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RESEARCH

Effect of Heat Treatment on Wear behavior of Hybrid Aluminum Metal Matrix Composites

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A B S T R A C T

The focus of the paper is the wear behavior of hybrid aluminum metal matrix composites. The main objective of the investigation is to conduct the wear test at room temperature for both the as-cast and age hardening conditions. Materials chosen for the study are Aluminum 7075 as a matrix, Silicon Carbide and Alumina are the reinforcements. Hybrid metal matrix composites are produced by utilizing stir casting route for 5–15 wt.% silicon carbide and alumina. Microstructural characterization of hybrid aluminum metal matrix composites reveals the homogeneous mixing of reinforcements. It is noticed that the higher composite hardness is obtained due to the raise in weight percentage of the reinforcement up to 10% of hybrid reinforcements. In the T6 heat treatment, there is a gain in hardness by 24 % for optimum percentage of reinforcement i.e. 10 % compare with as-cast composites.

1. INTRODUCTION

Aluminum matrix composites (AMC)[1] is the largest gathering of MMCs. AMCs are normally based on aluminium-silicon compounds and on the combinations of series 2000 and 6000 series. AMCs are reinforced by Al_2O_3 (Alumina) or SiC (silicon carbide) particles in proportions of 03-20 wt% might be as long/short fibres and/or particles of Al_2O_3, SiC, Graphite. AMCs can be prepared by Powder metallurgy (sintering); Stir casting; Infiltration methods. High strength even at raised temperatures, high load/deformation, low density, high thermal conductivity, increased wear resistance behavior [2] are the some of the properties of AMCs. Hybrid aluminum metal matrix composites (HAMMC) materials are an excellent substitute to conventional materials, because of the enhanced hardness, specific strength and creep resistance properties. Based on these properties, one can consider the HAMMC for the automobile and aerospace applications [3].

A surface phenomenon referred as wear will occurs by relocation & separation of material. It generally suggests a progressive loss of material and change of measurements over some undefined time frame. The main components that influences wear and friction behavior of aluminum alloys are sliding distance and speed, normal load, frictional temperature, surface finish and contaminants, hardness, microstructure etc.

Singla et al. [4] developed aluminium alloy/ SiC_p composites of varying weight fractions of silicon carbide (5-30 %) by stir casting techniques using a two step-mixing method. Al-SiC_p was tested to find the impact strength and hardness. From the results, it can be shown that impact strength and hardness increases with increment in weight percentage of reinforcement.

K. Ravi et al. [5] investigated the Al-fly ash composite prepared by utilizing stir casting method. Al-fly ash particles with 3-12 wt.% and different particle size are used to determine the dry sliding wear behavior for different loading, sliding speeds in pin-on-disc experiment. Outcomes of the experiments shows that composite materials reinforced with coarse particles of fly-ash demonstrate greater resistance to wear than fine particles of fly-ash.
Komai et al [6] conducted the experimentation to determine the mechanical properties of Al7075-SiC composite. From the result, it is observed that the better mechanical properties of A7075-SiC whiskers composite have been obtained. Rupa Dasgupta et al. [7] conducted experimentation to find the wear behavior and hardness of the A7075-SiC composite. From the outcomes, it is confirmed that the enhancement in hardness, wear resistance properties are obtained.

R.L. Deuis et al. [8] surveyed the wear behaviour of the materials and the development of fine equiaxed wear debris is related with a stable tribo-layer on the worn surfaces. The critical parameters for adhesive wear are applied load, sliding velocity, the surface hardness of worn surface and morphology in relative to the theories of wear encuontered by the materials. In this audit current wear hypotheses, issues identified with counter face wear, and wear systems are talked about.

V.C. Uvaraja et al. [9] studied wear behavior of Al6061 and Al7075 alloy with SiC and B_4C reinforcements. From the results obtained from the experiment it is concluded that the enhanced wear rate and hardness of Al7075 hybrid metal matrix composites was found as compared to Al6061 hybrid metal matrix composites.

Radhika et al. [10-11] has conducted the experiments to evaluate the wear characteristics of Al/Gr/Al_2O_3 hybrid MMC and suggested that the graphite reinforcement has boost up the resistance to wear. This increment is due to the forming a protective layer between the counterface & pin. Addition of the reinforcement Al_2O_3 has considerable influence in reducing wear rate of the composite.

Saleemsab Doddamani et al. [12] conducted experimentation on wear behaviour of Aluminum-graphite MMC. From the results it is found that the adding of particles of graphite has increased the resistance to wear of the MMC. Also it is reported that addition of particles of graphite in aluminum reduces the friction then that of the base alloy.

Rajesh AM et al. [13-15] conducted experimentations like hardness, wear behavior at as-cast and age hardened conditions etc on aluminum hybrid metal matrix composites. The matrix material considered is Al7075, and reinforcement material is SiC and alumina. From the results it is clear that the HAMMCs have better properties as compared to unreinforced aluminum alloy.

Mouritz et al. [16] reported changes of resistance to abrasive wear of aluminium matrix composite when subjected to the various aging environment. In aged conditions, composite materials exhibits relatively high wear resistance.

N. Radhika [17] studied abrasive wear behavior of cast aluminum-SiC composite with nickel coating. For the study of wear behavior they utilized Taguchi design of experiments and Analysis of Variance (ANOVA).

It is noticed from the literature that more work has been carried out on the wear characteristics of different aluminum MMCs. Although, an significant scope exists for research on the aluminum matrix particulate hybrid composite reinforced with alumina, silicon-carbide mainly in the area of wear behavior. The objective of the proposed work is to develop the hybrid MMC in-order to improve the strength and wear resistance characteristics of the material. The main objective of the investigation is to conduct the wear test at room temperature for both the as-cast and age hardening conditions.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

It is identified from the literature that more research work has been done on the wear behavior of Al-SiC$_p$, Al-graphite, Al-Fly Ash MMCs. In the background, hybrid aluminum metal matrix composites have a wide range of scope for the research in wear characterization. The material selected for the research work is Al7075 as matrix and silicon carbide and alumina particles as reinforcement.

