Determination of Mechanical and Corrosion Properties of Cobalt Reinforced Al-6061 Metal Matrix Composite

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Abstract - *Samples with different combinations of Aluminium and cobalt were produced to understand their mechanical and corrosion properties. In this present era composites are very important in manufacturing industries and knowing there behavior in different composition is very important for them to be used in appropriate requirements. The main objective of this paper is to study the mechanical and corrosion properties with different compositions by electrochemical impedence and SEM analysis. The fabrications of the composite were done using Al-6061 as metal matrix and Cobalt is used as reinforcement. The composite were produced by Stir casting method. The mechanical properties were checked by Hardness and Tensile test while the corrosion tests were done by Electrochemical impedence test and SEM analysis. The results confirmed that stir formed Al-6061 alloy with cobalt (1, 3, 5, 7 %) reinforced composites is clearly superior to base Al alloy 6061 in the comparison of ultimate tensile strength i.e. the tensile strength increases after addition of cobalt particles in the matrix.*

Key Words: **Composites; Al-6061; Co; Electrochemical impedence; SEM analysis.**

1. INTRODUCTION

Presently intensive materials research have provided a wealth of new scientific innovation to synthesize special materials with enhanced efficiency with low manufacturing cost to fulfill the long pending demands of the engineering sector. A new system of materials containing hard particulates embedded in a metal matrix have exhibited superior operating performance and improved mechanical behaviors. Among MMCs, aluminium alloy based composites had shown the significant development in the mechanical, thermal, electrical and mechanical properties to provide the demand of the industries. Al alloys are termed as versatile materials to be used for numerous engineering applications because of its better machining, joining and processability. In addition to this, low cost, increased strength to weight ratio and other environmental friendly characteristics of Al alloys make them a preferable material in engineering applications [1].

In order to achieve the optimum properties of the metal matrix composite, the distribution of the second phase in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. [3]. Rao and Das [4] prepared cast aluminium-alumina composites by incorporating alumina particles while stirring the molten alloy with an impeller. The particles were added in the molten metal during mixing and thus the process of stir casting emerged. In addition to this mixing of non-wetting particles into alloys was promoted by addition of alloying elements such as magnesium during the composite synthesis. The Al-6061 alloy is a highly corrosion resistant and is of excellent extricable in nature and exhibits reasonable strength and finds much more applications in the fields of construction, automotive and marine applications. The MMCs formed out of aluminum alloys are of wide concern due to their high strength, fracture hardiness, wear resistance and stiffness. In the recent days, Al matrix composites have been used for the production of automotive parts such as engine piston, cylinder liner, brake disc/drum etc. The case of escalation in particle reinforced metal matrix MMCs has been extensively researched in the long-ago; however no consent has been reached about its origin.

1.1. Composite Materials

A composite material is a material composed of two or more constituents. The constituents are combined at a microscopic level and are not soluble in each other. Generally, a composite material is collected of reinforcement (fibers, particles/ particulates, flakes, and/or fillers) embedded in a matrix (metals, polymers, ceramics, non- metals ect). The matrix holds the reinforcement to form the preferred shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. The most primitive man-made composite materials are straw and mud combined to form bricks for building construction [6].

1.2. Aluminium Metal Matrix Composite

Aluminum metal matrix composites (Al-MMCs or AMCs) are materials in which reinforcement, typically a metal-based material, is added with the purpose of improving the materials properties. In AMCs one of the constituent is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly metal such as cobalt. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction. AMC material systems offer superior combination of properties (profile of properties) in such a manner that today no existing monolithic material can rival. Driving force for the utilization of AMCs in these sectors include performance, economic and the environmental benefits. The key benefits of the AMCs in the transportation sector are lower fuel consumption, less noise and lower airborne emissions. AMCs can be viewed either as a replacement for existing materials, but with superior properties, or as a means of enabling radical changes in system or product design. Moreover, by utilizing near-net shape forming and selective-reinforcement techniques AMCs can offer economically viable solutions for wide variety of commercial applications. Recent success in commercial and military applications of AMCs is based on partly such innovative changes made in the component design. Processing route for AMCs are used stir casting process is described as it used in this study.

