ABRASIVE WEAR BEHAVIOR OF AL6061- FRIT PARTICULATE COMPOSITES

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ABSTRACT

In recent decades, aluminium alloy based metal matrix composites are gaining important role in several engineering applications. Al6061 alloy has been used as matrix material due to its good formability, excellent mechanical properties and etc., wide spectrum of the applications in industrial sectors. Inclusion of Frit particulates as reinforcement in Al6061 alloy material system improves its hardness, tensile strength, wear resistance. In this present investigation Al6061-Frit particulate composites were produced by 'VORTEX' method with varying percentages of Frit particulate from 0 wt% to 10 wt% in steps of 2.The as-cast matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 5300C for 2 hours followed by quenching in ice. The quenched specimens were subjected to both natural and artificial ageing. Microstructure studies were conducted on as cast and composites in order to investigate the distribution of frit particles retained in matrix material system. Densities of Al6061 matrix alloy and Al6061-Frit particulate composites were measured. Mechanical properties such as Hardness and sand abrasive wear test have been conducted on both Al6061 alloy matrix and Al6061-Frit particulate composite before and after treatment. It has been observed that under identical treatment conditions adopted, a Al6061-Frit particulate composites exhibited significant improvement in hardness, wear resistance and reduced density when compared with Al6061 matrix alloy.

***KEYWORDS**: MMC's, Solutionizing, Ageing, Hardness, Sand abrasive wear, Density*

1.0 INTRODUCTION

Improvement in the mechanical properties of wear resistance of Aluminium matrix composites can be achieved by adopting suitable treatment; (Das et al., 2008) have reported

the abrasive wear behavior of as-cast and treated SiC reinforced Al-Si composites. They have reported that un-reinforced matrix material suffers from higher wear rates then that of Al-Si/SiC composites in both as-cast and heat treated conditions. Further, heat treated Al-Si/SiC composites exhibits better performance under all studied conditions. (Modi et al., 2001) have reported the three body abrasive wear behavior of Aluminium-Zinc/ Al_2O_3 composites exhibited excellent wear resistance under all the test conditions employed.
A comparative study by (S.Das et al. 2007) on wear resistance of Zircon sand and Alumina reinforced AMC`s, revealed improved abrasive wear resistance with the decrease in particle size. Adhesive wear behavior of cast Al6061-TiO_2 composites studied by (Ramesh et al., 2005) reported that, the wear resistance of composites is superior when compared to Al6061 matrix alloy. Further, it increases with increase in TiO_2 particle content.

S.Das (2004) reported the effect of load on abrasive wear rate of LM13-alloy and LM13 – SiC composites, results revealed that wear rates increases as the applied load increases for both as-cast alloy and its composites.

An extensive review work on the dry sliding wear characteristics of composites based on aluminium alloys have been under taken by (Sannio et al., 1995) and abrasive wear behavior by (Deuis et al., 1996).In their studies and discussions, the effect of reinforcement volume fraction, reinforcement size, sliding distance, applied load, sliding speed, hardness of the counter face and properties of the reinforcement phase which influence the wear behavior of this group of composites are examined in detail.

Reinforcement of hard particles in Al matrix protects the matrix alloy surface against destructive action of the abrasive during the abrasive wear behavior and rake angle of the abrasive affects the behavior (ZumGhar K.H., 1979, Hutchings.J.M, 1987, Kulik.T et al., 1989, Jain-main.T 1985, Axen N, 1992). (Wang et al., 1989) Reported that coarse abrasive particles and high volume fraction of reinforcement results in decreased resistance; this is attributed mainly due to fragmentation of reinforcement phase. On the other hand, it was mentioned with decrease in the abrasive particle size.

2.0 EXPERIMENTAL

2.1 Material Selection

Al6061 matrix alloy was choosen as matrix material owing to its many advantages like excellent casting properties, strength, formability, and heat treatable. Table 1 shows the chemical composition of Al6061 matrix alloy material used in this present study.

