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ORIGINAL CONTRIBUTION

Tribological Wear Behaviour and Hardness Measurement of SiC, Al_2O_3 Reinforced Al. Matrix Hybrid Composite

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Abstract In the present study, Aluminium Matrix Hybrid Composite (AMHC) of 6061-T6 alloy reinforced with silicon carbide (SiC) particulate and further addition of aluminium oxide (Al_2O_3) particulate was fabricated by stir casting process. The wear resistance and frictional properties of that AMHC were studied by performing dry sliding wear test using a pin on disk wear tester. The experiments were conducted at a constant sliding velocity of 1.57 m/s and sliding distance of 1800 m under loading conditions of 10 and 20 N. Further tests were also carried out by keeping Al_2O_3 percentage (7%) constant and increasing the SiC percentage (10, 15, and 20%). The results show that the reinforcement of the metal matrix with SiC and Al_2O_3 reduces the wear rate range and also indicate that the wear of the test specimen increases with the increasing load and sliding distance. The coefficient of friction increases with load and increasing volume content of reinforcement. The worn surfaces were examined by scanning electron microscope to study the wear mechanism. By using wear mechanism analysis, the wear surfaces and wear properties of AMHC were determined.

Keywords Stir casting · Hybrid · Scanning Electron Microscope (SEM) · Aluminum Matrix Hybrid Composite (AMHC)

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Introduction

Aluminium Matrix Composites (AMCs) are widely used in aircraft, automobiles, and marine field due to the good strength, light weight and low cost. Wear behaviour can be observed in brakes, gears, valves, cams, bearings, clutches and other applications involving sliding contact or rolling contact. AMCs are one of the advanced engineering materials that have been developed for weight critical applications in the aerospace, and more recently in the automotive industries due to their excellent combination of high specific strength and better wear resistance [1, 2]. Hybrid composites have been developed recently with improved mechanical properties. Hybrid composites mean addition of more than one reinforcement with the matrix. Aluminum alloy 6061-T6 is widely utilized in aircraft, defense, automobiles and marine areas due to their good strength, light weight and better corrosion properties. But, it exhibits inferior tribological properties in extensive usage. In addition, aluminum based composites become brittle by the addition of reinforcements such as SiC and Al_2O_3 ceramic particles. The reinforcement particles which have effect on the wear and mechanical properties have been identified as SiC and Al_2O_3 [3].

Stir casting offers better matrix particle bonding due to stirring action of particles into the melts. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, temperature of molten metal, preheating temperature of mould and uniform federate of particles [4]. Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide selection of materials and processing conditions [5].

In most cases, hard ceramic particulates such as zirconia, alumina (Al_2O_3) and silicon carbide (SiC), have been introduced into aluminum-based matrix in order to increase the strength, stiffness, wear resistance, corrosion resistance, fatigue resistance and elevated temperature resistance. Among these reinforcements, SiC is chemically compatible with aluminum (Al) and forms an adequate bond with the matrix without developing inter-metallic phase and has other advantages such as excellent thermal conductivity, high machinability, good workability and low cost [6]. Wear rate of aluminum matrix composites reinforced with B_4C and SiC particles fabricated through the same route (pressure less infiltration method) were analysed; the wear rate and friction coefficient of Al–B_4C was found to be lower than those of Al–SiC under the same conditions [7]. It is observed that the composite with 2% by weight Al_2O_3 possesses a tensile strength and hardness values of 505 MPa and 123Hv respectively, over that of non-reinforced matrix alloy. Studies on Al-2024/Al_2O_3p composite has revealed that the hardness and tensile strength of the composite increases with increasing the weight percentage of the reinforcement [8]. The hardness value of SiC is higher than TiB_2 composite specimen. This reduction in hardness value for TiB_2 content indicates a reduction in the work of indentation [9].

The aim of the present investigation is to evaluate the dry sliding metal–metal wear behaviour of Al6061 alloy discontinuously reinforced with two different types of particles such as SiC and Al_2O_3. The hardness and wear properties are higher in case of composites when compared to non-reinforced matrix material [10]. The stir casting method is chosen for the manufacturing of AMHCs. The effect of SiC and Al_2O_3 addition and the applied load in the dry sliding metal–metal wear behaviour of composite is investigated using a pin on disk wear tester and the hardness of the Al6061 matrix composite reinforced with SiC and Al_2O_3 is determined using Rockwell hardness testing machine. The synergy effect of micro-texture, composite coating and boundary film of water improves the tribological properties of the materials [11]. The microstructures of the specimen are studied using scanning electron microscope (SEM) for the particle distribution and worn surfaces analysis.

