Synthesis and Testing of AA2014-Al_2O_3 (alpha) Nano-Composite

Muhammed Favas M K*, Thomas George Panicker, V. Umasankar
School of Mechanical and Building Sciences, VIT University Chennai – 600127
***Corresponding author: E-Mail: mailtofavas143@gmail.com**

ABSTRACT

Alpha Nano Alumina (Al_2O_3) reinforced Aluminium Matrix Composites give advanced mechanical & physical properties. They have voluminous applications in industrial, medical, defense, automobile, electronics, sports and many other fields. Various manufacturing techniques like stir casting, powder metallurgy, liquid infiltration, ultrasonic and compo casting, are used for the production of composites having Aluminium as its matrix phase. These composites reveal advanced material and mechanical properties like high tensile strength, low coefficient of thermal expansion, lower density, good wear resistance, high stiffness, high hardness and good corrosion resistance. Our paper retrospect the depiction of mechanical properties like tensile strength, hardness with production route for casting of Aluminium matrix- Al_2O_3 composite. A major challenging job in the manufacturing of this composite is the Al_2O_3 agglomeration with its progressing volume percentage. Magnesium powder of 0.5 weight% is added in pure form as wetting agent. Process parameters are optimized for the stir casting process of Aluminium composite. Tensile, hardness test AND microstructure study was performed to find the deviation from the Aluminium alloy.

KEY WORDS: Agglomeration, stir casting, Aluminium composite.

1. INTRODUCTION

The use of Aluminium alloys in automobile and aviation industries are remarkable because of its excellent mechanical properties and lower density. They have good resistance to corrosion and wear. Their thermal coefficient of expansion as lower compared to conventional other metals and their alloys. The purpose of the design of metal matrix composite materials is to blend the properties of metals and matrix materials. Studies are going on for the last many years for many demanding applications of Metal-matrix composites in aviation, defense and automobile industries, etc. Howsoever, MMCs have a tendency of easy fracture due to their small fracture toughness and ductility, hindering their far-flung usage. Metal Matrix Nano-composites (MMNCs) are those composites having nano-scale reinforcements engrafted in a metal with good ductility or its alloys.

MMNCs assure the purveyance of paramount properties but there is a problem in the circulating nano manufacturing methods. They are not that much cost-efficient and reliable for the production of complex MMNCs in huge volume. Conventional manufacturing methodologies for the production of nano-composites like sputtering, rapid solidification, high energy ball milling etc., is not apt for high volume production.

The main objective is to synthesize Aluminium 2014 alloy-Al_2O_3 composite which would find wide variety of applications in Aerospace and automotive industries and to attain uniform distribution of Al_2O_3 in AA2014 matrix using Stir Casting. Then testing of mechanical properties like Tensile strength, hardness etc., of AA-2014 composite. To study about the microstructure of the material used and the composite and to study about the deviation in mechanical properties of our new composite from the AA2014.

One major intriguing task in the production process is the non-uniform distribution of nano-range materials in metal matrix. This is because of their large surface to volume ratio and weak wettability in metal matrix which precede to agglomeration and clumping. Because of their high surface energy and small size, they easily get agglomerated. The disadvantages of poor dispersion are uniform dispersion of nano-scale materials in MMC is difficult and lower wettability of AA2014 matrix due to excess alumina. Stir casting with addition of magnesium less than 0.5% help to surmount the above obstacles if the methodology is proper in conformity with the optimized values and parameters.

2. MATERIALS AND METHODS

Metal Matrix Composite: As of indication from the name, in metal-matric composites, the matrix phase consists of a ductile metal. MMC's have effective usage high service temperature compared to their base metal; furthermore the reinforcement phase improves creep resistance, specific stiffness, thermal conductivity, specific strength, dimensional stability and abrasion resistance.

Stir Casting Methodology: It has a graphitic crucible which is having conical shape and it is employed in the synthesis of AMCs, due to the reason that it can bear elevated temperature which is greater than required temperature [680°C]. A temperature of 900°C is achieved in a time span of 45 minutes. In liquid stage, Aluminium is highly reactive to oxygen in the atmosphere. The action of stirring is initiated at a rate which is very slow. Here it is 30 rpm and it is elevated gradually in the range 300 to 600 rpm with the bolster of a speed controller. Al_2O_3 reinforcement is then added to the metal matrix which is now at a semisolid condition around 640°C. The time taken for dispersion

is about 5 minutes. This, slurry is then undergone reheating to a temperature which is beyond the melting point in order to confirm that slurry is liquid completely and it is then effused in to the mould.

