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Research Article

Synthesis and Characterization of Aluminium Alloy AA6061-Alumina Metal Matrix Composite

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Abstract

The experimental investigation on the effect of alumina reinforcement on mechanical properties of aluminium alloy Al 6061 composites samples, processed by stir casting method is reported in this paper. Three sets of composites were prepared with varying percentage of alumina (4%, 6%, and 8%) by weight fraction. The evaluated properties of the samples were tensile strength, hardness, corrosion, wear resistance and their microstructure were also observed. In the presence of alumina with aluminium, it was observed that the hardness, tensile strength, corrosion and wear resistance were increased but ductility of the hybrid metal matrix composites in comparison with unreinforced aluminium has decreased. From the experiment it was observed that the best properties were obtained from the sample containing 8% alumina as compared to the base metal. The microstructural characterization of the samples was carried out using Scanning electron microscopy.

Keywords: *Aluminum 6061, Hybrid MMC's, Alumina, Stir casting, characterization of MMC*

1. Introduction

Industrial technology is growing at a very rapid rate and consequently there is an increasing demand and need for new materials. Particulate reinforced composites constitute a large portion of these new advanced materials. The choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects. Incorporation of hard second phase particles in alloy matrices to produce MMCs has also been reported to be more beneficial and economical due to its high specific strength and corrosion resistance properties.

In the past, various studies have been carried out on metal matrix composites. SiC, TiC, TaC, WC and B_4C are the most commonly used particulates to reinforce in the metal or alloy matrix such as aluminium or iron, while the study of Al_20_3 reinforcement in AA6061 alloy matrix is still rare. Since very limited studies have been reported and the information and the data available on the mechanical, wear and corrosion properties are scarce and hence make this study a significant one.

In this investigation samples containing alumina particulates (avg. 20 microns) in different percentages (4%, 6% and 8%) reinforced in aluminium Al 6061 0 alloy matrix composites test were produced by Stir casting method and they were examined to study the differences in the mechanical behavior of the produced MMC composites samples. Various tests such as tensile test, Wear test, Corrosion test, Hardness test and SEM Microscopic examination of the specimens were carried out to assess the change in characteristics of the alloy composite at difference percentage of reinforcements.

2. Choice of Matrix

The melting point of most aluminium alloys is near that of pure aluminium, approximately 660°C; this relatively low melting temperature, in comparison to most other potential matrix metals, facilitates easy processing of aluminum based MMCs. (T. W. Clyne, 2001) Further, it is available in various forms for easy processing and a wide range of alloys are available to choose for a particular application.

Aluminum oxide, commonly referred to as alumina, possesses strong ionic inter-atomic bonding giving rise to its desirable material characteristics. It is the strongest and stiffest of the oxide ceramics, having excellent size and shape capability and is hard and Wear resistant.

Aluminium MMC was particularly selected as it possesses increased elevated temperature strength and wide range of extensive applications. For example, Honda has used aluminum metal matrix composite cylinder liners in some of their engines, including the B21A1 and H22A.

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2.1 Properties of aluminium 6061

Table 1 Chemical Composition of Al 6061 alloy

Element	Amount (wt %)
Aluminium	96.85
Magnesium	0.9
Silicon	0.7
Iron	0.6
Copper	0.30
Chromium	0.25
Zinc	0.20
Titanium	0.10
Manganese	0.05
Others	0.05

Table 2 Mechanical properties of aluminium 6061 0 alloy (99.5% pure)

Ultimate Tensile Strength (N/mm^2)	110
0.2% Proof Stress (N/mm^2)	88
Brinell Hardness (500kg load, 10mm ball)	32
Elongation 50mm dia (%)	15

3. Synthesis of AL-MMC with alumina

Among discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route and currently practiced commercially. The major advantages of stir casting are its simplicity, flexibility, applicability to large quantity production and capability to fabricate very large sized components.

In general, stir casting involves producing a melt of the selected matrix material followed by the introduction of the reinforcement material into the melt, obtaining a uniform distribution of the reinforcements. (Dr. Dmitri Kopeliovich, 2003)

Stirring is carried out vigorously to form a vortex where the reinforcing particles are introduced through the side of the vortex. The formation of the vortex will drag all the reinforcement particles into the melt.

