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EXPERIMENTAL INVESTIGATION OF TRIBOLOGICAL BEHAVIOR OF ALUMINIUM HYBRID METAL MATRIX COMPOSITE

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Abstract:

This research work explore the fabrication and tribological behavior of Aluminum 6061 alloy reinforced with hard ceramic particles like Alumina (1, 3 and 5 wt % Al_2O_3) and Boron Carbide (1,2 and 3 wt%B_4C).Stir Casting method was employed to fabricated MMC. The tribological properties of MMC was investigated by using dry sliding wear test on pin-on -disc tester .The trials were carried out according to the experimental plan created using Taguchi's technique. The data was analyzed using a L9 Orthogonal array. The investigation was done to find out influence of reinforcement of hard ceramic particles at constant processing parameters of pin-on-disc tester on wear rate and coefficient of friction. The experimentation was performed at track distance (30mm),Load (50N),Sliding Speed (200rpm) and time (15 min) and varying percentages of reinforcement. 'Smaller the better' model was selected as a objective to analyses the dry sliding wear resistance. At last, confirmation tests were performed to validate the results of the experiment, and worn surfaces were studied with a scanning electron microscope.

Keywords : Aluminium Composites, MMCs, Stir casting, Taguchi's techniques.

INTRODUCTION:

Due to their improved qualities, Metal Matrix Composites (MMCs) have been seriously examined to replace traditional materials for a variety of applications, including those in the aerospace, transportation, defense, house hold application, structural and sports industries[1].On account of their appealing mechanical and physical properties make them as an attractive option for manufacturer [2,3]. Number of manufacturing process are available according to reinforcement used like squeeze casting[4], liquid infiltration[5], spray co-deposition [6], compo casting process and stir casting [7].Among various manufacturing processes, many research scholar have applied stir casting technique to fabricated composites with different types of ceramic particles as a reinforcement and concluded that developed composites have better wear performance and mechanical properties [8–14].Advanced weapons systems such as satellite bearings, inertia navigation systems and laser reflectors use hybrid metal matrix composites, which are made up of more than one metal particles are added as reinforcement in base matrix [15]. The SiC reinforced MMCs, which are utilized more frequently to create cylinder heads, liners, brake motors and pistons have excellent hardness, stiffness, specific strength, and thermal properties.[16,17].

Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

Hashim et.al [18] used computer simulation to study impact of stirrer position in crucible and stirring speed on the flow pattern of particles. And compared it to the outcomes of visualization tests by using polystyrene and glycerol particles to distribution of reinforcement in matrix. But they found out some problems with fabrication of composite like not properly distribution of reinforcement in matrix. The existing processing techniques frequently result in agglomerated particles in the ductile matrix, which causes them to have very low ductility [19, 20]

Pandiyarajan et.al [21] study about the mechanical and metallurgical properties of B_4C and SiC as reinforcement in Aluminium. Among the various fabricated process they used the pressure die casting process to fabricate the composite by varying weight percentage of Silicon carbide (0,10,15,20) and boron Carbide(0,10,15,20) in aluminium. To find out the homogeneous dispersion of reinforcement into composite author used Energy Dispersion X-Ray (EDX) and Scanning Electron Microscope (SEM). Mechanical characteristics of composite was analyzed by microhardness machine and concluded that at 10 wt % of SiC and 20 wt % of B_4C maximum hardness was observed i.e 50.3 HV as compare to other composite.Vijaya Ramnath et al [22] fabricated the aluminium metal matrix composite by using stir casting technique and study about Mechanical characteristic of aluminium alloy-boron carbide and alumina composite. They fabricated three different samples. Sample 1 is made with pure aluminium. Sample 2 with 95% Al+3% Al_2O_3 + 2% B_4C and sample 3 made up with 95% Al + 2% Al_2O_3 + 3% B_4C and found that tensile Strength , flexural Strength and impact Strength is higher in pure aluminium sample. Also concluded that higher percentage of reinforcement increases the hardness value of composite [23]. Marigoudar et al [24] fabricated aluminium base composite with SiC and studies the wear behavior of composites. By incorporation SiC particles, it has been observed that wear resistance of composite were enhance. Also it was found out that with increasing SiC content, wear of material get decreases. Khoman Kumar et at[25] study tribological behavior of Al-SiC composite which was fabricated by centrifugal casting process. To create the experimental design and mathematical model RSM method was implemented. Author also studies the surface of worm out sample and purity size verification was checked by XRD. After doing the experimentation at high temperature they concluded that wear rate increases above 300^0 C .By ANOVA, contribution parameters was Sliding Distance 17.44%, temperature 70.87% ,and load 4.5 bar on wear. Among all din-on disc parameters temperature affect more.

