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Tribological properties of natural fiber hybrid reinforced polymer composite

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Abstract: In present scenario natural fibers are abundantly being utilized for production and improvement of composites with polymer matrices. In the present work produced mat/woven structure of Luffa cylindrica (loofah), coconut coir (medially coarse and fine) particulates and short bagasse fibers from the rind of sugarcane were utilized to form hybrid polymer composites with epoxy matrix. The fabrication was done with mercerized natural fibers in epoxy matrix by hand-layup technique. Experiments were conducted to examine erosive wear properties of fabricated composites using an air-jet erosive wear tester at room temperature. A steam of silica sand is chosen as the erodent striking the composite specimens with different impact velocities and pressures for an exposure period of 10 minutes. The erodent geed rate is kept constant. The impingement angle is set at 300, 450, 600 and 900. The erosion rate was calculated in each case to study their tribological properties.

Keywords: Loofah, coir, bagasse, epoxy, hand lay-up, erosion.

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1. Introduction: 'Wear' is related to mechanical, chemical and thermal interactions between two dynamically interacting mating solid surfaces that may lead to progressive loss, damage, deformation, alteration in shape, size and geometry of the surface and material as a whole. Wear may be abrasive, adhesive, fretting, fatigue, corrosive, erosive or reciprocating type **[1-2]**. Erosion wear is the removal of materials caused by impact of erodent with the materials surface carried in gas as the erodent carrier medium known as solid phase erosion or in liquid as carrier medium known as slurry erosion in a repetitive manner. Erosion wear is a widely encountered problem in industries such as the erosive wear in piping and pumping equipment associated with the movement of slurries, wind shields, desert structure and housing **[3]**.

Solid particle erosion is the removal of materials due to wallop of solid state particles impinging on another solid surface with significant velocity. In certain cases this can be considered advantageous as in abrasive jet machining where materials are needed to be removed from surface but in majority of cases it adversely affects performance of many engineering systems such as turbines, pipes or tubes carrying particles, etc. Solid state particle erosion occurs in two phases: in the first phase or primary process, there is a mechanical impact between erodent and targeted surface and in the second phase or secondary process, physical, chemical and thermal aspects of impact are involved **[4]**.

1.1 Erosion in Natural Fiber Reinforced Composites: Though the erosive wear mechanisms in traditional fiber polymer matrix composites have been described in various studies, lesser work has been done to study the solid particle erosive wear study of composites with natural fiber reinforcements **[3]**. The erosion mechanisms causing material removal in composites depends on the type of polymer matrix and nature of natural fiber reinforcements.

Wear resistance properties of composites with Luffa cylindrica fiber in epoxy matrix depicted semi-ductile nature of erosive wear at 45^0–60^0 impact angles which decreased with higher velocities of impact **[5]**. Erosion rate in bagasse reinforced composites accelerated with higher impact velocities and angles up to 90^0, indicating brittle mode of erosion wear. SEM analysis shows that pulverization of fiber is the dominant erosion mechanism in bagasse fiber reinforced composites **[6]**. In bio-waste reinforced composites such as coir dust fiber reinforced polymer composites, it was discovered that the rate of wear caused by erodent diminished with rise in the concentration of coir dust. The erosive wear mechanism is dominated by the softer fiber content compared to the harder polymer matrix material. The rate of material removal due to erosive wear mechanisms progresses with greater impact angles and also with greater impact velocities. Peak value of erosion rate attained at 90^0 impact angle denotes failure due to brittle mode. This may be due to increase in the tangential component of the impact force **[7]**.

Studies on erosive wear behavior of hybrid four ply woven jute (J) and glass fiber (G) reinforced laminated composite in J-J-G-J, J-J-G-G, J-G-J-G, J-G-G-J stacking order depicted semi ductile mode of failure with peak of erosion occurring at an impact angle of 45^o. J-G-G-J stacking sequence of fibers in epoxy based hybrid composite offered maximum erosion resistance at all velocities **[8]**. The interesting feature is that the composites containing only natural fiber may acquire paramount rate of erosive wear at 45^o, 60^o, 75^o or 90^o impact angles whereas hybrid composites containing combination of natural fiber and traditional fiber typically obtain it at 45^o and 90^o impingement angles. Thus maximum erosion rate in any composites takes place at lower impingement angle if abrasive wear is the prominent mechanism in material removal process. While if the kinetic energy of erodent is more prominent to material removal process, normal impact at 90^o causes erosion rate to be highest **[3]**.

2. Experimental

2.1 Materials: Three types of natural fiber reinforcements are used in the present study.

1) Hoop wall of Luffa which is in an intermingled mat form obtained from Luffa cylindrica plant of genus Luffa of Cucurbiteceae family,
2) Short fiber (≥ 9.18 mm) of dried sugarcane rind (bagasse) fiber such that the fiber does not fail during fiber pull out test,
3) Coir dust in coarse form with high fiber content as particulate reinforcement.

