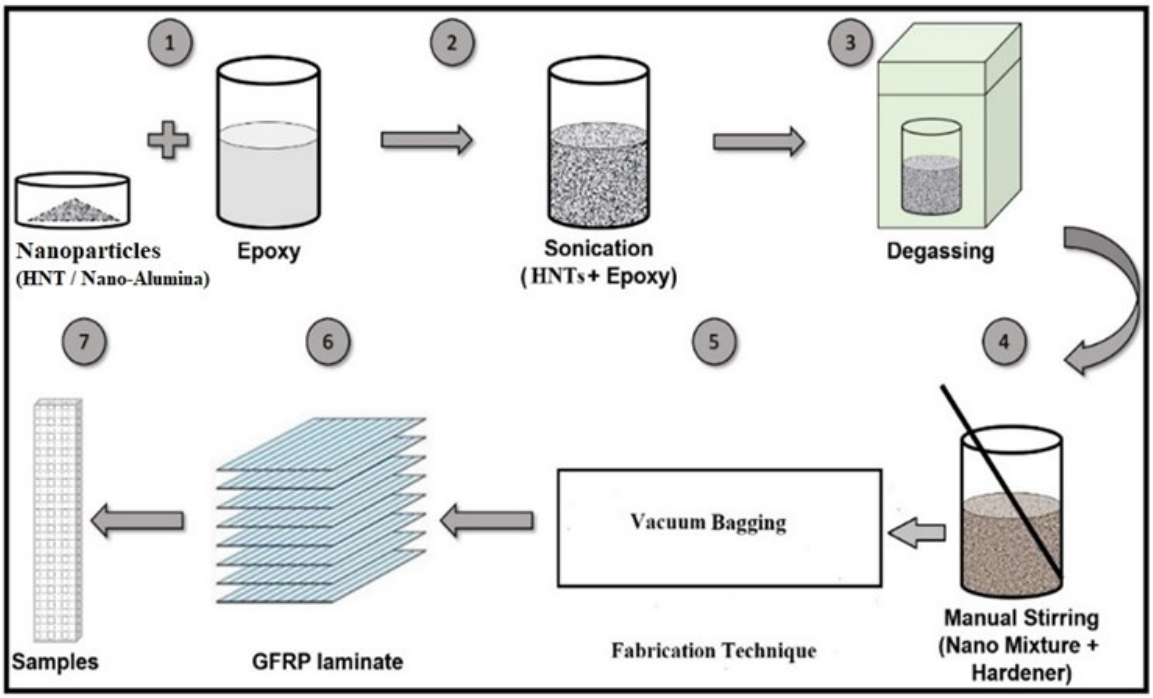

Fig. 2. The schematic representation of nanocomposite laminates fabrication procedure

Further, twelve layers of woven fabric E-glass mat are employed to achieve a laminate thickness of 2.5+0.2 mm. The adequate amount of impregnation of epoxy mixture on layers of fabric are effectively achieved by using roller. The vacuum bag film of 75µm thickness, Nylon peel plies, release films, breather plies and an aluminum plate are used to facilitate the "peeling off" of the composite plates from the mould after curing in order to generate the straight and compacted composite laminates. The steps involved in fabrication of nanocomposite laminates has been presented schematically in Fig. 2.

2.3. Characterization of nanocomposites

The specimens of neat and nanocomposites are prepared as per the ASTM standards subjected to tensile test (ASTM D3039), flexural test (ASTM D790) and ILSS test (ASTM D2344). These tests are conducted with a cross head speed of 2.5 mm/min at room temperature using computerized Universal testing machine (Kalpak Make, capacity of 100 kN). The Izod impact test (ASTM D256) is conducted with a pendulum striking velocity of 3.46 m/s using Pendulum impact tester (Mitutoyo make, Capacity of 10 kJ/m). The Statistical evaluation of the results are performed on the base of at least five individually test specimens for each experiment. The average value of each type of the test is recorded. The generalized microstructure of nanocomposite, fractured morphologies and failure analysis are carried out for selected samples and examined using field emission Scanning electron microscopy (SEM). Further, the Energy Dispersive X-Ray Spectroscopy (EDS) is accomplished for elemental analysis of the selected area identified with uniform dispersion of HNT and Nano Alumina fillers using the VEGA3 TESCAN make SEM.

3. Results and Discussions

3.1. Tensile Properties

The results obtained during tensile test viz. tensile strength and elastic modulus values are plotted graphically against the nanoparticle loading (wt. %) of Nano-Alumina and HNT as shown in Fig. 3 and Fig. 4 respectively. It is evident from the results, that tensile performance is improved by addition of nanoparticles (Nano-Alumina/HNT) content compared to neat composites. This may be due to uniform dispersion and cohesive interfacial interaction of epoxy with nanoparticles which leads to the effective transfer of stress between epoxy and nanoparticles, this is also supported by the SEM images of the microstructure of the epoxy Nano filler for 3 wt. % composition, wherein there is evidence of uniform dispersion of Al_2O_3 and HNT in the epoxy matrix composites respectively and also there is strong bonding between the filler-matrix interfaces. This is also substantiated from the findings reported by Santhosh et al. [25] in their research, wherein the tensile properties of the glass and carbon fiber reinforced composites increases due to strong bonding between the reinforcement and matrix phase.