DESIGN OF EXPERIMENT

Design of experiment is a crucial and effective statistical tool to find out the influence of multiple variables simultaneously and having set of activities to conduct sequence for experiment to enhanced process performance [26]. To see the outcomes of test conditions, every defined experiment needs to test a specific number of combinations of factors and levels. For finding certain test combinations, the Taguchi technique depends on factors in particular orthogonal arrays. The planning phase, the conducting phase, and the analysis phase are the main phases of DOE. The main aim of DOE is to find out the ideal combination of factors and levels who gives the preferred responses [27].A ratio of signal to noise is applied to analysis of the experimental data in order to identify the optimal design process. Many researchers have successfully used this

Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

method in tribological investigation. These techniques emphasis on enhancing manufacturing process design. In present research, plan order to performed number of experiment was develop by Taguchi technique using orthogonal arrays [28].

MATERIAL SELECTION

Al alloy is widely utilized in the marine and aerospace industries due to its excellent welding characteristics and high resistance to corrosion. To fabricated metal matrix composite, Al alloy is use as a base metal. Fig 1(a, b and c) shows the material used to fabricate the composite.

Aluminium 6061

Aluminium 6061 is used as a base material in MMCs. It is precipitation hardened alloy of aluminium which contains silicon and magnesium as major alloying elements. It having good mechanical and weldability properties. Aluminium materials are commonly used in automotive, mechanical and aircraft industries. Chemical composition of base metal is shown in Table 1. Aluminium is used for general -purpose. Table 2 shows Thermal and Mechanical properties of Aluminium 6061

Fig.1(a).Aluminium Alloy 6061 Fig.1(b) Alumina Powder (Al2O3) Fig.1(c) Boron carbide B_4C

Table 1 Chemical composition of Al6061

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Al
Percentage Composition(%)	0.10	0.70	0.80	0.60	0.40	0.10	0.05	0.05	Balance

Table 2.Thermal and Mechanical properties of Aluminium

Properties	Tensile Strength (Mpa)	Young's Modulus (GPa)	Melting Temp(^{O}C)	Density(g/cm3)	Thermal Conductivity (W/m-K)	Thermal expansion(/K)

Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

Aluminium	260	70	650	2.70	166	$23.4*10^{-6}$

Reinforcement

It is the hard ceramic particles which are added in metal matrix composite to improve the base metal properties.

Aluminium Oxide (Al_2O_3)

Aluminium Oxide is also called as "Alumina". Alumina is available in white crystalline form. It is usually found in corundum form and having amphoteric in nature. Because of its high melting point and good hardness, it can be used as a refractory material and as an abrasive material, respectively. Aluminium oxide increases as a reinforced phase in fraction volume results in lesser fracture toughness of MMCs[11].It having the ability to remain stable with aluminium and sustain high temperature. Table 3 shows Mechanical & Thermal properties of Al_2O_3.

Table 3. Mechanical and Thermal properties of Al_2O_3

Properties	Melting Temp(^{O}C)	Density(g/cm3)	Thermal Conductivity(W/m-K)	Thermal expansion(/K)
Alumina	2072	3.95	29	$7.4*10^{-6}$

Boron Carbide (B4C)

It is also known as 'Tetrabor' having blackish powder -like material. B_4C is one of the hardest ceramic materials that can be used in the manufacture of ballistic armour, vehicle armour and multitudinal industrial applications. In comparison to other materials, it has superior toughness and stability in radioactive environments. It is one of the hardest materials .Table 4 shows thermal and Mechanical properties of Boron Carbide (B_4C)

Table 4.Thermal and Mechanical properties of Boron Carbide (B_4C)

Properties	Melting Temp(^{O}C)	Density(g/cm3)	Thermal Conductivity(W/m-K)	Thermal expansion(/K)
Alumina	2763	2.52	31-90	$3.2*10^{-6}$

Fabrication Method

Stir casting process was used to manufacture MMC. In this technique material (base metal & reinforcement) is melted and stir continuously to avoid aggregation and then immediately placing the molten material into a cavity that has already been made, cooling it, and leaving it for solidification. One of the key problems with the stir casting process is agglomeration of particles,

