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An Investigation on the Mechanical Properties of Die Cast Zn-Al Alloy Reinforced With Boron Carbide

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Abstract:** The objective of the project is to develop Zn-Al alloy without reinforcement and as well as with reinforcements and to analyse the microstructure and find the mechanical properties such as hardness, tensile strength and %elongation of both the cases. Apart from above objective, a study is to be conducted to understand the effect of reinforcement on mechanical properties like hardness, tensile strength and %elongation of Zn-Al alloy under different reinforcement compositions. These properties of Zn-Al alloy will be found out at different compositions of reinforcement by keeping the casting temperature constant at 780°C

***Keywords:** Reinforcement, Blend Composite, Porosity, Nano-Indentation.*

I. INTRODUCTION

Die casting alloys are normally nonferrous and there are a large numbers available with a wide range of physical and mechanical properties. Aluminium alloy-base metal-matrix composite (MMC) materials are used in the design of ground transportation vehicles and aircraft.Compared with conventional non reinforced alloys; composite materials usually exhibit higher strength both at ambient and elevated temperatures.

1.1 Base Material

Zinc-Aluminium alloy represents a new family of zinc-based die casting materials. These alloys provide high strength characteristics plus high hardness and corrosion resistance. Thin-walled cast ability characteristics and die life of Zinc-Aluminium alloys are similar to zinc alloys. Zinc-Aluminium alloys are used as structural materials in automotive industry, railway sector. They are used in making of brake drums, cylinder liners, piston, cylinder blocks, connecting rods, bridge and overpass girders, armors of military vehicles and cryogenic pressure vessels. All zinc-aluminum alloys offer similar properties and are superior to standard zinc alloys. Commonly used reinforcement particles in developing Aluminium alloy-base metal-matrix composite (MMC) include carbides, nitrides, borides, and oxides. Sic, Al_2O_3 and heat resistant Mg are most commonly used reinforcements for aluminum matrix composite.

1.2 Reinforcement

Boron Carbide is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. Originally discovered in the mid-19th century as a by-product of the production of metal borides. Boron carbide powder is mainly produced by reacting carbon with B_2O_3 in an electric arc furnace, through carbothermal reduction or by gas phase reactions. For commercial use, B_4C powders usually need to be milled and purified to remove metallic impurities. In common with other non-oxide materials, boron carbide is difficult to sinter to full density, with hot pressing or sinter-HIP being required to achieve greater than 95% of theoretical density. Even using these techniques, in order to achieve sintering at realistic temperatures (e.g. 1900 - 2200°C), small quantities of dopants such as fine carbon, or silicon carbide is usually required. As an alternative, B_4C can be formed as a coating on a suitable substrate by vapour phase reaction techniques e.g. using boron halides or di-borne with methane or another chemical carbon source. Boron Carbide (B_4C) ceramics exhibit a low density (2.510 g·cm−3), high hardness (~30 GPa), high elastic modulus (~450 GPa). B_4C also has other favorable properties, such as high thermal conductivity (~40W·m−1·K−1 at room temperature), low thermal expansion coefficient (~5 × 10−6 °C−1), and good electrical conductivity (~3 Ω−1·cm−1 at room temperature), making it suitable for multifunctional applications. Furthermore, B_4C has a large neutron-capture cross-section (~4000 b). This, together with the high melting point (2447 °C) and excellent thermal stability, makes B_4C an attractive candidate material for use in nuclear reactor components and other high-temperature applications, such as reinforcement for metallic systems. In my work, I will be adding Boron Carbide powder of 45μm as reinforcement in the base material.

II Problem Definition

The Zn-Al alloys, exhibit some significant weaknesses, which restrict their applications. The main disadvantages include their decrease in strength properties with temperature rise (above 100◦c), susceptibility to cracking under impact load and susceptibility to corrosion. So in order to avoid above problems Sic, Al_2O_3 or heat resistant, Mg is added as reinforcement. Even though Sic, Al_2O_3, and heat resistant Mg increase the mechanical properties of Zn-Al alloys at elevated temperature, they have got some drawbacks. Cost of Heat resistance Mg is high and it is also having a poor recycling and castability. Sic and Al_2O_3 are susceptible to thermal and mechanical shocks. Even though Boron Carbide is having better mechanical properties (lighter weight, high strength)than Sic, Al_2O_3 and heat resistance Mg , its applications are not that much industrialized as compare to the rest. So in my work, I will be replacing Sic, Al_2O_3 and heat resistance Mg with Boron Carbide.

