Assessment of Mechanical and Tribological Properties of Mono and Hybrid Composite by Statistical Technique

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Research Article

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Abstract

In this study, experiments have been carried out by performing tensile strength, hardness and sliding wear tests of Aluminium (Al) 7075 alloy, mono-composite (Al7075 + 10% Al_2O_3) and hybrid composite (Al7075 + 10% Al_2O_3 + 5% SiC) as per ASTM. The mono-composite and hybrid-composite are developed through stircasting method. It was found that an increase of hard ceramic particulates resulted in improved hardness, enhanced tensile strength. However, hybrid composites have better hardness, improved tensile strength as compared with Al 7075 alloy. Wear studies were performed using pin-on-disc wear test rig. The wear parameters are optimized using Taguchi technique. The results have revealed that the load is more significant on wear behavior of Al7075 alloys followed by speed & sliding distance. The addition of Al_2O_3 and SiC particulates to Al7075 improves the tribological behavior in mono composite and hybrid composite. Micrograph studies revealed damages due to adhesion and abrasion. The moropology of the wornout surface of mono composite exibhits the side flow with deep grooves. It reveals the indication of abrasive mechanism of mono composites. The hybrid MMCs (Al7075 + 10% Al_2O_3 + 5% SiC) show better wear resistance compared to the monolithic and mono composites.

1 Introduction

Al MMCs are engineering resource materials generally, reinforced by a mixture of two or more different materials in a direction to achieve the beneficial properties of composite. Composite materials possess better strength and improved properties when compared to base materials. They are exhibiting high strength and stiffness. Aluminium MMCs are progressive materials used in many applications such as, automobile, aeronautics, defence and other various engineering areas. It is commonly used in aerospace applications like skin and fuselage structures. Higher wear resistance of metal composite is highly desirable in tribological condition like brake drums, cylinder blocks, liners and piston rings. Most of the reinforcing particulates are ceramics such as Al_2O_3 (alumina oxide), SiC (silicon carbide), B_4C (boron carbide), TiB_2 (titanium diboride) and so on. They are frequently used as reinforcing materials, in combination with Al alloys to obtain AMCs and SiC/Al_2O_3, in the form of particles and found to have significant compatibility. Composites possess strengthening mechanisms compared to the conventional engineering materials [1, 2] AMCs are produced by various techniques like, stir-casting, spray deposition, powder metallurgy, squeeze casting and liquid infiltration techniques. Among these different fabrication methods, stir casting method is economical, simple and is an attractive technique for manufacturing of Al composites [3–5]. In a stir-casting method, generally, the particles reinforced are distributed uniformly into the molten liquid because stirring process will be controlled mechanically. MMCs with reinforcement up to 25–30 wt. % can be produced in this technique. The main benefits of this technique are applicable to mass production. Generally, stir casting method costs less by mass production compared to powder metallurgical method [6, 7]. Due to this reason, stir casting technique is the most frequently viable method used for fabrication of Al composites. Recently, research has been done on uniform mixing of reinforcements in base matrix attained by choosing parameters like temperature of molten melt, continuous feed of the particulates and speed of stirring. Among other parameters, wt. % of hard ceramic particulates is described to be the most effective parameter influencing material properties of Al composites [8–11]. Adding of Al_2O_3 to Al shows improvement in mechanical and wear properties in composites. SiC particulates-reinforced Al MMCs have attracted lot of interest from researcher/s. Reinforcing particles interact electro-chemically or physically with the base matrix, significant to enhance oxidization. The relationship between the base material and reinforcement/s can also accelerate the oxidization.

Farzaneh Jafari et al. [12] examined the wear rate of Al + SiCp (5–15%) MMCs. They found that, increase in wt. % of particulates (reinforcements) led to reduce the wear rate in composite. And, also, they concluded that for all the loads, the as-cast sample had low wear resistance compared to composite materials. Ajith G. Joshi et al. [13] reported a paper on wear rate of Al-based composite reinforced by hard ceramics particulates like SiC particulates and graphite (Gr) manufactured by using stircasting method. Experimental outcomes shown that SiC reinforcement imparted better strength, high wear resistant with better COF to aluminium. Suresh et al. [14] examined the wear behavior of the hybrid MMCs produced by liquid state method. They observed that, the wear loss increased with increase in load applied and sliding distances. Mukesh Kumar [15] investigated the wear properties of Al-Al_2O_3 + SiC + Gr composite. It is concluded that increase in temperature due to increase in sliding distance. Ramesh K et al. [16] examined the effect of SiCp reinforcement on mechanical properties & wear behavior of B_4C/Talc reinforced Al6061 hybrid MMCs fabricated by stircasting method. Results revealed that, SiC, B_4C and talc particulates reinforced Al hybrid composites exhibited improved mechanical properties, increased wear resistance and reduced friction coefficient. S. Suresh et al. [17] evaluated the material properties of Al hybrid MMCs produced by stircasting technique. Al7075/Al_2O_3/SiC exhibited high wear resistance when compared to base matrix. However, increasing the content of reinforcements will resulted in the better wear resistance. Bialo et al. [18] in his paper presented the outcomes of the wear rate of 10 wt. % Al_2O_3 reinforced Al alloy reinforced by. The wear rate of the Al MMCs was strongly influenced by the properties of the mating material used in the wear tests. And, also, they reported that the COF in the composite was also influenced by the hardness within the counterface. With a harder counterface, the COF increased, caused by the embedment of the material separated from the composite in the counterface. Gurpreet Singh and Sanjeev Goyal [19] concluded that load, speed and interaction of these two parameters were more significant on wear behaviour of MMCs. The results showed full agreement with in the models evaluated. Shouvik G et al. [20] examined the wear rate of Al-7.5% SiC MMCs for varying load, time and sliding speed by using Orthogonal Array (OA) concept. It is revealed that “time” is more significant on the wear characteristics. They also concluded that accurate control of factors can affect the enhanced design of the AMMCs for wear applications. Ekka et al. [21] examined the wear rate of hybrid AMMCs using Taguchi design concept. They observed that combination of Cenosphere/SiCp MMCs exhibits the high wear resistance compared to other hybrid MMCs. And also they reported that friction coefficient was affected by factors like load, sliding speed had significant wt. % of reinforcement.

