Investigation on Optimization of Wear Properties on Aluminum Hybrid Metal Matrix using Taguchi Method

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Abstract: A study on the dry sliding performance of the aluminum hybrid metal matrix composites and optimization using Taguchi method. The parameters selected for this experimental study are applied load, sliding velocity and sliding distance. The wear test is performed using a pin-on-disk apparatus. The experiments were carried out using Taguchi technique with an L27 orthogonal array. The developed model is verified using Analysis of variance (ANOVA) technique. It can be inferred from the results that with increasing applied load, sliding distance and sliding velocity the wear rate were also increasing. Also MoS2-free composite exhibited more wear compared to the molybdenum disulphide composite.

Keywords- Aluminum Matrix Composites, Wear, Taguchi technique, Molybdenum Di Sulphide, Titanium Carbide.

I. INTRODUCTION

A Metal matrix composite is fabricated by a combination of materials (one of which is a metal) in which desired properties are attained by the calculated synthesis of different constituents. The matrix metal is reinforced with fibres, whiskers and particles of metals or ceramics. MMCs are usually found in aerospace, automobiles, marine engineering and turbine-compressor engineering applications owing to their light weight. Aluminum and its alloys play an important role in the production of MMC.AMC materials have greater advantages in a wide number of specific fields due to their high specific strength, stiffness, wear resistance and dimensional stability. Fabrication methods are important part of the design process for all structural materials including AMCs. Stir casting technique is the conventional and economical way to fabricate the metal matrix composites. In particulate reinforced MMC, reinforcement is added to the matrix of the bulk material to increase its stiffness and strength. Furthermore, the use of discontinuous reinforcement minimizes the problems associated with the fabrication of continuous reinforced MMC such as fibre damage, micro structural heterogeneity, fibre mismatch and interfacial reactions. It was reported that several key factors such as type, size and volume fraction of particles as well as the interfacial particle/matrix bonding had a pronounced influence on the wear behaviour of the reinforced composite. Only a few works on the wear characterisation of Al reinforced with TiC composite have been reported so far. S.Gopalakrishnan, N.Murugan researched the Production and wear characterization of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method. In this study Al–TiCp castings with different volume fraction of TiC were produced in an argon atmosphere by an enhanced stir casting method. It shows that the specific strength of the composite has increased with higher % of TiC addition and reveals the improved specific strength as well as wear resistance of Aluminum matrix composites [1]. Falcron-Franco L reported the Wear performance of TiC as reinforcement of a magnesium alloy composite. It was reported that several key factors such as type, size and volume fraction of particles as well as the interfacial particle/matrix bonding had a pronounced influence on the wear behavior of the reinforced composite [2]. Rajnesh Tyagi have investigated the Synthesis and tribological characterization of Al–TiCp composite produced by in situ process revealed that the wear rate decreased linearly as the volume fraction of TiC increased from 7% to 18% [3].. A.G.Kostornov investigated the prospects of improving the tribological characteristics of titanium composites without lubrication at different sliding velocities. It shows that the titanium-based composites are promising as antifriction materials at an increased sliding velocity [4]. Zhiwei Liu was introduced the quick preheating treatment of Al–Ti–C in the fabrication of in situ TiC/Al metal matrix composites.

