CHAPTER 1

INTRODUCTION

1.1 Introduction to Composite Materials

A Composite material is defined as a combination of two or more individual materials with different physical or chemical properties, and which remain separate and distinct on a microscopic or macroscopic level within the finished structure. The main advantage of composite material is there high strength and stiffness, combined with low density, when compared with bulk materials, allowing for weight reduction in the finished part.

Composites are made up of two materials, they are matrix and reinforcement. The matrix surrounds and binds together a cluster of fibers, particles, or fragments of a much stronger material called reinforcement.

The reinforcing phase provides the strength and stiffness. In most cases the reinforcement is harder, stronger and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composite have dimensions that are approximately equal in all directions. They may be spherical; platelets are any other regular or irregular geometry. Particulate composite tend to much weaker and less stiff than fiber composites, but they are usually less expensive. Particulate reinforced composites usually contain less reinforcement due to processing difficulties and brittleness.

1.2 Role of Constituents in a Composite

A Composite is made up of two constituent materials, matrix and reinforcement. Both the materials have specific roles to perform resulting in the function of the composite. In addition, the interface between the matrix and the reinforcement has also some specific role to perform.

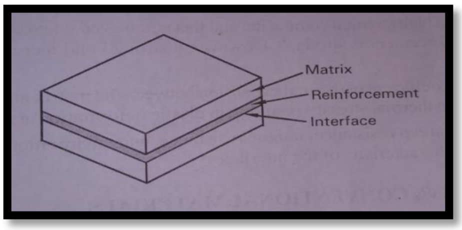


Figure 1.1: Composite

➢ Role of Matrix

- Holds the reinforcement material together and keep them aligned in a predetermined direction.
- Protects the reinforcement from mechanical and environment attack.
- Distributes the loads evenly between the reinforcement materials so that the entire reinforcement is subjected to the same amount of strain.
- Provides shape and form to the composite material.
- Improves impact and fracture resistance of the composite material.
- Helps to avoid propagation of crack growth through the reinforcement by providing alternate failure path along the interface between the reinforcement and the matrix.
- Carry inter-laminar shear.

➢ Role of Reinforcement

- Carry the load and provide strength and stiffness to the composite.
- Reinforcement help the composite to obtain the desired property in the direction preferred.
- Reinforcement serves certain additional purpose of heat resistance or conduction, resistance to corrosion, and provides rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements.
- Reinforcement helps to deflect the crack front in matrix thereby hindering crack growth.

➢ Role of Interface

- The interface is usually a discontinuity in terms of chemical nature, crystal structure, molecular structure, mechanical properties, etc. Hence, failure of a composite usually takes place at the interface.
- The matrix transfers the load to the reinforcement via interface. A strong interface is required to produce a high strength composite, and this is achieved when the bond between the matrix and the reinforcement is strong. However, a strong bond increases the chances of brittle failure.
- Large differences in coefficient of thermal expansion between the matrix and the reinforcement materials can result in thermal stresses resulting in plastic deformation at the interface.

- Other properties like creep resistance, fatigue resistance, and environmental degradation are also affected by the characteristic of the interface.

1.3 Composites versus Metals Comparison

Condition	Comparative behavior relative to metals
Load-strain relationship	More linear strain to failure
Notch sensitivity	Greater sensitivity
Static fatigue	Less sensitivity
Transverse properties	Weaker
Mechanical property	Higher
Fatigue property	Higher
Sensitivity to hydrothermal Environment	Greater
Sensitivity to corrosion	Much less
Damage growth mechanism	In-plane delaminating instead of through thickness cracks.

Table 1.1: Composite v/s Metal comparison

1.4 Advantages of Composite Materials

- High strength and strength to density ratio.
- Low density.
- High stiffness to density ratio.
- Toughness (impact and thermal shock).
- Improved fatigue strength, hardness and corrosion resistance.
- Improved creep strength, strength-rupture life and oxidation.
- Controlled thermal expansion conductivity.
- Multiple combinations of above properties.
- Ability to use low cost tooling materials.

1.5 Disadvantages of Composite Materials

- Fabrication time for the end product is long for the reason that set time needed to initiate and complete chemical reaction is long.

- Thermoset composites are strong but brittle in nature.
- They are very hygroscopic and thus material handling becomes difficult.
- Difficult to analyze for two-phase composite behavior.
- High cost of raw materials and fabrication.

1.6 Applications of Composite Materials

To list the various applications of composites is an endless process. A few major applications of composites in various fields are listed below.

- **Aircraft**

  Used to make rotor blades, fins, rudders, wing body, fuel tanks, propeller blades, helicopter frames, canopies, radomes, fairings, engine cowlings, landing gear doors, floor panels, fan ducts, interior pasts like overhead bins, sidewall panels, ceilings, partitions, cargo floor board liners, etc.

- **Spacecraft**

  Rocket motor casing, rotor blades, heat shields and nozzles, panel doors, structural truss elements, fuel tanks, turbine and combustion chamber components, high gain antenna boom, etc.

- **Marine**

  Propeller vanes, fans and blowers, condenser shells, valves and strainers, gear cases, small boats, hulls, etc.

- **Automobiles**

  Combustion engine components, disc brakes, brake parts, drive shaft components, steering wheel, bumpers, door and roof linings, radiator tank and supports, etc.

- **Construction Industry**

  Doors, door hinges, window frames, paneling, water tanks, furniture, interiors, sanitary ware, pipes, kitchen sinks, partitions, ceilings, wall panels, long span roof structures, bridge structural components, etc.

