Fabrication and Analysis of Aluminium based Metal Matrix Composites Reinforced with Aluminium Oxide

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Abstract-- **Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and Ceramics. Present work is foal2o3sed on the study of behavior of Aluminum Cast Alloy with aluminum oxide composite produced by the stir casting technique. Different % age of reinforcement is used. Hardness Test, corrosion and microstructure performed on the samples obtained by the stir casting process. Hardness attester is employed to evaluate the interfacial bonding between the particles and the matrix by indenting the hardness with the constant load and constant time**

Index Term-- Aluminium-Aluminium Oxide, Metal Matrix Composite, scanning electron microscopy(SEM), corrosion resistant, Hardness, Microstructure.

1. INTRODUCTION

This Chapter elucidates the origin and evolution of the composite materials. It also interprets the phases of development of the composite materials.

The origin of composite dates back to the pre-historic age when people started constructing houses for their livelihood. Early men constructed houses by combining straw and mud at some proportions. Straw and Mud used to blend together finely and serve as toughened product for construction. Wattle and daub are some of the initial and oldest man made composite materials available. They are generally soil, mud and clay combinations. Ancient people also tried to glue wood at different angle and stacking them so as to form a stiffened and strengthened composite material. This led to the invention of plywood. Even naturally, wood has certain similar properties of composite materials. When we take a look at the tree rings, it’s evident that, they have varying properties across their periphery. Papier Mache is also an old composite material developed by blending paper with glue. So, various materials which are blended with each other in order to obtain the desired product which satisfies all requirements lead to the stream of composite materials. As the days passed, the usage of composite materials increased drastically. During the time of world wars, plastic composite materials dawned its presence. Even before that, one of the most prominent thermosetting plastic material, Bakelite was invented which is used for manufacturing switches even now. In the Second World War, Europeans also deployed glass fibre reinforced plastics. In the late 70’s and early 80’s, scientists and researchers sought for harder materials with high tensile and impact strength but less in weight. This demand paved way for the exploration of composite materials. Composite materials were used in aerospace and automotive applications mainly due to their enhanced stiffness and reduced weight. The hinderances that researchers confront in the development of the composite materials are the adverse chemical reactions that ocal2o3r during the research program. After several developments, the composite materials are now employed for wide range of applications. Metal matrix composites of the two phases in which the reinforcing member (platelets, short fibres) is dispersed in a metallic alloy matrix. For commercial purposes, aluminium, magnesium and titanium alloys are used as metal matrices that are reinforced by ALUMINIUM OXIDEor aluminium oxide fibres. The reinforcement members are generally coated to prevent the chemical reaction with the matrix. Carbon fibres are generally coated with nickel or titanium boride. Zirconium carbide is also used as a protective coating and applied by chemical vapour deposition technique. Metal matrix composites are generally employed for applications involving wear resistance, thermal resistance and weight reduction since they possess high specific strength and specific modulus compared to non-reinforced alloys. The reinforcement members of the Metal Matrix Composites (MMC) should have good thermal stability, excellent mechanical and chemical compatibility. MMC finds its usage in automobile applications. Fibre reinforcements are made on the pistons of diesel engines and drive shaft of the transmission system in passenger cars. MMC’s possess appreciable temperature resistance, radiation resistance, electrical and thermal conductivities. In some cases, MMC’s are very complex to fabricate and involve high investment. Partial2o3late reinforcement can be explained with the "concrete" as a physical example. The cluster of coarse rock or gravel is impregnated in a matrix of cement. The cluster provides stiffness and strength while the cement supports as a binder to hold the structure together. The partial2o3lates, in reality are very small particles(less than 0.25 microns), chopped fibres (such as glass), platelets, hollow spheres or Carbon Nanotubes. They are mainly used for structural applications. As a non-conventional technique, electrically conductive reinforcement particles are embedded in a plastic matrix which adds some conductive property to the plastics. Partial2o3late reinforcement composites are generally manufactured by injection moulding machine. Metal Matrix Composites generally consists of light weight metal alloys of aluminium, magnesium or titanium alloys reinforced by ceramic partial2o3late member. Continuous reinforcement (long fibre or wire reinforcement) enhances the properties of metal matrix composites. Continuously and dis-continuously reinforced MMCs have different applications.