In situ TiC particles synthesized in the pure molten aluminum were spherical in morphology and most of which were smaller in size. The synthesizing temperature of in situ TiC/Al composites was decreased significantly by using the quick preheating treatment, at temperature lower than those used in the conventional methods. [5]. Friction appears to be the key factor in the wear studies, which shows that MoS2 composites have excellent anti-friction and wear-resistance performance and it is used in a wide range. W.O.Winer reported a review of the fundamental knowledge of MoS2 as lubricant. It discussed about the behavior of MoS2, frictional characteristics and the physical and chemical properties which are important to its use as a lubricant [6]. Jiaren Jiang reported the effect of ball diameter on wear and friction of a molybdenum disulphide (MoS2) coating deposited using the closed-field magnetron sputtering technique. It was observed that the wear rate of the coating decreased significantly with increase in ball diameter. Correspondingly, the average friction coefficient in the steady state of sliding increased with increase in ball diameter [7]. T.A.Stolarskia examined that thermally sprayed molybdenum coating is one of the most used wear resistance coatings in many practical applications. This paper reports a significant dependency of wear resistance of molybdenum coating on the spraying distance. It shows the influence of test configuration and conditions on the wear performance ranking of molybdenum coatings [8]. . S.Dhanasekaran reported the abrasive wear behavior of sintered steels prepared with MoS2 addition. In this study Abrasive wear tests were conducted by sliding against the SiC abrasive sheet at room temperature. It shows that MoS2 added material exhibited a high coefficient of friction and good wear resistance compared to the base composition compressive strength, hardness and density are influenced by the addition of MoS2 [9]. Xiong Dangsheng investigated the Lubrication behavior of Ni–Cr-based alloys containing MoS2 at high temperature and found out that the anti-bending strength of the alloy decreases and the tribological properties of the alloy were improved by adding MoS2. It shows that the synergistic action of oxides and residual sulphides in the wear surface and wear debris at high temperature is responsible for reduction of friction [10]. Song Wenlonga reported that the performance of a cemented carbide self-lubricating tool embedded with MoS2 solid lubricants in dry machining reduces the frictional coefficient. In this study the cutting forces, tool wear, and average friction coefficient at the tool-chip interface were measured and compared and finite element analysis (FEA) was used to analyze the effect of micro-holes on the mechanical properties of cutting tools [11]. S.C.Ray revealed the structure and optical properties of molybdenum disulphide (MoS2) thin film deposited by the dip technique. It shows that Molybdenum dichalcogenides appear to be very promising semiconductor materials for various applications such as solar cells, rechargeable batteries and solid lubricants for metallic and ceramic surfaces. They have also been widely used in space-technology where their low co-efficient of friction in vacuum is of particular value [12]. K.C.Wonga examined the surface and friction characterization of MoS2 and WS2 third body thin films under simulated wheel/rail rolling-sliding contact. In this study he predicted that the wear mechanism and chemical change of the MoS2 and WS2 during rolling-sliding are important factors governing the tribological performance in such aspects as friction level, retention time, lubrication regime and failure mode [13]. Qunji Xue have investigated the tribological properties of SiC whisker and molybdenum particle reinforced aluminum matrix composites under lubrication and revealed that the composites exhibited good friction- and wear-resistance properties. It shows that with increasing load, the wear rate increases quickly and the wear mechanism is plowing with delamination [14]. Basavarajappaet al.'s investigation on Al 2219-SiC and Al 2219-SiC- Graphite hybrid composites showed that the sliding distance, load, as well as sliding speed parameters were significant factors for wear by using Taguchi and ANOVA techniques [15]. S. Dharmalingam investigates the optimization of dry sliding performances on the aluminum hybrid metal matrix composites using gray relational analysis in the Taguchi method Using a pin-on-disk apparatus, the volume loss and frictional force are measured and the results used to evaluate the dry sliding performances are specific wear rate and coefficient of friction[16]. Aravind Vadiraj investigated the friction and wear behaviour of MoS2, boric acid, graphite and TiO2 at four different sliding speeds (1.0, 1.5, 2.0, 2.5m/s) and compared with the dry sliding condition. The results show the friction coefficient reduces with increase in sliding speeds for all the conditions [17].

II. EXPERIMENT DETAILS

2.1 Selection of Matrix Material

Aluminum, being the most widely used metal in industries due to its attributes, finds applications in almost all fields. The metal matrix selected for present investigation was based on Al-Cu-Mg alloy system, designated by the

American Aluminum Association as Al 7075. The chemical composition of the matrix material is as shown the Table 1.

Table1 Chemical composition of Al 7075 (weight %)

Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Be	V
0.92	0.76	0.28	0.22	0.10	0.07	0.06	0.04	0.003	0.01

This matrix was chosen since it provides excellent combination of strength and damage tolerance at elevated and cryogenic temperatures. It is an age harden able alloy suitable for high temperature and high strength applications like structural components and high strength weldments. It also has a high heat dissipation capacity due to its high thermal conductivity (Davis 1993).

