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RESEARCH

Wear Characterization of Aluminium/Basalt Fiber Reinforced Metal Matrix Composites - A Novel Material

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A B S T R A C T

Aluminum alloy based metal matrix composite participate have a wider applications in wear resistance applications. Attempt made in current study is that, basalt fiber reinforced aluminum metal matrix composite have been prepared using stir casting method. Different weight percentage of basalt fiber reinforced with Al (6061) metal matrix composites are used to study the wear resistance of the composites. For wear study, percentage of reinforcement, normal load and sliding velocity are the considered as important parameters. To study the effect of basalt fiber reinforcement on the dry sliding wear of Al6061 alloy composites the Pin On wear tester is used. Initially hardness of the composites was tested, it was found that increasing reinforcement in the composite hardness value of the composites also increased. Based on the Grey relation analysis (GRA) the effects of wear resistance of the composites were studied.

1. INTRODUCTION

Aluminum 6061 is a precipitation hardening aluminium alloy, has good mechanical properties, and exhibits good weldability. It is used in Aircraft and Aerospace components, Bicycle frames, Drive shafts and Brake components. Basalt fiber material made from extremely fine fibers of basalt, which can be used as Friction materials, High pressure vessels, Ship hulls, Car bodies, Wind mill blades etc. Most of the researchers are doing aluminium metal matrix composites reinforced with hard particles like Sic, B4C, fly ash etc. Ezhil Vannan et al. studied co-efficient of thermal Expansion (CTE) Al7075/basalt short fiber Metal Matrix Composites (MMCs) as a function of temperature and reinforcement. It was observed that CTE significantly increased with increasing temperature but decreased with increasing basalt fiber [1]. Leon et al investigated the dry sliding wear od Al –Ni/ Sic composites with invariable reinforcing content of 30 vol% SiC, prepared by directional infiltration of aluminum in Ni-coated particles to study influence of the applied load, sliding speed, and sliding distance. The result showed that higher the load, higher the wear loss and the higher the wear velocity, the lower the wear intensity [2]. The aluminium carbon nanotube (CNT) composites prepared by cold compaction and hot extrusion and effects of CNT content, sliding speed and applied load, on the wear behavior of the composites were studied. CNT significantly enhanced wear characteristics of the composites [3]. Radhika et al investigated that influence of applied load, sliding velocity and temperature on wear rate of AlSi10Mg alloy reinforced with 3 wt% graphite and 9 wt% alumina which was fabricated by liquid metallurgy and wear study was performed by using a pin-on-disc wear tester. It was observed that load has the highest contribution on wear rate followed by temperature and sliding velocity [4]. Baradeswaran and Perumal investigated the influence of graphite on the wear behavior of Al 7075/Al2O3/5 wt% graphite hybrid composite. The hardness, tensile strength, flexural strength and compression strength of the Al 7075–Al2O3graphite hybrid composites are shown increased by increasing of ceramic phase [5]. Pardeep Sharma et al. [6] studied the effect of silicon nitride particles varied from 0 to 12 % on the dry sliding wear of Al6082 alloy composites manufactured by stir casting method. It was observed that sliding distance is the most influenced parameter and % of reinforcement is the factor which affects the wear to the least. Haitao et al. [7] investigated the dry sliding wear behavior of TiB_2 + h-BN)/2024Al and TiB_2/2024Al composites using a pin-on-disk wear tester at room temperature. The results of dry sliding tests showed that the addition of h-BN improved the tribological performance significantly at low sliding speed and low load. Pei et al [8] studied the friction and wear properties of $Mg_2B_2O_5$ whisker reinforced 6061Al matrix composite fabricated power ultrasonic-stir casting process. It was reaveled that wear rate of the $Mg_2B_2O_5$ whiskers coated with ZnO reinforced aluminum matrix composites is the lowest among the materials fabricated and when applied load and sliding speed increased, the wear mechanisms of the composites shift from a mild to a severe regime. Jayakumar L. and Balamurugan Kulendran studied the reciprocating wear behavior of 7075Al/SiC composites and 6061Al/Al_2O_3 composites that was prepared by liquid metallurgy techniques to find out the effects of wt% of reinforcement and load using a reciprocating wear testing machine. The experimental result showed that the volume loss is greater in 6061Al/Al_2O_3 composites when compared to 7075Al/SiC composites. Akhlaghi et al. [10] investigated the applicability of basalt fiber as a