From the above survey shows the mechanical and wear behavior of MMCs with different ceramic reinforcement. However, the mechanical and wear characteristics of MMCs reinforced with different ceramic particles under various process parameters not clearly discussed. In this research work, the mechanical properties and wear behavior of Al7075 alloy (monolithic), mono and hybrid MMCs were studied. The present research shows influence of two different reinforcements on mechanical behavior and to evaluate the wear behavior of MMCs, varying factors/parameters such as load (N), speed (rpm) and sliding distance (m) were considered and evaluated through Taguchi method and compares the outcomes with the optimized values. Wornout surface of test samples have been studied by using SEM analysis.

2 Investigation Procedures

2.1 Materials and Process

Al alloy of grade 7075 was used as a base material. It is having better wear and corrosion resistance and good fracture toughness. It is extensively used in space applications, automobiles, and outer surface of supersonic aircraft. The material composition of Al7075 in wt. % is as depicted in Table 1. Al_2O_3 of average 100 mesh size of particulates with ph value of 6.5–7.5 and SiC of 220 mesh size were used as reinforcing materials. In the present research work, two different types of MMCs were manufactured i.e., mono composite (Al7075 + 10% Al_2O_3) and hybrid composite (Al7075 + 10% Al_2O_3 + 5%SiC) and were compared with Al7075. Both the composites i.e., mono and hybrid composites were fabricated using liquid metallurgical technique using a coke furnace. Stirring process was performed by using a 3-blade SS (stain less steel) stirrer at the average speed of 150 ± 5 rpm for the duration of 5 minutes to avoid agglomeration of particulates. Base alloy was melted using graphite crucible. While stirring, the preheated Al_2O_3 and SiC particulates were charged into the molten melt. Degasifying tablet was used to remove the inert gases present in molten melt. Molten melt of composite was poured in to the pre-heated mould box. Finally, the composites were machined by using CNC lathe. For the purpose of microstructure study, composite specimens were prepared with different cross-sections and were polished by using 400 grit sizes of emery paper with diamond paste. Finally, the test samples were polished using velvet-disk polishing equipment to get sufficient finish on the sample surface as per the procedure of metallographic study.

Table 1
Material composition of Al-7075 alloy with wt. %

Content	Zn	Cu	Mg	Si	Fe	Mn	Ni	Sn	Cr	Al
Wt. %	5.424	1.480	2.306	0.059	0.256	0.052	0.052	0.012	0.280	Rem.

3 Result And Discussions

3.1 Metallographic Study

The microstructure for Al7075, mono-composites (Al7075 + 10%Al_2O_3) and hybrid composites (Al7075 + 10%Al_2O_3 + 5%SiC) as shown in Fig. 1. Figure 1(a) depicts the micrograph image of monolithic and reveals the existence of intermetallic compounds. Figure 1(b) shows mono composite with uniform dispersion of Al_2O_3 particulates in the Al7075 matrix material. Generally, this is due to accurate stirring technique used at the time of fabrication. In Fig. 1(c), in hybrid composites, uniform dispersal of particulates of Al_2O_3-SiC is revealed in the micrographs. Reinforced particulates are observed to be randomly distributed with in the alloy. However, clustering of the particulates at some places was also seen. And similar results were obtained by other researchers [19, 22]. The agglomeration of particulates increased in certain places due to increase in the wt. % of hard ceramic reinforcements in the hybrid composites.

3.2 Hardness

Micro hardness of Al7075, mono-composites (Al7075 + 10%Al_2O_3) and hybrid composites (Al7075 + 10%Al_2O_3 + 5%SiC) were studied according to ASTM-E92 standards. Here, 10 mm indenter with diamond shape was considered under the constant load of 2 kg. The hardness of test samples were noted at 3 different regions on the test samples. Finally the average value of hardness was noted. The hardness value for all the compositions are depicted in Fig. 2. From the Fig. 2 it is seen that the mono composite and hybrid composites exhibit improved hardness values when compared to monolithic.

The hard ceramic particles are more closely bounded and uniformly dispersed throughout the base matrix. Therefore, higher stress is essential for movement of the dislocations once they encounter these hard ceramic particles. Thus, the uniformly distributed of hard ceramic particles may be attributed to improved dispersion strengthening through the appropriate particles dislocation interaction [6, 9, 11]. Therefore, the MMCs reinforced with two different hard ceramic particulates (Al_2O_3 + SiC) possess higher hardness.

3.3 Tensile Strength

The tests were conducted according to the ASTM-E8 standards by using U T M at a maximum load of 450 KN. In the present research, three test samples of a similar composition were tested to get an average value of tensile strength. Here, the variation of values was less than 5%. The results of tensile strength for all the compositions are shown in Fig. 3. When it is compared to the base alloy, the mono and hybrid composites exhibits enhanced tensile strength. The outcomes show that the UTS are improved by increasing in the content of hard ceramic particulates. This improvement in tensile strength may be due to the presence of hard particulates of Al_2O_3 in mono composites and Al_2O_3 + SiC in hybrid composites, which leds to improve the tensile strength. The improvement in tensile strength may also due to the uniform dispersal of particles and low degree-of-porosity in composites and hybrid composites. This observation conforms to the results of most hard ceramic particles reinforced MMCs [6, 8, 9].

