STUDY OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AL-Cu METAL MATRIX REINFORCED WITH B_4C PARTICLES COMPOSITE

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Abstract - ***Due to their excellent properties such as high specific stiffness, strength/weight ratio, and wear resistance, metal matrix composites (MMCs) with particulate reinforcement and related manufacturing methods have become important research topics in recent years. Aluminum-Copper MMCs are materials that are commonly used for fabrication of light-weight functional components. Aluminum-Copper MMCs that are reinforced with various fractions of B_4C (2, 4, 6, 8, 10 and 12 wt.%) were fabricated by powder metallurgy (PM) technique using a sintering cycle in a vacuum furnace at 590°C for 9 h.***

Fabricated composite were characterized for their mechanical properties like density, compressive strength , tensile strength , hardness. Microstructural characterization has also been carried out. Density of MMC decreases with increase in wt percentage of B_4C. Mechanical properties like hardness increases wt percentage of B_4C particles. The value of tensile strength and compressive strength increases with increase in weight percentage of B_4C up to 10% and then decreases.

Above synthesized aluminum copper B_4C can be used for automotive application due to improved physical mechanical properties.

Key Words: *MMC, Powder Metallurgy, Particulate reinforcement, Mechanical properties, Microstructures*

1. INTRODUCTION

The poor mechanical and tribological properties of pure Aluminium limit its wider range of usage. The potential as well as availability of Aluminium has been realized and considerable efforts are being made to explore the possibilities of improving the mechanical strength and wear resistance of aluminium so as to meet the requirements of various applications. Aluminium has played , playing and will continue to play vital role in the development of metal matrix composites (MMCs) reinforced with a variety of ceramic materials including Al_2O_3, TiC , B_4C, and SiC. From the wide range of MMCs systems studied thus far and on account of the attractive properties of B_4C {1}, Al-Cu/ B_4C composites have drawn the attention of a plethora of research scientists and technologists. Several aspects are to be considered with regard to the metallic matrix namely composition, response to heat treatments, mechanical and corrosion behaviour.The combination of light weight, environmental resistance and useful mechanical properties such as modulus, strength, toughness and impact resistance has made aluminium alloys well suited for use as matrix materials {21}. Moreover, the melting point of aluminium is high enough to satisfy many application requirements. Among various reinforcements, boron carbide is widely used because of its high modulus and strengths, excellent thermal resistance, good corrosion resistance, good compatibility with the aluminium matrix, low cost and ready availability. The main objective of using boron carbide reinforced aluminium alloy composite system for advanced structural components to replace the existing super alloys {3}.

In the present investigation aluminium (commercially pure having an assay of >99% of Aluminium) 4% copper and B_4C particulates have been used for the MMC fabrication. In the recent researches particle reinforced metal matrix composites have been extensively investigated. Usually, this kind of composites is produced by stir casting methods and also there are some investigations on generating them by powder metallurgy techniques. Powder metallurgy has got a great influence of producing net-shape components that minimizes the machining process particularly in case aluminium copper and boron carbide composite rapid tool wear rate takes place due to abrasiveness of the hard B_4C particles. The main advantage of using powder metallurgy method to generate MMC (Al/Cu/ B_4C p) is as it produces a uniform distribution of reinforcement in the matrix where as other manufacturing methods fail to satisfy.

1.1 Composites

Composites are made up of individual materials referred to as constituent materials. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination.

1.2 Powder Metallurgy

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape or form (compacting), and then heating the compressed material in a controlled atmosphere to bond the material (sintering). Powder Metallurgy (P/M) is a processing technology in which parts are produced by compacting and sintering metallic and/or nonmetallic powders. Therefore, P/M is a typical example of an additive manufacturing process.