reinforcing material in metal matrix composites through various experimental works. They found that from micro structural studies a good bonding between aluminum and basalt together with a reasonably uniform distribution of fibers within the matrix alloy. Seyed et al. [11] studied fibrous Al-basalt composites produced and basalt fibers coated with a thin layer of aluminum after cooling at room temperature. It was concluded that processing parameters were optimized to obtain composites with the least amount of porosity. The optimum pressure and temperature of HP were reported 630 MPa and 400 °C, respectively. Ezhil Vannan and Paul Vizhian [12] fabricated the Al/basalt Metal Matrix Composites (MMCs) contain basalt short fiber from 2.5 % to 10 % in steps of 2.5 wt% using squeeze infiltration technique. The results showed short basalt fiber content and was increased from 2.5 % to 10 % by wt%, an improvement in Young's modulus of 13.26 % has been observed. Sarada et al. [13] produced the aluminium hybrid metal matrix composite (LM 25+ Activated Carbon+ Mica) by stir casting method and compared with conventional composites (LM25+ Activated Carbon) and (LM25+Mica). The specimens were tested for hardness and wear properties were tested. Rama et al. [14] investigated the LM13 aluminium alloy reinforced with 15 and 20wt% rutile mineral of fine (50–75 µm) and coarse (106–125 µm) size of range was prepared through stir casting technique. Wear results found that the composites containing the fine size reinforced particles showed around two times higher wear resistance than a wide range of temperature than the composite-containing coarse particles. Kumar et al. [15] studied the effect of sliding distance on tribological behaviour of Al6061-T6 alloy and its composite reinforced with hard ceramic alumina (3 wt%) and solid lubricant graphite (3 wt%) fabricated through stir casting technique. It was observed that, for all combinations of applied load, sliding velocity and sliding distance aluminium hybrid metal matrix composite (AlHMMC) reveal superior tribological properties than the Al6061 alloy. Hui-Hui Fu et al. [16] reported that wear properties of Saffil/Al, Saffil/Al2o3/Al and Saffil/SiC/Al composites on pin–on – disk apparatus under dry sliding conditions. It was found that Saffil/SiC/Al has high wear resistance than other combinations and with the lubricant of liquid paraffin, Saffil/Al showed best wear resistance and Saffil/Al2o3/AL better than the Saffil/SiC/Al. Saravanan et al [17] investigated the wear behaviour of Al 6061 alloy reinforced with SiC, Al_2O_3 and E glass fiber composites. The experimental found that minimum wear was observed in 10 wt% of Al_2O_3, 6 wt% of SiC and 4%wt of E glass fiber compared with Al 6061 alloy. Ezhil Vannan et al. [18] studied corrosion behaviour of basalt short fiber reinforced aluminum (Al7075) metal matrix composites (MMCs) in alkaline solution using weight loss method. The result observed that increasing of basalt fiber in the composites, which became more corrosion resistance. Karthigeyan et al. [19] investigated the Coating Morphology of Basalt Short Fiber for Reinforcement preparation of Al/Basalt Metal Matrix Composites. Bhowmick et al. [22] investigated the wear and friction behavior of W-DLC and H-DLC coating sliding against aluminium under unlubricated and lubricated conditions. A lower coefficient of friction was observed when W-DLC using lubricant oil incorporating sulphur while the remained almost unchanged. Radhika and Raghu [23] investigated the manufactured LM 13 aluminium/B_4C matrix composites synthesized by liquid metallurgy techniques. Different weight percentages of B4C were incorporated. The wear behavior of the composites was studied by L16 orthogonal array. The experimental results revealed that load was the major influencing parameters followed by wt-% of reinforcement, velocity, and sliding distance. Senhadji et al [24] compared the frictional and wear behavior under mixed lubrication of bronze and brass sliding on a steel disc. All the tests were conducted in pin – on disc tribometer. It was concluded that friction coefficient and the wear coefficient of brass are significantly higher in comparison to bronze.

Surojo et al. [25] investigated the friction behavior of brake shoe using machining chips of cast iron and copper wire of electric motor as metallic filler. The results showed that cast iron and Cu short wire had effect on increasing coefficient of friction of the brake shoe materials. Kumar et al. [26] investigated the wear and friction behavior of in – situ AA5052 /ZrB2 composites with different volume percentage of zirconium diboride particles. Hardness of the composites improved significantly as compared to base alloy. The results showed that wear rate decreases with formation of ZrB2 particles and improves as the reinforcement amount increases whereas coefficient of friction of composites follows the reverse trends.

