STUDY OF BEHAVIORAL PATTERN IN WEAR APPLICATIONS COMPOSITE IN PRESENCE OF DIFFERENT GEOMETRIC SHAPES

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Abstract

This paper reports the manufacturing, composition gradient determination, preliminary characterization of mechanical properties of aluminium alloy with titanium diboride ($AlTiB_2$) reinforcement.

Analysis of volume fraction of the reinforcing particles is done through experiments by Taguchi approach..The effects of three different geometries of reinforcing particles on wear response of Functionally graded aluminium alloy reinforced with titanium diboride particles is investigated .

From the experimental investigation, it is found that Tetrahedron shape appears to be more promising for maximum particle segregation at outer surface due to minimum drag force.

Keywords: Titanium diboride, Functionally Graded Materials, Centrifugal Casting

1. INTRODUCTION

Metal matrix composites (MMCs) reinforced with ceramic or metallic particles are widely used due to their high specific modulus, strength and wear resistance. Furthermore, MMCs have been considered as an alternative to monolithic metallic materials or conventional alloys in a number of specialized applications. In particular, aluminum matrix composites (AMCs) have been reported to possess higher wear resistance and lower friction coefficient with increasing volume fraction of reinforcement particles, compared to aluminum alloys without reinforcement [1]. Functionally graded materials (FGMs) contain volume fraction distribution of reinforcement particles which varies continuously from the inner to the outer sections of the cast piece giving a controlled non-uniform microstructure with continuously changing properties. FGMs have continuous variation of material properties from one surface to another. The change of compositions is continuous or step-wised. For example, one side may have high mechanical strength and the other side may have high thermal resistant property, thus, there are "two aspects" in one material**.** The gradation of properties in an FGM reduces the thermal stresses, residual stresses, and stress concentrations found in traditional composites .Surface modification and coating methods provide this effect and are widely used to improve tribological properties of metallic materials, but the added surface treatment increases the manufacturing costs [2]. On the other hand, centrifugal casting appears to be an effective method to process FGMs. This type of pressure casting method involves pouring molten metal into a mould when the mould assembly is under the action of a centrifugal (inertial) force produced by a rotational or spinning motion**[**3**]**.This paper reports the manufacturing, composition gradient determination, characterization of mechanical properties, and wear response of FGM-AMCs reinforced with TiB_2 particle obtained by centrifugal casting [4]. The original semisolid material consisted of a uniform dispersion of $AlTiB_2$ particles entrapped in molten aluminum. The resulting redistribution of volume fraction of reinforcement particles is controlled by the inertial forces toward the outer region of the cast component during centrifugal casting [5]. This redistribution is assisted by the higher density of the TiB_2 particles compared to the molten aluminum. The forced segregation of hard titanium borides towards the outer regions of the casting provides a unique approach to improve surface hardness and wear resistance of the aluminium alloy [6].

1.2 Necessity and Importance of FGM

FGMs are useful in applications such as automobile clutches, brake discs where high wear resistance and high bulk toughness are a necessity. Therefore, special processing is required to produce these materials in order to exhibit characteristics that are not achievable by monolithic or homogeneous materials. Functionally graded materials reinforced with diborides have not been studied extensively despite being strong and lightweight materials [6].Aluminium LM-25 alloy combine the low density of the matrix with the high hardness of the reinforcement. For this reason extensive analysis and characterization of these aluminium alloy are relevant if they are proposed as alternative materials for high wear applications. Cast FGMs reinforced with titanium diborides represent an effective, alternative in automobile application where light weight, low-cost and wear resistance are a necessity

2. EXPERIMENTATION

A suitable experiment is carried out on centrifugal casting machine to prepare the samples as per ASTM G-99 standards as shown in Figure 1. The electric motor with 3HP power, 1440 rpm, with a belt drive is used to drive the cantilever die. A stepped pulley is mounted on one end of shaft and other end has cantilever die. Cantilever type Die resembles a Lathe Chuck. The speed of the casting is varied using stepped pulley. A special purpose die is manufactured in two halves and fitted in the cantilever die to prepare the 10 mm diameter by 50 mm length samples as per ASTM standards.

Fig. 1 Experimental Set up with Cantilever Die

Fig. 2 Ring of Sample pins

3. RESULTS AND DISCUSSIONS

3.1 Analysis of the Volume Fraction of Reinforcement

Figure 3 represents the distribution of reinforcement of TiB_2 volume fraction based on measurement of representative part and obtained by quantitative analysis performed manually. Composition prepared is based on weight fraction, and hence volume fraction is not calculated. The samples produced by centrifugal casting showed higher densities of reinforcement particles in the outer regions compared to the inner regions of the casting when viewed under optical microscope This happens since the dispersed particles are segregated by centrifugal forces and the thickness of particle-rich region is strongly influenced by the speed of rotation, local solidification time and the density difference between the base metal and the reinforcement particles**.** In addition, 2.5% reinforcement exhibited more significant reinforcement particles segregation than the 1.75% and 1% reinforcement.