3.4 Wear Behavior with Taguchi Design of Experiment

This method is an effective design concept [23, 24], usually designed to produce better quality products in a cost-effective manner and is extensively used for various industrial applications. Generally, it is used to evaluate the effect of varying parameters. The test samples were subjected to experimentation under the room temperature (27ºC) by considering Taguchi analysis of L_{27} orthogonal array (OA). Wear test samples were prepared based on the ASTM G-99 standard size of 8 mm dia and 35 mm of length. Figure 4 shows the wear testing equipment which was used for the present investigation. During wear tests, the test samples were held rigidly against the rotating hard disc (steel). The steel disc and test samples were cleaned thoroughly by using organic compound (acetone) to maintain the accuracy in outcomes. In the present investigation, wear behaviour is expressed as weight loss (Gms) of the test specimen. During the experimentations, the specimens were systematically cleaned by using acetone fluid, and then weighed by digital weighing apparatus to maintain the accuracy of ± 0.0001 gm. After each wear test trials, the samples were washed with acetone fluid and then the final weight of the test samples were measured precisely. Here a wear rate is calculated by difference of initial and final weights of test specimens. Test trials were performed based on the selected parameters and their levels, which is tabulated in Table 2. Orthogonal array (OA) of 27 tests and their outcomes of samples for the Al7075, mono-composites (Al7075 + 10%Al_2O_3) and hybrid composites (Al7075 + 10% Al_2O_3 + 5%SiC) are depicted in Table 3.

Table 2
Input parameters and their levels

Sl. No.	Process parameters	Level – 1	Level – 2	Level – 3
1	Load (N)	7.5	10	12.5
2	Sliding Speed (rpm)	150	300	450
3	Sliding Distance (m)	300	600	900

Table 3
Taguchi L27 orthogonal array and their response

Trial No.	Load (N)	Sliding Speed (rpm)	Sliding Distance (m)	Wear Loss (Gms)		
				(Al-7075)	Mono Composite (10% Al_2O_3)	Hybrid Composite (10% Al_2O_3 + 5% SiC)
1	7.5	150	300	0.035	0.015	0.011
2	7.5	150	600	0.042	0.020	0.013
3	7.5	150	900	0.049	0.030	0.026
4	7.5	300	300	0.038	0.017	0.012
5	7.5	300	600	0.041	0.018	0.013
6	7.5	300	900	0.059	0.030	0.021
7	7.5	450	300	0.056	0.025	0.023
8	7.5	450	600	0.064	0.032	0.028
9	7.5	450	900	0.071	0.038	0.035
10	10.0	150	300	0.049	0.020	0.017
11	10.0	150	600	0.068	0.041	0.039
12	10.0	150	900	0.074	0.050	0.045
13	10.0	300	300	0.060	0.042	0.040
14	10.0	300	600	0.072	0.051	0.042
15	10.0	300	900	0.075	0.055	0.050
16	10.0	450	300	0.056	0.030	0.026
17	10.0	450	600	0.064	0.038	0.036
18	10.0	450	900	0.066	0.045	0.038
19	12.5	150	300	0.048	0.020	0.018
20	12.5	150	600	0.052	0.039	0.030
21	12.5	150	900	0.068	0.040	0.036
22	12.5	300	300	0.071	0.055	0.051
23	12.5	300	600	0.072	0.056	0.049
24	12.5	300	900	0.079	0.060	0.057
25	12.5	450	300	0.081	0.065	0.061

Trial No.	Load (N)	Sliding Speed (rpm)	Sliding Distance (m)	Wear Loss (Gms)		
				(Al-7075)	Mono Composite (10% Al_2O_3)	Hybrid Composite (10% Al_2O_3 + 5% SiC)
26	12.5	450	600	0.085	0.070	0.065
27	12.5	450	900	0.089	0.073	0.070

The effect of process parameters were studied by ANOVA technique, main effect plots, regression analysis, normal probability plots and surface plots. The "smaller is better" condition is used for analysis of wear loss of the MMCs. The ANOVA outcomes are depicted in Table 4–6 for wear loss. The confidence level of P-value < 0.05 were measured as significant contribution to the performance [25, 26]. The significance of the parameters was confirmed through main effects plots as depicted in Fig. 5. ANOVA analysis for wear characteristics of Al 7075 alloy are as shown in Table 4. An ANOVA result indicates the load (36.20%) is more significant on wear loss followed by sliding speed (21.66%) & sliding distance (18.54%). Correspondingly, whereas in Al7075 + 10% Al_2O_3, load (48.01%), sliding speed (14.91%) and sliding distance (13.7%) have high influence on wear loss given in Table 5. However, for hybrid MMCs (Al7075 + 10% Al_2O_3 + 5% SiC), load (48.66%), sliding speed (16.17%) and sliding distance (10.59%) have great influences on wear loss given in Table 6. The outcomes reveal that, the load is the major significant parameter followed by other two parameters for wear loss in all the composites. From the outcomes it is confirmed that in hybrid composites (Al7075 + 10% Al_2O_3 + 5% SiC), exhibit higher low wear rate when compared to Al alloy (Al7075) and mono composite (Al7075 + 10% Al_2O_3) because of hard ceramic particulates. Similar outcomes have been observed by other researchers [27]. The ceramic particles protruding from the composites surface produced sharp asperity and formed non-uniform interaction (contact) between the samples and counter-face which tends to increase wear rate. On addition of secondary hard ceramic reinforcement in MMCs, the distances between particulates reduce affecting the presence of more reinforcing particulates. Earlier studies exhibited that the existence of hard reinforcement particulates led to enhanced hardness. The wear behaviour was related to the inversion of material hardness and wear loss [12]. From the Fig. 2(a-c), it is seen that the increase in wear parameters led to increase in wear loss. Generally, the key reasons for the obtained outcomes are due to the development of an oxide layer on the matrix surface resulting in more wear. And, also, due to increase in temperature as well as softening of the composite surface results in high wear. Whereas, in case of mono MMCs, the reinforcing of hard particulates improves wear resistance. As observed, the sliding speed generally increased the wear loss because of high strain rate and this led to delamination. The hybrid composites exhibit high wear resistance while compared to mono composites and monolithic [28, 29].