III EXPERIMENTAL PROCEDURE

Aluminium (LM0) ingot, pure Zinc and Boron Carbide having an average particles size of 46 µm were used for the fabrication of the test specimen. The details of the theoretically selected alloy composition and casting temperature are given in Table 1.

3.1 Alloy Composition

The details of the theoretically selected alloy composition and casting temperature are given in Table 1

TABLE I Alloy Composition and Casting temperature

Alloy N0	Zinc (g)	Aluminum (g)	Boron Carbide (Wt. %)	Casting temperature (°C)
1	480	320	0	780
2	480	320	1(8g)	780
3	480	320	3(24g)	780
4	480	320	6(48g)	780

Alloy no 1 is prepared at 780 ˚C without using reinforcement. All other alloys are prepared with the reinforcement, using same casting temperature.

3.2 Alloy Fabrication

Initially, Aluminium was placed inside the furnace [Fig. 3] and left for melting. Zinc was only added after aluminum was melted completely and Boron Carbide powder was added to the molten metal.

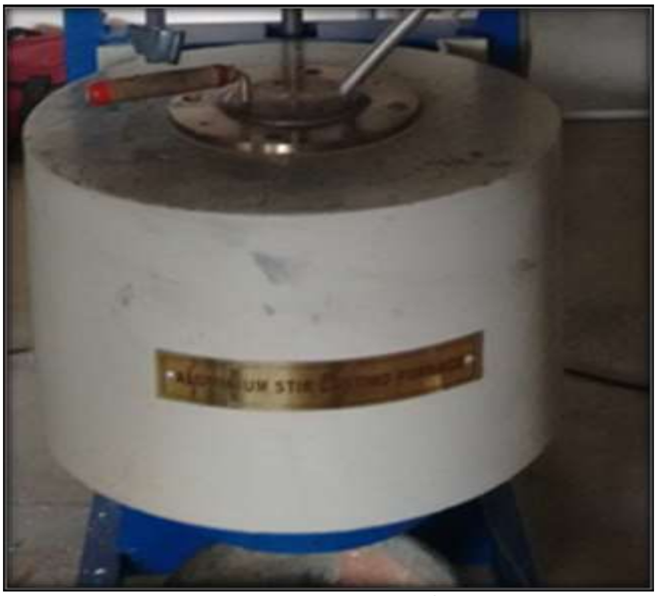

Fig. 1 Aluminium stir casting furnace

A mechanical stirrer [Fig. 4] was used to stir the molten material properly in order to obtain a required composition of the material.

Fig. 2 Stirrer

After the molten material was stirred for 5 minutes at 300 rpm, it was then poured into a metal die consist of 30 mm diameter and 300 mm length. As soon as the material was poured into the die, forging was done to avoid casting defects like blowholes. Castings were recovered after the solidification of molten material.