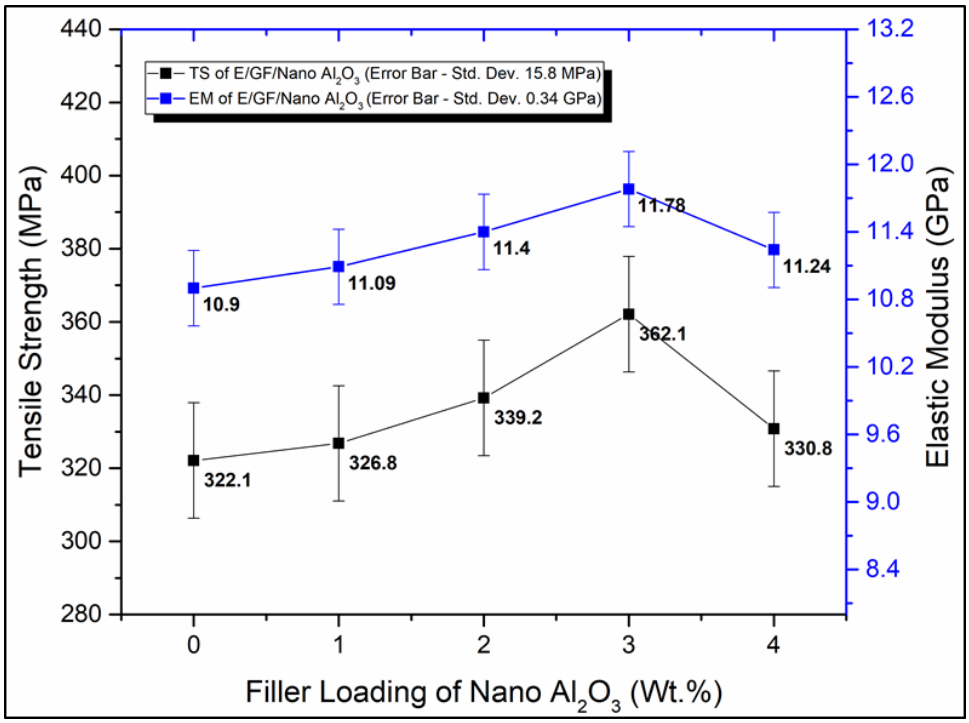

Fig. 3. Graph showing the variation of tensile strength and elastic modulus with filler loading of Nano Al_2O_3

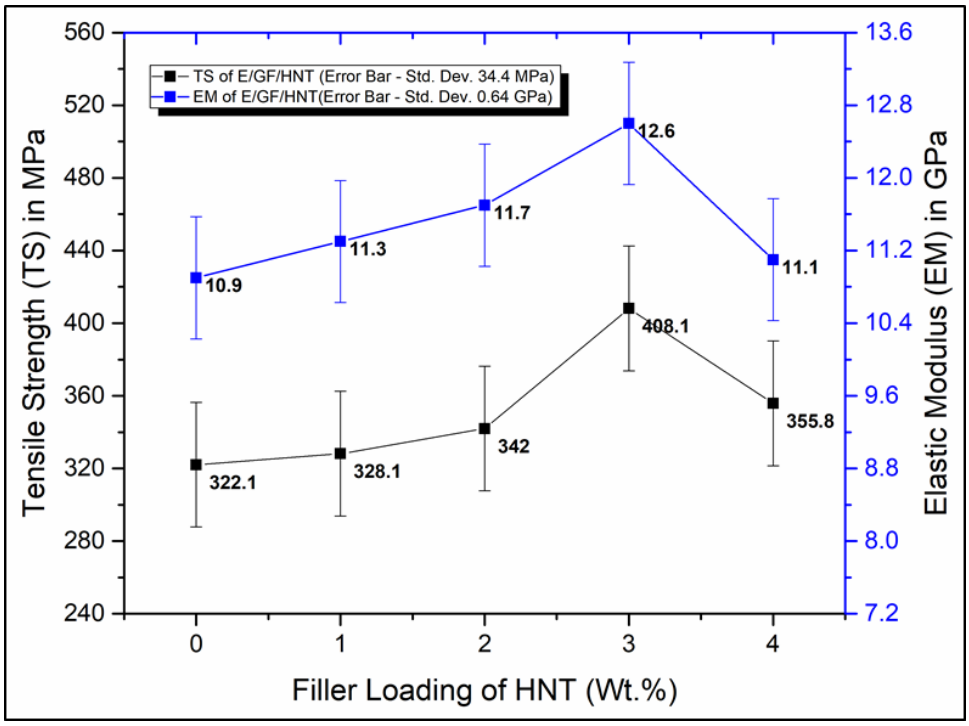

Fig. 4. Graph showing the variation of tensile strength and elastic modulus with filler loading of HNT

Composite specimens with HNT additions show a better tensile strength and modulus values, with an increase in the properties up to 12.7% and 6.96% respectively as compared with the Nano-Alumina contained specimens at a loading of 3 wt. % due to excellent level of cross linking tendency of HNT with epoxy resin. There is a considerable decrease in these properties at a higher loading ratio (4 wt. %) due to clustering or agglomeration of nanoparticles. As a result, there is an increase in hardness and weaker interface region which leads to consequent stress concentrations and reduction in mechanical properties.

From, the dataset represented graphically in Fig. 3 and Fig. 4 for tensile strength and elastic modulus for Nano Al_2O_3 and HNT filler based composites, it is clearly noted that the standard deviation for tensile strength for Nano Al_2O_3 and HNT reinforced composites are 15.8 MPa (Mean 336.2 MPa) and 34.4 MPa (Mean 351.2 MPa) respectively, while elastic modulus for the same are 0.34 GPa (Mean 11.25 GPa) and 0.64 GPa (Mean 11.55 GPa) respectively. The standard deviation values for the datasets clearly gives an overview of the mean values for the composite materials with varying weight percentage of filler loading and the deviation of the tensile properties with respect to the mean values.