The Al7075/SiC/Al_2O_3 particulate MMCs are discontinuously reinforced composites which are nearly isotropic [12] and also have exceptional combinations of tribological and weight reduction properties.

The motivation to utilize Al7075 is the tensile strength of the material which is higher than the any other grades of the aluminum. The main constituents in the Al7075 are Si=0.4 %, Zn = 6.1 %, Mg=2.9 %.

The SiC material is a blend of silicon and carbon, outstanding abrasive material. Now a day, the SiC material is formed into a technical grade better quality ceramic with excellent mechanical/physical properties. Some of the key properties of silicon carbide utilized here are Density – 3.1 g/cc, melting point – 2730 ^{0}C, molecular mass – 40.10 g/mol, particle size=100 μm,, Appearance –Black in color.

The alumina (Al_2O_3) is corundum. The alumina as a reinforcement is steadier with aluminum and withstand higher temperatures. Some of the key properties of aluminum oxide utilized here are density=3.69 g/cc, melting point – 2072 ^{0}C, particle size=60 μm, appearance - White in color.

2.2 Processing

Al7075-SiC/Al_2O_3 samples are formed at varied weight fractions of SiC/Al_2O_3 (5 %, 10 %, and 15 %) utilizing stir casting technique. The aluminum slabs were melted in the furnace as appeared in Fig. 1. In the wake of liquefying, liquid aluminum was superheated to 750 ^{0}C temperature.

The required measures of SiC/Al_2O_3 particles were added to the liquid aluminum while mixing with a stirrer at 600rpm speed [25]. The liquid Al7075-SiC/Al_2O_3 was filled a permanent mold and it was permitted to set. The Al7075-SiC/Al_2O_3 composite bars were taken out from the mold. The samples were set up from as-cast combinations for investigation of required properties.

Fig.1 . Induction furnace.

2.3 Age Hardening

The as-cast composite specimens were heat treated at a temperature of 465^{0}C for 02 hrs taken after by quickly quenched in cool water. After quenching the specimens, these are subjected to an age (precipitation hardening) by heat-treatment the specimens to 120 ^{0}C, maintaining this temperature for 05 hrs and after that taken after cooling in air to room temperature.

2.4 Hardness Test

The Vickers' indentation hardness measurement technique comprises of diamond indenter used to indent the test specimens. The diamond indenters used is having square base with pyramid shape and a point of 136^o in-between. The castings are machined to 10mm diameter and 35 mm length for Vickers' hardness test.

2.5 Experimental Wear Test

Dry sliding wear experimentation for a various samples is carried out by utilizing a pin-on-disc [20] wear testing machine. The machine model available in the laboratory is Wear & Friction Monitor TR-20 which was DUCOM made. The pin is held in opposition to the counterface of a rotating disk with 90mm wear track diameter. The pin is subjected to a load in opposition to the disc all the way through dead weight loading systems. The wear experimentation for all samples is carriedout for the load 2 kg, 4 kg, 6 kg and a fixed velocity of sliding of 0.942 m/s, 1.8849 m/s, 2.82 m/s for 200, 400, 600 rpm respectively for about 5 minutes. The pin specimens are of length 35 mm and diameter 10 mm. Before the wear tests the pins were polished by using emery paper (1000 size grit) in-ordered to make sure that efficient contact between the flat surfaces and the steel disc. Acetone is used to clean the specimens & wear track. The wear rate is determined by the weight loss method.

A steel disc as conterbody was used, to promote a mechanically mixed layer (MML). It was found from the literature that, the presence of major alloying elements in the Al-alloy that have high solubility in steel promoted a thick mechanically mixed layer. The solubility of Al-alloy elements in Fe is in the order of Si, Mn, Cu, Mg, which roughly approximates the thickness of the MML formed, while the Fe content of the MML also scaled in this order. As for the ceramic material, which also can be used as a conterbody during the wear test, the MML was derived from fracture of the slider, and also from transfer and re-transfer of the aluminium alloy. To analyze the true effect of the work hardening induced by wear, a ceramic slider was used, to minimize the formation of an MML [26].

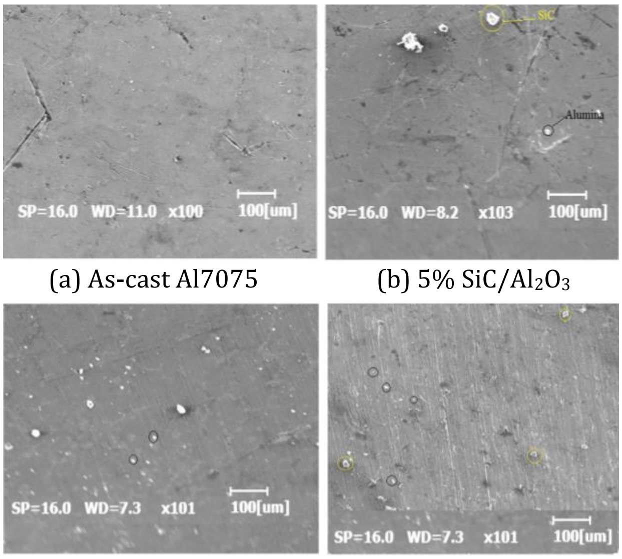
2.6 Taguchi's Optimization

Taguchi method of optimization is one of the most effective techniques because of its simplicity to conduct the design of experiment. The main objective of the Taguchi technique is to evaluate the statistical data which is the input function for optimization. The technique developed for the design of experiments to examine the different parameters and their effect on process mean and variance.

3. RESULTS AND DISCUSSIONS

3.1 Microstructure and EDX Analysis

In the microstructure, shown in Fig. 2, of the Al7075-SiC/Al_2O_3 particulate composite confirms uniform distribution of the reinforcement. In the process of the mixing, a whirling of molten material is formed from the rotation of the stirrer through which the SiC/Al_2O_3 particles are drained into the melt.



(a) As-cast Al7075 (b) 5% SiC/Al_2O_3

(c) 10% SiC/Al_2O_3 (d) 15% SiC/Al_2O_3

Fig. 2. Scanning Electron Micrograph shows a uniform distribution of particles.

