Development of Hybrid Aluminium Metal Matrix Composites for Marine Applications

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Abstract. Aluminium alloy components are light in weight and widely used in general engineering application. Aluminium based Metal Matrix Composites (MMC) have become a very valuable addition to the field of newer materials for high performance applications. Aluminium based composites are being increasingly used in automobiles, Aerospace and Marine applications. Aluminium matrix composites are normally processed by the liquid casting technique or powder metallurgy route. In this work, the casting was done by the liquid casting technique. The particulates were mechanically stirred and well distributed over the liquid metal, before casting and solidification. In the present work Fabrication and characterization of A5083/Fly ash/SiC hybrid MMCs, Micro structural, Mechanical and Tribological Properties are studied.

Keywords: Aluminium, Composite, Hardness & charpy impact

1. Introduction

The Al 5083 alloy is a very interesting material because of its mechanical properties, namely, low density, high strength, moderate ductility, marine corrosion resistance and toughness. Due to these properties, the alloy is mainly used for highly stressed structural parts. This material has a wide range of applications such as interior automotive, application trim, pressure vessels, armor plate, marine and cryogenic components.

In general, aluminum alloy components are light in weight and widely used in general engineering applications. But, aluminium alloys are poor against wear resistance under partial or boundary lubricated conditions [4]. With solid lubricant particles dispersed in the matrix of aluminum alloy, this material exhibits good potential for resistance to wear and consequently, becomes more suitable for tribological applications [1]. Aluminum based Metal Matrix composites (MMCs) have become a very valuable addition to the field of newer materials for high performance tribological applications. Aluminum based composites are being increasingly used in automobiles, aerospace, marine and mineral processing.
industries. Aluminum alloys are increasing applications in the marine fabrication industries due to its unique mechanical and corrosion properties. The effect of metallurgical changes in mechanical behavior and corrosion resistance of Aluminum alloy 5083-H111 is weldment. Microstructure analysis was carried out in the fusion zone and compared to the heat affected zone and parent metal region. The mechanical behavior of the weld was compared with its parent metal by performing microhardness, impact toughness, tensile behavior and formability test [5]. Marine transport is increasing its use of aluminum by capitalizing on its two leading qualities: lightness and corrosion resistance. The most popular aluminum alloys for use in corrosive environments such as seawater are the 5xxx and 6xxx series alloys, which demonstrate adequate strength and excellent corrosion resistance. The traditional and the most often used Al-alloys in shipbuilding are 5083 type Al-Mg alloy [10]. Aluminum matrix composites are normally processed by the liquid casting technique or powder metallurgy route. In this work, the casting was done by the liquid casting technique. The particulates were mechanically stirred and well distributed over the liquid metal, before casting and solidification. Thus, this research work aims to identify the ability of AA5083 to acquire resistance to corrosion, when they were cast as composites with fly ash and SiC as reinforcements. Fabrication, surface, morphology and corrosion matrix is investigated of AL7075 AL2O3 matrix composite in sea water and industrial environment. This experiment is performed in matrix and to study the corrosion behavior of base AL7075 fabricated by stir casting method [8]. In all the investigations, the impact, hardness and tensile tests were conducted at room temperature. Thermal management employing heat sinks is often compromised by the space constraints for a product design. Describe a new forming technology, friction-stir forming (FSF), to generate a low profile, ultra-thin fin [2]. Aluminium 5083 is a specific class of alloy which is known for its corrosion resistance in extreme environments and is used in aerospace components. On effect of reinforcement such has silicon carbide and fly ash on corrosion behavior of aluminium 5083 to study the mechanical and tribological characteristics. The fabrication of aluminium-silicon carbide, fly ash composites and study of the corrosion behavior of these composites. The composites are prepared by stir casting technique [6]. AA5083 alloy is an aluminum alloy with magnesium and traces of manganese and chromium. It is highly resistant to attack by seawater and industrial chemicals. Alloy 5083 retains exceptional strength after welding. Alloy 5083 is commonly used in shipbuilding, railroad cars, drilling rigs, coach work, and pressure vessels. In the current work Fabrication and characterization of A5083/ Fly ash/SiC hybrid MMCs were studied.

