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Erosive Wear Behavior of Nanoclay Filled Basalt - Epoxy Hybrid Composite

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Abstract: *Developments of nano clay particle reinforced plastics are of growing interest towards the emergence of new materials which enhance optimal utilization of natural resources and particularly of renewable resources. The effects of nano clay as filler in Basalt–epoxy composite systems on the tribological properties have been discussed in this article. Basalt fiber reinforced epoxy (BE) composite finds widespread application in erosive environment due to its several advantages like high wear resistance, high strength-to-weight ratio and low cost. Experiments were carried out to study the effects of impingement angle, particle velocity and filler material on the solid particle erosive wear behavior of BE composite. The erosive wear is evaluated at different impingement angles from 30° to 90° at three different velocities of 23, 42, & 60 m/s. The erodent used is silica sand with the size range (150 – 280 µm) of irregular shape. The result shows semi-ductile behavior with maximum erosion rate at 60° impingement angle. It is observed that wear rate increases with increasing particle velocity and decreases with increases of filler percentage. The morphology of the eroded surfaces was examined by using Scanning electron microscopy (SEM).*

Keywords: *Erosive wear, Basalt Fabric, Nanoclay, Vacuum Assisted Resin Infusion Technique, Wear Mechanism.*

I. INTRODUCTION

In the fast growing field of nanotechnology, polymer nanocomposites have become a prominent area of current research and developments. Considerable interest is being shown in the use of composite for high technology engineering components in such applications as wind mill blade, pipelines carrying sand slurries, petroleum refining, aircraft gas turbine compressor blades, radomes etc. All these applications may involve impingement by solid particles. Knowledge of impact and erosion behavior is necessary before composite can be used with confidence in these systems. It has been shown that dramatic improvements in mechanical properties can be achieved by incorporation of a few weight percentages (wt %) of inorganic exfoliated clay minerals consisting of layered silicates in polymer matrices.[1-3] Three main types of structures can be obtained when layered clay is associated with a polymer: (i) a phase-separated structure, (ii) an intercalated structure and (iii) an exfoliated or delaminated structure.[4-5] When the polymer is unable to intercalate (or penetrate) between the silicate sheets, a phase-separated composite is obtained and the properties stay in the same range as those for traditional microcomposites. In an intercalated structure, where a single extended polymer chain can penetrate between the silicate layers, a well-ordered multilayer morphology results with alternating polymeric and inorganic layers. An exfoliated or delaminated structure is obtained when the silicate layers are completely and uniformly dispersed in a continuous polymer matrix. When the filler has nanometer thickness and high aspect ratio (30–1000) plate-like structure, it is classified as layered nanomaterial (such as organo-silicate) [6]. In general, nanomaterials provide reinforcing efficiency because of their high aspect ratios [7]. 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. Nanocomposites are named when the dispersed phase particle size is less than 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. Visualizing the importance of polymer composites lot of work has been done by various researchers [8-9] to evaluate the erosion resistance of various types of polymers and their composites to solid particle erosion. Most of these workers have carried out wide range of thermo sets and thermoplastics polymer composite with synthetic fibers like glass, carbon, graphite and Kevlar. However there is no information available on erosive wear behavior of basalt fiber reinforced composite. The goal of this study is to improve the wear properties of Basalt-epoxy composites by incorporation of nanoclay. For this purpose, Basalt-epoxy composites containing various loading of clay was produced by VARI technique followed by thermal curing. In order to improve the dispersion and exfoliation of the Clay in the epoxy matrix, both sonication and mechanical stirring techniques were used together. It is believed that Nanoclay can improve the modulus, strength and impact properties of the Basalt-epoxy composites profoundly, provided that well exfoliated structure and good interfacial bonding can be achieved. In this study, erosive wear behavior of the Basalt-epoxy composites were characterized and discussed.

