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Research Paper

STUDY OF WEAR BEHAVIOUR OF ALUMINIUM BASED COMPOSITE FABRICATED BY STIR CASTING TECHNIQUE

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Aluminium based Matrix Composites (AMCs) possess tremendous potential for number of applications in addition to their present uses in different engineering fields. In the present study, aluminium composite with 5% reinforcement of Al_2O_3 + fly-ash was prepared using a cost effective stir casting technique. Hardness tests carried on the composite using Rockwell hardness tester showed increase in hardness over the monolithic aluminum metal. Testing of wear behavior was done on pin on disc apparatus at a normal load of 40 N and sliding velocities of 0.8 m/sec and 1 m/sec. The fabricated composites showed improvement in wear resistance over the monolithic aluminum metal. Considering all the factors, it can be concluded that aluminium based composite with 5% Al_2O_3 + fly-ash reinforcement possess better mechanical and wear resistance properties than rival specimen, i.e., pure aluminium.

Keywords: Aluminium composites, Fly-ash, Al_2O_3, Stir casting, Wear

INTRODUCTION

Metal Matrix Composites (MMCs) have been in existence since the 1960s, but their commercial applications have been limited due to their higher cost and lack of proper understanding. The motto to design MMC's is to combine the Metals and Ceramics, i.e., addition of high strength, high modulus refractory particles to ductile metal matrix [We Energies].

The selection of process of manufacturing of MMCs depends on shape and size, nature of matrix and reinforcements. Most metals have been explored for the matrix including aluminium, beryllium, magnesium, titanium, cobalt and silver. However Aluminium is by far the most preferred (Singh, 2012).

For reinforcements, ceramics are mostly used, which provide a very beneficial combination of stiffness, strength and.

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relatively low density. Some of the other reinforcement materials include SiC, Al_2O_3, B_4C, TiC, TiB_2, graphite and number of other ceramics (Singh, 2012).

Varieties of processes have been and are being developed for the manufacture of MMCs. Some of them are Sand casting, Stir casting, Die casting, Powder metallurgy, Centrifugal casting, Squeeze casting, Investment casting, Spray casting, and Liquid metal Infiltration (Singh, 2012). The stir casting process is preferred because of its low cost, easy adaptability and also near-net shape formation of the composites (Manchang Gui *et al.*, 2003). Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal 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 (www.Substech.com, 2013). During solidification of composite, particle-interface interaction plays a major role in the particle distribution as reported by various investigators or workers (We Energies, Mortensen, 1991; Mortensten *et al.*, 1992; Asthana *et al.*, 1993; and Michaud *et al.*, 1993). The technology is relatively simple and low cost (Rohatgi *et al.*, 1986).

Aluminum and magnesium are lightweight materials, when compared to iron and steel. However, they do not have the strength requirements necessary for several applications [We Energies]. So a material like an Aluminium Matrix Composite (AMC) having the characteristics of both light materials as well as strong or tough materials like steel would be much better than the today's monolithic materials [We Energies].

Aluminium Matrix Composites (AMCs) refer to the class of light weight high performance aluminium centric material systems. Over the years, AMCs have been tried and used in numerous structural, non-structural and functional applications in different engineering sectors (Lloyed *et al.*, 1989). Aluminium alloys are widely used in the automotive industry because of their high strength to weight ratio as well as high thermal conductivity (Bahera *et al.*, 2007). It is used particularly in automobile engines as cylinder liners as well as other rotating and reciprocating parts, such as the piston, drive shafts, covers, pans, shrouds, casings, pulleys, manifolds, valve covers, brake rotors, and engine blocks in automotive, small engine, the electromechanical industry sectors and in other applications in automotive and aerospace industries [We Energies]. The major reasons for the use of AMCs in these sectors include economic, performance and environmental benefits. The key benefits of AMCs in transportation sector are lower fuel consumption, improved productivity, lower maintenance cost, energy savings, less noise and lower airborne emissions [We Energies].

One of the major characteristics required of these AMCs used in the above mentioned areas is wear resistance, i.e., these composites must be wear resistant which they can be made by the introduction of better reinforcements like Al_2O_3, SiC, Fly-ash, etc.