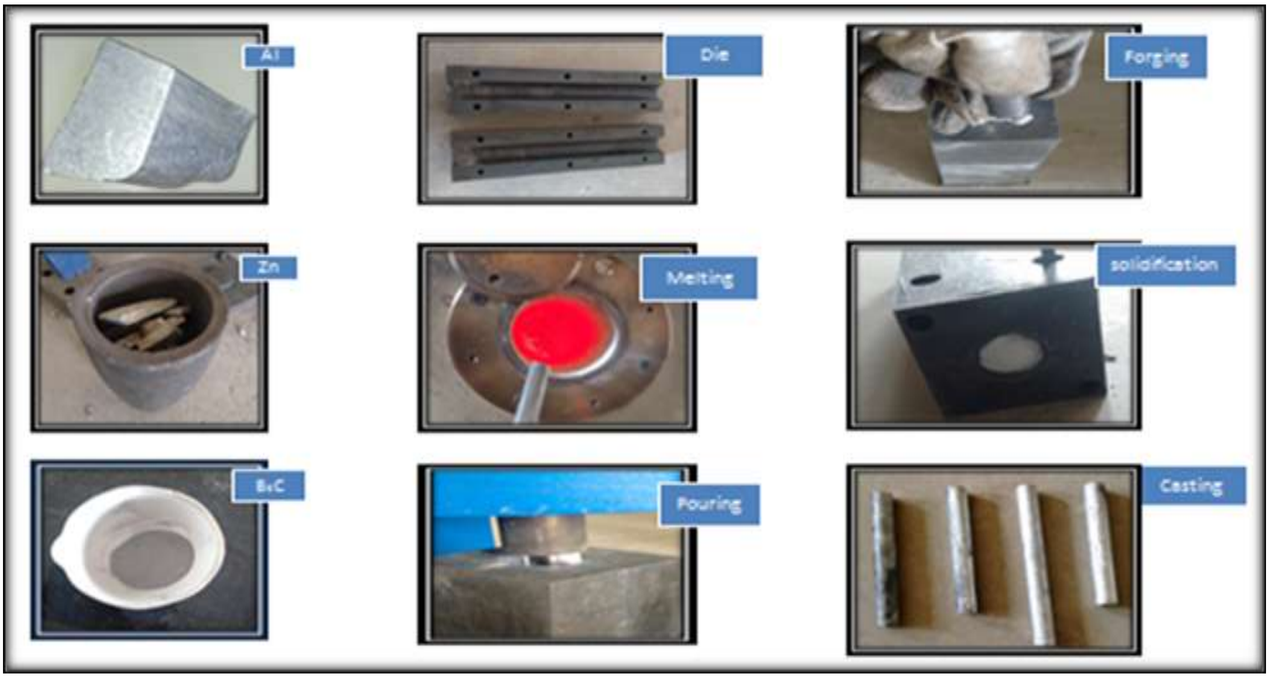

Fig. 3 Stir Casting Process

3.3 Material Testing
3.3.1 Ultimate Tensile Testing
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. Tensile testing, also known as tension testing is a fundamental material science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are an ultimate tensile strength, maximum elongation, and reduction in area. From these measurements, the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Alloys

have been machined according to ASTM standard [Fig. 6] to do tensile testing. The test was conducted on Universal Tensile Testing Machine.

Fig. 4 samples for tensile testing

3.3.2 Hardness Testing

Hardness is defined as the ability of a material to resist plastic deformation. Hardness was measured as per Vickers scale. The Vickers hardness test was developed in as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of Pascal's, but should not be confused with pressure, which also has units of Pascal's. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force and therefore not pressures. Alloys have been machined according to standard [Fig. 7] to do hardness testing. Hardness was measured as per Vickers scale.

Fig. 5 samples for hardness testing

3.3.3 Microstructure

The microstructure is the small-scale structure of a material, defined as the structure of a prepared surface of the material as revealed by a microscope above 25× magnification. The microstructure of a material such as metals, polymers, ceramics or composites can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low-temperature behaviour or wear resistance. These properties, in turn, govern the application of these materials in industrial practice. Microstructure at scales smaller than can be viewed with optical microscopes is often called nanostructure, while the structure in which individual atoms are arranged is known as the crystal structure. The nanostructure of biological specimens is referred to as ultrastructure. Microstructural evaluation ranges from simple determination of certain parameters such as grain size or coating thickness through porosity and pore structure to full characterization of multi-component systems or evaluation of degradation or failure mechanisms. To quantify microstructural features, both morphological and material property must be characterized. Image processing is a robust technique for determination of morphological features such as volume fraction, void, and crystal orientations. To acquire micrographs, optical as well as electron microscopy are commonly used. To determine material property, Nanoindentation is a robust technique for determination of properties in micron and submicron level for which conventional testing is not feasible. Conventional mechanical testing such as tensile testing or dynamic mechanical analysis

(DMA) can only return macroscopic properties without any indication of microstructural properties. However, Nanoindentation can be used for determination of local microstructural properties of homogeneous as well as heterogeneous materials. Alloys have been machined [Fig. 8] to study microstructure. Microstructures were studied under a Zeiss Axiovert Inverted Microscope.

Fig. 6 Samples for studying microstructure

CONCLUSION

a) Zn- Al alloy has been successfully reinforced with Boron Carbide powder.

b) Zn-Al alloy without reinforced Boron Carbide is found to have lower tensile strength than Zn-Al alloys which were reinforced.

c) Zn-Al alloy without reinforced Boron Carbide is found to have a lower hardness than Zn-Al alloys which were reinforced.

d) Zn-Al alloy without reinforced Boron Carbide has higher percentage elongation than the ones which were reinforced.

e) As the composition of reinforcement increases from 1% to 6%, it is observed that the hardness and tensile strength of Zn-Al alloys reinforced with Boron Carbide increase, whereas percentage elongation decreases.

