STUDY OF MECHANICAL AND TRIBOLOGICAL BEHAVIOR OF COMPOSITE MATERIAL AS A FAN SHAFT MEMBER

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Abstract - Demand for verity of application oriented engineering materials with suitable thermo- mechanical properties of the material, is a major problem faced by the majority of the industries. Modern industries adopt the latest technology which requires properties such as low weight density, better strength, stiffness, thermal strength stability etc. in industries like space research, aircraft, marine automobile etc. such properties cannot be achieved by the conventional engineering materials like metals, ceramics, plastics, polymers etc. but the required qualities can be obtained by the combination of various types of above mentioned materials and it is so called as composite materials.

Composite materials: It becomes our prime duty to know what actually composite material means " it is a mixture of two or more immiscible material in which major concentration constituent is known as Matrix and other variable concentration constituent with different physical & chemical composition suspended in the matrix which are immiscible is so called as Reinforcement. The so obtained material, possess better properties compared when compared with the individual material.

1. INTRODUCTION

Demand for verity of application oriented engineering materials with suitable thermo- mechanical properties of the material, is a major problem faced by the majority of the industries. Modern industries adopt the latest technology which requires properties such as low weight density, better strength, stiffness, thermal strength stability etc. in industries like space research, aircraft, marine automobile etc. such properties cannot be achieved by the conventional engineering materials like metals, ceramics, plastics, polymers etc. but the required qualities can be obtained by the combination of various types of above mentioned materials and it is so called as composite materials.

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2. NEED FOR DEVELOPING COMPOSITE MATERIALS

The draw back with the conventional engineering materials is the existence of the various mechanical properties in single materials. I.e. if a material possess good strength and wear resistant property then the weight density of the material may be very high or vice-versa. In majority of the case, engineering materials are expected to possess low weight density and good strength, as we know that the performances of any equipment's are directly dependent on the weight. So to meet the requirement, the concept of using different materials with various required properties come in to picture.

A suitable metal or a metal alloy is selected as a base material with major portion, and an immiscible impurity added known as reinforcement which may or may not be a metal which enhances the mechanical property, as well as reduces the weight density which makes it suitable for industrial applications.

Some of the properties that get enhanced in the composite materials are as follows:

- Strength
- Stiffness
- Weight
- Fatigue life
- Corrosion resistant
- Thermal insulation
- Thermal conductivity
- Temperature dependent behaviour etc.

Some of the most common application of the composite materials in the industry are as follows:

Automobile, marine& air craft industry: these industries require lower weight &extreme strength of the material.
Construction, Ceramic & Tails industries: Bath Tubs, Swimming pool, ready-made storage tank manufactures.
Electronics: Composites are adopted in Electronics department for manufacturing various types of circuit

boards and other circuit components because of their low thermal expansion.

Sporting goods: Sports goods like bicycle components, shoes for horse ride, helmet, golf sticks, sports racquets etc.

Defence: Because of the good wear resistant property & good strength the composite materials are used for manufacturing of bullet proof jackets, helmets, tankers, guns etc.

Composite materials can be broadly classified in to three main categories namely polymer, metal & ceramics. In particular, based on the matrix used in the synthesis of the composite material, they are classified as:

Polymer Matrix composites (PMC).
Metal Matrix Composites (MMC).
Ceramic Matrix Composites (CMC).

Classification of Composites:
Based on the Matrix Material used, the composite materials with examples are mentioned below:

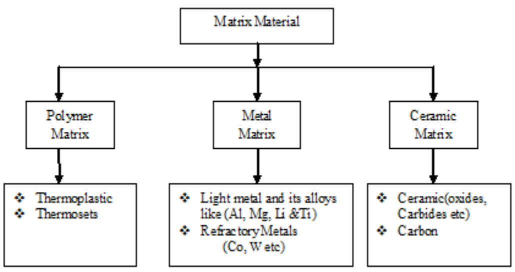


Table 2.1: Composite materials classification.

Metal Matrix Composites (MMC): As name indicates it means that the matrix of the composite material is made up of metals, some of the commonly used matrix materials are Al, Cu, Mg, Co. etc. in which suspended immiscible additives known as reinforcements are added. The most commonly adopted reinforcement materials are Pb, W (Tungsten), Mo (Molybdenum) etc.

Polymer matrix composites (PMC): As name indicates it means that the matrix of the composite material is made up of polymers, some of the commonly used matrix materials are polyester, epoxy, PVC, nylon etc. in which suspended immiscible additives known as reinforcements are added. The most commonly adopted reinforcement materials are Carbon, Steel or Kevlar fibers etc.

Ceramic Matrix Composites (CMC): As the name indicates Ceramic-Matrix, which means that the matrix of the composite material is made up of Ceramic, in which suspended immiscible additives known as reinforcements are added. The most commonly used reinforcement materials are ceramic fibers etc.

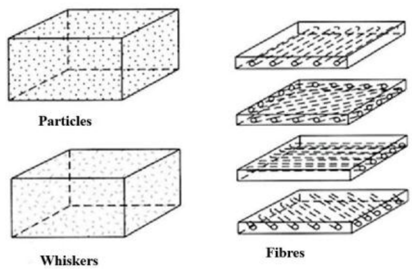
Among the above mentioned categories MMC's are most popularly adopted across the Engineering Domain because of its attractive Mechanical, Thermal & Electrical properties.

Characteristics OF MMCs

- Very high strength.
- Low thermal expansion coefficient.
- Retention of properties at high temperatures.
- Higher operating temperature.
- Better capability to withstand compression and shear loading.
- Much higher fracture toughness.

Based on the Reinforcement materials, the composite materials can be further classified in to following types:

a. Particulate
b. Whiskers
c. Fiber reinforcement



Particulate: The most commonly used type of reinforcement is the particulate reinforcement type of composite material because of its availability and its price. It can be classified in to two types based on the size of particles. The selection of size of particle depends on the required mechanical property. For achieving the better mechanical properties of the composite material, large sized reinforcements are used, which is caused because of the bonding between the matrix material & the reinforcement.

Similarly, the small sized reinforcement present in the composite materials increases resistance towards the plastic deformation, this is because of the lack of dislocation of the matrix. The strength of the plastic deformation depends upon the shape of the reinforced particle. The most commonly used shapes of the reinforcement triangle, square, circular etc.

Whiskers: These are the important category of the reinforcement which increases the directional strength of the composite materials. The reinforcement is classified in to two types depending on the length of the length of the whiskers material

Short fiber reinforced composite material: It is called so because the length of the fiber is less than 100 times that of its diameter

Long fiber reinforced composite material: It is called so because the length of the fiber is greater than 100 times that of its diameter

Again based on the orientation of the fiber material the compositesare further classified in to the different types as follows.

a) Random oriented composite material.
b) Definite oriented composite material.

ii) a) unidirectional composite material.
b) Bi-directional composite material.

Fiber: fibers are the type of whiskers materials reinforcement, which is a combination of different sized and different composition/ material fibers suspended in the matrix material which produces different mechanical properties depending on the fiber concentration and orientation.

Manufacturing Methods of MMC

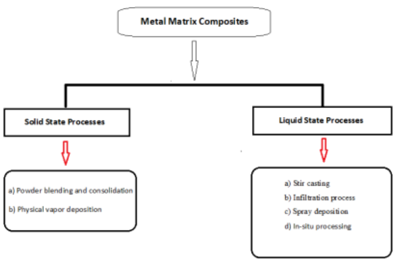
Different manufacturing techniques are been adopted for the manufacturing of the MMC's, based on the mechanical property requirement, texture, finishing & production cost of the so produced material etc.

Some of the commonly adopted techniques are mentioned below along with the sub classification techniques.

The first main classification of the production can be based on the state of the matrix material i.e.

(i) Solid matrix. (ii) Liquid matrix.

The above mentioned categories can be further sub divided in to following types;



The technique that has been adopted by me in the production of composite materials under Liquid State Process is "Stir Casting" Technique.