Frit particles size around 50 μm was used as reinforcement material in Al6061 matrix material. Table 2 shows the chemical composition of Frit particle reinforcement used in present study.

TABLE 1 Chemical composition of Al6061 (wt %).

Si	Cu	Fe	Mn	Mg	Zn	Pb	Ti	Sn	Al
0.809	0.355	0.155	0.027	0.8	0.008	0.023	0.010	0.010	97.390

TABLE 1 Chemical composition of frit (wt %).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3
68.90	9.41	0.40	15.22	4.30	0.75	0.42	<0.05

2.2 Composite production

Al6061-Frit composites were prepared using liquid metallurgy route (VORTEX).Particulate MMC`s are most commonly manufactured either by melt incorporation and casting technique or by powder blending and consolidation (Clyne T.W., 2001). AMC`s are synthesized via variety of manufacturing routes. These techniques include stir casting (S.Skolians. 1996, Kang C.G. et al., 1997, XUY et al., 1998), liquid metal infiltration (Seo Y.H. et al., 1995), Squeeze casting (Lee J.C., et al.,1998) and spray co-deposition (Bar J. et al.,1993). Stir casting route is generally practiced commercially (Skolianos S., et al., 1993, Banerji A. et al., 1982, Surappa M.K, et al., 1982) .Its advantage lies in its simplicity, flexibility and applicability to large quantity of production. Al6061 matrix alloy material was melted using 6 KW electrical resistance furnace. Pre heated Frit particles were slowly added into the molten matrix alloy material and mixed thoroughly by means of mechanical stirrer. Thoroughly mixed composite melt maintained at a temperature of 710^0C was poured into the preheated metallic molds. The proportion of Frit particles was varied from 2 wt% to 10 wt% in steps of 2 wt%. However Al6061 matrix alloy material was also casted for comparison. Cast Al6061 matrix alloy material and Al6061- Frit particulate composites were machined to test standards.

2.3 Heat treatment

Al6061 matrix alloy and Al6061-Frit particulate composites were subjected to thermal treatment by solutionizing at a temperature of 530^0C followed by ice quenching. Both artificial and natural ageing (0 h) were employed on the quenched specimens. Artificial ageing was performed at a temperature of 175^0C for duration of 2 h to 10 h in steps of 2 h.

2.4 Microstructure

Al6061 matrix alloy and Al6061-Frit particulate composites were subjected to microstructural studies. The standard metallographic technique was adopted on Al6061 matrix alloy and Al6061-Frit particulate composites for microstructural characterization. The polished specimens were etched with Keller's reagent.

2.5 Density test

The theoretical density was calculated using rule-of-mixture and experimentally, the density measurements were carried out on the base alloy and reinforced samples using Archimedes principle. The buoyant force on submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume, by measuring its mass in air and its effective mass when submerged in water (density=1 g/cc).This effective mass under water will be its actual mass minus the mass of the fluid displaced. The difference between the real and effective masses therefore gives the mass of the displaced water and allows the volume of the object to be calculated. Mass divided by the volume thus determined gives a measure of the average density of the object (Ramachandra M. et al., 2006). The density of material, which is ratio of weight to volume (Bermudeza M.D. et al., 2001, Ahmad S.N. et al., 2005), Theoretical density was derived from Halpin-Tsai equation.

$$\text{Density (theoretical)} = \rho_{(DRMMC)} = \rho_m v_{f(m)} + \rho_p v_{f(p)} \qquad \text{------------(1)}$$

$\rho_{(DRMMC)}$= Density of the DRMMCs, ρ_m= Density of matrix alloy,
ρ_p= Density of reinforcing particle, $v_{f(m)}$= Volume fraction of the matrix,
$v_{f(p)}$= Volume fraction of reinforcing particle.