2. EXPERIMENTAL DETAILS

2.1 Material used

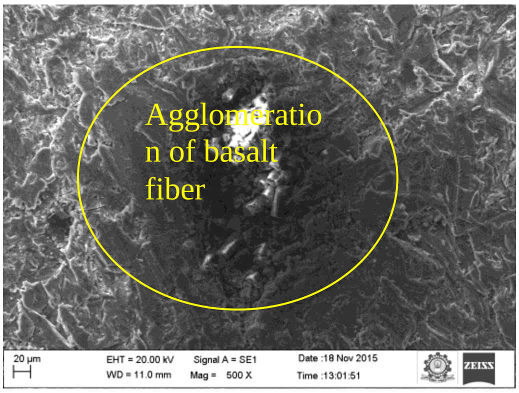
In this study, Aluminum 6061 as a matrix and basalt fiber as a reinforcement were used. The rod form of Al6061 was used and cut into small shapes for casting and purchased from Covai Metal Mart, Coimbatore. The reinforcing agent basalt fiber purchased from Asa. Tec, Austria. The raw Alumium and fabricated composites is presented in Figs. 1 and 2.

Fig. 1. Raw Alumium 6061.

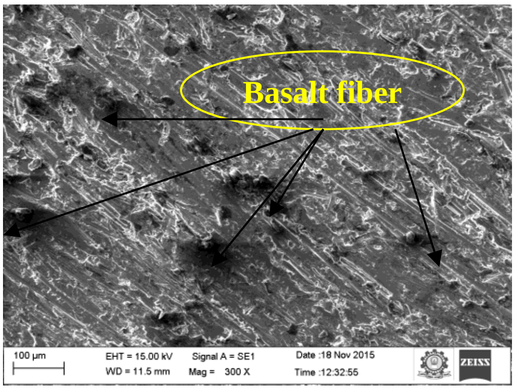
Fig. 2. Fabricated composite.

2.2 Fabrication of metal matrix composites

The stir casting techniques used to fabricate the Basalt fiber reinforced aluminum metal matrix composites. The Al heated to 650 ^{0}C and maintained for 2 hours to get perfect molten metal. The experiment started with reinforcing 20 mm of length of basalt fiber and finally the composites achieved the uniform distribution in 1 mm length of basalt fiber were noticed. It was observed that higher fiber length gives agglomeration of fiber. Experiment carried out with reduced length of fiber 10 mm, 5 mm, 2 mm and 1mm and at last, 1 mm length of basalt fiber has good uniform of distribution in the composites which is presented in SEM micrograph (Figs. 3 a and b).



a)



b)

Fig. 3. Reinforment of basalt fiber in Al composite a) Agglomeration of baslt fiber; b) unifrom distribution of basalt fiber.

2.3 Wear Study

Pin on disc wear tester used to study the dry sliding wear of the fabricated composites supplied by Pin on Disc Friction & Wear Testing Machine designed and developed by Magnum Engineers, Bangalore, India. Disc surface of the wear tester polished with emery papers and surface roughness of the counter plate was maintained.

2.4 Grey Relation Analysis (GRA)

The grey relation analysis is a multi-objective optimization technique used to determine the optimum combination of the input parameters and also to determine the influence of each machining parameter on the machining characteristics.

Step 1: S/N Ratio Calculation

The machining characteristics such as, Top kerf, bottom kerf and delamination are to be minimized and hence, the smaller-the-better characteristic is selected for the analysis. The signal to noise ratio (S/N ratio) can be determined using the equation 1. This is suitable for a problem where minimization of the response characteristics is anticipated.

$$\frac{s}{n}\,ratio = -10\,\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n} y_{ij}2 \qquad (1)$$

where n=number of replications; y_{ij}= observed response, i=1, 2… n; j=1, 2... k.

Step 2: Normalization

It is necessary to normalize the S/N ratio values before analyzing them using grey relation concept [14]. Here normalization is done for the experimental result of the responses and rated between 0 and 1. The normalization of the result is determined using the equation 2.

$$z_{ij} = \frac{\max\left(y_{ij,}i=1,\ 2.......n\right)-y_{ij}}{\max\left(y_{ij}i=1,2....n\right)-\min\left(y_{ij,}i=1,2.....n\right)} \qquad (2)$$

where y_{ij} is the j^{th} performance characteristic in the i^{th} experiment, and max y_{ij} and min y_{ij} are the maximum and minimum values of the j^{th} performance characteristic for alternative i^{th} experiment.