Aluminium matrix composites are generally reinforced by ceramic particles like SiC but production of such composites is quite costly. The alternative to this can be fly ash since it is cheaper than SiC and is readily available. Aluminium matrix composite manufactured by the dispersion or the reinforcement of coal fly ash have the potential of being the cost effective and ultra-light composites with improved mechanical properties such as hardness and abrasion resistance. Fly ash particles are potential discontinuous dispersoids used in metal matrix composites; they are low-cost and low-density reinforcement available in large quantities as a waste by-product in thermal power plants (Rajan *et al.*, 2007). Incorporation of fly ash particles improves the wear resistance, damping properties, hardness and stiffness and reduces the density of Al alloys. However, these have a disadvantage also that incorporation of fly ash reduces ductility of the material system. The significance of developing aluminium-fly ash composites can be fully understood only if we consider the overall benefit to various industries and to the environment [We Energies].

So this work concentrates on the production of low cost aluminum-fly ash-alumina hybrid composites with a cost effective production or processing method stir casting which can be used for mass production, determining their properties like hardness, wear behavior etc. and comparing them with monolithic aluminum. The hybrid composite is studied because fly ash can be used a replacement for SiC or Al_2O_3 but it reduces ductility so addition of Al_2O_3 can overcome this problem since Al_2O_3 increases ductility.

METHODOLOGY

The matrix material used in the experiment investigation was commercially pure Al with composition as listed in Table 1. The reinforcement consisted of 5% by weight Fly ash + Al_2O_3. Process used for fabrication of composites was Stir casting and the stir casting apparatus consisted of furnace, crucible, stirrer, mould, tools, etc.

A rectangular furnace was used having a heating range of 0°-1200 °C which was electrically operated. The size number 5 crucible of graphite was used with a capacity of up to 2 Kg of aluminium. The Stirrer consisted of motor, stand, blade with shaft. Motor used is a single phase AC supply, 230 V, 300 W motor with a speed range of 250 rpm to 1400 rpm however the speed used in the current investigation was around 500 rpm.

A mild steel mould made by two 1 inch thick plates of dimensions 25 cm x 17 cm was used which consisted of 6 cylindrical grooves of 2 cm diameter each with a depth of 8 cm. These grooves were joined at the bottom with a groove of 2 cm diameter and a gap of 1 cm was provided between each vertical groove as shown in Figure 1.

Guiding pins and locking arrangement was also provided in the mould along with diamond paste coating inside the grooves for smooth removal of casted materials. In addition to these, some other tools like tongs, gloves, unloading tool, pouring tool, etc., were also used.

Table 1: Composition of Material Selected

Aluminium	Iron	Copper	Silicon	Manganese	Zinc	Lead	Magnesium	Nickel	Tin
95.58	1.18	1.05	1.02	0.367	0.268	0.144	0.120	0.036	0.051

Figure 1: Mould

So in this investigation, 550 gm of aluminium is first heated in the furnace upto a temperature of 800 °C and then is allowed to cool down to a temp of about 600 °C to bring it to a semi solid state. Then the 5% by weight reinforcement of Al_2O_3 and Fly ash (i.e., 2.5% Al_2O_3 and 2.5% Fly ash) is added into the semi solid melt and is stirred for about half an hour at a speed of around 500 rpm. The melt with reinforced particulates were poured into the preheated permanent mild steel mould. The melt was then allowed to solidify in the mould. Specimens were then finish machined to make pins of 6 mm diameter and 30 mm along length.

Hardness testing was done on the specimen using Rockwell hardness testing apparatus while Wear testing was performed on these specimens on a pin on disk wear tester. The unit consists of a pivoted arm to which the pin is attached, a fixture which accommodates disks of a particular diameter, an electronic force gauge for measuring the friction force. Included with the Falex ISC-200 PC is a weight set capable of applying contacts stresses up to 2 GPa. The motor driven turntable produces up to 180 rpm. Wear was quantified by varying the parameters like wear track radius and dead weight keeping the machine r.p.m constant for a time interval of 2 minutes. The amount of material removed was calculated to get the wear rate. The wear rate of Al+ Fly ash + Al_2O_3 composite was also compared with the wear rate of commercially pure aluminium metal.

RESULTS AND DISCUSSION

The addition of reinforcements has resulted in the increase of hardness in aluminium as shown in Table 2. Also, there are a lot of variations in hardness values in case of hybrid composite. At one point, hardness was maximum of all the composites while another point has shown the lowest hardness. This may have happened due to the porosity of the composite or the agglomeration of the particles. This porosity or agglomeration may have occurred either due to the entrapment of gases while casting or improper wetting of the as received fly ash particles. 1% Mg by weight was used as a wetting agent in all the composites but fly ash composites may require higher Mg content for proper wetting.

