Dry Sliding Wear Behavior of AA2219 Reinforced with Magnesium Oxide and Graphite Hybrid Metal Matrix Composites

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Abstract **- Metal Matrix composites play a major role in engineering industries due to their high strength and many other advantages like superior mechanical properties, tribological properties, and corrosion resistance etc., Particularly Aluminium metal matrix composites are most widely used due to their easy manufacturability, easily tailored and availability. In the current work Aluminium alloy 2219 is reinforced with magnesium oxide (MgO) and graphite (Gr) and the hybrid composites were manufactured by stir casting. 0.5%, 1% and 1.5% weight percent of MgO were taken while the Gr weight percentage was maintained at 1% for all the composites. The composites were then tested for their wear properties by taking various factors like load, speed, sliding distance and percentage MgO. Design of Experiments(DOE) were done by Taguchi L29 orthogonal array and the analysis was done by Analysis of Variance (ANOVA). Regression equation was formulated for the response in order to obtain the optimum wear rate whose predictability was 90.4% as per the analysis. These composites can be used as a potential replacements in brake discs in automobiles.**

Keywords: AA2219, MgO, Gr, Wear, Taguchi, Regression

I. INTRODUCTION

Composite material is defined as the combination of two or more distinct materials having a recognizable interface between them. The composite has hybrid characteristics than those of individual components. Metal matrix composites is those which are based on metals as matrix. Usually the reinforcing component is distributed in the continuous or matrix components. Composite differ fundamentally, a second phase material is added to increase its performance, characteristics, structure & properties, which is not possible by using monolithic material.. As compared to light weight conventional monolithic alloys, MMCs have better structural applications and superior mechanical properties. Aluminum alloy reinforced with hard ceramic particles of WC, SiC, Al2O3, B4C and graphite for forming a composite to realize improvements in mechanical properties such as hardness, young's modulus, yield strength and ultimate tensile strength of the MMCs [1]. Aluminiun matrix composite is one in which Aluminium is matrix and it has the property of high strength to weight ratio and it gives unique balance of physical and mechanical properties. The Aluminium matrix composites are fabricated by different methods such as squeeze casting, compo casting, stir casting, powder metallurgy and liquid infiltration [2]. Among the fabricating methods, the stir casting is an attractive processing method for producing aluminium matrix composites. Stir casting usually involves prolonged liquid reinforcement contact, which can cause substantial interface reaction. By increasing the oxide percentage up to 4%, the hardness is increased [3]. Al-Si based alloy are used in stress non-critical application such as gear box housing, cylinder blocks, cylinder heads, pistons, fuel pumps, engine cooling fans, crank cases, air compressor pistons, compressor cases, rocker arms. Al-Cu based alloys are used in application such as floor beams, wing box, ribs, covers, brake components, fuel tanks, slot tracks wheel, fittings, fuel system, body skin connectors, engine piston and valve bodies [4]. The influence of graphite on the wear behavior of Al 7075/Al2O3/5 wt% graphite hybrid composite. The hardness, tensile strength, flexural strength and compression strength of the Al 7075– Al2O3graphite hybrid composites are shown increased by increasing of ceramic phase has been investigated [5].The effect of sliding distance on tribological behavior of Al6061-T6 alloy and its composite reinforced with hard ceramic alumina (3 wt.%) and solid lubricant graphite (3 wt. %) fabricated through stir casting technique. It was observed that, for all combinations of applied load, sliding velocity and sliding distance aluminium hybrid metal matrix composite (AlHMMC) reveal superior tribological properties than the Al6061 alloy [6]. A lot of studies are related to the influence of nature, size and wt. % contents of the disperse particles of silicon carbide, titanium carbide, tungsten carbide, titanium nitride, etc. The reinforcement of the aluminum alloy is realized by molding with different contents of micro particles in percentage of casting weight [7]. Graphite in the form of fibers or particulates has long been identified as a low friction and self-lubricant, low wettability by liquid metals, high thermal and electrical conductivity, low density material. Al/graphite particulate composite was used as a material for engine cylinder which exhibit higher seizure resistance and low frictional coefficient and wear rate. The effect of SiC and Graphite particulates content on the wear behaviour of Al2219–SiC and graphite particulates reinforced hybrid composites made by stir casting methodare discussed [8].Aluminium matrix reinforced with TiCp, fivedifferent weight percent of TiCp addition were performed without defects. In stir casting mixing of articulate with matrix is by mechanical stirring, mixing is very important character in MMC which will improve its mechanical properties but in stir casting method mixing is not proper also atmospheric reactions are unavoidable. Presence of hard ceramic particle reinforcement makes difficult in machining and a challenging task [9].The MMCs can prove considerably lower wear rates than unreinforced alloys over wider ranges of load, sliding distances and sliding speeds. The wear resistances of MMCs can be improved by making hybrid composites with fibers, particles, whiskers and nanoparticles with different wt. % of reinforcement particles [11].The influence of wear parameters such as applied load, sliding speed, and sliding distance on the dry sliding wear behaviour of the Al/Alumina/graphite hybrid metal matrix composites using Taguchi design of experiment. Graphite particles are effective agents in increasing dry sliding wear resistance of Al/SiC composite [12]. Hence investigation of wear resistance for AA2219 reinforced with magnesium oxide and graphite will have improved hardness and wear resistance by increased percentage of MgO%.