- Increased mechanical strength & impact strength
- Increased frictional resistance.
- Improved thermal stability.
- Excellent toughness & elasticity.
- Improved damping capabilities.
- Enhanced electrical properties.
- Effective fatigue strength & durability.
- Appreciable machinability.
- Wear & Tear resistance.
- Higher load resistance and less weight when compared to metals.
- Resistance to mechanical and thermal shocks.

In the MMCs, the matrix materials transfer the load to the reinforcement, binds or hold the reinforcement and protect the same from mechanical and thermal damage. The reinforcement is harder, stronger and stiffer than the matrix. The matrix in MMCs are generally Nickel, Aluminium or Aluminium oxide alloys and the reinforcement members are ALUMINIUM OXIDE, Aluminium oxide & Titanium Boride. Aluminium matrix composites are those that comprises of an aluminium alloy matrix reinforced by fiber or ceramic reinforcement members. The addition of reinforcement enhances the wear, creep, and fatigue resistance properties compared to traditional engineering materials. The AMCs are reinforced by either continuous or discontinuous fibers, whiskers or partial2o3lates, in volume fraction (percentage of mix) ranging from a few to 70%. The advantage of AMC is that different properities of AMCs can be obtained by varying the combinations of matrix, reinforcement members and blending techniques. Numerous researches have been carried out to improve the physical, mechanical, thermal, tribological properties of AMCs. The low density and high specific mechanical properties of Aluminium metal matrix Composites (AMC) makes these alloys one of the most interesting materials for light weight applications in automobile, aerospace streams. On an average, Aluminium MMCs possess similar wear resistance & strength as that of Cast Iron. The thermal conductivity of AMCs are almost thrice that that of cast iron. Discontinuously reinforced partial2o3late aluminium composites are less performant than the short fiber-reinforced composite materials. The mechanical properties of AMCs are depending on the nature, orientation and amount of fibres impregnated into the matrix. Boron carbide is one of hardest known element .Due to its high elastic modulus & fracture toughness, the addition of boron carbide (B_4C) in the aluminium matrix enhances the hardness properties of the AMCs. Depending upon the type of reinforcement material used, the AMCs are classified into the following types.

- ALUMINIUM OXIDEreinforced AMC
- Aluminium oxide reinforced AMC
- Boron carbide reinforced AMC
- Fibre reinforced AMC
- Zircon reinforced AMC
- Flyash reinforced AMC

From the earlier researches and experiments, it is evident that SiC reinforced AMCs have higher resistance that Al O MMC. The addition of fly ash reinforcement in aluminium matrix increases the wear resistance but detoriates the material's resistance to corrosion. AMCs are also classified based on the structure of reinforcement members. They are:

- Monofilament – reinforced AMCs
- Partial2o3late reinforced AMCs
- Laminate reinforced AMCs
- Short fiber reinforced AMCs
- Long fiber reinforced AMCs

Gnana et al. (2012) aluminium oxide is composed of tetra-hedron of carbon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. aluminium oxide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, aluminium oxide forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. aluminium oxide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. Chemical purity, resistance to chemical attack at temperature, and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. The electrical conduction of the material has lead to its use in resistance heating elements for electric furnaces, and as a key component in thermistors (temperature variable resistors) and in varistors (voltage variable resistors). Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high- performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing. Particle size range from 30-45 µm of the reinforcement (silicon carbide) is also one of the major factors influencing the mechanical and tribological behaviour of composites.