2. MATERIAL AND METHODS

2.1. Experimental Setup

For performing the experiment and testing of composites the following machines/equipments were used:

- Sieve Shaker
- Weighing Machine
- Matrix (Al 6061)
- Reinforcements (cobalt)
- Digital control Muffle Furnace
- Radial Drilling Machine
- Crucible (Graphite)
- Mould (Mild Steel)
- Stirrer (Graphite)
- Stainless steel rod (SS316) of diameter 12mm, Length 600mm
- Belt Grinder
- Laser Gun
- Hardness Testing Machine
- Universal Testing Machine
- Scanning Electron Microscope (SEM)
- CH Analyzer

2.2. Work Plan for Experiments

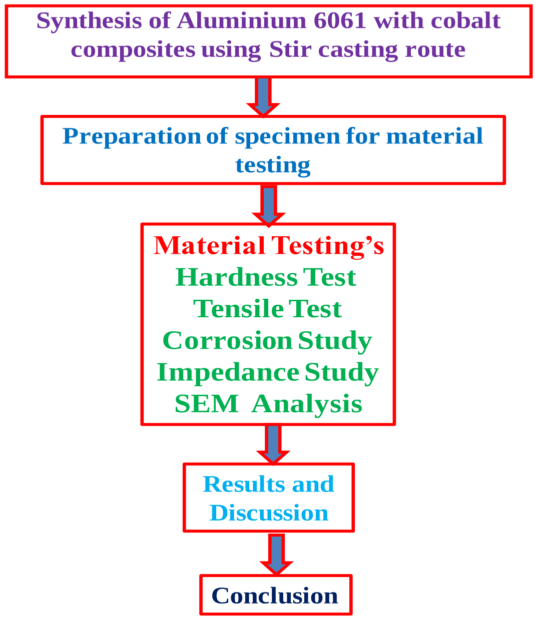

Fig-1: Flow chart of work plan for Experiments

2.3. Stir Casting

Stir casting set-up mainly consists a furnace and a stirring assembly as shown in Figure-2 and also the device used for stir casting sample preparations was proven in Figure-3.

In general, the solidification synthesis of metal matrix composites involves a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix.

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized.

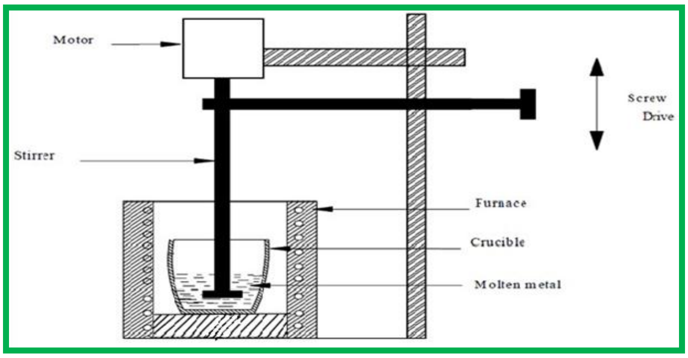

Fig-2: Stir casting method for preparation of MMCs

Fig-3: Muffle Furnace and Samples in Muffle furnace

2.4. SEM Analysis

A SEM could be a form of microscope that forms image of a sample by scanning it with a centered beam of electrons, its innumerable returns over optical magnifier. The SEM encompasses a large depth of field. The SEM uses a centered beam of high-energy electrons to come up with a spread of signals at the surface of solid specimens. It additionally produces pictures of high resolution. This suggests that energy fully spaced options may be inspected at a high magnification. SEM may be wont to withdraw into the surface morphology of materials. A schematic illustration of SEM is shown in Figure-4.