The ASTM (American Society for Testing and Materials) standard test method for Rockwell superficial hardness of metallic materials is issued under the fixed designation E 18.

3.2 Superficial Rockwell Hardness

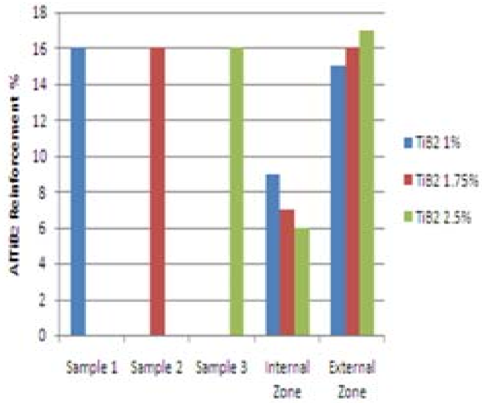


Fig. 3 Measured volume fraction of reinforcement

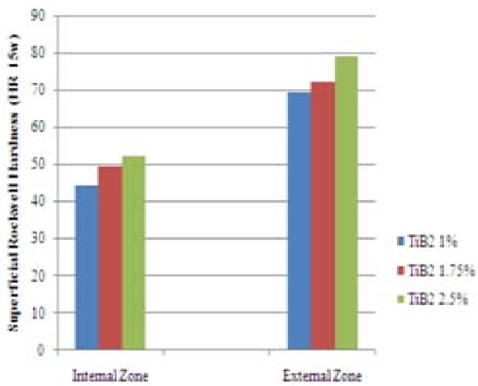


Fig.4 Rockwell superficial hardness (HR15w)

In the Rockwell superficial hardness test the preliminary test force is 3kgf (29N) and total test force are 15 kgf (147N), 30 kgf (294N), and 45 kgf (441N). The standard indenters are the diamond spheroconical and the steel ball indenters 1/16, 1/8, 1/4, 1/2 inch (1.588, 3.175, 6.350 and 12.70 mm) in diameter. The Rockwell superficial hardness scale used on the Al alloy with TiB_2 reinforcement was 15 HRW (15 kgf, 1/8 inch. indenter) .Figure 4 shows the variation of superficial Rockwell hardness on cross-sections of these Al alloy with TiB_2 reinforcement measured for the mentioned experimental conditions. The results revealed that the value of superficial hardness increases as a function of distance from the internal zone to the external zone in the experimental Al alloy with TiB_2 reinforcement .This increase from the internal zone to the external zone is more with increase in percentage of TiB_2..Hardness depends on TiB_2 particles distribution and the concentration of TiB_2 particles is nonlinear and is much more on outer surface, hence hardness need not be consistent.

3.3 Implementation of Taguchi method

Taguchi method is used for determining & verifying centrifugal casting process parameters with optimal wear result .In present study, three level process parameters are considered (speed of centrifugal casting machine, % of reinforcement particles, and time of centrifugation).The parameters are process requirement & their values at different level are given below in table 01.

Table 1. Process Parameters [required]

RPM of wear testing m/c	Process parameters	Trial 1	Trial 2	Trial 3
500 rpm	% of reinforcement particles	1	1.75	2.5
	Time (S)	20	40	60
	Speed (rpm)	750	1200	1650
800 rpm	% of reinforceme-nt particles	1	1.75	2.5
	Time (S)	20	40	60
	Speed (rpm)	750	1200	1650

Degree of Freedom (dof)

It is very important as it determine the minimum number of treatment conditions i.e. trials. Degree of freedom are calculated as follows

$$dof = [(no\ of levels - 1) \times (no.\ of parameters)] + [(no of levels - 1)^2 \times (no.\ of interacting parameters)] + 1$$

In the present study,

No. of levels = 3

No. of parameters = 3

No. of interacting parameters = 0

$$dof = (3-1) \times 3 + (3-1)^2 \times 0 + 1$$

$$dof = 7$$

Selecting the Orthogonal Array

The number of treatment conditions (trails) is equal to the rows in orthogonal array & must be equal to or greater than the degrees of freedom.

