Development and Characterization of Al7075+Gr+Hbn Metal Matrix Composite through Stir Casting

Raju B.S[1], S. Sagar G Noolvi[2], Sanju Patil[3], Sunil Kumar[4], Vishal Bale[5]
[1, 2, 3., 4, 5] Dept of Mechanical Engineering
[1, 2, 3, 4, 5] REVA University

Abstract- *Aluminium matrix composites with multiple reinforcements(hybrid) are finding increased application because of improved mechanical and tribological properties and hence are better substituents for single reinforced composites.AL MMC sought over other convention materials in the field of aerospace, automobile & marine application owing to their excellent improved properties. The present study focuses on the influence of addition of hBN Particulates as a second reinforcement on the behavior of AL matrix composites reinforced with graphite particulates.AL matrix composites reinforced with graphite & hBN are studied with regard to physical & mechanical characteristics. Physical characteristics are density & mechanical characteristics are tensile, compression, wear, hardness test. Hybrid composites exhibits better characteristics compared to pure AL matrix. Which is an end result of the work.*

Keywords- Hybrid composite, stir casting, hBN, graphite, material characterization.

I. INTRODUCTION

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and having bulk properties significantly different from those of any of the constituents. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical property of steel are similar to those of pure iron). Favorable properties of composites materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

MATRIX PHASE

1. The primary phase, having a continuous character.
2. Usually more ductile and less hard phase.
3. Holds the reinforcing phase and shares a load with it.

REINFORCING PHASE

1. Second phase (or phases) is imbedded in the matrix in a discontinuous form.
2. Usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Composites as engineering materials normally refer to the material with the following characteristics:

1. These are artificially made (thus, excluding natural material such as wood).
2. These consist of at least two different species with a well defined interface.
3. Their properties are influenced by the volume percentage of ingredients.
4. These have at least one property not possessed by the individual constituents.

Performance of Composite depends on:

1. Properties of matrix and reinforcement.
2. Size and distribution of constituents.
3. Shape of constituents.
4. Nature of interface between constituents.

1.2 CLASSIFICATION OF COMPOSITES

Composite materials are classified as

a. On the basis of matrix material.
b. On the basis of filler material.

1.2.1 On the basis of Matrix:

1. Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.

2. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and imbedded fibers of other ceramic material (dispersed phase).

3. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

1.2.2 On the basis of Material Structure:

1. Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles.

1. Composites with random orientation of particles.
2. Composites with preferred orientation of particles.

Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

2. Fibrous Composites

1. Short-fiber reinforced composites

Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter).

1. Composites with random orientation of fibers.
2. Composites with preferred orientation of fibers.

2. Long-fiber reinforced composites

Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.

1. Unidirectional orientation of fibers.
2. Bidirectional orientation of fibers (woven).

3. Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

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Applications

a) MMCs are primarily used in military and aerospace applications.
b) The most important commercial application to date is the MMC diesel engine piston made by Toyota. This composite piston offers better wear resistance and high-temperature strength than the cast iron piston it replaced.
c) Commercial applications include cutting tools and circuit-breaker contacts.
d) High-temperature fighter aircraft engines and structures; high-temperature missile structures and spacecraft structures.
e) Metal matrix composites with high specific stiffness and strength could be used in applications in which saving weight is an important factor, included in this category are robots, high-speed machinery, and high-speed rotating shafts for ships or land vehicles.
f) Good wear resistance, along with high specific strength, also favors MMC use in automotive engine and brake parts.
g) Application of aluminium matrix composites is gradually increasing in the automotive industries in making pistons, cylinder heads and connecting rods where the tribological properties of the material are very important.

II. LITERATURE SURVEY

- **M K Surappa et. al.in 2003 reported “Aluminium matrix composites: Challenges and Opportunities”.** Several challenges must be overcome in order to intensify the engineering usage of AMCs. Design, research and product development efforts and business development skills are required to overcome these challenges. In this pursuit there is an imperative need to address the following issues. Science of primary processing of AMCs need to be understood more thoroughly, especially factors affecting the microstructural integrity including agglomerates in AMCs. There is need to improve the damage tolerant properties particularly fracture toughness and ductility in AMCs. Work should be done to produce high quality and low cost reinforcements from industrial wastes and by-products. Efforts should be made on the development of AMCs based on non-standard aluminium alloys as matrices. There is a greater need to classify different grades of AMCs based on property profile and manufacturing cost. There is an urgent need to develop simple, economical and portable non-destructive kits to quantify undesirable defects in AMCs Secondary processing is an important issue in AMCs[1].

