Effect of T6 Heat Treatment on Dry Sliding Wear Performance of Al-7075/Al2O3/ TiC Hybrid Metal Matrix Composites

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Abstrat:- *The Present study discuss with influence of T6 heat treatment on dry sliding wear performance of Al-7075/Al2O3/TiC Hybrid Metal Matrix Composites (HMMC). By using the vortex technique, Al-7075 HMMC is fudged by imparting various weight fractions of self lubricated Al2O3(8,6,4,2,0) and high thermal resistible particles TiC (0,2,4,6,8). A set of cast samples are heat treated (T6). Wear test conducted on pin-on-disc apparatus and tribological behaviour analyzed in terms of wear rate. It was found that, compared to pure alloy the Al-7075 HMMC exhibited better wear performance due to the presence of Al2O3 and TiC as reinforcements in HMMC restrict plastic deformation and reduce wear loss. It was observed that during T6 treatment better grain refinement was formed in the Al 7075 HMMC and hence better wear resistance was exhibited by the treated samples than untreated HMMC. The optimized results were obtained at 8% of TiC and 0% of Al2O3 composition.*

Key Words: Al-7075, Al2O3, TiC, T6, Wear behavior

Introduction

In automobiles, aerospace, marine sectors most of the mechanical parts undergo relative motions and losses occur in the form of materials and energy caused due to wear and friction. The study and characterization of wear, friction and lubrication is termed as Tribology. To overcome these losses, researchers focused on new materials called Metal matrix composites (MMC) for achieving better mechanical and tribological properties. Demand for the utilization of MMC materials in the manufacturing of various parts in automobiles, aerospace, marine and military has increased due to their characteristics like high specific strength, stiffness, and wear resistance [1, 5]. In MMC, aluminum alloys are widely used as engineering materials due to low density, high thermal conductivity, good machiniability and wear resistance [2,6-7]. Due to the soft and ductile nature, the aluminum matrix alloys in wear applications is less implemented. Various reinforcements such as SiC, Al2O3, B4C, TiC, TiB2, MgO, TiO2 and BN etc are added to the Aluminum alloys for improvement in wear properties [1]. Because of possessing more strength and wide characteristics carbides, nitrides, oxides and borides are mostly using as reinforcements [12]. The addition of more than one reinforcements to the base metal alloy is termed as hybrid MMC. Compared to single reinforced composites, the hybrid MMC posses greater mechanical and tribological properties. Hybrid MMC have more thermal resistance, [1]. Compared to pure alloy the hybrid MMC reinforced with ceramic particles possess specific strength, good temperature properties, wear resistance, corrosion resistance [14].

The circumstances such as corrosion, erosion, abrasion or chemical processes results in gradual removal of material at the solid surfaces due to relative motion between the sliding faces. The failure of metal surfaces resulted by plastic deformation leads to wear. The inherent factors like surface finish, applied load, speed, sliding distance, sliding velocity, orientation of reinforcements, volume factors, temperature conditions, environment and the material properties and characteristics of the counter surface are essential to estimate the wear rate. Wear test is conducted using various apparatus like Pin-on-Disc, Pin-on-Flat, Pin- on-Cylinder, Thrust washers, Pin into- Bushing, Rectangular Flats on a Rotating Cylinder etc [8-9]. The MMC's like Al-6061/ Al2O3 exhibited increased wear resistance at high temperature conditions due to the presence hard ceramic particles. The Al-356/TiC exhibited high wear rate than pure Al-356 because of hard TiC particles. With 10% of TiC as reinforcement posses highest resistance than all. Al-7075/TiC posses good wear resistance [10]. The Al-2024/ Al2O3 MMC showed better abrasive wear properties [8]. The addition of Al2O3 particles improved the toughness of hybrid composites [4]. From the literature review, experimentation on wear behaviour is conducted on Al-7075 alloy as base metal and Al2O3 and TiC as reinforcements by stir casting method. This method is cost effective , easy to operate and possess homogeneous distribution of reinforcements in metal matrix composites manufacturing [11-13]. Also the effect of T6 is compared with the untreated. The process parameters are optimized by using Taguchi L9 Orthogonal array. This technique is effective to enhance the process parameters in designing and experiments analysis [14-15].