2. Fabrication and experimental

Stir casting of metal matrix composites was initiated in 1968, when Spray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders. In stir casting, molten metal is stirred with the help of mechanical stirrer (Schuster et.al 1989). This action disperses the reinforcing phase, which is added to the surface of the melt in the molten metal, and solidifies the composite. The crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminum alloy melt. The preheated ceramic particles are introduced into the charge and it was stirred which leads to uniform dispersion of particles. The uniform distribution of reinforcement depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification. Metal after reaching liquid state had cooled down to the semi-solid temperature.

The preheated materials added and stirred thoroughly, then the material is heated to its melting temperature and stirred. It provides better dispersion compared to conventional stirring. Particles usually have a thin layer of gas absorbed on their surface, which reduces bonding between the particles and matrix materials. The mixing of the particles in the
semisolid state can effectively break the gas layer because the high melt viscosity produces a more abrasive action on the particle surface. Hence, the breaking of the gas layer improves the wet ability in fully liquid. Also Stir casting is an economical process for the fabrication of aluminum matrix composites.

For fabrication, composition of materials where taken on the basis of weight percentage of aluminium, Sic and fly ash as shown in the table 1.

| Sl. No. | Alloy mixing ratio | Alloy designation |
|--------|-------------------|-------------------|
| 1      | AA5083+3%SiC+2%flyash | 5SF               |
| 2      | AA5083+5%SiC+2%flyash | 7SF               |
| 3      | AA5083+7%SiC+2%flyash | 9SF               |

Table 1 Composition of materials for fabrication

2.1 Fabrication of test Specimen
The mould was made to required dimension 110x110x8 in mm. Mould AA5083 heated to 750 degree Celsius, when reaches this temperature AA5083 solid phase changed into molten state. Then by using stirrer make a vortex flow in the molten AA5083. In liquid cast mixing of composites, we made a vortex flow to mix the composites for equal distribution of molten fluid everywhere. When vortex flow formed, we added the powdered particles of SiC and fly ash to required proportions, after around 15 minutes the molten state metal was changed into solidified alloy.

3. Analysis of Mechanical properties
Mechanical properties such as tensile strength, hardness and microstructure of the casted metal matrix composites were analyzed. The casted specimens should be cut as per ASTM standard for analyzing the mechanical properties.

3.1 Tensile strength
The ultimate tensile strength is the maximum engineering stress level in tensile test or it is the ability of material to withstand before fracture. Four specimens of various composition have to be analyzed to determine its ultimate tensile strength for the purpose and UTM is used. For analysis of the ultimate strength, ten pieces were cast with different composition. The cast specimens were cut into ASTM E8 standard shown in figure 1.
3.2 Hardness
The four pieces were prepared as per ASTM E18-20 standard and these four pieces are tested with the help of Rockwell hardness testing machine. Rockwell testing which forces a pointed probe into the surface and measures the increase in penetration, the penetration is in tens of micrometers and if the sample deforms or moves, significant errors may arise.

For the analysis of hardness of a specimen, it should be cut as per ASTM standard as shown in figure 2. Reading obtained from B scale reader.

![Figure 2 Standard specimen for hardness test](image)

First, the indenter is pressed with the test pre-force (also referred to as perforce or preload) to a penetration depth of \( h_1 \) in the specimen to be tested. \( h_1 \) defines the reference level (basis) for subsequent measurement of the residual indentation depth (h). Next, the additional test force is applied for a dwell period defined in accordance with the standard (several seconds), whereby the indenter penetrates into the specimen to a maximum indentation depth. The test pre-force plus the additional test force gives the total test force or main load.

After the dwell period, the additional test force is removed; the indenter moves up by the elastic proportion of the penetration depth in the total test force and remains at the level of the residual indentation depth (h - expressed in units of 0.002 or 0.001 mm). This is also referred to as the depth differential (difference in indentation depth before and after application of the total test force). Now the Rockwell hardness (HR) can be calculated using the residual indentation depth (h) and a formula defined in the standard, taking account of the applied Rockwell scale.

