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Effect of Silicon Carbide and Alumina Reinforcement of Different Volume Fraction on Wear Characteristics of AL 7075 Hybrid Composites Using Response Surface Methodology

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This study investigates the wear performance of Hybrid composite of Aluminium Al 7075 (SiC/Al_2O_3). The Reinforcements used for the Hybrid composite preparation are Silicon Carbide (SiC) and Aluminium Oxide (Al_2O_3). Reinforcements are added in 5%, 10% and 15% in volume percentage in to aluminium alloy for composite preparation. The wear performance of the developed composites was analysed using dry sliding test apparatus. The effect of wear study parameters such as load, sliding distance, sliding velocity on the response of wear rate were predicted. This study revealed that Wear rate was influenced by the load significantly. The addition of reinforcement in hybrid composite increases the wear rate up to 10% of addition and reduces the wear rate at 15% of addition. Scanning Electron Microscope (SEM) study displays the wear mechanism clearly. This study concludes that the introduction of reinforcements into the aluminium enhances the wear confrontation of the composites considerably. The developed composite may be used in high wear prone zones effectively.

Keywords: *Al 7075, SiC, Al_2O_3, Wear, RSM.*

1. Introduction

New material developers in structural, defence and aerospace industry require a low weight and high strength, better wear and corrosion resistance and higher mechanical properties[1,2]. Composite material plays a greater part in all type of application, because researchers are unremittingly trying to find new materials to meet their requirement with different materials and production methods[3-6]. Aluminium alloy and its composites play a vital role in the many engineering application but it shows poor wear properties[7,8]. To improve the tribological properties, hard reinforcements have been evenly distributed in the alloy matrix[9,10]. In aluminium matrix, the dispersoid particles like borides, carbides and oxides are insoluble and stable thermally at very high temperature are used[11]. Metal Matrix Composites (MMC) are developed by various methods such as powder metallurgy route, liquid metal infiltration, squeeze casting, electro-deposition and diffusion bonding method[12]. Out of these techniques, stir casting (liquid metallurgy) route is the best promising one to fabricate the composite because of its cost-effectiveness, simplicity, absence of size limitation and large quantity[13,14]. In MMC, various metals such as Copper (Cu), Magnesium (Mg), Aluminium (Al), Titanium (Ti) are used as a matrix material. Among these material, Al based composites are noted to be cheapest one[15].

Relative motion between two surfaces leads to material removal from one or both surfaces and it is known as wear. Sliding of one surface over the another due to applied pressure induces the adhesive wear[16]. High hardness materials with high strength and toughness produces lesser wear. Introduction of a reinforcement material particulates into MMC improves the wear behaviour along with higher stiffness and specific strength making them good candidate materials for many engineering situations[17,18]. The wear resisting capability of a material relies on its strength, ductility, hardness, toughness, type of reinforcement, weight/volume fraction and particle size and shape[19]. Particle reinforced MMC with higher bonding strength and the support of matrix prevent the initiation of cracks and increase the wear resistance[20]. The wear behaviour of Aluminium Matrix Composites (AMC) with various reinforcements have been investigated by various researchers. The most commonly employed AMC system is strengthened with hard ceramic particles such as SiC, Al2O3 or soft particles like graphite[21]. Al 7075 with SiC particulate reinforced AMCs under dry sliding wear conditions forms a relationship between the friction and the wear of the MML. SEM of the worn surfaces evidences the oxidation mechanisms[22].

Veeresh Kumar et al.[23] developed Al 7075/SiC composite material by liquid metallurgy route and studied the wear behavior. In their investigation, they found 6 vol. % SiC reinforced composite presented better tribological and mechanical properties in comparison with the base alloy. Kumar and Balasubramanian[7] in their study presented that when particle size inversely proportional to the wear rate, the sliding speed and volume fraction of reinforcement were in proportion to the rate of wear. Baskaran et al.[24] prepared Al 7075 – TiC Metal matrix composites by casting technique and identified the highly contributing parameter on the wear rate. Baradeswaran and Elaya Perumal[25] prepared the Al 7075/B_4C composites by stir casting method and made an inference that rate of wear decreased with increase in the addition of reinforcement. Baradeswaran and Elaya Perumal[26] fabricated