Polymer matrix to hold the fiber reinforcements was prepared with Epoxy LY 556. Its IUPAC name is 2-(chloromethyl)oxirane; 4[2-(4-hydrxyphenyl)propan-2-yl]phenol. Low viscosity aliphatic amine TETA (triethylene tetraamine), HY 951 served as hardener. It bears IUPAC name as N,N'-Bis(2-aminoethyl)ethane-1,2-diamine.

2.2 Chemical Treatment: Natural fibers before its use as reinforcement for polymer composites are chemically treated to reduce their hydrophilicity. The polymer matrices being generally hydrophobic reduce the wetting of fibers as well as fiber and matrix bonding at their interface. Therefore, treating with chemicals has been found to enhance the mechanical along with tribological properties of natural fibers in polymer matrices **[9]**.

Reinforcing fibers in the present study were treated with 5 % sodium hydroxide solution in room temperature for a period of four hours in a fiber to NaOH solution ratio of 1:15. This process is known as mercerization. These treated fillers were cleaned many times using distilled water to remove the sticking NaOH onto them and a neutral pH of 7 is obtained. It may be washed with acetic acid if required. The fibers thus obtained after the above process was dried in open air followed by drying in an oven at 60 ^{0}C were then ready to be used as reinforcement in epoxy matrix.

2.3 Fabrication of Composite: Hand layup method was utilized for preparing these natural fiber reinforced composites. Matrix was formed by thoroughly mixing ten parts of epoxy LY 556 resin with one part of hardener HY 951 by weight. The following composites were fabricated by reinforcing the mercerized fibers in the polymer matrix in the wooden molds: (a) luffa mat composite represented as L; (b) 20 wt. % bagasse composite- B; (c) 10 wt % coir dust composite- C; (d) 5 wt % coir and 5 wt % bagasse hybrid composite- CB; (e) 10 wt % bagasse layer between two luffa layers- LBL; (f) 5 wt % coir layer between two luffa layers- LCL; (g) 5 wt % coir and 5 wt % bagasse mixed layer between two luffa layers-L(CB)L. Epoxy cures at room temperature between 24 - 48 hours. This arrangement is kept under load to remove the entrapped air. Then the wooden molds were broken to obtain the fabricated composites.

2.4 Hardness Testing: Micro-hardness of the samples was determined on a German made Vickers hardness tester. Under a load a diamond indenter is forced into the material. The indents left by diagonals d_1 and d_2 was measured (in millimeters) on the surface of the material after the load has been removed. Vickers Hardness Number is given by:

$$\text{Vickers Hardness, } H_v = (2F\sin((136°)/2))/d^2$$

where, Load, F = 0.3 Kg F;

$$d = (d_1 + d_2)/2$$

2.5 Erosive Wear Test: The composite samples were cut in sizes of (20 x 20 x 4) mm^3. The erosion studies (solid particle erosion) on the composite sample were conducted on an Air- Jet erosion tester according to ASTM G76 standard. In this arrangement silica sand of appropriate size were mixed with pressurized air supplied from air compressor and this jet was targeted onto the test samples.

The erodent particles impact the composite specimens at angles of 30^o, 45^o, 60^o and 90^o. The testing conditions for erosion of different composite samples fabricated are tabulated in table (1) below:

Table 1: Experimental conditions

Erodent	Silica sand
Erodent Size	(200 ± 50) µm
Impact angle	30^o , 45^o, 60^o and 90^o
Impact velocity	48 m/s, 70 m/s, 82 m/s
Pressure	1 bar, 2 bar, 3 bar
Erodent feed rate	0.552 ± 0.02 gram/min
Temperature	Room Temperature
Stand-off distance	10 mm
Time	10 minutes

Test samples were first wiped with acetone and then dried. The samples weights were noted down before as well as after conducting the erosion tests. Rate of erosive wear was evaluated by using the following equation:

Erosive wear rate, $E_R = \Delta W/W_e$

where, ΔW corresponds to the loss in mass of specimen after erosive wear (in grams); W_e correspond to mass of erodent calculated as product of erodent flowing (testing) time and rate of erodent feed.

3. Results and discussion

3.1 Hardness: Surface hardness is a predominant factor affecting erosion resistance of any composite. Incorporation of bamboo fiber **[10]** and increasing the bamboo fiber content **[9]** in bamboo epoxy composites increases its hardness since hardness depends on amount of fiber content and its modulus **[11]**. The Vickers hardness of the different composites is plotted in the graph in Figure (1).