- **Electrical/Electronics**

  Power line insulators, switch gear frames, parabolic antenna, street light canopies, ladders, insulation brackets, junction boxes, circuit breaker components, brush holder, Fuse blocks, knobs, fan regulator cover, meter covers, electricity utility poles, circuit boards, etc.

- **Medical**

  Artificial parts made from composites to replace lost arms and legs, teeth, optical lenses, spinal braces, crutches, wheel chairs, etc.

- **Sports**

  Drum sticks, tennis rackets, ice hockey sticks, snowboards, golf rods, archery equipment, bicycle frames, ski poles, canoes, protective sportswear, etc.

- **Consumer products**

  Washing machine parts, camera parts, wrist watches components, house hold mixer casing, refrigerator and air conditioner components, chairs, tables, chimney duct parts, etc.

1.7 Classification of Composites

Composite materials are commonly classified as the following two distinct levels:

The first level of classification is usually made with respect to the matrix constituent. The major composite classes include polymer matrix composites (PMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The Polymer Matrix Composites (PMCs) and Carbon Matrix Composites commonly referred to as carbon-carbon composites.

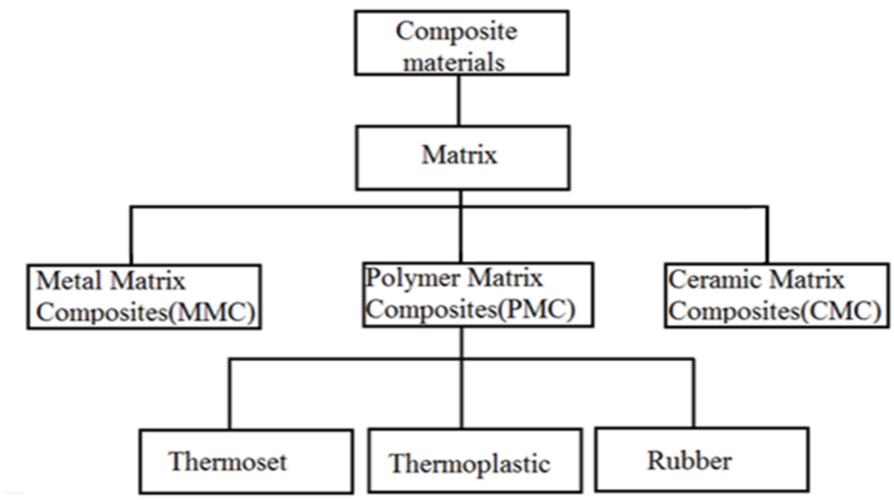


Figure 1.2: Classifications Based On Matrix Constituent

These three types of matrixes produce three types of composites

- Polymer Matrix Composites (PMCs), of which GRP is the best-known example, use ceramic fibers in a plastic matrix.

- Metal Matrix Composites (MMCs) typically use silicon carbide fibers embedded in a matrix made from an alloy of aluminum and manganese, but other matrix materials such as titanium, copper and iron are increasingly being used. Typical applications of MMCs include bicycles, golf clubs and missile guidance systems; an MMC made from silicon carbide fibers in a titanium matrix is currently being developed for use as the skin (fuselage material) of the US National Aerospace Plane.
- Ceramic-matrix composites (CMCs) are the third major type and examples include silicon carbide fibers fixed in a matrix made from a borosilicate glass. The ceramic matrix makes them particularly suitable for use in lightweight, high temperature components such as parts for airplane jet engines.

The second level of classification refers to the reinforcement form - fiber reinforced composites, laminar composites and particulate composites. Fiber reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibers.

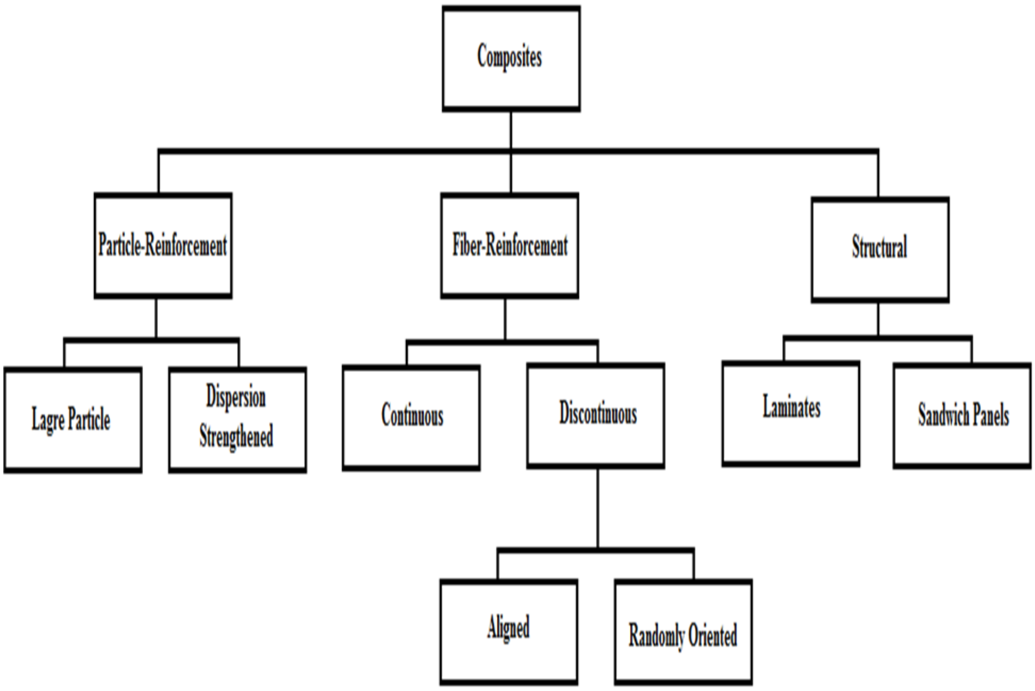


Figure 1.3: Classifications Based On types of reinforcement

These three types of reinforcement produce three types of composites

- Fiber reinforced composites are composed of fibers embedded in matrix material. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length. On the other hand, when the length of the fiber is such that any further increase in length does not further increase, the elastic modulus of the composite is considered to be continuous fiber reinforced.