The next step is the solidification of the melt containing suspended particles under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix.

3.1 Stir casting procedure

The weighted quantity of Al was melted in an induction type tilting furnace (with Graphite crucible) in the temperature range of 810^{0}C.

The alumina particles were preheated in a separate furnace at about 810^{0}C for about 20 minutes before introducing them into the melting furnace. (Nripjit, et al, 2009)

A stirrer (made of Mild steel) is used to obtain an output of 600 rpm. During experimental work, a four bladed 450 angled stirrer was chosen. The stirrer position should be such that 35% of material should be below the stirrer and 65% of material should be above the stirrer.

The casting is carried out in a molding die. The die made of cast steel preheated up to 250°C for about 1 hour. The total volume of the die is 1250 cm^3. In order to avoid sticking of molten metal on the die's wall a special type of coating (wulfrakote) is applied.

When ladle is used to pour the molten metal mixture into the die atmospheric gases may react with it and cause undesirable casting defects. To minimize this effect a novel method of down pouring technique (Jasmi Hashim, 2001) is deployed. In this technique, a passage is provided on the bottom of the crucible which can be opened or closed by a spring loaded valve. The die is placed below the opening and the molten metal is straightly poured into the die by actuating the valve.

On mixing the particle with the base metal it was noted that there is no uniform distribution of the reinforcement particles under normal conditions. This can be related to the following facts:

- The alumina particles have greater specific density value than the matrix metal and so they float on the surface,
- The high surface tension and
- Poor wetting between the particles and the melt.

A mechanical force can usually be applied to overcome surface tension to improve wettability. To obtain better mixing manual stirring can also be done along with mechanical stirring. Small pallets of magnesium wrapped in aluminium foil were added to improve wettability thereby aiding uniform distribution of the reinforcement particles. (Nakae, *et al,* 1998) The cast is then machined to obtain plates of size 100 mm x 50 mm x 5 mm.

Fig. 1 Stir Casting - laboratory setup

Fig. 2 Typical aluminium 6061 rods

Fig. 3 Typical Al MMC casting along with machined plates

4. Characterization of the fabricated MMC

To characterize the fabricated MMC, the following tests were carried out.

- Corrosion test
- Wear test
- Tensile test
- Hardness test
- Microstructure examination

5. Corrosion test

Pitting corrosion test as per ASTM G61-78 standard was carried out on the produced MMC samples with different wt% of alumina reinforcement to determine their corrosion behavior.

5.1 Sample preparation

The machined plates were sized to 15 mm x 15 mm x 5 mm. The test surface of the samples were ground with 240, 320, 400, 600 and 800 -grit silicon Carbide paper and polished with 5 & 2 micron diamond paste on a struers cloth. They were rinsed in demineralized H_2O and were placed in desiccators before the test.

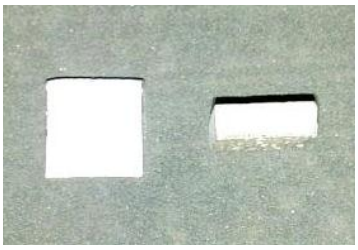

Fig. 4 Typical corrosion test specimens

5.2 Testing procedure

The test specimen was subjected to a corrosive environment, 3.5 wt. % NaCl solution in this case, (Zuhair M. Gasem, *et al*, 2002) thereby simulating the service environment of the material. The pitting corrosion is calculated in terms of mm/yr. Weight loss studies were conducted in accordance with ASTM standard G31-72. All electrochemical measurements were made in accordance with ASTM standard G5-87 for making potentiostatic and potentio dynamic measurements and G61-78 standard for cyclic potentio dynamic measurement. All polarization measurements were made with reference to a standard Ag- AgCl reference electrode. The corrosion potential was measured by switching the instrument to the corrosion potential mode. Polarization was commenced at a scan rate of 10 mVs and continued until the pitting potential was reached.

The specimens were then subjected to corrosive environment (3.5% NaCl) and sufficient potential is applied across the closed circuit so that pitting corrosion occurs on the surface of the composites.

A plot of current vs. potential is obtained and from that data corrosion rate is computed. The following figure shows the laboratory setup.