Table 4
ANOVA results of Al 7075 alloy (monolithic)

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Cont. (%)	Remarks
Load (N)	1	0.0020056	0.0020056	0.0020056	35.3014	0.0000047	36.20	Significant
Sliding Speed (rpm)	1	0.0012005	0.0012005	0.0012005	21.1310	0.0001271	21.66	Significant
Sliding Distance (m)	1	0.0010276	0.0010276	0.0010276	18.0868	0.0002998	18.54	Significant
Error	23	0.0013067	0.0013067	0.0000568			23.58	
Total	26	0.0055403					100	
R-Sq = 76.41%								

Table 5
ANOVA results of mono composite

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Cont. (%)	Remarks
Load (N)	1	0.0035561	0.0035561	0.0035561	46.0132	0.0000006	48.01	Significant
Sliding Speed (rpm)	1	0.0011045	0.0011045	0.0011045	14.2916	0.0009689	14.91	Significant
Sliding Distance (m)	1	0.0009680	0.0009680	0.0009680	12.5253	0.0017526	13.07	Significant
Error	23	0.0017775	0.0017775	0.0000773			24.00	
Total	26	0.0074061					100	
R-Sq = 76.00%								

Table 6
ANOVA results of hybrid composite

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	Cont. (%)	Remarks
Load (N)	1	0.0036125	0.0036125	0.0036125	45.5658	0.0000007	48.66	Significant
Sliding Speed (rpm)	1	0.0012005	0.0012005	0.0012005	15.1423	0.0007366	16.17	Significant
Sliding Distance (m)	1	0.0007867	0.0007867	0.0007867	9.9232	0.0044813	10.59	Significant
Error	23	0.0018235	0.0018235	0.0000793			24.56	
Total	26	0.0074232					100	
R-Sq = 75.44%								

The response for mean has been evaluated based on the rank allotted to the mean values as shown in Table 7–9. The factors are statistically significant and also it could be seen that the load is an important factor as the delta of means ranked it as 1 followed by the speed and sliding distance for Al alloy and composite materials.

Table 7
Response data for means for monolithic

Levels	Load (N)	Sliding speed (rpm)	Sliding distance (m)
1	0.05056	0.05389	0.05489
2	0.06489	0.06300	0.06222
3	0.07167	0.07022	0.07000
Delta	0.02111	0.01633	0.01511
Rank	1	2	3

Table 8
Response data for means for mono composite

Levels	Load (N)	Sliding speed (rpm)	Sliding distance (m)
1	0.02500	0.03056	0.03211
2	0.04133	0.04267	0.04056
3	0.05311	0.04622	0.04678
Delta	0.02811	0.01567	0.01467
Rank	1	2	3

Table 9
Response data for means for hybrid composite

Levels	Load (N)	Sliding speed (rpm)	Sliding distance (m)
1	0.02022	0.02611	0.02878
2	0.03700	0.03722	0.03500
3	0.04856	0.04244	0.04200
Delta	0.02833	0.01633	0.01322
Rank	1	2	3

Regression analysis exhibits the relationship among two / more predictor variables by using a linear regression equation. A regression equation establishes the correlation among the wear parameters and their interactions. The regression equations for monolithic, mono composite and hybrid composite are shown in Eqs. (1), (2) and (3) respectively.

Wear loss of Al7075 alloy = -0.011 + 0.004 Load + 5.44e-005 Sliding Speed + 2.51e-005 Sliding Distance	**(1)**
Wear loss of mono composite = -0.04 + 0.005 Load + 5.22e-005Sliding Speed + 2.4e-005 Sliding Distance	**(2)**
Wear loss of hybrid composite = -0.050 + 0.0056 Load + 5.4e-005 Sliding Speed + 2.20e-005 Sliding Distance	**(3)**

Generally, regression equations have been used to study the reactions within the parameters. To check the accuracy of predicted values, the test trials have been conducted and the comparison among the experimentation and predicted values is depicted by graphical illustrations. The response of predicted and experimental values for wear behavior of Al7075, mono composites and hybrid MMCs is shown in Fig. 6.

The contour plots which are executed by the regression model and drawn to show the combined effects of parameters used in the present investigation. Generally, these plots are used to identify the interactions between the two parameters. By studying these plots, the optimized values of the each parameter could be predicted [30]. The contour plots for wear loss versus the independent parameters of all the materials are shown in Fig. 7.

Figure 7 exhibits the outcomes of wear loss in variation of wear parameters with material compositions. It is observed that wear loss increases by increasing in load, speed and sliding distance. High friction was detected at higher load and speed. Due to this, the temperature developed in the test specimen surface has increased. Therefore, the hardness of materials has reduced due to brittleness and wear loss on the test specimen has increased. As the temperature increases, the bonding among matrix and reinforcement gradually reduces and the material becomes soft [31].

Confirmation test is the main purpose of studying the confirmatory trial was to evaluate the optimal levels of varying process parameters selected. Confirmation trials were conducted based on the optimized values from the MEP (Fig. 4(a-c)). The selected levels of parameters are depicted in Table 10. The confirmatory experimental trails were carried out and the outcomes were compared with OA experimental values and are tabulated in Table 11. The result indicates that the calculated errors are less than 10% for all the composite materials. This is within acceptable limit.