The degree of freedom is 7. Therefore OA9 orthogonal array is selected. In orthogonal array OA9 there are 9 experiments (i.e. trials or treatment conditions) which must be carried out.OA9 (L9) Orthogonal array for the experimental condition with taguchi combinations is given in table 02

Table 2. Taguchi Combination

Exp. No.:	Combinations		
1	S1	S1	S1
2	S1	S1	S1
3	S1	S1	S1
4	S2	S2	S2
5	S2	S2	S2
6	S2	S2	S2
7	S3	S3	S3
8	S3	S3	S3
9	S3	S3	S3

Where,

S1 = 1%,S2 = 1.75%,S3 = 2.5%
T1 = 20 sec,T2 = 40 sec,T3 = 60 sec,
N1 = 750 rpm,N2 = 1200 rpm,N3 = 1650 rpm

Calculations of Loss function and S/N Ratio

For all 09 trials wear result are obtained from pin on disc test for both the rpm. Since our target is to achieve **zero wear** we select smaller the better approach amongst 03 (larger the better, nominal the better) of loss function and S/N ratio. The formulae of loss function & S/N ratio for smaller the better approach is as follow.

$$L_i = \frac{1}{m}\sum y_i^2 \text{……………………} (1)$$

$$n_i = -10\log_{10}(L_i)) \text{……….......} (2)$$

m = no. of times the i^{th} trial is repeated
L_i = Overall loss of i^{th}trial,n_i = S/N ratio of i^{th} trial $_{,i}$= wear of i^{th} trial

Table 3. Response Table

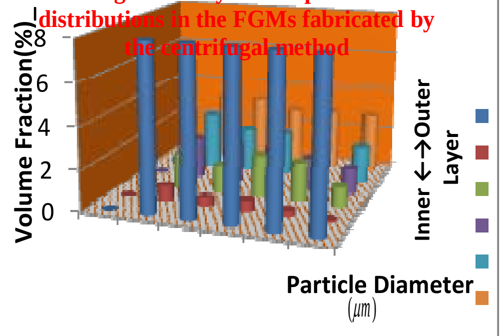
Wear testing m/c rpm	Process parameters	S/N Ratio dB			Total mean S/N
		Level 1	Level 2	Level 3	
500 rpm	Percentage of particles	-36.94	-32.26	-27.56	-32.58
	Speed	-35.41	-31.98	-30.38	
	Time	-32.46	-33.4	-31.87	
800 rpm	Percentage of particles	-37.6	-34.26	-29.87	-33.91
	Speed	-36.47	-33.8	-31.46	
	Time	-33.77	-34.35	-33.62	

The level with greater S/N value represents the optimum parameter values for obtaining optimum wear results. Therefore the **optimum trial is S_3, N_3, T_3 i.e. 2.5%, 1650 rpm, 60 sec**

3.4 Effect of Geometry of Reinforcement Particles in Al alloy.

Samples are prepared with three different geometries of reinforcing particles. The geometries chosen are cylindrical, right circular cone and tetrahedron shape particles. Figures 5, 6, 7 shows the effect of cylindrical, right circular cone and tetrahedron shape reinforcement particles on distribution in FGMs fabricated by centrifugal casting method**.** The most remarkable point is that the particle size is gradually distributed in each region. The distribution of TiB_2 is nonlinear as it approaches the outer surface. The average particle size at the outer region is greater than that in the inner region. The fraction of larger particles is greater than that of smaller particles in the outer region. On the contrary, in the inner region, the fraction of smaller particles is greater than that of the larger ones. With increase in particle size, the drag force increases. It is seen that in right circular cone and tetrahedron shape reinforcement particles, the fraction of particles is greater in outer region compared to cylindrical particles. Pin on wear testing machine is used to find wear with help of windúcom software. Graphs 1, 2 ,3 shows Wear, Coefficient of friction, Frictional force versus time for cylindrical ,right circular cone and tetrahedron shape reinforcing particles. Graphs reveals that wear is minimum with tetrahedron shape particles compared to right circular cone and cylindrical particles due to minimum drag force.

Fig. 5 The Cylidrical particle distributions in the FGMs fabricated by the centrifugal method



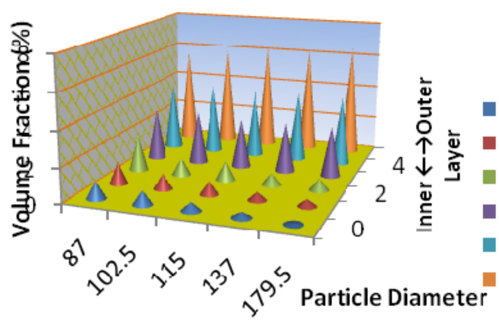


Fig. 6 The Conical particle distributions in the FGMs fabricated by the centrifugal method

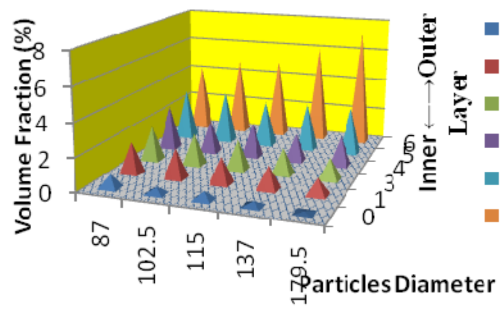


Fig. 7 The Tetrahedron particle distributions in the FGMs fabricated by the centrifugal method.