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Al 7075/Al_2O_3/graphite hybrid composites by liquid metallurgy method and found that graphite containing composites shows superior wear resistance. Both Al7075 and Al6061 are heat treatable and in T6 condition Al7075 has nearly double the tensile strength as compared to Al6061 and shear strength of Al7075 is 1.5 times of AL6061. AL7075 is harder because it contains zinc content. In transport applications including automotive, marine and aviation 7075 is often used due to its high specific strength. Daoud et al.[27] have studied the Al 7075/Al_2O_3 composites developed by squeeze casting method. Their investigation also revealed lower wear rate than that of the base aluminium. Rao et al.[28] have studied the wear behavior of AA7010/SiC composites prepared by stir casting method. They found that wear behavior is altered strongly due to the type of reinforcement and surface condition of the pin. Boopathy and Prasath[29] have studied the mechanical property of Al 6061-SiC-Al_2O_3 composites prepared by stir casting method. They found that composite with higher SiC particles improves the tensile strength. Increasing the processing temperature also improve the hardness.

From the above literature review, dry sliding wear behaviour of aluminium composites were studied based on two or more factors like Type of reinforcement, amount of reinforcement, manufacturing technique, Load, Sliding velocity, sliding distance. There is very limited work was done on Al 7075 hybrid composites. So, the main objective of the present research is to develop Al 7075/SiC/Al_2O_3 hybrid composites material by two step stir casting method and predict the wear behaviour of fabricated composite. Response surface methodology (RSM) involves more number of experimentation compared to Taguchi method and less number of experimentation compared to Full factorial design method (FFD).

2. Materials and Method

2.1. Composite preparation

The hybrid composite material contains Al 7075 aluminim alloy and SiC and Al_2O_3. The composites were developed through two step stir casting process. Al 7075 alloy of 1.5kg was melted in an MS container by PID controlled electric furnace as shown in Figure 1a. Two step stir casting methods has been used to make sure proper mingling of reinforcement into the molten metal. Initially, alloy material was heated above the melting temperature. Then the tempratures was brought to below the liquidus (semi solid state) temperature to continue slurry in the state. Based on the literatures 5, 10 and 15 volume percentage of reinforecements (Al_2O_3+SiC) was selected. The preheated SiC and Al_2O_3 were put in the molten aluminium alloy and mix the particles physically. Now the composite slurry was reheated above the liquidus temperature and mechanical mixing was performed for about 10 -15 min. The crucible and the die used for the composite preparation are shown in Figure 1b. The volume percentage of prepared composite materials are presented in Table 1.

Table 1. Composition of composite materials.

Proportions (ASA- Al 7075+SiC+ Al_2O_3)	ASA0	ASA5	ASA10	ASA15
Al7075 (Vol.%)	100	95	90	85
SiC (Vol.%)	0	2.5	5	7.5
Al_2O_3 (Vol.%)	0	2.5	5	7.5

