Development and Testing of Metal Matrix Composite by Reinforcement of B4C Particles on Al LM25 Alloy

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Abstract - *With the increasing demand of light-weight materials in the emerging industrial applications, fabrication of aluminum boron carbide composites is required. In this context aluminum alloy -boron carbide composites were fabricated by liquid. On the other hand, aluminum and aluminum alloys are vital in the aerospace, automotive industries, architectural applications and also important in other areas where the durability, strength, and light weight are desired.*

Metallurgy techniques with different particulate weight fraction (5%, 7.5% and 10%).Microstructure analysis was done with scanning electron microscope. Scanning electron microscopy images shows that boron carbide particles are uniformly distributed in aluminum matrix. The composites were characterized by hardness and compression tests. With the increase the amount of the boron carbide, the density of the composites decreased whereas the hardness is increased. The ultimate compressive strength of the composites was increased with increase in the weight percentage of the boron carbide in the composites.

Key Words: Al LM25 Alloy, Boron carbide, Density, Hardness, Tensile Strength, Modulus of Elasticity, etc

1. INTRODUCTION

1.1 ANALYSIS OF MECHANICAL PROPERTIES

1.1.1 DENSITY: The density, or more precisely, the volumetric mass density, of a substance is its mass per unit volume. The symbol most often used for density is ρ (the lower case Greek letter rho). Mathematically, density is defined as mass divided by volume: $\rho = \frac{m}{V}$

1.1.2 HARDNESS: Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials, such as metal, are harder than others. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: *scratch hardness*, *indentation hardness*, and *rebound hardness*.

1.1.3 TENSILE STRENGTH: Tensile strength is a measurement of the force required to pull something such as rope, wire, or a structural beam to the point where it breaks.

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure, for example breaking.

1.1.4 MODULUS OF ELASTICITY: An elastic modulus, or modulus of elasticity, is a number that measures an object or substance's resistance to being deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region:[1] A stiffer material will have a higher elastic modulus. An elastic modulus has the form $\lambda=\frac{stress}{strain}$

1.2 COMPOSITES:

A composite is when two or more different materials are combined together to create a superior and unique material.

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite we can easily tell the different materials apart as they do not dissolve or blend into each other.

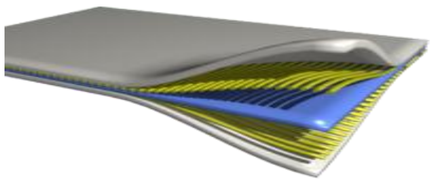

Figure1.2: Composites are formed by combining materials together to form an overall structure that is better than the sum of the individual components.

1.2.1 Division of composite materials:

1. Natural composites
2. Man-Made composites

1. Natural Composites:

Many of us may not be noticed that several, naturally formed materials around us are composites.

Wood is a composite made from cellulose and lignin. The advanced forms of wood composites can be ply-woods. An excellent example of natural composite is muscles of human body. The muscles are present in a layered system consisting of fibers at different orientations and in different concentrations. These result in a very strong, efficient, versatile and adaptable structure. The muscles impart strength to bones and vice a versa. These two together form a structure that is unique. The bone itself is a composite structure.

2. Man-Made Composites:

These composites are made by artificial mixing of two or more materials in definite proportions under controlled conditions. Mud mixed straw to produce stronger mud mortar and bricks, Plywood, Chipboards, Decorative laminates, Fibre Reinforced Plastic (FRP), Carbon Composites, Concrete and RCC, Reinforced Glass etc. The composites exist in day to day life applications as well. The most common existence is in the form of concrete. The concrete is a composite made from gravel, sand and cement. Further, when it is used along with steel to form structural components in construction, it forms one further form of composite.

Typical engineered composite materials are man-made composites that include:

- Composite building materials such as cements, concrete
- Reinforced plastics such as fibre-reinforced polymer
- Metal Composites
- Ceramic Composites (composite ceramic and metal matrices)

1.2.2. Applications of composites:

- Composites are no longer considered "space-age" materials utilized only for stealth bombers and space shuttles. This versatile material system has become a part of everyday life.