Methodology

Fabrication Method

The Al 6061 matrix composite reinforced with 10, 15 and 20 wt% SiC and 7 wt% Al_2O_3 were prepared by a stir casting process. A research on Al_2O_3 addition at various percentages showed better results at 7 wt%. So in this investigation 7 wt% is considered and retained as constant. Figure 1 shows the stir casting setup. About 1.0 kg of Al6061 alloy was melted in a graphite crucible heated to 720 °C. When the temperature of the melt is 720 °C the preheated stirrer was introduced into the melt. Agitation of the melt was started and created vortex due to the rotation of stirrer. SiC particulates which were preheated at 200 °C were introduced in the wt% of 10, 15 and 20 and followed by the addition of 7 wt% of Al_2O_3. The mixture was stirred at 350 rpm for 5 min by means of a stirrer coupled to a motor and the temperature was kept at 850 °C. Due to the stirring action, the melted aluminum alloy was split into droplets owing to the shear forces brought by the impeller due to the existence of Al_2O_3. The stirring was continued to ensure a proper mixing. The slurry of the composite thus prepared was poured into the preheated steel moulds. Figure 2 shows the prepared casting of aluminum matrix hybrid composite (AMHC). The test specimens for hardness and wear test were prepared from these composites. Figure 3 shows the sequence of steps involved in stir casting process.