Stir Casting:
The most adopted technique of the production of the composite material is stir casting. It is a most commonly accepted technique because of low operation cost along with it, the technique is capable of producing a wide Varity of composite material of different composition.

The composite material is manufactured by adopting the following steps.

The matrix material basically a metal or a metal alloy of known mass is taken in a crucible and is heated to its molten state in a furnace.

At the same time a suitable reinforcement which has to be added is pretreated and is added to the crucible.

The electrical stirrer present in the furnace is continuously operated. The main function of the stirrer is to produce vortex in the molten metal which results in the formation of anequal distribution of the suspended reinforcement particles.

The so formed molten immiscible mixture is then casted as per the required shape and size & then taken to the machining process.

The so formed composite materials properties& qualityare dependent on various parameters starting from the molten composite manufacturing till the casting process. Few such parameters are mentioned below.

Pretreatment of the reinforcement material.

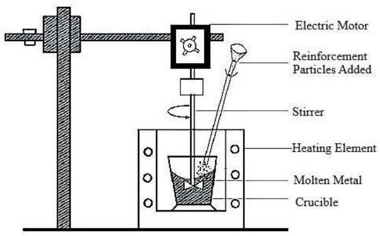
Continuous and uniform stirring using a suitable stirrer as shown in the figure below. Improper stirring results in non-uniform distribution of the reinforcement material results in non-uniform material property.

Smooth and steady mixing avoids the formation on the air bubbles which increases the material strength.

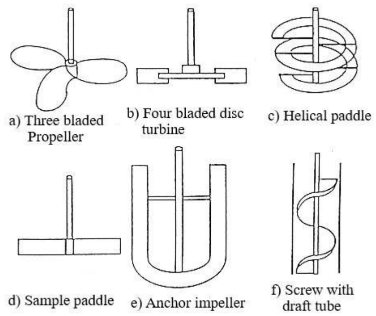
Proper material selection at the appropriate composite formation condition is to be done to avoid reaction between the matrix & reinforcement. (Chemical stability). etc.

Note: The better property of a composite material is due to the wettability among the matrix material and reinforcement material.

Line diagram of stir casting experimental is shown below along with the different types of stirrers that are commonly adopted which produces vortex during stirring process which results in the formation of a homogeneous mixture.



Stir Casting Setup



Different types of stirrer used in stir casting

The two main function of the stirrer are:

To produce homogeneous mixture.

To maintain the particles of reinforcement in the state of suspension in the molten metal matrix.

Important Properties:

Wettability: It is a capability of a molten liquid to form an adhesive force between the suspended solid substances when both are mixed in rancidity. The strength of wettability is a function of cohesive & adhesive force between the molten metal & the suspended particles.

Some of the defects commonly found are distribution of the suspended particles and wettability, both the problems can be avoided by uniformly mixing of the molten and suspended impurity smooth and steadily by using a suitable stirrer operating at an appropriate speed. Another commonly faced problem found during the stirring process is mixing up of unwanted impurity present in the melt along with it the formation of the air bubble in the molten material which weakens the composite strength.

The wettability of the material also depends on the type of suspended particles added. The direct use of the fiber & ceramic particle as a suspended particle are limited in the application as these particles possesspoorwet ablecharacteristicsin aluminum molten metal and hence a suitable wetting agents such as magnesium, copper, tin etc. are used in small composition to increase wettability.
The addition of these particles slightly changes the metallic composition of the composite material but the end products so formed possess excellent mechanical properties than the base material.

The above mentioned materials are some of the commonly used impurities that are added to the molten metal for increasing the wetting behavior of the molten metal.

Mechanical properties:

It is very important to know about the various properties like elasticity, hardness, strength etc. for an engineering material, so that it becomes easy for a person to select an appropriate material for a desirable application based in the desired property depending on the required property.

Strength: It is defined as the property of a material which states the resistance for the deformation or failure of the material when it is subjected to forces like compression, tension, bending torsion etc. Corresponding strengths of a given material is obtained by taking the ratio between the ultimate strength and the instantaneous cross-sectional area.

Hardness: It is a property of an Engineering material which offers resistance to the surface penetration when a hard material is farced against it. It is a major factor in deciding the workability. It bears constant relationship to the tensile strength of given material.

Wear Resistant: The resistance offered by an engineering material for the surface removal when subjected to a repetitive constant contact wear force. These forces are commonly observed when one material slides or moves on the other material.

3. LITERATURE REVIEW

Chuandong wu et. al [6]: In their research, on Al-7075 and B4C composite material in which the prepared composite material was sintered over duration of three minutes at a temperature of 530°C and it was subjected to a microstructure analysis and also they have conducted experiments to determine the various mechanical strengths of the so produced composite material. In his paper the various results were tabulated as below.

Hardness value calculated by Vickers hardness testing machine 181.6HV

Bending strength of the given material was mentioned as 1100.3 MPa.

Compressive strength of the given material was mentioned as 878 MPa.

Fracture strength of the given material was mentioned as 469.3 MPa.

All the strengths mentioned are slightly on the better end of the base material.

Auradi et. al [7]: in his paper, study that has been conducted indicates about the composite composition and their respective mechanical properties and given the conclusion about the most suitable blend with reinforcement. He has used Al 6061 as the matrix material and B4C as a composite material. He has used 11% by wt. as the reinforcement concentration to produce the composite material and conducted test to determine various mechanical properties and found that the properties are much better than the base material i.e. the UTS of the material has increased up to 44% when compared with the parent base material alone.

Pradeep V Badiger et. al [8]: In their investigation, they have selected Al 6061 as the matrix material and the reinforcement material was been selected as B4C. They have varied the concentration of reinforcement as 7% and 9% by the mass fraction and studied the hardness and ultimate strength of the material. The result of their work indicates considerable increase in the above mentioned properties were observed, the ultimate strength of both the compositions were 17% and 38% found to be increased when compared with the base matrix material alone and similarly the compressive strengths were 330 N/mm2 and 355N/mm2 respectively for the combination which is slightly greater than the matrix material alone.

Vettivel et. al [9]: In their study they have conducted test of mechanical properties by considering a hybrid composite where the suspended reinforcement material was taken as B4C and graphite with two different base material of aluminum i.e. Al 7075 and Al 6061. And came to a conclusion that composite material with Al 7075 shows better wear resistance as well as possess slightly greater elongation behavior.

Canakci et. al [10]: in their research they have studied about the abrasive wear behavior of an Al 2025 reinforced with B4C. In their study they have varied the composition of the suspended reinforcement particle and its size.Their study revealed a fact that, increasing volume of reinforcement and reducing the size of reinforcement the density of the so formed composite material decreases but at the same time the hardness of the material and porosity of the so formed composite increases.

Baradeswaran et. al [11]:In their research they have studied about the influence of addition of B4C reinforcement in Al 7075 matrix on the wear characteristics. They have concluded that the wear life of the composite has increased considerably.

Gopal Krishna U.B et. al [12]: Their research mainly involves the study of variation of mechanical properties with variation of the reinforcement particle size. The study was conducted for various reinforce size and concentration. The study revealed that Vickers hardness value for the aluminum B4C reinforced composite material is maximum for 250 microns when the concentration of reinforcement was found to be 12% by Wt. and at the same time the tensile strength of the material was found to be maximum for reinforcement size of 105 microns and when its concentration was found to be 8% by Wt.

Ibrahim et. al [13]: Their research mainly involves the study of variation of Ductility of the material on variation of the reinforcement concentration. His research involves the study of concentration in volume basis. In his research that has concluded states that ductility of composite material reduces gradually with increase in the reinforcement concentration. The fracture of composite material under tension was following cleavage mechanism type..

Kalaiselvan et. al [14]: The material that they have chosen for their research was Al 6061 reinforced with B4C composite material where they have studied about the micro and macro hardness of the composite material and its variation due to the variation in the composition.