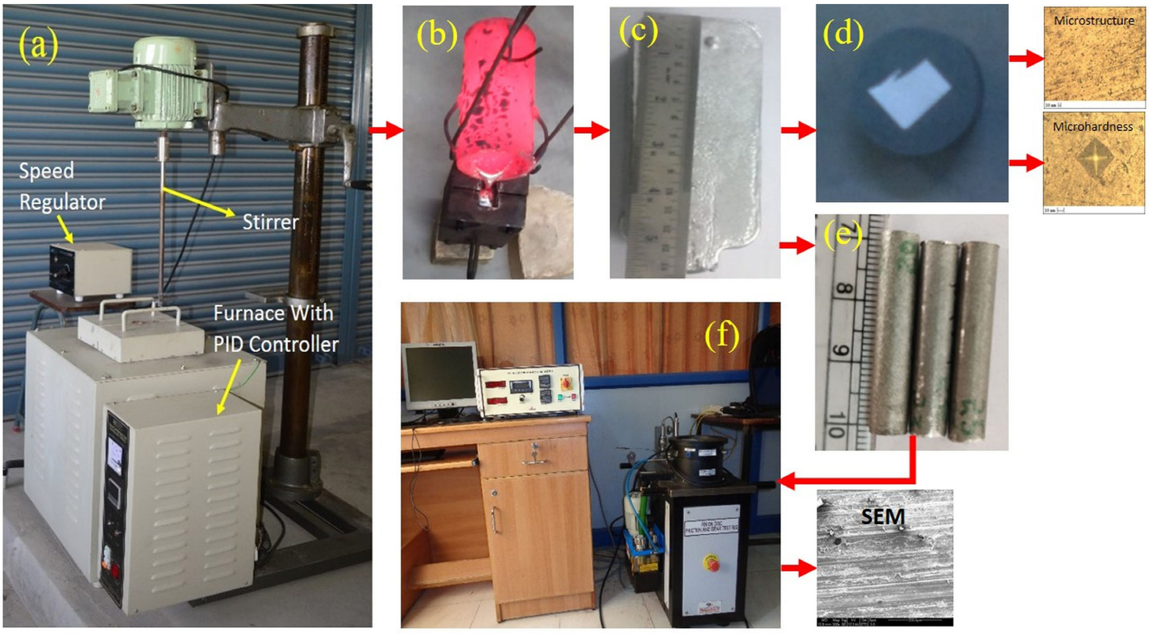

Figure 1. (a) Stir Casting Setup (b) Photographic view of pouring the molten metal into the die, (c) ASA Composite, (d) Mould specimen, (e) Wear test pin and (f) Wear test setup.

2.2. Sliding wear study

The wear experiment was performed following ASTM: G99 to study the wear chracteristics of Al 7075 hybrid composite with a help of pin on disc friction and wear test rig supplied by magnum as shown in Figure 1f. Wear pin samples have been prepared from as cast condition composite (Figure 1c) with diameter of 6mm and height of 30 mm (Figure 1e). polishing of Contact surfaces of the wear pin samples were done by using the polishing machine to ensure 100% contact between pin and counterpart. Firstly Wear pin samples were arrested in the pin holder above the 100mm diameter rotating counterpart disc which is made of EN32 steel. Before and end of the every test the cleaning of disc was performed by using acetone to eliminate the debris and pin masses were calculated by using weighing machine with accuracy of 0.0001g. Wear testing parameters like kind of reinforcement, the amount of reinforcement, sliding distance, applied load, sliding velocity was identified from the literature and the test conditions are tabulated in Table 2. The Design parameter table and experimental predictions are tabulated in Table 3. The coefficient of friction was recorded with computerized data acquisition system. Loss of material and the wear rate have been calculated according to the following Equation 1 and 2[24]. Tested wear pin composite samples are shown in Figure 2.

$$Volume\ loss\ \left(mm^3\right) = \frac{\text{Initial Mass in gram} - \text{Final Mass in gram}}{\text{Density}\left(g / mm^3\right)} *1000 \quad (1)$$

$$Wear\ Rate\ \left(mm^3 / m\right) = (Volume loss / Sliding\ Distance)x1000 \quad (2)$$

Table 2. Wear Test Conditions.

Pin material	ASA0, ASA5, ASA10, ASA15
Temperature	Room Temperature
Pin Diameter (mm)	6
Pin Height (mm)	30
Track Radius (mm)	60
Load (N)	10, 20, 30
Sliding Distance (m)	1000, 2000, 3000
Sliding Velocity (m/s)	1, 2, 3

3. Result and Discussion

The volume loss of the ASA composite was identified by changing the experimental parameters such as percentage of reinforcement, sliding velocity, sliding distance and the load applied. The process parameters values are presented in Table 4. The different statistical methods such as regression analysis, analysis of variance (ANOVA) and F-test were

Table 3. Design parameter table and experimental predictions.