- Commercial, pleasure and military aircrafts, including components for aerospace and related applications.

- Composite applications for the household and office including appliances, power tools, business equipment, etc.

- The largest of the markets, products include parts for automobiles, trucks, rail and farm applications.

1.2.3. Advantages of Composite Material:

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. When composites are selected over traditional materials such as metal alloys or woods, it is usually because of one or more of the following advantages:

- Cost:
  - Prototypes
  - Mass production
  - Part consolidation
- Weight:
  - Light weight
  - Weight distribution
- Strength and Stiffness:
  - High strength-to-weight ratio
  - Directional strength and/or stiffness
- Dimension:
  - Large parts
  - Special geometry
- Surface Properties:
  - Corrosion resistance
  - Weather resistance
  - Tailored surface finish

1.2.5. Disadvantages of composites: Even though composites have distinct features over metals, they do have few limitations or drawbacks. So the drawbacks or limitations in use of composites include High Cost High cost of fabrication of composites is a critical issue

1.3. COSTITUENTS OF COMOPSITE MATERIALS:

In a composite, typically, there are two constituents. One of the constituent acts as a reinforcement and other acts as a matrix. Sometimes, the constituents are also referred as phases.

1.3.1. Matrix Phase:

The primary phase, the monolithic material into which the reinforcement is embedded, and having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase.

Classification of Matrix:
The matrix in a composite material can be grouped based on the type of material as below:

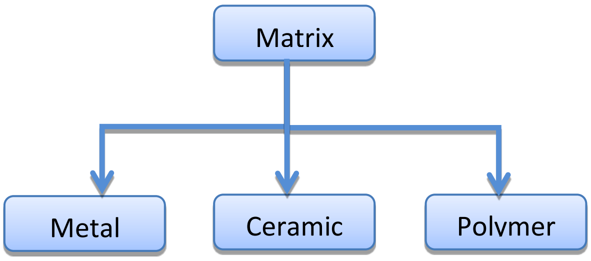

Figure 1.3.1.: Classification of Matrix

1.3.2. Reinforcement (Dispersed) Phase:

The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Reinforcement usually adds rigidity and greatly impedes crack propagation. Thin fibres can have very high strength, and provided they are mechanically well attached to the matrix they can greatly improve the composite's overall properties.

Classification of Reinforcements:

The reinforcements in a composite material come in various forms.

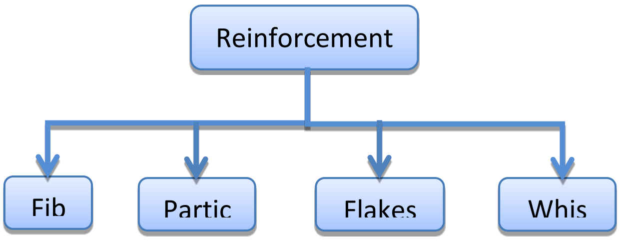

Figure.1.3.2: Classification of Reinforcements

1.3.2.1 Fibre:

Fibre is an individual filament of the material. A filament with length to diameter ratio above 1000 is called as a fibre. The fibrous form of the reinforcement is widely used.

Figure1.3.3: Differences in the way the fibres are laid out give different strengths and ease of manufacture

Fibre-reinforced composite materials can be divided into two main categories normally referred to as

a. Short fibre-reinforced materials

b. Continuous fibre-reinforced materials.

1.4 METHODOLGY
1.4.1 Metal Matrix Composite Manufacturing:

MMC manufacturing can be broken into three types—solid, liquid, and vapour.

A. Liquid state methods
Stir casting

Stir Casting is a liquid state method of composite materials fabrication, in which a discontinuous reinforcement is mixed with a molten matrix metal by means of mechanical stirring. The layout of conventional Stir Casting set up is shown below.