He has mentioned clearly that the hardness value has risen from 51.3 HV to 80.8 HV and in the meanwhileBHN has increased from 34.48 to 58.6 BHN. At the same time for the same composition the tensile strength of the specimen shows an increasing value from 182 MPa to 212 MPa

Mathazhagan et. al[15]: their study revealed about increase in the concentration of graphite in the Al-B4C hybrid composite material enhances few properties of the composites and adversely affect few mechanical property. In particular the hardness of the composite reduces with excessive positive variation in the graphite concentration.

4. OBJECTIVES OF CURRENT WORK

Based on the vigorous study and base work of the literature work below mentioned are some of the few basic outcomes of the work that we have carried out.

Study and understand the various manufacturing techniques available for synthesis of the composite material and at the same time clarity about the selection techniques.

To study about the microstructure of the so formed composite material by using SEM.

A shaft member, is subjected for testing of various mechanical properties like tensile test, wear test and Fatigue test etc. and to conclude that weather the composite is suitable for the shaft application or not.

5. METHODOLOGY

This chapter discusses about the experimental set-up followed by the experimental procedures used in the present research, Solidification processing of cast composites and their characterization in respect to microstructure and mechanical properties.

5.1 Selection of Matrix Alloy

Al 1100 is chosen as the matrix alloy to study its density, which is important parameter in manufacturing of lightweight components, low melting point that facilitates casting process with ease, high thermal conductivity, easily available, low economy, which has increased its application for experimental as well as industrial application. Table 4.1 gives the description about the physical properties of Al 1100. The present investigation, which involves synthesis of composites using pure Al 1100 with concentration of 99.674% and magnesium whose purity is 99.92%. To enhance the wettability between the suspended particles and the Al 1100 alloy, Mg of suitable concentration is used. This is done to retain the reinforcement particles inside the molten material. Table 4.2 gives the details about compositions of the commercial Al 1100 and Mg ingots, on weight basis.

Table 5.1: Physical properties of Al 1100

Properties	Values
Elastic modulus (GPa)	69
Density (g/cc)	2.71
Poisson's Ratio	0.33
Brinell Hardness	23-35
Tensile Strength in MPa	90
Melting Temperature	646-657°C

Table 5.2: Composition of the commercial Al 1100 and Mg used in the Research work

Composition on weight basis									
Material	Fe	Mn	Cr	Cu	Zn	Si	Ti	Mg	Al
Al 1100-Ingot	0.132	0.052	-	0.041	0.022	0.074	-	0.005	Bal.
Mg-Ingot	0.020	0.002	0.001	0.016	0.002	0.006	0.001	Bal.	0.023

5.1.1 Applications of Al 1100 alloy

Following details gives the various areas where Al1100 finds its application:

- Food and chemical handling equipment
- Heat exchangers
- Sheet metal, plumbing and fin stock
- Dials and name plates cooking utensils
- Decorative parts
- Giftware, rivets and reflectors

5.2 Selection of Powders or Reinforcement

In the present work, Boron carbide is used for reinforcement. It is having high strength, low density, odorless and insoluble in water, high hardness and high elastic modulus and is non-flammable. Some of the properties of B4C are shown in Table 4.3. The weight density and purity of B4C powders used are as in Table 4.4.

Table 5.3: properties of B4C powder

Properties	Boron Carbide
Molar mass	55.255 g/mol
Melting point	2763°C
Boiling point	3500°C
Appearance	Dark Gray or Black Powder
Odor	Odorless
Solubility in water	Insoluble

Table 5.4: Specification of Boron Carbide (B4C) powder used in this research

Particle Type	Purity (%)	Density (g/cm3)	Supplier
B4C	98.7	2.52	F N Z Solutions

5.2.1 Properties of Boron Carbide

- Extreme hardness.
- Difficult to sinter to high relative densities.
- Effective chemical resistance.
- Dominant nuclear properties (Neutron Absorption).
- Low density.

5.2.2 Uses of B4C:

- Padlocks.
- Grit blastingnozzles.
- Scratch and wear resistant coatings.
- Cutting tools and dies.
- Abrasives.
- Neutron absorber in nuclear reactors.
- High-pressure waterjet cutter nozzles.
- Personal and vehicle anti-ballistic armor plating.

5.3 SELECTION OF CASTING PROCESS

For casting of Al 1100 based composites stir-casting type casting process is commonly used. The setup is as shown in the fig. 4.1.

Stir Casting strategy is a fluid metallurgical procedure where the second stage materials (reinforcements) are brought into the liquid matrix and allowing the blend(mixture) to solidify. Here, the main intention is to increase the wetting property between the suspended particle so called reinforcement and the molten aluminum or its composite, this is the least difficult and most monetarily utilized procedure and called as the vortex method or the stir casting method. The experimental set up mainly of the following parts:

a) Melting unit
b) Stirring arrangement

The melting unit consists of an electrical resistance heating vertical furnace designed for a temperature of 1200°C. One end of the muffle was kept open and the other end was closed with a hole at its center. A suitable steel structure was fabricated to assemble the furnace, leaving sufficient clearance from the floor for placing a mould conveniently right below the furnace.

Melting of the Al 1100 was carried out in a clay graphite crucible that is cleaned regularly to avoid contamination. The graphite crucible (No-6) has a cylindrical tapered shape with an average inner diameter 80 mm and a hole of 12 mm in diameter at the center of its bottom. The graphite crucible is placed inside the furnace and the bottom hole of the crucible is plugged tightly by inserting a graphite stopper in it through the bottom of the furnace. The stopper held in place with the help of a lever arrangement as shown in Fig 4.1.

A stirring arrangement was made for stirring the melt in the crucible. A ½ HP electric motor, having a maximum rated speed of 300 rpm was used to drive the stirrer. The motor was mounted above the furnace by a fixture arrangement as shown in Fig 4.1. The stirrer was coupled to the shaft of the motor by a screw coupling arrangement. A provision was also made for the stirrer height adjustment.

A power supply unit was connected to a supply voltage of 240 V. A suitable thermocouple is adapted to measure temperature of the furnace close to the crucible wall.

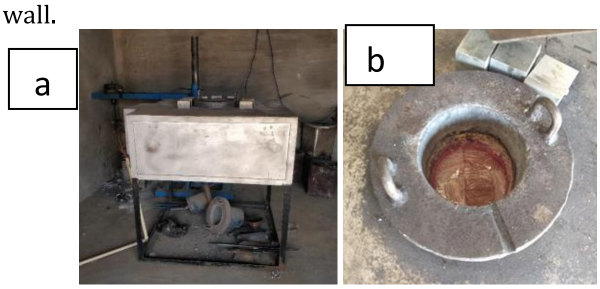


Fig 5.1: Photographs showing a) Stir casting apparatus b) Clay graphite crucible

5.3.1 Mould box details

Permanent split type of two mould made of mild steel is used for casting the composites in present study. First type of mould contained four cavities of 24 mm diameter and length 190 mm and second type of mould with four cavities of 20 mm diameter and length 200 mm. The mould is as shown in the Fig 4.2.

is as shown in the Fig 4.2.

Fig 5.2: Photography showing mould assembly

5.3.2 Selection of stirrer

The use of axial stirrer for agitating the molten metal or alloy would result in the both axial and radial flows and their relative magnitudes could be controlled by the design of stirrer to suit a desired condition of mixing. Further, the viscosity of mixing system, the melt-particle slurry is very important. Three types of stirrer such as flat blade stirrer, turbine blade stirrer and pitched blade stirer were commonly used for the solidification processing of composites by stir casting.

5.3.3 Curved radial blade Stirrer

The stirring process of molten alloy during fabrication is made by using steel blades which is known as mechanical stirrer, and it is coated by very fine alumina powder in sodium silicate followed by curing in the furnace at 100°C over a period to avoid unwanted contamination of molten Aluminum due to significant dissolution of stirrer during stirring of melt Ceramic-coated impeller which is immersed up to ¾ of melt top of molten metals rotated at the speed of around 500 rpm to create the vortex.