II. EXPERIMENTAL DETAILS

2.1 Material Used

Basalt woven fabric 360 g/m2 obtained from M/s. APS Austria. The basalt fabric diameters 18 μm was used as reinforcement. Multifunctional epoxy-Bisphenol A-epichlorohydrin (MY 740) and cyclo aliphaticamine (HY 951) (room temperature cure system) were obtained from M/s. S& S POLYMERS, Bangalore, India. The resin is a clear liquid, its viscosity at 250C is 10000– 14500 mPa s and density is 1.15-1.20 gm/cc. The hardener is a liquid and its viscosity is 50–80 mPa s and specific gravity is 1.59. The commercially available Nano clay powder was procured from M/s Sigma Aldrich, Bangalore, India.

2.2 Fabrication of Composite Specimen Material

The composite fabrication consist of mixing of the epoxy resin and filler using a mechanical stirrer, mixing of the curing agent with the filled epoxy resin, fiber impregnation and consolidation and curing of fabricated composites. In the first step a known quantity of filler was mixed with epoxy resin using a high speed mechanical stirrer to ensure the proper dispersion of filler in the epoxy resin and the hardener was mixed into the filled epoxy resin using a mechanical stirrer and then an ultrasonic mixing was used to distribute various content of nanofillers in epoxy resin. The ratio of epoxy resin to hardener was 100:30 on weight basis. The composites were fabricated using the VARI process as described elsewhere [10]. Fig1. shows schematic representation of VARI. Basalt fabrics were cut into required dimensions. A granite mold was used for the fabrication. Granite mold was cleaned by using an acetone and it is pre-coated with a releasing agent (suitable wax) to facilitate easier removal of the part from the mold. The basalt fabrics are placed on a granite mold. On the top layer of the basalt fabrics, a peel ply (porous teflon film) and breather were placed. This peel ply enables separation of the part from the vacuum bag and breather ensures uniform distribution of vacuum. A two sided insulated tape (acts as a sealant) was placed all around the fabrics at a distance of about 75 mm around the perimeter of the mold, an open spiral tubes were attached and connecting to a vacuum pump, which acts as a air channel from inside the mold when vacuum is applied. Air is evacuated by a vacuum pump and maintained at 0.0965Mpa of pressure, and a low viscosity epoxy resin is infused into the lay-up to impregnate the fabrics. once the layers were wet with resin system, the vacuum bagging was removed. The entire assembly was again covered with vacuum bag with a new peel ply and breather and allowed to cure under vacuum at 0.0965Mpa of pressure at room temperature up to 24 h. To improve the consolidation and reduces the voids and dry spots, the epoxy resin was injected into the mould before going into VARI. Finally the panels were post cured at 100^0C for 3 h in a controlled oven.

The details of the composites are provided in Table 1.The laminate of dimensions 300 mm x 300 mm x 2.6 ± 0.2 mm was fabricated. The specimens for the required dimensions of 30mm X 30mm were cut using a diamond tipped cutter. Density of the composite specimens was determined using a high precision digital electronic weighing balance of 0.1 mg accuracy.

2.3 Testing

The method used is the one involving dry and compressed air accelerating the solid particles to strike the surface of specimens. (as in Fig. 2) which was designed for the tests consists of main reservoir, pressured particle tank, universal valves, pressure indicator, flow control and pressure regulators, nozzle, specimen holder, recycling box and a compressor. The particles impact velocities used in the tests (23, 42 and ≈60 m/s) were adjusted by using the double disc method in which two discs were connected to a common shaft from a driving prime mover [11]. The impingement angle, one of the most important parameters affecting solid particle erosive wear was varied by turning the test specimen holder around its own axis, in addition, moving the specimen holder up and down to adjust the standup distance. (Between the nozzle and the test specimen).