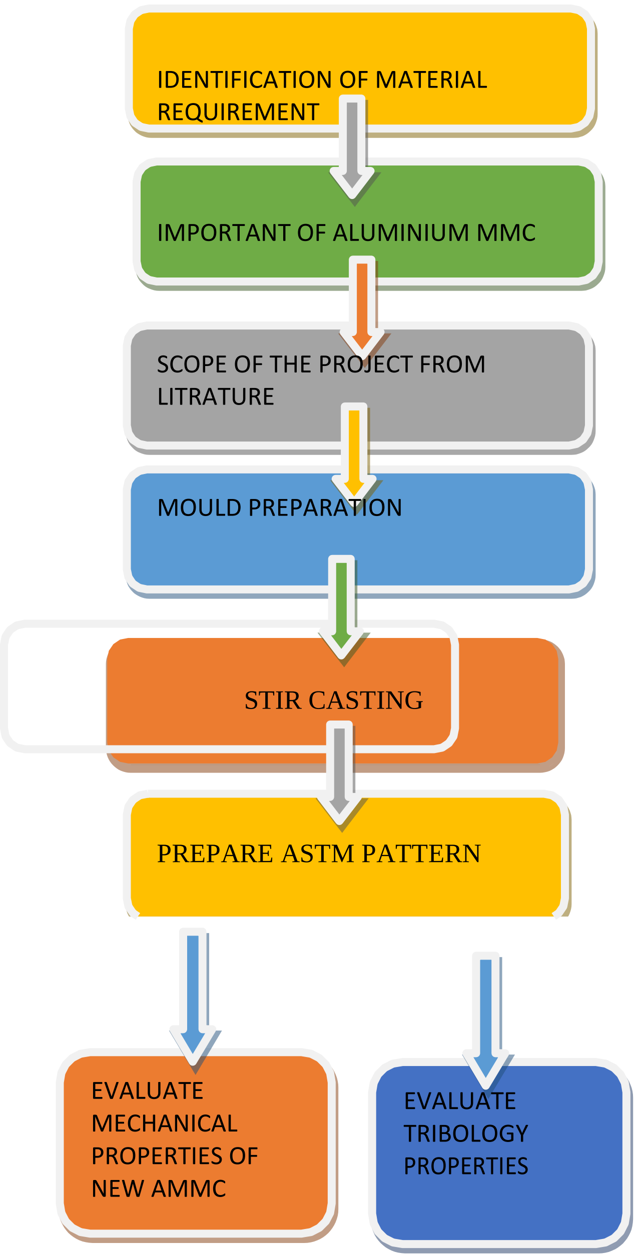
2. EXPERIMENTAL

The prime objective of this study is to maximize the mechanical and wear properties of Al2o3-reinforced Aluminium metal matrix composite.Prior to these studies numerous research activitieshave been transpired about the composite materials. (K.S.Susitharan et al 2013) studied the wear behaviour of Aluminium alloy (6063) reinforced by Zircon sand produced using stir casting technique.The study was exeal2o3ted by controlling various casting parameters.Different volume fractions of, 0,2%,4%,6%,8% weight % of al2o3-reinforced AMC.Aluminium alloy (6063)is taken for the study purpose since it is the material having good strength,light weight,corrosion resistant and resistance to thermal shocks. (Manjunath Melgi and GA Purohit 2013)conducted a study on the Al2o3partial2o3late reinforced LM6 alloy matrix. Composites fabricated by gravity die casting method.In this method, the volume fraction of Al2o3 is increased in adjacent stages.It is found that the increase in Al2o3 % increased the tensile strength and toughness of the composite material. Al2o3 is used as a reinforcement material

2 3

reinforced AMCs. The wear resistance of SiC reinforced aluminium MMCs is higher than Boron Carbide reinforced and high specific modulus. The study will be exeal2o3ted by using Aluminium Alloy 6063 as the matrix material and Al2o3is used as a reinforcement material. Various types of composite materials can be obtained by altering the design variables. There are numerous design variables which can be controlled and uncontrolled depending on the person who conducts the study. The uncontrolled variables in this study are reinforcement material (Al2o3) and the Aluminium alloy (6063) matrix material and the random dispersion of the partial2o3late Al2o3re in reinforcement in the metal matrix. The controlled variables are the scaling size of the Al2o3 particles which are in the order of Nanometer (30 – 45 µ) and Nano meter for reinforcing the matrix and volume fraction. Volume fraction is the mix percentage of Al2o3 reinforcement in the aluminium alloy matrix Volume fractions are increased as 2%, 4%, in the composite mixture. The Al2o3 reinforced AMC is fabricated by the Stir casting technique. The Equipment for the Stir casting technique includes a Coupling motor, Gear box, a mild stirrer for stirring and an oil fired furnace to melt the alloy. The scraps of aluminium were preheated at 450ºC for 3 to 4 hours and Al2o3 particles were also preheated at 1100ºC for 1 to 3 hours. The furnace temperature is maintained above the liquids to melt the alloy scrap completely and then cooled down below the liquids to keep the slurry in a semi solid state. Initially manual mixing is done when the alloy was in a semi solid state. After sufficient manual mixing, the composite slurry was reheated to a fully liquid state and then automatic mixing is carried out for about

10 minutes at a normal stirring rate of 600rpm. In the automatic mixing process, the furnace temperature was controlled within 660 ºC – 860 ºC.After the fabrication of the Al2o3 reinforced AMC, the mechanical properties and wear properties are tested by using various testing equipment. Microscope is used to examine the Material Morphology. In this study, the scaling size of the reinforcement composite material is varied in nano meter. The volume fraction is also increased in the order of 2% from 4%.