The densities of the respective specimen were determined basically by measuring the mass and the volume by using the balance and the measuring cylinder respectively. It is then estimated from the formula given below (Aigbodin V.S. et al., 2007, Ogucha I. A, 1997).

Density (gm/cc) =Mass (gm)/Volume (cc) -------------- (2)
Density of reinforcement material (Frit) =2.52 g/cc.
Density of matrix material (Al6061) = 2.70 g/cc.

2.4 Hardness test

Hardness is one important property which effects wear resistance of any metal or alloy, hardness measurements were carried out on Al6061 matrix alloy and Al6061-Frit particulate composite specimens of both as-cast and treated. Brinell hardness measurements were carried out in order to investigate the influence of Frit particulate on the matrix alloy hardness. The applied load was 500 Kgs and an indenter of 10 mm diameter steel ball (HB500). Round specimens of 20 mm in diameter were prepared and polished on different grits of emery paper. The polished specimens were tested using Brinell hardness tester. The test was carried out at five different locations to controvert the possible effect of indenter resting on the harder particles. Hardness was determined by measuring the indentations diameter produced. The average of all the five readings was taken as the hardness of as-cast and composite specimens. FIGURE 1 & 2 shows the hardness test specimen before and after indentation.

FIGURE 2 Pictorial view of hardness test specimens after indentation

2.7 Sand Abrasion test

The three body abrasion test was carried out at room temperature on Al6061 matrix alloy and Al6061-Frit particulate composites of as-cast and thermal treated conditions. The tests were performed using standard rubber wheel abrasion testing apparatus as per ASTM G65-81 standards. Figure 3 is the photograph of the sand abrasion tester. Details of the sand abrasion tester employed in this present study are reported in Table 3. The test specimens of size 75 X 25 X 8 mm were metallographically prepared and polished. Loads were varied from 2 N to 10 N in steps of 2 N at constant wheel speed of 200 rpm. Silica sand of grain size 50 μm was used as the abrasive media. Test duration of 30 minutes was adopted for all specimens. Using digital weighing balance of accuracy 0.1 mg wear loss was measured.

TABLE 3 Details of the sand abrasion testing apparatus

Sl. No.	Description	Particulars
1	Abrasive material	AFS 50-70 test sand
2	Rubber wheel speed	200 rpm through a helical geared motor of 1.5 kW (3 Phase)
3	Test load	1 to 45 N
4	Rubber wheel diameter	228 mm
5	Power	430 V AC (3 Phase)
6	Specimen dimension	75 x 24 x 8 mm
7	Erodent	AFS3080
8	Sand mass flow rate	0.25 kg/min or 2.45 N/min
9	Rubber hardness	60-62 shore A
10	Duration	30 min
11	Pressure	5.88 N/mm^2
12	Load	12.75 N

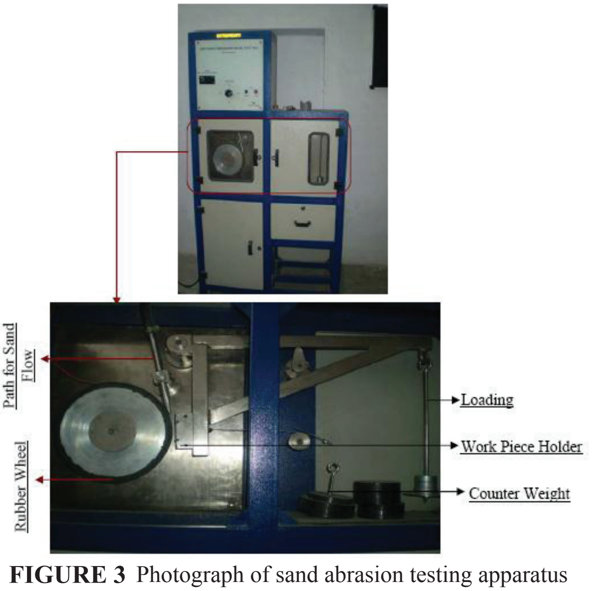
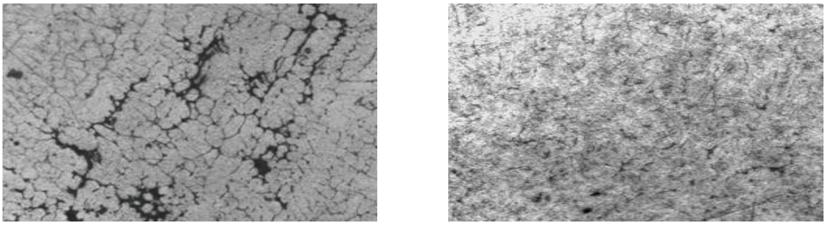