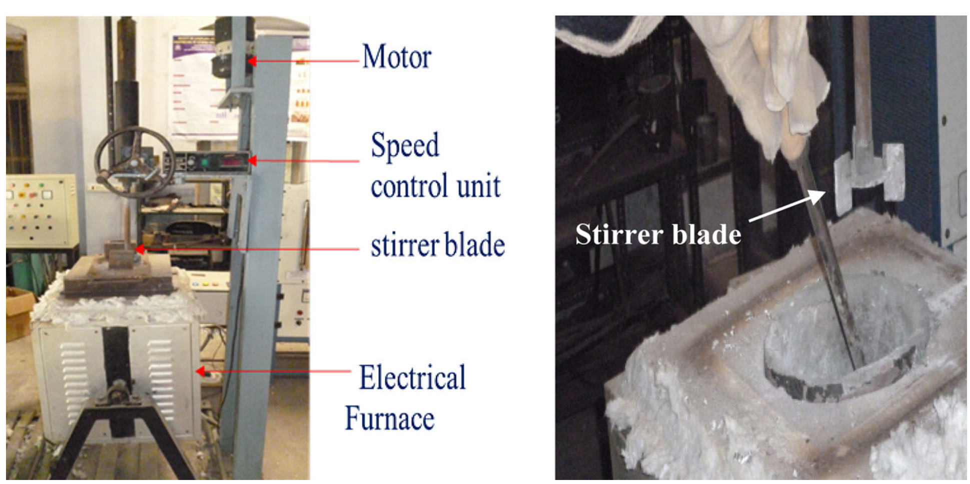

Fig. 1 Stir casting setup

Fig. 2 Casting of AMHC

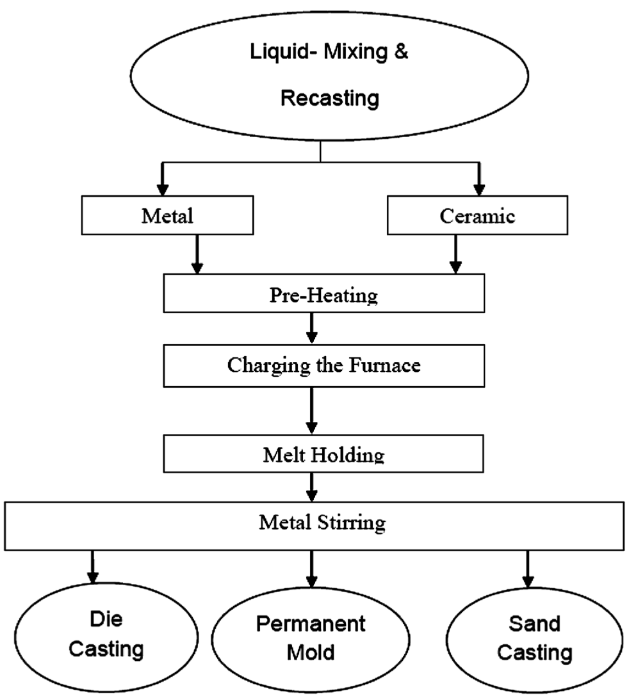

Fig. 3 Stir casting process

Results and Discussion

Hardness Testing

The effects of reinforcement on the hardness of the composite obtained from hardness test are shown as graph under Fig. 4 which shows the graph between wt% of SiC and hardness value (HRB). The hardness tests for the specimen were carried out on a Rockwell hardness testing machine and measurements were taken. It is observed that the hardness of the Al6061/SiC/Al_2O_3 hybrid composite increases with the addition of SiC. The observed values are tabulated in Table 1.

Specification parameters used for hardness test:

- B-scale used
- Load applied = 100 kg
- Time taken = 15 s

Morphological Analysis

SEM analysis of the worn surfaces of hybrid composites specimen are shown in the Figs. 5, 6 and 7. An examination of the morphologies of the worn surfaces indicates the existence of abrasion and delamination wear mechanisms in these composites.

Figure 5 shows the worn surface of the Al 6061/7 wt% Al_2O_3/10 wt% SiC hybrid composite. Surface damage in the form of decohesion and detachments of the material near the contact surface were observed. Cracks and small cavities are also visible on the surface. Distinct grooves are visible in the sliding direction.

The smeared graphite particles from the worn surface of composites form a thin rich tribo film between sliding surfaces, which prevent direct metal contact. This clearly indicates that wear rate can be related to the presence of SiC, which may act as a protective layer. This reinforcement prevents the breaking of hard SiC particles from the pin surface, which results in less surface damage. Delamination wear are found in localized regions.

Figures 6 and 7 show the worn surfaces of Al 6061 with 15 and 20 wt% of SiC respectively and 7 wt% Al_2O_3 retained as