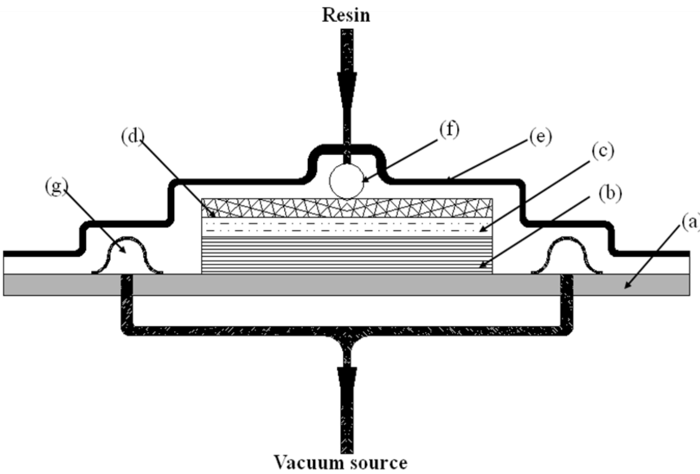


Fig. 1 Schematic of VARTM setup (a) Granite molding tool, (b) Dry Basalt fabrics, (c) peel ply and breather material (d) distribution medium, (e) Vacuum bag (f) resin inlet (g) vacuum outlet.

Table1. Formulation of composite specimen with measured density

Materials	Sample code	Matrix (Wt.%)	Filler (Wt.%)	Density (gm/cc)
Basaltfibre-Epoxy composite	BE	40	-	1.987
1% clay filled Basalt -Epoxy Composite	1CL-BE	39	1	1.976
2% Clay filled Basalt -Epoxy Composite	2CL-BE	38	2	1.947
3% Clay filled Basalt -Epoxy Composite	3CL-BE	37	3	1.914

The solid particle erosion experiments were carried out as per ASTM-G76 standard on the erosion test rig. The silica sand of size 150–280 μm is used as erodent. The normalized erosion rate (Ws) was expressed in terms of equation (1):

$$W_S = \frac{Wc}{W_{Er}}\ gm/gm \qquad (1)$$

Where Wc is the loss in weight of the composite material and W_{Er} is the total weight of erodent used for erosion of each specimen. Wc is determined by weighing the sample before and after the erosive wear test using a digital electronic balance, 0.1 mg accuracy. Each erosive wear test was performed twice and average values for wear loss were calculated. The experimental details are presented in TABLE 2.

The graphical plots of erosion rate versus impingement angles at two different velocities of filled and unfilled composite systems are shown in Fig. 3.