- **Estrada-Guela et.al. studied in 2008 investigated, "Effect of Graphite nano particle dispersion in 7075 aluminum alloy by means of mechanical alloying method in a high energy ball mill".** Dispersion of metalized graphite nano particles (GNP) of 20–30μm reinforcements in 7075 aluminum alloy and composites were micro structurally and mechanically characterized. Composites were cold compacted, sintered, and hot extruded in order to obtain samples for mechanical evaluation (hardness and tension). From a micro structural point of view, milling time and graphite concentration had an important effect on the refining sequence and mechanical properties of prepared composites. The correlation among the different stages of MA with the powder morphology, particle size, and apparent density is clear. In accordance to morphological results, density variation versus milling time indicates severe plastic deformation of the aluminum powder during milling which form flake-like particles with low density during the early stages of processing; when the hardening particles were addeBd, they accelerated the milling process of the aluminum matrix, reached a stable state condition, and; consequently, the density rate increases considerably. The results of the tensile test and hardness measurements for the prepared composites show a significant increase (40%) in maximum tensile strength and inhardness (20%) as compared to the blanks (as-mixed and extruded sample) [2].

- **G. B. Veeresh Kumar1 et.al.Studied in 2010,"Al7075-Al2O3 Metal Matrix Composites".** Particle reinforced composites have a better plastic forming capability than that of the whisker or fiber reinforced ones. The composites are prepared using the liquid metallurgy technique, in which Al2O3 reinforced 2 to 6 wt. % of size 20μm particulates were dispersed in the base matrix in two steps. The particles were preheated before being introduced into the vortex and stirring of the molten composite were accomplished for 10 minutes at 400 rpm starrier speed. Pouring temperatures adopted were 720ºC. The cylinders of 22mm X 210mm cast composites of Al7075-Al2O3 were obtained. Test material as pin and high carbon EN31 steel (HRC60) as counter-surface, equipped with LVDT and digital display system served to record the wear height loss in microns . Al2O3 resulted in improving the hardness and density of their respective composites. Further, the increased % of these reinforcements contributed in increased hardness and density of the composites. Micro hardness of the composites found increased with increased filler content and the increase in hardness Al7075-Al2O3 composites are found to 80-109VHN.It can be observed that the hardness of the Al7075-Al2O3 composite are higher2.83g/cc at 6% Al2O3.Tensile strength increases by 24% as Al2O3 reinforcement increases from 2 to 6 % and is upto 280MPa at 6 % Al2O3 reinforcement. Variation of Wear Factor at different RPM for Al7075 -Al2O3 composites sliding, under applied load of 10N at a speed of (a) 100 rpm, (b) 300 rpm & (c) 500 rpm it shows as sliding speed and distance and applied load increases wear rate also decreases [3].

- **Baradeswaran et.al.in2.13 reported, "Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites".** Ceramic particles along with solid lubricating materials were incorporated into aluminium alloy matrix to accomplish reduction in both wear resistance and coefficient of friction by using liquid metallurgy route.The Al7075/Al2O3/graphite hybrid composite was prepared with 5 wt.% graphite particles addition and 2, 4, 6 and 8 wt.% of Al2O3 about an average particulate size of 16μm. The hardness, tensile strength, flexural strength and compression strength of the hybrid composites are found to be increased by increased weight percentage of ceramic phase. The wear properties of the hybrid composites containing graphite exhibited the superior wear-resistance properties. The composite were given a T6 heat treatment. Pin specimens of 6 mm diameter and 15 mm height for wear test was prepared. An OHNS (Oil Hardened Nickel Steel) 55 mm diameter steel disc of 60HRc was used as the counter surface in the wear test. The test was conducted with various loads of 20 N, 40 N and 60 N at a sliding speed of 0.6, 0.8 and 1.0 m/s for the constant sliding distance of 2000 m. The test was conducted at room temperature (30ºC) and relative humidity of 60–65%. The hardness tests were carried out according to ASTM E10-07 standards using Brinell hardness testing machine with a 10 mm ball indenter and 500 kg load for 30 s. As per the ASTM E08-8 standard, the tensile strength was evaluated on the cylindrical rod of casted composites. The 1200 grit grinding SiC paper was used to polish the test specimens in order to decrease the machining scratches and the effects of surface defects on the sample. The universal testing machine (UTM-Auto instrument) loaded with 10 kN load cell was used to conduct the tensile test. The tensile strength was evaluated at cross head speed of 2.5 mm/min. The compression test was performed on these samples with computerized universal Testing Machine (UTM-Auto instrument)) at room temperature and ultimate compression strength of these samples was measured as per ASTM E9-09 standards. The test was conducted at a cross head speed of 1 mm/min. The higher hardness values for the hybrid composites containing 8 wt.% of Al2O3 is due to the presence of hard Al2O3 particles The tensile strength was increased with increasing Al2O3 content. The graphite addition normally decreases the strength but with the addition of Al2O3 particles improves the mechanical properties [4].