Fig 5.3: Curved radial blade impeller used for the Stir casting

5.3.4 Solidification Processing of Composites

In the present research, the matrix material is selected as Al 1100 which is mixed withmagnesium around 2% on weight basis to increase the wetting ability along with the boron carbide particles, the reinforcement concentration was varied in the steps of 2% starting from zero concentration, gradually rising to 2%, 4%, and finally 6%.
Around 1kg and 800grams of Al 1100 was been placed in a muffle furnace using a clay graphite crucible and gradually heated till it melts in a molten state and at the same time it is maintained at a definite temperature for curing. Prior to addition, skimming was done to clean the surface of the melt. Further, base Aluminum pieces were added into the crucible for heating. To enhance the quality of Aluminum composite casting the crucible was covered by flux and degassing agents. Around 900°C a suitable weighed quantity of powder was added to the molten Al 1100. The boron carbide particles were pre-heated to a temperature of 500°C before adding to the melt to remove the moisture content in the powder. A curved radial blade stirrer which is coated was utilizedto facilitate mixing up of the boron carbide particles inside the molten metal. The stirrer speed was kept constant at 500 rpm. The speed of stirrer was measured using non-contact type speed sensor. To

determine the temperature of the molten material a suitable digital indicator which is connected to a chromel-alumel thermocouple is used.

During the processing molten mixture is made sure without varying the temperature continuous stirring process was adapted within the temperature fluctuation limit of 10°C. After adding the boron carbide particle around 2% of magnesium lump on weight basis enclosed in aluminum foil was forced into the molten metal. After the stirring timeis elapsed (10-15 minutes), the stirrer speed is reduced. Further, the crucible is taken out from the furnace and the molten material that has been poured into the module cavity which is of steel moulds split pattern type whose surface is coated with graphite one having four cavities of 24 mm diameter and length of 190mm and another having 20 mm diameter and length of 200 mm as shown in Figure 5. Themolten material in the module cavity is allowed to cool in atmospheric air which is placed exactly below the graphite stopper in order to achieve uniform distribution of particles during the casting process which in turn helps in enhancing the properties of material. The pieces of Al 1100employed for casting and the cast composite are as shown in Figure 4.4 (a) and (b) respectively. At any stage of processing the practice of degassing the melt or the slurry was strictly ruled out.

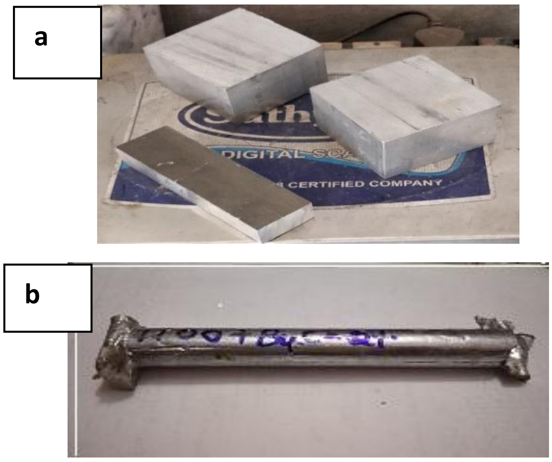


Fig 5.4: a)Aluminum 1100 Ingot andb) Cast Composite

The designation of the cast composite is done on the basis of its constituents and the first letter A indicates the base metal of Al 1100 and the next letter M indicates the alloying element of magnesium, which was kept at 2 wt%. AM is followed by a letter P which represents the presence of boron carbide powder, the letter P is followed by value indicating the wt% of boron carbide powder added. Different composites synthesized by solidification processing and their designations are given as AM for unreinforced cast composite, AMP2 for composite with reinforcement of 2 wt% of B4C particles. Similarly AMP4 for 4 wt% of B4C and AMP6 for 6 wt%ofB4C particles as reinforcement.

Al 1100-Mg alloy has also been synthesized using a vertical electric resistance furnace as shown in Fig 4.1. To attain molten state, pure Al 1100pieces were heated in a graphite crucible. With help of a perforated flat coated spoon dross accumulated on the melt surface is taken out in order to clean the melt. When the temperature of the melt reaches 900°C, the magnesium pieces wrapped by Aluminum foil were into the molten Al 1100. The molten material was continuously stirred in order to obtain a homogeneous metallic composition before it was casted into the module cavity. The nominal composition of alloy and composites is demonstrated in table 4.5.

Table 5.5: Nominal composition of the Aluminum magnesium alloy

Cast Alloy	Al 1100 (wt%)	Magnesium (wt%)
Al 1100-Mg	98	2

5.3.5 Specimans in the Ingot

For investigation of the microstructure, distribution of reinforcing particles and the emanated mechanical properties, the cast ingot below the shrinkage pipe were cut and the three smaller diameter rods were used for fabricating tensile specimens and bigger diameter rodswere utilized for preparing metallographic and hardness specimens.

5.4 X-RAY DIFRACTION ANALYSIS

For investigation of structural characterization of materials, the powder diffraction technique, powdered or micro crystalline samples are commonly used samples for X-ray neutron or electron diffraction process. The equipment that are commonly used to carry out such process is called powder diffract meter.

The B4C particles used for reinforcement are subjected to X-ray diffraction steady-ray diffract meter in the two-theta range of 5-80°Cusing CuKα radiation target and nickel filter. The dwell time and step size were accordingly controlled in order to extract good signal to noise ratio. To obtain the values at intensity peaks and respective values of 2θ, the estimation of inter-planner spacing was done using Bragg's law.

$\lambda = 2d\sin\theta$

Where, λ is wavelength of CuKα radiation used for diffraction and its value was taken to be 1.5413 Å for estimating the d values, in order to identify various phases with the help of inorganic JCPDS X-ray diffraction.

5.5Microstructural Characterization of Al-B4C MMC

5.5.1 Optical Microscope

It is commonly cited as the light microscope, for magnification of imagesit uses lenses and visible light. The invention of optical microscopes in the 17th century prove to be one of are the classical design of microscope. Primitive optical microscopes carry simple design with no complications, whereas with high quality resolution and sample contrast the complex ones are often preferred over the former.

A micrograph is generated using the image from optical microscope captured with help of normal, photosensitive cameras. Earlier photographic films were employed to capture the images but with developments in technology in CMOS and charge-coupled device (CCD) cameras, paved way to capture digital images. Fully digitalized microscopes employing a CCD camera are now available which is used to examine the sample, thus providing the digested image directly on the computer screen eliminating the use of eyepieces.

5.5.2 Scanning Electron Microscopy (SEM)

A focused beam of electrons is impinged on the surface of the sample to generate the images of the sampleby SEM. Adopting standard procedure for metallographic inspection of the cast ingots of the alloy and composites, the samples were prepared and examined under SEM. SEM studies were carried out with ZEISS EVO LS 15kV Scanning Electron Microscope made in Germany. Rather than light beam the Scanning Electron Microscope (SEM) uses electron beam for analysis and generates high resolution images. Fig 4.5 shows ZEISS EVO LS 15 Scanning Electron Microscope.

Fig 5.5: ZEISS EVO LS 15kV Scanning Electron Microscope.

5.6 Studies on Mechanical Properties

5.6.1 Macro Hardness Testing

Brinell hardness test was conducted as per ASTM E10standards for the determination of hardness cast composite material. Materials with coarse grain structure posses rough surface whose hardness are determined by using Brinell hardness teste.g., castings and forgings. High test load of around 3000 kgf are applied with a suitable indenter of around 10mm diameter is used in order to generate indentation that averages out most surface and sub-surface.

A carbide ball indenter of suitable diameter (D) is used for indentation process by applying a suitable load over a stipulated time interval and the load is gradually removed after the designated time interval. The diameter of impression generated on the sample is taken for two diameters which are placed at right angles to each other and then the diameter of indentation are measured separately by using suitable microscope, the results are then tabulated for the variance values of load. The calculation shown below is used to calculate the Brinell hardness number, the averaged number is the converted to BHN using standard chart.