II. EXPERIMENTAL

2.1 Materials and Properties

Aluminium alloys (AA2219) were obtained in billet form from M/s RSA Metals, Coimbatore. Graphite powder is added in order to improve the wear resistance of aluminium alloys and it is collected from Lobal chemie, Coimbatore. Graphite of 1% is added to individual cast specimen. Magnesium oxide powder is added to increase the hardness and it is collected from nice chemicals, edapally, kochi. It is mixed in different percentage viz. 0.5, 1, and 1.5 %. General properties of Aluminum alloy, Magnesium oxide and Graphite powder are shown in table 1, table 2 & table 3.

Table 1 - Properties of Graphite Powder

S.No	PROPERTIES OF GRAPHITE	VALUES
1	Bulk density(g/cm^3)	1.3-1.95
2	Porosity (%)	0.7-53
3	Modulus of Elasticity (Gpa)	8-15
4	Compressive strength (Mpa)	20-200
5	Thermal Conductivity (W/m.k)	240

Table 2 – Properties of Aluminium Alloy AA2219

S.NO	PROPERTIES OF AA2219	VALUES
1	Density(g/cc)	2.84
2	Hardness(BHN)	49.5
3	Modulus of Elasticity(Gpa)	73.1
4	Shear Strength(Gpa)	285
5	Thermal conductivity(W/m-K)	120
6	Melting Point (°C)	643-750

Table 3- Properties of Magnesium Oxide

S.NO	PROPERTIES OF MAGESIUM OXIDE	VALUES
1	Density (g/cm3)	3.58
2	Molar Mass(g/ cm3)	40.30
3	Melting Point(°c)	2852
4	Boiling point(°c)	3600

2.2 Preparation of composite

Stir casting is a liquid state method of composite materials fabrication, (as shown in fig 1) in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies.

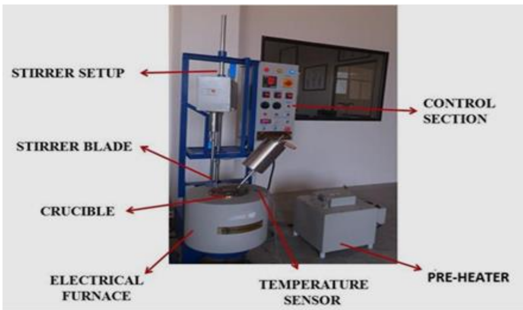

Fig.1. Stir Casting Setup

During Stir casting is two-step mixing process was carried out. Aluminium alloy was melted at a temperature of 800°C by keeping it in a crucible, the graphite (avg. size 75 µm) was preheated to 400°C in an electric furnace for 30 minutes and magnesium oxide also preheated to 400°C for 30 minutes. As the metal reaches its molten state, both the preheated reinforcement is added into the matrix. For uniform dispersion and thorough mixing, mechanical stirring was done for 7 minutes with a stirrer speed of 420 rpm. The mould into which the molten metal is to be poured was preheated to 300°C. Samples with AA2219, 1% graphite and 0.5, 1, 1.5% Magnesium oxide were separately prepared and removed from the mould allowing it to cool in the room temperature.