Std. Order	Run order	Reinforcement (%)	Applied load (N)	Sliding velocity (m/s)	Sliding distance (m)	Wear rate
1	18	5	10	2	1500	0.0085051
2	25	15	10	2	1500	0.0023256
3	23	5	30	2	1500	0.0109215
4	20	15	30	2	1500	0.0122045
5	29	10	20	1	1000	0.007309
6	21	10	20	3	1000	0.0016611
7	22	10	20	1	2000	0.0036047
8	10	10	20	3	2000	0.0042525
9	5	5	20	2	1000	0.0062457
10	12	15	20	2	1000	0.0046645
11	28	5	20	2	2000	0.0027304
12	13	15	20	2	2000	0.0017572
13	14	10	10	1	1500	0.0045914
14	26	10	30	1	1500	0.0166323
15	6	10	10	3	1500	0.0076035
16	1	10	30	3	1500	0.0135659
17	17	5	20	1	1500	0.0047782
18	4	15	20	1	1500	0.0036848
19	8	5	20	3	1500	0.0033447
20	15	15	20	3	1500	0.001065
21	19	10	10	2	1000	0.0114618
22	7	10	30	2	1000	0.0106312
23	2	10	10	2	2000	0.0029236
24	16	10	30	2	2000	0.0193422
25	11	10	20	2	1500	0.0181617
26	24	10	20	2	1500	0.0181617
27	9	10	20	2	1500	0.0158538
28	27	10	20	2	1500	0.0181617
29	3	10	20	2	1500	0.0181617

Figure 2. Tested wear test pin of ASA Composites.

executed to validate the developed model. Goodness of the model fit was found by applying ANOVA and the significance of the coefficients in the developed model was estimated.

The statistical model is developed with 95% confidence level. From the ANOVA result shown in Table 5, it is identified that the developed model having p-value less than 0.001 which is less than 0.05 and is significant. This shows that the input variable are significant on the output variables. The F-value of lack of fit is 1.70 and it implies that it is not significant relative to the pure error. p value is greater than 0.5 for lack of fit and this model can be applied for calculating the response. If $p < 0.05$ then the expressions used to develop model are significant. In this analysis, the process parameters A, B, AB, BC, BD, CD, A^2 and C^2 are having p values less than 0.05, so these terms are significant model terms. From Table 6, R^2 value 0.9789 indicates that the developed model relation shows a good fit among the actual experimental data and the model. Large value of R^2 and adj. R^2 recommend that only important terms were contained within the developed model. The acceptable precision value obtained from the analysis is > 4 which is desirable and it shows the model having enough discrimination. The actual value obtained is 19.06 and the model can be successfully applied to evaluate the volume loss. The usual probability ratio of the residuals is depicted in Figure 3. In that, the residuals are falling in the straight line which shows normal distribution of the errors.

Table 4. Levels of Process parameters.

Factors	Designation	Levels (coded)		
		-1	0	1
Reinforcement (%)	A	5	10	15
Applied load (N)	B	10	20	30
Sliding velocity (m/s)	C	1	2	3
Sliding distance (m)	D	1000	1500	2000

Table 5. ANOVA results.

Source	Sum of squares	DOF	Mean square	F-value	p value Prob.>F	
Model	0.001	14	0.0001	46.3	< 0.0001	significant
A-A	9.76E-06	1	9.76E-06	6.1	0.027	
B-B	0.0002	1	0.0002	109.56	< 0.0001	
C-C	6.91E-06	1	6.91E-06	4.32	0.0566	
D-D	4.52E-06	1	4.52E-06	2.82	0.1152	
AB	0	1	0	8.69	0.0106	
AC	3.52E-07	1	3.52E-07	0.2197	0.6465	
AD	9.24E-08	1	9.24E-08	0.0577	0.8136	
BC	9.24E-06	1	9.24E-06	5.77	0.0308	
BD	0.0001	1	0.0001	46.45	< 0.0001	
CD	9.91E-06	1	9.91E-06	6.19	0.0261	
A^2	0.0004	1	0.0004	257.94	< 0.0001	
B^2	2.91E-06	1	2.91E-06	1.82	0.1989	
C^2	0.0003	1	0.0003	184.38	< 0.0001	
D^2	0.0002	1	0.0002	154.97	< 0.0001	
Residual	0	14	1.60E-06			
Lack of Fit	0	10	1.82E-06	1.7	0.3202	not significant
Pure Error	4.26E-06	4	1.07E-06			
Cor Total	0.0011	28				

Table 6. R-squared and adequate precision values.