Step 3: Grey relational coefficient

The Grey Relational Coefficient (GRC) for the response characteristics from the normalized values can be calculated using the equation 3.

$$\gamma\left(y_0(k),y_i(k)\right)=\frac{\Delta\min+\xi\Delta\max}{\Delta_{0j}(k)+\xi\Delta\max} \qquad (3)$$

where,

i. j=1, 2… n; k=1, 2…m, n is the number of experimental data items and m is the number of responses.

ii. $y_0(k)$ is the reference sequence ($y_0(k)$=1, k=1, 2 ...m); y_j (k) is the specific comparison sequence.

iii. $\Delta_{oj}=y_0(k)-y_1(k)$ The absolute value of the difference between $y_0(k)$ and $y_j(k)$.

iv. $\Delta\min=\min\ \min\left\|y_0(k)-y_1(k)\right\|$ is the smallest value of $y_j(k)$

v. $\Delta\max=\max\ \max\left\|y_0(k)-y_1(k)\right\|$ is the largest value of $y_j(k)$

vi. ξ is the distinguishing coefficient, which is defined in the range $0\le\xi\le1$.

Step 4: Grey Relational Grade

The Grey Relational Grade (GRG) for the combined objectives of the responses can be calculated from the GRC of all the output responses and it is ranked in the order. The evaluation of the performance characteristics are based on this GRG and it is determined using the equation 4.

$$\delta_j = \frac{1}{k}\sum_{i=1}^{m} y_{ij} \tag{4}$$

where, δ_j is the grey relational grade for the jth experiment and k is the number of performance characteristics.

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3. RESULT AND DISCUSSION

3.1 HARDNESS

The Al (6061) metal matrix composites fabricated with the reinforcement of basalt fiber with different fiber wt%. The Vickers micro hardness of fabricated composites are estimated using diamond indenter at an applied load of 50N are presented in Fig. 3. Initially hardness of the composites was measured, based on the hardness test it was observed that hardness is higher for the basalt fiber reinforced composites than unreinforced composites. Al composites having higher % of basalt fiber revealed higher hardness.

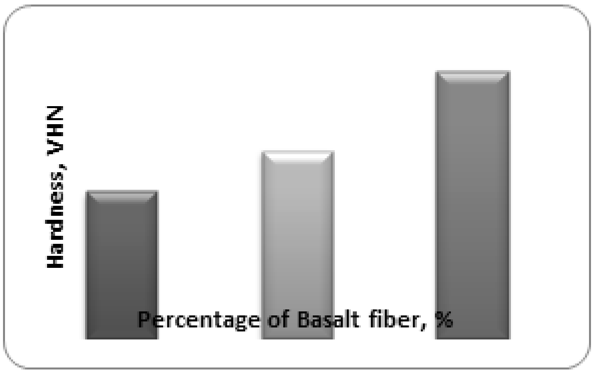


Fig. 3. Hardness of the composites.

3.2 Density

The density of the composites also measured and value presented in Figure 4. The aluminum metal matrix composites with basalt fiber reinforced have comparatively higher density than pure aluminum metal matrix composites. The density of the composites increased with increasing of basalt fiber reinforcement.

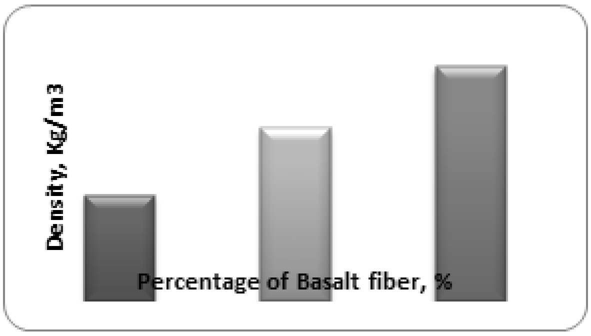


Fig. 4. Density of the composites.

3.3 Grey Relational analysis

Experimental parameters taken for current study is presented in Table 1.

Table 1. L_{27} orthogonal array and Wear tested values.