RESULTS AND DISCUSSIONS

5.1 Hardness

Hardness is defined as the ability of a material to resist plastic deformation or more elaborately it is defined as the resistance of a material to deformation, indentation, or penetration by means such as abrasion, drilling, impact, scratching, and/or wear, measured by hardness tests such as Brinell, Knoop, Rockwell, or Vickers. Hardness was measured as per Vickers scale. The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and they're average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. Hardness values obtained for each alloy are listed in Table 2

Table II Hardness value for all alloys

Alloy No	Description	Hardness(HV)
1	with out reinforcement	90
2	with 1wt.%reinforcement	98.2
3	with 3wt.%reinforcement	105
4	with 6wt.% reinforcement	116.3

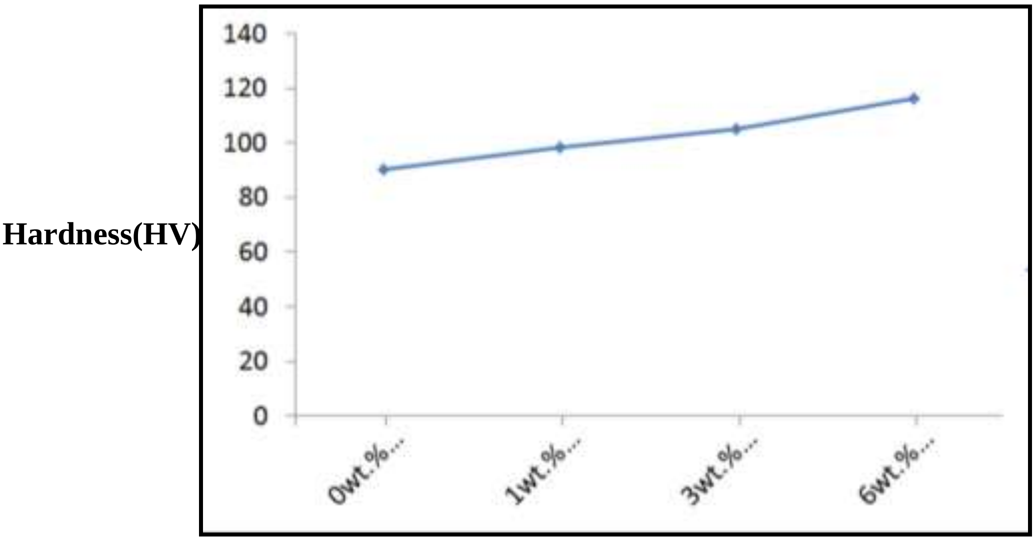

Fig. 7 Graph-Reinforcement Composition vs Hardness

Alloy 1 that was prepared without reinforcement has a hardness value of 90 HV, which is actually less when compared to the hardness value of Alloy 2, Alloy 3 and Alloy 4 with hardness 98.2 HV, 105 HV and 116.3 HV respectively. Alloy 4 which was prepared with 6wt. % reinforcement has the highest hardness. Here it is observed that as the composition of reinforcement increases hardness value also increases, i.e., the composition of reinforcement is proportional to the hardness of the alloy.

5.2 Tensile Strength and % elongation

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. The UTS is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress-strain curve is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence of surface defects, and the temperature of the test environment and material. Percentage elongation quantifies the ability of an element or compound to stretch up to its breaking point. Tensile strength and Percentage elongation values obtained for each alloy are listed in Table 3

Table III UTS and % elongation values for all alloys

Alloy No	Description	Tensile Strength(Mpa)	Percentage elongation(mm)
1	with out reinforcement	205	8
2	with 1wt.%reinforcement	214	8
3	with 3wt.%reinforcement	240	7
4	with 6wt.% reinforcement	310	5