Table 10
Confirmatory test parameters for different compositions

Process parameters	**Load (N)**	**Sliding speed (rpm)**	**Sliding distance (m)**
Optimized values of all the composition	7.5	150	300

Table 11
Confirmation test results for all the composition along with regression values

Composition	**Process parameters**	**Confirmation test results**	**OA experimental values**	**Error %**
Base alloy (Al-7075)	Load (N) : 7.5 Sliding speed (rpm) : 150 Sliding distance (m) : 300	0.036	0.035	2.85
Mono Composite (10% Al_2O_3)		0.014	0.015	6.66
Hybrid Composite (10% Al_2O_3 + 5% SiC)		0.012	0.011	9.09

To evaluate the wear characteristics of the MMCs, SEM investigation on the wornout composites samples was conducted. Usually, the wear behaviour will be influenced by the characteristics of the wornout surface of the MMCs. Figure 8 depicts the SEM image of wornout surface of monolithic, mono and hybrid MMCs tested at load of 12.5 N, speed of 450 rpm and sliding distance of 900 m. The SEM images clearly exhibit how the wear track produced on the surface of Al7075, mono-composites and hybrid composites. Figure 8(a) shows wornout surface of base alloy Al7075. The image reveals unstiffening of the monolithic at interface temperature which creates plastic deformation. At higher level of load, speed and sliding distance, adhesive wear mechanism was seen in Al7075. The image clearly shows that the wear intensity is high without the presence of reinforcement. It concludes that the matrix without reinforcements generally, undergoes wide plastic deformation. Therefore, more losses in material are seen in wear surface. Figure 8(b) depicts the SEM image of Al7075 + 10% Al_2O_3 composite with more number of shallow grooves. Due to presence of hard reinforcement, generally, the wear resistance will be high. And also, the wornout surface observed is rough because of ceramic particulates exposed in resisting the wear loss of the composite during sliding on the steel disc. The pull out of the hard particulates leds to abrasion on the composite surface causing in the plastic deformation of particulates. It reveals that the addition of Al_2O_3 particulates led to minimum wear loss in mono composite compared to monolithic. Figure 8(c) indicates the SEM image of the Al7075 + 10% Al_2O_3 + 5%SiC composite. Here, wear resistance increases due to presence of Al_2O_3 and SiC particulates. Image shows that hybrid composite has much rougher surface compared to mono composite and monolithic. The composite exhibits large deep grooves and cavities on the wear surfaces. The wear resistance is high in case of high wt. % of reinforcement. Wear mechanism has been studied for the effect of adding of hard ceramic particulates which gives many causes for the high wear resistance of hybrid MMCs. Development of Mechanical Mixed Layer (M M L) when the temperature raises, due to the hard reinforcement of SiCp undergoes a chemical interactions at the time of sliding and generally, which acts as a lubricant, particularly at high sliding speeds. The protection provided by MML is witnessed to increase by increasing the reinforcement content. Similar outcomes were observed by other researchers [32–35].

EDS (Energy Dispersive Spectroscopy) study of monolithic, mono-composite and hybrid MMCs is shown in Fig. 9. EDS study made on the wornout surface of mono composite shown in Fig. 9(a), revealed the presence of oxygen (“O” peak) due to the presence of an oxidized layer, which suggests the existence of Al_2O_3 (aluminum oxide) content in the composite. In hybrid composite (Fig. 9(b)), in addition to the mono reinforcement, the existence of “Si” peak was also observed. This shows the presence of SiC particles in the hybrid composite. These carbide particulates greatly influence the wear behavior of composite, since in the presence of hard particulates, the wear loss is reduced compared to mono composite and monolithic. Similar outcomes have been reported by other researchers [36–39].

4 Conclusions

In conclusion, significant outcomes from the performance evaluation of Al7075, mono composite (Al7075 + 10% Al_2O_3) and hybrid composite (Al7075 + 10% Al_2O_3 + 5% SiC) have been revealed. They are:

1. In the present investigation, the monolithic, mono composite and hybrid composite materials were successfully produced using stircasting technique. It was seen that an increase of hard ceramic particles content resulted in enhanced hardness and tensile strength. However, hybrid composites have better hardness, improved tensile strength as compared to mono composite and Al alloy.
2. Addition of SiC reinforcement to produce hybrid composite materials has been found to have high wear resistance, when compared to monolithic and mono composite material. ANOVA analysis shows the applied load (N) is more significant on the wear behaviour compared to sliding speed (rpm) and the sliding distance (m).
3. Regression analysis of correlating process parameters with wear behaviour has been formulated. Coefficient of determination, R-Sq (R^2) was determined and was found to be within the acceptable limits. The error related with monolithic, mono-composites and hybrid composites is less than 10% indicated in the confirmation test results.
4. SEM image shows that wornout surface of hybrid composite has high abrasion wear when compared to mono-composite and monolithic. It is due to presence of hard ceramic reinforcements like Al_2O_3 and SiC content presence in the developed mono and hybrid composites. EDS results indicates the presence of Al_2O_3 content in mono composite and Al_2O_3-SiC content in hybrid composite material.

5. From the confirmatory experiment test results, a maximum of 9.09% of error was found in hybrid MMCs whereas for other two compositions it was much less. This is within acceptable limits.