- **R.Keshavamurthy,et.al.in 2013 studied, "Microstructure and Mechanical Properties of Al7075-TiB2 in-situ composite".** Stir casting technique was adopted to fabricate Al7075-TiB2 composites. Micro hardness, yield strength and ultimate tensile strength of Al7075-TiB2 composite are considerably higher when compared with unreinforced alloy. However, the ductility of the composite was decreased when compared with unreinforced alloy. It is observed that there is a remarkable improvement in the micro hardness of the composite when compared with unreinforced alloy. An improvement of 32.5% is observed in the hardness of the composite when compared with the unreinforced alloy. The hardness behavior of composite is also affected by grain refinement of matrix alloy and fine and even distribution of reinforced particles. Reduction in grain size always enhances the hardness of the composites. Smaller the grain size, higher will be the obstructions for dislocation motion, thereby improving the resistance to plastic deformation resulting in increased hardness. It is observed that composite shows higher ultimate tensile strength and yield strength when compared with unreinforced alloy. A maximum improvement of 33.9% and 13.55% has been observed in tensile strength and yield strength of the composite. Optical micrograph shows reasonably uniform distribution of TiB2 and AlTi3 particles. Average grain size of the composite was lower than unreinforced alloy. A considerable improvement in the hardness 148 VHN of the composite is observed when compared with the unreinforced alloy. Al7075-TiB2 composite exhibited higher tensile strength, yield strength 118 N/mm2and lower ductility when compared with unreinforced alloy [5].

- **AdeyemiDayoIsadarea et.al. in 2013 find out, "Effect of Heat Treatment on Some Mechanical Properties of 7075 Aluminium Alloy".** From the outcome of this study, there is formation of micro segregations of MgZn2 during the gradual solidification of 7075 aluminium alloy due to solute redistribution of Mg and Zn but this was suppressed during rapid solidification. However, the micro segregations that were formed when it was gradually cooled are dissolved to form a homogeneous phase during the soaking period of heat treatment operations. As a result of age hardening heat treatment operation there is formation of small and finely uniform dispersed precipitate of MgZn2 in the aluminium matrix. While coarse grains of MgZn2 phase was formed in aluminium matrix as a result of annealing heat treatment operation it has been found that rapid solidification process and heat treatment eliminate the formation of micro segregation and significantly improved some mechanical properties. Age hardening heat treatment operation was found to improve yield strength, ultimate tensile strength and hardness values but lower ductility and impact strength. On the other hand annealing heat treatment operation improves impact strength and ductility but lower yield strength, ultimate tensile strength and hardness values[6].

III. SCAN OF LITERATURE REVIEW

From literature survey, It is observed that only of a few investigations have carried out to find the mechanical and physical properties of hybrid metal matrix composite using stir casting technique.

- Formation of metal matrix composite according to required composition.
- The investigation done only on the combination such as AL7075/AL_2O_3/Gr, AL7075/SiC/Gr, AL7075/Zirconium/Gr, The presence study explains about combination of **AL7075/hBN/Gr.**
- Casting is obtained by the most affordable technique that is stir casting technique.
- To develop the specimen from the casting is machined to desired dimensions(ASTM) for the test to be carried out.

IV.OBJECTIVES

- To develop the metal matrix composite of AL7075/Gr/hBN through the stir casting process.
- To study the characterization of the cast material by different mechanical tests like tensile, compressive, hardness, wear .And to study the density of the metal matrix composite.
- To study the microstructure behavior of the metal matrix composites.

V. MATERIAL CHARACTERIZATION

The following tests have been carried out:-

- TENSILE TEST

Tensile testing, also known as tension testing, is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking 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. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. Some materials use biaxial tensile testing.

$$S = F/A \quad ....(1)$$

Where,
S=Breaking strength
F=Force that caused the failure
A=Least cross section area of the material

- COMPRESSION TEST

Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate. In other words, compressive strength resists compression (being pushed together), whereas tensile strength resists tension (being pulled apart). In the study of strength of materials, tensile strength, compressive strength, and shear strength can be analyzed independently.