The critical inferences from Tensile Strength (TS) and Elastic Modulus (EM) of the nano composite laminates are clearly validated from the findings of Shirisha et al. [26] and Gujjala et al. [27], they have worked on the mechanical characterization of composite laminates and have reported that the tensile characteristics increase with the increase in the filler content up to 3 wt. %, beyond which the properties decrease due to agglomeration and micro-coring.

3.2. Flexural Properties

The experimental results of flexural tests for Nano-Alumina and HNT are exhibited graphically in the Fig. 5 and Fig. 6 respectively. It is evident from the graphs, that there is a significant increase in flexural strength and flexural modulus of nanoparticle included composites as compared to plain or neat. This may be due to the restriction of nanoparticles slippages at filler-matrix interfaces which leads to increase in stress transfer efficiency by developing the large amount of flexural strain.

From, the datasets represented graphically in Fig. 5 and Fig. 6 for flexural strength and flexural modulus for Nano-Alumina and HNT filler based composites, it is clearly noted that the standard deviation for flexural strength for Nano Al_2O_3 and HNT reinforced composites are 57.2 MPa (Mean 452.2 MPa) and 71.9 MPa (Mean 500.9 MPa) respectively, while flexural modulus for the same are 0.90 GPa (Mean 7.6 GPa) and 1.07 GPa (Mean 8.14 GPa) respectively. The standard deviation values for the datasets clearly gives an overview of the mean values for the composite materials with varying weight percentage of filler loading and the deviation of the flexural properties with respect to the mean values.

The error bars are included for the graphs in terms of standard deviations of the data and it can be clearly seen that the properties, both

tensile and flexural are maximum for 3 wt. % of filler content, beyond which there is decrease in the properties owing to the agglomeration and coring of the reinforcements with increased percentage of inclusion in the matrix phase in spite of trials for appropriate dispersion, this is also due to the cohesive attraction between the agglomerate particles in the matrix phase.

It is also obvious that enhancement of flexural strength and modulus of about 5.46 % and 4.49 % is observed in case of 3 wt. % HNT as compared to the same wt. % of Nano-Alumina additions in the composites. A decrease in the flexural property at higher loading of nanoparticles (more than 3 wt. %) may be due to the overloading of nanoparticles that favors agglomeration which constitutes a weak interfacial bond with epoxy matrix and further leads to debonding under stress. Due to debonding, voids occur around the nanoparticles which enhances the stress concentrations around these voids and decreases flexural properties.

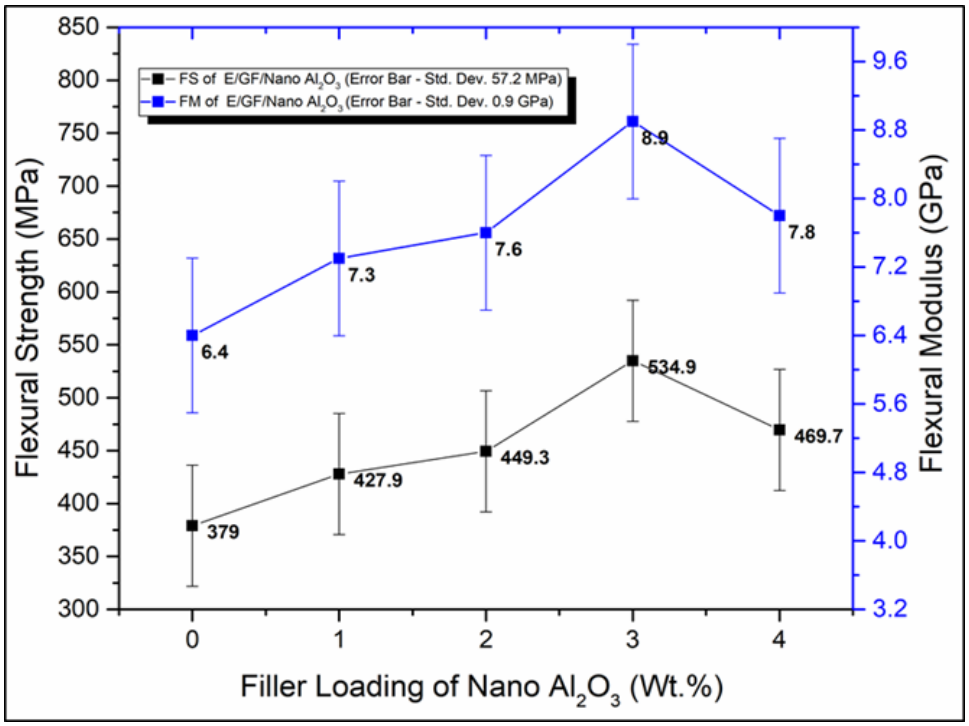

Fig. 5. Graph showing the variation of flexural strength and flexural modulus with filler loading of Nano Al_2O_3