2.3 Wear Test specimen and parameters

Wear test on the specimen was carried out using a Pin-on-Disc tester (Make: CONMAT) with the pin dimensions as φ10 mm and height 30 mm. Tests were conducted at room temperature under dry conditions conforming ASTM G99-95 standard. Contact face of the pins with the counter facing disc were finely polished with a 10 grit emery paper in order to obtain a smooth surface. Parameters considered for the optimization of wear properties are speed (N), load (P), sliding distance and percentage of magnesium oxide (%MgO). From the

ISSN: 2278-0181

literature survey it was found that addition of Graphite (solid lubricant particles) and Magnesium oxide in various proportions improve the mechanical and tribological properties of the composites. Following table 4 shows various factors and levels taken for design of experiments.

Table 4. Major Factors and Levels

LEVELS	ROTATIONAL SPEED (N), rpm	LOAD (P), N	SLIDING DISTANCE(L), m	Wt. % of MgO (%MgO)
1	400	2	750	0.5
2	600	3	1500	1
3	800	4	2250	1.5

Design of experiments was done using Taguchi L27 orthogonal array (OA) with 26 degrees of freedom (DOF) and the columns were assigned accordingly. As the wear rate of the composite is expected to be minimum, 'Smaller the better' concept was used and the Signal to Noise ratio (SN ratio) values were interpreted suitably. Table 5 shows various levels and results obtained from dry sliding wear test.

Table 5.Experimental Value of Wear Test

S. no	Load, P (kg)	Speed, N (rpm)	%MgO	Distance, L (m)	Wear (microns)
1	2	400	0.5	750	138
2	2	400	1	1500	175
3	2	400	1.5	2250	210
4	2	600	0.5	1500	140
5	2	600	1	2250	175
6	2	600	1.5	750	212
7	2	800	0.5	2250	137
8	2	800	1	750	180
9	2	800	1.5	1500	200
10	3	400	0.5	750	166
11	3	400	1	1500	200
12	3	400	1.5	2250	215
13	3	600	0.5	1500	152
14	3	600	1	2250	180
15	3	600	1.5	750	255
16	3	800	0.5	2250	165
17	3	800	1	750	186
18	3	800	1.5	1500	235
19	4	400	0.5	750	152
20	4	400	1	1500	192
21	4	400	1.5	2250	233
22	4	600	0.5	1500	168
23	4	600	1	2250	198
24	4	600	1.5	750	260
25	4	800	0.5	2250	154
26	4	800	1	750	205
27	4	800	1.5	1500	227

III. RESULTS AND DISCUSSION

For analyzing and optimizing the results the following interpretations were considered: i) Main effects plot and response table, ii) Analysis of Variance (ANOVA table), iii) Regression equation. Statistical software used is MINITAB 16 which was widely used by many researchers.

3.1 Main effects plot and Response table

Wear rates and S-N ratios for the corresponding wear loss were tabulated in table4. S-N ratio is calculated based on the average values of the S-N ratio values at corresponding levels. The process parameter that contains maximum S-N ratio gives minimum variance. The ranking for each parameter is obtained based on the influence of the process parameters such as speed, load and percentage graphite on the S-N ratio. These values are listed in table 5. Response of the process parameters vary when the parameters move from one level to the other. By such consideration speed was found to be most influencing factor followed by load and percentage graphite. Figure 2 shows the main effects plot from which the optimum parameters are obtained: speed as 400 rpm, load as 2 kg, sliding distance 750 m and percentage MgO as 0.5%.

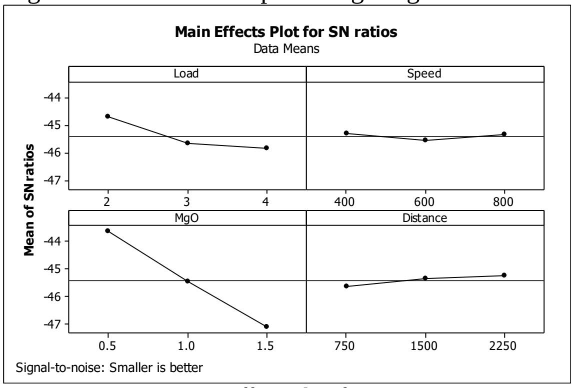

Fig.2. Main effects plots for SN ratios

3.2 Analysis of Variance

ANOVA is used to analyze the influence of considered process parameters over the wear behaviour of the composites. Experimental results with a significance of 95% and above or with a value of 0.05 or less may be considered as significant. This means that if the P-value is more than 0.05 the process parameter is not significantly contributing towards the objective. Table 6 shows the response table for wear S-N ratio and tbale 7 shows the ANOVA table SN ratio showin the significance levels of the various factors considered.

