ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 9, Issue, 12, pp.63753-63757, December, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

STUDY OF ALUMINUM BASED FUNCTIONALLY GRADED MATERIALS WITH REINFORCED ALUMINA NANO-PARTICLES USING CENTRIFUGE CASTING TECHNIQE

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ARTICLE INFO

Article History:
Received 19th September, 2017
Received in revised form
23rd October, 2017
Accepted 05th November, 2017
Published online 31st December, 2017

Key words:
Functionally Graded Material,
Centrifuge Casting,
Alumina, Stirring Process.

ABSTRACT

Functionally graded materials play a majors important role in engineering and other applications. One of the fabrication methods for functionally graded materials (FGMs) is centrifuge casting technique. This study represents a new concept of refining and enhancing properties of cast, aluminum alloys by adding nano-particles using centrifuge technique. In this work, the effect of adding alumina (Al_2O_3) to Al as a base metal was investigated. Alumina nano-powders were stirred in the Al matrix with different weight percentage ratios from 1g to 3g and keeping constant stirring speed as 1500rpm at 850°C and constant stirring time of one minute thirty seconds. The cast microstructure exhibits change of grains from dendritic to spherical shape. The fracture surface showed the presence of nano-particles at the interdendritic space which is confirmed by EDAX analysis. The results of this study shows the mechanical properties of the casting were improved compared to that of the materials without nano-particles.

Citation: Sukruth M, Mallikarjun, Chethan, K. S. and Dr. Kiran Aithal, S. 2017. "Study of aluminum based functionally graded materials with reinforced alumina nano-particles using centrifuge casting techniqe", *International Journal of Current Research*, 09, (12), 63753-63757.

INTRODUCTION

Functionally Graded Materials (FGM) are the materials in which the microstructure or composition or both are locally varied so that a certain form of the local material properties is attained, thus it gives rise to different functions within the material. For example one side may have high mechanical strength and the other side may have high thermal resistant property, thus it will be characterized by different aspects in a single material. This multifunctional behavior of Functionally Graded Materials enables a wide scope in aerospace, automobile, electronics, biomedical applications etc. The components such as part of turbine, rocket nozzle, medical implant, tool inserts and optical devices need to meet functional performance requirements that vary with location within the component. Functionally Graded Materials provide best solutions under such situations (Birman Victor and Larry W Byrd, 2007). The concept of Functionally Graded Materials consists of two important features. The first feature is the ability to tailor the microstructure and chemical composition as per the desired function, while the second feature is the availability of the fabricating process which has good and controlled reproducibility of the desired properties. Centrifuge casting set-up is purely based on centrifuge technique, consisting of an arm, which is centrally mounted on 0.5 HP capacity of motor shaft. One end of arm is fixed by mould which is allowed to swing and other end is fixed by counter weight to balance the mould weight it shown in Figure 1. Permanent mould is used in centrifuge casting and rotated in its axis at the speed of 800rpm to produce cylindrical shape cast. This is an effective method to obtain functionally graded materials by considering several parameters (Madhusudhan *et al.*, 2013), such as rotational speed of arm, centrifugal force and pouring temperature of molten metal.

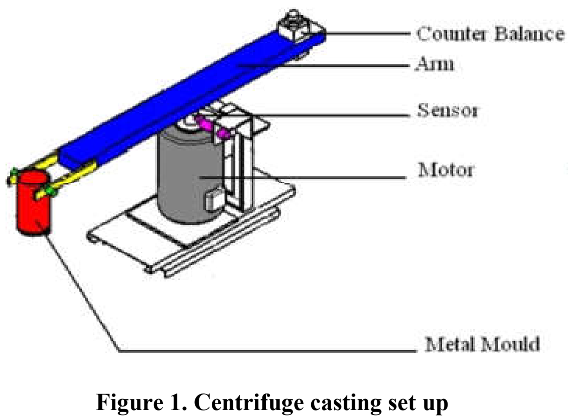

Figure 1. Centrifuge casting set up

Usually the position of reinforcement relied on 'G' during solidification. Where 'G' is a centrifugal force magnitude which is given by,

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Where,
G = Centrifugal force magnitude.
ω = Arm rotational speed in rad/sec,
r = Radius of arm in meter,
g = Acceleration due to gravity and