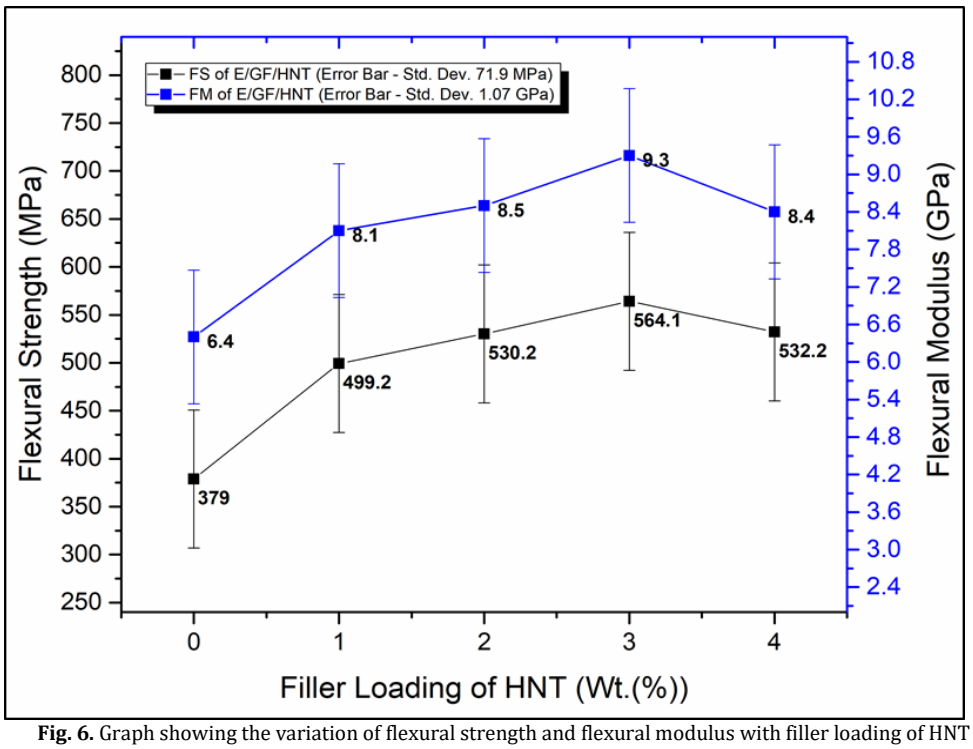

Fig. 6. Graph showing the variation of flexural strength and flexural modulus with filler loading of HNT

Minh et al. [28], have reported that the flexural characteristics enhance with the incorporation of filler content and interfacial bonding between the fiber and reinforcements, further Omar et al. [29], have worked on the mechanical characterization at higher loading of filler material and have reported that the flexural characteristics have increased up to 3 wt. % of filler content beyond which it leads to coring and micro segregation and void formations which leads to decrease in the properties. These inferences are further substantiated by the findings of Ekramul et al. [30] and Mirjalili et al. [31], which are base aspects for validating the results of the present work.

3.3. Interlaminar shear strength (ILSS) and Impact energy

It is evident from the plot (Fig. 7), that there is an enhancement of ILSS value in glass-epoxy composites irrespective of the type of the nanoparticle loading. This enhancement is probably due to the development of a strong interfacial bonding between matrix and nanoparticles. The addition of HNT resulted in an improvement in the strength by 7.44 % for 3 wt. % as compared to the same wt. % of Nano-Alumina loaded composites. This may be due to the hollow cylindrical morphology of HNT which acts as an interlocking agents between glass fibers and epoxy resin and as a result, reduces the frictional slippages between them. However, further addition of nanoparticles (4 wt. %) leads to a decrease in ILSS value which is due to the agglomeration at this loading. The agglomerated structure of nanoparticles acts as stress concentration site, resulting in the decrease in ILSS value.

Fig. 7 also shows the role of wt. % of nanoparticles on the impact energy of glass-epoxy composites. The incorporation of the nanoparticles increased the impact loading resistant property of the composite systems. It can be also observed that a significant improvement in impact resistant capability of nanocomposite is achieved with 3 wt. % of reinforced nanoparticles (for both HNT and Nano-Alumina). This might be attributed to the presence of strong and tough ceramic particles which forms a better interfacial interaction with epoxy matrix, and imparts the intrinsic toughening property and enhances the energy absorption capability of nanocomposites. The toughness property of 3 wt. % HNT reinforced nanocomposite increased up to 119.3% as compared to Nano-Alumina included nanocomposites. This may be due to the effect of the shape of the HNT. The hollow cylindrical shape of HNT has particle bridging mechanism which leads to toughness enhancing quality whereas, Nano-Alumina has crack pinning and bowing mechanism due to spherical shape which restricts flexibility and flowability of polymer chains. Beyond the loading of 3 wt. % of Nanoparticles, there is a decrease in impact strength due to clustering and improper distribution of nanoparticles in the epoxy resin which may offer lower impact energy for prepared nanocomposites.