Std. Dev.	0.0013	R^2	0.9789
Mean	0.0088	**Adjusted R^2**	0.9577
C.V. %	14.43	**Predicted R^2**	0.8951
		Adeq Precision	19.0648

Figure 4 displays that the closeness of the forecasted and actual values of wear rate clearly. The most of the values are in the vicinity of centreline without unusual pattern which indicates the model is in good fit.

3.1. Analysis of Wear performance

RSM will gives closer to the global optimal settings. Central composite design (CCD) method is selected with alpha value as 1 and 29 experiments were conducted. The surface plots indicate the collective effect of various process parameters as shown in Figure 5. Among the interaction plots, the sliding velocity and applied load have higher loss of material compared to percentage of reinforcement. The volume loss is minimum at minimum load, higher value of sliding distance and percentage reinforcement. During wear study the tribo-layer may be formed and the wear properties of ASA composites are improved due to the existence of hard SiC reinforcement at the contact surface.

Figure 5a illustrates the combined effect of percentage of reinforcement and given load on the volume loss of the ASA composite. The wear rate seems minimum at low load, but it increases with increase of load. The SiC particles in the contact surface causes fewer contact of the surface during low load, which causes less interface temperature on the contact surface. The less contact temperature effects in little plastic deformation on the interface surface. The rise in wear resistance shows stronger bonding between the base metal and reinforced particle. At greater applied loads the volume losses increases due to increase in contact surface temperature. Volume loss reduced with increase in reinforcement and also it is very less at higher levels of reinforcement[30].

Figure 5b displays the collective influence of sliding velocity and applied load. It is inferred from this plot that the loss of material gets increased on the increase in applied load. The volume loss appears high when there is a high applied load and medium sliding velocity. But the increasing sliding velocity causes to decrease the wear rate. At medium velocity, the specimen have higher surface contact which results in large wear rate. Because the tribo-layers were formed at higher temperature[31]. At the interface, thick oxide layer were formed and possesses low shear strength. The coefficient of friction between the interface surfaces gets reduced and reduced contact surface increases the wear resistance of the material[32].

Figure 5c displays the collective effect of velocity of sliding and given load on the volume loss of the ASA composite material. Surface plot shows the minimum volume loss at low sliding velocity and low applied load. This is due to the growth of mechanically mixed layers (MML) on the gliding contacts. The volume loss gets decreased when there is an increase in the sliding velocity, because of rise in frictional heating temperature at the interface surface and the growth of MML on the sliding surface. A thin molten layer was

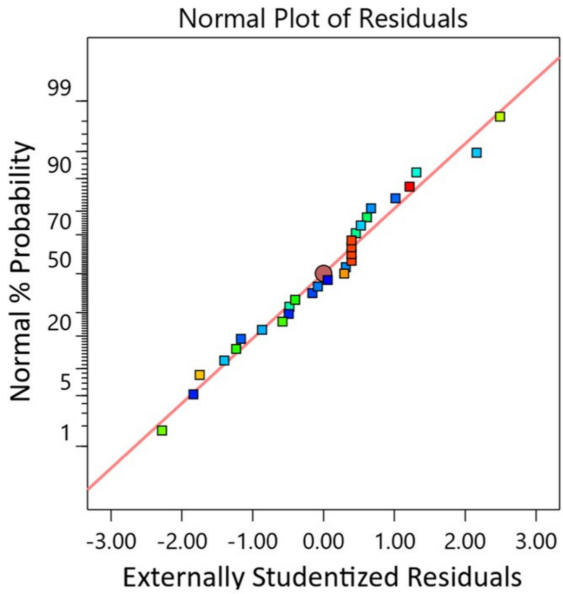

Figure 3. Normal probability plot of residuals for wear rate.