- Fibers are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibers must be supported to keep individual fibers from bending and buckling.
- Laminar composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate composite are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards fall under this category.

1.8 Metal Matrix Composites (MMC)

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metal and alloys could be used as matrices and they require reinforcement material which needs to be stable over a range of temperature and non-reactive too. However the guiding aspects for the choice depend essentially on the matrix material. Light metals from the matrix for temperature application and the reinforcements in addition to the mentioned reasons are characterized by high module.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, aluminum and magnesium are popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements.

The strength to weight ratios of resulting composites can be higher than most alloys. The melting point, physical and mechanical properties of the composites at various temperatures determine the service temperature of composites.

Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

1.8.1 Types of Metal Matrix composites

Metal matrix composite can be reinforced by strong second phases of three dimensional shapes (particulate), two dimensional shapes (laminar) or one dimensional shape (fibrous). All these three types differ in both mechanical properties and fabrication techniques.

- **Particle Reinforced Composites**

  Particle reinforced composites although having a hard reinforcing dispersed phase differ from the dispersion hardened materials in the sense that they have a higher volume fraction of dispersed, smaller sizes of particles and inter particle spacing. With particle based reinforced composites such as tungsten-carbide-cobalt, the reinforcing phase is the principal load-bearing phase and the matrix is used for transferring the load and for ease of fabrication. High matrix-constraint factors produced by the hard reinforcement are used to prevent yielding in the matrix and the composite strength generally increases linearly with decreasing volume fraction of the matrix.

  The three-dimensional reinforcement can lead to isotropic properties, since the material is symmetrical across the three orthogonal planes. Strength of the particulate composites normally depends on the diameter of the particles; inter particle spacing and volume fraction of the reinforcement. Matrix properties, including the work-hardening coefficient, which increases the effectiveness of the reinforcement constraint, are also important.

- **Laminated Composites**

  Laminated composite materials are considered to be reinforced by a repeating lamellar reinforcement of high modulus and strength, which is contained in the more ductile and formable metallic matrix material Boron-Carbide-titanium composites, in which the repeating reinforcing, structural constituent consists of chemical-vapors deposited boron carbide films of 5.25 mm thickness, can be an example of the laminated composite materials; another kind of example can be the eutectoid composites of Ni-Mo and Al-Cu, in which two phases solidify in a lamellar array. The elastic constants of a structural lamellar composite have been predicted by laminate theory. The strength of laminated composite materials relate more closely to the properties of the bulk reinforcement.

Since the reinforcing lamellae can have two dimensions that are comparable in size to the structural part, flaws in the reinforcement can nucleate cracks of lengths to that of the part. Since the most important reinforcing materials are brittle in nature, their strength is related to the population of their flaw density and intensity.

The reinforcement of strength in all directions of the plane is a good advantage but then strength, elongation and ductility is lower than the fiber reinforced Composites, since the corresponding values of films are longer than the values for fibers.

- **Fiber Reinforced Composites**

Generally these kinds of systems have relatively ductile low-yield-strength matrices and high-strength, high-modulus, brittle fibers.

When the metal- matrix composite with continuous uni-axially aligned fibers is stressed parallel to the fibers, four stages of stress-strain behavior is observed. In first stage, both the fiber and the matrix deforms elastically.

The second stage comprises the region in which the fiber is extending elastically and the matrix is extending plastically. Since the fiber is usually in high volume fraction and has a considerably higher elastic modulus that the matrix, $E_2$is nearly equal to E_1. The modulus of the composite would be the addition of the slopes on the stress strain curve of the two phases times their volume fractions.

The third stage is observed when both fiber and matrix can undergo plastic deformation and includes normal plastic extension of the two phases. This deformation mode may deviate from the performance of the constituents alone with respect to necking or other inhomogeneous plastic flow.

Forth stage in the stress-strain performance of the composite includes the fracturing of the high strength fibers. During this stage, the matrix transfers load from broken fiber ends to unbroken segments and flows around the opening pores or cracks. Fracture of the composite normally terminates the fourth stage. The transverse or the shear properties of fiber-reinforced composite materials are considerably more influenced by the matrix behavior than the longitudinal properties.

1.9 Aluminium Alloys

Aluminium-Silicon alloys are known for their excellent combination of characteristics namely, low density, excellent cast ability, formability, good mechanical properties, cryogenic properties and good machinability. Aluminium and its alloys have wide range of applications particularly in automobile, aerospace and marine sectors on account of their light weight, good surface finish, resistance to wear and corrosion, high

Strength to weight ratio, Since components with complex geometries can be produced cost effectively, they find enhanced utility particularly in aerospace sectors. Large aluminum extrusion components can be produced with fewer joints, resulting in less welding. Reduction in weight due to low density leads to increased load capacity, increased mileage, reduced pollution of environment and higher profits to the manufacturers. The low melting temperature, ease of handling, easy formability, easy recycling has led to increased demand for aluminum alloy components.