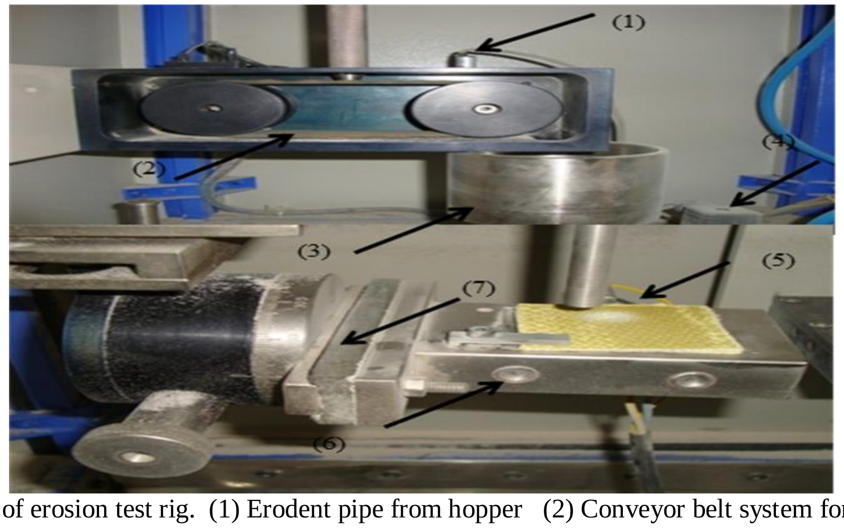


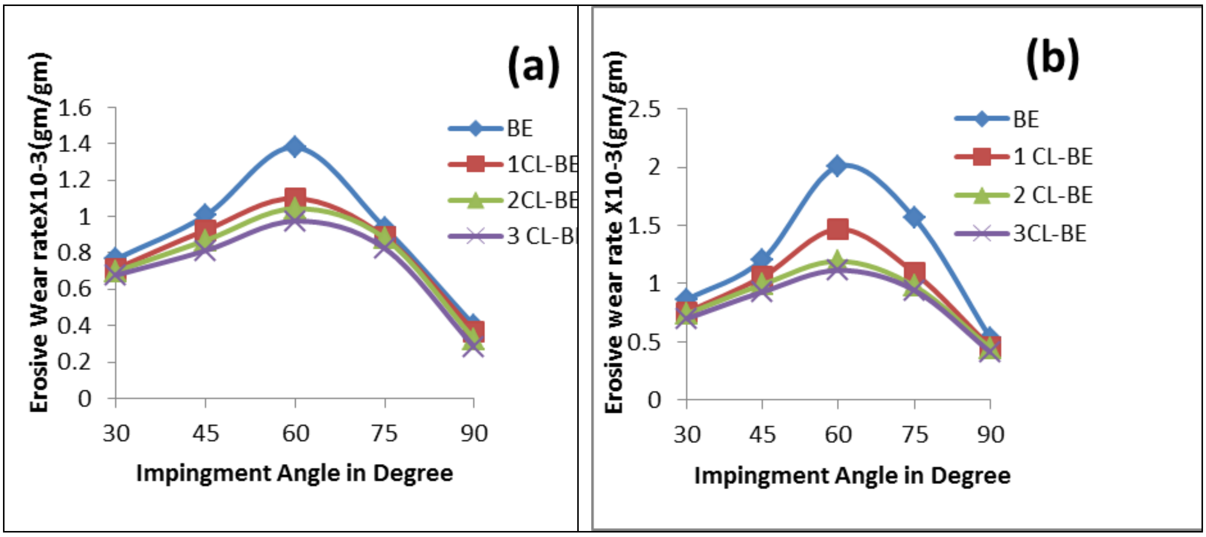
Fig.2 Details of erosion test rig. (1) Erodent pipe from hopper (2) Conveyor belt system for sand flow (3) Particle -air mixing chamber (4) Pressure transducer (5) Nozzle (6) X-Y and axes assembly (7) Sample holder.

Table.2 Erosion Test condition

Test parameter	
Erodent	Angular silica sand
Erodent size(µm)	150-280
Impingement angle (degree)	30, 45, 60, 75 & 90
Impact velocity (m/s)	23, 42, & 60 m/s
Erodent feed rate(gm/min)	5.5
Test Duration(min)	3
Test temperature	RT
Nozzle to sample distance(mm)	10
Nozzle diameter (mm)	3

III. RESULTS AND DISCUSSION

The Impingement angle is one of the important parameters for the erosive wear behavior of composite materials. Dependence of erosion rate on the impingement angle is largely determined by the nature of the target material and other operating conditions. In the literature, materials are broadly classified as ductile or brittle, based on the dependence of their erosion rate with impingement angle. The ductile behavior is characterized by maximum erosion rate at low impingement angle i.e. typically in the range of (15° -30°). On the other hand, if the maximum erosion rate occurs at normal impact (90°) then the behavior of material is purely brittle mode [12]. Fig. 3 shows the effect of impingement angle on erosion rate of composites with and without nanoclay fillers. From fig.3, it is observed that the peak erosion rates are observed at an impingement angle of 60° for all composite samples. This shows semi-ductile erosion response for the basalt fiber reinforced composites. Minimum volume loss was observed at an impingement angle of 90◦ and lower erosion rate was observed. At this juncture, the authors are pleased to quote the research work of Hager et al. and Mohan.et al [13-14] stated that no fixed trends are available which correlate ductility and brittleness of materials and maximum or minimum angle of impingement. Some polymers erode in ductile manner some other are shows the both ductile and brittle nature. As compared to unfilled composite, nanoclay filled composite shows minimum erosion rate at all experimental conditions.