3.3 Microstructure
For analyzing the microstructure of the specimen are used after the hardness test. These specimens were prepared by polishing with different grades of abrasive paper and finally surfaces were smoothened by single disc polishing machine.

After tested hardness test these specimens are used to microstructure study. First step is to wet polish and then sample was grind by different grades of abrasive paper 400, 600, 1000. Then specimens were polished using aluminium oxide and finally etchant with NaOH solution. After getting a glass faced surface, the specimens were taken for microstructure study. The microstructure of the specimen examined from 50x to 1000x. As the microstructure plays an important role in the overall performance of a composite and the physical properties are depends on microstructure, reinforcement particle size, shape and distribution of alloy. Prepared samples were examined using a Scanning electron microscope (SEM) to study the distributions pattern of fly ash in the matrix.
3.4 Impact test

For the impact test analysis, four pieces were prepared as per ASTM standard and these four pieces were tested with the help of charpy impact testing machine. Impact test are used to study the toughness of material. A material's toughness is a factor of its ability to absorb energy during plastic deformation. Brittle materials have low toughness as a result of a small amount of plastic deformation that they can endure. The impact value of a material can also change with temperature. Generally, at lower temperatures, the impact energy of a material is decreased. The size of the specimen may also affect the value of the Izod impact test because it may allow a different number of imperfections in the material, which can act as stress risers and lower the impact energy. For the analysis of impact test a specimen as shown in figure 3.

![Figure 3 Standard charpy impact test specimen](image)

The Charpy Impact test striking a notched impact specimen with a swinging weight attached to a swinging pendulum. The specimen breaks at its notched cross-section when impact, and the upward swing of the pendulum is used to determine the amount of energy absorbed in the process. Energy absorption is directly related to the brittleness of the material. Since temperature can affect the toughness of a material, the charpy test is performed at a series of temperatures to show the relationship of ductile to brittle transition in absorbed energy. Four specimens were tested with different temperatures for the impact test.

4. Experimental results and discussions

Variation of tensile strength, hardness and microstructures on the ten specimens is to analyse the effect of Nano particles in the metal matrix composites.

4.1 Analysis of the effect of reinforced particles on ultimate tensile strength

Here an experiment is done on the effect of compositions of flyash and SiC on the metal matrix composites on tensile strength for each specimen in table 2.

| Sl. No. | AA5083 (g) | SiC (%) | Fly ash (%) | Tensile strength (Mpa) |
|---------|------------|---------|-------------|-----------------------|
| 1       | 515.97     | 0       | 0           | 100                   |
| 2       | 478.93     | 5       | 2           | 135                   |
| 3       | 468.62     | 7       | 2           | 190                   |
| 4       | 459        | 9       | 2           | 140                   |
From the above table 2 it clearly shown that increase in SiC increases the ultimate tensile strength within the range 5% and 7% for a constant fly ash of 2%, Ultimate tensile strength decreases with increase in SiC after 7% of SiC. Strength of Al 5083 alloy with SiC and fly Ash hybrid composites, it is observed that the strength increased up to 7% SiC particles beyond that it decreased. Also the maximum value of tensile strength is observed 190Mpa for Al (7% SiC) which is about 15.65% improvement over that of Al (5% Sic).

4.2 Analysis of the effect of reinforced particles on hardness test

Here an experiment is done on the effect of compositions of flyash and SiC on the metal matrix composites on hardness test for each specimen in table 3.

| Table 3 | Hardness test result |
|-----------------|---------------------|
| Sl. No. AA5083 (g) SiC (%) Fly ash (%) HRB (Kgf) | |
| 1 | 515.97 | 0 | 0 | 50 |
| 2 | 478.93 | 5 | 2 | 60 |
| 3 | 468.62 | 7 | 2 | 78 |
| 4 | 459 | 9 | 2 | 67 |

From the above table 3, it clearly shown that increase in SiC increases the hardness value within the range 5% and 7% for a constant fly ash of 2%, hardness decreases with increase in SiC after 7% of SiC. In the composites it was observed that the hardness value increased up to 7% of SiC particles and beyond that it decreased. The maximum value of rockwell hardness B scale is 78 Kgf for Al (7% SiC and 2% fly ash).