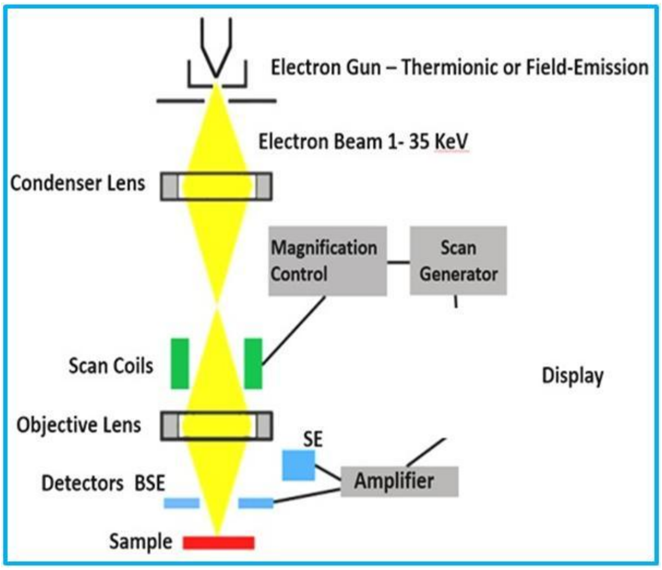

Fig-4: Schematic diagram of SEM

The magnifier creates a beam of electrons at the maximum by heating of an aluminiferous filament. The nonparticulate radiation completes a vertical way the segment of the magnifier. That knowledgeable magnetic fascination lenses. Light emission center and direct towards the sample. Ones it achieves the specimen. Discharges elective electrons from the material detectors gather the secondary electrons and convert them to a proof that is sent to a survey screen. Of these are disseminated underneath high vacuum. In region of the gift study we tend to be exploitation Hitachi table high TM-3000 scanning microscope instrument for morphology of the specimens and are appeared in region of the Figure-4. This was rendered in to a 2D depth distribution which will be considered and stored as a digital image, If the beam enters the sample perpendicular to the surface, the quantity of electrons "escapes" from most of the pattern and activated place was uniform.

2.5. Tensile Test

Tensile tests are performed for several reasons and the results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality and are often measured during development of new materials and processes, so that different materials and processes can be compared. Finally, tensile properties often are used to predict the behavior of a material under forms of loading other than uniaxial tension. The strength of a material may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. These measures of strength are used, with appropriate caution (in the form of safety factors), in engineering design

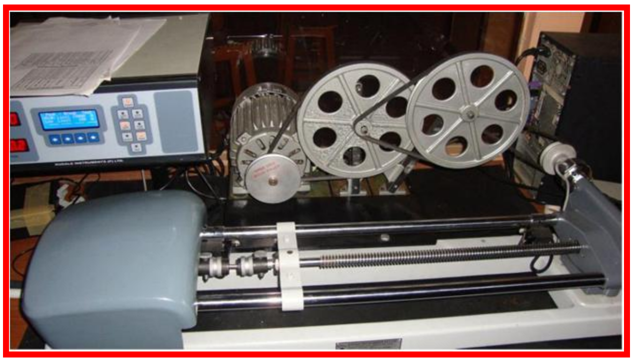

Fig-5: Equipment setup for tensile test

By following the ASTM standard tensile specimens with diameter of 6mm and gauge length of 30mm are prepared Ultimate tensile strength(UTS), often shortened to tensile strength (TS) ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking , which is when the specimens cross-section.

2.6. Hardness Test

2.6.1. Brinell Test

The Brinell hardness test method consists of indenting the test material with a hardened steel or carbide ball. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation.

Fig-6: Brinell hardness test equipment setup.

2.7. Corrosion measurement

The Corrosion kinetic parameter like i_{corr} derived from these curves is presented in Table-1. From the Table-1 it is clear that the corrosion current (i_{corr}), decreasing the value of Aluminium with 5% cobalt as compared to other samples.

Table-1: Electrochemical polarization parameter for different samples in 5% NaCl

Sample composition	i_{corr} (µA/cm²)
Pure Aluminium	2650
Aluminium with 1% Co	1280
Aluminium with 3% Co	950
Aluminium with 5% Co	640
Aluminium with 7% Co	990

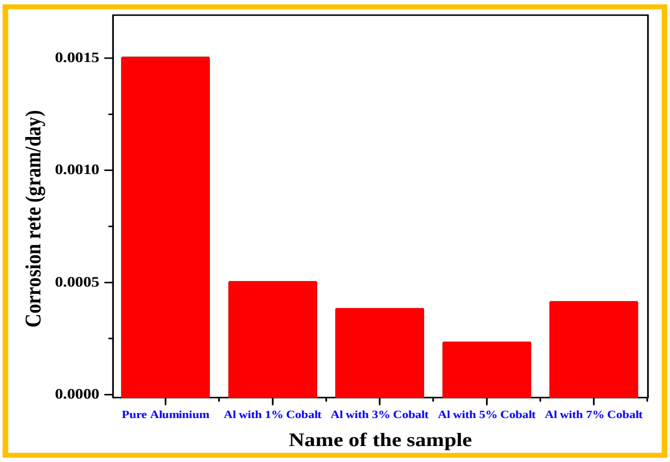

Fig-7: Comparing corrosion per day of different samples.