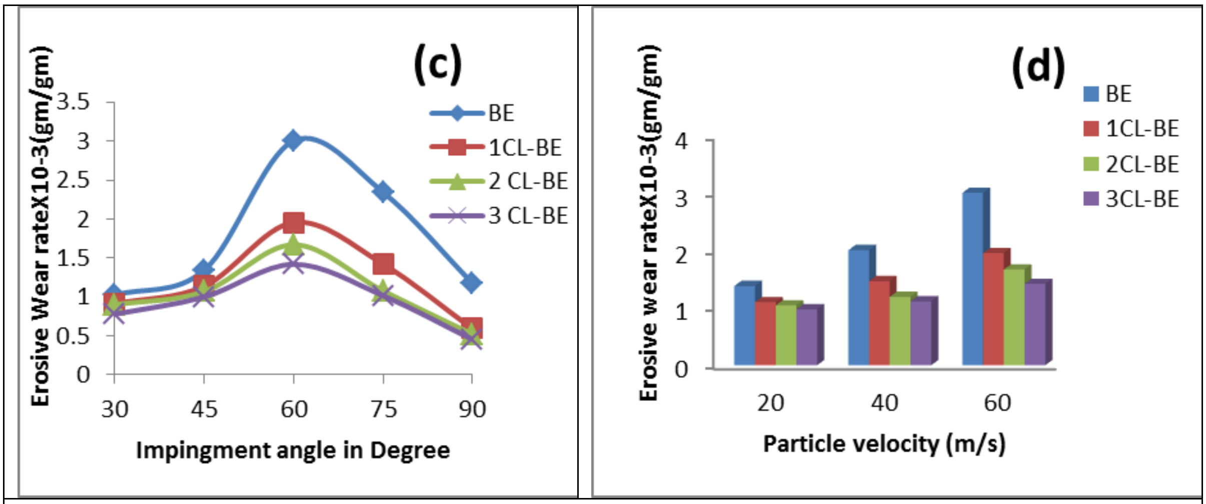
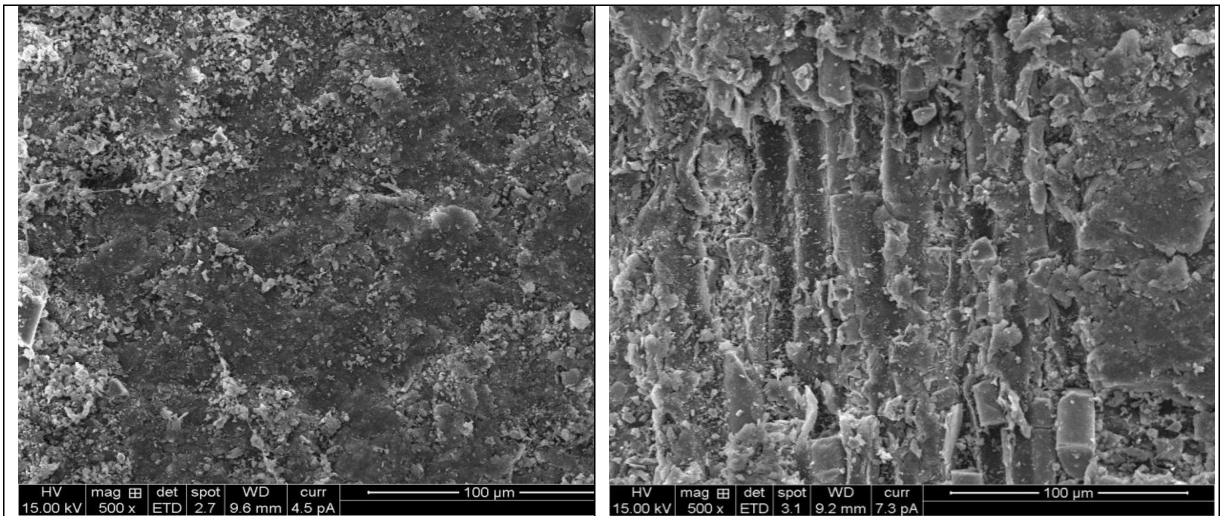


Fig.3: Erosion Rate versus Angle of Impingement for the composite at (a) 23 m/s, (b) 42 m/s (c) 60 m/s and (d) Variation of Erosion Rate as a function of Impact Velocity at 60° Impingement Angle.

Worn Surface Morphology

To identify the mode of material removal, the morphologies of eroded surface are studied under scanning electron microscope. Fig. 4(a) shows a portion of the composite after erosion occurred. It shows good bonding of nanoclay particulate with epoxy and basalt fiber. At a velocity of 23m/s and at an impingement angle of 60°, matrix removal was observed.