4.3 Analysis of the effect of reinforced particles on charpy impact test

An experiment is done on the effect of compositions of flyash and SiC on the metal matrix composites on impact strength for each specimen in table 4.

| Table 4 | Impact strength test result |
|-----------------|---------------------|
| Sl.No. AA5083 SiC(%) Fly ash(%) Impact energy(j) | |
| 1 | 515.97 | 0 | 0 | 0.7 |
| 2 | 478.096 | 5 | 2 | 2 |
| 3 | 468.62 | 7 | 2 | 4 |
| 4 | 459 | 9 | 2 | 4 |

From the above table 4, maximum value of charpy impact energy 4 joule was observed for Al 5083 (7% SiC + 2% Fly ash) and Al 5083 (9% SiC + 2% Fly). Which are about 50% improvements over that of Al 5083 (5% SiC + 2% Fly ash) composite.

4.4 Microstructure analysis

In the microstructure, the dark line shows the presence of SiC in matrix. Microstructure of a material can strongly influence physical properties such as strength, toughness, ductility,
hardness, corrosion resistance, and wear resistance. Silicon carbide and fly ash were uniformly distributed on the microstructure obtained from the test result. The presence of silicon carbide has an important role in the case of tensile strength and hardness. Microstructure of Al5083 with 5\% SiC and 2\% flyash as shown in figure 4. Microstructure of Al5083 with 7\% SiC and 2\% flyash as shown in figure 5. Microstructure of Al5083 with 9\% SiC and 2\% flyash as shown in figure 6. In these hybrid Al5083 composites, composite having 7\% SiC and 2\% flyash exhibits the highest tensile strength and Impact strength.

**Figure 4** Microstructure of 5SF

**Figure 5** Microstructure of 7SF
Figure 6 Microstructure of 9SF

4.5 Marine applications

Aluminum alloys are a great choice in marine applications because of its high corrosion resistance, less weight and were considered economical in good life. Aluminium alloy materials are mostly used in marine applications such as shipbuilding, boat lifts, docks, and other offshore structural applications. Here we used hybrid aluminium alloy of different composition of SiC and fly ash. From the test conducted to find tensile strength, impact strength and hardness test for the composite Al 5083 added to 7% Sic and 2% fly ash, we found good values in the test. So, this aluminium alloy composite can used in marine based applications for the result of high corrosion resistant, tough, moderately strong.

5. Conclusions

The nanoparticles like silicon carbide and fly ash were added with Al 5083 aluminium alloy at different composition and then casted. The mechanical and metallurgical characterizations of hybrid aluminium metal matrix composites were investigated. In this work, four pieces with different composition were casted. The stir casting process is used, since it is efficient casting process for the fabrication of hybrid metal matrix composite. For these cast, different tests like Ultimate tensile strength test, Hardness test, and Impact test and microstructure analysis were conducted to determine the optimum composition. Tensile test, impact test and hardness test are conducted to evaluate the mechanical properties of the composite. While comparing the hardness and tensile strength, it is found that SiC have more influence compared to fly ash. Therefore, SiC has more influence in aluminium alloys in terms of hardness and tensile strength compared to fly ash. The maximum value of ultimate tensile strength obtained is 190 MPa. From the microstructure study, it was found that there is a uniform distribution of silicon carbide throughout the work piece. Uniform distribution of silicon carbide indicates that this alloy has greater strength and all the mechanical properties will influence the percentage of silicon carbide. Finally, we conclude Al 5083 with 7% Sic and 2% fly ash given good results like hardness, impact and strength for the use of marine applications. The present research work leaves a wider scope for the future investigators to explore many other aspects of metal matrix nano composites. Other mechanical properties like wear test, etc. can also be investigated.
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