Table.6. Response Table for signal to noise ratios (wear) – Smaller is better

Level	Load, P (N)	Speed, N (rpm)	% MgO	Distance, L (m)
1	-44.34	-45.17	-44.31	-45.38
2	-45.46	-45.22	-44.96	-45.07
3	-45.62	-45.34	-46.15	-44.97
Delta	1.27	0.17	1.84	0.41
Rank	2	4	1	3

Table.7. Analysis of variance for wear SN ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	6.83	6.83	3.41	17.16	0.001
Speed	2	0.28	0.28	0.14	0.72	0.041
MgO	2	54.21	54.2	27.1	136.1	0.000
Distance	2	0.65	0.65	0.32	1.65	0.020
Load*Speed	4	0.56	0.56	0.14	0.71	0.602
Load*MgO	4	0.50	0.50	0.12	0.64	0.646
Residual Error	10	1.99	1.99	0.19		
Total	26	65.0				

DF – Degree of freedom, SS – Sum of squares, MS – Mean of squares, Seq. – Sequential, Adj. – Adjusted, Pc – Percentage contribution.

3.3 Regression

A linear regression model was formed to obtain a relation between the wear parameters and response. It was also found that the regression coefficient (R^2) value is 92.1% is close enough to adjusted regression coefficient (adj. R^2) value which is equal to 90.7%. Since both the values are appreciably close and greater than 90%, the predication capability is good and the correlation between the wear parameters and responses can be realistically obtained. The following is the regression equation obtained for the response S = 10.5068

Wear = 85.6 + 12.3 load + 0.0022 speed + 75.0 MgO – 0.00644 distance ------------------- (1)

From the regression equation it could be observed that the load and speed coefficients are positive and Gr coefficient is negative. This is due to the fact that the wear (response) increases when the positive coefficients increase and decreases with the negative coefficients. A confirmation experiment was conducted based on the prediction of the regression equation and to confirm the predicted value. For the optimal values of the process parameters obtained the wear rate was calculated to be 148 µm whereas when verified with an experiment the value obtained was 143.28 µm. Predicted and experimental values may be considered as same with permissible error rate. Figure 3 shows the all in one residual plot for the regression equation.

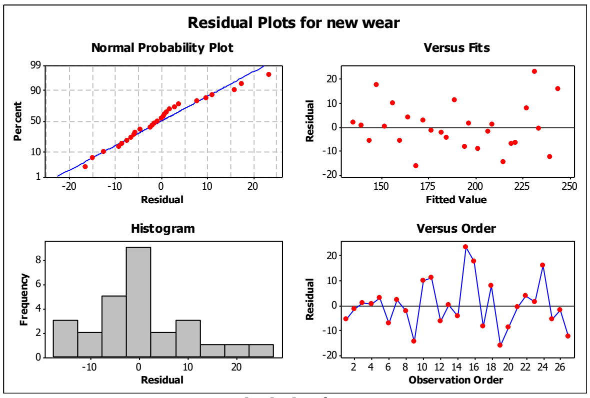

Fig.3. Residual plot for Regression

IV. CONCLUSION

Dry sliding wear tests were carried out in aluminum alloy AA2219 – MgO - Gr using pin-on-disc tester and the experiments were designed using Taguchi L27 OA. ANOVA was performed on the results and a regression equation was obtained. Thus the effect of speed, load, sliding distance and percentage MgO on the wear rate of the composites was analyzed in detail and the following conclusions were arrived at.

1. As per the responses obtained the wear rate of AA2219 – MgO - Gr was majorly influenced by percentage MgO followed by load, sliding distance and speed in order.
2. Significant contribution on the response was made by %MgO, load and distance whereas the significance level of all interactions was not satisfactory. When load, speed and %MgO increases wear rate increases whereas it decreases with sliding distance.
3. Regression model predicted that optimum conditions would render 143.28 µm wear which was confirmed by an confirmation experiment which resulted in 148 µm of wear and this value lies within the error range which can be accepted.

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