Table 2: Hardness of Specimen

S. No.	Pure Al (RHN)	Al + Fly Ash + Al_2O_3 (RHN)
1.	42	41
2.	33	56
3.	37	38
4.	35	32
Mean	36.75	41.75

The wear tests were done for a normal load of 40 N at a two sliding velocities of 0.8 m/sec and 1 m/sec. The variation of Cumulative Wear Rate (CWR) and cumulative wear loss with sliding distance has been discussed in the subsequent paragraphs for the various cases under investigation.

The variation of the cumulative wear rate with the sliding distance for the pure Al and Al + Al_2O_3 + Fly ash composite at a normal load of 40 N and sliding velocity of 0.8 m/sec has been plotted in Figure 2 whereas the CWR data have been shown in Figure 3. It is evident from the plots that CWR is high even during the start of the process for pure Al. For first three cycles, CWR increases steadily for pure Al but for Al + Al_2O_3 + Fly ash composite rate of increase was higher for third cycle and after that CWR increases linearly. In case of pure Al, CWR increases linearly for first three cycles and rate of increase slightly improves for fourth cycle and slightly decreases for fifth cycle while for sixth cycle, CWR again increase sharply. The reason for such behavior is that during initial phases of wear, oxide film formed on the surface of pure Al composite may have caused resistance to wear but after its removal, the surface gets exposed and results in higher wear thereafter. For Al + Al_2O_3 + Fly ash

Figure 2: Variation of Cumulative Wear Rate for the Pure Al and Al + Al_2O_3 + Fly Ash Composites Subjected to Wear at Normal Load of 40 N and Sliding Velocity of 0.8 m/sec

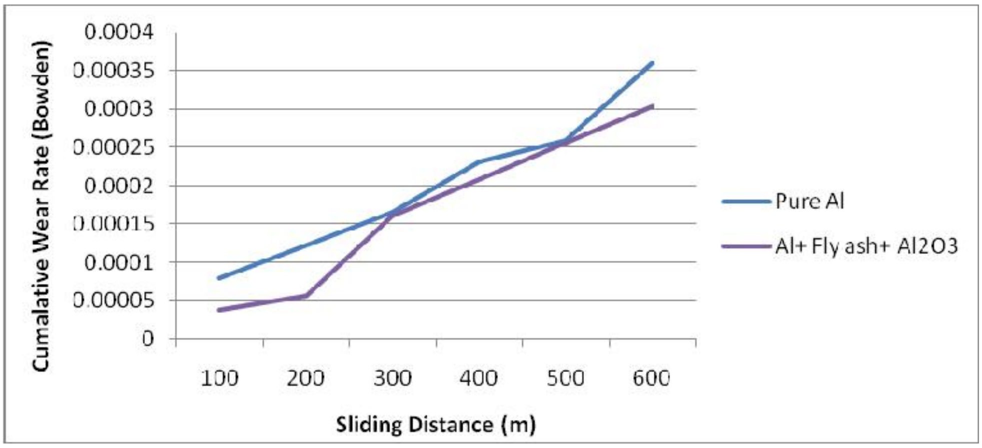
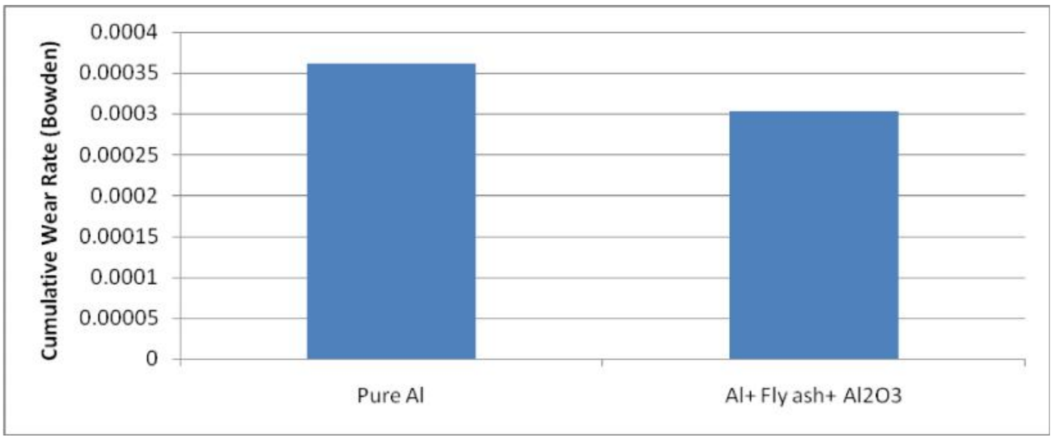


Figure 3: Cumulative Wear Rate for the Pure Al and Al + Al_2O_3 + Fly Ash Composites Subjected to Wear at Normal Load of 40 N and Sliding Velocity of 0.8 m/sec After a Sliding Distance of 600 m



composite, CWR increases linearly for first two cycle and then suddenly increases sharply but afterwards increases linearly. This type of behavior may be attributed to the fact that initially the contact surfaces are usually rough having hills and valleys which get interlocked with each other during the initial periods of wear. However with the passage of sliding distance, these hills and valleys get smoother, contributing to somewhat lower CWR.