The force gave by mixing the molten material with a mechanical stirrer beats the surface vitality hindrance because of poor wettability of SiC/Al_2O_3 by Al composite. Once the SiC/Al_2O_3 particles are moved into the molten aluminum, the dissemination is firmly influenced by certain flow transitions. From the momentum transfer and the outspread flow of melt, lifting of SiC/Al_2O_3 particles will take place and also causes prevention of particle settling in the matrix. Meanwhile, local hydrodynamic forces are induced on the particle grouping of SiC/Al_2O_3 particulates.

These forces induced are capable of separating the clustering of SiC/Al_2O_3 particles which in turn leads to homogeneous microstructure all through the cast segment. A strong homogeneous microstructure between the reinforcement and matrix helps in the load exchange from the reinforcement to the matrix. Thus, the break happens in the composite via the reinforcement and not along the interface. Despite the fact that the SiC/Al_2O_3 is a non-load bearing ingredient, a solid particle/matrix interface helps the SiC/Al_2O_3 particles install themselves into the matrix legitimately, enhancing the crack resistance. It has been reported that during solidification, an enhancement in the interfacial relationship between the aluminum matrix and SiC/Al_2O_3.
By reason of the uniform distribution and good bonding of SiC/Al_2O_3 particles in the aluminum matrix, Al7075-SiC/Al_2O_3 particulate composites have greater tribological properties such as the

good machinability, low wear rate, high damping capacity, and their outstanding properties.

To determine the chemical composition of the Al7075-SiC/alumina composites, EDX measurements are carried out in the SEM on individual specimens. The EDX analysis indicates the foremost composition of Al7075-SiC/alumina composites silicon, magnesium, Fe, carbon and aluminum. Small amount of oxygen are also observed. The signals of oxygen may arise from the contamination of the aluminum oxide.

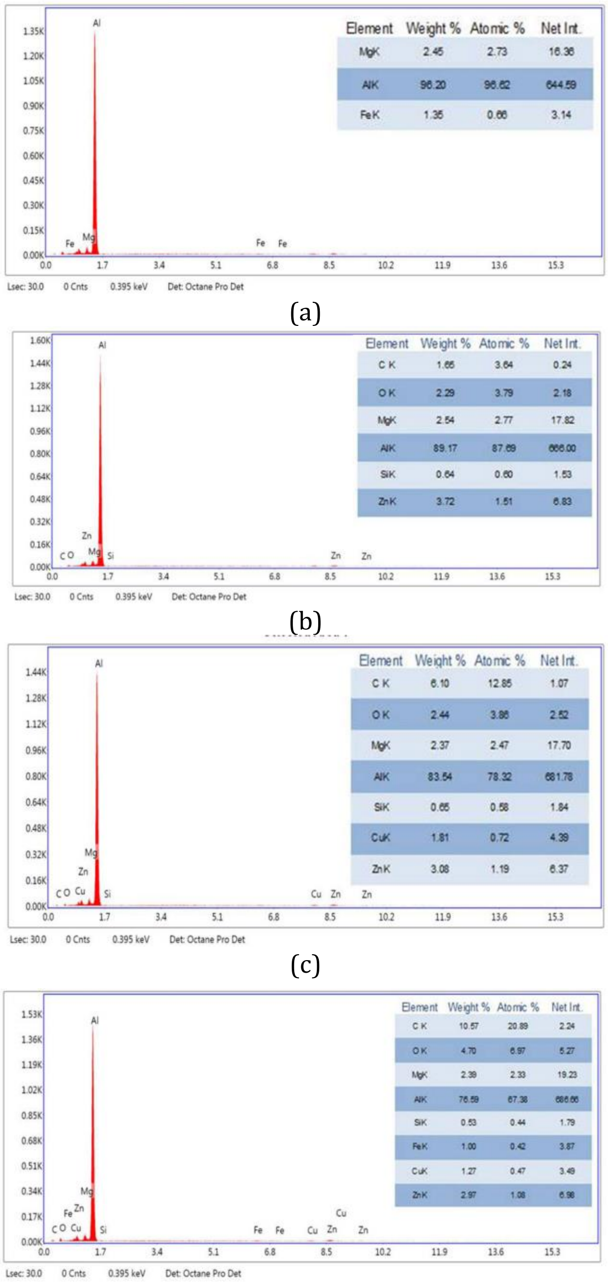


Fig. 3. EDX profile analysis for the surfaces: a) 0 % reinforcement, b) 5 % reinforcement, c) 10 % reinforcement, and d) 15 % reinforcement.

Table in the Fig. 3 describes the atom percentage of Si, magnesium, carbon, and aluminum. These outcomes specified that the chemical composition of the Al7075/SiC/alumina is consistent. The atomic percentage of carbon is high than compared to silicon and magnesium. The presence of carbon indicates the adding up of SiC, alumina reinforcement with the Al7075 matrix.

The content of silicon (0.63 to 0.91) and magnesium (0.6 to 2.54) indicates that the presence of Si and Mg in the Al7075 alloy. From the EDX analysis (Fig. 3), it is found that Al7075-SiC/alumina MMCs are rich in both Si and Mg. The existence of $MgAl_2O_4$ at interfaces was confirmed in a detailed study on the interfaces in discontinuously reinforced MMCs. In all the compositions of Al7075-SiC/alumina, oxygen (O) content has been obtained. The content of O is due to the formation of Al_2O_3 on the top of the pits as the main compound on the surface.

O- mapping, in addition, is performed to know if any sample of oxidation tested at along with Fe, O was likewise in age hardened Al7075 reinforced with SiC and alumina specimens. The O present in an O_2, though, no clarity though it is an FeO_2 or Alumina.

3.2 Micro-hardness Measurement

The Vickers' indentation hardness measurement technique has been utilized to conduct the experimentation. For each composition of the composite three specimens are utilized. The average of all the results has been considered and displayed in the Table 1.

Table 1. Vickers' Hardness Number (VHN) for specimens of different composition and conditions.