China Petroleum Processing and Petrochemical Technology

Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

which can be resolved by doing continuously stirring at high temperature. The setup of stir casting is displayed in Fig.2(a & b)

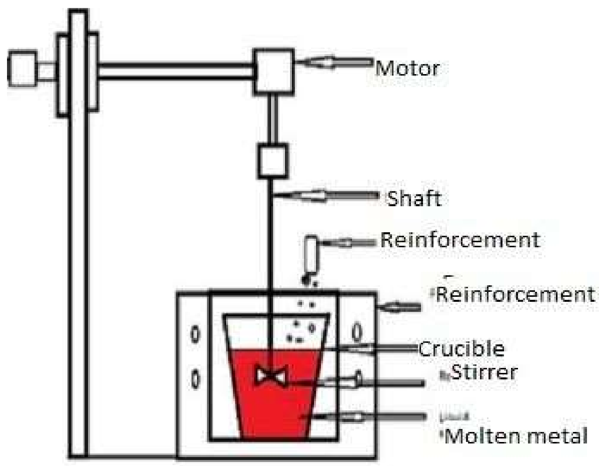
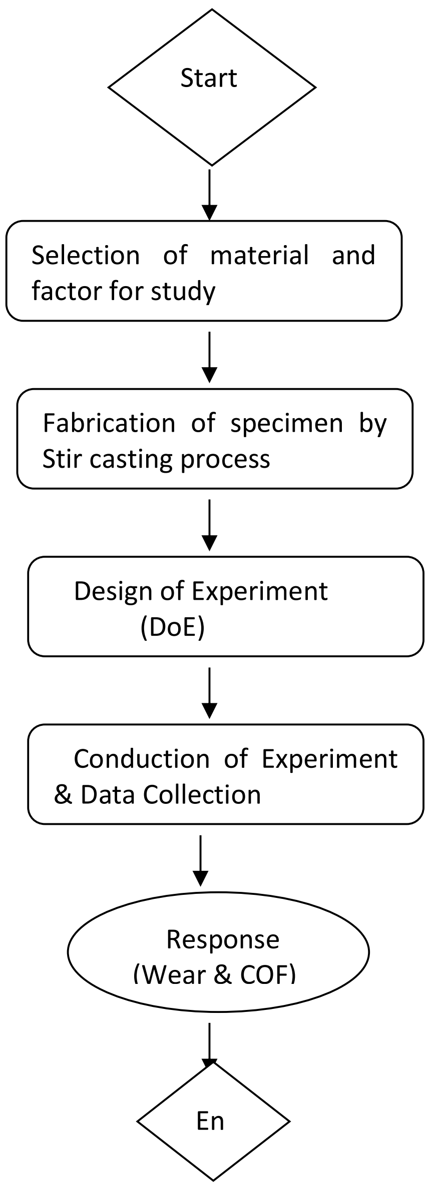


Fig. 1 (a) Stir casting Layout **Fig. 1 (b) Stir casting setup**

In the present investigation, stir casting process was used to fabricate composites with an Al6061 matrix reinforced with Al_2O_3 and B_4C. The base metal Al6061 was melted at temperature 660 ^{0}C in a graphite crucible using electric furnace. A weighted amount of reinforcement Al_2O_3(1,3 and 5) and B_4C(1, 2 and 3) were preheated to remove the moisture present in it and added at constant rate into molten metal. The composite slurry was stirred continuously at a speed of 300 rpm for 15 minutes. To increase the wettability of matrix alloys and dispersed phase 1 wt % of magnesium were added to solution of metal. Also Solid dry hexachloroethane tablet (degassing agent) was added to remove the gasses present in molten metal. In order to ensure proper mixer of reinforcement in base matrix alloy, stirring was continued around 10 min even after completion of adding particulate. The composite slurry was poured into preheated predefined cylindrical mould of 20 mm diameter and 200 mm length. It was kept in mould nearly 5 min for solidification and after sample were removed. A Aluminium hybrid MMC sample is shown in fig.3. The cast composite sample were machined into 10mm dia and 25 mm length in lathe machine for testing wear and coefficient of friction.