- WEAR TEST

Several standard test methods exist for different types of wear to determine the amount of material removal during a specified time period under well-defined conditions. ASTM International Committee G-2 standardizes wear testing for specific applications, which are periodically updated. The Society for Tribological and Lubrication Engineers (STLE) has documented a large number of frictional, wear and lubrication tests. Standardized wear tests are used to create comparative material rankings for a specific set of test parameter as stipulated in the test description.

- HARDNESS TEST

Hardness is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion. Some materials (e.g. metals) are harder than others (e.g. plastics). 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.

- DENSITY TEST

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), although the Latin letter D can also be used. Mathematically, density is defined as mass divided by volume where ρ is the density, m is the mass, and V is the volume. In some cases (for instance, in the United States oil and gas industry), density is loosely defined as its weight per unit volume although this is scientifically inaccurate – this quantity is more specifically called specific weight.

$$\rho = m/ V. \ (gm/cm^3).......................(2)$$

- MICROSTRUCTURE

Compared to many other metals and alloys and many other materials, such as carbides, ceramics and sintered carbides, aluminum and its alloys are low in strength and hardness. Aluminium is a soft, silvery metal with a face-centered cubic crystal structure, a hallmark of ductile metals. Its softness makes it somewhat difficult to prepare but the alloy is not sensitive to problems that plague preparation of magnesium and titanium, that is, a sensitivity to mechanical deformation that generates mechanical twins.

VI. RULE OF MIXTURE

- Casting is categorized into 4 parts :-

i. Al7075
ii. Al7075+ 5% Graphite+ 1.5% hBN
iii. Al7075+ 5% Graphite+ 3% hBN
iv. Al7075+ 5% Graphite+ 4.5% Hbn

VII. RAW MATERIALS USED

- **Hexa Boron Nitride (hBN):**

Boron nitride has excellent thermal and chemical stability and also high hardness. The particle size of hexa boron nitride used in this study is 7-11 microns. The grade of hexa boron nitride used is HCV grade. HCV grade is a basic grade of boron nitride and this serves as a starting block for the production of many advanced materials.

- **Aluminium 7075**

Aluminium 7075 has an excellent machinability property. It exhibits well resistant to corrosion under both ordinary atmosphere and marine conditions. [2] Aluminium 7075 (Al7075) is chosen as the matrix material since, it is low cost and has better properties like good thermal conductivity, high shear strength, abrasion resistance, high-temperature operation, non-flammability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment. It possesses excellent casting properties and reasonable strength. This alloy is best suited for mass production of lightweight metal castings. The density is 2.81 g/cm^3 and melting point of aluminium is 800^{o}C.

- **Graphite**

The acoustic and thermal properties of graphite are highly anisotropic, since phonons propagate quickly along the tightly-bound planes, but are slower to travel from one plane to another. Graphite's high thermal stability and electrical and thermal conductivity facilitate its widespread use as electrodes and refractories in high temperature material processing applications. The density of graphite is 2.26 g/cm^3 and melting point is 4300K.

VIII. RESULTS AND DISCUSSION

Tensile Test:

The tensile tests are conducted in TENSOMETER, having load capacity 20KN and also have an accuracy of ±1%. Specimens were prepared according to ASTM for testing. Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract.

The tensile test specimens are shown in below figure:

Fig : Specimens before testing **Fig :** Specimens after testing

Table :experimental ultimate tensile strength is tabulated..

SL NO	COMPOSITION	TRUE UTS(N/mm^2)
1	Al 7075	143.0
2	Al+5%Gr+1.5%HBN	86.0
3	Al+5%Gr+3%HBN	167.9
4	Al+5%Gr+4.5%HBN	109.3

Density Test :