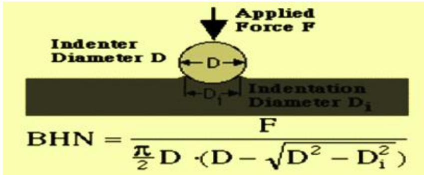


Fig 5.6: Indentation of Brinell hardness number

Where

BHN= Brinell hardness number

F= Load applied in kg

D= Diameter of the spherical indenter in mm

Di = Diameter of indentation in mm

5.6.2 Tensile Testing

Tensile testing often referred as tension test, is an elementary test of materials science and engineering, which involves controlled application of tensile load on standard test specimen until failure occurs. The following are the basic fundamental mechanical properties that are obtained ultimate tensile strength, failure strength, deformation along the length and cross sectional area. Further, the following properties can be deduced with the help of the fundamental mechanical properties that are obtained earlier yield strength, young's modulus, Poisson's ratio and strain-hardening characteristics. Uniaxial tensile testing is one of the most preferred that is carried out for the materials which possess characteristics like isotropic material composition.

The following properties are determined from tensile test

Yield Strength

Tensile Strength

Percentage of elongation

Stress-Strain curve

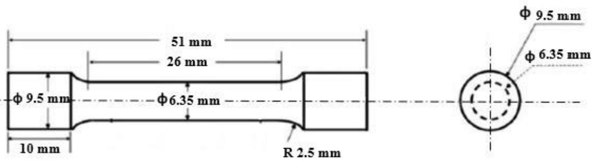


Fig 5.7: Tensile test specimen ASTM E8 standard

Fig 5.8: Tensometer

Fig 5.9: Tensile Test specimens as per ASTM standard

5.6.3 Fatigue Characterization

The fatigue test of the cast composite material were carried out by using Rotating beam fatigue testing experimental set up test rig. ASTM E466 industrial standards were adapted to prepare the test specimen for conducting fatigue testing and is shown in figure 4.10 and 4.11.

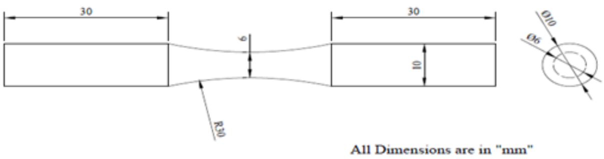


Figure 5.10: Fatigue test specimen as per ASTM E466 standard

Figure 5.11: Fatigue test specimen

A speed of around 2000 rpm was maintained during the fatigue test. The load is applied on to the specimen through weight pan and specimens are tested until failure. The failure life of the given specimen is calculated. The specifications of fatigue testing machine are listed in table 4.6.

Table 5.6 Specifications of Fatigue testing machine

Maximum bending moment	Up to 20Nm
Preset counter with speed	6 digits indicator
Maximum load applied	Up to 200N
Specimen dimensions	Length 70mm-90mm with neck Diameter 4mm-8mm

5.6.4 Rotating Beam Bending Test

Rotating beam bending test is used to find the fatigue life of the component. It consists of two load bearings on which the load can be applied. The specimen is held in firm position and is rotated by the motor. The motor is coupled to the main bearing through a flexible coupling. The number of cycles required for breaking of the specimen is obtained in this test. It will give the fatigue life of the component. Schematic diagram of the rotating beam bending test arrangement is shown in figure 4.12.

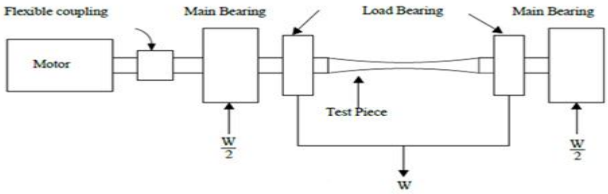


Fig.5.12 Schematic diagram of Rotating Beam Bending test arrangement

5.6.5 Fatigue test procedure

Figure 4.13 shows the rotary beam fatigue test machine. The above manufactured specimen is been rigidly mounted on the rotary beam fatigue testing machine subjected to 3Kg load and at the same time the machine is made to operate with a speed of 2000 rpm and run till failure of the specimen. The same procedure is repeated for different specimens. In the similar fashion life span for various compositions are calculated. Steps that are to be followed for the fatigue test are listed below.

- Measure the dimension of specimen.
- Fix the specimen in its position.
- Apply the loads in the pan attached to the spring.
- Set the reading on the counter to zero and switch on the motor.
- Note down the number of revolution for the failure of the specimen.
- Repeat the test on number of specimen.

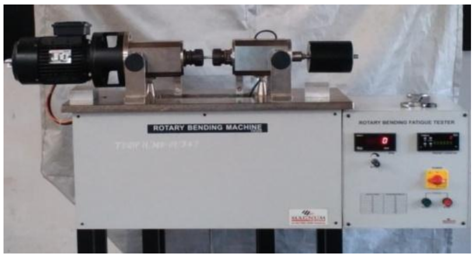


Figure 5.13 Rotating beam fatigue test machine

5.7 Tribological characterization

5.7.1 Pin on disc

The Pin on Disc Friction & Wear Test Rig is essentially adopted for investigation of the tribological characteristics of materials of wide range under various conditions of normal loads & temperatures. Tests under dry & lubricated conditions with different environmental conditions can also be carried out. Figure 4.14 shows the pin on disc apparatus and table 4.7 shows the specifications.

Figure 5.14: Pin on disc apparatus

Table 5.7: Pin on disc apparatus specifications

Parameter	value
Normal load range	Upto 200N
Frictional force range	Upto 200N
Disc speed	100-2000 rpm
Track radius	10mm-100mm
Specimen diameter	3mm-10mm
Pin length	Maximum 30mm
Preset time	Upto 99hrs

For investigation of the tribological properties of the composites, experiment was conducted on pin on disc wear testing machine. The wear test specimen was prepared according to ASTM G99 standard with 10mm diameter and 28mm length. The table 4.8 shows the parameters incorporated for triboligical characterization.

Table 5.8: Experimental parameters for wear and friction test

Experimental parameter	Value
Load	2 kg
Speed	1000rpm, 2000rpm
Sliding radius	20mm
Test run time	15min

The specimens prepared for various percentage of reinforcement were tested under the above mentioned conditions and the results were noted down.

5.8 Numerical Analysis

Finite element analysis is carried out using ANSYS workbench on specimen shaft shown in fig 4.15 to determine the stress and deformation for various percentage of B4C. The boundary conditions and meshing are shown in fig 4.16 and 4.17.

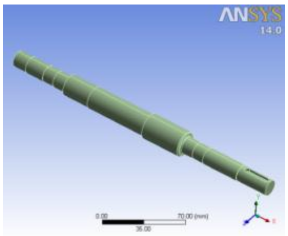


Fig 5.15: Specimen shaft

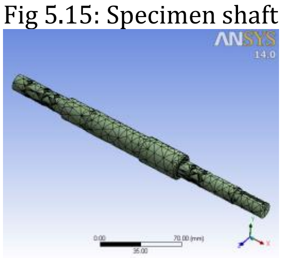


Fig 5.16: Mesh generated in shaft

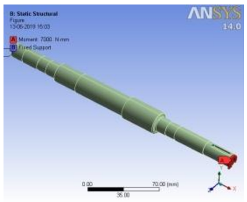


Fig 5.17: Boundary conditions applied

6. RESULTS AND DISCUSSION

6.1 MORPHOLOGY OF B4C PARTICLES

The composite materials were manufactured by adapting Al 1100 as the matrix material mixed with 2 wt% of magnesium in order to increase wettability of B4C particles which are incorporated as reinforcement in quantity of 2, 4 and 6 wt% respectively. Using SEM the shape and microstructure of B4C particles in the powder are investigated. The results of SEM are shown in Fig 5.1. The particle shape was found to be irregular with average particle size of 1µm.