Specimen ID	Composition	VHN	
		As-cast	Aging
1	Al7075	105	121
2	Al7075/5%SiC&Al_2O_3	114	131
3	Al7075/10%SiC&Al_2O_3	116	140
4	Al7075/15%SiC&Al_2O_3	110	125

The Table 1 shows the Vickers hardness number of Al7075 based hybrid composites. There is a significant raise of hardness in all composite as there is raise in reinforcement percentage. The highest hardness number of 116 VHN is obtained for 10 % SiC & 10 % alumina reinforced hybrid composites. The raise in hardness number is because of the enlarged bonding area at the interfacial region of the matrix and reinforcement along with grain structure refinement [19]. The standard deviation for the hardness test for as-cast specimens is 3.06 to 4.58 whereas for age hardened specimens it varies from 2.08 to 3.51.

The Fig. 4 shows the effect of the addition of reinforcements on the composite hardness. The evidence is that as percentage of reinforcement is varied by weight, the hardness number of the composites increased monotonically and significantly from 106 to 116 VHN. It is also observed that the hybrid composite with 10 % SiC 10 % alumina shown good hardness property.

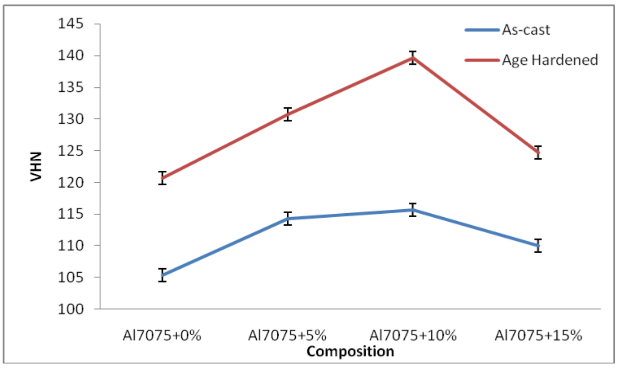


Fig. 4. Vickers' hardness number v/s compositions of specimens for as-cast and age hardened conditions.

Micro-hardness of hybrid composites found incremented with raise in content of reinforcement and enhance in hardness number of Al7075+Al_2O_3+SiC composites are in the range of 110-140VHN for with heat treatment. In T6 heat treated, aged HAMMCs the observed hardness was 120, 130, 140 AND 115 respectively for various wt% of SiC and alumina reinforcement in HAMMCs.

It resulted in increase of 20 % of hardness in aged HAMMCs when compared with as-cast HAMMCs. The highest hardness was noticed in composites for aged with 10%SiC+10%Al_2O_3 reinforcement. There is a gain in hardness of 20 % due to heat treatment in HAMMCs. In T6 heat treatment of HAMMCs, the thermal mismatching of matrix and reinforcement thermally promotes dislocation density improvement in dislocation densities outcome in advanced resistance to plastic deformation, led to better hardness. It is reported that the addition of SiC+alumina to Al7075 in metal-alloys lead to superior hardness number and strength.

After 10 % of reinforcement it is observed that for both the as-cast and age hardened conditions there is a decrement in hardness. This decrement is may be due to particle grouping in the surrounding matrix, which in turn it alter the hardness of material.

3.3 Analysis of variance (ANOVA)

In the present work, optimizing the parameters of the Al 7075/SiC/Al_2O_3 specimen is carried out using the Taguchi method. Three parameters and three factors are considered to optimize the parameters. Factors considered are material composition, load and sliding distance. Loads considered are 2 kg, 4 kg, and 6 kg and material compositions considered are 5 %, 10 %, and 15 % of SiC/Al_2O_3 reinforcement in the Al7075 matrix. The experimental data i.e composition, load and sliding distance are input functions for the Taguchi design. For the given input functions, Taguchi design has been analyzed. The analysis outcomes are shown in Fig. 5a.

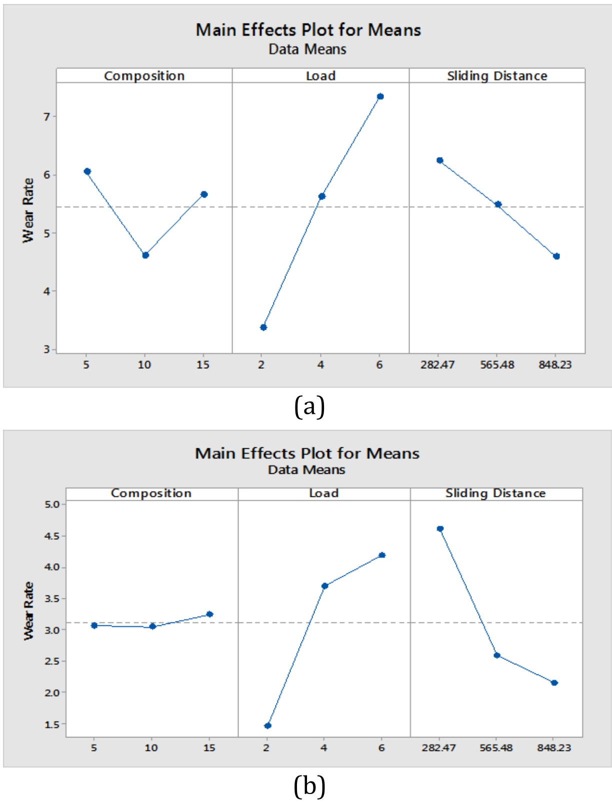


Fig. 5. Wear rate vs Composition, Load and Sliding Distance at the a) as-cast condition, and b) age hardened condition.

From the Taguchi method, it is observed that as load increases the wear rate of the composite increases. As composition increases wear rate reduces up to 10 % of Sic/Al_2O_3 reinforcement in the Al7075 matrix and increases for 15 % Sic/Al_2O_3.

From Fig. 5b it is seen that as sliding distance increases as wear rate decreases for the composite. It is obvious that as the increment in the applied load gives the increment in the wear. As composition increases wear rate decreases for 10 % of SiC/Al_2O_3 and increases by 15 % SiC/Al_2O_3.