1.9.1 Classification of Aluminium Alloys

Aluminium alloys are classified into following three groups:

- Wrought, non-heat treatable alloys
- Wrought heat treatable alloys
- Cast alloys

➢ Wrought, Non-Heat Treatable Alloys

Primarily cold working is employed for heat treating non-heat treatable alloys such as commercial pure aluminum series [1xxx] which have good corrosion resistance, thermal conductivity, exceptionally high formability and can be easily joined by soldering, welding and brazing. The Al-Mg series [3xxx] have high formability, corrosion resistance and can be joined by all commercial procedures. The Al-Si [4xxx] has good flow characteristics, good tensile strength and can easily be joined by conventional methods such as brazing and soldering. The Al-Mg series [5xxx] are easily weldable, have superior carrion resistance and find application in automobile, cryogenic and marine sectors. Few of the 4xxx alloys are hardened by heat treatment, while others hardened by cold working.

Fine dispersion of precipitates for alloys that respond to ageing has dominant effect in inhabiting dislocation motion resulting in increased yield and tensile strength. Dislocation produced by cold working in substance in case of wrought alloys and the grain size of cast alloys are of prime importance

- **Wrought, heat treatable alloys**

  Heat treating in its broadest sense, refers to any of the heating and cooling operations are performed for the purpose of changing the mechanical properties, the metallurgical structure, or the residual stress state of a metal product.

  When the term is applied to aluminum alloys, however, its use frequently is restricted to the specific operations employed to increase strength and hardness of the precipitation-hardenable wrought and cast alloys. These usually are referred to as the "heat-treatable" alloys to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling.

- **Cast Alloys**

  Cast alloys in comparison with wrought alloys contain higher proportions of alloying elements such as silicon and copper which result in largely heterogeneous cast structure. These alloys produced by various casting processes such as sand casting, permanent mould casting etc. have low tensile strength compared to wrought alloys but have wide acceptability on account of its attractive combination of physical properties and exceptional cast ability. Wrought products are generally produced in the form of round rods and rectangular sections whereas cast products can be produced with complex geometries. Cast alloys have inferior mechanical properties, particularly ductility when compared to wrought alloys with similar chemical composition. Porosity and relatively high shrinkage are the other major problems with cast alloys.

1.10 A356 Alloy and its Equivalent in LM (Light Metal) and Wrought Series

The cast A356 alloys find applications in automotive, aerospace industries, and general engineering, on account of its superior combination of properties like good fluidity, high strength-to-weight ratio, good wear resistance and corrosion resistance.

Chemical composition, impurities, melts treatments and solidification rate strongly influence the mechanical properties attainable in this alloy. These alloys are categorized as premium quality castings which assure higher quality and reliability than conventional cast products. These alloys possess high mechanical properties, low porosity levels, good dimensional accuracy and good surface finish. They guarantee minimum property levels in any part of the component. The alloy group can be arranged as 3xx, 4xx, 5xx, 2xx and 7xx in the order of decreasing castability.

1.11 Stir Casting

Stir casting is a liquid state method of composite material fabrication, wherein, the reinforcement is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies. Stir casting is the simplest and the most effective method liquid state fabrication method.

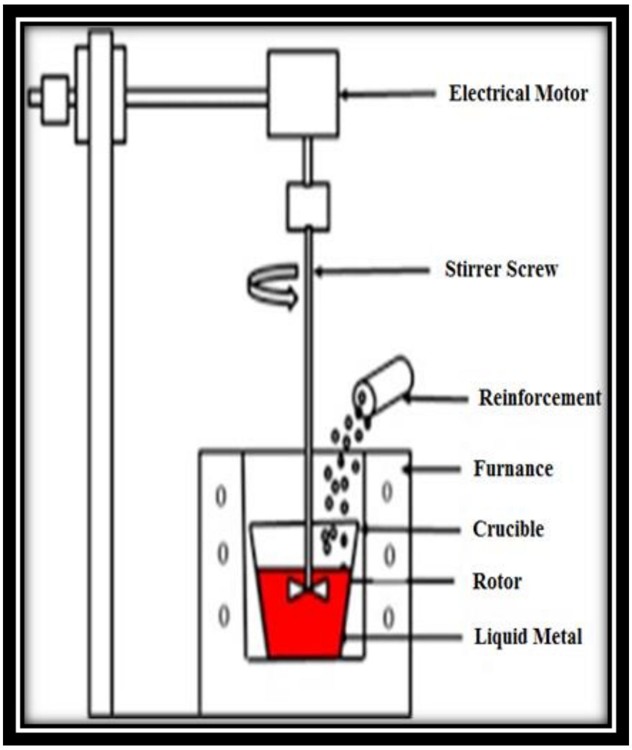


Figure 1.4: Stir Casting Method

In the stir casting process, the alloy matrix, is melted at controlled temperature and the desired quantity of reinforcement material is added to the molten alloy. The molten alloy is stirred continuously to create a vortex to force the slightly lighter particles in to the metal. Stirring continues to disperse the reinforcement particles as uniformly as possible in short time. The molten mixture is then transferred in to a pre heated and pre coated transfer ladle. The mixture is stirred again and then poured into preheated permanent mould having the desired shape of the composite to be produced. Sufficient time is allowed for solidification of the material, which in turn is cut into shape and surface cleaned.