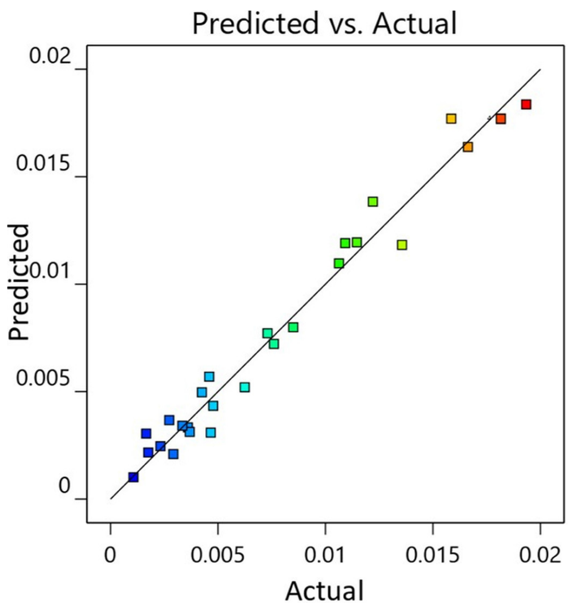

Figure 4. Normal probability plots of actual and predicted values.

developed at the contact surface due to higher temperature produced during sliding, which decreases the coefficient of friction between the interface surfaces[33]. At low sliding velocity and low applied loads the MML is stable, but, as the applied load increases the MML might broken, which results in amplified wear rate[34].

Figure 5d displays the collective influence of sliding velocity and sliding distance on the loss of material the ASA composite material. The volume loss is maximum when the sliding velocity and distance is medium, after that it is decreases. Increasing sliding distance rises the time of contact among the asperities. This leads to plastic deformation at the interface surfaces. High contact surface temperature causes

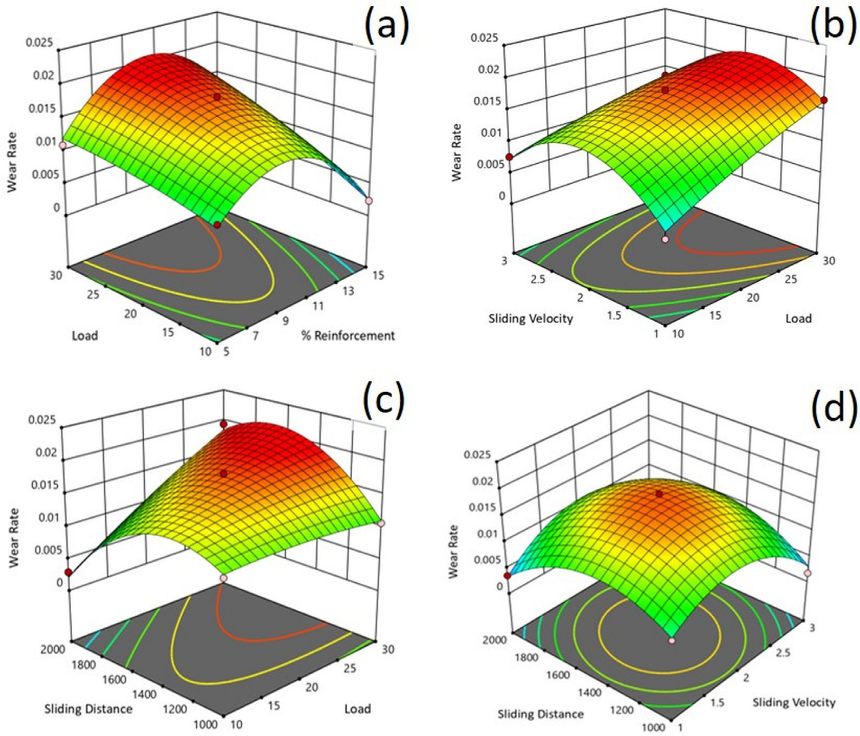

Figure 5. Response graphs for wear rate of ASA Composite.

the soft surfaces and the more material is removed from the contact surface of the ASA composites[35]. Design expert v 12 was used to analyse the wear results. The actual factors are utilized to predict the response for the levels of all factor are given in Equation 3. Here, the levels should be specified in the original units for each factor.