The optimize composition is at 10% SiC/Al_2O_3 based on load, sliding distance, and composition of the Al7075- SiC/Al_2O_3 composites for both the conditions age hardening and without age hardening treatment. From the Taguchi analysis, on the specimens, Al7075- 10%SiC/Al_2O_3 is the optimized composition and wear rate reduces for the optimized composition.

ANOVA referred as analysis of variance utilizes the data from the Taguchi's array. ANOVA techniques can be utilized to optimize the parameters and their performance behavior.

Analysis of variance in short called ANOVA is a statistical tool used to evaluate the level of the individual involvement of the process parameter on the responses such as sliding distance and load carrying capacity, and furthermore, give precisely the arrangement of the process parameters. Individual optimal values for the process parameters and their predefined performance attributes can be found. Table 2 shows the results of ANOVA for Load, composition and sliding distance.

From the ANOVA outcomes it is observed that, the factors affecting the wear rate are the composition (10.48 %), load (76.02 %) and sliding distance (13.05 %) at as cast condition and for age hardened condition the factors affecting the wear rate are the composition (0.29 %), load (52.52 %) and sliding distance (42.69 %).

Table 2a. ANOVA for Wear rate at as-cast condition.

Source	DF	Seq SS	Adj MS	F-Value	P-Value	%confi-dence level
Compo-sition	2	3.311	1.6558	23.19	0.041	10.48
Load	2	24.024	12.012	168.21	0.006	76.02
Sliding Distance	2	4.123	2.0618	28.87	0.033	13.05
Error	2	0.142	0.0714			0.45
Total	8	31.602				100.00

Table 2b. ANOVA for Wear rate for aging condition.

Source	DF	Seq SS	Adj MS	F-Value	P-Value	%confi-dence level
Compo-sition	2	0.070	0.035	0.07	0.939	0.29
Load	2	12.545	6.272	11.67	0.079	52.52
Sliding Distance	2	10.197	5.098	9.48	0.095	42.69
Error	2	1.075	0.537			4.50
Total	8	23.888				100.00

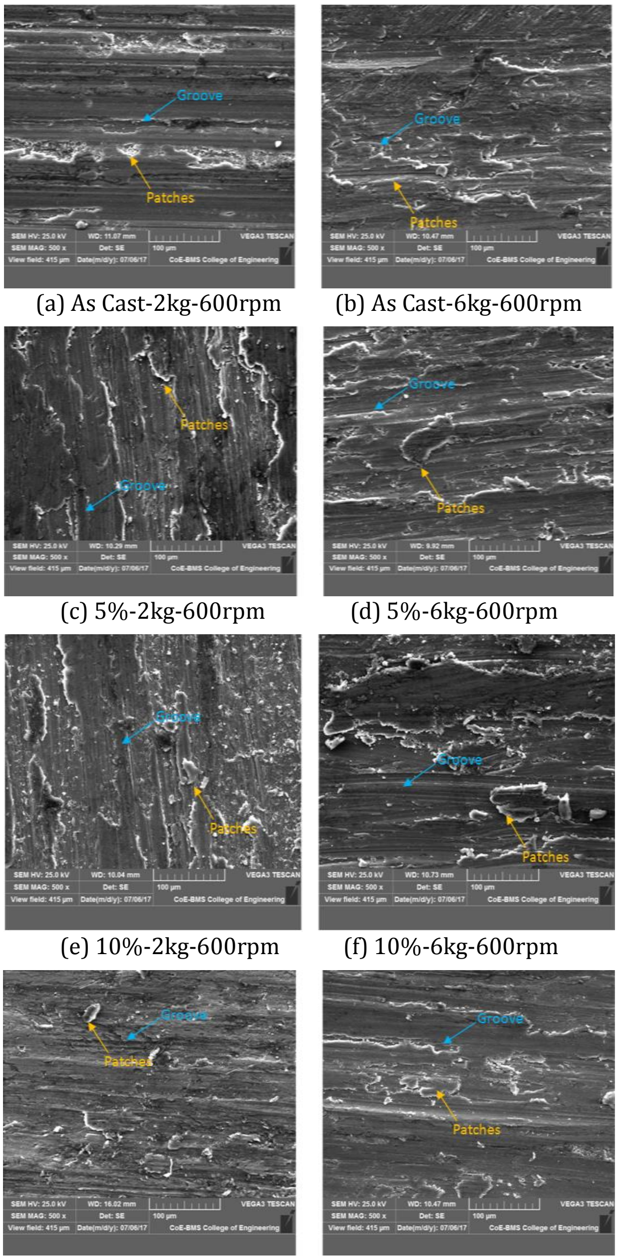
DF=Degrees of freedom, SS=sum of squares, MS=Mean Square, F=Variance & P= test statics.

The ANOVA analysis demonstrates that the wear rate of the material mainly influenced by load, sliding distance than the composition of the material. It is obvious that as load increases wear rate increases. Also, the factors affecting the wear rate are the sliding distance, and composition The ANOVA analysis demonstrates that wear rate of the material mainly influenced by the composition of the material and also by the load and sliding distance. It is obvious that as composition increases wear rate decreases, in turn, reduces the wear.

3.4 Microstructure of Worn Surface

The Figs. 6 and 7 shows that the surface morphology of as-cast and age hardened Al7075/SiC-Al_2O_3 HAMMCs respectively, tested under ambient temperature with load and speed.

These wear scars are the primary characteristic of abrasive wear. On further analyzing, it has been found that grooves are fine on the worn pin surface of Al alloy. From the micrographs (Figs. 6 and 7) some cracks have seen and these are propagated in dissimilar directions. This might be due to strain hardening of aluminum based metal matrix composites with a load because of pulling up of hard phase particle. The enhancement in resistance of wear composite at short load is a because of the existence of reinforcements in between the composites and the counterface contact surface there is creation of a thin layer. The morphologies of the worn surfaces of base alloy and both the composites in as-cast and heat treated condition after the wear test for an applied different load were examined on scanning electron microscope.