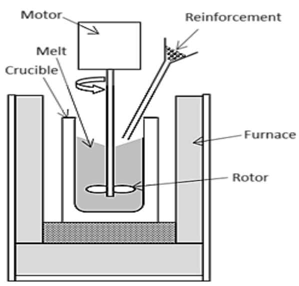

Figure1.4.1: Stir Casting Process

1.4.2 Solid state methods:

Powder blending and consolidation (powder metallurgy): Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment (possibly via hot iso static pressing (HIP) or extrusion).

Figure 1.4.4: 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). The powder metallurgy process generally consists of four basic steps: Powder metallurgy is also used in "3D printing" of metals. See selective laser melting and selective laser sintering.

1.4.3 Sand Casting:

Sand casting, also known as **sand moulded casting**, is a metal casting process characterized by using sand as the mould material. The term "sand casting" can also refer to an object produced via the sand casting process. Sand castings are produced in specialized factories called foundries. Over 70% of all metal castings are produced via a sand casting process.

1.4.4 Vacuum moulding:

Vacuum moulding (V-process) is a variation of the sand casting process for most ferrous and non-ferrous metals, in which unbounded sand is held in the flask with a vacuum. The pattern is specially vented so that a vacuum can be pulled through it. A heat-softened thin sheet (0.003 to 0.008 in (0.076 to 0.203 mm)) of plastic film is draped over the pattern and a vacuum is drawn (200 to 400 mmHg (27 to 53 kPa)).

1.4.5 FOUNDRY:

In metal working, casting involves pouring liquid metal into a mold, which contains a hollow cavity of the desired shape, and then allowing it to cool and solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting is most often used for making complex shapes that would be difficult or uneconomical to make by other methods

Melting: Melting is performed in a furnace. Virgin material, external scrap, internal scrap, and alloying elements are used to charge the furnace. Virgin material refers to commercially pure forms of the primary metal used to form a particular alloy.

Figure1.4.8: Melting metal in a crucible for casting

Pouring

In a foundry, molten metal is poured into moulds. Pouring can be accomplished with gravity, or it may be assisted with a vacuum or pressurized gas. Many modern foundries use robots or automatic pouring machines for pouring molten metal. Traditionally, moulds were poured by hand using ladles.

Figure 1.4.11: Bronze poured from a crucible into a mould, using the ancient lost-wax casting process

Finishing: The final step in the process usually involves grinding, sanding, or machining the component in order to achieve the desired dimensional accuracies, physical shape and surface finish.

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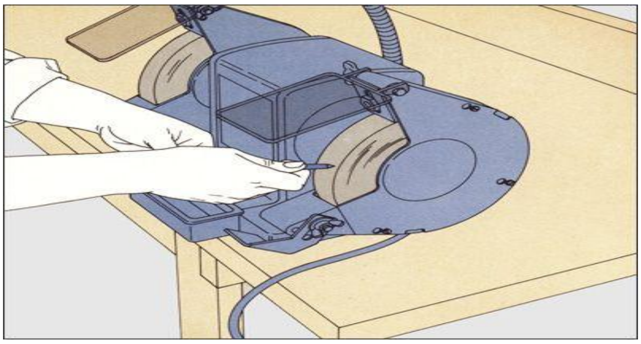

Figure 1.4.12: Grinding Operation

1.5 EXPERIMENTAL WORK

For the present work we require a stir casting furnace with 4 blade stainless steel stirrer. Since stir casting is not a conventional casting method we have to design a suitable one. Even though some stir casting furnaces are readily available in the market, a custom made conventional stir casting furnace is a lot cheaper and is best suited for the present work to vary process parameters according the requirements.

Experimental Procedure:

After heat treatment of samples the following operations were performed.

1. Specimens were analyzed for variation in density as per Archimedes principle.
2. Specimens were freed from risers and turned to required dimensions on a lathe machine.
3. Hardness test was conducted on the riser sections.
4. Tensile test was conducted on turned samples with the help of Universal testing machine and average values of each composition were noted.