$$\begin{aligned}&Wear\ Rate = -0.065618 + 0.005485 \times A - 0.000712 \times \\&B + 0.025140 \times C + 0.000049 \times D + 0.000037 \times A*B - \\&0.000059 \times A*C + 6.08000 \times 10^{-8} \times A^{*}D - 0.000152 \times \\&B*C + 8.62460 \times 10^{-7} \times B*D + 3.14785 \times 10^{-6} \times C*D - \\&0.000319 \times A^2 - 6.7008510^{-6} \times B^2 - 0.006747 \times C^2 - \\&2.47427 \times 10^{-8} D^2\end{aligned} \quad (3)$$

The validation test was conducted by picking the set of parameters shown in Table 7. The value of developed model was calculated using Equation 3 and tabulated as shown in Table 8. The confirmation experiment value and its corresponding model values are compared. The calculated error values varies from 1.2% to 6.61% for wear rate. The comparison of values confirms the closeness of the developed model and the experimentation values. The data means for the validation test values were 0.015347 and this value lies between the 95% prediction intervals (PI).

3.2. Micro structural analysis of the composites

Figure 6 shows the microstructural characterization, micro hardness and wear track of the three different compositions 5%, 10%, 15%. Ceramic particles and porosity are clearly seen from the Figure 6. The imperfect wetting causes the porosity and agglomeration. The existence of particles in the 7075 Al disturbs the dendrite structure. Micro hardness gets increased with increase in the addition of more reinforcements. Ploughing marks are having lesser penetration due to arrest of movement of materials when more amount of reinforcements are added.

Table 7. Process parameters used in confirmation test.

Test No.	Reinforcement (%)	Applied load (N)	Sliding velocity (m/s)	Sliding distance (m)
1	10	20	2	1500
2	10	20	1	1500

Table 8. Comparison of regression model with experimental value.

Test No.	Regression model	Experimental value	% Error
1	0.017902	0.018121	1.2
2	0.011911	0.012754	6.61

3.3. SEM

SEM micrographs of the developed Hybrid composites Al 7075/SiC/Al_2O_3 with 0% to 15% volume fraction are presented the Figure 7. The figures are representative of the sliding distance of 2000m of total distances covered by the experiments. The Figure 7b-c reveals the cavities and ploughing marks on the worn out surface of the Hybrid composite alloys.

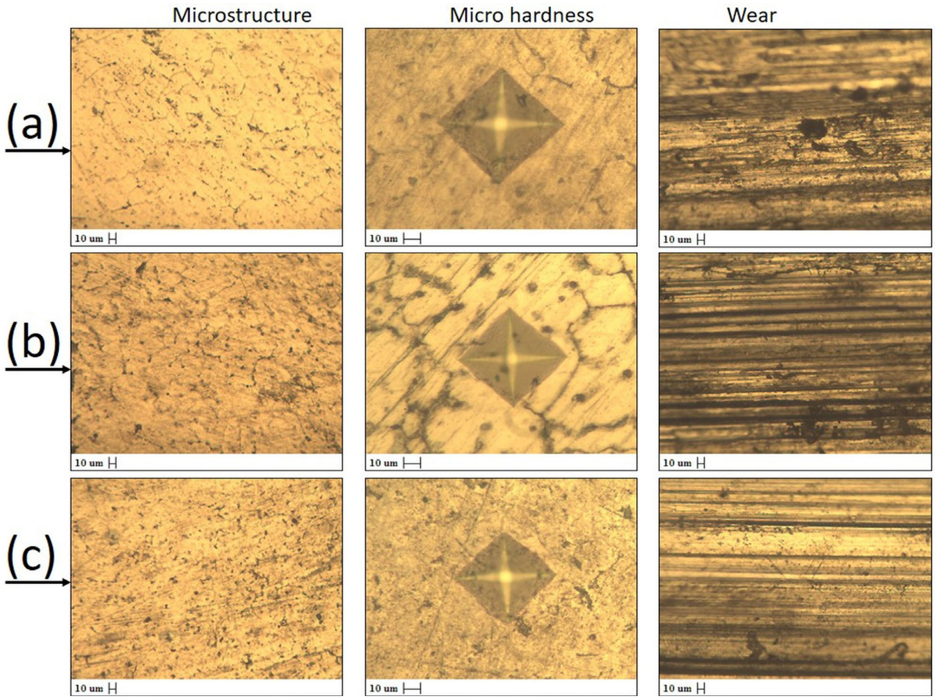

Figure 6. Optical micrograph with microhardness and wear of (a) ASA 5 (b) ASA 10 (c) ASA 15.