1.12 Squeeze Casting

Squeeze casting consist of entering liquid metal into a preheated, lubricated die and forging the metal while it solidifies. The load is applied shortly after the metal begins to freeze and is maintained until the entire casting has solidified

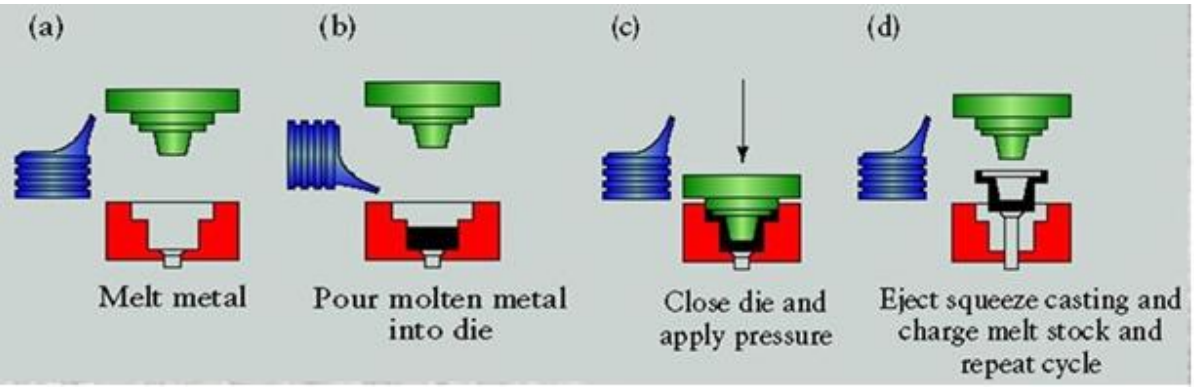


Figure 1.5: Squeeze Casting

CHAPTER 2

LITERATURE SURVEY

M. Chen and A.T. Alpas and M. Chen have studied the effects of silicon particles morphology in maintaining the UMW regime for eutecticAl-11%si, Al-12 Si alloys and Al-18 5% Si alloy. The characteristics of UMW were similar for eutectic alloys. The matrix hardness played a major role in controlling the wear mechanism for a given aspect ratio and size of Si particle.

S.A Kori and T.M Chandrashekharaiah studied the effect of grain refiners on the dry sliding wear test on hypo-eutectic and eutectic Al-Si alloy for varied parameters such as composition, loads, sliding speeds and sliding distances. They observed increase in mechanical and tribological properties with the addition of Al-Ti-B grain refiner and modifier, strontium due to change in microstructure and formation of fine particles.

Fang Wang et.al studied the effect of Si content on the dry sliding wear properties of spray deposited Al-Si alloys with Si varying from 12 to 25% under loads of8.9, 17.8, 26.7 and 35.6N. at lower loads the wear rate decreased with increase in Si content and at higher load, the alloy Al-12Si exhibited superior wear resistance.

L.Lasa and J.M Rodriguez-I babe tested wear behavior of eutectic and hyper-eutectic Al-Si alloys with various compositions and processing routes against a composite brake pad using pin-on-Disc configuration. They observe that at lower disc speed, the influence of the composition and alloy processing was very strong and a severe wear transition was observed for alloys with low Si content. At higher speed, the alloys offered higher resistance to wear.

D.S. Mehta investigated the wear properties of the die cast and sand cast magnesium alloys and Aluminium alloys under dry and wet sliding conditions at different loading condition using pin-on-disc test rig for varied wear track, load, sliding distance etc. and found them to be alternative materials for automotive applications.

Ma et al (2006) investigated the effects of FSP on the microstructural evolution of cast A356 Al alloy. In this investigation single pass FSP was performed on 6.35mm thick plates.

Different tool rotational speeds (300,500,700,900 rpm) and different traverse feeds (51,102,203 mm/min) were used to process the Al alloy. FSP resulted in a significant break up of fibrous Si particles and aluminum dendrites and redistribution of fine and equiaxed Si particles in the aluminum matrix. Fine grains of the order of 3 to 4 microns were generated due to FSP.

The tensile properties of A319 and A356 are strongly dependent on porosity levels, scale of the microstructures and heat treatments and the independent effects of a single variable may be difficult to isolate. However, ultimate tensile strength and ductility’s generally improve as porosity levels 21 and microstructure scale decrease. The tensile behavior of the friction stir processed A356 and A319 are consistent with this behavior pattern.

Karthikeyan et al (2009) investigated the effects of FSP on Cast 2285 alloy and reported that due to FSP the mechanical properties and microstructure are altered substantially. Around 30% improvement in yield and tensile strengths were observed and ductility increased around 4 fold. The improvement in mechanical properties is due to reduced porosity and grain size.

Tsai and Kao (2012) studied the improvement of mechanical properties of a cast Al-Si base alloy by friction stir processing. They reported that the tensile properties of cast AC8A alloy could be improved considerably 23 after FSP, particularly the tensile elongation, which increased from < 1% to 15.4%. The tensile strength of FSPed AC8A alloy was the result of a combination of dissolution, coarsening and reprecipitation of strengthening precipitates, which was influenced by the FSP parameters.

Elangovan and Balasubramanian (2008) studied the influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminum alloy and reported that square pin profiled tool produced defect free FSP region, irrespective of welding speeds. The FSW joint fabricated using square pin profiled tool at a welding speed of 0.76mm /s exhibited maximum tensile strength, higher hardness and finer grains in the FSP region.