Fig.3 Cast Composite Sample

Flow Chart of Methodology



Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

Wear Behavior:

The experimental plan helps to determine the best combination of reinforcement with Al6061 alloy to obtain minimal rate of wear and coefficient of friction at constant machining parameter of pin-on -disc machine i.e track distance (30mm), Load (50N), Sliding Speed (200 rpm) and time (15 min).experimental plan was developed based on orthogonal array. Pin-on-disc setup was used to find out the dry sliding wear loss of composite. Nine specimens with different composition were made to measure wear loss and coefficient of friction. For measuring wear, contact surface of cylindrical pin was made flat to been in contact with circular rotating disc. During testing this specimen pressed against a rotating EN31 carbon steel disc (Hardness of 65 HRC) at applied load acting as a counterweight and balanced the specimen.

Further, amount of weight loss was obtained for each specimen by weighing before and after experiment on electronic weighing machine with accuracy of 0.0001 g.

The results of various experiment was obtained as per Taguchi orthogonal array and shown in table 1.

Run of experiment	Al6061	Al2O3	B4C	Wear (gm)	COF
1	98	1	1	0.0334	0.44
2	98	3	2	0.0384	0.46
3	98	5	3	0.0314	0.42
4	95	1	1	0.0474	0.52
5	95	3	2	0.0484	0.43
6	95	5	3	0.0341	0.42
7	92	1	1	0.0453	0.41
8	92	3	2	0.0371	0.44
9	92	5	3	0.0326	0.41

Catalyst Research Volume 23, Issue 2, November 2023 Pp. 3982-3992

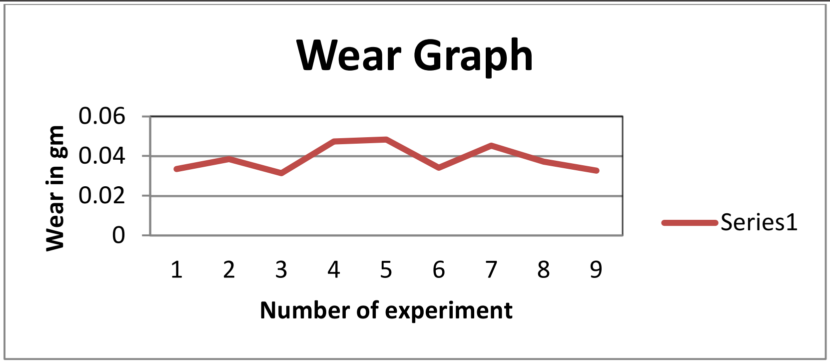


Fig.4 Wear in gram of run of experiment

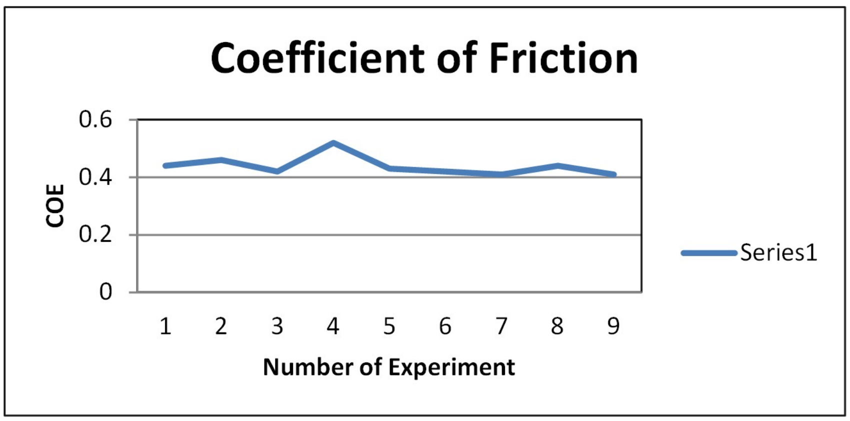


Fig.5 coefficient of friction of run of experiment

SEM image of Al6061+5 wt% Al2O3+3wt%B4C of composite are shown in fig.6. From this figure it has been clearly observed that reinforcement are uniformly distributed in Aluminium matrix. It also indicated that relatively good distribution of alumina and boron carbide reinforcement in aluminium matrix. In image Al2O3 particles are shown as whitish phases and B4C are seen in dark phase in Al6061 alloy structure.