FIGURE 3 Photograph of sand abrasion testing apparatus

3.0 RESULTS AND DISCUSSION

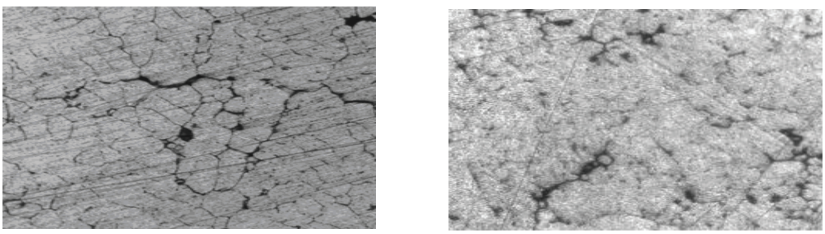
3.1 Microstructure

The optical micrograph of the cast Al6061 and Al6061-Frit particulate composites are shown in fig.4. a & b. The micrograph clearly indicates the distribution of Frit particles is fairly uniform. Further the micrograph reveals an excellent bond between the matrix alloy and the reinforcement as shown in fig.5.



Un-heat treated Heat treated

FIGURE 4.a. Microstructure of as cast Al6061 matrix alloy



Un-heat treated Heat treated

FIGURE 4.b.

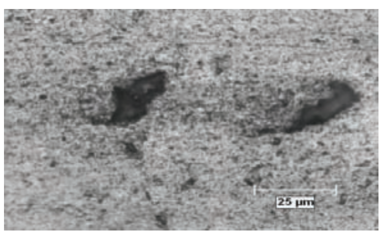


FIGURE 5 Optical micrograph of aluminium /frit composite indicating good bond between the matrix and frit particles.

3.2 Density

The fig. 6. Is presented with comparison of theoretical density obtained by rule of mixture and measured density values by experiment for Al6061 matrix alloy and Al6061- Frit particulate composites studied. The results reveal that the presence of frit particles has an effect on the density of the MMC`s. From figure it can be concluded that the experimental and theoretical density values are in line with each other and confirms the suitability of the liquid metallurgy route for successful composite fabrication. This result is similar to that of other researchers (Aigbodion V.S. et al., 2010). M.Ramachandra et.al. (2006) reported the density of the reinforced particulates has effect on the density of the MMC`s and variation of density with reinforcement content is in line with experimental density values of Al6061-frit composites. It is observed that as the weight % of the reinforcement increases the density of the composites decreases.