2. EXPERIMENTAL PROCEDURE

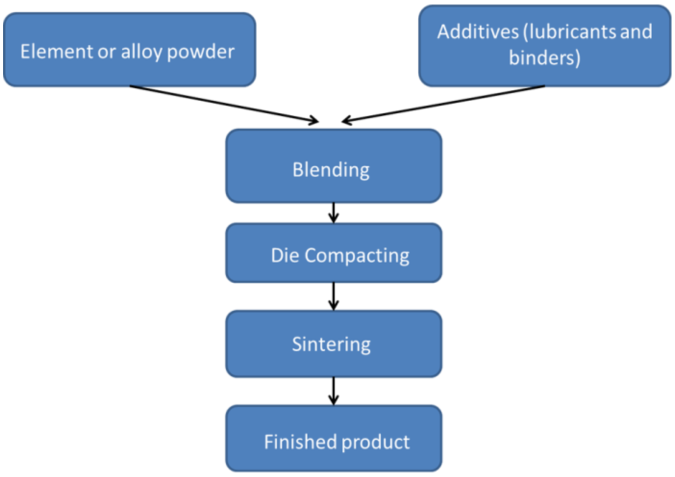

Fig 1

2.1 Ball milling

A ball mill is a type of grinder used to grind materials into extremely fine powder for use in mineral dressing processes, paints, pyrotechnics, and ceramics.

Procedure

- After keeping the desired amounts of Al, Cu , B_4C and Zinc sterate in the ball mill the cap of the mill is closed.
- After that ball mill has to be started.
- The rotation of the ball mill took place at 100 rpm.
- The significance of steel balls in the rotation is that on each rotation the balls will fell on the powder inside the mill.
- Due to the falling balls the powder will get mixed thoroughly because of the punching action.
- Argon is fed continually at a pressure of 0.5kg/cm^2 to avoid oxidation of Al powder.
- After 4 hours (when the powder is thoroughly blended) the powder is taken out of the mill.
- The steel balls also come out with the powder.
- These steel balls are separated from the powder by using a sieve.
- The powder is then taken away and is ready for compacting.

2.2 Compaction

It is a process in which particles of constituent powders are made cohesive through mechanical densification by applying heavy loads through a hydraulic press or UTM to form a green compact.

Procedure:

- First the powder is filled in the die to be kept under UTM .
- The compaction starts and when the load of 10 tonne has achieved the UTM has to be kept stationary for 2-2.5 minutes so that the powder may get compacted properly.
- After this the green compact (briquette) has to be taken out of the die.
- The compact which comes out has a volume of nearly 33% of the volume of powder used.
- Some of the compact are as shown in figure.
- This compact is now ready to get sintered.

2.3 Sintering

Procedure

The sintering procedure is done in the Aluminum sintering furnace or a strip annealer. Do not use other furnace tubes for this step. Use the push rod, boat and boat holder designated for Aluminum sintering. The sintering furnace is set at 580 degrees centigrade. Open the Argon valve at the back of the furnace and make sure that the flow rate is maintained.

- Remove the end cap off the furnace tube and set it on a petri dish.
- Load your samples to be annealed (metal side up) on the boat using metal tweezers. Slowly push the boat in to the flat temperature zone over 2 hrs.
- Wait 5 minutes for the wafer to warm up to the furnace temperature. Open the argon valve at the back of the furnace and ensure that the pressure is 1.5kg/cm^2. Leave the argon on for the desired sinter time.
- Turn off the argon valve and pull the boat out to the mouth of the furnace over 2 hrs. Remove the

boat from the furnace on a boat holder and unload your samples.

3. TESTING

3.1 Microstructure Analysis

The microstructures of the Al-Cu-B_4C composites were studied using scanning electron microscope. For this purpose small samples were cut from the cylindrical pins fabricated by powder metallurgy process. The samples were first machined on Lathe and then polished using polishing papers of gradually increasing fineness. The polished samples were then lapped on polishing machine using diamond-lapping paste and velvet cloth for about 40 minutes so that mirror finish is obtained on the samples. The samples were etched with 1 % Keller Reagent for about 45 seconds and washed with distilled water before the microstructural analysis. Then the scanning electron micrographs of powder Al- Cu and B4Cp composite samples with only 10 weight % of B_4C were taken because of lack of facilities available and studied for microstructural analysis.