Fig. 5 Corrosion test sample preparation

Fig. 6 Corrosion test setup

Table 3 Estimated Corrosion rate of Al MMC

Percentage of alumina	Corrosion rate	
	mm/year	mils/yr
4	6.7019813	263.85753
6	3.7457866	147.47191
8	2.4914536	98.088724

6. Wear test

The wear test was performed to study the influence of percentage of reinforcement content on the dry sliding wear behavior of the composites.

6.1 Testing procedure

ASTM G99 - 05 Standard Test Method was followed. A pin- on- disc test apparatus was used to investigate the dry sliding wear characteristics of the composite. The wear specimens of cross section 4 mm x 4 mm was cut from cast samples , machined and then polished using silicon carbide papers (240, 320, 400, 600 and 800 grades). The initial weight of the specimen was measured in a single pan electronic weighing machine. During the test the pin was pressed against the steel disc having hardness value of 62 HRC by applying the fixed load of 4 kg and the sliding velocity being 2 m/s. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. (Ames, *et al*, 1995) The difference in the weight measured before and after the test gave the wear of the composite specimen.

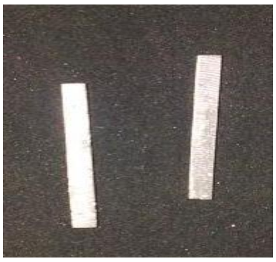

Fig. 7 Typical wear test specimen

Fig. 8 Wear test setup

The wear of the composite was studied as a function of the volume percentage of the reinforcement and the estimated wear rates are tabulated below:

Table 4 Estimated wear rate of Al MMC

Percentage of alumina	Wear rate
	mm^3/min
4	0.509
6	0.463
8	0.370

The microstructures (Fig. 9 & 10) of the specimens (at x100) indicated that the wear in 4% was plough type wear where as the one in 8% specimen was adhesive type.

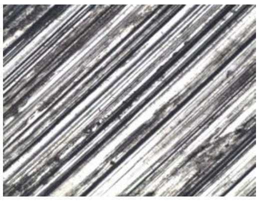

Fig. 9 4% sample

Fig. 10 8% sample

7. Tensile test

For testing the tensile strength of the composite, ASTM E8M-04 standard was adopted and the test specimens were prepared according to the specification as given in the standard.

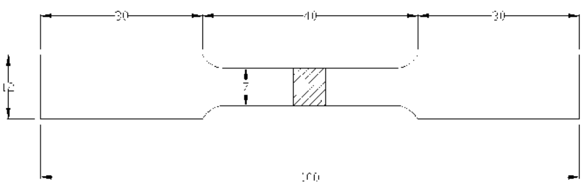

Fig. 11 Typical Tensile test specimen

Table 5 Tensile strength test results

Reinforcement (%)	Yield stress, (N/mm^2)	Ultimate tensile stress, (N/mm^2)	Breaking stress, (N/mm^2)	% Elongation
4	52.82	111.98	81.18	14.22
6	58.15	118.94	86.24	11.31
8	65.01	127.11	89.14	7.58

8. Hardness test

The Vickers hardness test method, also referred to as a microhardness test method, is used for both bulk and micro hardness measurement. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. (T. Lim, *et al*, 1992) The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH)

8.1 Testing Procedure

The surface of the test specimen was properly prepared and the specimen was fixed on anvil. A load of 0.5 kg is applied for a time period 15 sec then the diagonals of the diamond indenter's impression were measured from which the Vickers hardness values were calculated.

Fig. 12 Microhardness testing apparatus

Table 6 Estimated Microhardness

Percentage of alumina	Microhardness
4	56
6	66
8	70

9. Microscopic examination

Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25× magnification. The microstructure of a material (which can be broadly classified into metallic, polymeric, ceramic and composite) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance, and so on, which in turn govern the application of these materials in industrial practice.

Fig. 13 Optical microscopy setup

9.1 Sample preparation

The samples were ground with 240, 320, 400, 600 and 800 –grit silicon carbide paper and polished with 5 & 2 micron diamond paste on Velvet cloth. They were rinsed in demineralized H_2O .The specimens were placed in desiccators before use.