Exp. No	Sliding velocity	Normal Load	% Ref.	Volume wear rate	Co efficient of friction	Specific Wear	Frictional force
1	2	20	0	0.0105	0.4200	0.000136	8.4
2	2	20	5	0.0068	0.4115	0.000088	8.23
3	2	20	10	0.0068	0.3730	0.000088	7.46
4	2	40	0	0.0066	0.3625	0.000042	14.5
5	2	40	5	0.0100	0.4200	0.000064	16.8
6	2	40	10	0.1280	0.3290	0.000819	13.1
7	2	60	0	0.0231	0.4317	0.000098	25.9
8	2	60	5	0.0179	0.4267	0.000076	25.6
9	2	60	10	0.0165	0.4400	0.000070	26.4
10	3	20	0	0.0077	0.5030	0.000099	10.0
11	3	20	5	0.0120	0.4200	0.000154	8.4
12	3	20	10	0.0082	0.3915	0.000105	7.8
13	3	40	0	0.1748	0.3758	0.001109	15.0
14	3	40	5	0.0082	0.3750	0.000052	15
15	3	40	10	0.0389	0.3725	0.000247	14.9
16	3	60	0	0.1524	0.3893	0.000656	23.3
17	3	60	5	0.0165	0.3650	0.000071	21.9
18	3	60	10	0.0324	0.3817	0.000140	22.9
19	4	20	0	0.1870	0.4300	0.002372	8.6
20	4	20	5	0.0134	0.3865	0.000170	7.7
21	4	20	10	0.0051	0.4400	0.000065	8.8
22	4	40	0	0.0655	0.3675	0.000423	14.7
23	4	40	5	0.0810	0.4200	0.000523	16.8
24	4	40	10	0.0643	0.3690	0.000415	14.7
25	4	60	0	0.1285	0.3843	0.000548	23.0
26	4	60	5	0.1102	0.4322	0.000470	25.9
27	4	60	10	0.1065	0.4000	0.000454	24

Table 2.

Exp. No	S/N ratio VWR	S/N ratio COF	S/N ratio SW	S/N ratio FF	GRG	Order	Error
1	39.5	7.5	77.3	-18.48	0.817	7	1
2	43.3	7.7	81.1	-18.30	0.845	4	2
3	43.3	8.5	81.2	-17.45	0.902	1	3
4	43.6	8.8	87.4	-23.22	0.819	6	2
5	40	7.5	83.8	-24.50	0.730	12	3
6	17.8	9.6	61.73	-22.38	0.662	16	1
7	32.7	7.2	80.20	-28.26	0.646	20	3
8	34.9	7.3	82.4	-28.16	0.665	15	1
9	35.6	7.1	83.1	-28.43	0.659	17	2
10	42.2	5.9	80.1	-20.05	0.761	10	1
11	38.4	7.5	76.2	-18.48	0.810	8	2
12	41.7	8.1	79.5	-17.87	0.865	3	3
13	15.1	8.5	59.1	-23.53	0.519	24	2
14	41.7	8.5	85.6	-23.52	0.792	9	3
15	28.2	8.5	72.1	-23.46	0.701	13	1
16	16.3	8.1	63.6	-27.37	0.500	26	3
17	35.6	8.7	82.9	-26.80	0.741	11	1
18	29.7	8.3	77.1	-27.19	0.673	14	2
19	14.5	7.3	52.4	-18.69	0.505	25	1
20	37.4	8.2	75.3	-17.76	0.882	2	2
21	45.8	7.1	83.7	-18.89	0.824	5	3
22	23.6	8.6	67.4	-23.34	0.653	18	2
23	21.8	7.5	65.6	-24.50	0.561	21	3
24	23.8	8.6	67.6	-23.38	0.653	19	1
25	17.8	8.3	65.2	-27.25	0.527	23	3
26	19.1	7.2	66.5	-28.27	0.497	27	1
27	19.4	7.9	66.8	-27.60	0.531	22	2

From the above calculation (Table 2) of grey relational grade it was found that the Sliding velocity (m/sec) is 2, Normal load (N) is 20. Reinforcement of basalt fiber (%) is 10 maintaining the highest value of 0.90202.

Table 3.

Parameters	Level			
	L1	L2	L3	Max -Min
Sliding velocity	0.750	0.707	0.626	0.123
Normal Load	0.801	0.677	0.605	0.196
% Ref.	0.638	0.725	0.719	0.086
Error	0.667	0.710	0.705	0.043
Average Mean: 0.6871				

Analysis of Variance (ANOVA) is a statistical tool applied to determine the influence of each parameter on the combined responses. A single objective method cannot find the contribution of input parameters and hence, the ANOVA applied to identifying the contribution of each input on the combined objectives, which is shown in Table 3.