Therefore it can be concluded that wear resistance of Al has got increased after the introduction of reinforcement in it. This means Al + Al_2O_3 + Fly ash composite is better on the basis of wear resistance than pure Al.

The variation of the cumulative wear rate with the sliding distance for the pure Al and Al + Al_2O_3 + Fly ash composite at a normal load of 40 N and sliding velocity of 1 m/sec has been plotted in Figure 4 and the CWR data have been shown in Figure 5. It is evident from the plots that CWR is higher for pure Al than Al + Al_2O_3 + Fly ash composite. For pure Al, CWR increases linearly in all the cycles but the rate

Figure 4: Variation of Cumulative Wear Rate for the Pure Al and Al + Al_2O_3 + Fly Ash Composites at Normal Load of 40 N and Sliding Velocity of 1 m/sec

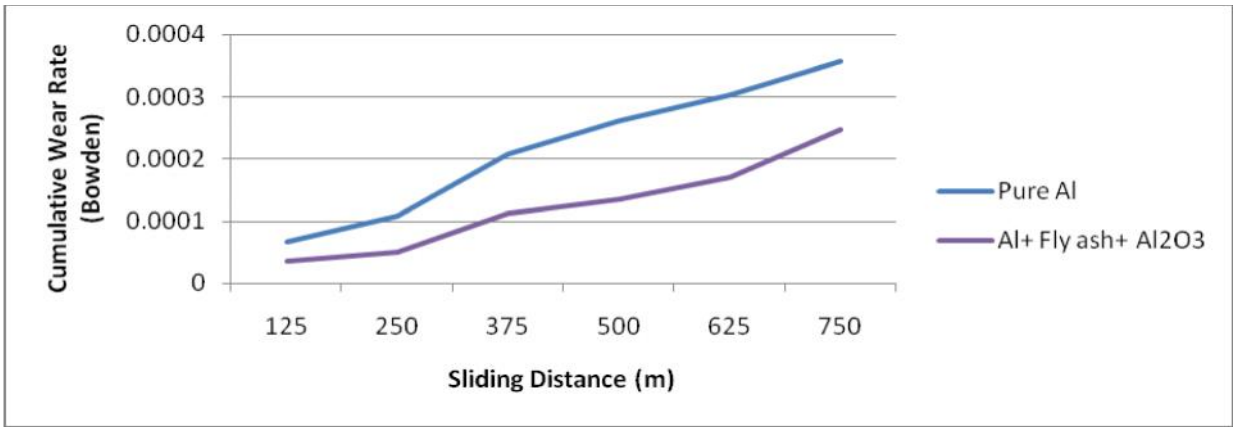


Figure 5: Cumulative Wear Rate for the Pure Al and Al + Al_2O_3 + Fly Ash Composites at Normal Load of 40 N and Sliding Velocity of 1 m/sec After a Sliding Distance of 750 m