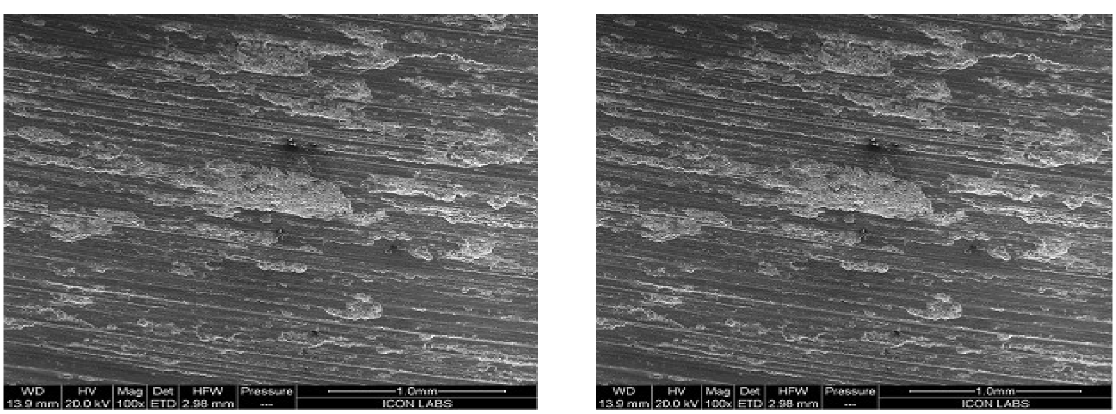
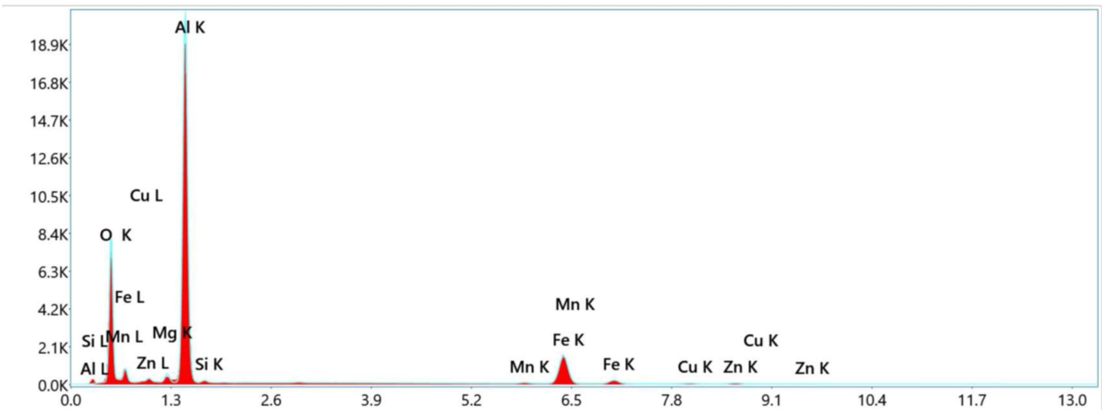


Fig .6 SEM images of Al6061+5 wt% Al2O3+3wt%B4C composite

Energy Dispersive Spectroscopy (EDS) show the aluminium matrix near B4C and Al2O3 in fig.7 . The aluminium on peak then silicon, magnesium, copper, carbon and oxygen peak gives the confirmation of element presence in the aluminium matrix incorporation of Al2O3 and B4C particles in the EDS. Small amount of oxygen also detected through Energy Dispersive Spectroscopy is probably coming by oxide present during preparation of composite.



RESULTS AND DISCUSSIONS

The main focused of the research work is to identify best combination of reinforcement which influences the wear process in order to obtain minimum wear loss and coefficient of friction. From Table no.01 it has been observed that combination of 98 wt% of Al6061+5 wt% Al2O3+3wt%B4C shows minimum wear. By adding the more reinforcement, wear loss of composite material is decreases. This is because reinforcement acting as a load bearing constituents which restricted the metal removal in composites. Hence reinforcement percentages increases area of hard ceramic also increases which increases the load carrying capacity, leading to reduces the wear loss.

CONCLUSION

In present work, Stir casting method is successfully used for fabrication composite of aluminium Hybrid MMC with different composition of boron carbide (1,2 &3 wt %) and alumina (1,3,& 5 wt %) . Different samples with different composition are fabricated and tested, sample No.3 (98 wt% of Al6061+5 wt% Al2O3+3wt%B4C) has lower wear loss i.e 0.0314 and coefficient of friction 0.42 is obtained due to the presence of high amount of reinforcement.

From SEM it has been observed that there is uniformly dispersion of reinforcement in aluminium matrix. This work can be further extended by preparing composite with different fabricating process and comparing it with tribological behavior of composites.

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