Selection of Reinforcements: Aluminum has very poor wear resistance compared to ferrous alloys. To increase the hardness and wear properties of Aluminum alloy, reinforcement must possess relatively high hardness and wear resistance.

Boron Carbide: Boron carbide has a complex crystal structure typical of icosahedrons-based borides. There, B_{12} icosahedra form a rhombohedral lattice unit (space group: *R3m* (No. 166), lattice constants: a = 0.56 nm and c = 1.212 nm) surrounding a C-B-C chain that resides at the centre of the unit cell, and both carbon atoms bridge the neighboring three icosahedra.

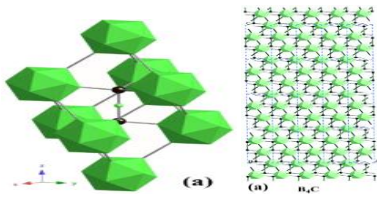

Figure1.4.13 Fragment of the B_4C crystal structure

1.6 RESULTS AND DISCUSSIONS
Properties of Aluminum LM 25 and LM 25-B4C COMPOSITES
1.6.1 Mechanical Properties
I. Aluminum LM25 Alloy

S.NO	Test Parameter	LM25
1	Hardness (BHN)	98
2	Tensile Strength (N/mm^2)	253
3	Elasticity of Modulus(N/mm^2)	70.8

II. Aluminum LM 25-B4C Composite material

S.NO	Test Parameter	5%B4C	7.5%B4C	10%B4C
1	Hardness (BHN)	107	113	121
2	Tensile Strength (N/mm^2)	278	287	294
3	Elasticity of Modulus (N/mm^2)	71.2	71.5	71.7

1.6.2 Physical Properties

I. Aluminum LM25 Alloy

S.NO	Test Parameter	LM25
1	Density(g/cc)	2.678

II. Aluminum LM 25-B4C Composite material

S.NO	Test Parameter	5%B4C	7.5%B4C	10%B4C
1	Density(g/cc)	2.671	2.665	2.661

RESULTS:

After heat treatment of all samples, each sample was separately tested for the density, hardness and tensile strength and the average values were analyzed by comparing with the zero sample. The results in various tests were discussed below.

1.6.3 Density

Density of each sample was measured based on Archimedes principle in a calibrated glass jar. We can notice that the density of Group 0 is more compared to the other groups because the density of Boron carbide is less compared to Aluminum. Further, the density of Aluminum is decreased because of the increase of B4C composition in the composite.

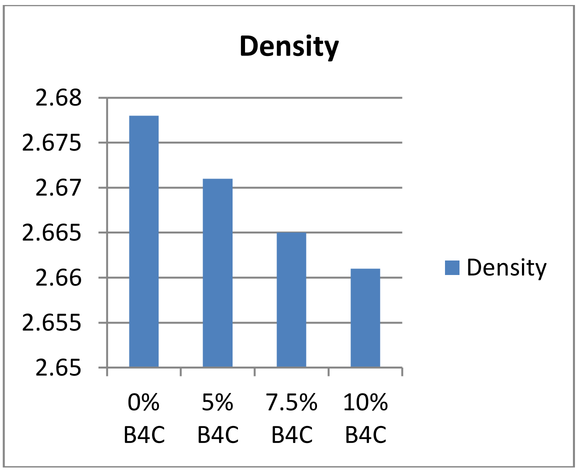

Figure **1.6.1. Comparative bar graph of Density**

1.6.4 Hardness

Since the B4C is superior to Aluminum and B4C, in general we can expect the dominance of B4C in increase of hardness of the composite. The practical observations revealed that the hardness of the composite increased considerably. It was noticed that the increase of hardness from Group 0 to Group 1 is form 98 BHN to 107 BHN has a difference of 09 BHN, the increase form Group 1 to Group 2 is from 107 BHN to 113 BHN has a difference of only 06 BHN and from group 2 to group 3 is increased from 113 BHN to 121BHN (see Figure). This can be considered that the incorporation of B4C in the Aluminum gives hardness to the composite but the further increase of B4C has given a little increase in hardness due to the domination of Aluminum alloy over the composite since the composition of B4C is only 10% of weight. Further addition of B4C may give a considerable increase in hardness at some point but may affect interfacial strength and uniform distribution of reinforcement and also the other mechanical properties like density, tensile strength.