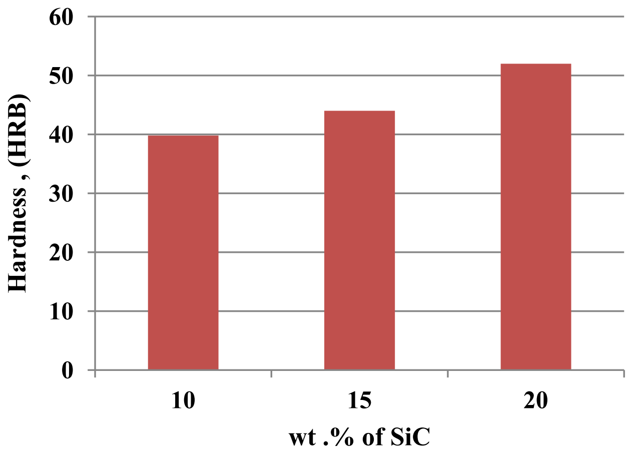

Fig. 4 Rockwell hardness of Al 6061/SiC/7 wt% Al_2O_3 hybrid composite

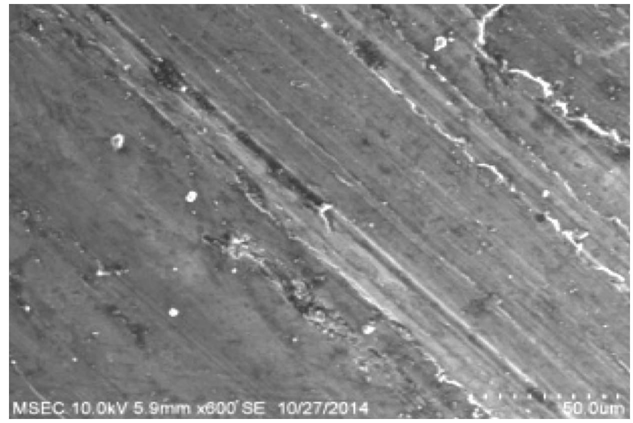

Fig. 5 SEM of worn surface of Al 6061 + 10 wt% SiC + 7 wt% Al_2O_3

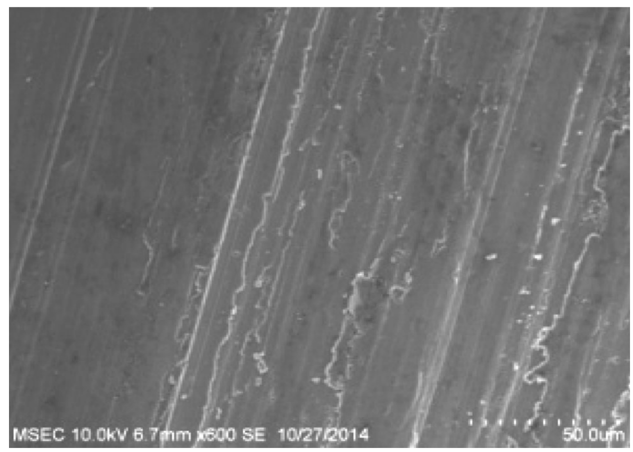

Fig. 6 SEM of worn surface of Al 6061 + 15 wt% SiC + 7 wt% Al_2O_3

constant. Due to increase in SiC particle on the surface of matrix, the plastic deformation of matrix can be resisted with the presence of SiC which act as a barrier to the moment of dislocation which causes more wear resistance than base alloy. Mild patches and grooves are noticed.

Wear Behaviour of the Composites

Figure 8 shows the wear mass loss of the composite samples as a function of sliding distance. For any given specimen, the mass loss continuously increases with increasing sliding distance. It can be clearly seen that the wear rate of the composites is considerably improved by the addition of the reinforcement particles and wear rate decreases by increasing SiC weight fraction from 10 to 20 wt%. Figure 9 shows the plot of specific wear rate, which is defined as the volume of material worn per unit applied normal load as a function of wt% SiC for different applied loads.

This is possibly due to the work hardening experienced by the alloy and composites at higher loads during the wear testing which improve the load bearing capacity and consequently imparts better wear resistance.

The specific wear rate decreases as the amount of SiC reinforcement (10, 15 and 20%) increases for all applied normal loads. Even at higher loads, as the amount of reinforcement is increased, the specific wear rate is decreased. However, the variation is less as compared to lower loads.

The coefficient of friction increases with the increase in SiC content (10, 15 and 20%). The effect of Al 6061/7 wt% Al_2O_3/10 wt% SiC hybrid composite on friction coefficient is shown in Fig. 10. The presence of SiC in the hybrid composite increases the coefficient of friction.

Conclusions

The aluminum matrix hybrid composite (AMHC) was prepared by stir casting setup successfully. The hardness of hybrid composites was found to be higher for the Al6061-

Table 1 Weight % of SiC in AMHC versus average hardness

S. no	Weight % of SiC	Hardness values					Average hardness (HRB)
		1	2	3	4	5	
1	10	32	46	33	42	46	39.8
2	15	42	40	46	36	45	44
3	20	46	42	42	47	36	52

