STUDY OF EROSION CHARACTERISTICS OF MWCNT'S- ALUMINA HYBRID EPOXY NANOCOMPOSITES UNDER THE INFLUENCE OF SOLID PARTICLES

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The influence of solid particle on erosion characteristics of multiwall carbon nanotubes (MWCNTs) – alumina (Al_2O_3) hybrid epoxy nanocomposites has been investigated in this work. Tests were carried out to investigate the influence of hybrid nanofillers and impingement angle during solid particle travel over the surface. The erosive wear was evaluated with various five weight fractions of 0.5, 1.0, 1.5, 2.0 and 2.5 (by wt.%) of hybrid nanofillers filled with pure epoxy and at three different impingement angles: 30º, 60º and 90º. The erodent used is irregular silica sand particles (with size range of 100±20µm) with an impact velocity of 70m/s and the flow time of 5 min. The experimental results exhibit the maximum erosion rate at 60º impingement angle and the material removal was semi-ductile in nature. The lowest wear rate was observed in pure epoxy filled with 1.5 (by wt.%) hybrid nanofillers due to debonding of fiber and matrix restricts by the fillers. The pure epoxy without any hybrid nanofillers exhibits highest erosive wear due to weak bonding strength. The morphology of eroded surface was examined by field emission scanning microscope and possible mechanisms were discussed.

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1. Introduction

Solid particle erosion is the phenomenon where the progressive material removes itself from a solid surface due to the high velocity stream of solid particle travel over the surface. Polymer composites are extensively used as bulk structural materials for aerospace, marine, automobile and refining industry due to their excellent specific properties. In the past few decades polymer composites materials in erosive environment are increasing with wide range of engineering applications like aircraft engine blade, aircraft operating in desert environments, helicopter rotor blades and pipe line carrying sand slurries in petroleum refining. Srivastava and Pawar [1] reported that addition of GFRP composites with fly ash fillers in epoxy resin improve the erosive resistance due to fillers restricts the fiber – matrix debonding. Further, Fouad et al [2] have reported that the erosion behavior of epoxy/GFRP has changed from ductile to brittle at 60 º impingement angles with high erosion losses. Zhang et al [3] investigated research on solid particles erosion behavior of carbon fiber (CF) woven fabric and carbon nanofiber paper coated epoxy composites. The CNF was able to provide a much stronger erosion resistance compared to the CF reinforced epoxy composites, which is attributed to the high strength of CNFs and their nanoscale structure. Tilly and Sage [4] reported that the erosion resistance depends upon the type of fiber used resulting in the improvement or worsen of epoxy and nylon 66 composites. Tewari et al [5] investigated that the erosion wear of the unidirectional carbon and glass fiber reinforced epoxy composites exhibits semi-ductile erosion behavior, with maximum erosion rate at 60º impingement angle and the fiber orientations had significant influence on erosion. Extensive

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research has been carried by Patnaik et al [6] on the solid particle erosion characteristics of various filler such as SiC, flyash and alumina on polymer composites. The investigation reveals that addition of fillers in the considerable weight fraction in the matrix will yield good results. It is well known that the erosion rate of polymer composites is usually higher than that of neat polymers. During the last decade, many investigations have been reported with epoxy [7], Polypropylene [8], nylon [9], polyethylene [10], ultra high molecular weight polyethylene [11], polyetheretherketone [12], rubber [13, 14], hybrid composites [15]. In general fiber/filler content in the composites controls the mechanical and tribological properties. In order to obtain the desired material properties for a particular application, it is important to know how the material performance changes with the fiber content under given loading conditions [16]. The behavior of fiber content polymer composites has been studied to a limited extend [17, 18].

The aim of this present experimental investigation was to study the influence of solid particles on MWCNTs – alumina hybrid nanocomposites of erosion behavior with pure epoxy composites. The influences of hybrid nanofillers weight fraction and impingement angle on the solid erosion of composites was studied.