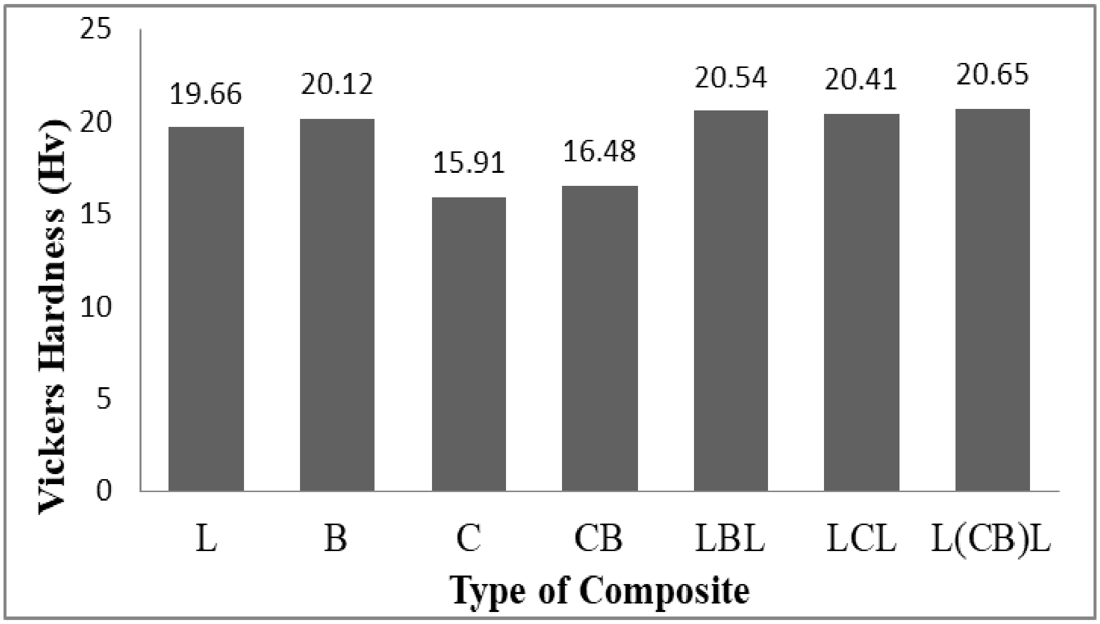

Figure (1): Hardness graph of various fabricated composites.

Similar results were obtained in several other studies **[5-6, 12-13]**.

3.2 Erosion Rate: Rate of erosive wear increases with an increase in striking speed of erodents. This is because when speed is very low, stresses due to impact are insufficient to cause plastic deformation and wear proceeds by surface fatigue. But when speed increases, the eroded material deforms plastically on particle impact. Due to this plastic deformation more amount of material removal takes place **[9]**. Also with increase in impact velocity, increased penetration of particles occurs due to larger quantities of thermal energy dissipation onto the target surface causing more damage to the surface, increased subcritical crack growth and therefore reduce resistance to erosion **[14]**.

Rate of erosive wear (E_R) versus impact angle graph the composite samples for various velocities of impact is illustrated in Figures (2), (3) and (4) below.

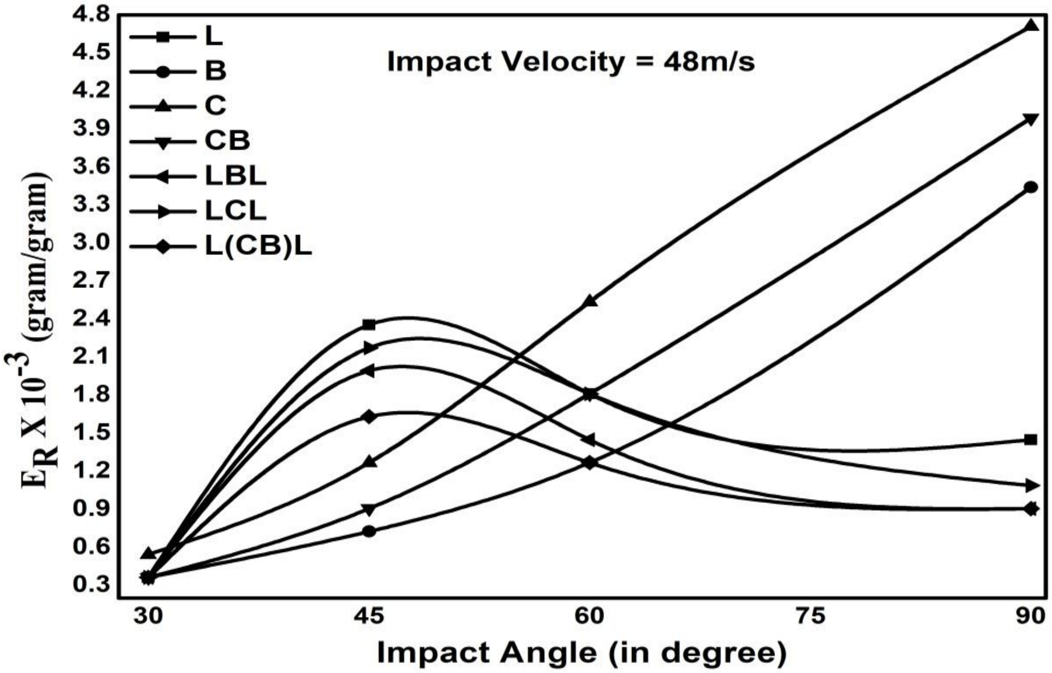

Figure (2): Plot of E_R versus Impact angle for impact velocity of 48m/s.