MATERIALS AND METHODS

A. Material Selection

In today's world, Aluminum alloy is used more in automotive industries since, they have high specific toughness, high specific modulus, good strength, good machinability and good wear properties. Aluminum is one of the lightest engineering metals and is the third most common element comprises 8% of the earth's crust. Low strength and hardness of aluminum, which limits its use in many engineering applications, could be increased through the addition of nano-particles. Aluminum matrix nano composites have a wider application area because of their low density and high specific stiffness (Adil Nazaruddin and Krishnakumar, 2015). The properties and quality of the nano-particle material is directly influenced by achieving a uniform distribution of reinforcing particles in the Al matrix, which play an important role in limiting the overall properties of the cast material. Introducing Al_2O_3 nanoparticles to the cast alloy in the semi-solid state with mechanical stirring has a beneficial effect on improving the strength–ductility relationship in these alloys. Al_2O_3 improves the base material in terms of mechanical strength and damping properties. This is attributed to the modification of the dendritic columnar structure into a smaller and equiaxed globular grain arrangement, resulting from semi-solid casting conditions. Moreover, the enhanced viscosity of the semi-solid processing would serve to improve the ceramic particle/melt wettability and entrap or capture the reinforcement material physically (El-Mahallawi *et al.*, 2010). Al_2O_3 nanoparticles possess appropriate properties that are compatible with the Al alloy relatively high thermal conductivity and thermal expansion coefficients that affect its role as nano dispersion for reinforcement in the Al alloy matrix.

Figure 2. Al_2O_3 Nano-particles Powder

Methodology

For different weight percentage of Al_2O_3, Al alloys are fabricated by centrifuge casting. Al_2O_3 is dispersed into the Al for reinforcement by using stirring method. In this technique several parameters plays important role such as constant temperature (850°C) and rotational speed of arm (200rpm). Initially, weigh 250g of Al which is considered as base metal using electrical weighing machine and placed it inside the furnace to melt. Once the molten metal is ready, incorporate Al_2O_3 (1g) by stirring at the speed of 1500rpm with a stirring tome of 90seconds. When the stirring is finished, the molten metal is ready to cast. Before pouring check whether the centrifuge set-up is ready for the operation, later pour molten metal into mould using a tongue. Instantly set the rotational speed to 200rpm and run for few minutes. Because of the rotation, centrifugal force is created towards the rotation axis, due to which the light weight Al_2O_3 particles gets deposited on top region of the cast. Finally allow the mould to cool and remove the cast specimen. Repeat the procedure for 2g and 3g of Al_2O_3. Figure 2 and Figure 4 shows material before casting and after casting.

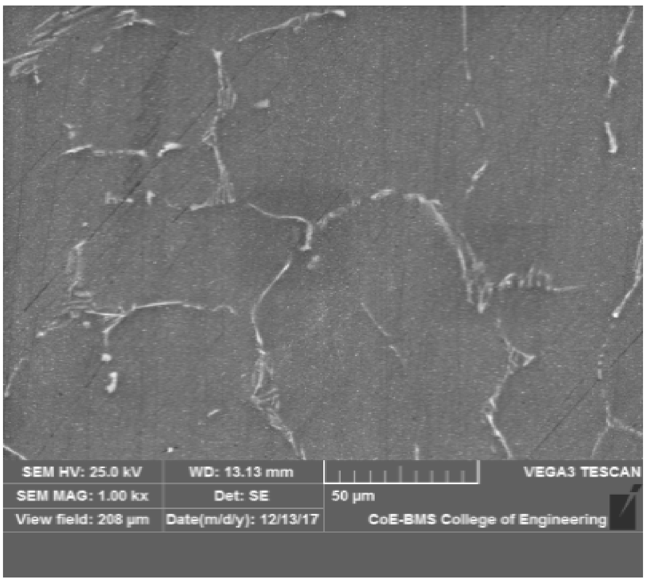
Figure 3. Materials before Casting Figure 4. Material after Casting

As the castings are obtained, standard specimens are made for testing purpose. Microstructure images are obtained by SEM (Scanning Electron Microscope), the hardness and tensile tests are also conducted. The respective results are observed and analyzed.