2.2 Selection of Reinforcement Materials

Metal-matrix composites are discontinuously reinforced and TiC particles are the most commonly used reinforcement materials. Using TiC particles as reinforcement improves stiffness, strength, thermal conductivity, wear resistance, fatigue resistance, and reduces thermal expansion. The chemical composition of TiC is shown in Table 2. Additionally, TiC reinforcements are typically low-cost and have a relatively low density. Particle size and shape are important factors in determining materials properties. Fatigue strength is greatly improved with the use of fine particles. The TiC particles, which were used to fabricate the composite, had an average particle size of $23x10^{-6}$ m and average density of $4.93g/cm^3$. It is the second hardest material after diamond with a Mohr's hardness of 9.5. The melting point of the TiC is 3160^0C. The MoS_2 particles used for hybrid composites are of $45x10^{-6}$ m size and average density of 2.25g/ cm3. The chemical composition of MoS2 is shown in Table 3. It is a soft material with a hardness of 1-2 Mohr's scale, with a melting point of 3650^0C. In order to improve the consolidation of particles in the layer, external excitation of loading system has been used using pin-on-disk device. Experimental results show that MoS_2 particles have excellent anti-friction and wear resistance performances with high load carrying capacity. Addition of MoS_2 as lubricant enhances wear resistance rate by 30-50%.

Table 2 Chemical composition of TiC (weight %)

Ni	Fe	Mo	Cr	Ti+Ta+Ni	Co	C	O
<0.3	<0.5	<0.1	<0.1	1.64	11.63	6.1	<0.08

Table 3 Chemical composition of MoS2 (weight %)

Fe	Pb	MoO_3	SiO_2	H_2O	KOH	Oil
0.3	0.2	0.2	0.20	0.20	0.50	0.50

2.3. Composite preparation

To obtain superior mechanical properties in the composite, a good interfacial bonding (wetting) between the dispersed phase and the liquid matrix has to be attained. To attain this, stir-casting technique is deployed as it is one of the simplest and cost effective methods to fabricate metal matrix composites which have been adopted by many researchers. This method is most economical to fabricate composites with discontinuous fibres and particulates and was used in this work to obtain the as cast specimens. In this process, matrix alloy (Al 7075) was first superheated above its melting temperature and then temperature is lowered gradually below the liquidus temperature to keep the matrix alloy in the semisolid state. At this temperature, the preheated TiC particles were introduced into the slurry and mixed. The composite slurry temperature was increased to fully liquid state and automatic stirring was continued to about five minutes at an average stirring speed of 300-350 rpm under protected organ gas. The Aluminum-TiC- MoS_2 composite was fabricated with a blended mixture of TiC and MoS_2 particle respectively. This blended mixture is introduced into the molten liquid slurry and stirring is continued. The TiC particles help in distributing the MoS_2 particles uniformly throughout the matrix alloy. The molten metal was then poured into a permanent cast iron mould of diameter 26mm and length 300mm. The die was released after 6 hours and the cast specimens were taken out. The pin-on-disc test apparatus shown in Fig. 1 is used to investigate the dry sliding wear characteristics of the composite as per the ASTM G99-95 standard. During the test, the pin is pressed against the counter face EN32 steel disc with a hardness of 65 HRC. After traversing a fixed D, the specimen is removed, cleaned with acetone, dried, and weighed to determine the mass loss due to wear.

2.4. Design of experiments

Design of experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test combinations.

Table 4 Parameters used for conducting the experiment

Experiment No	Column 1	Column 2	Column 3
1	1	1	1
2	1	1	1
3	1	1	1
4	1	2	2
5	1	2	2
6	1	2	2
7	1	3	3
8	1	3	3
9	1	3	3
10	2	1	2
11	2	1	2
12	2	1	2
13	2	2	3
14	2	2	3
15	2	2	3
16	2	3	1
17	2	3	1
18	2	3	1
19	3	1	3
20	3	1	3
21	3	1	3
22	3	2	1
23	3	2	1
24	3	2	1
25	3	3	2
26	3	3	2
27	3	3	2

In the present work, a plan order for performing the experiments was generated by Taguchi method using orthogonal arrays. The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate. The experiments were developed based on an orthogonal array, with the aim of relating the influence of sliding velocity, applied load and distance travelled. Table 5 shows the experimental details of design factors and their levels for the wear test results. The above mentioned pin on disc test apparatus was used to determine the sliding wear characteristics of the composite. The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array show in Table 4. Dry sliding wear test was performed with three parameters: applied load, sliding speed, and sliding distance and varying them for three levels. According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters, a L27 Orthogonal array which has 27 rows and 3 columns was selected. Dry-sliding wear tests were conducted using a pin on a disc apparatus and the variations in wear rate of specimens with different applied loads, sliding velocity, distance travelled under dry sliding condition are given in

Table 6.

