National Conference on Recent Advances in Mechanical Engineering and Materials
International Journal of Scientific Research in Mechanical and Materials Engineering
2021 IJSRMME | Volume 4, Issue 7 | ISSN : 2457-0435

Synthesis and Characterization of Aluminium and Silicon Carbide Based Functionally Graded Metal Matrix Composite

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ABSTRACT

Functionally Graded Metal matrix composites are one of the emerging materials in material science and engineering applications. The functionally graded composites have wide variety applications in different fields of engineering because the properties of the FGM materials can be tailored by changing the microstructure of the materials along any direction. Functionally graded composite materials can be manufactured by different methods such as Centrifugal casting, powder metallurgy, deposition methods etc. In this work aluminium based functionally graded composite is synthesized and analyzed for its mechanical characteristics. Silicon carbide particles are used as reinforcement in producing the functionally graded composite.

Keywords : Aluminium, Silicon Carbide Particles, Centrifugal Casting, Functionally Graded Materials

I. INTRODUCTION

Metals have played a very vital role in the advancement of mankind and it has been a continuous journey of scientific endeavors to explore their behavior and to expand the horizons of their applications. Metallic alloys are homogeneous mixtures of two or more materials, one of them is necessarily the base metal which is mixed with constituent materials to result enhancement of properties of the base metal.

At the same time, we are witnessing an exponential growth in development and applications of composite materials in last few decades. Contrary to alloys, composites are heterogeneous mixtures of a wide range of reinforcements to the base material (commonly known as matrix). Composites club the benefits of both the matrix and the reinforcements.

Metal Matrix Composites (MMCs) are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper etc.) and a dispersed medium of ceramics (oxides, carbides etc.) or metallic particles (lead, tungsten, molybdenum etc.). The influence of size of reinforcement also present a very interesting scope of study.

Functionally Graded materials (FGMs) are the recent developments in the field of material science, but naturally we are surrounded with FGMs. Bones, human skin and bamboo are some of the examples of naturally available functionally graded materials. Functionally Graded Materials are the materials in which composition changes gradually in a preferred direction or axis. This graduation makes the FGMs superior relative to homogeneous materials. The application of FGMs includes heat exchanger, flywheels, turbine blades and so on where abrupt change in material is not desired. The gradual variation in composition of FGM makes the material to have different properties depending on the variation of composition.

Aluminium is one of the most important materials that finds applications in every walk of life. Pure aluminium is soft, ductile, corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide higher strengths needed for structural applications. Aluminium is one of the lightest engineering metals, having a strength to weight ratio superior to that of steel.

Silicon carbide (SiC) also known as carborundum is a semiconductor and contains silicon and carbon. Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that are widely used in applications requiring high endurance, such as car brakes, clutches and ceramic plates in bulletproof vests. Silicon carbide is an excellent abrasive and is very widely used in grinding wheels and in other abrasive products. Silicon carbide is an important non-oxide ceramic which has diverse industrial applications. In fact, it has exclusive properties such as high hardness and strength, chemical and thermal stability, high melting point, oxidation resistance, high erosion resistance, etc. All of these qualities make SiC a perfect candidate for high power, high temperature electronic devices as well as in abrasion and cutting applications.

Centrifugal casting or roto casting is a casting technique that is typically used to cast thin-walled cylinders. It is typically used to cast materials such as metals, glass, and concrete. A high quality is attainable by control of metallurgy and crystal structure. Unlike most other casting techniques, centrifugal casting is chiefly used to manufacture rotationally symmetric stock materials in standard sizes for further machining, rather than shaped parts tailored to a particular end-use.

II. LITERATURE

Ebhota et al comprehensively presents throwing systems and their uses, practically reviewed metal framework composites (FGMMCs). Contemplations were given to practically reviewed aluminum lattice composites (FGAACs) creation forms. Fluid metal producing procedures of FGAACs creation, for example, penetration process, crush throwing, erosion throwing or compo casting, mix, and diffusive throwing were discussed [1]. The section gives essential ideas of the procedures and outline of their handling parameters, for example, form rotational speed; fortification particles size and volume; degassing technique; liquefying and pouring temperatures; weight; and stirrer. The examination noticed that practically evaluated materials (FGMs) are regularly utilized in car, flying machine, aeronautics, synthetic, therapeutic, designing, sustainable power source, atomic vitality, and optics hardware industry.