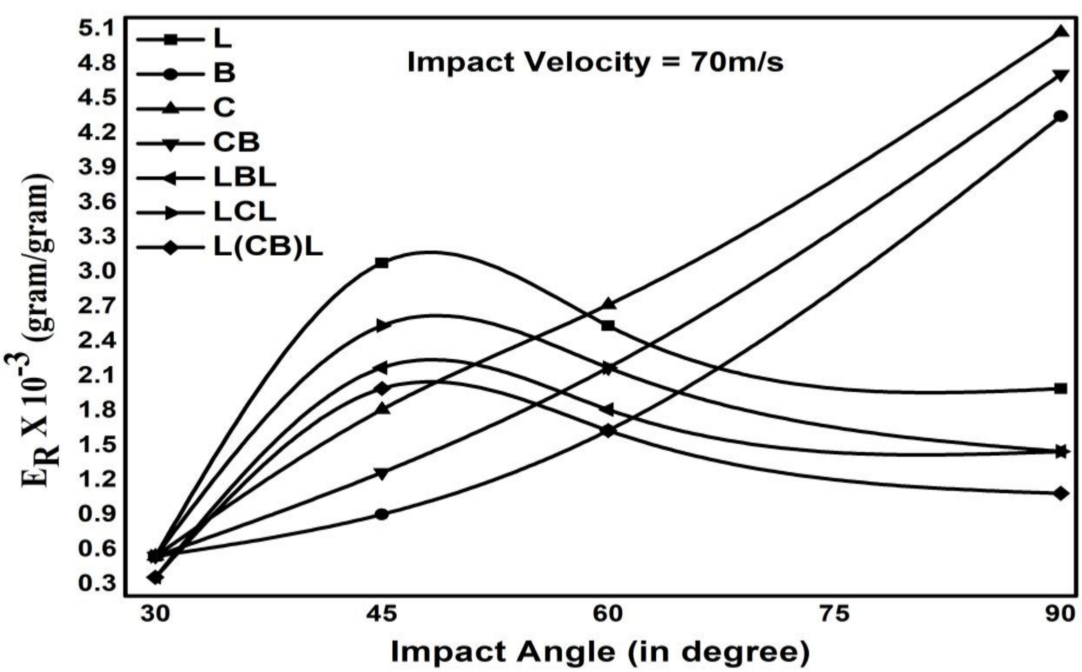

Figure (3): Plot of E_R versus Impact angle for impact velocity of 70m/s.