3.2 Density Test

In density test we will analyze the change in density of the prepared specimen before and after sintering.
For that we calculated the volume and mass of specimen before and after sintering with the help of venire caliper and electronic weighing machine. Shrinkage occurs during sintering resulting in densification and enables significant improvement in physical properties.
Porosity of the sintered as well as un-sintered compacts was determined by Archimedes principle. The compacts were first weighed in air and then tied with string and weighed while hanging in water. The density was determined using the following formula:

$\rho_s = (ma \times \rho_w)/(ma - mw)$ -------------------------------(1)

Where, ρ_s = Density of sintered specimen (gm/ cm3)
ρ_w = Density of water (gm/ cm3)
ma = Weight of sample in air (gm)
mw = Weight of sample in water (gm).

The porosity was determined using the following formula:

$E = 1 - \rho_s / \rho_t$ --(2)

Where, E = porosity (%)
ρ_s = Density of sintered part (gm/cm^3)
ρ_t = Theoretical density (gm/cm^3)

The theoretical density was determined by comparing the sum of volume (weight divided by the density) of constituents and the volume of composite.

3.3 Hardness Test

Rockwell hardness was measured on the polished surfaces of the Al-Cu-B_4C composite samples using B scale on Rockwell hardness tester. A 1/16 inch hardened steel ball indentor with fixed indentation load of 100 kg was used for all tests. Five readings were taken for the samples of each composition and the average hardness was determined.

3.4 Indirect Tensile Strength

The indirect tensile strength of the powder metal Al-Cu with 2,4,6,8,10 and 12 weight % of B_4Cp were measured. For this purpose Al-Cu-B_4C composite samples of right circular cylindrical shape were fabricated by powder metallurgy process. The indirect tensile strength was measured on 1000 KN universal testing machine. In this test a right circular cylinder is compressed diametrically between two flat plates. The maximum tensile stress is developed normal to the loading direction with a constant magnitude between two lines of contact. The tensile stress G is given by

$G = 2P/ \pi.d.t$ --------------------------------------(4)

Where,
P = Applied load (N)
d = Specimen diameter (m)
t = Specimen thickness (m)

3.5 Compressive strength test

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength and, for some materials, compressive strength. Compressive strength is often measured on a UTM.Compression test was performed on Al-Cu-B_4C composite specimens with length to diameter ratio of 1.5. Tests were performed on UTM of 1000 KN capacity. The sample was compressed between two flat platens and the maximum failure load was recorded.

4. RESULTS AND DISCUSSION

4.1 Microstructure analysis

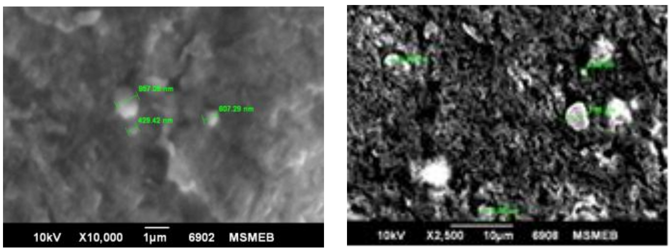

Fig 2

(i) SEM images of 10% B_4C Sample: Powder after mixing

There is a perfect mixing of Al-Cu with 10% B4C after milling the powder of samples (milled for 9 hrs). It was observed that B4C particles were uniformily distributed with average particle size of 1.8075µm . The particles are visualized individually because of considerable difference in particle size of Al and B4C due to which diffusion was not at all possible among the particles.