Experimental Procedure:

Sample Preparation:

The synthesis of hybrid metal matrix composites is prepared using liquid stir casting method. In this process, the Al 7075 alloy material is weighed and is melted in a graphite crucible for a temperature of 700^0C. A degassing agent is added to the molten metal for the removal of the impurities and moisture content. The slag powder was sprayed to remove the slag content. The reinforcements Al_2O_3 and TiC as per weight percentage ratios are preheated to a temperature of 300^0C and are added to the molten slurry. An automatic stirrer at 400 rpm for 20 minutes is used to stir the molten slurry. The melt was poured into permanent moulds of 20mm in diameter and 210mm height. The Al 7075 hybrid metal matrix composite is fabricated using stir casting method by varying weight percentages of Al_2O_3 and TiC reinforcements. The wear samples as per ASTM G99 standards with dimensions of 30x8mm are prepared by using CNC lathe machine as shown in Figure 1.Polishing of wear samples is done by using grit papers of sizes 220, 240, 300, 400, 1/0, 2/0, 3/0, 4/0 to attain plane finishing for the contact of samples with disc of the apparatus. For getting fine finish the samples are subjected to disc polish. The samples are cleaned with acetone and methanol and are tested on pin-on-disc apparatus. The test specimen was kept stationary in the holder of apparatus over the sliding surface and the load is applied via pulley mechanism.

Figure 1: Wear Specimens

Heat Treatment:

The samples are heated in muffle furnace to a temperature of 475^0C for an hour and then cooled in water for 10 minutes, this process is called quenching. The samples are further aged to a temperature of 127^0C for 24 hours. This process (quenching + aging) is called as T6 heat treatment.

Wear Parameters:

The present work investigates the influence of applied load, velocity and sliding distance on the wear loss of Al7075 with Al_2O_3 and TiC hybrid composites using pin- on-disc apparatus. The heat treated and untreated samples are tested on pin-on-disc apparatus by varying parameters like load, velocity and sliding distance. The test was conducted at normal room temperature (25^0C).The optimized composition is determined by Taguchi method. This method is used to evaluate the optimized effect of independent parameters on effect of process parameters on the wear rate. Is implemented to find out the effect of process parameters on the wear rate. Table 1 shows wear parameters based on L-9 orthogonal array.

Table1: Wear Parameters

S. No	Load (N)	Velocity (m/sec)	Sliding Distance(m)
1.	20	2	3000
2.	30	2	3000

3.	40	2	3000
4.	20	4	3000
5.	30	4	3000
6.	40	4	3000
7.	20	6	3000
8.	30	6	3000
9.	40	6	3000

Testing Procedure:

Cylindrical samples (Φ8 X 30 mm) with a flat surface in the contact region and conducted wear tests under normal loads of 20 N, 30N and 40N at constant sliding distance 3000m with three sliding velocities (2.00 m/s, 4.00 m/s and 6.00 m/s) on a pin-on-disc machine as shown in figure 2

After each test the pin was removed from the holder and disk was cleaned with methanol and acetone to remove wear debris.

Figure 2: Pin-on-Disc Machine

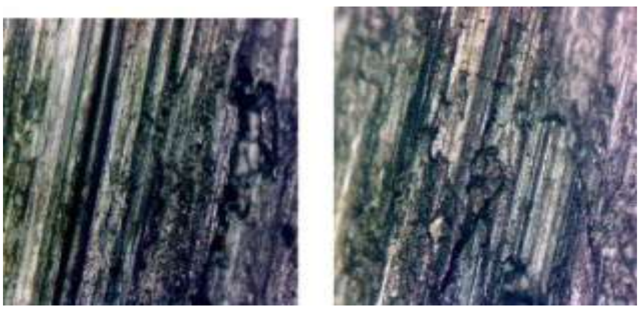
The wear was measured by weight loss, as a difference of weights of the wear pins, before and after wear tests to an accuracy of 0.001 g.