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Figures

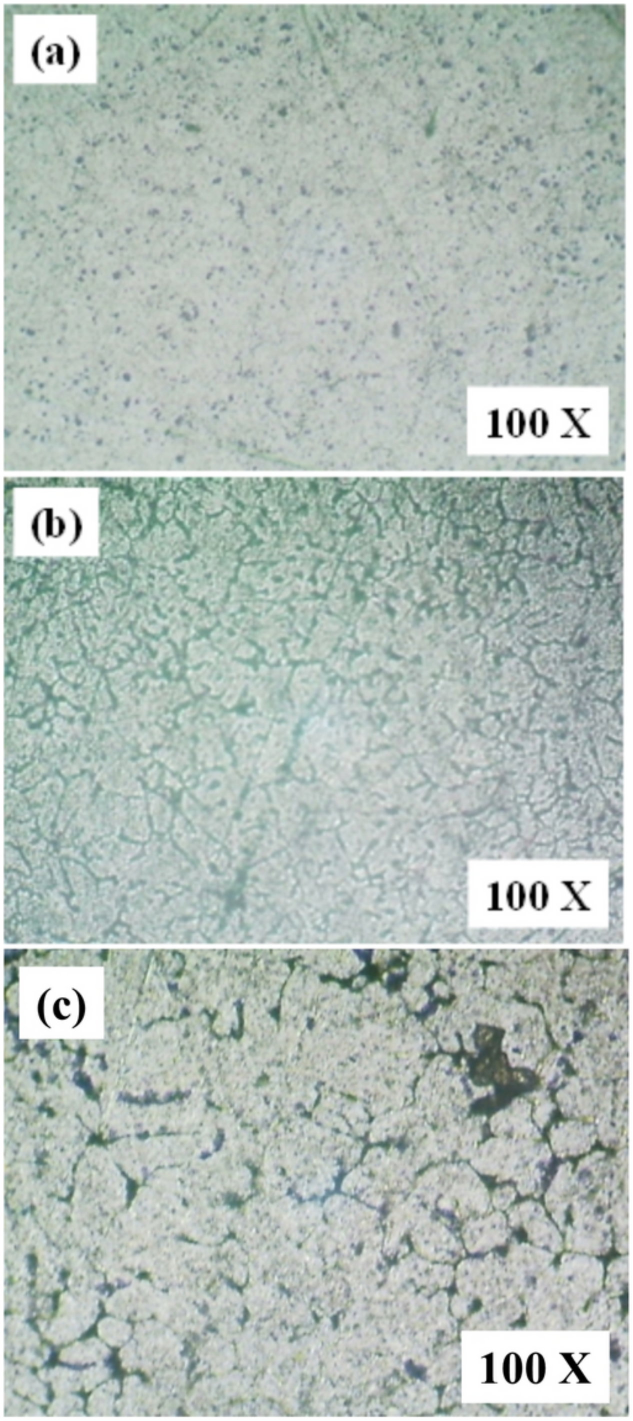


Figure 1

Microstructure of (a) Al-7075 (monolithic), (b) mono-composites (Al-7075 + 10% Al_2O_3) and (c) hybrid composites (Al-7075 + 10% Al_2O_3 + 5% SiC)