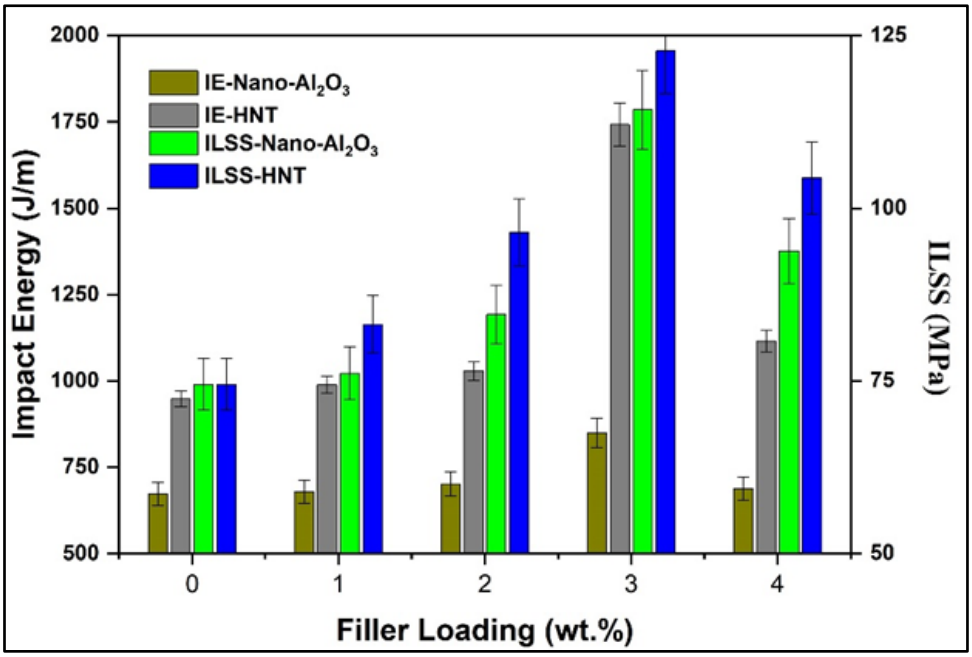

Fig. 7. Graph showing the variation of Impact energy and ILSS with filler loading

3.4. Micrographs of HNT and Nano-Alumina filled composites

The dispersion of the filler content in the matrix is identified through the Scanning Electron Microscope images of 3 wt. % Nano-Alumina and HNT filled composites in Fig. 8 (a) and Fig. 8 (b) respectively. The Nano-Alumina is uniformly dispersed in the matrix phase and there is strong cohesive bonding between the filler and the matrix phase. Similarly HNT is uniformly dispersed in the matrix phase, this is majorly due to the processing technique employed in present work for fabrication of the composite laminates. The uniform dispersion and cohesive bonding of the fillers up to 3 weight percentage is the major attribute for enhancement of the tensile and flexural characteristics. This is also ascertained from the technical reports of the supplier (Sigma Aldrich) vide Certificate of Analysis and Specification sheet for Product category no. 54483 for Nano Al_2O_3 [32], and 685445 for HNT filler [33].

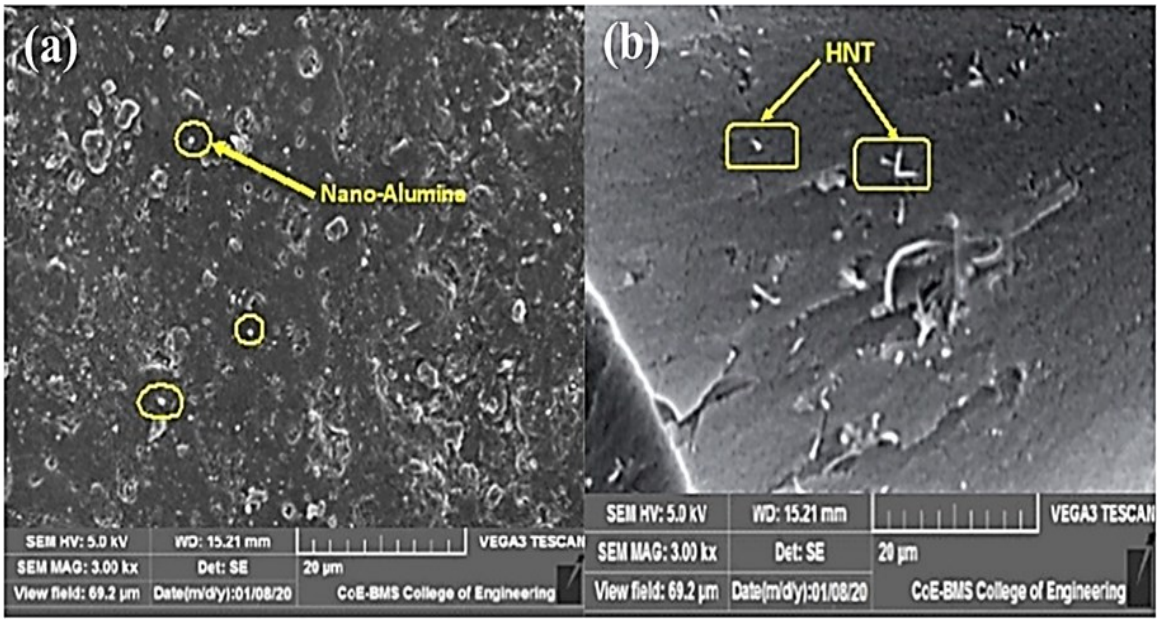

Fig. 8. SEM images of (a) 3 wt. % of nano-alumina and (b) HNT filled glass-epoxy composites