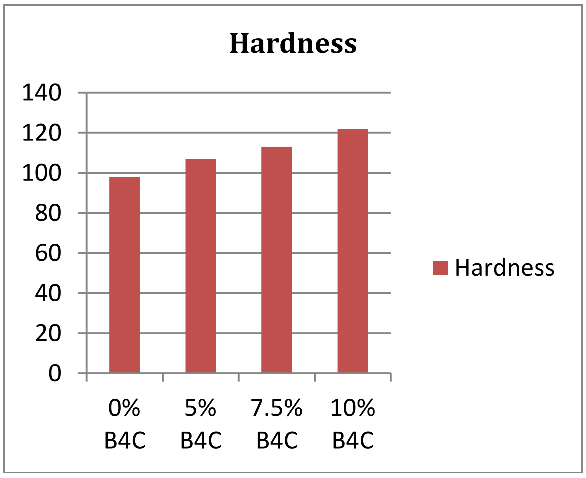

***Figure* 1.6.2. Comparative bar graph of Hardness**

1.6.5 Tensile Strength

As it was the maximum stress that a material can withstand while being stretched, interfacial bonds may affect greatly on the tensile strength of the composite. In Figure 5.3., we can see that the tensile strength was increased in the composites and have comparable variation. Weak interfacial bonds may result in decrease in tensile strength of the composite, but here the increase of tensile strength shows that there was good interfacial strength. Since the reinforcements were preheated before mixing with aluminum there might be uniform distribution and smooth interface while mixing. From this result we can expect good interfacial strength when we heat the reinforcements at higher temperatures which will facilitate uniform distribution of more amount of composite without losing the strength.

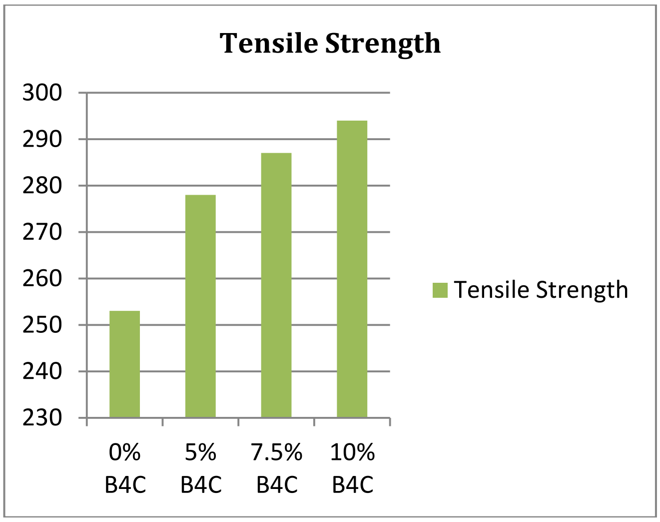

***Figure* 1.6.3. Comparative bar graph of Tensile Strength**

1.6.6 Modulus Of Elasticity

Modulus of elasticity shows linear relation with tensile strength as same as conventional materials. In Figure.1.6.4 we can observe that the modulus of elasticity was increased but not greatly as same as tensile strength. The elongation of material is similar to the base alloy, almost negligible amount of elongation for all the groups. Since all the samples are fully heat treated, the samples will gain brittleness and hardness losing ductility which might be resulted in tendency of brittle failure.