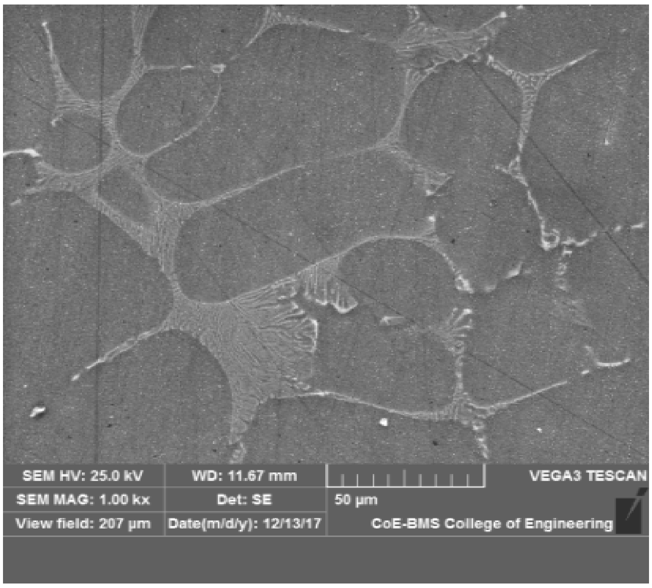
RESULTS AND DISCUSSION

A. SEM analysis

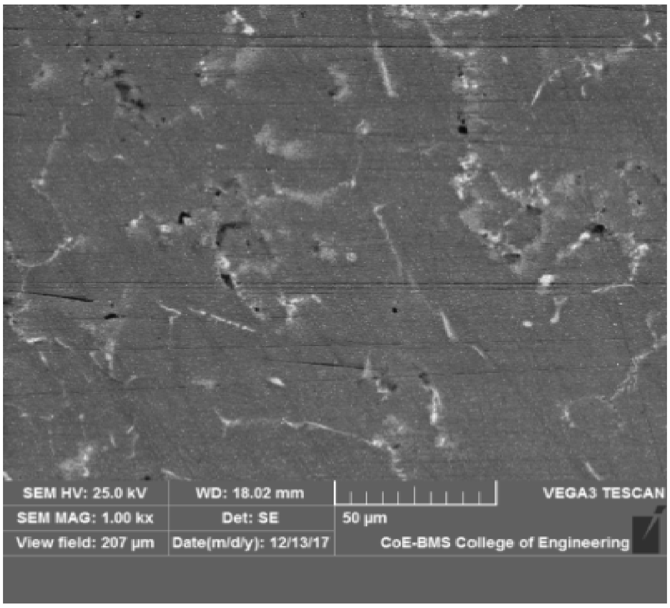
Above Figure 4 shows microstructure images of different regions of Al+1g Al_2O_3 material obtained from SEM testing under 850°C temperature. The figure shows clearly, Al_2O_3 percentage is increased from bottom to top region due to action of centrifugal force.