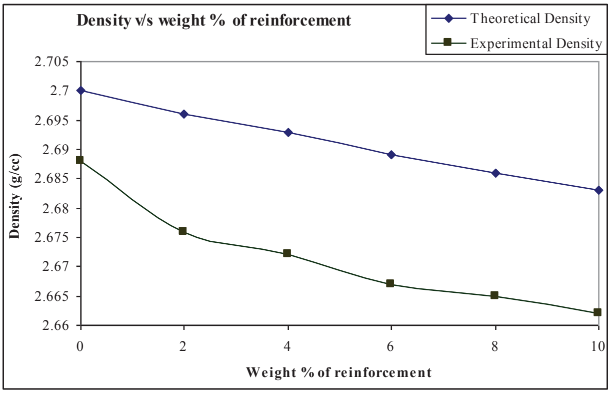


FIGURE 6

3.3 Hardness

Fig. 7 and 8. Shows the variation of hardness of Al6061 matrix alloy and Al6061-Frit particulate composites in as-cast and treated conditions. It is observed that hardness increases with increase in weight percentage of Frit particles in matrix alloy in both as-cast and treated conditions. A maximum of around 29 % and 44 % improvement is observed in as-cast and treated Al6061- 6 Wt % Frit composite respectively.

Increased hardness with increased weight percentage of Frit particles in the Al6061 matrix alloy can be attributed to the following reasons.

- Higher hardness of Frit particles in ductile and soft Al6061 matrix alloy enhances the hardness in general (Ganesh V.V. et al., 2002).
- Good interfacial bond between matrix alloy and particle reinforcement as shown in fig. 4.
- Reinforcement content weight percentage increase in the matrix alloy.

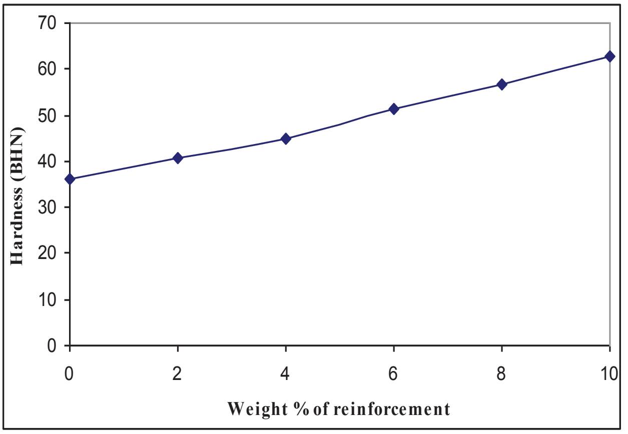


FIGURE 7 Variation of hardness with increase in weight % of reinforcement for as cast Al6061 matrix alloy and Al 6061-Frit particulate composites

3.4 Sand Abrasion

3.4.1 Effect of Reinforcement

Fig.9. Shows the variation of abrasive wear loss (weight loss) of as-cast and heat-treated Al6061 matrix alloy and Al6061- Frit particulate composites. It is noticed that weight loss decreases with increase in reinforcement content in matrix alloy in both as-cast and thermally treated conditions. In the all the specimens studied, heat-treated specimens exhibited better abrasive wear resistance than as-cast matrix alloy and its composites. Decrease in weight loss with in increase in weight percentage of reinforcement indicates higher hardness of composites. The inclusion of hard Frit particles in soft ductile matrix alloy protects and reduces the extent of penetration of the abrasive particles on the surface. (Mondal D.P. et al., 2006). Higher hardness results in better abrasive wear resistance of the materials.

The major factor that influences the wear behavior of composites is good interfacial bond between the matrix alloy and the reinforcement. A large wear results in absence of good interfacial bond, under three body abrasion wear conditions (Zhang Z.F. et al., 1994, Ramesh C.S. et al., 2007).

The three body abrasion wear results of all specimens studied indicated no plucking of Frit particles from matrix alloy. This shows the good interfacial bond between Frit particles and the matrix alloy. It is reported that the wear behavior of particle reinforced composites mainly depend on the type of interfacial bond between the Al matrix alloy and the reinforcement. (Kok M., 2006).