This chapter presents the major points of the variety of experimental procedures concerned to this study. In the first phase of the project, the properties and composition of Al6063 aluminium alloy and nano and nano sized Al2o3particles are disal2o3ssed. The second phase involves the various stages involved in manufacturing the composite specimens and nano structural studies of the composite specimens. The third phase disal2o3sses in detail about the procedures involved in conducting the experimental investigations to study the tensile strength, impact strength, hardness, corrosion, wear and frictional behaviour of different composites specimens. The Scanning Electron Microscope (SEM) examinations were carried out to learn the effect of nano and nano sized Al2o3particles on tensile fracture of the specimen. In this al2o3lture, aluminium alloy (Al6063) was used as base alloy. The production of the Metal Matrix Composite (MMC) used in the present study was carried out by liquid metallurgy technique (stir casting method).

Properties of aluminium (Al6063) alloy

The composition of Al2o3and magnesium were used with a motive to accomplish the higher wettability, high hardness, high elastic modulus and precipitation - hardening capability. Commercial Al alloy 6063 was procured from General foundries Ltd., Bangalore. The composite reinforced Al2o3 particles were purchased from Hindustan traders, Chennai. A collection of fine particles with substantial quantities of magnesium was used for the present investigation. The size of the Al2o3was measured using a sieve. As per the analysis, Al2o3particle size was in the range of 30-45 μm. The properties of Al2o3is presented in Table.

Tensile Strength	241 MPa
Impact Strength	9.81 Joules
Hardness	73 BHN
Density	2.7 g/cm^3
Elongation	2.3%

PROPERTIES OF NANO SIZED AL2O3

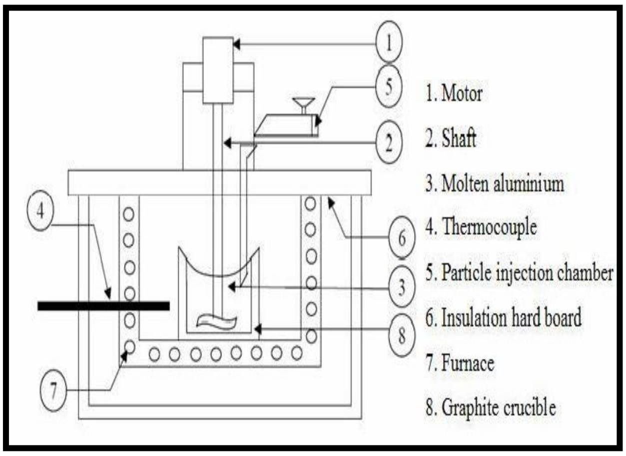
Flexural strength	550 MPa
hardness	9.6 mohs
Density	3.95 g/cm3
Melting point	2730ºC
Specific heat	750 J/kg/k

The Nano particles are produced from the nano particles by High Energy Ball Refinement Process. Gray Al2o3 nano powder of 40 μm obtained from Hindustan traders Chennai.India. The 40 μm Al2o3 powder was milled in high energy planetary ball mill (model Fritsch pulvert-5 high energy planetary ball mill) to produce nano powder of 500nm. About 25 grams of gray Al2o3powder (40μm) were placed in 80 ml tungsten carbide mixing jar. This powder is mixed together with 5 tungsten carbide milling balls of 10mm diameter and one tungsten carbide milling ball of 15mm diameter; giving a ball-to-powder weight ratio of 10:1. The jars were agitated using a high energy planetary ball mill at 20 rpm for 18 hours. There might some risk of adhesion of the balls to the jar walls. Hence, about 2ml of methanol is added as a Process Control Agent(PCA) to encounter this issue. High energy ball mill and the mixing jar loaded Al2o3 and tungsten carbide balls are shown in Fig.