Table 5 Parameters used in the wear test

Level	Sliding Velocity (m/s)	Distance Travelled (m)	Applied load (N)
1	1	200	10
2	1.5	350	15
3	2	500	20

Table 6 Experimental results of wear rate for metal matrix composites

LEVEL	SLIDING VELOCITY (M/S)	DISTANCE TRAVELLED (M)	APPLIED LOAD (N)	WEAR RATE ($X10^{-6}MM^3/M$)
1	1	200	10	30.45
2	1	200	10	30.50
3	1	200	10	31.62
4	1	350	15	35.00
5	1	350	15	34.09
6	1	350	15	33.69
7	1	500	20	41.02
8	1	500	20	39.06
9	1	500	20	40.05
10	1.5	200	15	35.02
11	1.5	200	15	35.05
12	1.5	200	15	35.07
13	1.5	350	20	40.06
14	1.5	350	20	40.79
15	1.5	350	20	40.33
16	1.5	500	10	30.12
17	1.5	500	10	30.32
18	1.5	500	10	30.33
19	2	200	20	41.03
20	2	200	20	40.95
21	2	200	20	41.11
22	2	350	10	31.09
23	2	350	10	31.11
24	2	350	10	31.32
25	2	500	15	36.09
26	2	500	15	36.14
27	2	500	15	35.99

FIG 1: Schematic view of Pin on disc apparatus used in this study.

III. RESULTS AND DISCUSSION

3.1. Analysis of Variance Results for Wear Test

Analysis of Variance (ANOVA) is employed for verifying data from the experiments. It investigates the influence of applied load, sliding speed, and sliding distance that significantly affects the performance of the composite. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. ANOVA results for wear rate of Al7075 metal matrix composites reinforced with 10wt% TiC and 10wt% MoS2 for three factors are varied and the interactions of those factors are shown in Table 7.
This analysis is carried out for a significance level of α=0.05, i.e. for a confidence level of 95%. Sources with aP-value less than 0.05 were considered to have a statistically significant contribution to the performance measures.

TABLE 7 Analysis of Variance for wear rate

Level	SS	DOF	MS	F	P	Pr (%)
Applied load	0.000000	2	0.000000	2.31	0.302	0.25
Sliding speed	0.000003	2	0.000001	29.89	0.032	37.5
Sliding distance	0.000005	2	0.000002	52.75	0.019	62.5
Error	0.000000	2	0.000000			1.25
Total	-	8				100.0

3.2. Multiple linear regression model

Statistical software “MINITAB 15” had been used for developing a multiple linear regression model. The predicted wear rate found using multiple linear regression model is shown in Table 8. The regression equation developed for Al7075 / 10wt% TiC and 10wt% MoS2 MMCs wear rate as follows

$$Wr = 19.5 + 1.04\ V - 0.000622\ D + 0.973\ P \quad (1)$$

TABLE 8 Confirmation results of wear rate

Level	Sliding Velocity V(m/s)	Distance Travelled D(m)	Applied load P(N)	Wear Rate, (Y) ($x10^{-6}$mm/m)	Predicted Wear Rate(Wr) ($x10^{-6}$mm/m)
1	1	200	10	30.45	30.1456
2	1	200	10	30.50	30.1456
3	1	200	10	31.62	30.1456
4	1	350	15	35.00	34.9170
5	1	350	15	34.09	34.9170
6	1	350	15	33.69	34.9170
7	1	500	20	41.02	39.6890
8	1	500	20	39.06	39.6890
9	1	500	20	40.05	39.6890
10	1.5	200	15	35.02	35.5506
11	1.5	200	15	35.05	35.5506
12	1.5	200	15	35.07	35.5506
13	1.5	350	20	40.06	40.3223
14	1.5	350	20	40.79	40.3223
15	1.5	350	20	40.33	40.3223
16	1.5	500	10	30.12	30.4990
17	1.5	500	10	30.32	30.4990
18	1.5	500	10	30.33	30.4990
19	2	200	20	41.03	40.9156
20	2	200	20	40.95	40.9156
21	2	200	20	41.11	40.9156
22	2	350	10	31.09	31.0923
23	2	350	10	31.11	31.0923
24	2	350	10	31.32	31.0923
25	2	500	15	36.09	35.8640