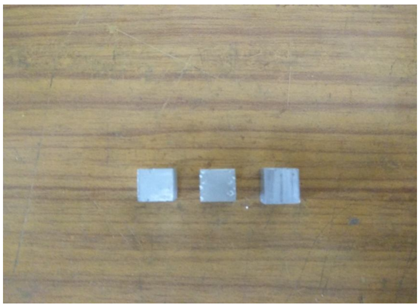
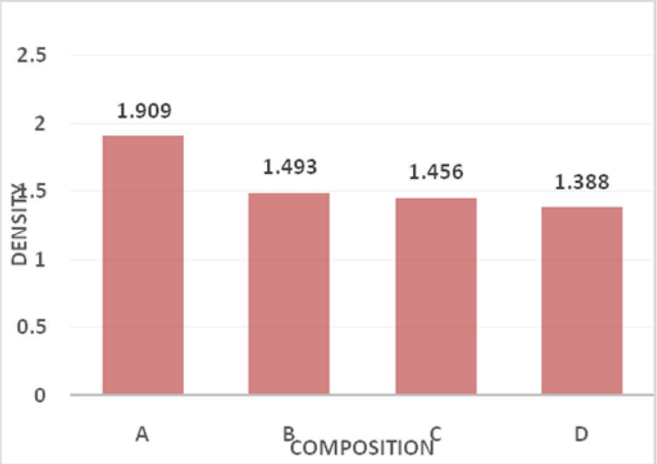


Fig : Density specimens

Table : Density test results

Sl no	COMPOSITION	DENSITY ρ(gm/cm^3)
1	Al 7075	1.909
2	Al+5%Gr+1.5%hBN	1.493
3	Al+5%Gr+3%hBN	1.456
4	Al+5%Gr+4.5%hBN	1.388



Graph: Effect of hBN particles on density of composite

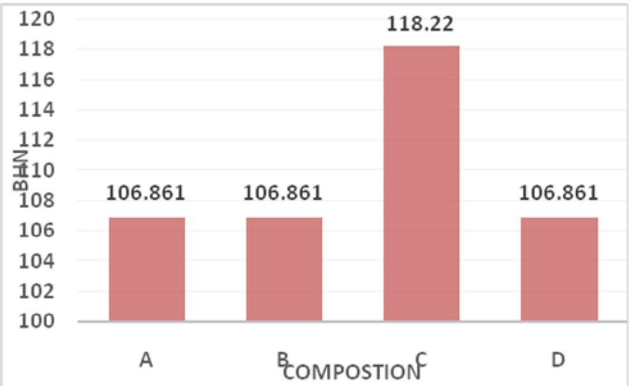
Density is found to be decreasing with increasing in percentage of reinforcement. This is because of the fact that graphite and hBN light materials.

Hardness Test:

Brinell hardness test is conducted to know the hardness of composites. Here load of 250Kgf is applied for about 10 seconds and the diameter of impression made was measured using the Brinell microscope. BHN is calculated using brinell hardness formula.

Table : Shows the hardness test results

SL NO	COMPOSITON	AVG BHN (kgf/mm^2)
1	Al7075	106.861
2	Al+5%GR+1.5%hBN	106.861
3	Al+5%GR+3% hBN	118.22
4	Al+5%GR+4.5%hBN	106.861



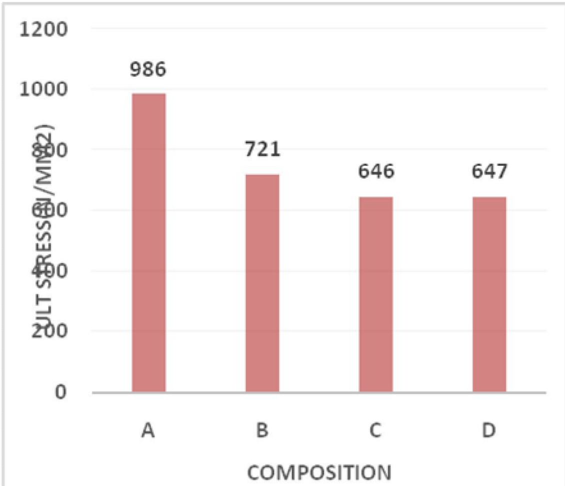
Brinell hardness found to be increasing with increasing percentage of the reinforcement. This is because of the reason that there is uniform distribution of matrix phase and also the hard nature of the hBN(third hardest known after graphite and boron nitride) used as reinforcement.

Compression Test:

The incorporation of hBN particles enhances the compression strength of the matrix, The compression strength shows a decreasing relationship with the quantity of particle addition. The maximum compression strength is found to be **986.0 N/mm^2** for pure aluminium**.**

Table: Compression test results

SL NO	COPOSITION	ULT STRESS (N/mm^2)
1	Al 7075	986.0
2	Al+5%Gr+1.5%hBN	721.0
3	Al+5%Gr+3%hBN	646.0
4	Al+5%Gr+4.5%hBN	647.0