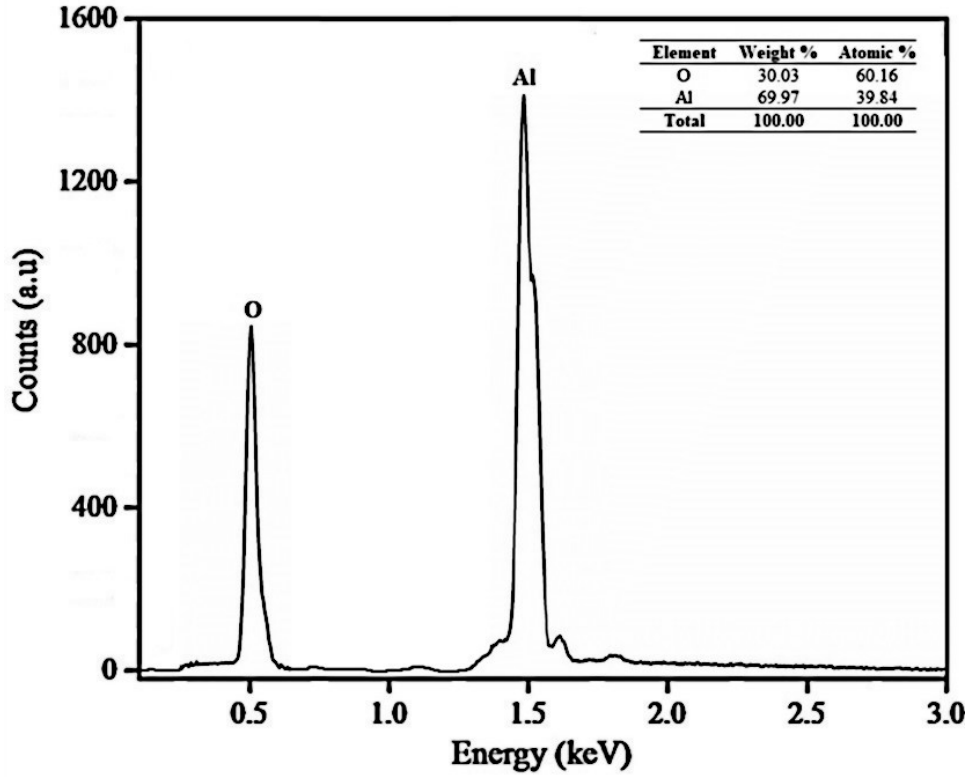

Fig. 9. EDS results of nano-alumina (Al_2O_3)

The Energy Dispersive X-ray Spectroscopy is also accomplished through VEGA3 TESCAN scanning electron microscope setup to determine the elemental composition in the selected area, for the presence of Nano Alumina (Al_2O_3) and Halloysite nanotube (HNT) respectively, it is evident from the EDS results in Fig. 9, that the wide distribution of Nano Alumina (Al_2O_3) in the matrix is depicted with the major composition of oxygen of 30.03 wt. % and aluminum of 69.97 wt. % , which is also similar to the values reported in the literature. Further, the distribution of HNT is evident from the EDS results depicted in Fig. 10, with the major composition of oxygen of 58.07 wt. %, silicon of 18.92 wt. %, aluminum of 18.48 wt. %, and carbon of 4.53 wt. %, which is in parlance with the values reported in several other research articles on HNT.

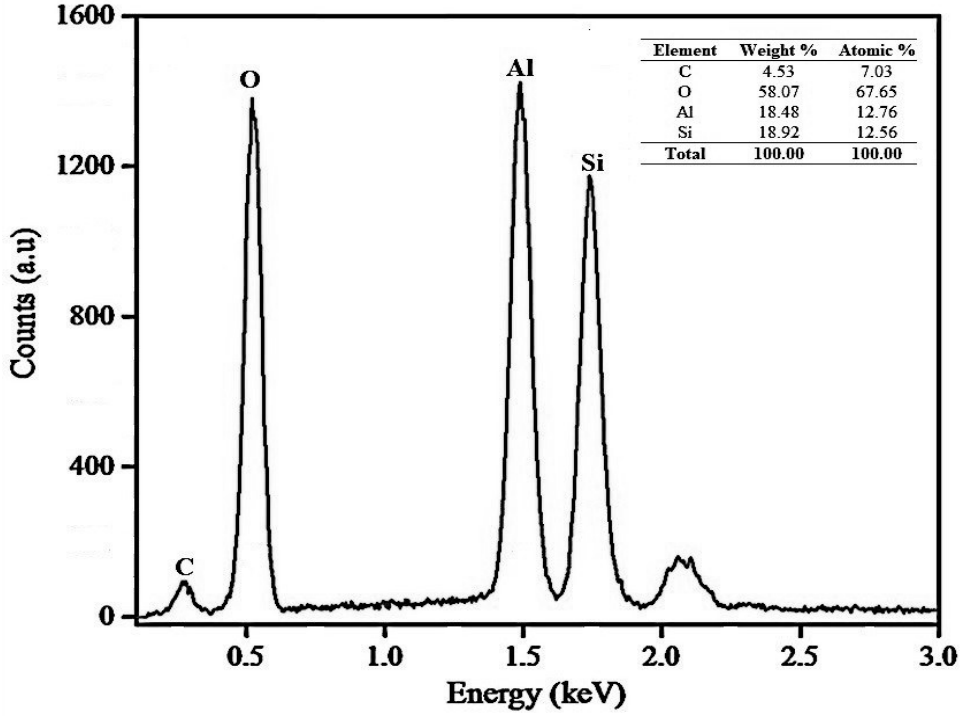

Fig. 10. EDS results of halloysite nanotube (HNT)

3.5. Fractured morphology studies by scanning electron microscopy

Tensile fractured surfaces of HNT included nanocomposites have been studied by SEM and shown in Fig. 11 (a-d). Fig. 11 (a) shows a good interfacial bonding among the fibers and epoxy with HNT (3 wt. %) which exhibits the maximum strength over other class of nanocomposites. Fig. 11 (b) reveals severe amount of fiber pull out and lower matrix drainage in 2 wt. % HNT nanocomposites as compared to 4 wt. % HNT included nanocomposite shown in Fig. 11 (c), it evident that a severe matrix drainage results in lowering strength of a nanocomposite, which is almost equal to the tensile characteristics of 1 wt. % HNT incorporated nanocomposites. Fig. 11 (d) clearly depicts that there is an interfacial debonding between fibers and matrix composition due to agglomeration of nano particles at one site at higher loading percentage of Nano fillers. The fractographical studies give the overview of fracture mechanisms and the effect of filler on the composite and its properties, thus the fracture mechanisms with reference to crack pinning, crack path deflection, and nanotube pullout are clearly depicted in the SEM images.