3.4 Analysis of Variance (ANOVA)

The Analysis of variance used to investigate the design parameters that significantly affect the wear rate of the composites which is presented in the Table 4. The significant wear rates of the composites are Normal Load (58.15 %), Sliding velocity (23.23 %) and % of reinforcement in the composite is 13.68 %.

Table 4. Calculation of ANOVA value.

Param Eters	DOF	SS	MS	Contri-bution	F – Ratio	
Sliding velocity	2	0.02	0.01	23.23	70.54	Significance
Normal Load	2	0.05	0.02	58.15	176.55	
% Ref.	2	0.01	0.006	13.68	41.54	
ERROR	20	0.003	0.0001	3.29		
Total	26	0.10				

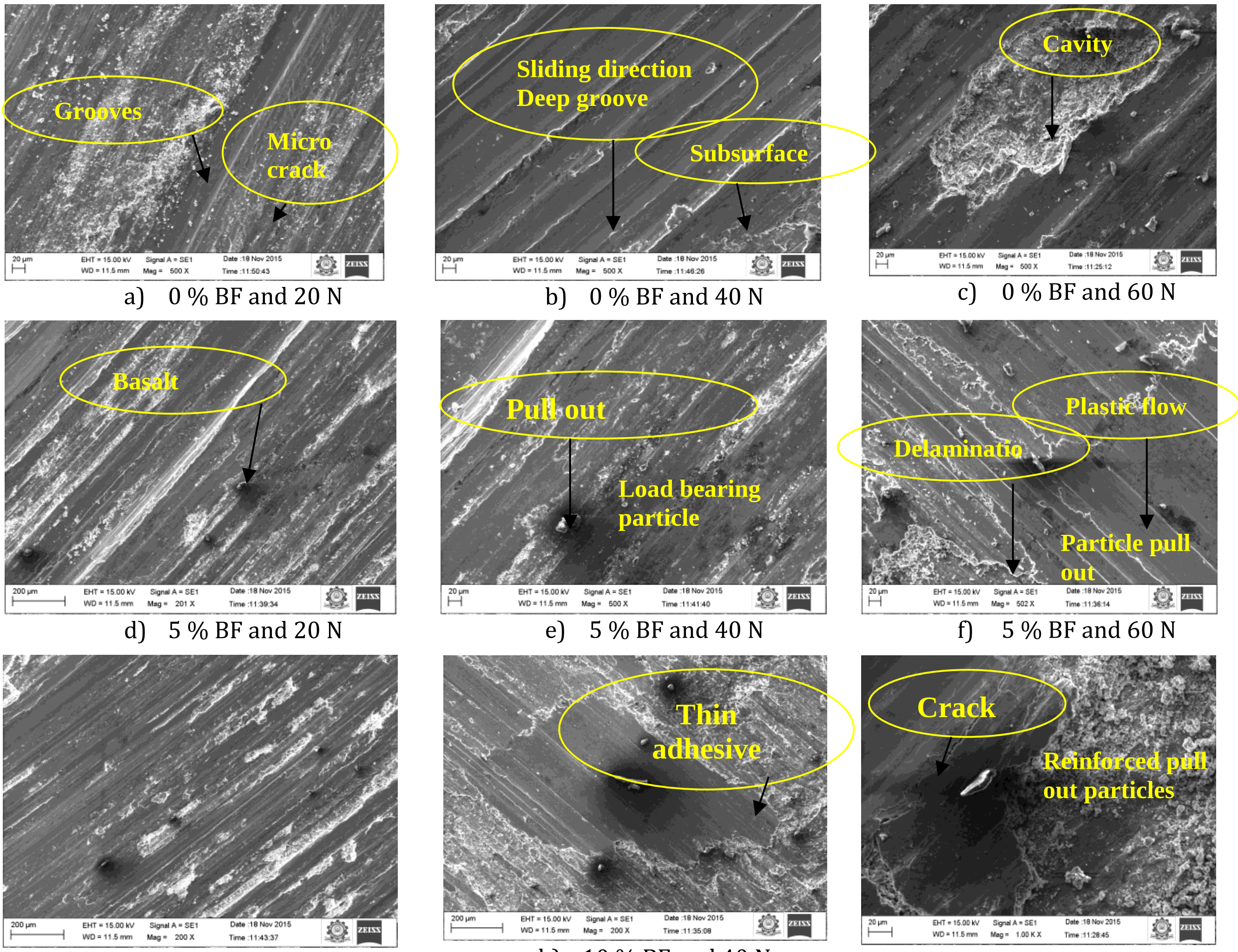
3.5 Worn Surface Analysis

SEM image of the worn out surface of the Al/ basalt fiber reinforced metal matrix composites are visualized in Fig. 5. In the Fig. 5(a-i) clearly indicating the wear track of the composites and wear rate of the unreinforced basalt fiber Al metal matrix composites is higher than the reinforced composites, which could be seen in Fig. 5 (a-c). Figure 5(a) micrograph shows that there are small micro crack due to the stress developed during the periodical motion of the hard substrate. The repeated loading causes fatigue wear on the surface and subsurface region leads to the formation of micro cracks. It also shows fine grooves in the surface and plastic deformation at a few places as shown in Fig. 5(a). Figure 5(b) shows the presence of deep grooves in different size observed repetitively on the worn surface of the composites. The structure of such grooves propagates subsurface crack along the sliding direction. Further increasing load leads to the process of delamination. In pure aluminum composites at load of 60N showed the larger size of cavity in the surface which indicating the severe losses in the materials. Larger size cavity occurred due to when the material sliding over another material with higher velocities that soften the parent material due to increases in temperature. The temperature rise resulted in particle pull out was observed.

Figure 5 (c-e) shows the 5 % of Basalt fiber, when load increase gradually the morphology of the worn out surface of the composites appeared from fine scratch to distinctive grooves. In general, the wt% of reinforcement has stronger effect on the specific wear rate of the composites. Figure 5 (c and d) micrographs shows that there small grooves and basalt fiber pull out particles may be borne the load acting on the aluminum materials by which there is reduced coefficient of friction and specific wear rate compared to pure aluminum composites.