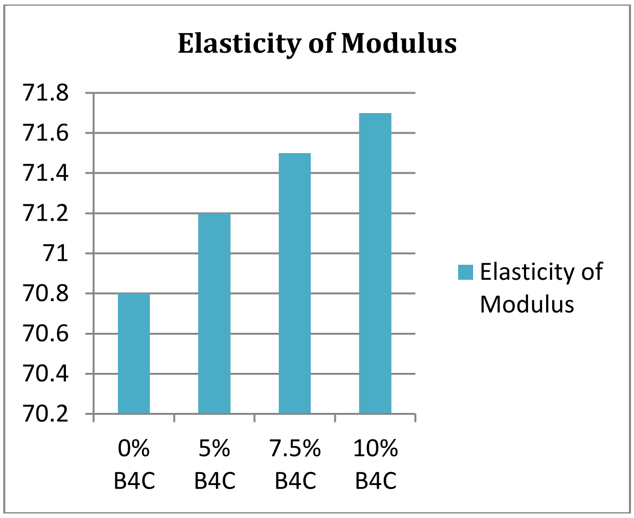

***Figure* 1.6.4. Comparative bar graph of Elasticity of Modulus**

1.6.7 Comparative Line Graph of Mechanical Properties of LM25 –B4C:

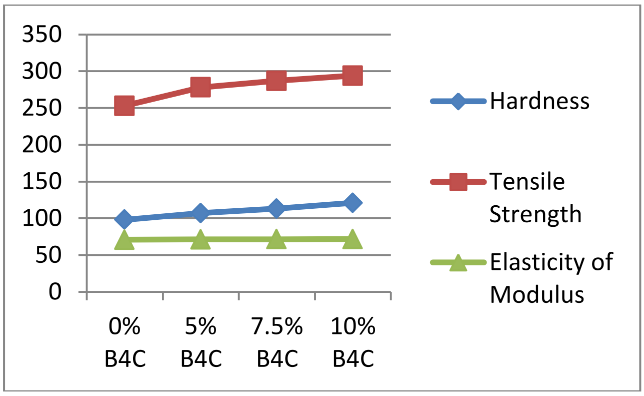

Figure **1.6.5. Comparative bar graph of Mechanical Properties of AL25-B4C**

CONCLUSION

From the results obtained for the experiments conducted and by studying research of various authors we can say that the mechanical parameters like Hardness, Modulus of Elasticity and Tensile Strength has increased when there is a presence of Boron Carbide with some proportions in Aluminum LM25

1. Density of Composite material LM25 B4C is decreases when compared to pure aluminum LM25.
   - 5% of Composite material LM25 B4C is decreases when compared to pure aluminum LM25.
   - 7.5% of Composite material LM25 B4C is decreases when compared to 5% of LM25 B4C.
   - 10% of Composite material LM25 B4C is decreases when compared to 7.5% of LM25 B4C.
2. Hardness of composite material LM25 B4C is Increases when compared to pure aluminum LM25.
   - 5% of composite material LM25 B4C is Increases when compared to pure aluminum LM25.
   - 7.5% of composite material LM25 B4C is Increases when compared to 5% of LM25 B4C.
   - 10% of composite material LM25 B4C is Increases when compared to 7.5% of LM25 B4C.
3. Tensile Strength of composite material LM25 B4C is Increases when compared to pure aluminum LM25.
   - 5% of composite material LM25 B4C is Increases when compared to pure aluminum LM25.
   - 7.5% of composite material LM25 B4C is Increases when compared to 5% of LM25 B4C.
   - 10% of composite material LM25 B4C is Increases when compared to 7.5% of LM25 B4C.

SCOPE OF FUTURE WORK

More weight % of Boron Carbide (B4C) can be mixed by preheating it up to 1100°C. Process can be repeated on the casted product in order to improve its interfacial bonding. We have taken the maximum of B4C up to 10% but the mechanical properties of the LM25-B4C composite may increase or decrease above the 10% B4C content. It depends on the proportions of the composites. Al LM25 is not only mixed with B4C but also with other reinforcements. There is a future work going on other reinforcement materials with LM25.

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BIOGRAPHIES

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