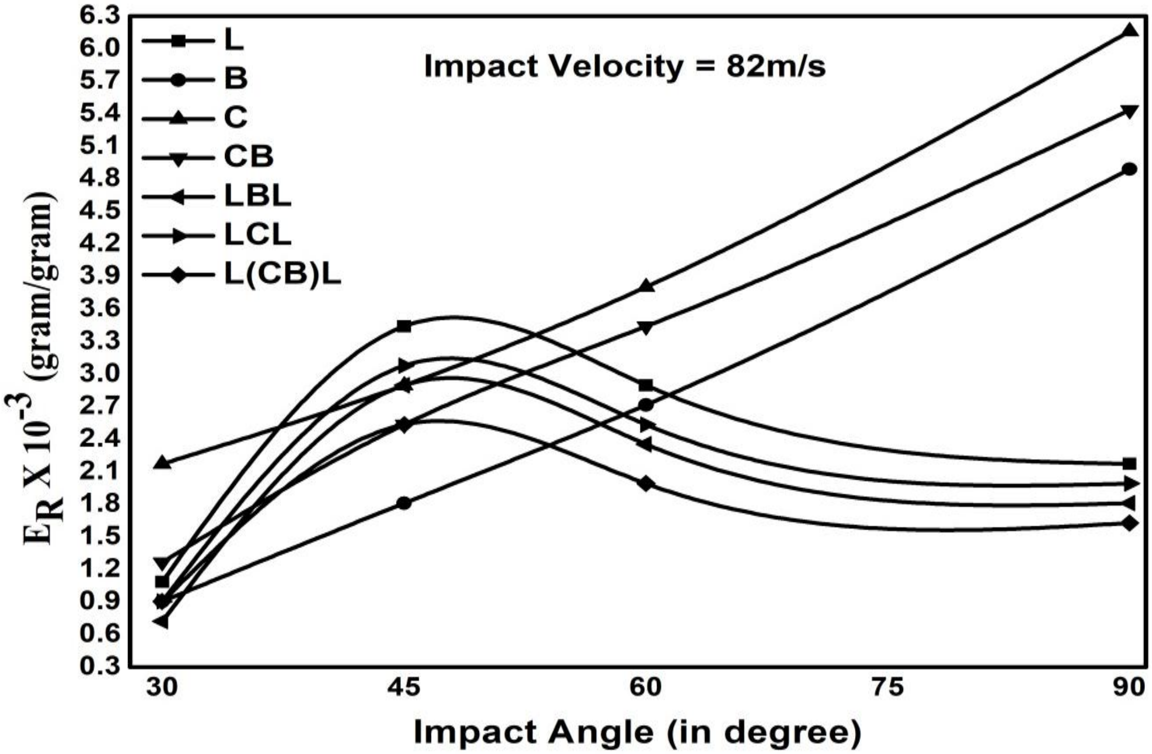

Figure (4): Plot of E_R versus Impact angle for impact velocity of 82 m/s.

It was observed that bagasse and coir dust composites depict brittle behavior (maximum erosion occurring at $\alpha = 90^0$) while luffa and hybrid composites with first layer as luffa fiber, which encounter the solid impacting particles illustrate a semi ductile type of behavior (maximum erosion occurring at $\alpha = 45^0$-60^0). Similar results were obtained by several researchers examining tribological properties of natural fiber composites such as Mohanta et al. **[5]** for Luffa cylindrica; Mishra et al. **[6]** for bagasse; and Aireddy et al. **[7]** for coir dust polymer matrix composites.

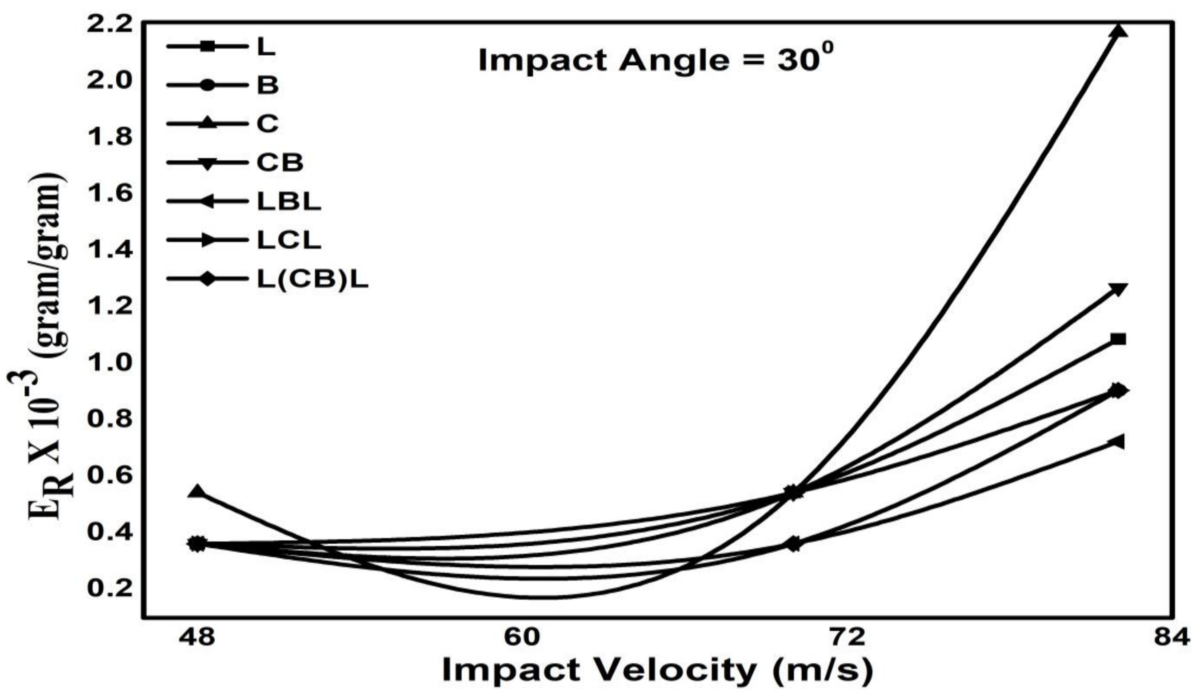

Figure (5): Plot of E_R versus Impact velocity for $\alpha = 30^0$.

The plot between erosion rate (E_R) versus impact velocity graph for various composite samples for various impact angles is depicted by graphs in Figures (5), (6), (7) and (8) below.

The demarcation between brittle behavior of coir and bagasse (and their hybrids) composites and luffa and its hybrid composites is well depicted in Figure (8).