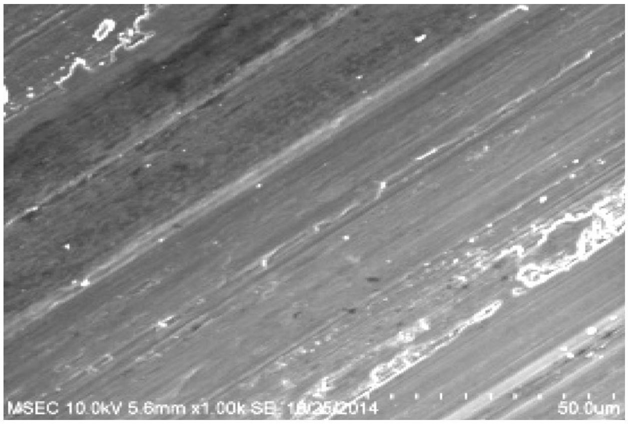

Fig. 7 SEM of worn surface of Al 6061 + 20 wt% SiC + 7 wt% Al_2O_3

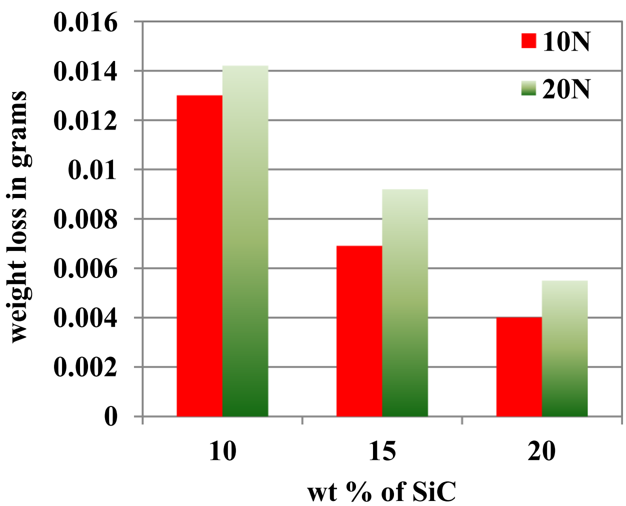

Fig. 8 Weight loss versus Al6061-T6 + wt% of SiC and 7%Al_2O_3

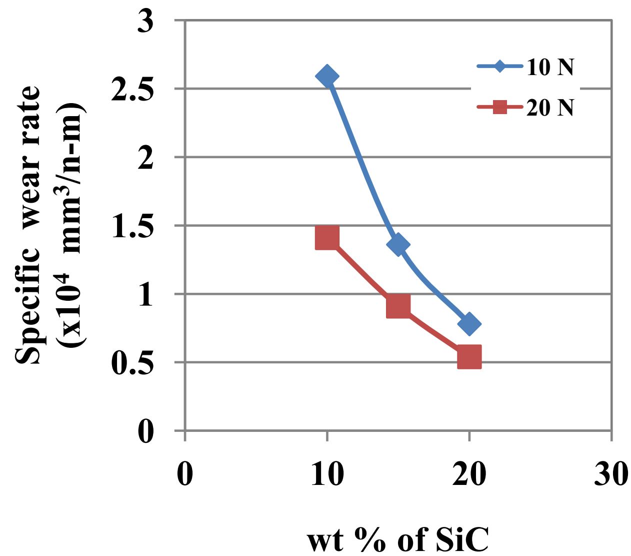

Fig. 9 Specific wear rates versus Al6061-T6-wt% of SiC and %Al_2O_3

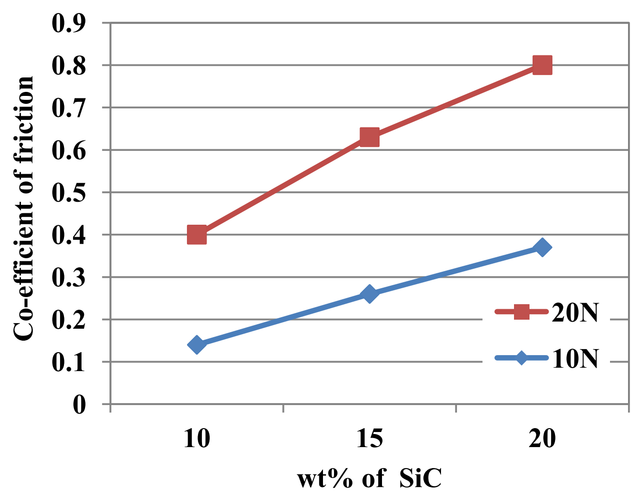

Fig. 10 Coefficient of friction of Al 6061/SiC/7 wt% Al_2O_3 hybrid composite

20% of SiC compared to Al6061-10% of SiC. The hardness values of hybrid composites increases from 39.8 to 52 HRB with increasing SiC (10, 15 and 20%) and it was higher than that of base alloy in all compositions. Thus the results show that the addition of SiC particle increases the hardness. The hardness value of hybrid 20% SiC and Al6061 composition was found to be higher than the 10% SiC and Al6061 composition.

The wear rate is dominated by different parameters in the order of applied load (10, 20 N), sliding speed (500 rpm), and sliding distance (1800 m). The test concludes that, as sliding distance increases the wear rate also increases. Sliding distance has the highest influence on wear rate followed by sliding speed and applied load for Al6061-20% SiC metal matrix composites. The SiC and Al_2O_3 improve the wear resistance of composites by forming a protective layer between pin and counter face.

The above conclusion reveals that sliding distance and sliding speed have the highest influence on wear rate in Al6061 + 20%SiC + 7%Al_2O_3 hybrid composite. Morphological analysis was done. It was observed from the SEM analysis that micro cracks, transverse cracks, mild wear and severe wear were found from the worn surfaces and wear structure of the composite.

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