Procedure: The stir casting was initiated by keeping the crucible into muffle. The temperature was adjusted to 300°C and is gradually increased to 700°C. Melting of aluminium can be made easy by keeping temperature inside the muffle to a higher value, which in turn reduces oxidation level and enhances wettability of nano-alumina (Al_2O_3) reinforcement in the aluminum alloy. Then required aluminium (97.5wt%) alloy mentioned was cleaned to remove from any foreign substances like dust, grease, etc. present in it and is poured into crucible, so that it starts melting due to high temperature inside muffle. Alpha-Alumina powder (Al_2O_3) used as reinforcement is properly weighed (10g) and 0.5 weight% (2.5g) of pure magnesium powder is used to increase wettability of alumina in aluminium matrix. The alumina reinforcements are preheated to a temperature of 450°C for 30minutes, so that moisture content present in it will be removed. After 2minutes the matrix will be in molten stage so that stirring process can be initiated. The speed of the stirrer was increased from 0 to 360rpm using a speed controller. The heater temperature was adjusted to 630°C. Temperature at this stage is below the melting point of aluminium alloy in such way that a semi-solid stage can be attained. Then reinforcements with magnesium powder was poured manually into the muffle while the stirrer is rotating in it.5 minutes will be taken for the dispersion of alumina particles in the aluminium matrix. So the stirrer keeps rotating for 5 minutes during the same semisolid stage. Then the molten mixture of reinforcements with aluminium alloy was heated to a temperature of 840°C to ensure that the same is in a fully liquid stage. Using the speed controller, speed of stirrer was decreased to zero. The metallic mould was placed beneath the muffle and the mould was preheated to a temperature to ensure that it enters and fills the mould in a molten stage. So the molten composite mix was poured into the same mould. Movement of the molten slurry should be continuous so as to prevent formation of gas inside the material. It was finally air-quenched to decrease the time for settlement of reinforcement particles in the base matrix. The experiment was also conducted without reinforcement. Then it was machined as per ASTM standards for tensile testing as shown in figure2. The stirrer used for the experiment was 310 grade SS and impeller type blade.

Table.1. Composition of Aluminium 2014-Alumina nano-composite

MATERIAL	WEIGHT %
AA2014	97.5
Al_2O_3	2
Magnesium	0.5

Process Parameters: There are many process parameters which are to be maintained carefully for the efficient casting process. The important process parameters are mentioned below.

- **Stirrer Speed**: One of the important process parameter in Stir Casting is stirring speed. Stirring is crucial in elevating wettability, which makes it an essential process parameter i.e. bonding among matrix and reinforcement. Stirring speed also has a direct effect on molten metal's flow pattern. Controlled turbulence flow is preferred over parallel flow as later will not give proper mixing of matrix and reinforcement. Inward to outward flow pattern is the excellent one among all. In our casting process we kept speed between 300 to 400rpm.
- **Stirring Temperature**: It is also relevant as that of stirring speed. 650^{o}C is the melting point of Aluminium. Stirring temperature is associated with the melting point. Viscosity of Al matrix influences the processing temperature. Particle distribution is also greatly affected by the viscosity change. When stirring time is increased, temperature of processing also gets increased and this results in decrease of viscosity. Chemical reaction between reinforcement and matrix is also affected by the stirring temperature. In our casting, operating temperature is maintained at 630^{o}C.This helps in keeping AA2014 in a semisolid form.
- **Reinforcement Preheating Temperature**: Preheating of the reinforcement is done at 450^{o}C for 30 minutes for removing the moisture content and extra gases trapped in it. Wettability is also increased by preheating.
- **Magnesium Addition**: Mg is added to improve wettability. We add **0.5wt%** of magnesium during the process. Uniformity in distribution is affected if Mg addition exceeds 1wt %. This is due to the viscosity increase of the slurry.
- **Stirring Time**: Stirring is essential for uniform particle distribution. Interface bond betwixt the matrix and reinforcement is assured due to stirring. Stirring time is also very important in casting. Here we provide a stirring time of **5 minutes**.
- **Preheated Temperature of Mould**: One of the main defect in casting is porosity. Preheating is mandatory to prevent porosity. Without this step, the entrapped gases will not be eliminated from mould. Mechanical behaviour if the composite is also greatly improved by preheating. . The preheated temperature of mould was 500°C.

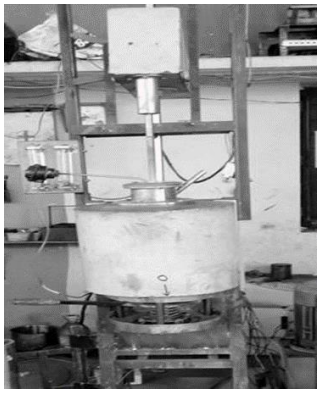

Figure.1. Stir Casting Machine

Figure.2. (a) Tensile specimen of aluminium -Alumina nano composite; (b) cast aluminium-alumina nano composite

3. RESULTS

Tensile Test: Tensile test was conducted to study about the improvement in tensile strength of the new composite from the base metal. The Young's Modulus value was also obtained from the tensile test. The tensile test specimen was created by machining the casted element on a lathe.