The real necessity for progression in engineering& innovation is to give high caliber of throwing item to all driving assembling enterprises. Al compound is one of the propelled materials that is utilized for high caliber of throwing item because of its high accessibility and minimal effort, yet unadulterated Al is delicate and fragile that is the reason it doesn't meet with the prerequisite of different assembling businesses. In any case, it very well may be fortified by including fortifying material and it is known as Al compound or metal network composite. MMC can be gotten by accepting metal as network and hard molecule/earthenware production as support. It has wide scope of utilization with air scope, car atomic, biotechnology, and gadgets ventures. Its property is additionally relying on assembling strategies, heat treatment and its procedure parameter. This study gives an outline on Al composites material and its manufacture strategy. This study additionally gives survey on the impact of fortification material on Al compound and the impact of procedure parameter of radiating castings [2].

[3] Rajesh et al, has discussed the grid amalgam, the fortification material, the volume and state of the support, the area of the support, and the creation technique would all be able to be fluctuated to accomplish required properties. Metal matrix composites (MMCs), for example, SiC molecule strengthened Al, are one of the generally known composites in light of their unrivaled properties, for example, high quality, hardness, firmness, wear and consumption.

[4] Karvanis et al have studied the use of Al-SiC Metal Matrix Composites is continually expanding in the most recent years because of their one of a kind properties, for example, light weight, better properties when compared to other metals, high explicit modulus,, high hardness and low thickness. Al-SiC composites of different carbide arrangements were created utilizing a diffusive centrifugal casting machine. Checking electron microscopy was utilized to think about the microstructure-property relationship. It was seen that the elastic and the compressive quality of the composites expanded as the extent of silicon carbide ended up higher in the composites. Additionally, with expanding extent of silicon carbide in the composite, the material ended up more earnestly and seemed to have littler qualities for all out dislodging and absolute vitality amid effect testing

In this research work, aluminum-silicon carbide (Al-SiC) metal matrix composites (MMCs) of various composition layers were set up under various compaction loads. Three distinct sorts Al-SiC composite examples having 10%, 20% and 30% volume divisions of silicon carbide were manufactured utilizing traditional powder metallurgy (PM) course. The examples of various structures were set up under various compaction loads 10 ton and 15 ton. The impact of volume division of SiC particulates and compaction load on the properties of Al/SiC composites were examined. The got outcomes demonstrate that thickness and hardness of the composites are incredibly impacted by volume portion of silicon carbide particulates. Results likewise demonstrate that thickness, hardness and microstructure of Al-SiC composites are fundamentally impacted relying upon the compaction load [5]. The expansion in the volume portion of SiC improves the thickness and hardness of the Al/SiC composites. For 15-ton compaction load, the composites show expanded thickness and hardness just as improved microstructure than the composites arranged under 10-ton compaction load. Moreover, optical micrographs uncover that SiC particulates are consistently disseminated in the Al network

III. METHEDOLOGY

Functionally graded aluminium silicon carbide metal matrix composite was produced using centrifugal casting machine at a constant mould rotation speed of 1000 rpm. In this experimental procedure aluminium 1100 is used as base metal or reinforcement. The properties of Al 1100 is given in the below Table 1. The silicon carbide used in this study is of 50μm of particle size.

TABLE 1: Properties of aluminium

Property	Value
Density	2700 kg/m3
Melting point	Around 660°C
Composition	Al (99.6%)
Corrosion Resistance	Excellent
Anodizing	Good
Formability	Good
Machinability	Good
Weldability	Good

In this study four specimens were created with 0, 5, 10 and 15% of SiC particle by volume with base metal aluminium 1100. To melt the metals an electric arc furnace was used. Initially the Crucible made up of graphite is preheated then the aluminium powders were poured into it. Then the Crucible is heated till the aluminum melts completely. To this molten metal reinforcement were added according to the table 2 to prepare four specimens.

TABLE 2: Composition of each specimen

Specimen	Aluminium (%) by volume	SiC (%) by volume	SiC by weight
Specimen 1	100	0	0 g
Specimen2	95	5	77.4 g
Specimen 3	90	10	154.81 g
Specimen 4	85	15	232.226 g

The furnace used is electric resistance furnace with maximum temperature of 1400°C. Where heating coils are made up of Silicon Carbide, and platinum sensors are used. The furnace is checked up to the final temperature.