2. Material and methods

2.1 Materials

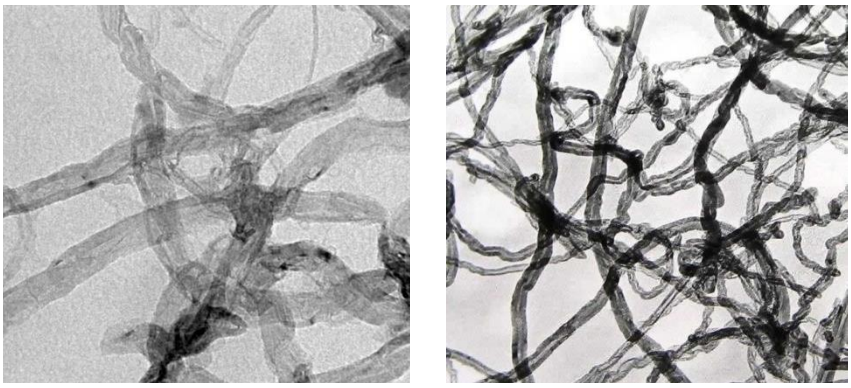
The matrix used was a diglycidyl ether of bisphenol A, hardened by an amine based curing agent HY951. The nominal MWCNTs length amounted 15µm, the average diameter around 30nm, specific surface area of wall is $200 m^2 g^{-1}$ and countable surface wall around 8 numbers. Similarly, the gamma phase alumina particle with a size of 100nm and melting temperature 2100ºC supplied by bottom up technologies, India. The carbon nanotubes synthesize by chemical vapour deposition (CVD) and the wall surface was enhanced by means of COOH functionalization.

2.2 Preparation of MWCNTs – Al_2O_3 hybrid powder

The predetermined quantity of MWCNTs were dispersed in acetone containing sodium dodecycl sulphate (SDS) suspension using an ultrasonicator for 2 hours at room temperature to form a suspension. The required amount of alumina was added to the suspension and the sonication process continued for another two hours. The mixture suspension was milled using ball milling machine with 200 rpm for 12 hours. The milled suspension was collected in tray and kept in oven for 100ºc for eight hours. Furthermore, the dried mixture changed to vacuum chamber plate and drying continued for another 24 hours at the same temperature. During the entire process the MWCNTs – Al_2O_3 weight ratio is maintained at 1:4 [19].

2.3 Sample Preparation

MWCNTs-alumina hybrid nanofillers were dispersed in the epoxy resin with the various weight percentages of 0.5, 1.0, 1.5, 2.0 and 2.5 (by wt.%) using ultrasonicator. The mixture temperature was maintained between 50°C to 60°C during the sonication process. The obtained suspension was kept in the vacuum chamber to remove the micro air bubbles. The curing agent HY951 was added in the suspension with the volume ratio of 10:1. The hybrid nanofillers suspension was poured into the acrylic plastic mould of dimension length, width and height is 85, 25 and 10mm, respectively. The mould was kept in the oven at 100°C for 24 hours for curing. The cured specimens were cut into square piece of 25 * 25 * 10 mm and taken for fine grinding process. The sample surface was cleaned with acetone before and after the erosion test. The TEM image of purified and COOH functionalized MWCNTs as shown in Fig.1 (a) and Fig.1 (b) respectively.



(a) (b)

Fig.1 (a) TEM image of purified MWCNTs, (b) TEM image of COOH functionalized MWCNTs

2.4 Erosion Test

The solid particle erosion tests were carried out as per ASTM G76 and the conditions under which the erosion tests were carried out are listed in Table 1.The erosion test rig was used to evaluate the erosive performance of pure epoxy and hybrid nanofillers filled epoxy. The test rig consist of a micro feeder, air drying unit, air compressor, accelerating chamber and air particle mixing unit. In this study, the particles had an average particle size of 100±20µm. Silica sand particles was mixed with compressed air in mixing unit and then accelerated by passing the mixture through a convergent brass nozzle of 3 mm internal diameter. The erosion test was carried out in room temperature. The rotating disc method was used to determine the velocity of eroding particles. The mass flow rate and average particle velocity distribution throughout the flow cross section were obtained from pressure *(p)* at various distances from the nozzle tip. It was found that the average uniform velocity at higher pressure was attained at 12mm distance from nozzle tip around the flow axis. This setup is capable of developing erosive situation for assessing erosion resistance of the nanocomposites samples. The erodent particles impact the sample which can be mounted on in the swivel specimen holder. The sample size is approximately 25 * 25 * 10 mm. The mounted specimens were subjected to three impingement angles between 30º to 90º with an increment of 30º. Wear was measured by weight loss of the specimen. Electronic balance with sensitivity of 0.1mg was used to measure the weight loss before and after erosion test. The eroded surface morphology of some specimens was examined by the field emission scanning electron microscope to understand the mechanism of material removal. The samples were gold-sputtered to reduce electrostatic charging of the surface.