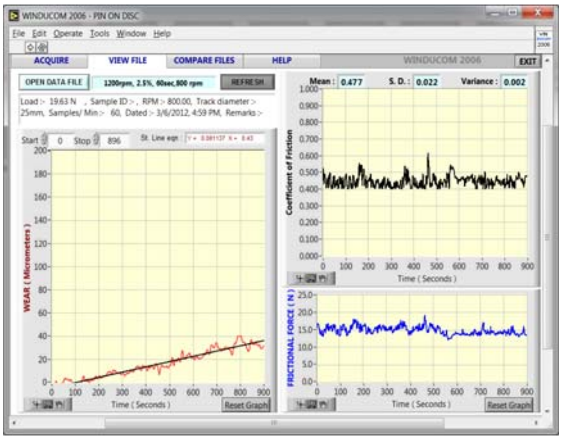


Fig. 8 Wear, Coefficient of friction, Frictional force versus time for cylindrical particles

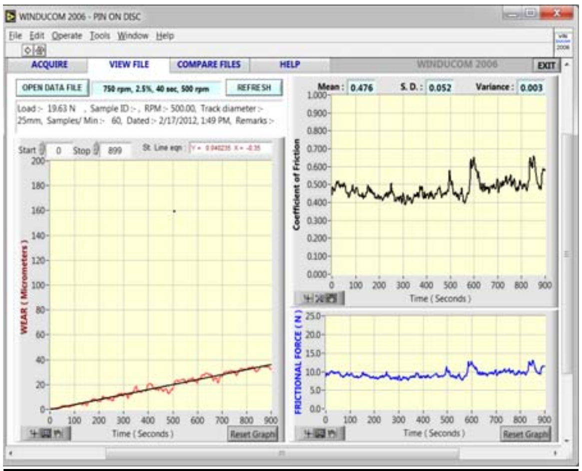


Fig. 9 Wear, Coefficient of friction, Frictional force versus time for right circular

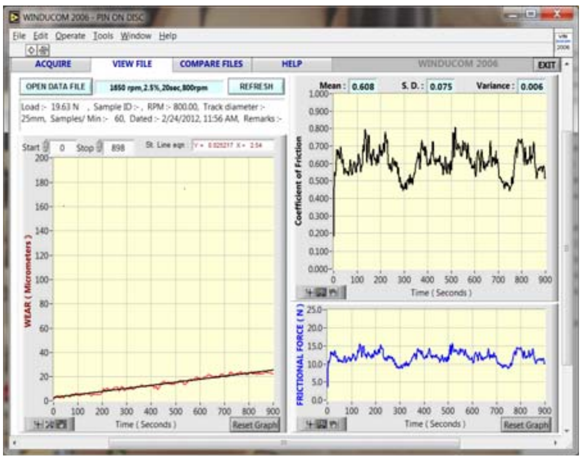


Fig. 10 Wear, Coefficient of friction, Frictional force versus time for tetrahedron shape particles

4. CONCLUSIONS

Experiments on functionally graded Al alloy with TiB_2 reinforcement having appropriate dimensions for mechanical testing are carried out as per ASTM standards. The micro-hardness results revealed that the value of superficial hardness increases as a function of distance from the internal zone to the external zone in the experimental $AlTiB_2$ metal matrix composite. This increase from the internal zone to the external zone is more with increase in percentage of TiB_2.The Taguchi method revealed the three optimum parameters, 2.5 percentage of reinforcing particles, 1650 rpm die speed and 60 sec centrifugation time which confirms for minimum wear experimentally. It can also be concluded that out of the three geometric shapes considered, tetrahedron shape appears to be more promising for maximum particle segregation at the outer surface due to minimum drag force. The wear behavior of Al/TiB_2 FGMs obtained from pin on Disc test is helpful for predictions of FGM Material for various wear resistant applications like high speed grinding wheels, clutches, brake drum, brake disc, battle field tanks etc.

5. REFERENCES

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