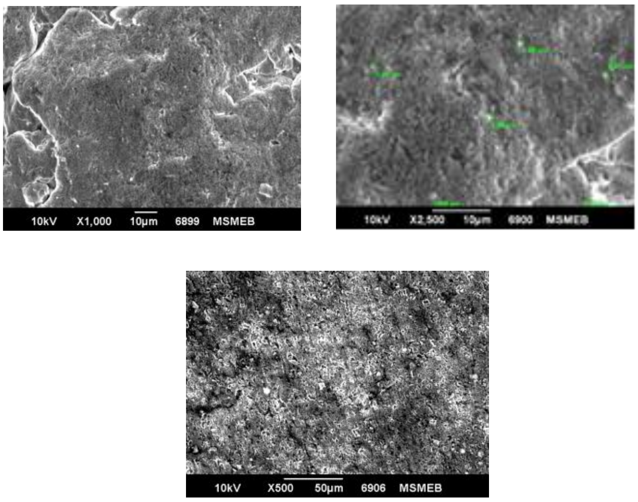

Fig-3

(ii) SEM images of 10% B_4C sample: Specimen after sintering

4.2 Density and Porosity

At all the magnification the porosity is clearly observed . This is due to the evaporation of environmental at the time of sintering process and simultaneously evaporation of oil used as the lubricant. Also it was observed that the particles joint together after sintering due to thermal welding.

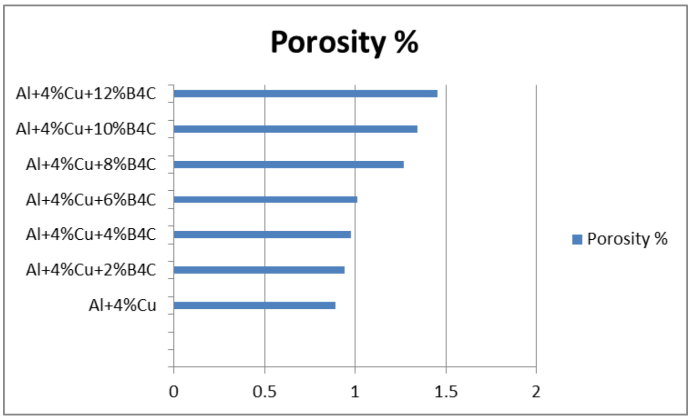

Fig-5

The experimental density of Al-Cu alloy B_4C composites have been measured by Archimedes method. The theoretical densities were calculated using the rule of mixtures porosity was calculated by difference between theoretical and experimental density.

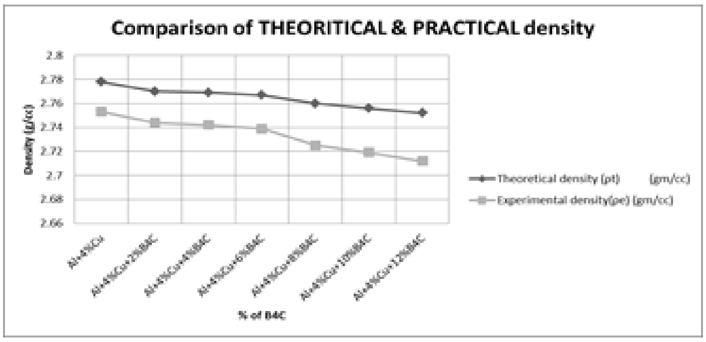

Fig-4

The variation of density with respect to wt% of B_4C composite is shown in figure.

It is observed from the figure that with increasing wt% of B_4C composite density decreases. It is due to effect of low wettability at high reinforcement content and pore nucleation at the matrix B_4C particle interfaces.

4.3 Hardness

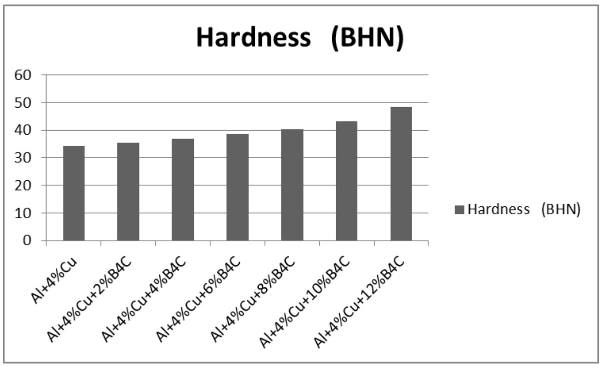

Fig-6

Hardness test were carried out to observe the effect of wt% of B_4C on aluminium alloy matrix. Variation of hardness of aluminium alloy B_4C composites are shown in figure. It is observed that with increasing the wt% of B_4C composite hardness of composite increases. The hardness of composite is higher than the unreinforced alloy. The higher hardness of composite relates to the existence of B_4C hard particles acting as a obstacle in the motion of dislocation. Moreover the presence of more wt% of B_4C particles increase hardness of composite because Carbide itself is hard particle.