Bottom Region

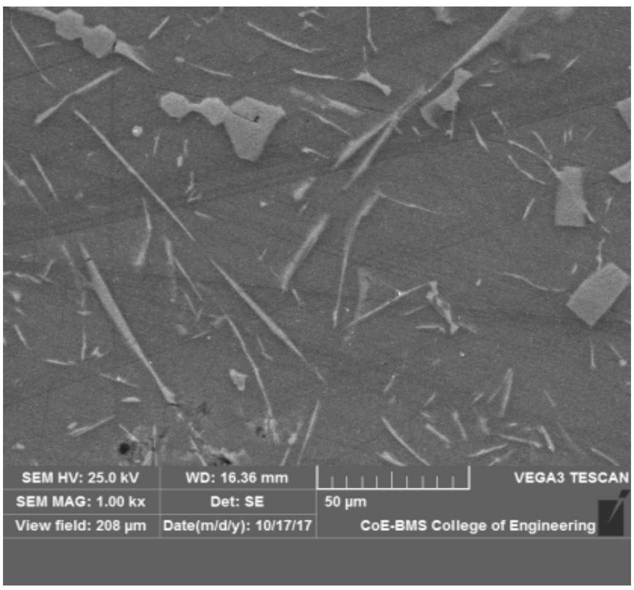


Middle Region



Top Region

Figure 4. Microstructure of Al+1g Al_2O_3 in Three Regions



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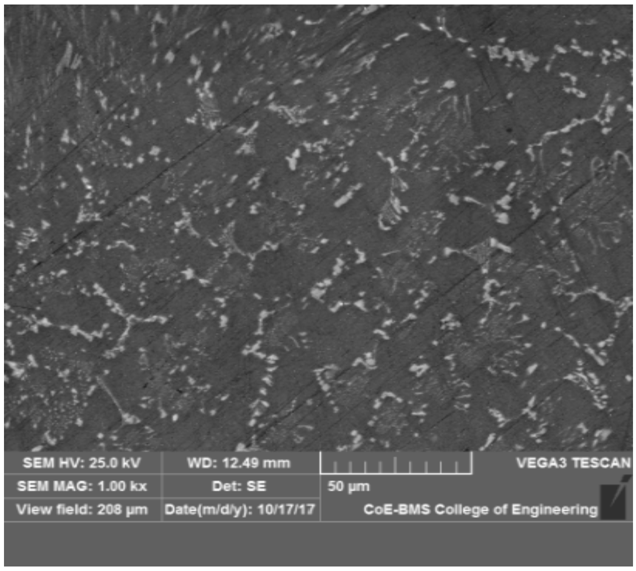
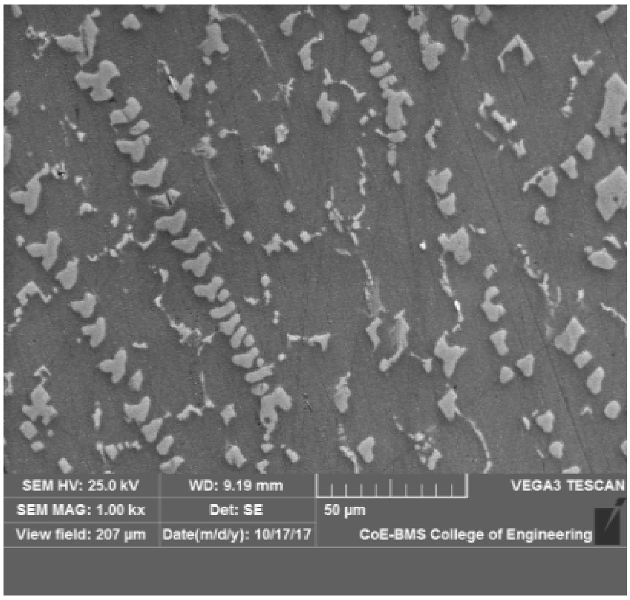


Middle Region



Top Region

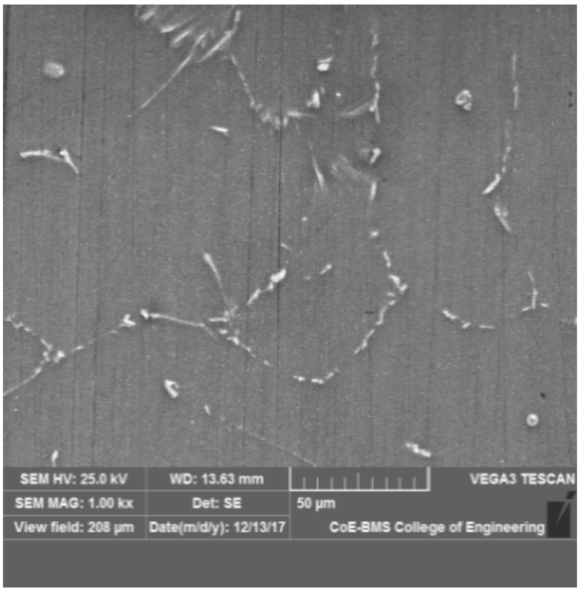
Figure 5. Microstructure of Al+2g Al_2O_3 in Three Regions

Above Figure 5 shows microstructure images of different regions of Al+2g Al_2O_3 material obtained from SEM testing for the same temperature. Figure shows clearly Al_2O_3 percentage is increased from bottom to top region due to action of centrifugal force. Difference between Figures 4 and 5 is deposition of Al_2O_3 is more on top region in Figure 5.

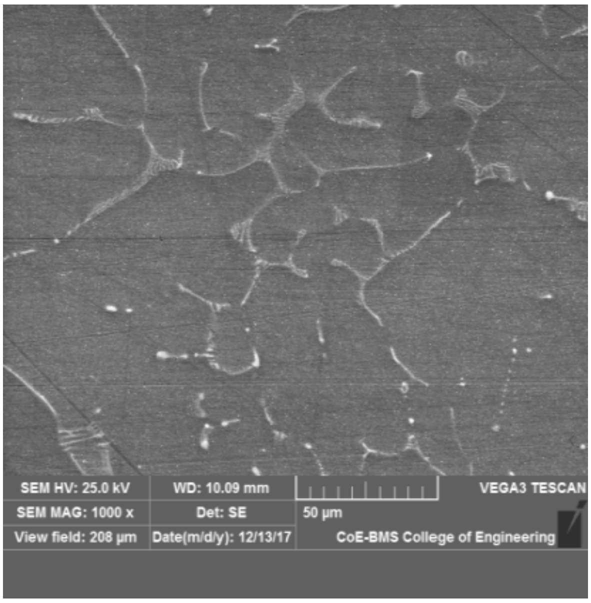
Below Figure 6 shows microstructure images of different regions of Al+3g Al_2O_3 material obtained from SEM testing for the same temperature. In figure it shows clearly, silicon percentage is increased from bottom to top region due to action of centrifugal force. Al_2O_3 is more on top region and it is distributed uniformly.