Table .1 Solid particle erosion tests parameters

Erosion Test Conditions	
Erodent	Silica sand
Erodent size (µm)	100 ± 20
Impingement angle (°)	30, 60 & 90
Impingement time (min)	5
Impingement area (mm^2)	625
Nozzle to sample distance (mm)	12
Nozzle diameter (mm)	3
Test temperature	Room Temperature ($25^oC \pm 2^o$)

3. Results and discussion

The erosion behavior polymer depends on whether the material is thermoplastics or thermosetting. The mechanism of erosion failure can be grouped into ductile, brittle and semi-ductile ones. In general ductile behavior will occur on thermoplastic and brittle behavior on thermosetting polymer.

3.1 Effects of impingement angle

The impingement angle is usually described as the angle between the eroded surface and the trajectory of the impact particle. It is well known that the important factor influencing the erosion are impingement angles, impact velocity, size of the eroding particle, their shape and hardness and flow rate, properties of sample material and flow rate. All these have important effects on erosive weight loss. The erosion weight loss was measured as a function of impingement angle of ductile and brittle material. Taking these factors as a reference, the experiments conducted have generally shown that the maximum erosion rate of ductile materials occurs at impingement angle of 15-30º, whereas maximum erosion rate of brittle materials occurs at 90º impingement angle. The maximum erosion rate of semi-ductile material was found to occur at impingement angle of 45 - 60º.

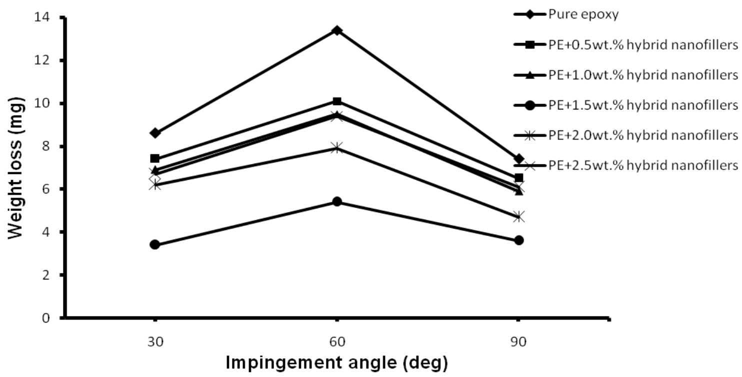


Fig.2 Weight loss as a function of impingement angle.

The influence of impingement angle of erosive wear on pure epoxy and hybrid nanofillers at various weight fractions of 0.5, 1.0, 1.5, 2.0 and 2.5(by wt. %) of epoxy composites are as shown in Fig.2. In the present investigation the erosive weight loss has been found maximum at 60º impingement angle for all the composition. The morphology analysis of eroded surface reveals that the material removal is mainly caused by the damage mechanism as micro cracking, pinch hole due to the impact of silica sand particle. It is stated that hybrid nanofillers as reinforcement of epoxy matrix are a typically semi ductile materials so that the maximum weight loss occurred at 60º impingement angle.

3.2 Effect of exposure time

Exposure time is the measure of accumulation of exposure to material surface to remove the material in erosion environment. The graphical representation of erosion diagram as a function of exposure time is depicted in Fig 3.In case of brittle material the material removal rate increases linearly with increasing time, in ductile material the erodent particle embedded in the target surface causing weight gain. This period is generally known as incubation period. At the end of incubation period, material removal usually proceeds at a constant rate. The maximum weight loss can be found at 60 º impingement angles, it demonstrated as semi-ductile in nature.