Al2o3 nano powder

HIGH ENERGY BALL MILL AND THE MIXING JAR

Cleaned aluminium ingots were melted above the super heating temperature of about 800^{O}C in graphite crucibles under a layer of flux using an electrical resistance furnace as shown in Figure 3.1. The melt was d e g a s s e d at 800 °C using solid dry hexa-chloroethane (C_2C_{l6}) degasser. The preheated Al2o3partial2o3lates were then added to the molten metal and stirred continuously for about 15 minutes at an impeller speed of 600 rpm. Aluminium matrix and Al2o3particles were weighed using an electronic weighing



machine (Acal2o3racy 0.0001 g). During stirring, 1% by weight of magnesium was added to increase the wettability of Al2o3particles. The melt with reinforced particles was poured by gravity casting into the dried, cylindrical permanent metallic mouldsof size 14 mm diameter and 120 mm length. The melt was allowed to solidify in the moulds for about 3 minutes and cooled to room temperature. For the purpose of comparison base alloy samples were also cast under similar processing conditions. A samples of different weight percentages of the cast composite specimen is shown in Figure

SCHEMATIC SET UP OF STIR CASTING TECHNIQUE

Micro Vickers hardness tester

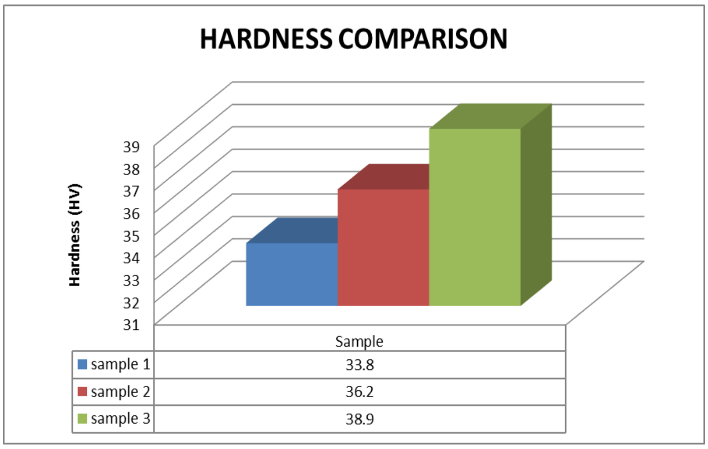
3. RESULTS AND DISCUSSION

HARDNESS TEST

Abrasive wear or erosion and thermal deformation are caused by reduced hardness of the material therefore it is important to identify the sample with greater hardness. The three test samples are subjected to Hardness test using Wilson Wolpert Micro hardness tester. Each sample was tested at four locations with the test specimen being subjected to a load of 0.5 kg for a dwell time of 10 seconds for each location. The specifications of the test are given below:

Machine Name : Micro Vickers Hardness Tester
Testing load range :10 grams to 1 Kg Load
Make : Wilson Wolpert – Germany
Vernier caliper least count : 0.01 mm
Available Hardness testing Scale : HV, HRA, HRC, 15N, 30N etc

Locations	H.V. @ 0.5 Kg load.(avg)
Sample A (1,2,3)	33.8
Sample B(1,2,3)	36.2
Sample C(1,2,3)	38.9



Effect of weight % of nano sized Al203 with Al 6603 on hardness

CORROSION TEST

Sample id: Hi-tensile aluminium –ceramic composite 3 Nos.

History: Three aluminium composite specimen was subjected to salt spray corrosion test as per ASTM B 117 - 14. The sample was loaded in the chamber for 24 hours and the details are given below.

Shows the component loaded inside the salt spray chamber in hangers.

Details of testing parameters:

1) Humidity: 98% as measured by hygrometer during the test.
2) Temperature of the test: 33 Degrees centigrade.(continuously indicated).
3) Pressure of Air for atomizing: 2 to 3 bar continuously by pressure regulator.
4) Composition of the salt solution: For 1 liter of solution. 5% of Sodium chloride:1% of Magnesium chloride: 94% of De-ionized water:
5) pH of the solution: Maintained at 7.2 by addition of buffer solution. Determined by calibrated by pH meter with standard buffer solution.
6) Measurement of pH: measured once in 8 hours.
7) Type of loading of castings: Tied with plastic wire and hung in the hangers.