Surekha et al (2009) investigated the effect of FSP on the hardness of AA2219 alloy and reported that the processed alloy at different tool rotational speeds and traverse feeds showed a lower hardness compared to the base metal. This could be attributed to the dissolution of precipitates during FSP. FSW/FSP creates a softened region around the weld Centre/stir zone in a number of precipitation hardened aluminum alloys.

Hassan et al (2003) have reported that a low heat input during FSW results in an exceptionally fine grain structure along with dissolution of precipitates. When FSP is carried out with higher heat inputs, the grains in the nugget are coarser due to grain growth.

DRAWBACKS

- Scanty information is available upon literature survey of Al-Si-Mg alloy based hybrid composite.
- Though there is information that automobile companies like Honda are using hybrid composites for engine blocks, information has been kept secret by these companies and no information on sizes, compositions and sequence of addition of reinforcements is available.

CHAPTER 3

METHODOLOGY

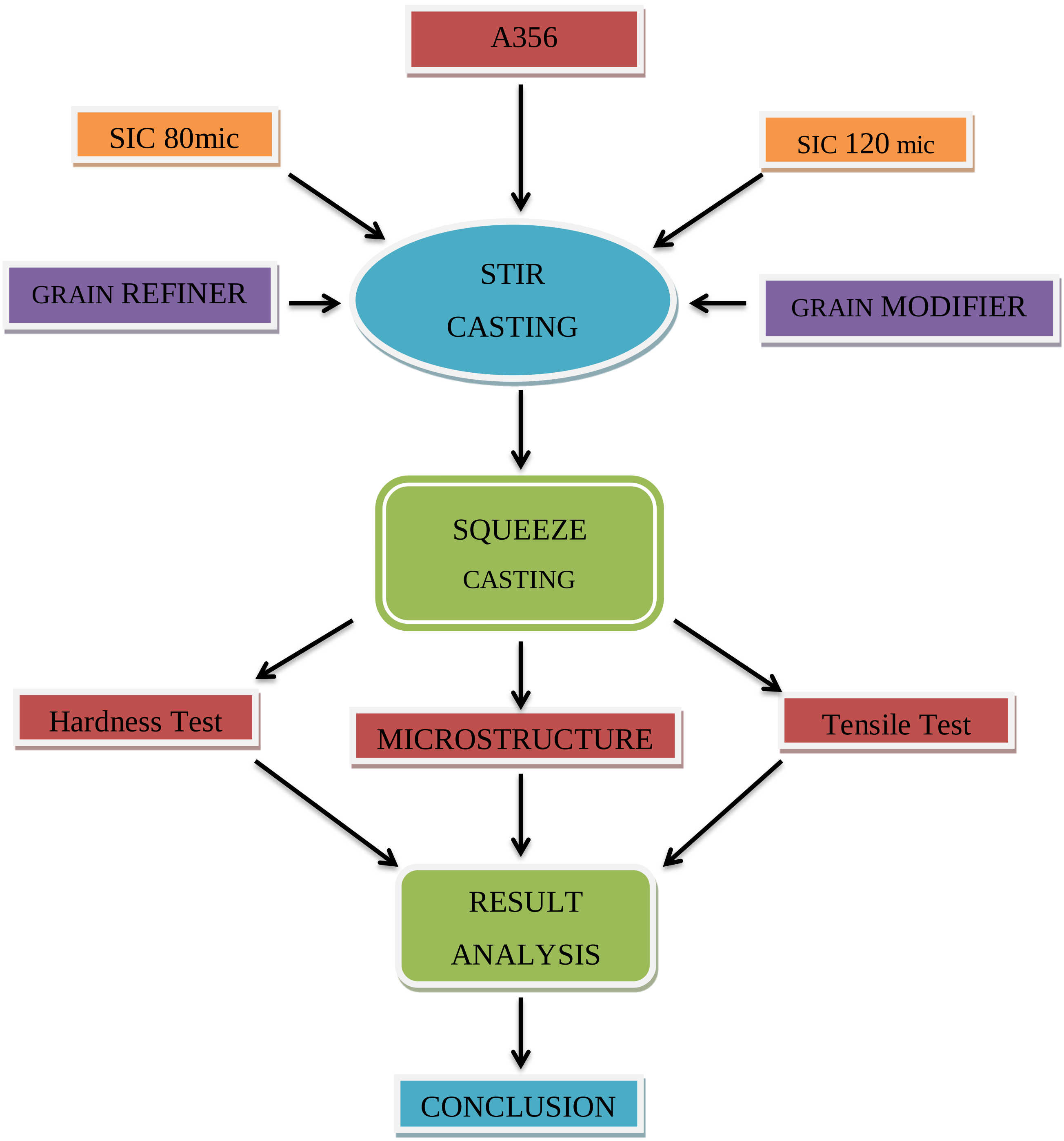


Figure 3.1: Methodology

A356 and its composites are casted in the form of cylindrical bars. The chemical composition of the alloy is obtained using Optical Emission Spectrometer. Reinforcing of alloy with varied percentage of dual size Silicon carbide, graphite with Strontium as grain refiner and Titanium-Boron as Grain modifier. The specimens for microstructure analysis, hardness and wear are prepared and tested as per ASMT standards.

- Samples for microstructure examination are prepared and analyzed using ASTM E407-07 standard metallurgical procedures.
- Tensile test is conducted as per ASTM E8 Standards, using UTM apparatus.
- Hardness test is conducted as per ASMT E10 standards, using Brinell hardness Tester.

CHAPTER 4

EXPERIMENTATION

4.1 Material Procurement

- **Aluminium A356**

  Aluminium A356 was bought at SRL Castings located at Electronic city Bengaluru.

