Study on Mechanical Properties of Al 2017 HMMC's

Hari Kiran M P
Research scholar
Department of Mechanical Engineering
Channabasaveshwara Institute of Technology
Gubbi, Tumkur, Karnataka

Rohith M S
Assistant Professor
Department of Mechanical Engineering
Channabasaveshwara Institute of Technology
Gubbi, Tumkur, Karnataka

Sudheer Kini K
Assistant Professor
Department of Mechanical Engineering
A J Institute of Engineering and Technology
Mangalore, Karnataka

Malteshkumar Deshpande
Assistant Professor
Department of Mechanical Engineering
PES Institute of Technology and Management
Shivamogga, Karnataka

Abstract **- Aluminum metal matrix composites (MMC) are being extensively used in automotive, aircraft and various engineering applications due to their superior mechanical properties over conventional materials. In the present study the Aluminium alloy Al 2017 is reinforced with 9% Boron carbide and 3% graphite flakes / graphite powder to prepare the hybrid metal matrix composites using stir casting technique. The microstructure reveals uniform distribution of reinforcements in the matrix phase. The study of mechanical properties were done for base material, mono and hybrid composites. The specimens were prepared as per ASTM standards for testing. Hardness properties of the composite showed an improvement as compared to the base alloy without reinforcement additions. The tensile and compressive strengths of hybrid composites were also greatly enhanced with the addition of B_4C and a slight increase was observed when graphite was added to the mono composite. The present paper highlights the salient features of casting technique and characterization of aluminum alloy Al 2017 and B_4C-Graphite hybrid metal matrix composite.**

Keywords- Aluminium 2017; boron carbide; graphite flakes, tensile strength

I. INTRODUCTION

Metal matrix composites are designed to achieve high strength properties. Metal matrix composites (MMCs) reinforced with ceramic particles are widely used because of their high specific modulus, strength and wear resistance. Many of the investigations have shown improved mechanical properties but are limited with low and poor ductility. An optimized combination of surface and bulk mechanical properties may be achieved if Al-MMCs are processed with a controlled gradient of reinforcing particles and also by adopting a better method of manufacturing [1-3].

Among the metals, aluminium is the most commercially used lightweight, cost-effective alloy in aerospace and automobile industries. The lightweight properties have high influence in minimizing cost and environment pollutions through reducing the weight and fuel consumption [4]. However, the strength, thermal stability and tribological properties of these alloys are still a concern and need to be improved. The Aluminium composites to most extent have replaced the conventional Al alloys especially in tribological applications such as sliding contacts, bearings, piston rings, brake rotors, clutch, brake shoes or pads and so on. The presence of particle reinforcements helps to improve the mechanical properties, wear resistance by resisting the matrix plastic deformation in addition to enhancing the high specific strength, stiffness and damping capacity [5].

Many processing methods such as stir casting, spray deposition, squeeze casting, mechanical alloying and powder metallurgy were established to fabricate aluminium matrix composites (AMCs)[6,7]. Among these processing methods, the stir casting (liquid state) method is most widely used because of its low capital cost, excellent bonding characteristics between the matrix and the particles, near net shape and high volume production. In this process, second phases are mixed with a molten matrix by means of mechanical stirring. The stirring action ensures the uniform dispersion of second phases and also, refines the matrix microstructure by breaking dendrites during solidification [8]. Hence in the present research work stir casting technique is selected for fabrication of metal matrix composite. Hybrid metal matrix composites consist of a metal or an alloy matrix with strongly embedded multiple reinforcements to enhance the wear resistance properties [9-11].

Among the Al alloys, the Al 2017 alloy is used for various applications due to its high strength with excellent fatigue strength, having density of 2.79 g/cm^{3}and melting point of 641°C. Currently, this alloy is extensively used in rocket fuel tanks and airframe contact parts [12]. Thus, the Al 2017 alloy is selected in the present research work. Next important constituent responsible for mechanical, thermal and tribological properties improvements is particle reinforcements [13]. The B_4C is the third hardest material which comes after diamond and cubic boron nitride. The unique properties of B_4C such as high impact resistance, good wear resistance, high melting point (2450°C) and elastic modulus (445 GPa), outstanding resistance to chemical agents, high neutron absorption capacity and low density

($2.51\ g/cm^3$) makes this an ideal reinforcement in Al alloy matrix [14,15].