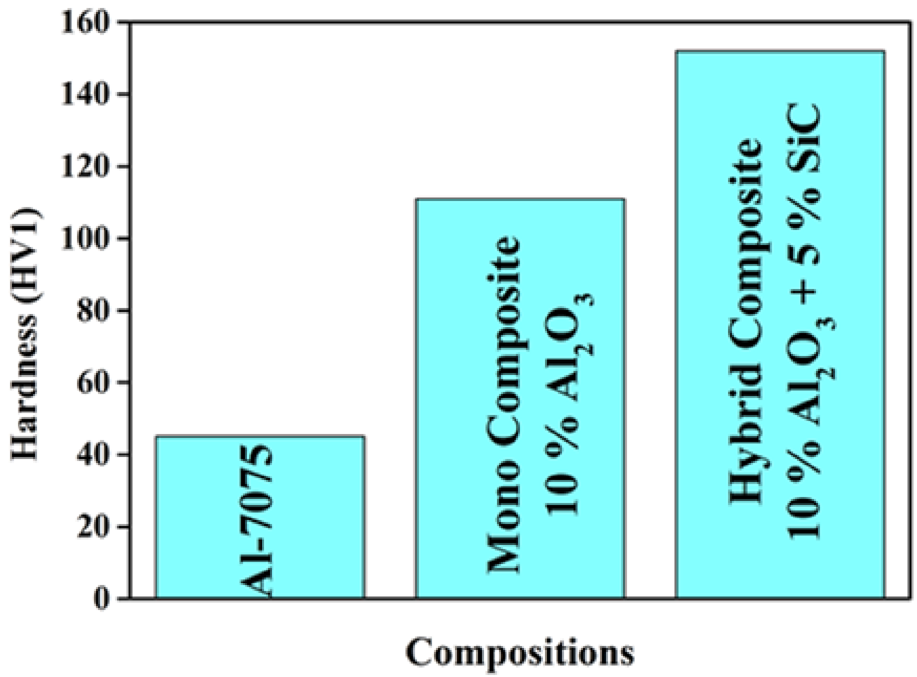


Figure 2

Hardness of monolithic, mono composites and hybrid composites

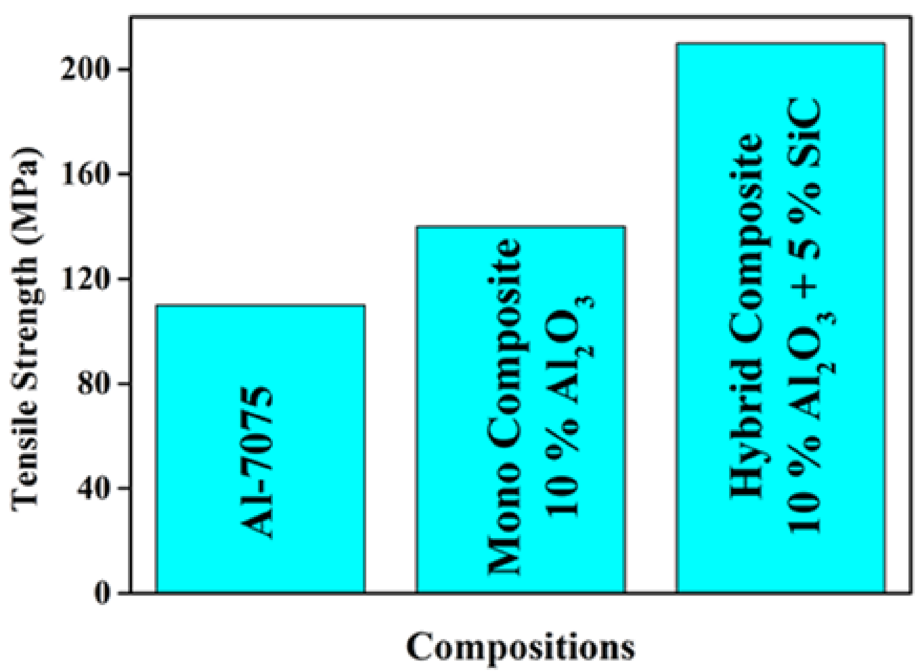


Figure 3

Tensile strength of monolithic, mono composites and hybrid composites

Figure 4

Pin-on-disc wear testing equipment

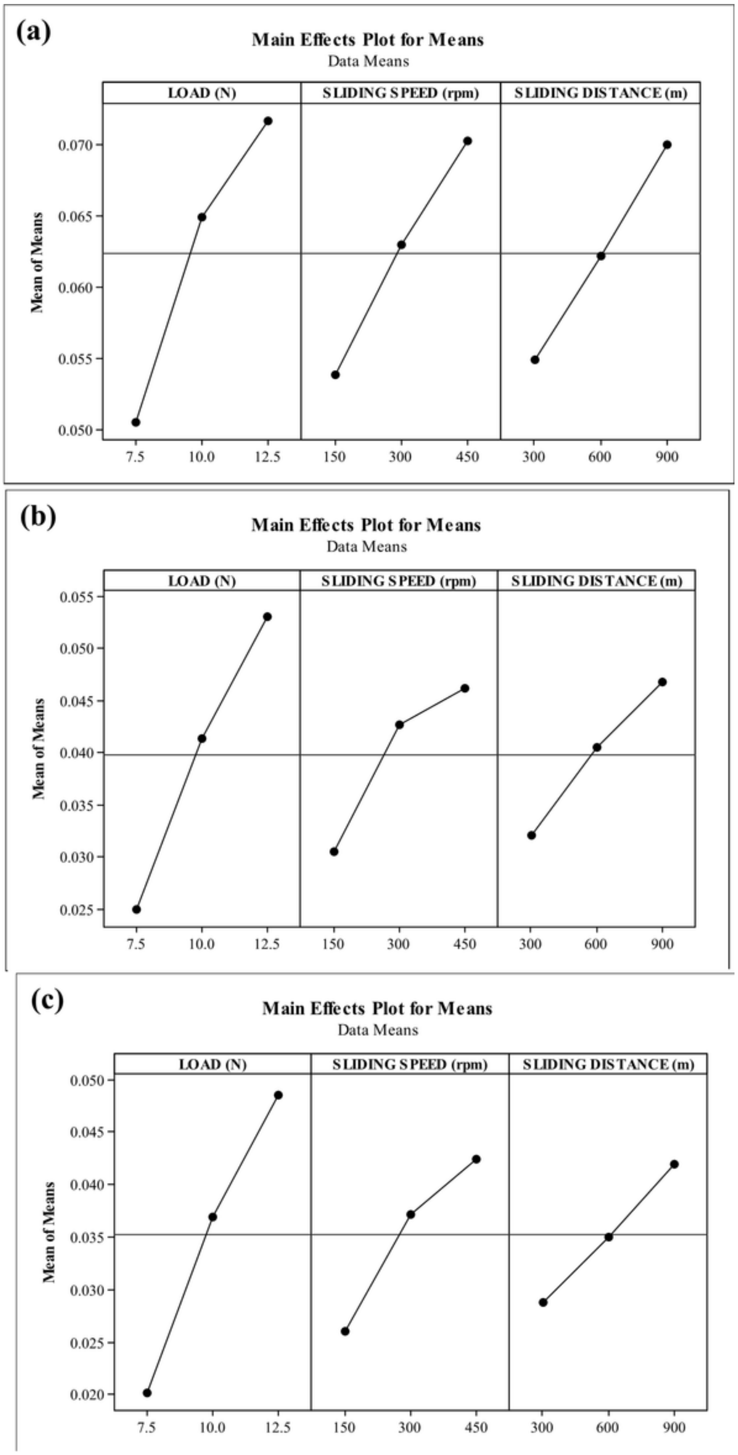


Figure 5

Main Effects Plots for (a) Al7075, (b) mono composites and (c) hybrid composites

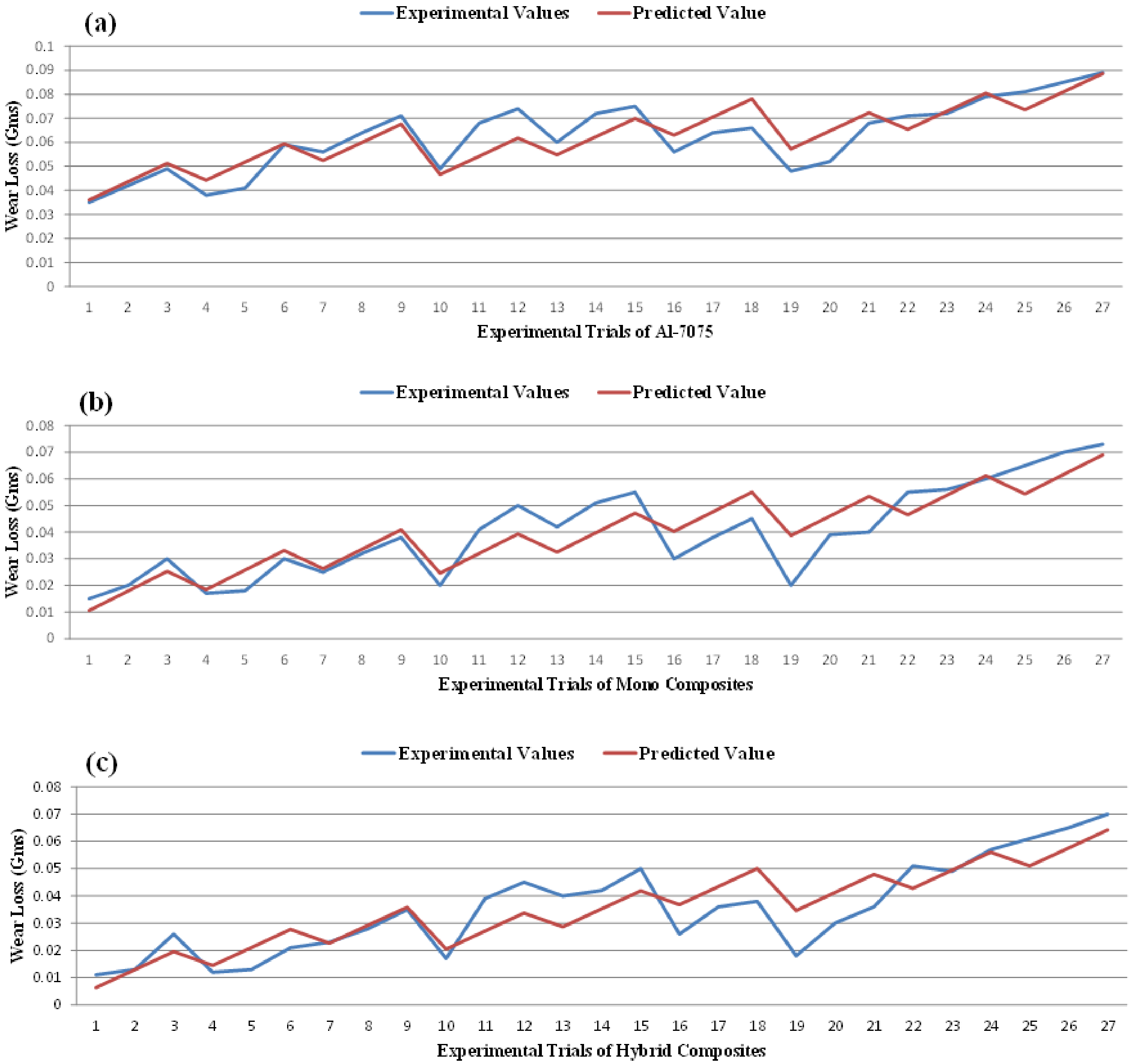
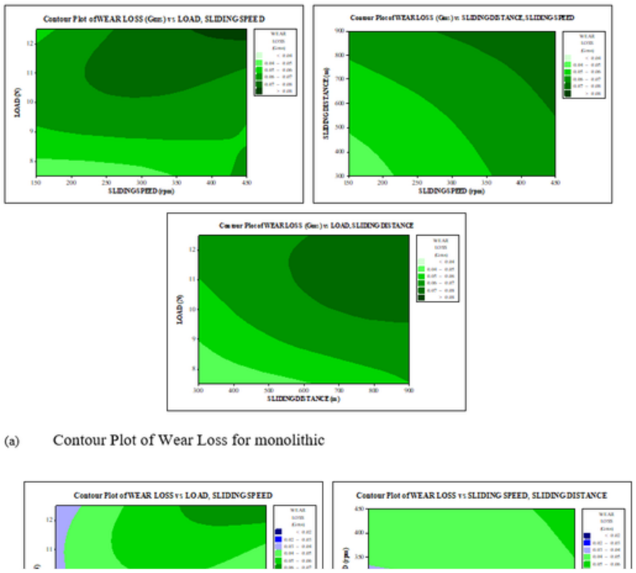


Figure 6