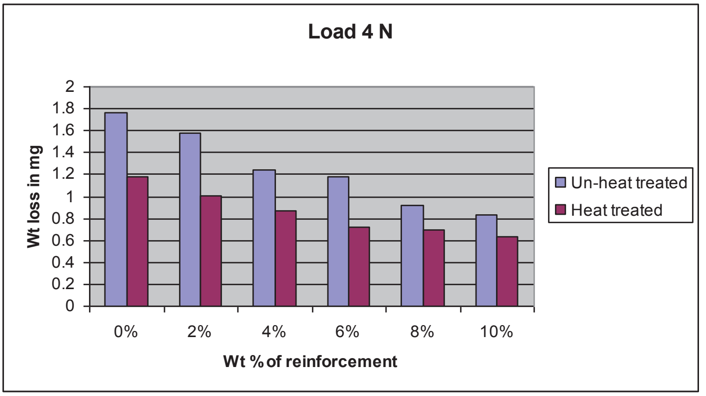


FIGURE 8 Variation of weight loss of Al6061 matrix alloy and l6061- Frit particulate composites.

3.4.2 Effect of Load

The variation of weight loss of Al6061 matrix alloy and Al6061-Frit composites with load in as-cast and heat-treated condition is shown in fig. 10 and 11. There is a steady increase in wear up to a load of 8 N and a steep increase is noticed at 8 N for all the specimens studied.

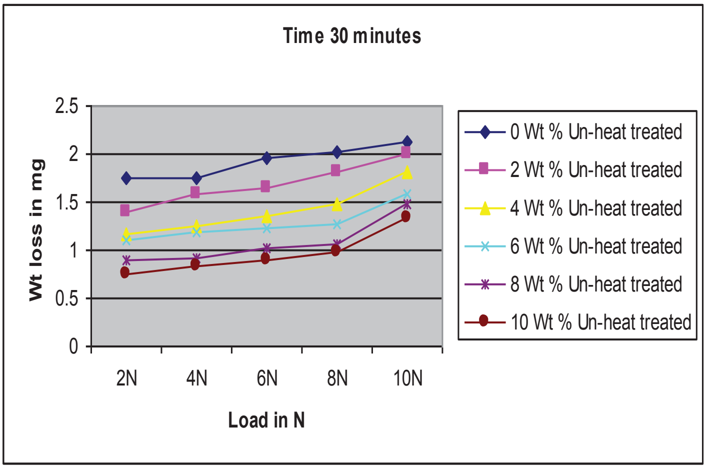


FIGURE 9 Variation of weight loss with increase in load for Al6061 matrix alloy and Al 6061-Frit particulate composites under un-heat treated conditions

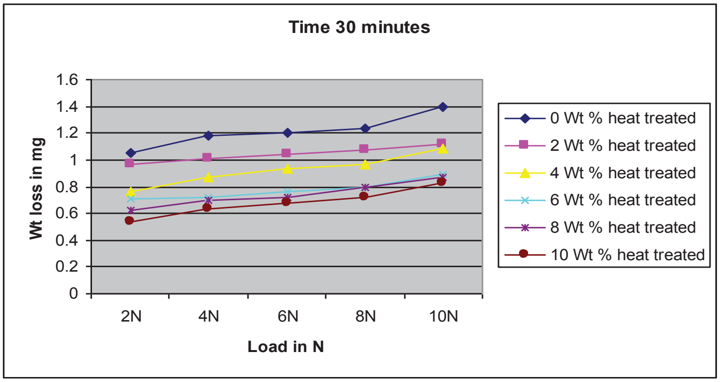


FIGURE 10 Variation of weight loss with increase in load for Al6061 matrix alloy and Al 6061-Frit particulate composites under heat treatment conditions

4.0 CONCLUSION

Microstructural studies clearly indicate a fairly uniform distribution of frit particles in the Al6061 matrix alloy with a good interfacial bond between the reinforcement and Al6061 matrix alloy. Density measurement studies reveals as the weight percentage of reinforcement increases the density of the composites decreases. Hardness increases with ageing duration reaches a peak value at 6 h, and with further increase in ageing duration, there is a decrease in hardness. Al6061- Frit particulate composites exhibit superior abrasive wear resistance than Al6061 matrix alloy in as-cast and heat-treated conditions.

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