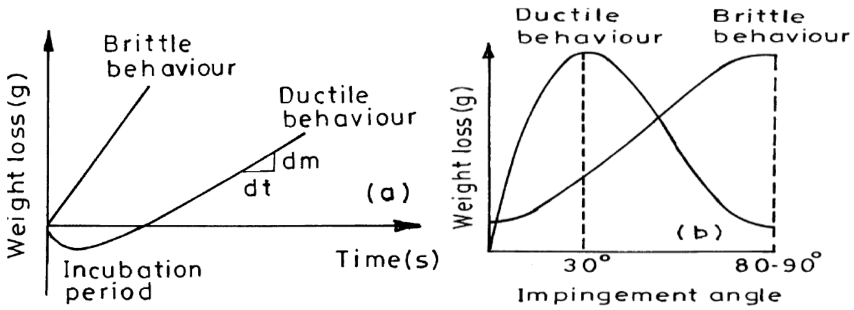
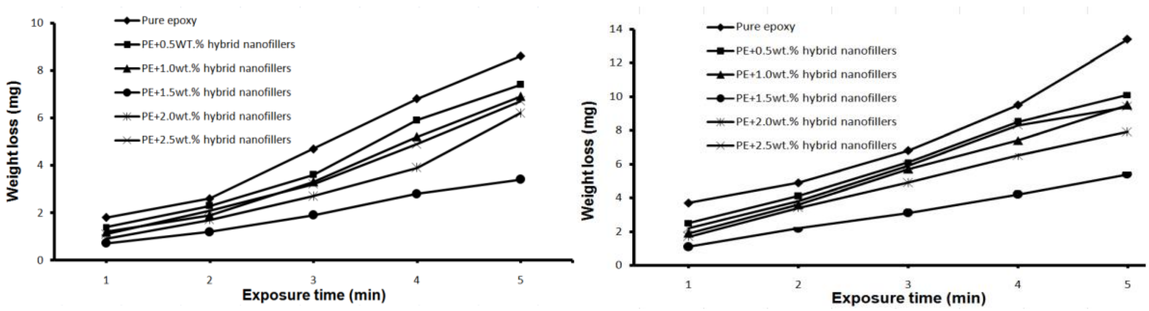
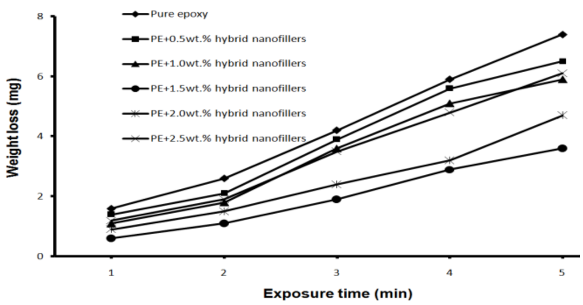


Fig.3 graphical representation of ductile and brittle type of erosive wear (a) based on time (b) based on impingement angle [20].

Fig.4 (a-c) shows weight losses as a function of exposure time at different weight fraction of hybrid nanofillers at different impingement angles of 30º, 60º and 90º.The erosive wear was increases linearly with increasing exposure time for pure epoxy and 2.5 (by wt.%)hybrid nanofillers composites. Whereas 0.5, 1.0, 1.5, and 2.0 by wt. %filled composites shows small incubation period, thereafter erosive wear increases linearly with time. Similarly semi-ductile erosion has been observed in 1.5 (by wt.%) nanofillers filled nanocomposites and it has been attributed to restrict the debonding of nanofillers due to homogeneous distribution and dispersion of hybrid nanofillers in the host matrix. Furthermore, the composites with 1.5 (by wt.%) exhibit better erosion resistant when compared to pure epoxy. Whereas, the 0.5,1.0, 2.0 (by wt.%)hybrid nanofillers exhibits 24%, 29% and 41% improved erosion resistance when compared to pure epoxy, respectively. The investigation clearly stated that the excessive addition of hybrid nanofillers will not improve the erosion resistance.



(a) (b)



(c)

Fig.4Weight loss as a function of exposure time and impingement angle a) 30º b) 60º c) 90º

3.3 Surface morphology of eroded surface

In general, thermoplastic matrix composites exhibit plastic deformation, ductile tearing and plugging on eroded surface due to its ductile nature. Similarly, crack initiation and propagation of lateral surface on brittle in nature of thermosetting matrix composites. The erosion behavior of composite materials depends on matrix reinforcement, dispersion in the host matrix, experimental conditions (impingement angle, erodent etc).The erosive particle hit the material surface at low angles, the impact force can be divided in to two components: one force parallel (F_P) to surface of the material and other force vertical (F_v) to the surface. The abrasive and impact phenomena controlled by F_P and F_V respectively. The parallel force F_P become marginal when the impact angle shifts towards 90º, it exhibits micro cracking and pinch hole due to impact. In the same way micro plugging and micro cuts observed in oblique angle.