In the present study, the hybrid MMC's were developed by stir casting technique. The mechanical properties of Al 2017 reinforced with Boron carbide (B_4C) and graphite flakes / powder Hybrid Metal Matrix Composites (HMMC's) were studied.

II. EXPERIMENTAL WORK

Hybrid MMCs were formed by reinforcing the base matrix with more than one reinforcements having different properties. Those composites which have a mixture of two or more reinforcement particles are capable of enhance the mechanical properties of the composite. The performance of hybrid composites is a collective effect of the individual constituents in which there is a better balance between the inbuilt advantages and disadvantages. Owing to their advantages of Hybrid composites the matrix and reinforcement materials selected in the present work are as follows.

A. Matrix material

Among the Al alloys, the Al 2017 alloy is used for various applications due to its high strength with excellent fatigue strength, having density of $2.79\ g/cm^3$ and melting point of 641^0C. The chemical composition of Al 2017 alloy is given in table 1. Currently, this alloy is extensively used in rocket fuel tanks and airframe contact parts. Thus, the Al 2017 alloy is selected in the present research work. Other applications where excellent castability and good weldability, pressure tightness, and good resistance to corrosion are required.

TABLE 1. COMPOSITION OF Al 2017 ALUMINIUM ALLOY

Element	Content(%)
Copper(Cu)	4.5
Iron(Fe)	0.6
Manganese(Mn)	0.8
Magnesium(Mg)	0.5
Silicon(Si)	0.4
Zinc(Zn)	0.2
Titanium(Ti)	0.1
Chromium(Cr)	0.1
Aluminium(Al)	Balance

B. Reinforcements

- The Boron carbide (B_4C) is the third hardest material which comes after diamond and cubic boron nitride. The unique properties of B_4C such as high impact resistance, good wear resistance, high melting point (2450°C) and elastic modulus (445 GPa), outstanding resistance to chemical agents, high neutron absorption capacity and low density ($2.51\ g/cm^3$) makes this an ideal reinforcement in Al alloy matrix. Boron carbide ceramic material is used in tank armor, bullet proof vests and numerous industrial applications.

- *Graphite* is the most stable form of carbon under standard conditions. Therefore, it is used in thermochemistry as the standard state for defining the heat of formation of carbon compounds. There are three principal types of natural graphite, each occurring in different types of ore deposit; Crystalline flake graphite occurs as isolated, flat, plate-like particles with hexagonal edges, Amorphous graphite occurs as fine particles, Lump graphite (also called vein graphite). Graphite and graphite powder are valued in industrial applications for their self-lubricating and dry lubricating properties. There is a common belief that graphite's lubricating properties are solely due to the loose inter-lamellar coupling between the sheets in the structure.

- In this research work, the hybrid MMC's will be developed by stir casting technique. The mechanical properties like hardness, tensile strength and tribological characteristics of Al 2017 reinforced with Boron carbide (B_4C) (size 20 - 40 µm) and graphite flakes (size 0.5 to 0.8 mm) Hybrid Metal Matrix Composites (HMMC's) has been studied.

C. Fabrication of MMC by stir cast method

The metal matrix composites of Al2017 alloy reinforced with B_4C and graphite flakes were prepared in an Electric resistance furnace. The Stir casting set up used for fabrication of HMMC's and layout is shown in fig 1. Initially the base metal Al 2017 castings were made. The measured weight of Al 2017 is heated in a graphite crucible and melted which is then poured in to the preheated die.

Fig. 1. Photograph of stir cast setup

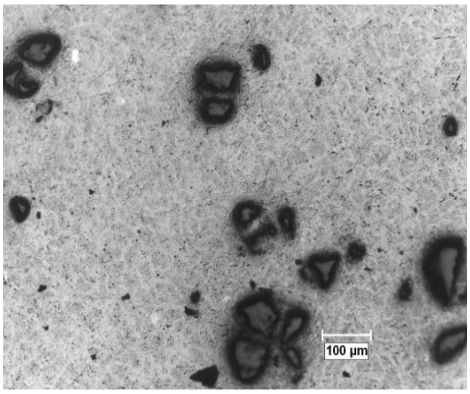

Fig. 2. Optical micrograph of HMMC showing B4C and graphite flakes

D. Procedure for fabricating AHMMC's

- Heating to 750ºC and melting the measured weight of Al 2017 in a graphite crucible.