4.4 Indirect Tensile Strength

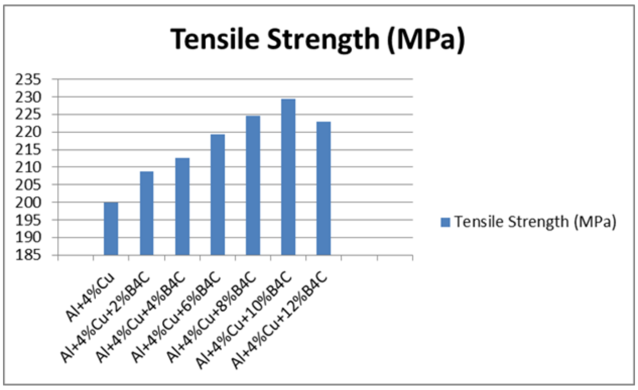

Fig-7

The variation of tensile strength of aluminium matrix – Boron Carbide composite with different wt% of reinforcement is shown in figure. With increase in the wt% of B_4C composite the tensile strength increases up to 10 wt% B_4C composite. It is due to more B_4C particle present in the matrix which gives more strength to the matrix. The % increase in tensile strength of alloy with addition of alloy with addition of 10 wt% B_4C particles is 14.7 %.

The tensile strength of composite with 12% B_4C particles decreases when compared with the 10 wt% of B_4C composite. It may be due to the agglomeration and clustering of the particles in the matrix which makes composite more brittle. When we compare with the tensile strength of 8% B_4C composite and 12% B_4C composite, the value of tensile strength for 8% B_4C composite is more than the 12% B_4C composite. This is due to the uniform distribution of the B_4C composite in the matrix which enhanced the tensile strength of composite.

4.5 Compressive strength

Variation of compressive strength with different wt% of B_4C particles are shown in figure. It is clear from the figure that the compressive strength increases with increasing wt% of B_4Cparticles and composite shows higher compressive strength than the aluminium alloy. this is due to the grain refinement and strong multi-directional thermal stresses at the aluminium B_4C interfaces which plays a significant role in high strength of composite.

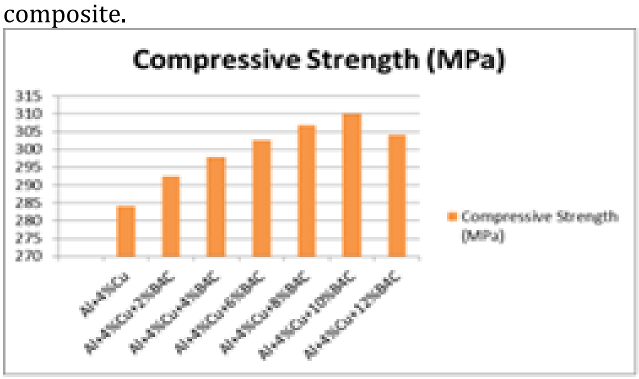

Fig-8

B_4C particle and itself Boron have grain refinement strengthening effect which is improved with increasing wt% of B_4C particles therefore they act as heterogeneous nucleation catalyst for aluminium during solidification.

5. CONCLUSIONS

1) Aluminium Copper matrix B_4C composite of variable wt% (2%, 4%, 6%, 8%, 10%, 12%) have been successfully fabricated by powder metallurgy.
2) The experimental density is nearer to the theoretical density of the object.
3) The tensile strength increases with increase in wt% of B_4C particles up to 10% and then decreases. The maximum/optimum value of tensile strength is 229.4 MPa
4) The compressive strength increases with increase in wt% of B_4C particles up to 10% and then decreases. The maximum/optimum value of compressive strength is 310 MPa
5) The hardness of composite is found to be directly proportional to the increase in wt% of B_4C. At 12% B_4C composition the hardness value is 48.5BHN.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude and appreciation to all the staffs of Maulana Azad National Institute of Technology (MANIT), Bhopal for their co-operation and support throughout the duration of this work.

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