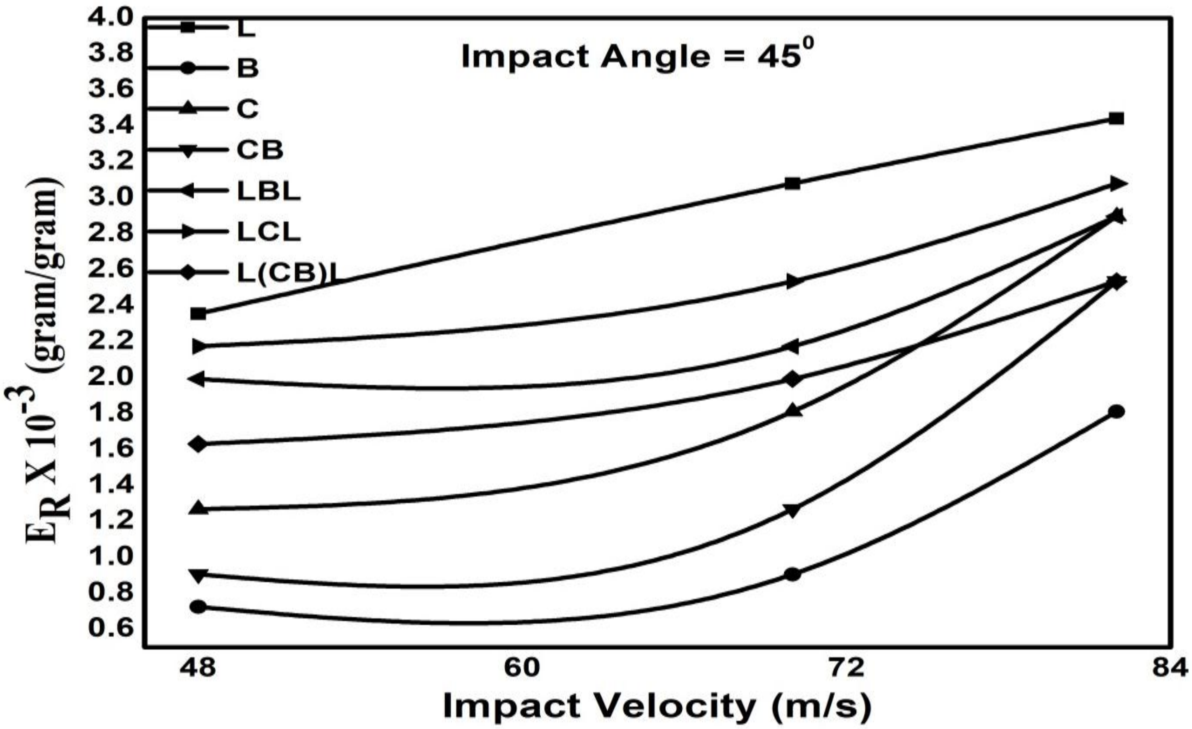

Figure (6): Plot of E_R versus Impact velocity for $\alpha = 45^o$.