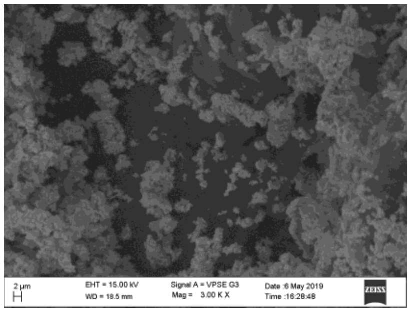


Fig 6.1: SEM micrographs indicates the Size and particle geometry of the B4C powder

The x-ray difraction (XRD) of powder was investigated using X-ray diffrcto meter in the two theta range of 10-90o using nickel filter and CuKα radiation target. Step size and dwell time were accordingly maintained in order to identify various phases along with the help of inorganic Joint Committee On Powder Diffraction Standards extra diffraction data card depicted the boron carbide particles were fairly pure.

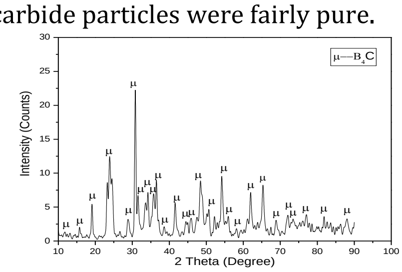


Fig 6.2: XRD pattern of Boron Carbide particles used in casting of Al 1100 (Mg)-B4C

6.2 Cast composites

Reinforced Al 1100 cast composites have been developed by distribution of B4C powder into molten Al 1100addedexternally that causes solidification of slurry resulting in cast composite. Composites having various concentration of reinforcement as given in Table 5.1 have been synthesized and are designated as AM, which denotes Al 1100-Mg alloy and P represents particle content which is followed by number indicating the percentage weight of reinforcement added. The process of synthesis was carried at 800°C by dispersing the powder into the molten alloy with constant stirring, and the slurry obtained has been cast in permanent steel mould to get cast composite ingot. The preparation of Al 1100-Mg alloy have been prepared by adding 2 wt% of magnesium into Al 1100 melt and designation AM is adopted for the alloys.

Table 6.1: Material Concentration of the composites

Designation of composites	Magnesium (wt %)	Particle (wt %)
AM	2	0
AMP2	2	2
AMP4	2	4
AMP6	2	6

6.2.1 Chemical composition

The material concentration of commercial Al 1100 and commercial magnesium used for making composites are again shown in Table 5.2. Iron, Silicon and Manganese are the major elements other than the Al in the ingots of Al 1100, Iron and Aluminum are the major impurities observed in the ingots of magnesium.

Table 6.2: Material concentration of the Al 1100 and commercial magnesium ingots

Chemical composition (wt %)					
MaterialFe	Mn	Cr	Cu	Zn	Si
Ti	Mg	Al			
Al 1100-Ingot	0.132	0.052	-	0.041	0.022
0.074	-	0.005	Bal.		
Mg-Ingot	0.020	0.002	0.001	0.016	0.002
0.006	0.001	Bal.	0.023		

6.3 Microstructure Characterization

6.3.1 Scanning Electron Microscopy (SEM)

It has been adopted for micro structural characterization of unreinforced and reinforced samples of composites. Prior to examination the samples of the composites were polished. Characterization is carried out in etched condition. Using the scanning electron microscope, SEM micrographs of composite were extracted. According to requirement the images were extracted both in secondary electron (SE) mode and back scattered electron (BSE) mode. With use of scanning electron microscope (SEM), investigations on morphology, particle size and micro structure were carried out.

The SEM micrographs is used as a reference for this study, Fig 5.3 (a) shows the Al 1100-Mg alloy cast following the same processing route as that of cast composites. The particle size ranges from 5 μm to 25 μm. For in this investigation 10 μm and 20 μm particle size are observed during the SEM micrographs. All three microstructures Fig 5.3 (b) AMP2 (c) AMP4 and (d) AMP6 respectively contain same phases. The powder particles are uniformly distributed and it is seen that with increase in percentage of B4C powder added the porosity also increases. The distribution of particle in the composites as shown in Fig 5.3 (b), (c) and (d), indicated presence of individual particles and no dominant clustering is visible.

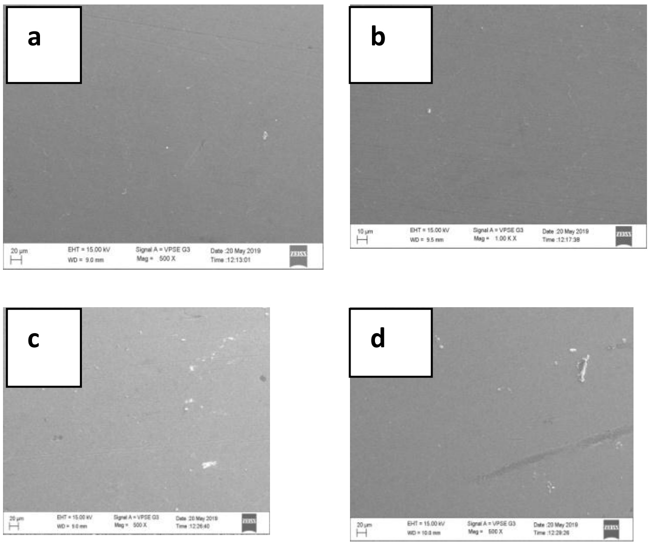


Fig 6.3: SEM micrographs of alloy and different cast composites developed by increasing amounts of B4C powder designated as (a) AM, (b) AMP2, (c) AMP4 and (d) AMP6 respectively .

6.4 Mechanical properties of al 1100 (mg)–b4c composites

Porosity is very common in cast material and it is well known that the presence of porosity has adverse affect on properties of materials. the mechanical properties of alloys and cast particulate composites tend to deteriorate in presence of porosity. Porosity in cast materials reduces the effective cross sectional area and creats stress concentration around pores that damages load bearing capability of the material. Shape, size, distribution, nature of particle matrix interface, volume fraction of porosity and reinforcing particles influences the mechanical properties of the material.

6.4.1 HARDNESS

The hardness of un-reinforced alloy and cast composites prepared by addition of B4C have been measured by brinell test using a 5 mm hardened stell ball indentor under 100 kg load. Four indentation have been taken for each sample, the distance of 6 cm have maintained from one indentation centre to another indentation center. The designation of alloys and composites accordingly with 0, 2, 4 and 6 wt% B4C powder as reinforcement, are AM, AMP2, AMP4 and AMP6 respectively. The average hardness of cast in-situ compositesand unreinforced alloy are given in Table 5.3. with increase in wt% of B4C powder added to AM2 base alloys, it was found that there is considerable increase in the hardness of the composite material. The composites having 6 wt% of B4C powder exhibit higher hardness than the composites having 2 and 4 wt% of B4C powder. However, the alloy without reinforcement powder showed lowest hardness. Therefore with increase in % of reinforcement contents in the matrix material, the hardness of the composites is found to be increased as shown in Fig 5.4.