B. Tensile test

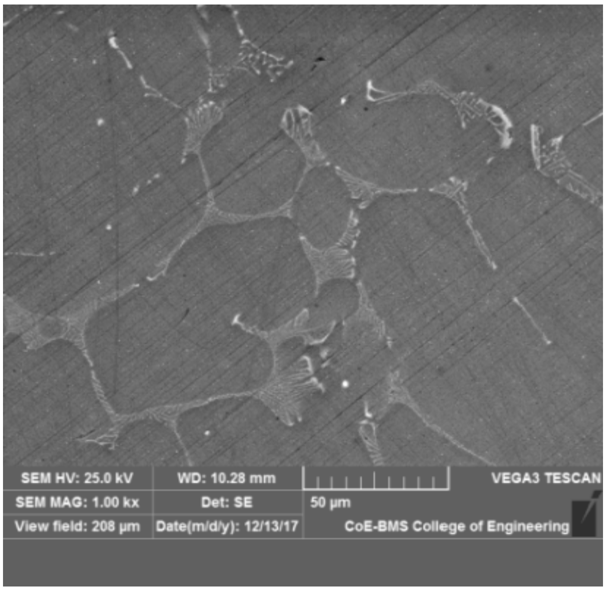
Electronic tensometer is used to carry the tensile test for different weight percentage of Al_2O_3 with Al. Test results show that there is improvement in UTS (Ultimate Tensile Strength) as the Al_2O_3 percentage increases in Aluminum matrix. Figure 7 shows the incremental of UTS from 1g Al_2O_3 to 3g Al_2O_3 with pure Al.



Bottom Region



Middle Region



Top Region

Figure 6. Microstructure of Al+3g Al_2O_3 in Three Regions

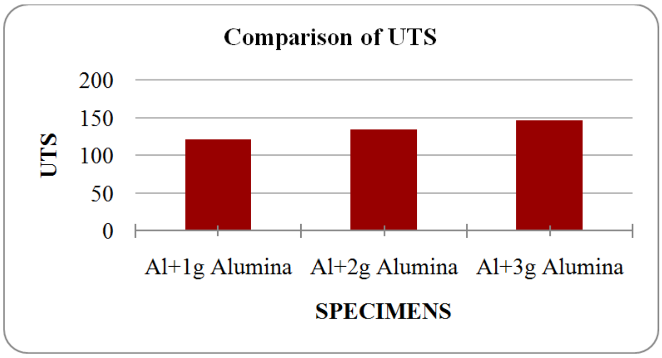


Figure 7. Comparisons of UTS of Al with Al_2O_3

C. Hardness test

Brinell Hardness Testing machine is used to test the hardness of the cast material for different regions. For different weight percentage of Al_2O_3, hardness increase from bottom to top region at constant temperature and stirring time. Comparison of the various weights is shown in the Figure 8 below. It shows the incremental of hardness number from bottom to top region. We observe that 2g and 3g Alumina with Al matrix is harder than 1g of Alumina.

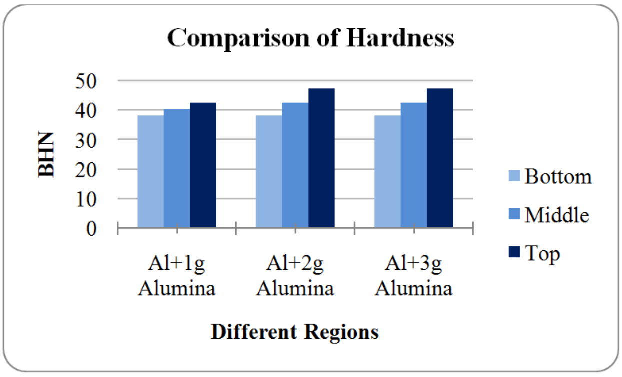


Figure 8. BHN Comparisons of Al with Al_2O_3

Conclusion

- The work includes detail study on centrifuge casting and features of Al and Al_2O_3 reinforced functionally graded materials.
- The properties of the obtained materials are compared which helps in the selection of required nano material for suitable application.
- With the help of mechanical stirring method, the dispersion of Al_2O_3 in pure Al was successful.
- The mechanical properties of Al alloys can be improved with the increasing weight percentage of Al_2O_3, and because of clustering of Al_2O_3 it strengthens the material.
- The SEM shows microstructure in three different regions, if the weight of Al_2O_3 is increased gradually, which shows improvisation in the grain boundaries.
- Hardness increases from bottom to top region as Al_2O_3 is deposited more in upper region due to action of centrifugal force. The hardness of Al with 1g Al_2O_3 is comparatively less than 2g and 3g of Al_2O_3 with pure Al.

- Therefore Al_2O_3 reinforced functionally graded materials provides better results than pure Al without Al_2O_3.

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