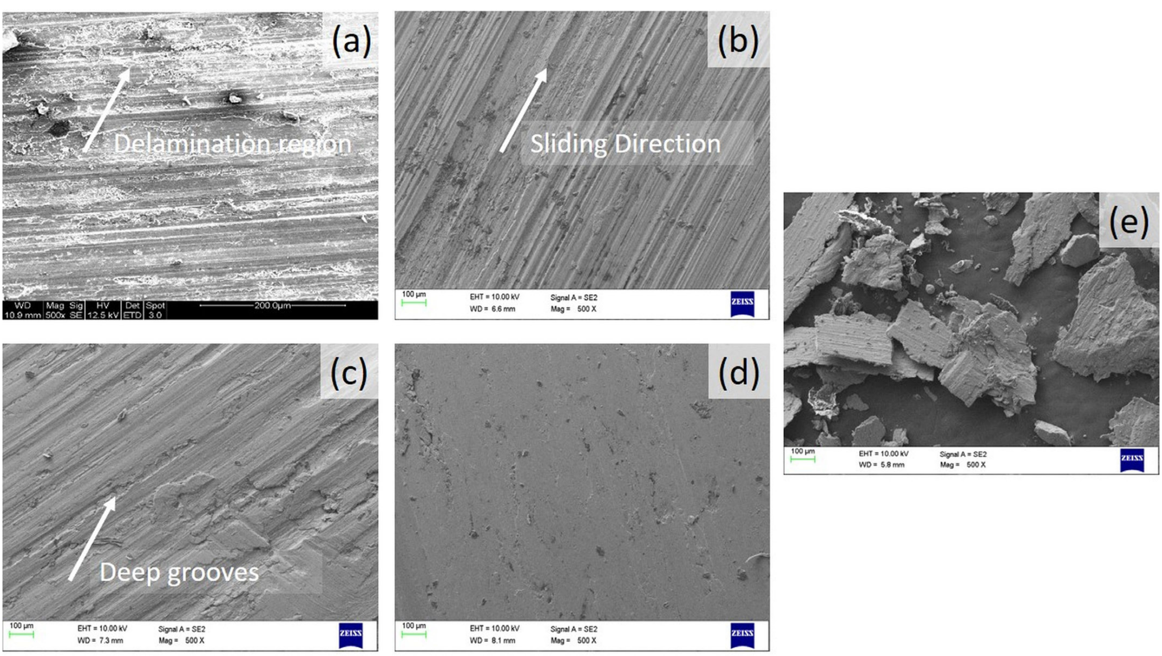

Figure 7. SEM images of worn out surfaces (a) ASA 0, (b) ASA 5, (c) ASA 10, (d) ASA 15 and (e) ASA 5 debris.

The reinforced particles are creating cavities on the surface because of the breaking and pulling out of the particles from matrix. The wear mechanism is abrasive in nature because of the exposures of hard ceramics reinforcements on the worn out surface. Since the ceramic particles hinder the delamination process, the composite alloy possess low rate of wear. The debris of the ASA 5 is also presented in Figure 7e. The debris generated during experimentation was collected for analysis by SEM. More amount of debris were generated during the test at 30N load and velocity 3m/s.

4. Conclusion

This study developed a new composite with varying volume percentage of Aluminium hybrid composites (Al 7075/SiC/Al_2O_3). The developed composite was subjected to wear study. The results are appreciable when compared to base alloy. Two stage stir casting helps in the evenly distribution of the particles thus increasing the resistance to wear capacity of the developed composites. The reason for the improvement in wear properties is the better interaction of SiC/Al_2O_3 ceramic particles into the base alloy. SiC/Al_2O_3 Particles improves the ductility of the materials which in turn helps to attain better wear behaviours. When compared with base alloy the Al 7075 reinforced with SiC/Al_2O_3 reinforcements resulted in good wear characteristics.

5. References

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