- **Silicon Carbide (Sic)**

  Silicon Carbide 1kg of two different sizes (1) 80 microns (2) 120 microns each was bought at Ananya Flour polymer Coating 2nd stage Peenya.

- **Titanium-Boron and Strontium**

  Titanium-Boron and Strontium of 300grams each was bought at Vasa Scientific Co. in Bengaluru.

4.1.1 Introduction to Aluminium A356 Alloy

Introduced in 1943, alloy A356 have been the standard workhorse 3XX.X series alloy within the aerospace industry ever since. It was the first successful Al-Si-Mg-Cu high strength alloy using the beneficial effects of the alloying addition of chromium to develop good stress - corrosion cracking resistance in sheet products. Although other 3XX.X alloys have since been developed with improved specific properties, alloy A356 remains the baseline with a good balance of properties required for aerospace applications. This heat treatable alloy is considered high in strength. Corrosion resistance and machineability is fair. Rated low on workability and welded only by the resistance process.

- **A356 Aluminium Alloy Application**

  300.0 series alloy such as A356 are often used in transport applications, including marine, automotive and aviation, due to their high strength-to-density ratio. The strength and light weight is also desirable in other fields. Rock claiming equipment, bicycle components and hang glider airframes are commonly made from A356 Aluminium alloy.

  Hobby grade RC models commonly use A356 and A356 for chassis Plates. One interesting use for A356 is in the manufacture of M16 rifles for the American military, it is also commonly used in shafts lacrosse sticks, and camping knife and fork sets. Desert tactical Arms and French armament company PGM use it for their precision rifles.

Due to its strength, high density thermal properties and ability to be highly polished, A356 is widely used in mould tool manufacture. This alloy has been further refined into other 300.0 series alloys for this application.

Alloy A356 sheet and plate products have application throughout aircraft and aerospace structures where a combination of high strength and with moderate toughness and corrosion resistance are required. Typical applications are skin sheet, structural plate components up to 4 inches in thickness and general aluminum aerospace applications.

- **Chemical Composition of Aluminium A356 Alloy**

Element	% Weight Present
Cu	0.24
Mg	0.31
Si	7.39
Fe	0.18
Mn	0.03
Ni	0.02
Pb	0.01
Sn	0.01
Ti	0.20
Zn	0.06
Al	REM

Table 4.1: Chemical Composition of Aluminium A356 Alloy

Figure 4.1: Aluminium A356 Alloy Ingots

4.1.2 Introduction to Silicon Carbide

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractoriness, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing

Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, Sic forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength give this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. Chemical purity, resistance to chemical attack at temperature, and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. The electrical conduction of the material has led to its use in resistance heating elements for electric furnaces, and as a key component in thermostats (temperature variable resistors) and in varistors (voltage variable resistors).

(a)

(b)

Figure 4.2: Silicon Carbide (a) **80 Microns and (b) 120 Microns**

4.1.3 Introduction to Strontium

Strontium is a chemical element with symbol Sr and atomic number 38. An alkaline earth metal, strontium is a soft silver-white yellowish metallic element that is highly reactive chemically. The metal forms a dark oxide layer when it is exposed to air. Strontium has physical and chemical properties similar to those of its two vertical neighbors in the periodic table, calcium and barium. It occurs naturally in the minerals Celestine, strontianite, and putnisite, and is mined mostly from the first two of these. While natural strontium is stable, the synthetic 90Sr isotope is radioactive and is one of the most dangerous components of nuclear fallout, as strontium is absorbed by the body in a similar manner to calcium. Natural stable strontium, on the other hand, is not hazardous to health.

Figure 4.3: Strontium

4.1.4 Introduction to Titanium-Boron

Titanium Boron is a lustrous transition metal with a silver color, low density, and high strength. Titanium Boron is resistant to corrosion in sea water, aqua regia, and chlorine. Titanium Boron can be alloyed with iron, Aluminium, vanadium, and molybdenum, among other elements, to produce strong, lightweight alloys for aerospace (jet engines, missiles, and spacecraft), military, industrial process (chemicals and petrochemicals, desalination plants, pulp, and paper), automotive, agro-food, medical prostheses, orthopedic implants, dental and endodontic instruments and files, dental implants, sporting goods, jewelry, mobile phones, and other applications.

The two most useful properties of the metal are corrosion resistance and strength-to-density ratio, the highest of any metallic element. Titanium Boron is used in steel as an alloying element to reduce grain size and as a deoxidizer, and in stainless steel to reduce carbon content. Titanium Boron is often alloyed with Aluminium (to refine grain size), vanadium, copper (to harden), iron, manganese, molybdenum, and other metals. Titanium Boron mill products (sheet, plate, bar, wire, forgings, castings) find application in industrial, aerospace, recreational, and emerging markets. Powdered titanium is used in pyrotechnics as a source of bright-burning particles.

Figure 4.4: Titanium Boron

4.2 Fabrication of Test Specimens

The microstructure of any material is a complex function of the casting process, cooling rates. Therefore composites fabrication is one the most challenging and subsequent difficult task. Stir casting technique of liquid metallurgy is used to prepare A 356 Hybrid composites.

4.2.1 Aluminium based MMC preparation by Stir Casting

A stir casting setup consists of an Electrical Resistance Furnace and a stirrer assembly, was used to synthesize the composite.

Figure 4.5: Stir Casting

4.2.2 Composite preparation furnace

Three phase electrical resistance type of 10 KW capacities is used. The temperature range of the furnace is 800^0c with a controlled accuracy of $\pm 10^0$c fitted with a digital temperature controller.