It was then dipped in aqueous solution of sodium hydroxide, and then dropped in the etchant (11c Beraha) until bluish brown color appears. Later, the sample is dried to remove moisture if any present, and then placed under the optical microscope (x500) for observation.

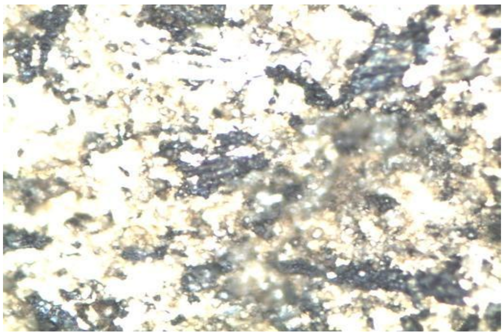

Fig. 14 4% MMC sample @ x500

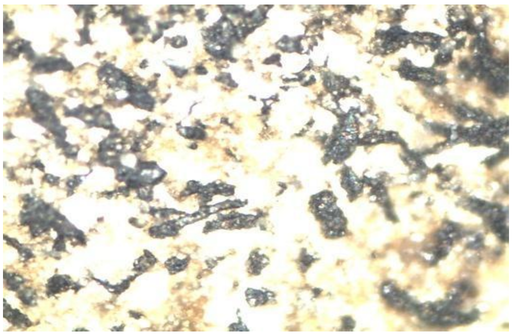

Fig. 15 6% MMC sample @ x500

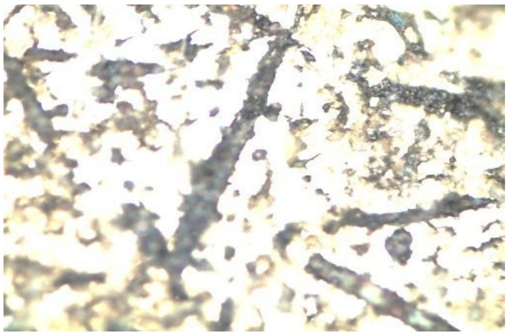

Fig. 16 8% MMC sample @ x500

Conclusion

The aluminium MMC with 4, 6 and 8% alumina were produced using the stir casting technique and the castings were found to have less casting defects and shown better wettability between the particles and the matrix owing to the preheating of the alumina particles, Vigorous stirring and addition of Mg as wetting agent.

Aluminium by itself shows high corrosion resistance furthermore the alumina is the strongest corrosion resistant material among all the oxides (Kok, M., 2005). So naturally reinforcing alumina in aluminium matrix will result in decreased corrosion rates of the MMC. Table 3 shows clearly that the corrosion rate decreases with increasing alumina % in the MMC.

Aluminium being a soft and ductile metal shows poor wear resistance which dampens the use of aluminium in highly demanding environments. On the other hand alumina (Al_2O_3) is a highly refractive material shows superior wear resistance. The MMC has intermediate value of wear resistance between the base metal and the reinforcement. The table 4 shows effect of amount of reinforcement on the wear rate and it is observed that the wear rate decreases with increasing reinforcement.

The key property of the MMC is its high specific strength value compared to its base material. It is evident from the table 5 that with increasing reinforcement percentage in the composite the resistance offered by the material to necking is substantially increased while the % elongation is reduced.

The Vickers hardness test reveals that the hardness of the specimen is increased significantly with the increase in the alumina percentage as shown in table 6.

The microstructure examination (fig. 14, 15 & 16) of the composite exhibits different colors owing to the action of the color etchant 11c. The Al-Cu-Fe-Mn appears blue, CuAl2 appears slightly colored, FeSiAl5 appears brownish blue, NiAl3 appears brown, and while the base metal (Al) remains uncolored the reinforcement (Al_2O_3) appears as bright spots. (Beraha. E., and B. Shpigler 1977)

Scope for future work

Scope for future work in this topic is immense. In this work the variation of mechanical properties due to the percentage of reinforcement were studied. So further studies can be carried out to study the change in the material properties of the composite considering both the size and the percentage of the reinforcement particles, different metal joining techniques (like welding) which can be adopted to fabricate the Al MMC composites, various machining parameters which should be deployed while machining Al MMCs can be studied and optimized.

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