In Fig.5 (a) shows the eroded surface of pure epoxy with impingement angle of 60º and an impact velocity of 70m/s. It can be seen that, when the hard erodent particle impact and penetrate the surface of the sample and it causes the material removal by micro plugging, cutting, cracking and plastic deformation, which is the dominant wear mechanism of pure epoxy. Fig.5 (b-f) shows eroded surface of hybrid nanofillers filled epoxy nanocomposites. Fig.5 (b) shows cutting and deep groove found in the eroded surface at the same time minimum level of plugging and deep holes are also found. Similarly, (Fig.5 (c)) 1.0 wt.% nanofillers filled nanocomposites exhibits localized groove on the surface due to erodent bombardments. The above morphology investigation clearly exhibit the material transformation from brittle to ductile nature due to addition of hybrid nanofillers in the pure epoxy [21]. In Fig.5 (d) the 1.5(by wt.%) fraction of hybrid nanofillers eroded surface, shows large smooth surface and small amount of crack on the surface which exhibits good erosion resistance. However, the excessive quantity of 2.0 by wt.% and 2.5 by wt.% fraction of hybrid nanofillers leads to transcrystalline and intercrystalline rupture on the surface, respectively as depicted in Fig. 5(e) and Fig. 5(f).

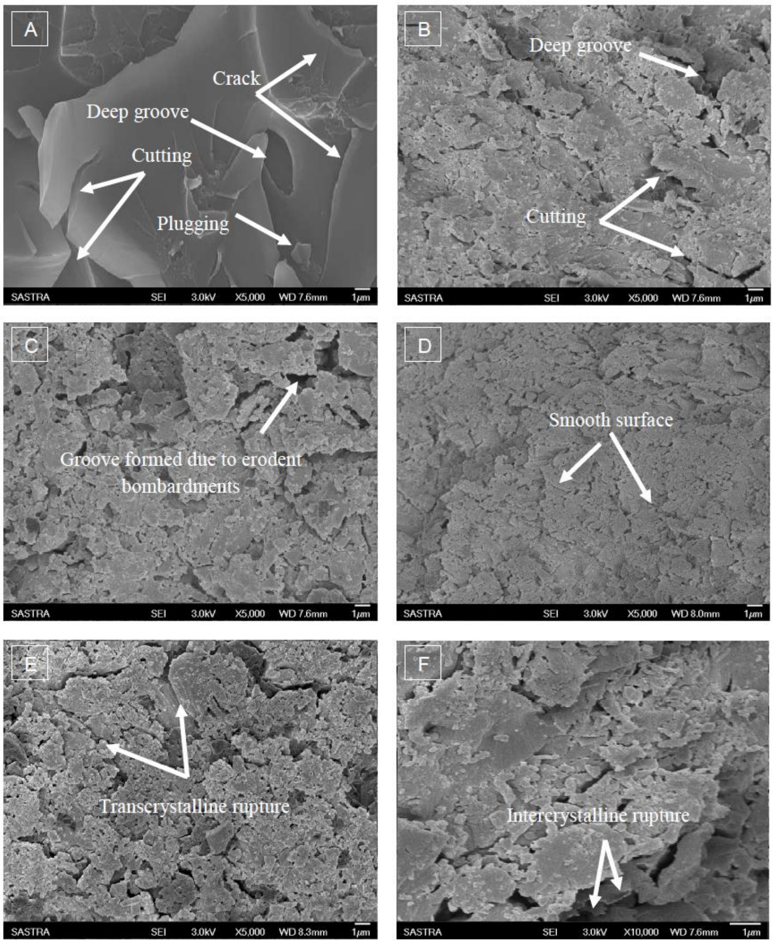


Fig.5 SEM micrographs of a) pure epoxy, b) 0.5wt.%, c) 1.0wt.%, d) 1.5wt.%, e) 2.0wt.% and f) 2.5wt.% of hybrid nanofillers filled nanocomposites eroded with silica sand particle size=100±20µm; v = 70 m/s; exposure time = 5 min; impingement angle = 60º;

4. Conclusion

The following conclusions are drawn based on the erosion characteristics of MWCNTs-Al_2O_3 hybrid nanofillers composites:

Inclusion of hybrid nanofillers in the pure epoxy with the considerable quantity will improve the erosive properties. The erosive wear of 1.5 by wt. % hybrid nanofillers filled epoxy composites recorded lower erosive rate compared to host matrix.

The material erosion mechanisms are in close relationship with the impingement angles. Semi-ductile erosive wear was observed in 60º impingement angle and the erosion efficiency varies from 24% to 60%.

The morphology of eroded surfaces observed by FESEM, confirmed that the overall erosion is characterized by cracking, cutting, plugging, transcrystalline and intercrystaline rupture.

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