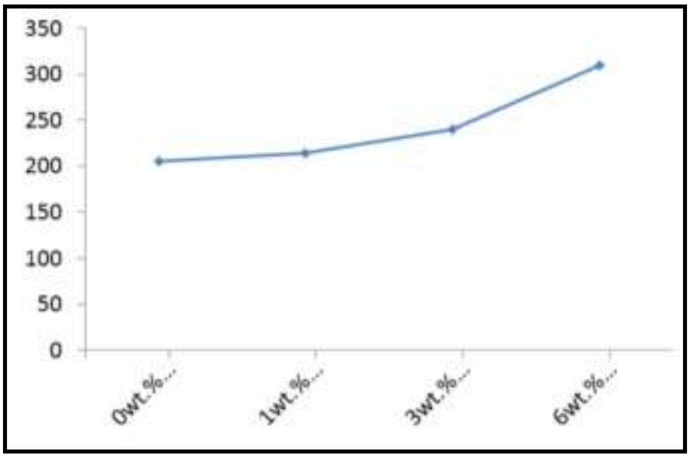

Fig. 8 Graph- Reinforcement Composition vs. Tensile Strength

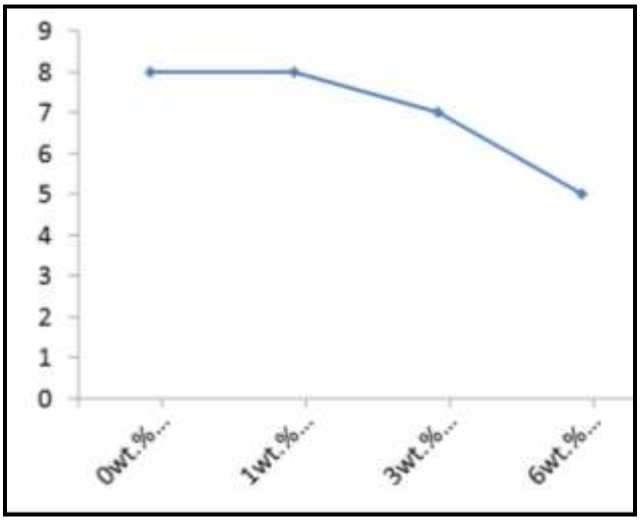

Fig. 9 Graph- Reinforcement Composition vs % elongation

It is found that alloy 1 which was prepared without reinforcement is having a UTS value of 47.85 MPa, which is actually low when compared with the UTS values of alloy 2, alloy 3 and alloy 4 which are having 61 MPa, 85.6 MPa and 96 MPa respectively. Zn-Al is a ductile material so when Boron Carbide (ceramic in nature which is basically brittle) is added to the Zn- Al alloy, the ductile property of alloy gradually reduces. We can also find that as the composition of reinforcement increases, UTS values of alloys decreases. Since % elongation is inversely proportional to UTS, %elongation decreases when the composition of reinforcement was increased. Alloy 1 that was prepared without reinforcement has a % elongation of 8% which is actually high when compared to the % elongation of Alloy 3, and Alloy 4 which is 7%, 5% respectively.

4.3 Microstructure Analysis

The microstructure of all the alloys was observed and captured using Zeiss Axiovert Inverted Microscope.

Fig. 10 Microstructure of Zn-Al alloy without reinforcement from the microstructure of Zn-Al alloy [Fig. 12] it is clear that grains which are formed are coarse, this is the reason behind in getting low hardness.

Fig. 11 Microstructure of Zn-Al alloy reinforced with 1% of B_4C

From the microstructure of Zn-Al alloy reinforced with 1% B_4C [Fig. 13] it is clear that B_4C particles are formed and are distributed uniformly. So hardness and tensile strength will be more when compared to the earlier case.

Fig. 12 Microstructure of Zn-Al alloy reinforced with 3% B_4C

From the microstructure of Zn-Al alloy reinforced with 3% B_4C [Fig. 14] it is clear that B_4C particles which are formed are more when compare to B_4C particles formed in Zn-Al alloy with 1% reinforcement. Hardness and Tensile strength will be higher when compared with Zn-Al alloy without reinforcement.

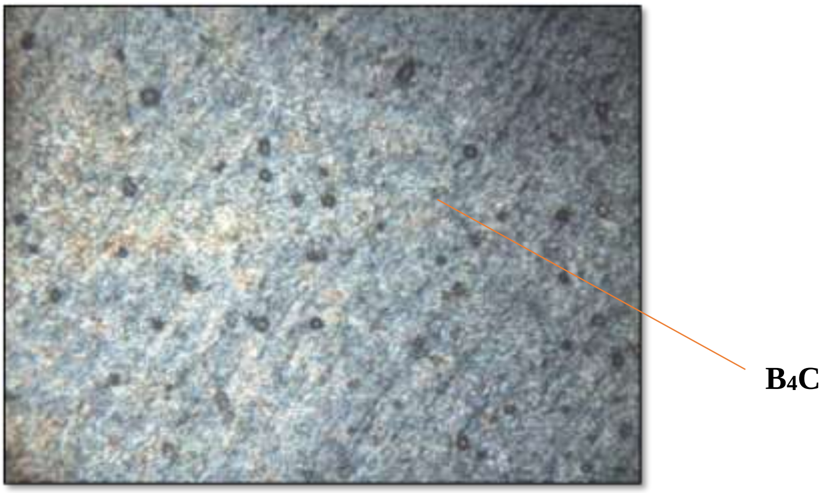

Fig. 13 Microstructure of Zn-Al alloy reinforced with 6% of B_4C

From the microstructure of Zn-Al alloy reinforced with 6% of B_4C [Fig. 15] it is clear that B_4C particles which are formed are more when compare to B_4C particles formed in Zn-Al alloy with 1% and 3% reinforcement.

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