After the final temperature of the furnace is been checked the crucible is been placed into the furnace and it is preheated up to 300°C. The crucible is made up of Graphite which can resist up to 4000°C.

After preheating of the crucible required amount of Aluminium is added into the crucible and the furnace is closed and temperature is set to 1050 C and the furnace is left until Aluminium is melted to a molten state.

When Aluminium reaches its molten state Silicon Carbide is added (Figure 1) according to the ratio required and it is stirred until it is well mixed with Al.

Fig 1: Addition of Silicon Carbide

After the estimated duration, the furnace lid is opened. Using stirrer Aluminium and Silicon Carbide are uniformly stirred, the crucible is taken out from the furnace. The centrifugal casting machine is cleaned thoroughly for clearance of chips and dust. The centrifugal casting machine (Figure 2) is turned on and set at constant speed of 1000 rpm.

The pouring basin is adjusted accordingly to pour the molten metal (Figure 3). The mixture of aluminium and SiC particles in molten stage from the furnace is removed using tongs after mixing. And the same mixture is poured into the rotating die placed inside the casting machine using pouring basin.

Fig 2: Centrifugal Casting Machine

After the mould gets solidified, the centrifugal casting die cap is removed, and by using tong the cast is removed from the die and placed on a sand container. The same procedure is followed for all four specimens.

Fig 3: Pouring basin

IV. TESTING

A. Hardness test

Brinell hardness test was performed to measure the hardness of the specimen. Three regions were identified in the specimen. The hardness was measured at three different regions of the specimen, one at outer region, middle region and inner region. For all the four specimens the BHN values are compared at different regions. In Brinell hardness test ball type of indentation was used with the applied load of 250kg. The diameter of indentation was 10mm.

Test Procedure for Brinell hardness

1. Prepare the Sample to be testing by smooth Polishing Surface.
2. Place the sample on the Instrument.
3. Apply the load of 250 kg with 10mm ball for 10Sec.
4. Remove the Sample and measure the indentation using microscope.
5. Calculate and report for same.

B. Tensile test

The specimen used for tensile test was of ASTME E8M standard (Figure 4). The tensile test conducted on the specimen from an Universal tessting Machine of capacity 0 to 20 tons.

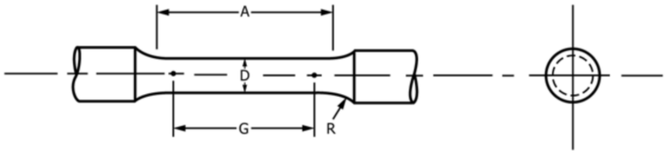

Fig 4: Tensile test dimensions

Test Procedure for Tensile Testing

1. Prepare the Test Specimen as specified in Indian Standard (IS 1608/ASTM E8M)
2. After Specimen receipt check for the dimensions is as per the specified standard, if found ok process for test
3. Punch for Gauge length mark on the sample and measure the Initial Gauge Length.
4. Hold the Specimen to the fixtures and gradually apply the Load
5. Stops the test when the tensile Specimen Breaks
6. Arrange the Specimen to check for the Final Gauge Length
7. Calculate for Tensile, yield strength and elongation and report for same with Graph

C. Microstructure

Optical microscope of 100x and 400x magnification was used to study the microstructure of the produced samples. The outer region is studied under 100x magnification and middle region was observed under 400x magnification. The same standard procedures are used for studying microstructure of all the specimens.

Test Procedure for Microstructure observation

1. Select the region and cut the sample.
2. Grind the specimen using successive fine emery papers and metallographic polish
3. Etch with suitable etching agent like 0.5% HF
4. Observe under metallurgical microscope at different magnification.

V. RESULTS AND DISCUSIONS

A. Hardness test results

In the hardness test (middle) we have seen that, there is decrease in the hardness for trial 2 and 3 and again there is slight increase in the hardness. In the hardness test inner the hardness reduced for the trial 2 further hardness has slight increase in the hardness. Ignoring any discrepancies during casting, we can consider the trial 4 to be the most desirable material due to high yield strength. But it is also possible that the casting may have been inconsistent and therefore there are so many variations in hardness.