At 40 N load, the due to the increases in load the basalt fiber pulled out from the composites. When further increase in load for the 5 % of basalt fiber composites the delamination mechanism was observed due to increases in sliding velocity. Similarly, the plastic flow was observed due to the presence of scars adhered on the surface of the sliding materials. When the plastic flow of the material increased which required to higher shearing action to peel off the wearing surface and leads to delamination mechanisms (ANTONY).

While increasing the load, it was found from Fig. 5 (f) there is protrusion from irregular surface that causes abrasive wear. Thin adhesive layer was observed in the surface of the 10 % of basalt fiber composites in Fig. 5 (h). This was evident that high plastic strain encourages the shear instability of the basalt fibers. From Fig. 5(g) can understand that, the presence of large number of particles avoids the mechanism of abrasion wear by which only limited number of wear traces is visible.



a) 0 % BF and 20 N
b) 0 % BF and 40 N
c) 0 % BF and 60 N
d) 5 % BF and 20 N
e) 5 % BF and 40 N
f) 5 % BF and 60 N
g) 10 % BF and 20 N
h) 10 % BF and 40 N
i) 10 % BF and 60 N

Fig. 5. SEM micrograph of wear tested specimens.

It is attributed because three bodies wear mechanism, since the particles between the specimen and load acting member will act as grinding medium. Because of the particles gets grinded introduced load transmitted to the specimen.

From the worn surface showed the fractured basalt fiber that endorses the more losses of materials. Grooves in worn out surface represent the abrasion type wear in the composites. At higher loading conditions, the damaged and crack surfaces are evident. It was the severe deformation and crack in the composites resulting in higher wear rate (Sivakumar). When the increases in temperature of the contact surfaces resulted in soften the surface of the materials. It will further initiate the crack in the composites is seen in Fig. 5(i).

4. CONCLUSION

The basalt fiber reinforced Al metal matrix composite was prepared using stir casting techniques with different reinforcing % of basalt fiber successfully. The wear rate of the composites was measured with parameters such as % of reinforcement, Sliding velocity and Normal load using Grey relation analysis. Based on the optimization technique, all the parameters taken for the wear study are significant and the most significant parameter was on Normal load. The optimized parameters are Sliding velocity (m/sec) of 2, Normal load (N) of 20, Reinforcement of basalt fiber (%) of 10.

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