Corrosion observation & meaurements: The tool after cleaning with organic solvents and degreasing solution washed with D.M. water dried and weighed. The initial weight before loading and the final weight after 24 hours exposure were measured and given below.

The casting surfaces were periodically observed and the images of the surfaces were captured after 24 hours.

Images after 24 hours exposure in salt spray chamber:

Given data: For sample 1

Initial weight of the tool: 6.102 Gms.

Final weight of the tool: 6.085 Gms.

Density: 2.740g/cm^3

Area: 176.71mm^2 Hrs: 24

To find:

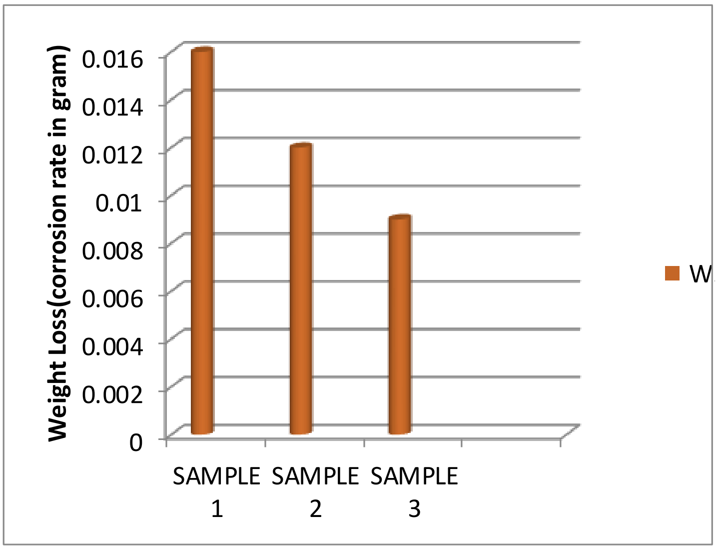
Weight loss: 0.017 mg

Corrosion loss mm per year: 0.00001

Corrosion loss mils per year: 0.0005

Same as

Various composition in tungsten carbide sample	Initial weight in gms	Final weight in gms	Weight loss in gms
Sample 1	6.102	6.085	0.017
Sample 2	6.106	6.120	0.014
Sample 3	6.116	6.128	0.012



EFFECT OF NANO SIZED AL2O3 PERCENTAGE ON CORROSION

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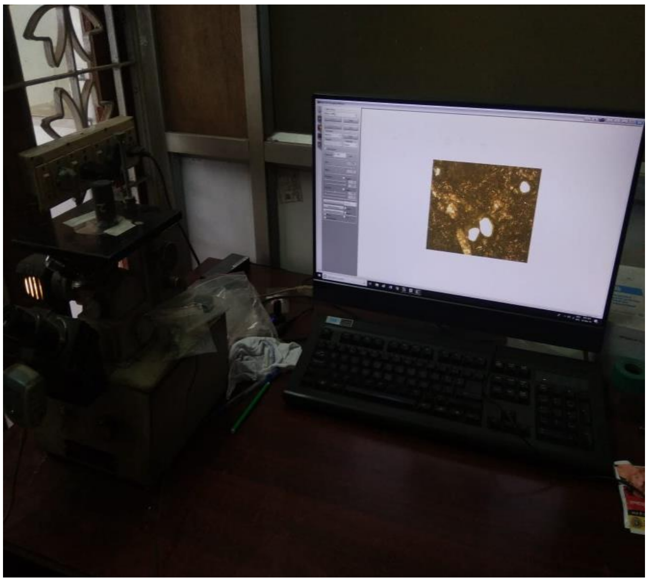
MICROSTRUCTURES:



Polished condition:

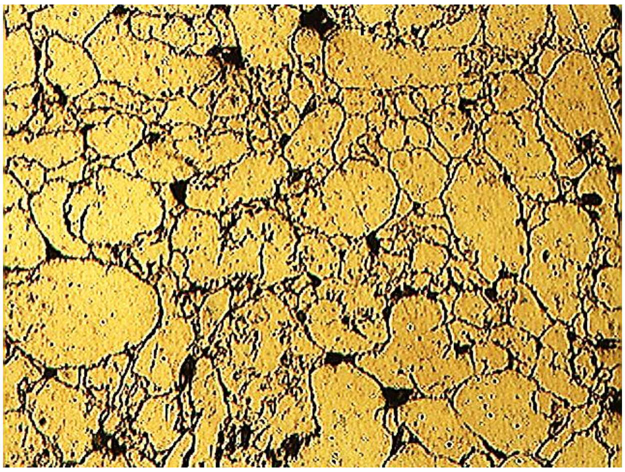


Photo-1 100X

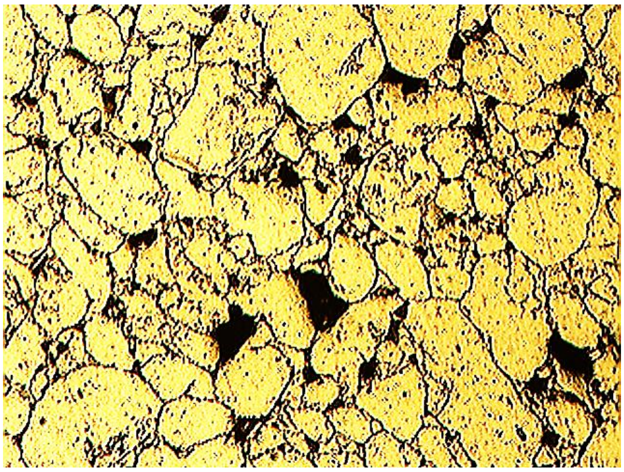


Photo-2 200X

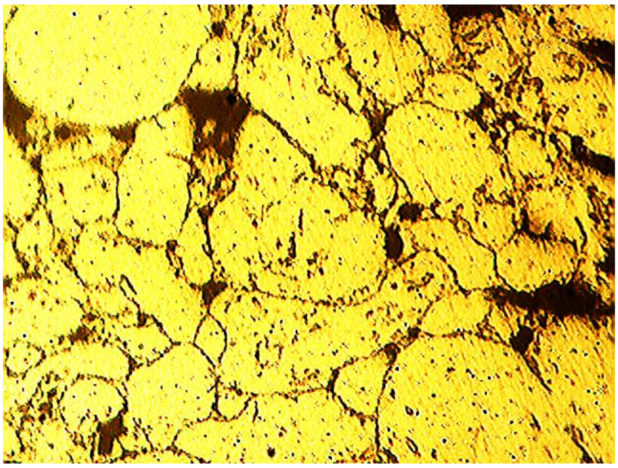


Photo-3 500X

Magnifications 100X & 200X Not etched.

Photo-1 & 2: Shows the "As polished" matrix of the powder metallurgical compacted and sintered sample microstructure. The polished matrix at 100X shows the grains of copper powder sintered grain boundaries and the pores that are formed in between the grains of the powder. The grain boundaries showed complete fusion and unfused free grains observed. Photo-3: Shows the same sample at higher magnification of 200X. The magnified image shows the clear fused grain boundaries of the aluminium grains. The grain size is measured as 40 to 50 microns. The pores content in the matrix is less than 8%

Etched condition:

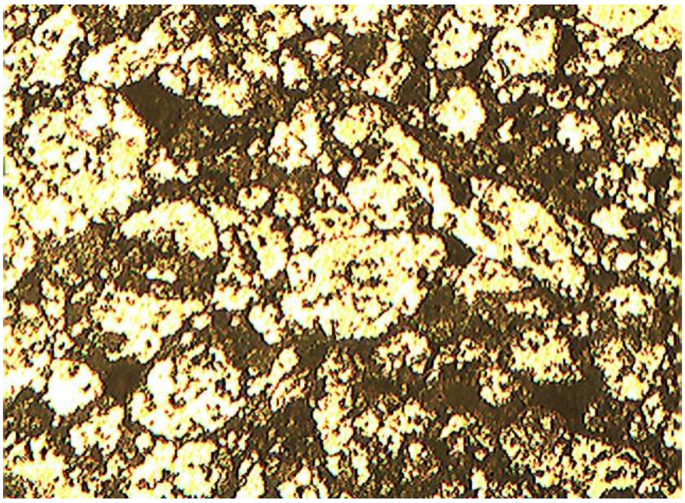


Photo-1

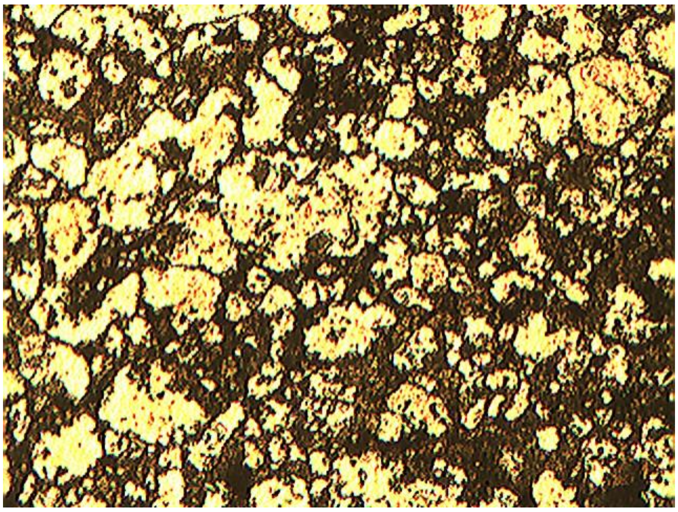


Photo-2

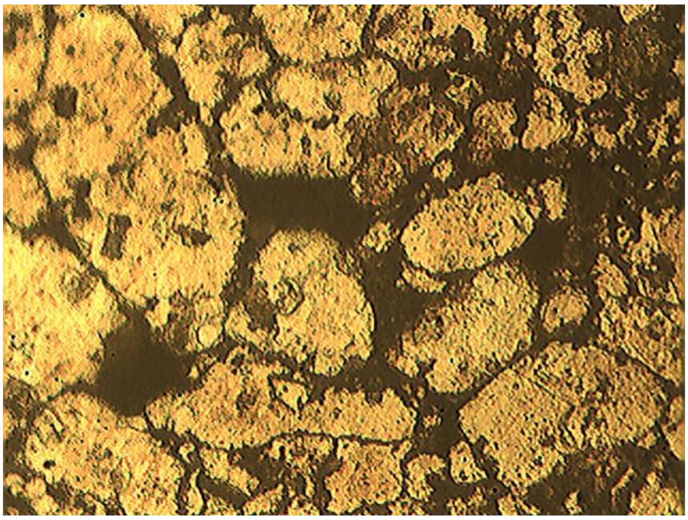


Photo-3

Magnifications: 100X, 200X, & 500X Etchant: Acidified Pot. Dichromate soln.

Photo-1: Shows the microstructure of the powder metallurgical compacted and sintered sample. The microstructure shows grains of alpha white colored grains in matrix of beta phase. The beta phase is dark colored at the grain boundaries. The dark spots are the pores present in the matrix. The grain shows complete fusion and the grain boundaries are filled with beta phase precipitation.
Photo-2: Shows the same sample at higher magnification and the higher magnification resolved the grain boundaries and the two phases of alpha and beta. The beta is the solid solution in which alphas grains are present.
Photo-3: Shows the further magnified microstructure of the same sample at 500X magnification. The higher magnification further resolved the microstructure as alpha and beta in aluminium solid solution. The grain boundaries voids are in dark colored spots.

4.CONCLUSION

Based on the outcome presented, the subsequent conclusions can be drawn:

- The paper examined the nanostructure and mechanical behavior by reinforcement of aluminium with different weight fraction of Al2o3. The specimens were prepared by Stir casting method with various volume fractions of Al2o3 as per the standard of as per ASTM B557M to find the mechanical behaviour. Micro Vickers hardness test was carried out to find out hardness and optical nanoscope was used to obtain the nanostructure at different locations of nano sizes Al2o3 specimens. From the test results, it was observed that the hardness of the composite is increased gradually from 2% to 4%. .Further the increase in the volume fraction of nano sized Al2o3 with aluminium increases the mechanical strength.
- The improvement of corrosion rate up to a maximum of 24 % and 28 % respectively. strength is gradually improved to increase in weight fraction and It lets out that the rising of weight fraction of Al2o3 in aluminium will give better results in improvement of tribology properties
- samples 3 have 4 % of Al2o3 resembles less the degree of particles distribution when compare with 2%.the dispersion of particles is moderate in 2 % samples. But

2 & 4 % samples gives distribution is more uniform than the other cases because of less segregation during solidification. It clearly shows that the increase of uniformity in particle distribution leads better mechanical behaviour. So there is no doubt in that the application of this material in auto and space industries will be scope for the future.

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