- Adding cover flux to remove impurities, then solid hexa chloro ethane tablet is added to remove inert gases.
- The measured weight % of B_4C(9%) and B_4C+Gr flakes(3%) with K_2TiF_6(1%) (Wettability agent) is preheated to 150ºC.
- The reinforcement is divided into two parts which is added to melt one by one followed by stirring at 150 RPM for 10 minutes.
- After continuous stirring, mixture is then poured into preheated cast iron die to obtain the composite samples.
- Castings of Al 2017 base metal, Al 2017+B_4C and Al 2017+B_4C+Gr flakes were obtained individually

III. RESULTS AND DISCUSSIONS

Mechanical properties like Tensile strength, Compression strength and Micro hardness are found for the prepared composites. The present work also attempts to understand the influence of reinforcement on the matrix alloy.

Samples were prepared for micro structure analysis by sectioning and polishing the fabricated composites. The optical micrograph as well as SEM image of the aluminium metal matrix composite reinforced with 9% B4C+3%Gr flakes is shown in Fig. 2. The distribution of B4C and B4C+Gr flakes in these composites is found to be fairly uniform. Due to enhanced wettability no pores occurred in these composites as seen from the microstructure.

A. *Micro Hardness*

The hardness of the hybrid composites specimens and of the base alloy, is given in table 2 and plotted against the type of material as shown in fig 3. It follows from the graph that the specimens show an increase in Micro hardness with the addition of B_4C which further increased when Graphite was added. The material with Graphite flakes yields best results in its properties.

TABLE 2. MICRO HARDNESS OF DIFFERENT COMPOSITE SAMPLES

Sl. No.	Composition	Micro Hardness (VHN)
1	Al2017	84
2	Al2017+9%B_4C	110
3	Al2017+9%B_4C+3%Gr powder	113
4	Al2017+9%B_4C+3%Gr Flakes	118

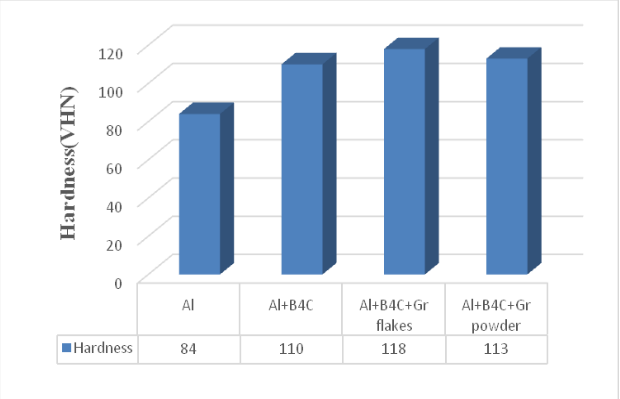

Fig. 3. Variation of Micro Hardness with Reinforcement

B. *Tensile strength*

The ultimate tensile strength of the hybrid composites specimens and of the base alloy are tabulated in table 3, plotted against the type of material as shown in fig 4. It follows from the graph that the specimens show an increase in UTS with the addition of B_4C which further increased when Graphite was added. The material with Graphite flakes yields best results in its properties.