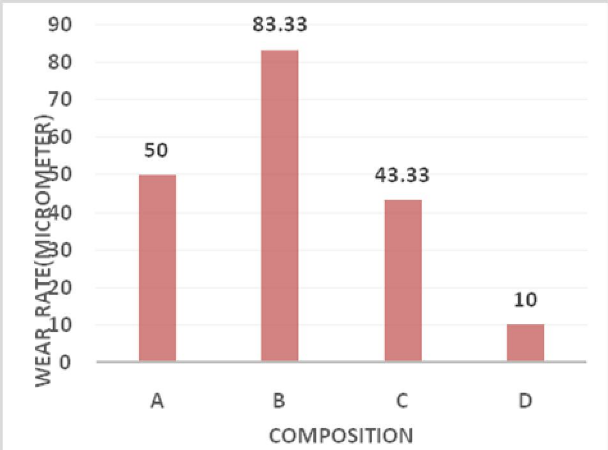
Graph: Effect of hBN particles on compressive strength of composite

Wear Test:

The experimental work carried out on wear test shows that by keeping speed constant and with the time interval of 10 min the wear rate has been gradually decreased.

Table : Wear test results

SL NO	COMPOSITION	Wear (micrometer)
1	Al 7075	50
2	Al+5%Gr+1.5%hBN	83.33
3	Al+5%Gr+3%hBN	43.33
4	Al+5%Gr+4.5%hBN	10



Graph: Effect of hBN particles on wear rate of composite

By increasing the % of hBN, the wear rate has been increased for the composition B and after it the wear rate is decreased.

Micro Structure:

Microstructure tests are conducted for each specimen by using optical metallurgical microscope. Microstructure tests are conducted for each sample. Microstructure test revels that the uniform distribution of the reinforcements in the aluminum alloy.

The below figure shows the microstructure of Al 7075 alloy with reinforcement of graphite and hBN .

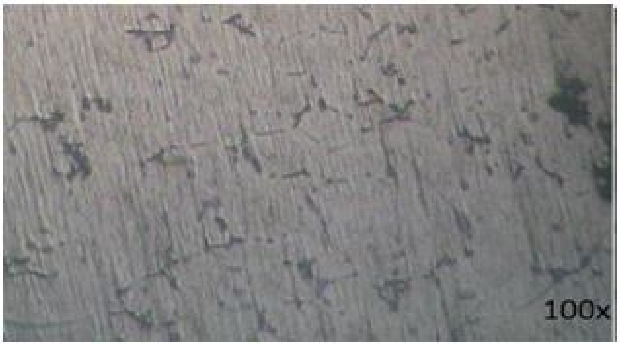


Fig : Microstructure of Al7075

Fig: Microstructure of Al7075+5%Gr+1.5%hBN

Fig : Microstructure of Al7075+5%Gr+3%hBN.

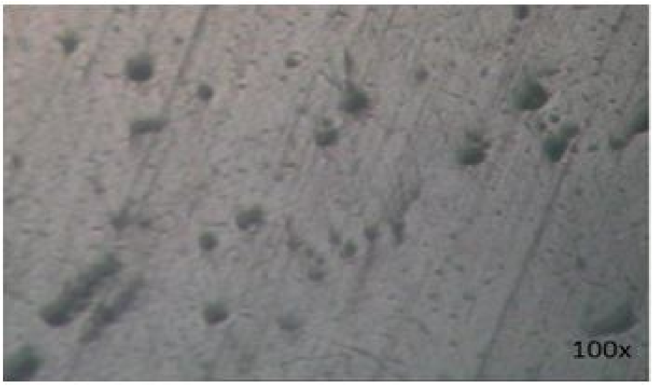


Fig : Microstructure of Al7075+5%Gr+4.5%hBN

Microstructure Structure studies reveals that uniform distribution of hBN particles in the Al7075 alloy. The microstructure clearly indicates fairly uniform distribution of hBN particles in the matrix along with evidence of minimal porosity in both the base alloy and the composite. Further, an excellent bonding between the matrix and the reinforcement particles was observed.

IX. CONCLUSION

- Aluminum based hybrid metal matrix composites have been successfully fabricated by stir casting method by addition of reinforcements combined with preheating of particles.

- The density of composites was found to decrease with the increase in the % weight of the hBN. The density is less for the composition D(5%Gr and 4.5% hBN) than the other composites due to light weight property Gr and hBN.
- The hardness of the composites was found to be enhanced with the increase in the % weight of the hBN . The hardness is more for the composition C(5% Gr and 3% hBN).
- The UTS was found to be decrease with the increase in hBN content. Increase in hBN content significantly reduces the ductility and tensile strength by incorporating brittle nature.

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