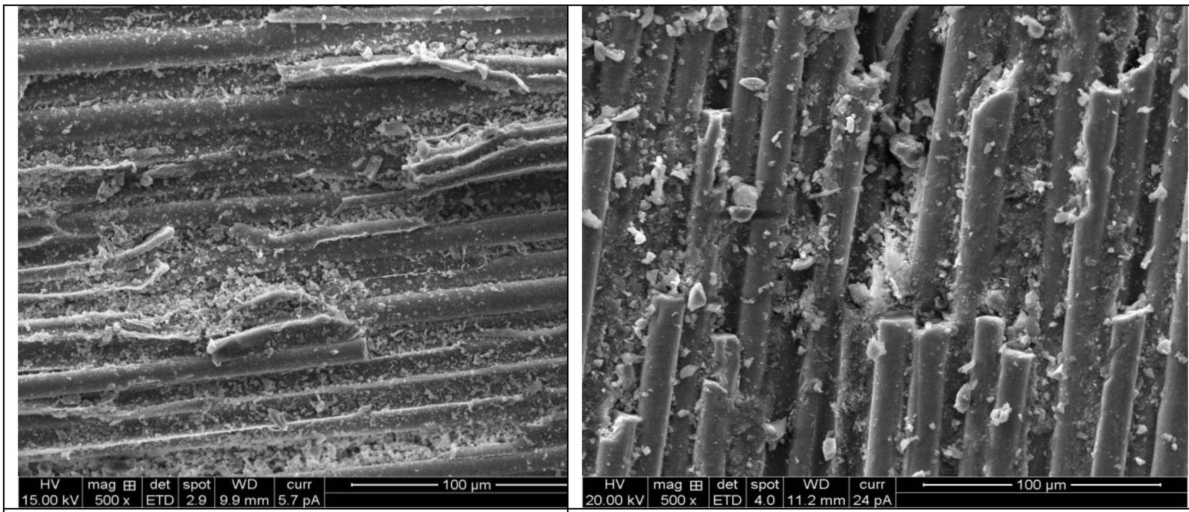
Fig. 4(b) shows the worn surface of BE composite, it can be seen from the micrograph that, when impacting at angles, the hard erodent particles can penetrate the surfaces of the samples and cause material removal by fiber cutting and removal of fibers are seen. It indicates plastic deformation and micro cracking as the dominant wear mechanisms. Repeated impact of the erodent caused roughening of the surface of the material and cutting with chip formation is reflected in Fig. 5(b). Erosion along the fibres and clean removal of the matrix to expose glass fibers and breakage is also seen, the matrix shows multiple fractures and material removal. The exposed fibres are broken into fragments at some points along with some amount of cavitations and thus can be easily removed from the worn surfaces



(a) Filled	(b) Unfilled

Fig. 4: SEM Images of Eroded Surfaces at a velocity of 23 m/s at 60° Impingement angle.

Fig.5(a) shows the removal of matrix material is observed with greater degree of severity as compared to Fig.4(a). Fiber breakage is more in this case because of the higher magnitude of the impact velocity. Fig.5(a) shows the good bonding of matrix and fibre because the nano clay restricts the debonding of materials even at higher velocity.



(a) Filled | (b) Unfilled

Fig. 5: SEM Images of Eroded Surfaces at a velocity of 60 m/s at 60° Impingement angle.

IV. CONCLUSION

- Addition of nanoclay in B-E composite shows minimum erosion rate as it restricts the fiber–matrix deboning, without any filler shows highest erosion rate due to weak bonding strength and has adequate potential for tribological applications.
- Influence of the impingement angle on erosive wear of all composites under consideration exhibits semi-ductile behavior with maximum erosion at 60° impingement angle.
- SEM studies of worn surfaces support the wear mechanisms involved and indicated pulverization of wear debris, exposure of fibers, micro-cutting, crushing of fibre and cavities due to detachment of broken fibers from the resin matrix and cracks at higher particle velocity.

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