Response of experimental vs. predicted values for wear loss of (a) Al7075, (b) mono composites and (c) hybrid composites



(a) Contour Plot of Wear Loss for monolithic

Figure 7

Contour Plot for monolithic, mono composites & hybrid composites

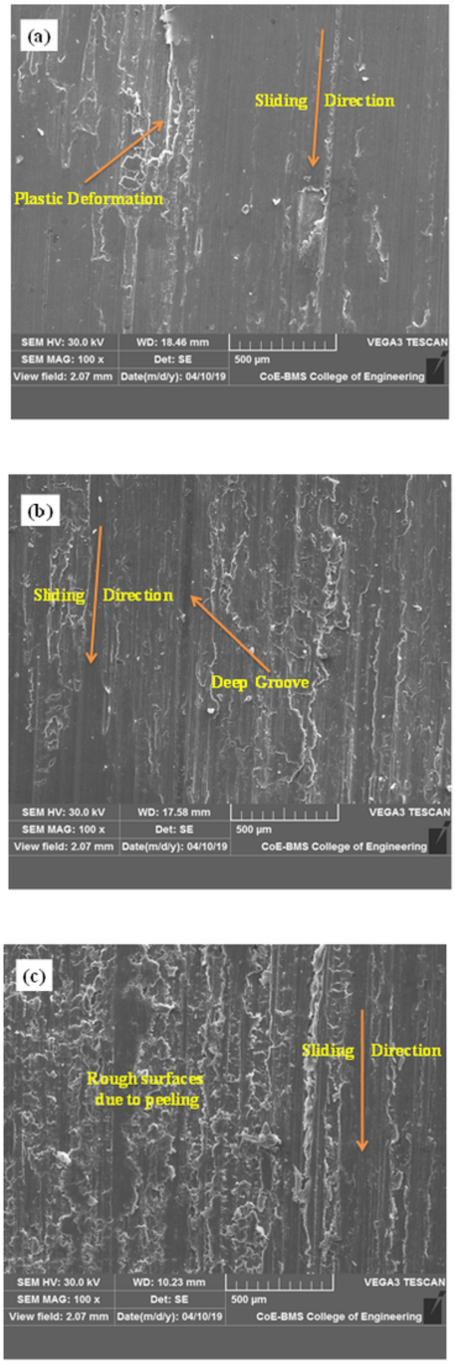


Figure 8

Wornout surface of (a) base alloy (Al7075), (b) mono composites and (c) hybrid composites

Figure 9

EDS profiles of (a) mono composites (Al7075 + 10% Al_2O_3) and (b) hybrid composites (Al7075 + 10% Al_2O_3 + 5% SiC)