Figure-7.shows that corrosion per day which is decreased with increasing the content of cobalt, once it reaches 5%, the corrosion rate undergoes increases.

2.8. Electrochemical Impedance Spectroscopy (EIS)

The impedance spectra of Pure Al and Aluminium reinforced with 1%, 3%, 5% and 7% Cobalt show a depressed two-dimensional figure ensuring charge transfer resistance within the high-frequency region, and a slope associated with Warburg resistance within the low-frequency region [44-46], Figure-8 Presents the electrochemical impedance spectra for Pure Al and Aluminium reinforced with 1%, 3%, 5% and 7% Cobalt at steady state. The resistance of pure Aluminium is far smaller than that of Aluminium reinforced with 1%, 3%, 5% and 7% Cobalt, which means that the charge transfer resistance of pure Al precedes a lot simpler than other samples. This can be additionally related to the charge transfer resistance (Rct) and double layer capacitance (C) values obtained from fitting circuits for impedance spectra.

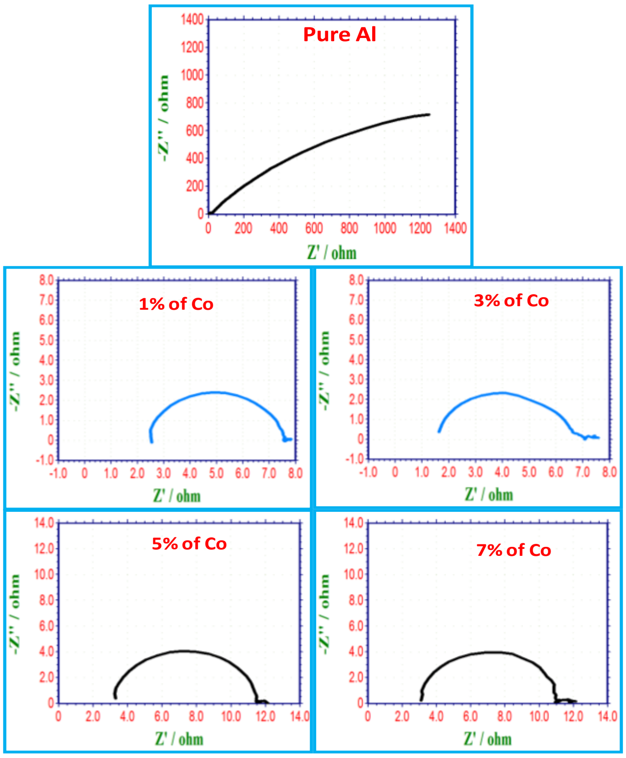

Fig-8: Nyquist plot of Pure Al and Aluminium reinforced with 1%, 3%, 5% and 7% Cobalt.

2.9. SEM Analysis

Figure-9 shows the corroded specimen from electrochemical corrosion testing specimen of developed composite. The SEM photographs of the corroded surfaces of the specimens containing pure aluminium and aluminium with 1, 3, 5 and 7 wt% cobalt. These images are taken by secondary electrons in order to study the fracture mechanisms of Al-Co composites. It can be seen through the naked eye that the cathodes experienced sporadic setting after the test. The SEM photographs of the corroded cathode surface of distinctive Al-Co composites shows that the anodes after polarization in NaCl electrolyte. It is also seen from Figure-9 that the pure

Aluminium underwent severe corrosion indicating the formation of large swollen blisters with shallow pits on the surface. It is clear from the results that the composite containing 5 wt% dispersoid is the most susceptible to corrosion followed by other. This means that the reinforcement of 5% Co with Al is more advanced corrosive resistance than other samples