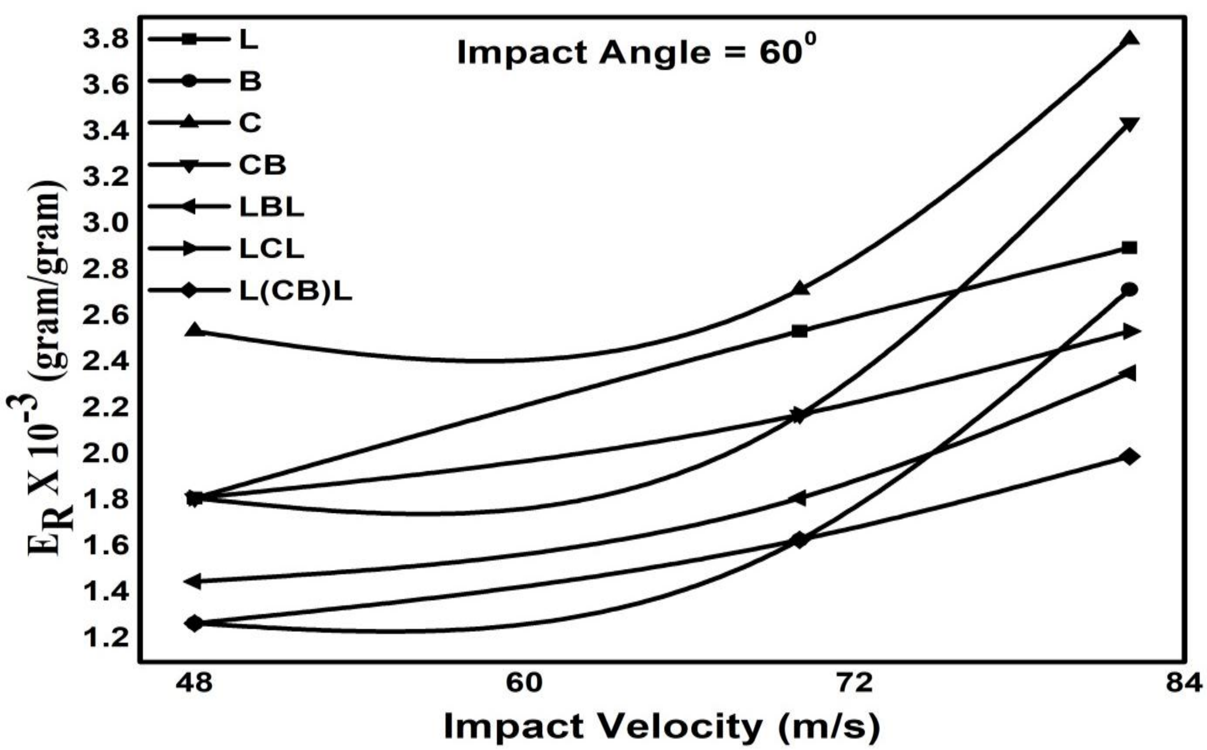

Figure (7): Plot of E_R versus Impact velocity for $\alpha = 60^o$.

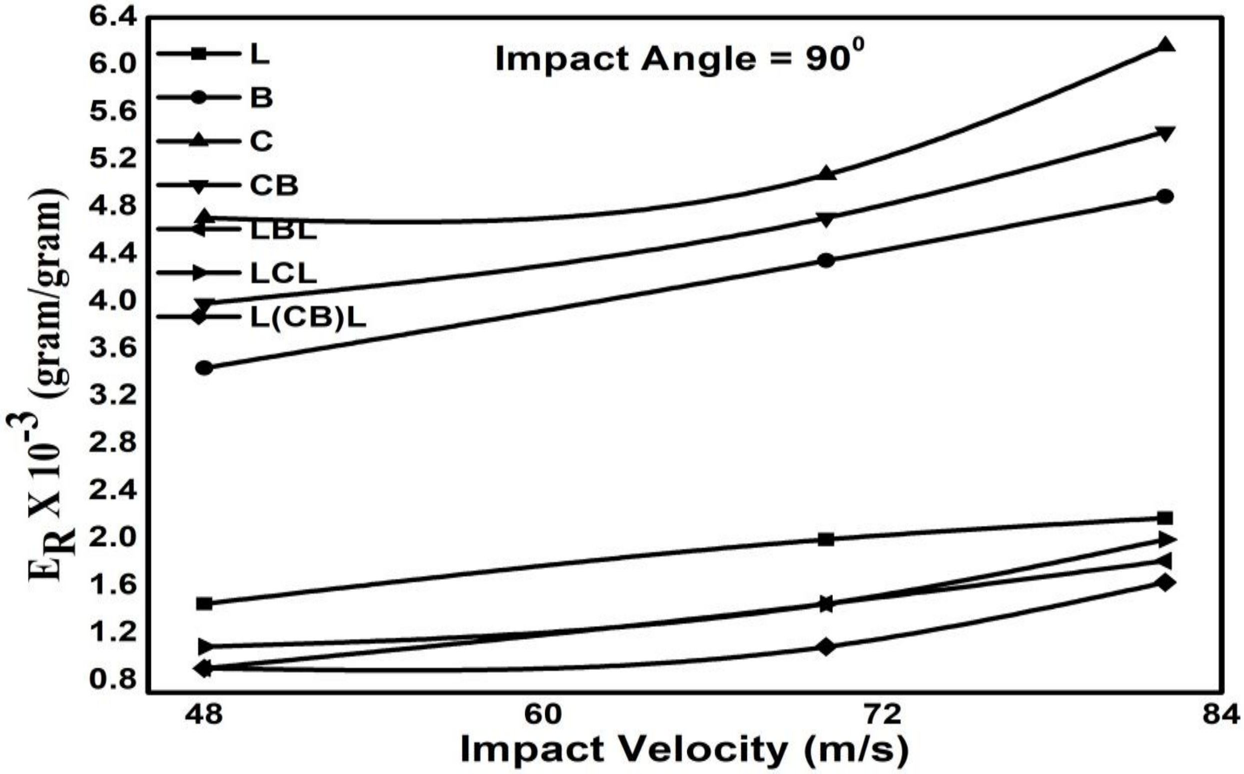

Figure (8): Plot of E_R versus Impact velocity for $\alpha = 90^o$

3.3 SEM Analysis: After experimentation, SEM analysis was carried out to find out wear mechanisms occurring during material removal process in the composites. The eroded surfaces were made conductive for enhanced viewing by coating a thin gold film on to them. Figures (9) and (10) show the SEM micrographs of L and LCL composites respectively eroded at 45^0. More erosion wear occurs in L-composite than in LCL- hybrid composite. The micrographs indicate the degradation in fibers during erosion caused by their breaking and micro-cutting.