Table 6.3: Average Hardness of alloy and cast composites

Designation of alloy/composite	BHN
AM	24.96
AMP2	27.66
AMP4	30.49
AMP6	33.94

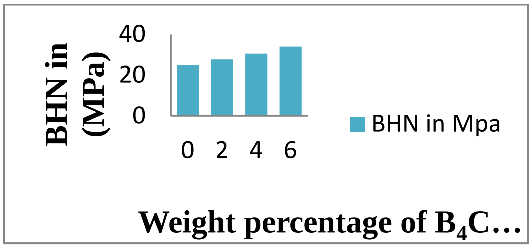


Fig 6.4: Variation of hardness of unreinforced base alloy and cast composites
Developed by addition of B4C

6.4.2 TENSILE PROPERTIES IN CAST COMPOSITES

Composite materials and alloys were been subjected to Tensile test process by using UTM for the study of stress v/s strain behaviour under the loading condition, the composite that have been prepared by addition of varying quantity of reinforcement powder. The stress-strain characteristics for similar type of Al-Mg alloy composition with that of the same matrix has done and it is subjected to comparison process. Significant increase in the strength and ductility is observed in composites with reinforcement powder designated as AMP2, AMP4& AMP6 when compared with base alloy. Slight decrease in ductility is seen in case of AMP6 when compared with AMP4. The strain hardening was found to be increased of composite material when compared to that of the regular base alloy material. Upon comparing the stress-strain behaviour of composites, highest tensile strength is exhibited by AMP4 comprising of 4 wt% B4C powder while the next best is shown by AMP2 comprising of 2 wt% B4C powder. The composite AMP6 exhibits lower strength and ductility than AMP2 and AMP4, but when compared to base alloy it has higher strength and ductility. In-situ aluminum matrix composites have been prepared by the addition of B4C powder into aluminum melt followed by 2% addition of magnesium to promote wetting. Table 5.4 shows the tensile properties of the alloy and composites with 0, 2, 4 and 6 wt% B4C added to Al 1100-Mg alloys.

Table 6.4: Tensile properties of alloy and composites

Designation of alloy /composites	Yeild Strength in MPa	Ultimate Tensile Strength in MPa	Percentage Elongation
AM	80.5	94.6	2.6
AMP2	95.0	113.9	5.2
AMP4	101.8	126.0	13
AMP6	84.2	111.4	7.8

The below mentioned graphs represents Variation of various mechanical properties such as yeild strength, tensile strength and percentage deformation of alloy material as well as composite material whose reinforcement concentration of 0, 2, 4 and 6 wt% B4C powder were studied.

With increase in wt% of powder the yeild strength is found to increase, with 2 wt% the yeild strength increases mildly and 4 wt% significant increase in yield strength is observed. It was readily observed from the test result that yield strength of the composite material starts decreasing gradually when the concentration of the reinforcement particle was around 6% on weight basis and the details were demonstrated with graph below. The tensile strength also follows the same trend where it is seen to have predominant improvement with 4 wt% reinforcement as shown in Fig 5.6. When comparision with 6% composite material the yeild strength of the 4% reinforced composite material was found to much better and on further increasin the concentration of B4C powder it was found that the properties gradually reduce. The ductility of alloy shows 2.6% of elongation as the addition of powder increases to 4 wt% and then ductility increases to 13% as shown in Fig 5.7. The variation in the flow behaviour along the interface between the particles and the metal matrix results in shear stress which causes debonding of the particles is the important reason for loss of ductility. The size of the particle is directly propostional to the magnitude of the shear stress induced. Larger shear stress is can be observed with larger particle size and disassociation of bonding takes place at much lower strain.

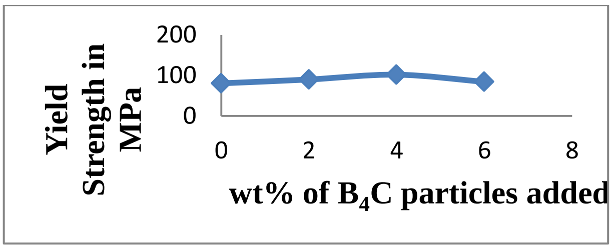


Fig 6.5: Variation of Yield strength in alloy and cast composites

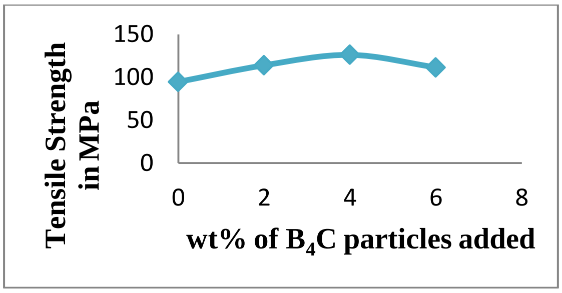


Fig 6.6: Variation of Tensile strength in alloy and cast composites

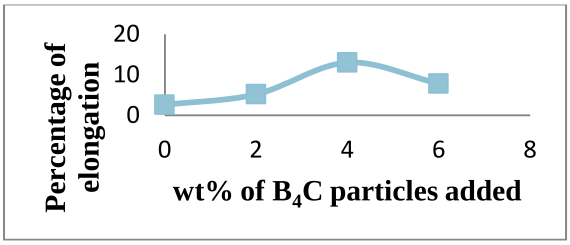


Fig 6.7: Percentage elongation variation in cast composites

6.5 Fatigue strength

The stir cast specimen of the Al-B4C material were subjected to rotating beam bending test as discussed previously so as to investigate the fatigue strength parameters of composites. The specimens with 0%, 2%, 4%, 6% B4C were subjected to fatigue test and the results are discussed in detailed in table 5.5. It was found that with increase in the concentration of the reinforcement particles there is considerable increase in the fatigue strength of the material.

Consistent distribution of the B4Cparticulate reinforcement in the aluminum matrix alloy and excellent interfacial bonding between the matrix and the reinforcement phases are the basis of increased strength of composites. B4Creinforcement with its higher mechanical properties like hardness and tensile strength imparts better mechanical properties to composite structure, when good interfacial bond is developed between the matrix and reinforcement phases. The fatigue life of specimen with 6% B4C is found to be decreased which is due to inconsistent distribution of reinforcement or due to debonding of the particle caused by shear stress created by difference in flow behaviour.

Table 6.5 Fatigue test results

Designation of alloy /composites	Load applied (in kg)	Number of cycles for failure
AM	3 kg	9,61,352
AMP2		9,77,184
AMP4		9,93,906
AMP6		9,81,360

6.6 FEA Results

The figures 5.8 -5.11 show the variation of stress and deformation of shaft for various percentage of B4C reinforcement added. Finite element analysis was performed on shaft using ANSYS workbench incorporating the material properties of composite obtained from test conducted.

With increase in the concentration of reinforcement particle to the aluminum matrix the deformation of the shaft under load is seem to be gradually reducing. Which indicates that the reduction in deformation implies gradual increase in the strength of the material.

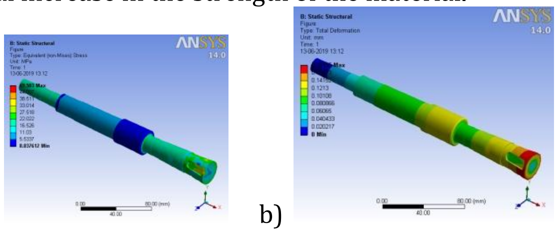
a) b)


Figure 6.8: a) Stress and b) deformation for 0% reinforcement

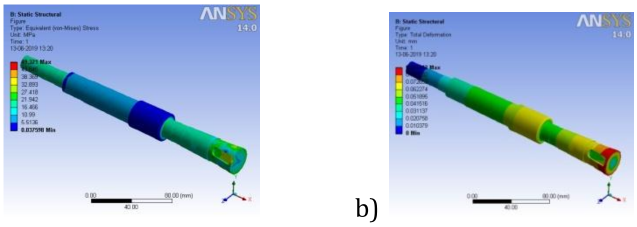
a) b)


Figure 6.9: a) Stress and b) deformation for 2% reinforcement

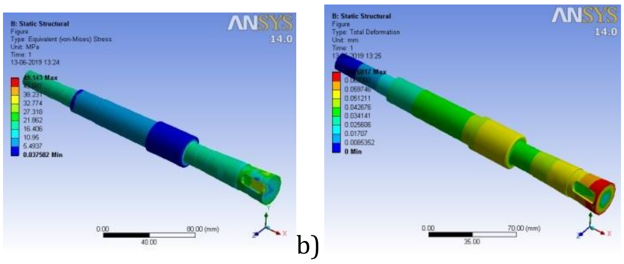
a) b)


Figure 6.10: a) Stress and b) deformation for 4% reinforcement

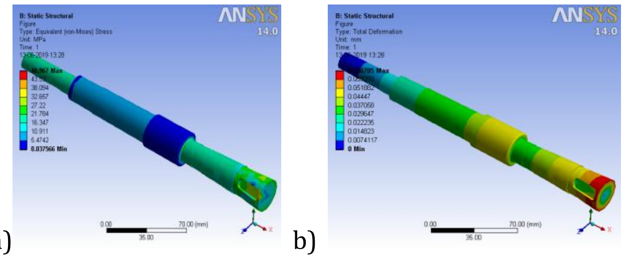
a) b)


Figure 6.11: a) Stress and b) deformation for 6% reinforcement

Table 6.6: FEA results

Designation of /composites	Stress in MPa	Deformation in mm
AM	49.503	0.1819
AMP2	49.321	0.0934
AMP4	49.413	0.0768
AMP6	48.967	0.0670

The fatigue life of shaft as obtained from ANSYS for 0% B4C is shown in fig 5.12 and is found to be 1x106 cycles.