(a) As Cast-2kg-600rpm (b) As Cast-6kg-600rpm

(c) 5%-2kg-600rpm (d) 5%-6kg-600rpm

(e) 10%-2kg-600rpm (f) 10%-6kg-600rpm

(g) 15%-2kg-600rpm (h) 15%-6kg-600rpm

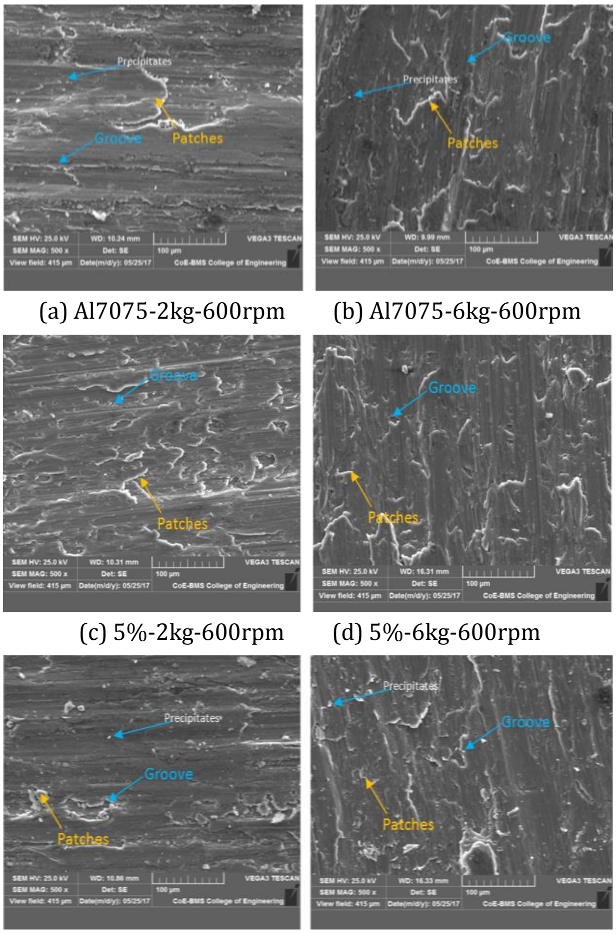
Fig. 6. SEM Micrographs of worn surface of as-cast HAMMCs.

The micrographs show that a number of continuous grooves had appeared on the worn surface. These parallel grooves are the evidence of micro plugging and similar worn surfaces with increased severity were seen. Extensive plugging can be observed on the worn surfaces which indicate that prominent wear mechanism in the composites.

The reattachment of wear debris on the worn surfaces was also noticed. Composites exhibit the same worn surfaces after the 2 kg(19.62N), and 6 kg(58.86N). The wide and shallow grooves were noticed on the as-cast worn surface of composites as shown in Fig. 6. Similar behavior was observed in age hardened composites shown in Fig.7. However in reinforced heat treated HAMMCs worn surfaces were relatively smooth fine grooves and at the edge of the grooves slight plastic deformation was observed in composite.

Micrographs reveal the smooth surface with fine ploughing grooves. Similar trend was obtained for other researchers who have studied on Al6061-Al_2O_3 and Al7075-SiC composites with similar wear behavior [21,22]. The as-cast matrix alloy grooves on the worn surfaces were coarse and there is plastic deformation and the grooves edge is heavy when compared with the extruded matrix alloy [23].

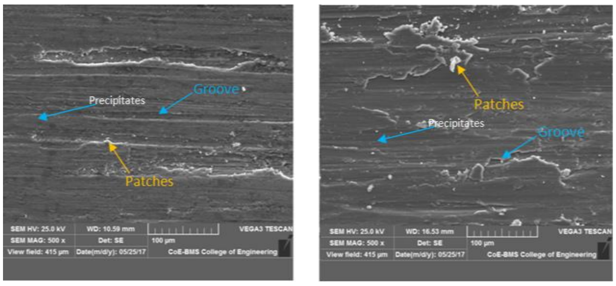
Exhibits the grooves along the direction of the sliding and material delamination were observed on the worn surface of the hybrid composite. By increasing the reinforced material SiC and Al_2O_3 the grooves are reduced and some smooth wear tracks could also be seen. Small size grooves are seen with oxide patches.



(a) Al7075-2kg-600rpm (b) Al7075-6kg-600rpm

(c) 5%-2kg-600rpm (d) 5%-6kg-600rpm

(e) 10%-2kg-600rpm (f) 10%-6kg-600rpm



(g) 15%-2kg-600rpm (h) 15%-6kg-600rpm

Fig. 7. SEM Micrographs of worn surface of age hardened HAMMCs.

3.5 Comparisons of wear behaviour: as-cast and age hardening conditions

For each condition of wear test, three specimens were tested and standard deviation is calculated. For the same error bars are added as shown in Figs. 8, 9 and 10.

Figure 8 shows the comparison of as-cast and age hardened HAMMCs for different load and at a sliding distance of 282.47 m. At lower loads, 2 kg (19.62 N), the contact resistance is high, due to which mild wear occurs. The rubbing surfaces form the fine wear debris which mainly consists of aluminum and FeO_2. The rubbed face appears to be polished.

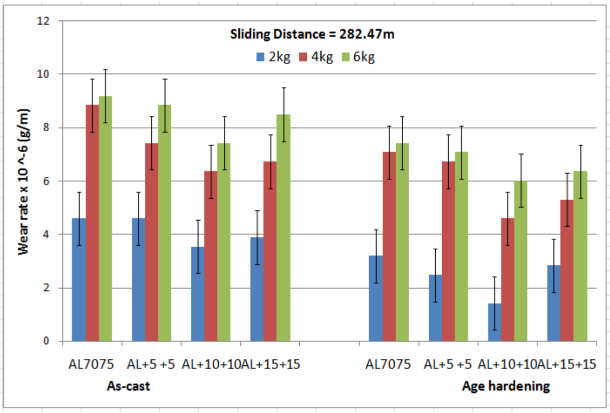


Fig. 8. Influence of load on wear-rate at 252.47m.

The wear rate was uniform at medium loads, 4kg (39.24 N), the wear rate in as-cast, HAMMC and heat treated as cast, and heat treated HAMMC composite decreases. At higher loads, 6 kg (58.86 N), the contact resistance was low, leads to severe wear.