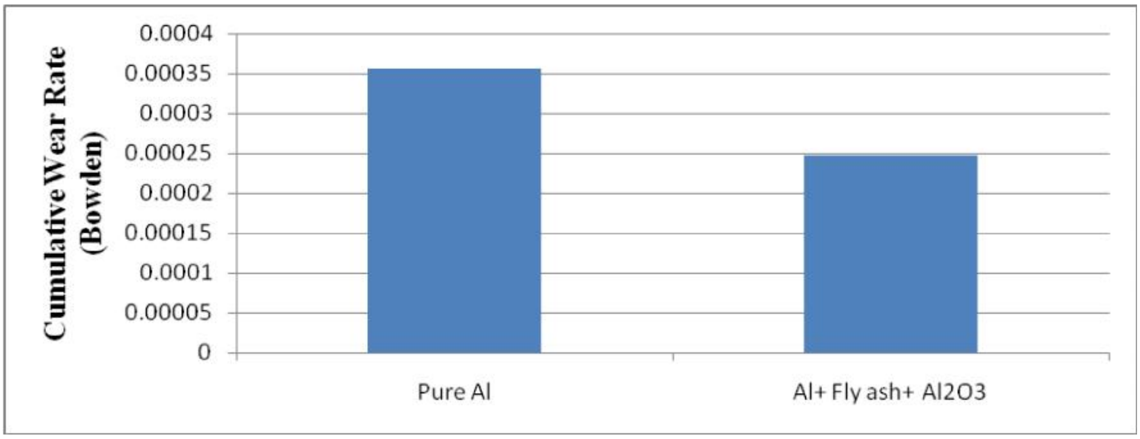
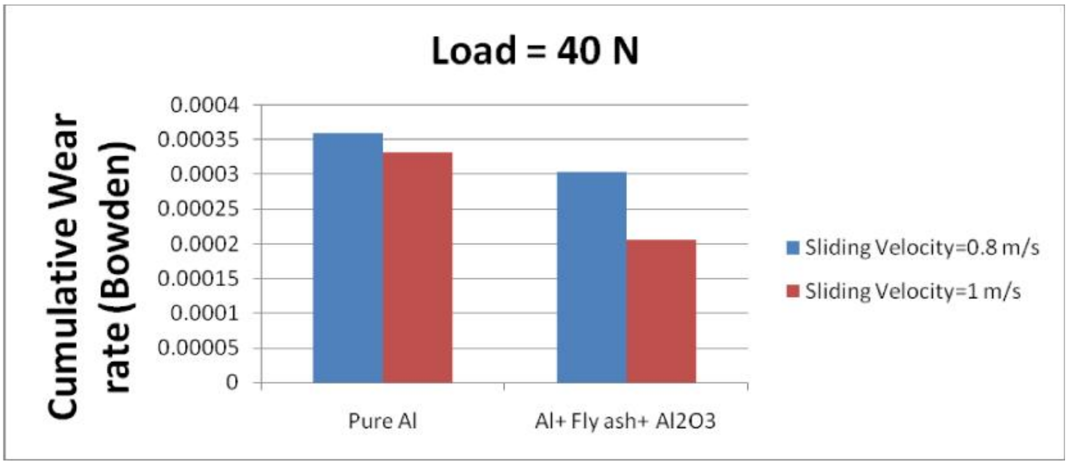


Figure 6: Comparison of Cumulative Wear Rate for Pure Al and Al + Al_2O_3 + Fly Ash Composites Subjected to Wear at Normal Load of 40 N at Two Sliding Velocities of 0.8 m/sec and 1 m/sec



of increase was highest in third cycle. Al + Al_2O_3 + Fly ash composite behaves such that CWR increases initially with rate of change being higher in third cycle and then this rate of change suddenly decreases slightly and in last cycle again increases. From Figure 5, it can be concluded that Al + Al_2O_3 + Fly ash composite has performed much better than its counterpart, i.e., pure Al. So, Al + Al_2O_3 + Fly ash composite is better on the basis of wear resistance at a normal load of 40N and sliding velocity of 1 m/sec.

The comparison of the cumulative wear rate with the two sliding velocities of 0.8 m/sec and 1 m/sec for the Pure Al and Al + Al_2O_3 + Fly ash composite at a normal load of 40 N has been plotted in Figure 6. There was no significant effect of change in sliding velocity on CWR of Pure Al and that of Al + Al_2O_3 + Fly ash composite, CWR decreased considerably with increase of velocity.

So, it can be evaluated that Al + Al_2O_3 + Fly ash composite showed better wear resistance at sliding velocity of 0.8 m/sec and normal load of 40 N than pure Al while at 1 m/sec, Al + Al_2O_3 + Fly ash composite showed even better wear resistance while for pure Al, wear resistance remained almost same at the same parameters.

CONCLUSION

1. Al + Al_2O_3 + Fly ash composite was successfully fabricated using cost effective stir casting technique.
2. Hardness of aluminium was found to increase significantly with the addition of reinforcement, i.e., Al_2O_3 + Fly ash.
3. The wear resistance was also found to increase significantly with the addition of reinforcements in aluminium.
4. Wear resistance of Al + Al_2O_3 + Fly ash composite was found to be better at load of 40 N and both the sliding velocities of 0.8 m/sec and 1 m/sec than pure Al.
5. Comparison of wear behavior of specimens at normal load of 40 N revealed that wear resistance of pure Al

and Al + Al_2O_3 + Fly ash composite increased with increase in sliding velocity even though this increase was marginal for pure Al while for Al + Al_2O_3 + Fly ash composite it was considerable.

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