26	2	500	15	36.14	35.8640
27	2	500	15	35.99	35.8640

3.3 Microstructure Study:

Fig.2 shows the optical micrographs of the TiC- MoS_2 particles and of the composites show as-cast structures consisting of Al 7075 reinforced with TiC- MoS_2 alloy. The microstructures of the composites (Al 7075/ TiC- MoS_2) are significantly finer, affected probably by the heterogeneous nucleation caused by MoS_2 particles. The tiny TiC particles were pushed by dendrites to the dendrite/grain boundaries during the solidification. Aluminum matrix exhibits the finest microstructure due to the higher fraction of TiC- MoS2 particles added. Figures show that TiC-MoS2 particles were uniformly distributed in the matrix. A compositional analysis of composites was performed by means of SEM to evaluate the dispersion of MoS2.

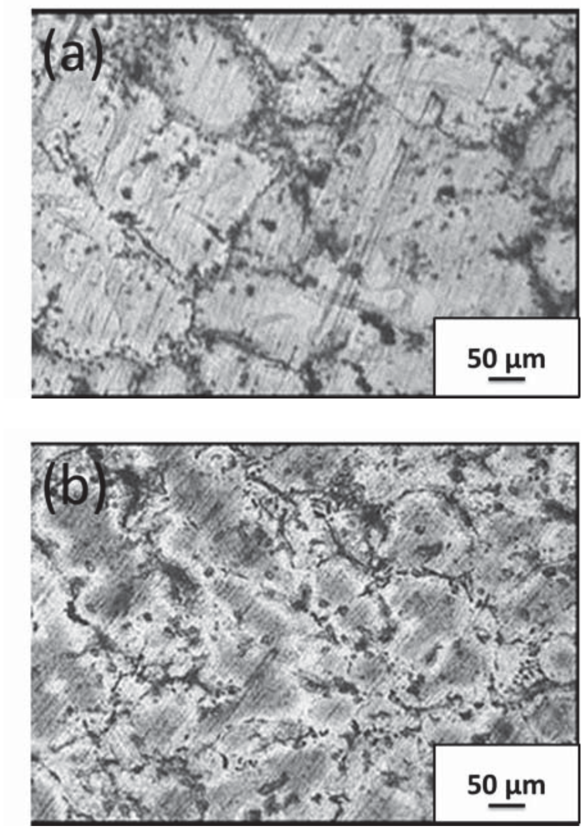
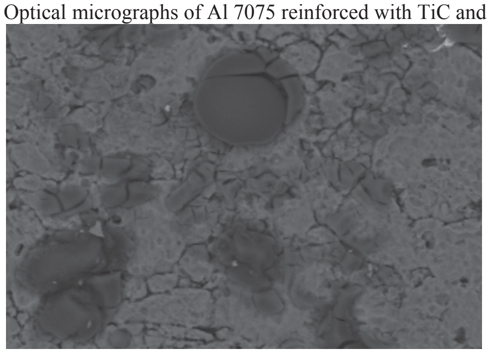


Fig 2: Optical micrographs of Al 7075 reinforced with TiC and MoS_2



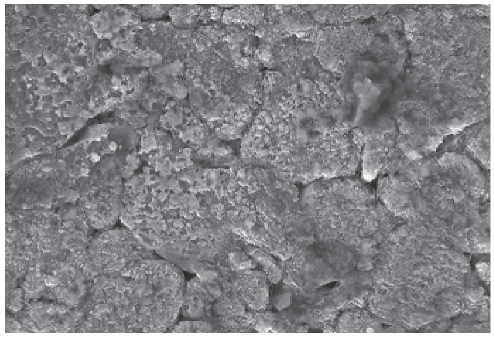


Fig 3: SEM Micrograph of AA7075 reinforced with TiC and MoS2

IV.CONCLUSIONS

The developed model can be effectively used to predict the wear rate of Al 7075 reinforced with TiC and MoS2 composite material fabricated by stir casting method. Orthogonal array is used to optimize the multiple performance dry sliding characteristics of aluminum hybrid composites. Based on the ANOVA, molybdenum disulfide percentage followed by sliding velocity, and applied load exert a significant influence on the specific wear rate of aluminum composites. The sliding velocity is having directly proportional relationship with wear rate and finally the interactions between applied load, sliding velocity, and molybdenum disulfide percentage on the dry sliding are found.

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