Figure 9 shows the comparison of as-cast and age hardened HAMMCs for different load and at a sliding distance of 565.48m. The wear rate of the heat treated composite decreases as compared to as-cast condition. The oxide film formed on the wearing surface prevents the metal to metal contact. In as-cast and heat treated Al7075-10%Sic- 10%Al_2O_3 HAMMCs the particulate acts to restrain the change to a severe wear rate. The wear rate of heat treated HAMMCs were lesser than that of HAMMCs.

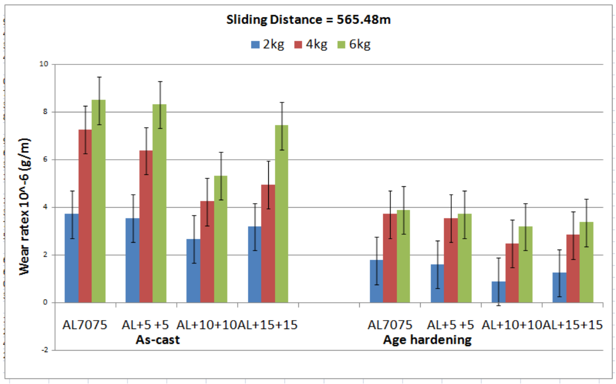


Fig. 9. Influence of load on wear-rate at 565.48 m.

Figure 10 shows the comparison of as-cast and age hardened HAMMCs for different load and at a sliding distance of 848.23 m.

In the Metal Matrix Composites (MMCs) increase wt% of SiC+Al_2O_3 reinforcement improves the hardness.. Addition of hard particulate reinforcement in the composites restricts the composites from getting soft. It results in reductions in the wear rate [24]. It was observed that the volumetric wear rate decreased in heat treated HAMMCs with increased SiC+Al_2O_3 reinforcement and aging When compared with the base alloy the weight loss was decreased in MMCs. In HAMMCs the weight loss was further reduced when compared with aged HAMMCs. Remarkably the lowest weight loss was observed in Al7075-10wt%SiC-10wt%Al_2O_3 with aged HAMMCs.

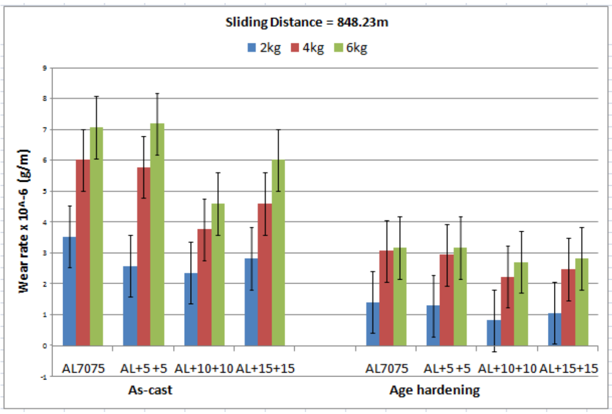


Fig. 10. Influence of load on wear-rate at 848.23 m.

At 15 wt.% of reinforcement, it is observed that decrease of wear rate on increment of sliding distance. With increase of sliding distances tribo-oxidation intensify. More tribo-oxides results in the decrease of coefficient of friction and wear rate.

The incorporation of reinforcement materials in an aluminum alloy increases the load bearing capacity. The investigation of wear behaviour of Aluminum Matrix Composites (AMCs) against friction materials is receiving particular attention because of the possibility of using these materials for disc brakes in automotive application [24]. The addition of reinforcement in an aluminium matrix increases the load bearing capacity and higher wear resistance. The role of $SiC+Al_2O_3$ reinforcement has proved to be valuable in better wear resistance of the HAMMCS The improvement of resistance of wear of the hybrid composite is due to the adding up of $SiC+Al_2O_3$ reinforcement.

Higher wear rate and weight loss at 15 % reinforcement is due to agglomeration of reinforcement particles in the surrounding matrix.

4. CONCLUSION

From the investigation the following conclusions were drawn on the mechanical and wear performance of as-cast and age hardened HAMMCs.

1. Stir casting technique is an economically appropriate process for the production of HAMMC. The micro-structural study of SEM and XRD techniques shows the homogeneous distribution of the particulates in the hybrid composites.
2. From the Vickers's hardness test, age hardened hybrid composite gain the hardness by 24 % for 10 wt.% reinforcement as compared with as- cast composites.
3. From the ANOVA, load is identified as the main parameter, which influences the wear loss of composite by sliding distance and weight fraction of SiC and alumina.
4. The age hardened Al7075/ SiC+Al2O3 composite shows excellent resistance to wear as compared to as-cast hybrid composite.
5. As compared to base alloy, age hardened HAMMC has improved wear resistance properties.

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REFERENCES

[1] D.B. Miracle, S.L. Donaldson, ASM Handbook, *Composites*, vol. 21, ASM International, 2001.

[2] N. Stoloff, D. Alman, *Innovative Processing Techniques for Intermetallic Matrix Composites*. MRS Proceedings, vol. 194, pp. 31-43, 1990, doi: 10.1557/PROC-194-31

[3] J. Goni, I. Mitxelena, J. Coleto, *Development of low cost Metal Matrix Composites for commercial Applications,* Material Science and Technology, vol. 16, no. 7-8, pp. 743-746, 2000, doi: 10.1179/026708300101508739

[4] M. Singla, D.D. Dwivedi, L. Singh, V. Chawla, *Development of aluminium based silicon carbide particulate metal matrix composite*, Journal of Minerals and Materials Characterization and Engineering, vol. 8 no. 6, pp. 455–467, 2009, doi: 10.4236/jmmce.2009.86040

[5] K.R. Kumar, *Aluminium/fly-ash composites Effect of particle size on mechanical properties and tribological behaviour of aluminium/fly-ash composites,* Science and Engineering of Composite Materials, vol. 19, no. 3, pp. 247–253, 2013, doi: 10.1515/secm-2011-0139