Wear Calculation:

The wear rate is calculated based on density of the Al- 7075 HMMC samples, the sliding distance and the mass loss during wear process. The relationship between these parameters is represented in the below formula.

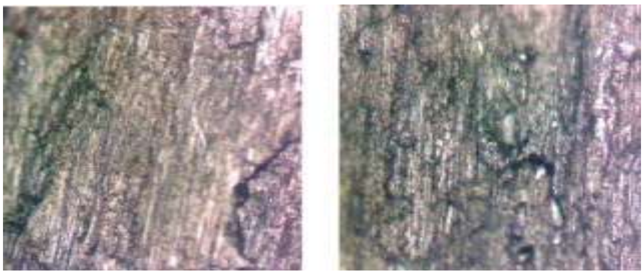
Wear Rate = loss in mass / (density (ρ) * sliding distance) m3/m

Wear Results:



(a) (b)

Figure 3: Microstructural images of worn surface - Pure Al- 7075(100X)



(c) (d)

Figure 4: Microstructural images of worn surface – Al- 7075 with 8% TiC and 0 % Al2O3 composition (100X)

The figure 3 represents worn microstructural images of pure Al-7075. It is observed from the image (a), the parallel grooves are formed by shifting the material to the sides of the wear groove. The material is not removed from the surface and called as ploughing. Also the image (b) shows the removal of material from the surface of the samples and called as cut.

The figure 4 represents the microstructural images of heat treated Al HMMC samples. Both the images(c) and (d) show less formation of groves and it is evident that the cutting did not form on the surface of the samples. This might be due to the presence of more percentage of hard ceramic particles(TiC), these particles protected the surface from material removal during the mating of samples with the counter disc. Hence it is understood that the materials after T6 heat treatment show less worn out due to the fine grain refinement, better interfacial bonding between the Al-matrix and reinforcements, the dislocation density parameters further improves the hardness and strength of the Al HMMC and thus decrease in the wear rate.

Table 2: Experimental design using L9 orthogonal array

S.No.	Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	Wear Rate (m3/m)	S/N Ratio
1	20	2	3000	9.5	-19.5545
2	30	2	3000	14.33	-23.1249
3	40	2	3000	22.7	-27.1205
4	20	4	3000	10.752	-20.6298
5	30	4	3000	17.921	-25.0672
6	40	4	3000	21.505	-26.6508
7	20	6	3000	28.673	-29.1495
8	30	6	3000	32.258	-30.1727
9	40	6	3000	37.037	-31.3727
10	20	2	3000	3.401	-10.6321
11	30	2	3000	4.535	-13.1315
12	40	2	3000	6.802	-16.6527
13	20	4	3000	5.668	-15.0686
14	30	4	3000	7.936	-17.992
15	40	4	3000	10.204	-20.1754
16	20	6	3000	12.471	-21.918
17	30	6	3000	14.739	-23.3694
18	40	6	3000	15.873	-24.0132

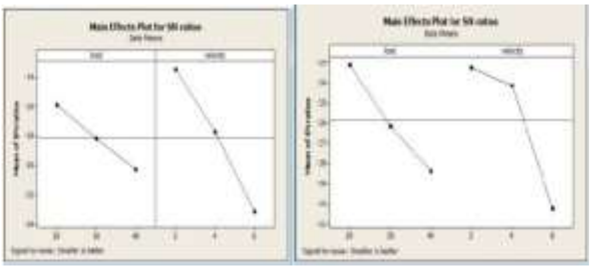


Figure 5: S/N Ratio for wear rate of Al-7075/ Al_2O_3/TiC

Effect of control parameters on wear rate:

The design of experiments consists of three control parameters; two parameters are varied and keeping one constant at three levels. The S/N ratio is calculated for each level and a plot is generated as shown in figure 5. It is observed that at level one with 2m/s sliding velocity and composition 8% of TiC, 0% of Al_2O_3 exhibited less wear rate. The increase in applied load and sliding velocity, the wear rate increases [7]. The wear rate is effected by applied load and sliding velocity. This might be due to the presence of hard ceramic particles in the Al matrix. The increase in sliding velocity increases the temperature of the worn surface and surface softening occurs due to frictional heating. The embedded hard particles may come out of the surface and act as third body at the mating interface causing wear rate. At initial stage oxidation of the surface occurs which avoids the direct metal to metal contact resulting in less wear rate and the wear mechanism is mild. But with increase in the sliding velocity, the wear rate increases rapidly due to the fragmentation of the hard oxide layer and the wear mechanism changes from mild to severe.

Among all composites, Al composites with multiple reinforcements show minimum wear rate. Due to higher hardness than single reinforcement. Increase in reinforcement percentage leads to improve the hardness nature and restrict the flow of materials during sliding wear rate decreases [16]. The worn surface shows high amount of plastic deformation and broken oxide layer with higher surface roughness values.

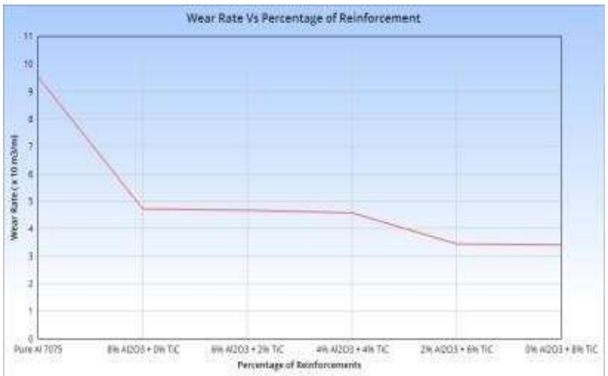


Figure 6: Wear rate Vs Percentage Reinforcements

From the figure 6, it is observed that the increase in the amount of hard ceramic particles (TiC) in the Al-7075 HMMC decreases the wear rate. This takes place due to the formation of mechanically mixed layer (MML) on the surface of the HMMC. This MML acts as additional reinforcement by protecting layer and as a solid lubrication. The hardness of the MML increases with the increase in the amount of reinforcement in the Al HMMC. The MML restricts the loss of material from the surface of the samples and the wear rate decreases. The wear rate decreases because of the interaction of the hard reinforcement particles with the counterface, restricting the flow of material under sliding motion and hence the wear rate decreases. The wear rate further decrease with increase in the thickness of MML depends on the volume fractions of reinforcements.

From figure 7, it is understood that the wear resistance increases with increase in TiC Wt. % in the Al-7075 HMMC. The TiC particles are harder than other reinforcement (Al_2O_3) and will provide a more effective barrier to subsurface shear by the motion of the adjacent steel counter-face. With increase in loads, it is observed that the wear resistance decrease. The graphs shows increase in mass loss indicates increases in wear rate. Also if load and sliding velocity increase, the wear rate also increases. Hence it indicates that sliding velocity and load majorly affect the behavior of wear rate.