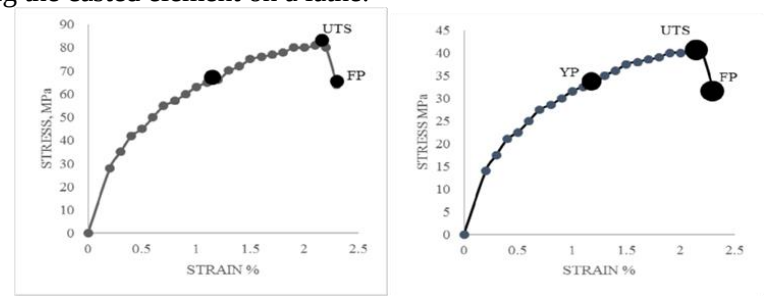

Figure.3. Stress-strain graph of composite and base metal

Figure.3, shows the stress-strain behaviour of AA2014-alumina nano composite and AA2014 alloy. From the above two graph, it is inferred that tensile strength and other properties were improved due to the alumina reinforcement in aluminium 2014 alloy.

Hardness Test: Hardness testing was also conducted. Brinell hardness method was used for finding hardness value.

For Aluminium-Alumina nano composite,

P=Load Applied =250Kgf

D=Diameter of ball indenter=5mm

d=Diameter of indentation =1.5mm Brinnel Hardness Number=138BHN

For aluminium2014 alloy,

d=Diameter of indentation=2mm

Brinnel Hardness Number =77BHN the hardness was increased by 79% from the aluminium 2014 alloy.

Table.2. Property comparison of aluminium 2014 alloy and Nano composite

Material Properties	AA2014 without Reinforcement	AA2014 with 2% Alpha Alumina Reinforcement
Young's modulus (GPa)	120	300
Yield strength (MPa)	32	65
Ultimate tensile strength (MPa)	40	82
Fracture strength (MPa)	32	64

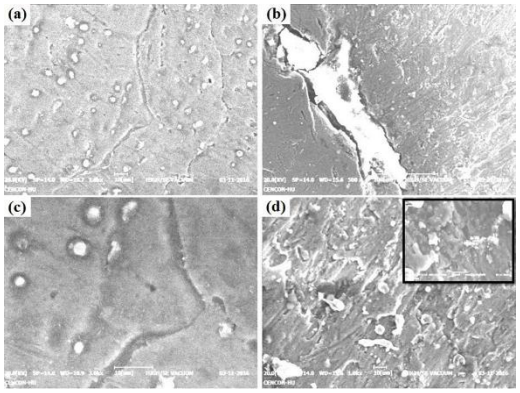

Figure.4. SEM images of aluminium-alumina nano composite

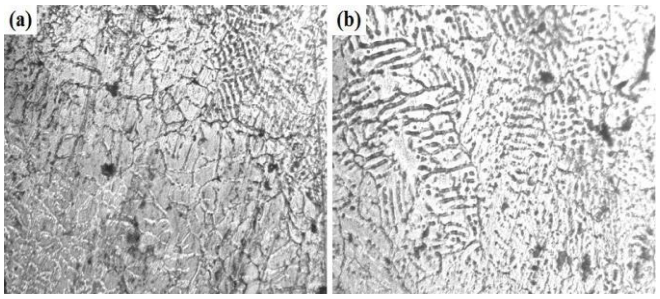

Figure.5.Optical micrograph of aluminium-alumina nano composite

Figure.4, shows the SEM images of aluminium-alumina nano composite under different magnifications. Figure.5, shows the Optical micrograph of the aluminium-alumina nano composite. From the morphological studies conducted based on SEM images and optical micrographs, it is observed that alumina particles are uniformly distributed in the matrix.

4. CONCLUSIONS

The AA2014- Al2O3 composites were produced through stir casting method. The mechanical properties of the samples were evaluated and compared with base metal properties. The following conclusions are made from the study.

- The tensile Strength of AA2014 with nano Alumina (Al_2O_3) reinforcement showed 205% increase from the Aluminium 2014 alloy.
- The Hardness was increased by 79% for Aluminium-Al_2O_3nano composite.
- The Young's modulus was increased by 250% for the Aluminium-Alumina nano composite.
- Yield Strength was increased by 200% from the Aluminium 2014 alloy.
- The microstructure study was conducted using SEM images and optical micrograph.

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