TABLE 3: Hardness each specimen

	Hardness		
	Outer	Middle	Inner
	BHN	BHN	BHN
PURE ALUMINUM	21.75	21.75	21.75
5% SIC	20.65	19.60	18.60
10% SIC	20.65	19.60	19.60
15% SIC	19.60	20.65	19.60

B. Tensile test results

According to ASTME E8 standard the specimens were created and tensile tests were conducted. The results of the tensile test reviles that that yield strength has increased for the trial 4 i.e., 15% of SiC in 85% of aluminium. Also, it decreases suddenly at the trial 3 i.e., 10% of SiC in 90% aluminium and, it gradually increases since then.

TABLE 4: Yield strength of each specimen

	Yield Strength
PURE ALUMINUM	58.546 MPa
5% SIC	58.578 MPa
10% SIC	56.77 MPa
15% SIC	65.71 MPa

C. Microstructure results

For all the specimens the microstructure was studied at two different regions one at the outer region and at the middle region and the results were compared. Following images gives the information about the microstructural results.

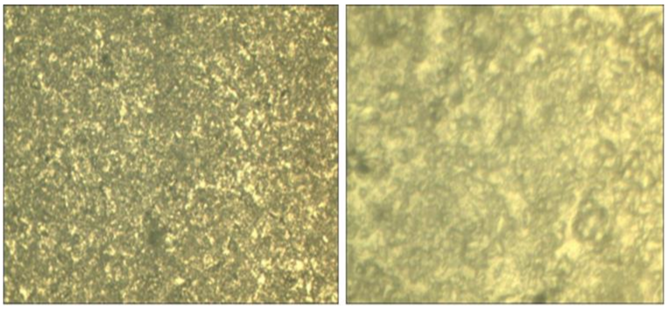

Fig 5: Microstructure of 5% SiC reinforced aluminium composite at outer and middle region at 100x and 400x composition respectively

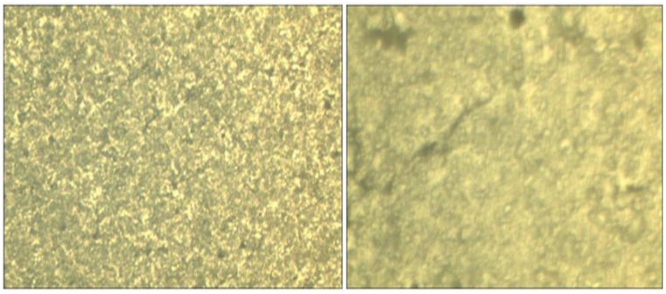

Fig 6: Microstructure of 10% SiC reinforced aluminium composite at outer and middle region at 100x and 400x composition respectively

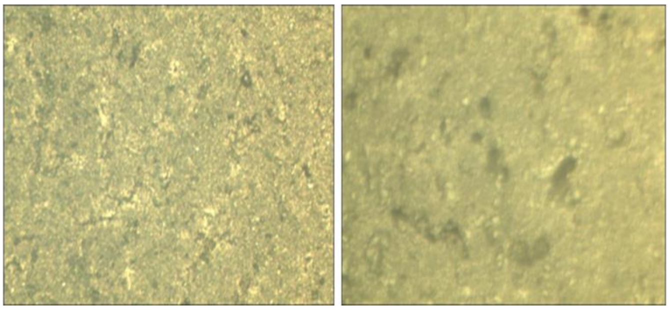

Fig 7: Microstructure of 15% SiC reinforced aluminium composite at outer and middle region at 100x and 400x composition respectively

From all the microstructural images it was found that the amount of SiC particle are found more at the outer region than in middle region. This is because the SiC particles have higher density which makes them to move away from the center at the high rotational speed due to centrifugal force.

VI. CONCLUSION

This work represents the study of Silicon Carbide reinforced aluminium alloy in even ratios and how it performs under various tests. After the test results and discussion, we can conclude that for required properties, the above-mentioned ratios can be used. However, the degree of improvement of hybrid reinforcements in aluminium alloys still need to be studied.

As the percentage of the Silicon Carbide increases till 10%, the yield strength of the material will decrease and then it increases for the 15% of Silicon Carbide. Since solidification is also main parameter for the required properties, air cooling was done after the casting process.

The optical microscope revealed a reasonably non-uniform distribution of Silicon Carbide particles in the matrix. Optical microscope confirmed the validation of manufactured composites. The microstructure of specimens (5%, 10%, 15%) of magnification 100X at the outer region and 400X at the middle region of the casted specimen is obtained.