TABLE 3. TENSILE STRENGTH OF DIFFERENT COMPOSITE SAMPLES

Sl. No	Composition	Tensile strength (MPa)	Elongation (%)
1	Al2017	126.1	5.0
2	Al2017+9%B_4C	155.8	3.0
3	Al2017+9%B_4C+3% Gr powder	170.6	2.3
4	Al2017+9%B_4C+3% Gr flakes	175.8	2.1

B_4Cp, being harder and stiffer than the matrix, takes the initial stress. Addition of hard B_4Cp combined with uniform dispersion imparts strength to matrix alloy, thereby causing increased resistance to tensile stresses resulting in improved hardness and ultimate tensile strength. Addition of B_4Cp results in increased work hardening of the matrix owing to lesser amount of metal. Hence, higher load is required for proliferation and nucleation of void; thereby strength increases. Presence of graphite particles further increases the strength which could be attributed to reduction in the inter-special distance between particulates, which cause an increase in the dislocation pile-up as the particulate content increased. This leads to restriction to plastic flow due to the random distribution of the particulate in the matrix, thereby providing enhanced strength to composites. Slight increase in hardness as well as UTS with the addition of graphite flakes is due to the reinforcements that act as barriers to the dislocations in the microstructure.

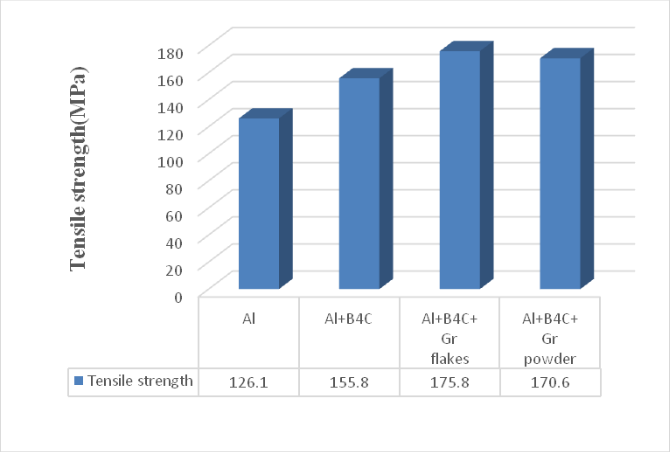

Fig. 4. Variation of Tensile strength with Reinforcement

C. Compressive strength

The ultimate compressive strength increases with the addition of reinforcements. We can observe an increase compressive strength of around 10 – 20 % for hybrid composites when compared to base alloy. Table 4 shows the values of compressive strength obtained. Fig 5 shows the effect of reinforcement on compressive strength of the matrix alloy.

TABLE 4. MICRO HARDNESS OF DIFFERENT COMPOSITE SAMPLES

Sl. No	Composition	Compressive strength (MPa)
1	Al2017	264
2	Al2017+9%B_4C	282
3	Al2017+9%B_4C+3% Gr powder	290
4	Al2017+9%B_4C+3% Gr flakes	293

The ultimate compressive strength of the hybrid composite was increased because the composites became tougher with the addition of reinforcement particles. This was persistent till the matrix can lodge the particles without distortion. B_4C particles being hard and brittle lead to dispersion hardening of matrix. These particles act as second phase in the matrix and resist the movement of dislocations and hence increases the compressive strength.

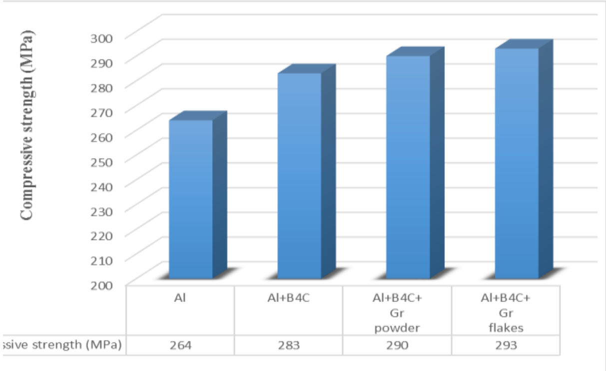

Fig. 5. Variation of compressive strength with Reinforcement

IV. CONCLUSION

- Mono and hybrid composites were successfully prepared with B_4C and Gr flakes / Powder reinforcements respectively using stir casting method.
- Study of microstructure using optical images reveals uniform distribution of reinforcements within the matrix material.
- Mechanical properties such as density, hardness, tensile strength and compressive strength were determined and hybrid composites were found to have superior values in comparison with base material and mono composite.
- Hardness and tensile strength increases with the addition of reinforcements because due to condition of B_4C & graphite particles cuts as the obstacles to motion of dislocation.

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