Fig. 12 (a-d) depicts different morphologies of fracture mechanism as observed in a tensile fracture surface of the Nano-Alumina filled glass-epoxy composites. It is evident in Fig. 12 (a), that there is a tremendous amount of matrix deformation, which ensures that, a smooth transfer of stress from matrix to fibers occurs for a loading of 3 wt. % of Nano-Alumina. Fig. 12 (b) reveals severe fiber pull out and matrix hardening, which shows a development of huge deformation strain resulting in improvement in the tensile performance. The other morphologies such as fiber imprint and river-line marking are clearly observed in Fig. 12 (c) and Fig. 12 (d) for 4 wt. % of Nano-Alumina embedded nanocomposites. These marks are less apparent, when the toughness of the matrix increases. The river-line marking is considered as a most valuable feature to identify the crack growth direction. The fiber imprint signifies that, there is a delamination of fibers from the matrix that *eventually results in the reduction of tensile properties at 4 wt. % Nano-Alumina filled nanocomposites.*

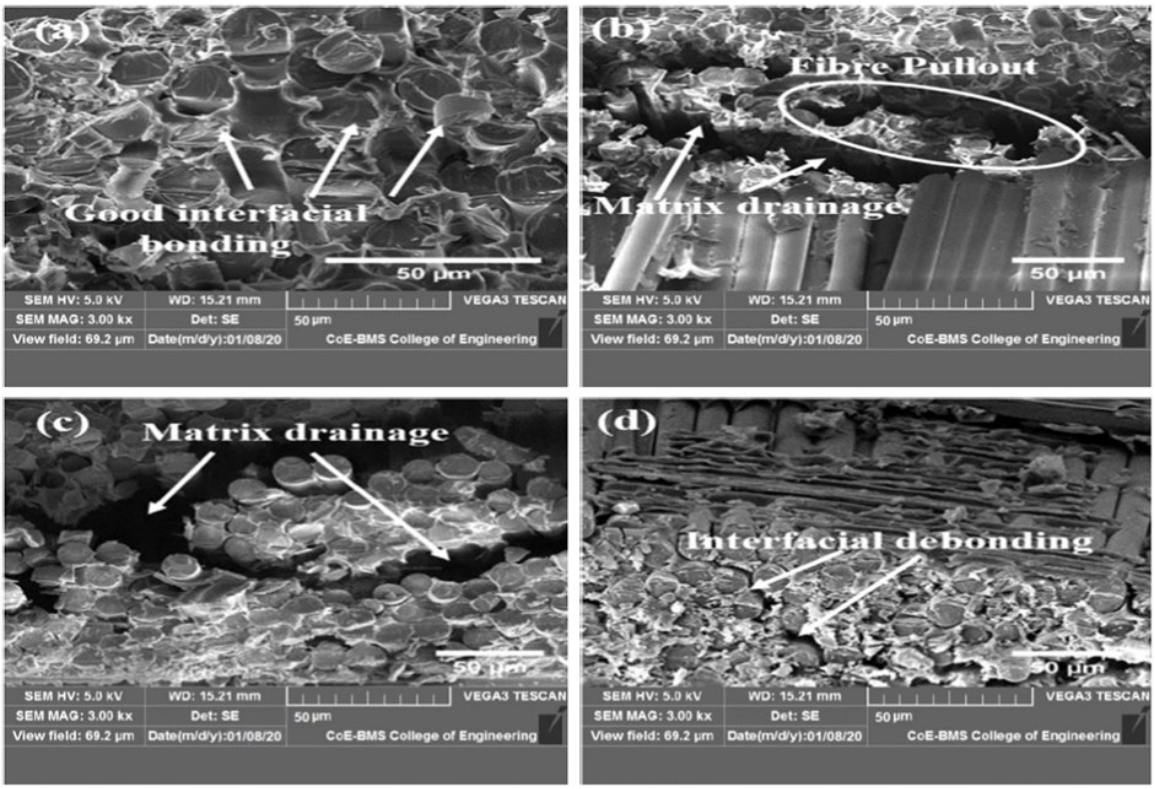

Fig. 11. Morphology of fractured specimen observed in HNT filled glass epoxy composites (a) good interfacial bonding, (b) matrix drainage and fiber pullout, (c) matrix drainage (d) interfacial debonding