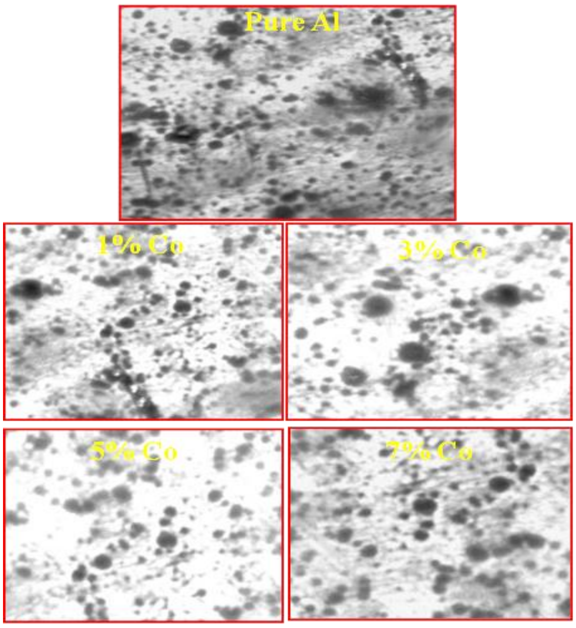

Fig-9: Surface Characterization by SEM for Pure Aluminium and Aluminium reinforced with 1%, 3%, 5% and 7% cobalt.

3. RESULTS AND DISCUSSIONS

3.1. Hardness Test

Table-2: Results of Hardness Tests

Sample composition	Hardness (BHN)
Pure Aluminium	55
Aluminium with 1% Co	59
Aluminium with 3% Co	64
Aluminium with 5% Co	70
Aluminium with 7% Co	95

3.2. Tensile test

Table-3: Results of tensile testing

Sample composition	Tensile Strength(N/mm^2)
Pure Aluminium	143
Aluminium with 1% Co	164
Aluminium with 3% Co	185
Aluminium with 5% Co	192
Aluminium with 7% Co	206

4. CONCLUTIONS

- Aluminium based metal matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of cobalt particulates.
- For synthesizing of composite by stir casting process, stirrer design and stirrer position, stirring speed and time, particles preheating temperature, particles incorporation rate etc. are the important process parameters.
- Prepared metal matrix composites are corroded per day which is decreased with increasing the content of cobalt, once it reaches 5%, the corrosion rate undergoes increases. It is clear that the corrosion current (i_{corr}), decreasing the value of Aluminium with 5% cobalt as compared to other samples.
- The results confirmed that stir formed Al alloy 6061 with cobalt (1, 3, 5, 7 %) reinforced composites is clearly superior to base Al alloy 6061 in the comparison of hardness i.e. the hardness increases after addition of cobalt particles in the matrix.
- The results confirmed that stir formed Al alloy 6061 with cobalt (1, 3, 5, 7 %) reinforced composites is clearly superior to base Al alloy 6061 in the comparison of ultimate tensile strength i.e. the tensile strength increases after addition of cobalt particles in the matrix.
- The SEM images revealed that cobalt particulates are fairly distributed in Aluminium alloy Matrix. It also revealed from SEM images that at some places voids has been occurred before wearing. From the optical micrographic grooves, ridges and some cracks have been appeared after wearing. The grooves and ridges running parallel to the sliding direction but cracks are propagated in arbitrary directions.

5. REFERENCES

[1] S. Ray, “Review Synthesis of Cast Metal Matrix Particulate Composites”, J. Mater Sci., 28 (1993) 5397-5423.

[2] N. Wang, Z. Wang and G.C. Weatherly, “Formation of Magnesium Aluminate (spinel) in Cast SiC Particulate-Reinforced Al (A356) Metal Matrix Composites”, Metall. Mater. Trans., 23 (1992) 1423-1431.

[3] J. Hashim, L. Looney and M.S.J. Hashmi, “Metal matrix composites: production by the stir casting method”, J. Mater. Proces. Technol.,92 (1999) 1-7.

[4] Rao R N, and Das S. “Effect of SiC content and sliding speed on the wear behaviour of aluminium matrix composites”. Mater. Dsgn.,32(2011) 1066-1071.

[5] P. R. Prasad, S. Ray, J. L, Gaindhar and M L Kappor, “Mechanical properties of Al-10% Cu alloy particulate composites”, Scr. Mater., 19(1985) 1019-1022.