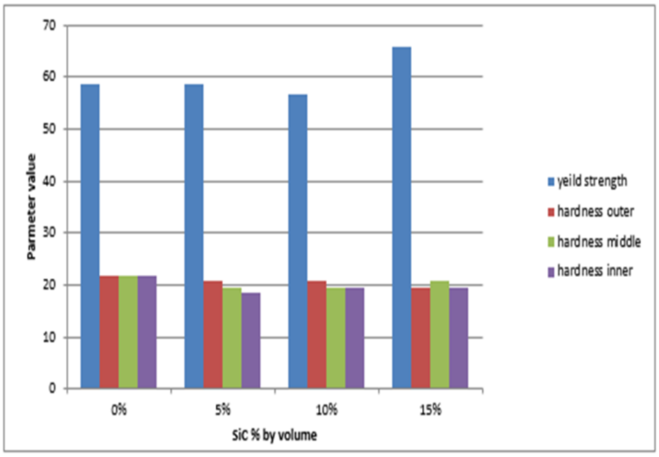

Fig 8: Bar graph showing tensile and hardness results

Functionally graded metal matrix composites made of commercially pure aluminium reinforced with SiC has been fabricated successfully through horizontal centrifugal casting technique. Different weight fractions (0%, 5%, 10%, and 15%) of SiC have been investigated. Same rotational speeds of 1000 rpm is used. Investigation of microstructure reveals that the concentrations of the SiC particles in the outer zone of the cast tubes reach its maximum value followed by a gradual decrease in the direction of inner diameter. In case of large particle sizes and higher rotational speeds, all fabricated tubes revealed high concentration of reinforcing particles in the outer zone due to higher centrifugal force and particle mass.

VII. SCOPE FOR FUTURE STUDY

- The results can be studied by varying the percentage of the SiC in small range.
- By changing the rpm of the Centrifugal Casting Machine, the characteristics can be studied.
- Preheating the mould before pouring the motel metal into it will give better results.
- By varying the grain size of SiC particles.
- Still better processing techniques needs to be developed for better results.

VIII. REFERENCES

[1]. Williams S. Ebhota, Tien-Chien Jen, Casting and Applications of Functionally Graded Metal Matrix Composites. Advanced Casting Technologies. doi:10.5772/intechopen.71225

[2]. Sanjay Kumar Jha and Shatrudhan Pandey A Review on Aluminium Metal Matrix Composite Fabricated through Centrifugal Casting International Conference on Evolutions in Manufacturing: Technologies and Business Strategies for Global Competitiveness 2016

[3]. Rajesh Agnihotri, Santosh Daga, Mechanical Properties of Al-SiC Metal Matrix Composites

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[4]. K Karvanis, D Fasnakis, A Maropoulos, S Papanikolaou Production and mechanical properties of Al-SiC metal matrix composites IOP conference series: Material Science and Engineering, Volume 161, 20th Innovative Manufacturing Engineering and Energy Conference (IMANEE 2016)

[5]. D M Nuruzzaman F F B Kamaruzaman, Processing and mechanical properties of aluminium-silicon carbide metal matrix composites IOP conference series: Material Science and Engineering, Volume 114 2nd International Manufacturing Engineering Conference and 3rd Asia-Pacific Conference on Manufacturing Systems 2015.

[6]. Gupta, Ankit,Talha, Mohammad, Recent development in modeling and analysis of functionally graded materials and structures, Progress in Aerospace Sciences, Volume 79, p. 1-14 November 2015

[7]. Miyamoto, Y, Kaysser, W. A, Rabin, B. H., Kawasaki, Ford, R. G. Functionally Graded Materials Design, Processing and Applications Functionally Graded Materials. Materials Technology Series. 1999 doi:10.1007/978-1-4615-5301-4

[8]. R. Kumar, D.C.N. Chandrappa, Synthesis and characterization of Al-SiC functionally graded material composites using powder metallurgy techniques, Int. J. Innov. Res. Sci., Eng. Technol. 3

[9]. F. Erdemir, A. Canakci, T. Varol, Microstructural characterization and mechanical properties of functionally graded Al2024/SiC composites prepared by powder metallurgy techniques, Trans. Nonferrous Metals 25 (2015) 3569–3577.

[10]. P. Muller, P. Mognol, J.-Y. Hascoet, Modeling and control of a direct laser powder deposition process for functionally graded materials (FGM) parts manufacturing, J. Mater. Process. Technol. 213 (2013) 685–692.