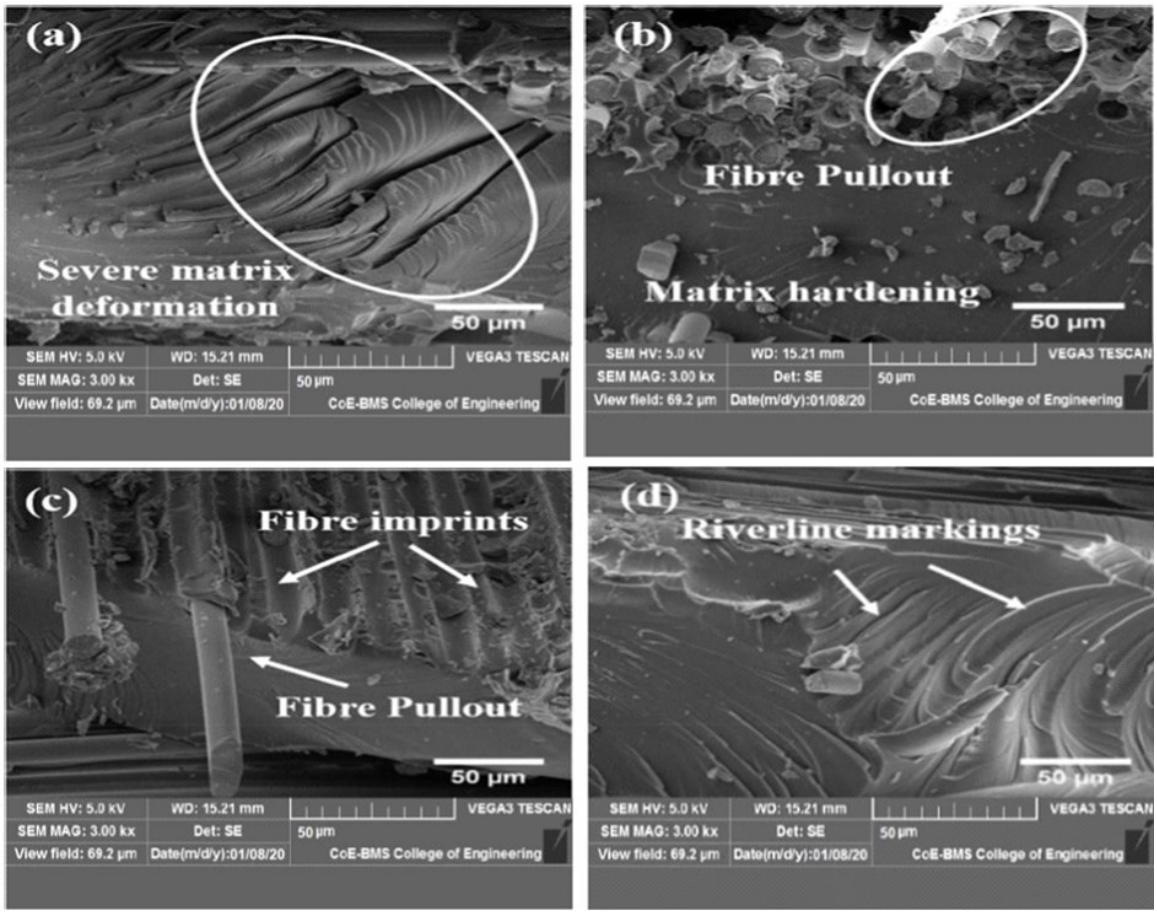

Fig. 12. Morphology of fractured specimen observed in nano-alumina filled glass epoxy composites (a) sever matrix deformation, (b) matrix hardening and fiber pullout, (c) fiber imprints and fiber pullout and (d) river-line markings

The microstructural observations of Lau et al. [34], have found parlance for the findings with respect to the present microstructural observations with respect to severe matrix deformations, fiber pullout and interfacial bonding that eventually results in fracture of the composite laminates, which are substantiated from the findings of Wu et al. [35] and Zhao et al. [36], wherein the base for severe matrix deformation and river line markings are reported for fracture of the hybrid composite laminates.

From, the fracture mechanics of HNT and Nano alumina filled glass epoxy composites, as observed in Fig. 11 and 12, it is evident that the river-line markings, crack pinning, crack path deflection and subsequent nanotube pullout and propagation of the toughness failure lines along the crack periphery leads to failure of the laminates. Also, the effect of fillers can be distinctly inferred from the types of failure mechanisms, which depicts that the incorporation of fillers in the matrix enhances the toughness and thereby imparts resistance against fracture, however, with the increased load, the toughness bands are formed that propagate before eventual failure due to embrittlement and cracking. Also, the findings of Zhou et al. [37] have reported the crack initiation and crack propagation mechanisms for the failure that have eventually occurred around the crack periphery and failure lines, impacting the fracture of the composite laminates and its subsequent failure amidst the fracture propagation within the matrix band of the nano composites fabricated.

Further, the findings of Rajanish et al, [38] have inferred that the inclusion of alumina nano particles enhance the tensile properties of Glass/Epoxy composites, since the nano particles enter the cross links and create good interface between the matrix and reinforcement leading to better mechanical properties supporting the findings of present research.

4. Conclusions

The present investigation determines the effect of different weight percentage addition of HNT and Nano-Alumina particles on the mechanical properties of glass-epoxy composites. In conclusion, the tensile, fracture and inter-laminar shear strength of the composite laminates significantly improve due to the strong bonding facilitated by the nano filler in the matrix, this is in general supported by the tests conducted and the micrographs and EDS accomplished to ascertain the distribution of HNT and Nano Al_2O_3 in the matrix. Further, the fracture mechanisms are studied using SEM micrographs. Based on the experimental results and their pertinent analysis, it is evident that the addition of nanoparticles (both HNT and Nano-Alumina) in the glass-epoxy composites significantly strengthens the fiber/matrix interface as well as the matrix, this is achieved through a successful fabrication of laminates by vacuum bag moulding technique. Finally, the tensile properties, fracture strength and inter laminar shear strength of the composites with Nano fillers up to 3 wt.% composition in the composite exhibit significant improvement which is also supported by the uniform distribution of HNT and Nano Al_2O_3 and the morphological features of fractured surfaces, wherein certain features viz. river-line markings, micro cracking, fiber breakage, crack pinning etc., are observed only in composites with more than 3 wt. % of filler content owing to micro coring and aggregation at one site due to the increased addition of filler nano particles beyond threshold limit.

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