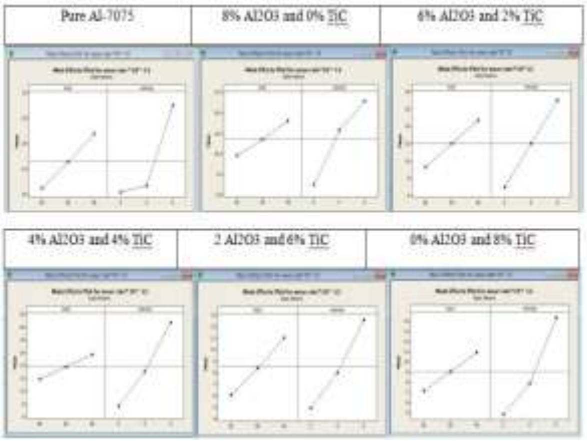


Figure 7: Main effects plots for Al-7075 HMMC

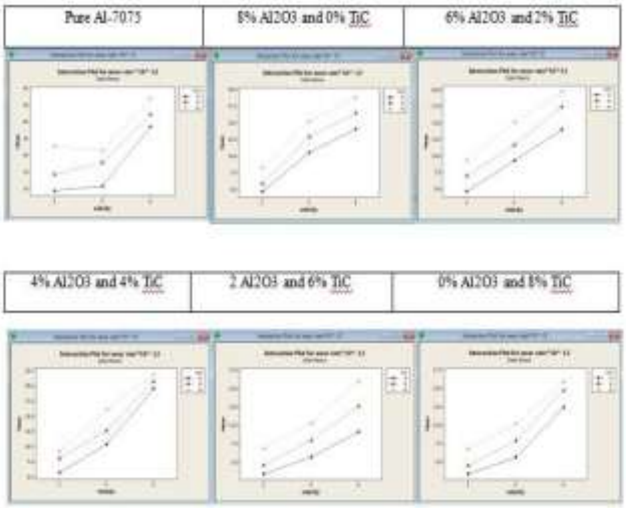


Figure 8: Interaction plots for Al-7075 HMMC

Figure 8, indicates the wear performance of Al-7075HMMC at different loads with varying sliding velocities. By the addition of TiC Wt. % in the Al-7075 HMM composite, the maximum reduction in wear rate is observed at 40N and 6 m/s sliding velocity. Compared to pure Al-7075 the maximum mean wear rate value is reduced from 9.5m3/m to 3.4 m3/m. Also the addition of Al_2O_3 ceramic particles reduced the wear rare. But the addition of TiC hard particles further reduced the wear rate. This may be due to the hard nature of TiC particles. Because of the hard nature the worn out of the surface is reduced. The increase in the wear resistance may be due to better distribution of the particles in the matrix, which is due to the improvement in the wettability of the reinforcing phase with the matrix. The effect of T6 heat treatment improved the wear resistance than cast Al7075 HMMC.

This may be due to the increase in hardness of the specimens when subjected to heat treatment. The hardness and strength are the predominant factors for wear behavior of materials. Higher the hardness and strength of the materials will retard the onset of adhesion which in turn leads to lesser material loss. After T6 heat treatment the wear rate was decreased from 7.17m3/m to 2.27m3/m at 40N load and 6m/s sliding velocity. It indicates that the heat treatment improved the wear resistance of Al-7075 hybrid metal matrix composites. The thermal mismatch between the plain matrix alloy and the reinforcement particles enriches the dislocation density, enhanced dislocation densities resists the plastic deformation of the material, during sliding. Hence, the amount of wear is drastically increased with the increase in sliding time. [13]. In laboratories, wear Tribological Behavior tests are conducted at ambient temperature by varying loads and sliding velocities and the wear resistance are calculated. A test specimen was loaded against a larger moving surface of disc and tests were performed. The sliding may be repeated on the same counter- face or under single path conditions for which fresh tracks of the counterpart are moved against the loaded specimen.

Conclusions:

1. The mechanical properties of Al7075 alloy improved by adding Al_2O_3 and TiC as reinforcement particles. These properties were further increased with heat treatment effect.

2. The calculated wear values revealed that increase in wear resistance of Al 7075/TiC/Al_2O_3 composite than pure 7075 alloy.

3. The wear resistance has improved at (Al_2O_3 and TiC), the sample with 8% TiC exhibited good wear resistance.T6 treatment also influenced in reduction of wear rate.

4. Applied load is inversely proportional to wear resistance in dry sliding wear.

5. As sliding velocity is increased, the wear rate increased due to the rise in temperature.

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