[6] K. Komai, K. Minoshima, H. Ryoson, *Tensile and fatigue fracture behavior and water-environment effects in a SiC-whisker/7075-aluminum composite*, Composites Science and Technology, vol. 46, no. 1, pp. 59–66, 1993, doi: 10.1016/0266-3538(93)90081-Q

[7] R. Dasgupta, H. Meenai, *SiC particulate dispersed composites of an Al– Zn–Mg–Cu alloy: Property comparison with parent alloy*, Materials Characterization, vol. 54, iss. 4-5, pp. 438-445, 2005, doi: 10.1016/j.matchar.2005.01.012

[8] R.L. Deuis, C. Subramanina, J.M. Yellup, *Dry sliding wear of aluminium composites-a review*, Composites Science and Technology, vol. 57, iss. 4, pp. 415-435, 1997, doi: 10.1016/S0266-3538(96)00167-4

[9] V.C. Uvaraja, N. Natrajan, *Comparison on Al6061 and Al7075 alloy with SiC and B4C reinforcement hybrid metal matrix composites*, Journal of Minerals and Materials Characterization and Engineering, vol. 11, pp. 757-768, 2012.

[10] N. Radhika, R. Subramanian, V.S. Prasat, *Tribological Behaviour of Aluminium /Alumina/Graphite Hybrid Metal Matrix Composite using Taguchi's Techniques*, Journal of Minerals and Materials Characterization and Engineering, vol. 10, no. 5, pp. 427-443, 2011.

[11] N. Radhika, R. Subramanian, V.S. Prasat, B. Anandavel, *Dry sliding wear behaviour of aluminium/alumina/graphite hybrid metal matrix composites*, Journal of Industrial Lubrication and Tribology, vol. 64, iss. 6, pp. 359-366, 2012, doi: 10.1108/00368791211262499

[12] S. Doddamani, M. Kaleemulla, Y. Begum, K.J. Anand, *An Investigation on Wear Behavior of Graphite Reinforced Aluminum Metal Matrix Composites*, Journal of Research in Science, Technology, Engineering and Management, Special issue, pp. 1-6, 2017.

[13] A.M. Rajesh, M. Kaleemulla, *Experimental investigations on mechanical behavior of aluminium metal matrix composites,* Materials Science and Engineering, vol. 149, 2016, doi: 10.1088/1757-99X/149/1/012121

[14] T. Bharath, A.M. Rajesh., M. Kaleemulla, K. Rangasravantha, *Experimental investigations on mechanical and wear behavior of hybrid aluminium alloy*, International Journal of Research in Engineering and Technology, vol. 5, iss. 13, pp. 128-131, 2016.

[15] A.M. Rajesh, M. Kaleemulla, *Effect of heat treatment on hybrid aluminum metal matrix composites*, International Journal of Emerging Research in Management & Technology, vol. 6, iss. 5, pp. 548-551, 2017.

[16] W.Q. Song, P. Kraulis, A.P. Mourrtz, S. Bandyopadhyay, *The effect of thermal ageing on the abrasive wear behaviour of age-hardening 2014 Al/SiC and 6061 Al/SiC composites*, Wear, vol. 185, iss. 1-2, pp. 125-130, 1995, doi: 10.1016/0043-1648(95)06599-7

[17] N. Radhika, *Analysis of Three Body Abrasive Wear Behaviour of Centrifugally Cast Aluminium Composite Reinforced with Ni Coated SiC using Taguchi Technique*, Tribology in Industry, vol. 40, no. 1, pp. 81-91, 2018, doi: 10.24874/ti.2018.40.01.07

[18] M. Bai, Q. Xue, X. Wang, Y. Wan, Liu, *Wear mechanism of SiCwhisker-reinforced 2024 al-alloy matrix composites in oscillating sliding wear tests*, Wear, vol. 185, iss. 1-2, pp. 197-202, 1995, doi: 10.1016/0043-1648(95)06617-9

[19] M.K. Surappa, R.K. Uyyuru, S. Brusethaug, *Effect of reinforcement volume fraction and size distribution on the tribological behaviour of Al-composite/brake pad tribocouple*, Wear, vol. 260, iss. 11-12, pp. 1248–1255, 2006, doi: 10.1016/j.wear.2005.08.011

[20] ASTM G99-95, *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*, Annual Book of ASTM Standard, 1995.

[21] T. Alpas, J. Zhang, *Effect of SiC particulate reinforcement on the dry sliding wear of aluminum-silicon alloys (A356),* Wear, vol. 155, iss. 1, pp. 83-104, 1992, doi: 10.1016/0043-1648(92)90111-K

[22] J.P. Tu, Y.Z. Yang, *Tribological behavior of All8B4033-whisker reinforced hypoeutectic Al-Si-Mg-matrix composites under dry sliding conditions*, Composite Science Technology, vol. 60, iss. 9, pp. 1801-1809, 2000, doi: 10.1016/S0266-3538(00)00067-1

[23] M.D. Kulkarni, P.S. Robi, R.C. Prasad, P. Ramakrishna, *Deformation and fracture behavior of cast 7075Al-SiCp composites at room and elevated temperatures*, Material Transactions, JIM, vol. 37, no. 3, pp. 223-229, 1996, doi: 10.2320/matertrans1989.37.223

[24] A.A. Hamid, P.K. Ghosh, S.C. Jain, S. Ray, *The influence of porosity and particles content on dry sliding wear of cast in situ Al(Ti)–Al_2O_3(TiO_2) composite*, Wear, vol. 265, iss. 1-2, pp. 14-26, 2008, doi: 10.1016/j.wear.2007.08.018

[25] A.M. Rajesh, M. Kaleemulla, D. Saleemsab, *Effect of addition of SiC and Al2O3 on wear behavior of hybrid aluminum metal matrix composites*, Acta Technica Corviniensis – Bulletin of Engineering, vol. 12, iss. 1, pp. 43-52, 2019.

[26] M.J. Ghazali, W.M. Rainforth, M.Z. Omar, *A comparative study of mechanically mixed layers (MMLs) characteristics of commercial aluminium alloys sliding against alumina and steel sliders,* Journal of materials processing technology, vol. 201, pp. 662–668, 2008, doi: 10.1016/j.jmatprotec.2007.11.158