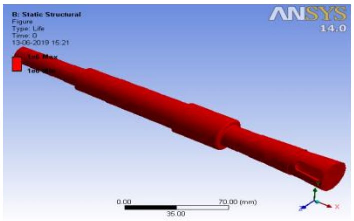


Figure 6.12: Fatigue life of shaft

6.7 Tribological characteristics

The test was carried out on various specimens for sliding velocity of 2.09m/s and sliding distance of 1900m at 1000rpm, 4.18m/s and 3800m at 2000rpm. With the increase in the percentage of reinforcement particle, it was found experimentally that there is a gradual reduction the wearing behavior of the material. The figure belowgives the details about variation of wear with concentration of reinforcement particle. The decrease in wear is due to decrease in amount of plastic deformation at contact region due enhancement in hardness of the composite with inclusion of reinforcement.

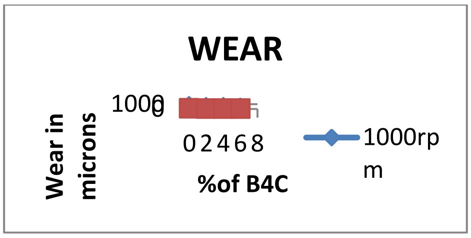


Figure 6.12: Variation of wear rate with % of B4C reinforcement

The variation of coefficient of friction is shown in figure 5.13. It can be observed that the coefficient of friction is lower for composite with higher percentage of reinforcement which is attribute to abrasive nature of wear caused due to increased hardness. The figure shows variation of COF with reinforcement percentage.

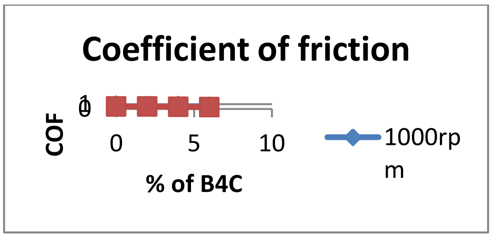


Figure 6.13: Variation of COF with % of B4C reinforcement

Further the frictional force is also seen to be decreased with increase in reinforcement owing to enhancement in strength of the composite.

Figure 5.14-5.19shows the experimental graphs of wear, frictional force and coefficient of friction for 0%(purple), 2%(red), 4%(blue), 6%(green) B4C reinforcement for 1000 rpm and 2000rpm obtained from the pin on disc wear test machine.

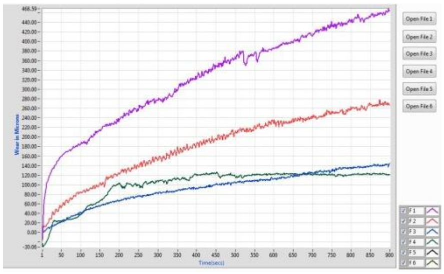


Fig 6.14: Wear at 1000rpm

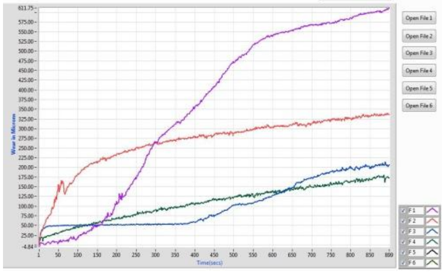


Fig 6.15: Wear at 2000rpm

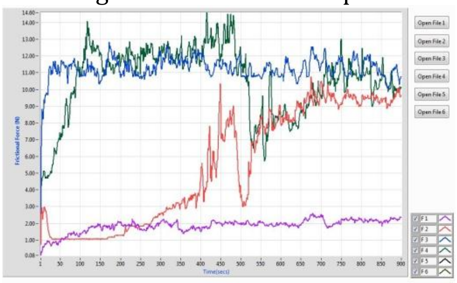


Fig 6.16: Frictional force at 1000rpm


Fig 6.17: Frictional force at 2000rpm

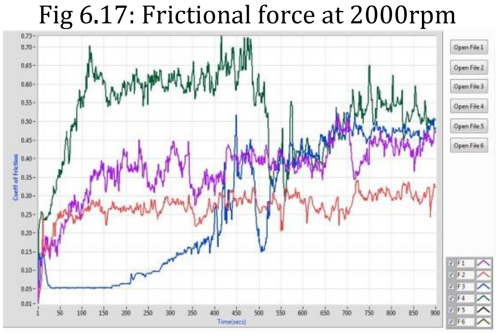


Fig 6.18: Cof at 1000rpm

Fig 6.19: Cof at 2000rpm

7. CONCLUSIONS

The synthesis of in-situ cast composites have been carried out by introduction of B4C powder as reinforcement by varying the wt% as 2, 4 and 6 wt% into molten industrial grade Al 1100-Mg alloy, followed by the casting process in a suitable mould cavity. Investigation of composite material for various mechanical properties under different reinforcement concentration of B4C powder in the range of 2, 4 and 6 % were carried out and the following results were drawn, along with it the microstructure analysis of the same were carried out.

i. The stir casting technique, one of the liquid metallurgy technique for synthesis of Al 1100-Mg-B4C alloy and composites comprising 0, 2, 4 and 6 wt% of B4C powder as reinforcement was effectively adopted.

ii. Investigation through XRD and SEM indicated the particles of B4C powder have irregular shape and are finely pure.

iii. With increase in wt% of B4C powder reinforcement added to composite, significant increase in hardness is observed.

iv. The yield strength of the composites is seen to enhance up to 4 wt% of reinforcement addition and decreases with 6 wt% of reinforcement addition due to loss of strength.

v. The tensile strength of the composites was found to be gradually improved up to 4 wt% of reinforcement addition and decreases with 6 wt% of reinforcement addition due to large shear stress that causes deboning of particles.

vi. Percentage of elongation is found to elevate up to 4 wt% of reinforcement addition and decreases in 6 wt% of reinforcement addition due to loss of ductility because of difference in flow behavior.

vii. With the increase in wt% of reinforcement particle it was found that the wear rate and coefficient of friction of the composite material has improved along with it hardness has also been improved.

viii. The fatigue results indicate increase in number of cycles for failure up to 4% of reinforcement and slightly decreased for 6 wt% due to inconsistent distribution of reinforcement particles in metal matrix.

8. SCOPE FOR FUTURE WORK

i. In the present study the amount of reinforcement in the matrix material is limited to 6 wt%. Similar studies can be conducted with higher weight percentage of reinforcement with varying the particle size.

ii. Studies related to wear analysis, fatigue characteristics, high temperature wear analysis, erosive wear, and corrosive wear and damping test can be carried out.

iii. The studies also can be carried out after heat treatment and secondary process of the composite like hot forging, rolling, extrusion etc.

iv. Similar study can be done with other reinforcement materials such as Al2O3, MnO2, SiC, TiO2 and graphite.

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