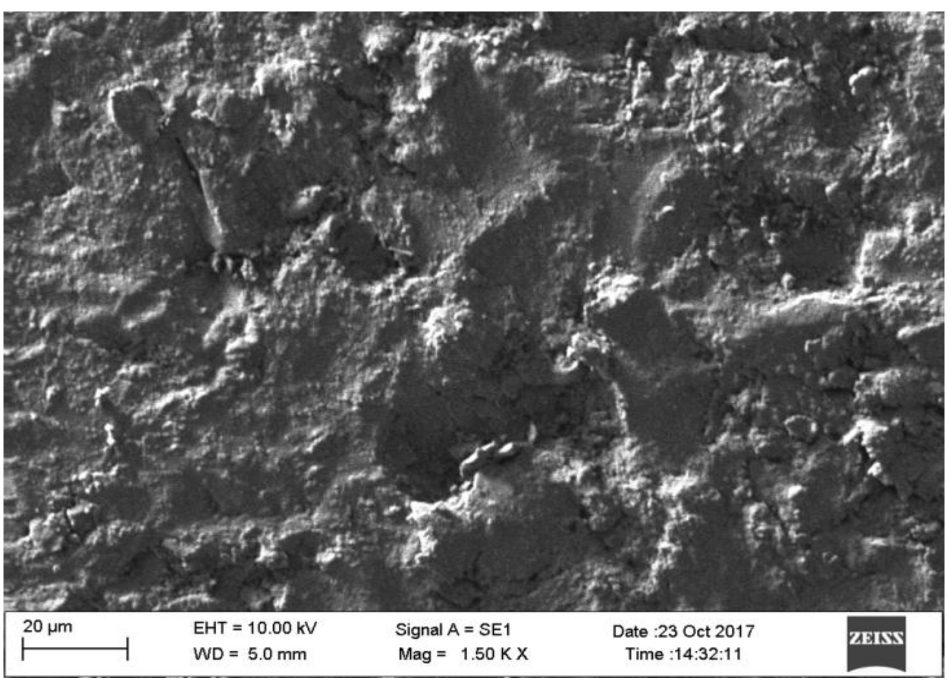

Figure (9): SEM micrograph of surface of L- composite after erosion.

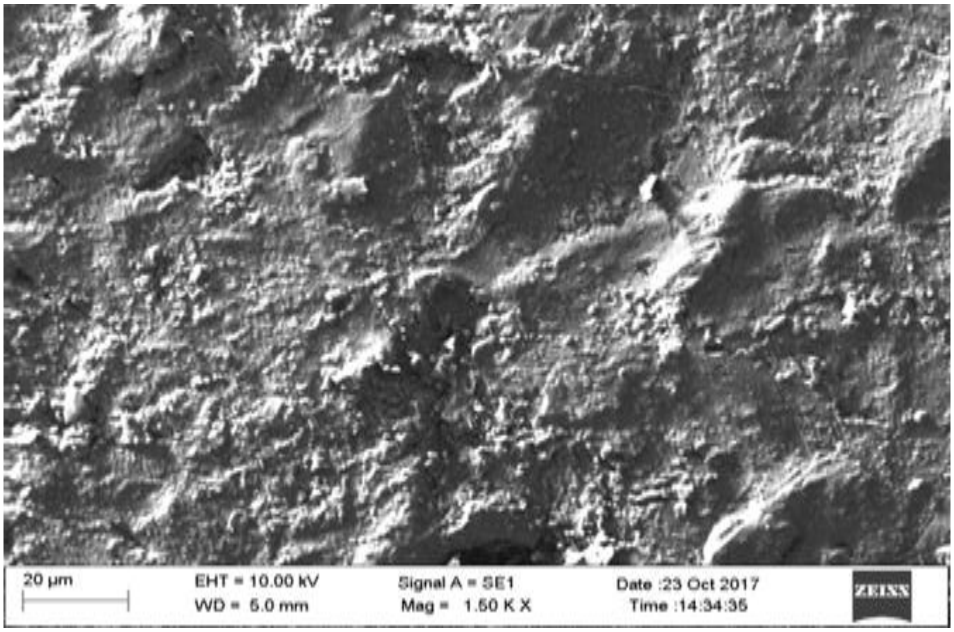

Figure (10): SEM micrograph of surface of LCL- composite after erosion.

Similar results reported by several other researchers establishes that in luffa epoxy composites micro ploughing as well as micro cutting cutting causes eviction of materials from surface [5]; studies on Epoxy/bagasse fiber composites showed intensive debonding, breakage of fiber, fiber micro cutting leading to damage and pulverization [6]; and in epoxy/coir dust composites, advancement of pulverization process occurs with increase in impact angle, debonding and fiber breakage, micro cracking and micro cutting [7].

4. **Conclusions:** Following conclusions are made in the present study: (1) hardness increase with more fiber content of composites; (2) bagasse and coir dust composites depict brittle behaviour while luffa and hybrid composites with first layer as luffa fiber, which encounter the erodent particles, shows semi-ductile behaviour; (4) In luffa in epoxy composites micro-ploughing and micro-cutting occurs during erosion. While for bagasse in epoxy composites, debonding, breakage of fiber, and microcutting occurs during erosion. In coir dust in epoxy composites, debonding, fiber breakage, microcracking and microcutting is the major phenomenon occurring.

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