4.2.3 Preheating of Reinforcement

Muffle furnace was used to preheat the particulate to a temperature of 500^0c. It was maintained at the temperature till it was introduced into the aluminum A356 alloy melt. The preheating of the reinforcement is necessary in order to reduce the temperature gradient and to improve wetting between molten metal and the particulate reinforcement.

4.2.4 Melting of Matrix Alloy

The melting range of aluminum A356 alloy is $600\text{-}700^0$c. a known quantity of aluminum A356 ingots were pickled in 10% NaOH solution at room temperature for 10 minutes. Pickling was done to remove the surface impurities. The smut formed was removed by immersing the ingots for 1 minute in a mixture of one part nitric acid and one

part water followed by washing in methanol. The melt was superheated to a temperature of 700^0c and maintained at that temperature. The molten metal was then degassed using degasser 190 tablet for about 8 minutes.

4.2.5 Mixing and Stirring

Aluminium coated stainless steel impeller was used to stir the molten to create a vertex. The impeller was of centrifugal type, the three blades welded at 45^0 inclination and 120^0 apart. The stirrer was rotated at the speed of 300 - 400 rpm and a vertex was created in the melt. The depth of immersion of impeller was approximately $1/3^{rd}$ of the height of the molten metal from the bottom of the crucible. The preheated particulates of alumina and graphite were introduced into the vertex at a rate of 60grams per minute. Stirring was continued until interface degassed using degassing tablet and after rehearsing to superheated temperature it was poured into the preheated die.

4.2.6 Pouring of Molten Metal into dies

After few minutes of stirring the, liquid metals with reinforcements are poured into dies to get the required castings. The dies were preheated to ease the process of removing castings.

4.2.7 Proof Machining

After solidification the required cast are obtained are sent for proof machining on a center lathe the scaling from the surface.

4.2.8 Specimen Preparation

The casted specimens obtained were machined on a CNC Lathe according to ASTM standards for Tension test and Hardness test.

4.2.9 Composition of Specimens Prepared

- The first specimen prepared was As Cast with nil percentage of Sic, Strontium and Titanium Boron.
- The first composite was prepared with Nil Silicon Carbide, and 2% of both Strontium and Titanium-Boron.
- The next set composites were prepared with 5% of Silicon Carbide (80 Microns and 120 Microns), and 2% of both Strontium and Titanium Boron.

Figure 4.6: A356 Ingots

Figure 4.7: Crucible

Figure 4.9: Die Pre-Heating

Figure 4.9: Degassing tablet

Figure 4.10: Molten Metal

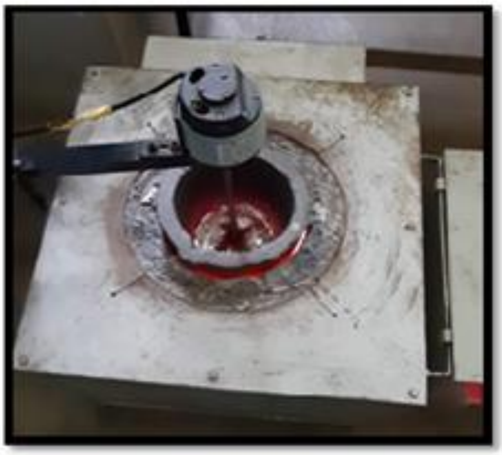


Figure 4.11: Stirrer

Figure 4.12: Adding Reinforcement

Figure 4.13: Pouring Molten Metal

Figure 4.14: Squeezing

Figure 4.15: Center Lathe

4.3 Experimental Procedure

4.3.1 Microstructure

All technological properties of materials are directly connected to their microstructure. Among these properties are their strength and deformation characteristics, their wear and high temperature behavior, and also their corrosion behavior and the failure behavior under fatigue loads. Some of these properties can be changed dramatically by slight changes in the microstructure. The Specimens for microstructure analysis were prepared in the form of cylindrical pieces of 20 mm diameter, 15 mm thickness and polished to obtain mirror surface finish by proper grinding, polishing and etching.

The cross sections of specimens were ground using 150 grade Silicon carbide papers. Then the specimens were emerged with water proof emery sheets of grid 400, 600, 800
and 1000 respectively in the order, on the rotating grinding disc. The emerged specimens were polished over rotating disc with the polishing cloth and alumina paste. The specimen
Were cleaned with acetone and dried.

Figure 4.16: Microstructure Specimen

4.3.2 Polishing and Etching

Polishing is done to remove the material deformation introduced by grinding and to obtain a flat mirror like surface. During successive steps of mechanical polishing, finer and finer abrasive particles (Diamond paste) from 3 to 0.25 µm with alcohol based lubricant and rotational speeds of 150 RPM for duration of 0.5 to 3 minutes were used. Final polishing was carried out for 0.5 minute using diamond polishing to obtain flat surface without scratches. Microstructure specimens were prepared as per standard metallurgical procedures, etched in etched prepared using 90 ml water, 4 ml HF, 4 ml H_2SO_4 and 2gm CrO_3 and photographed using Optical Microscope.

Figure 4.17: Optical Metallurgical Microscope

Figure 4.18: Polishing Machine

4.3.3 Hardness Test

Hardness is the measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong Intermolecular bonds. There are three types of tests used with accuracy by the metal industry; they are Brinell hardness test, Rockwell hardness test, and the Vickers hardness test. But in our present work we have considered only Rockwell hardness test as per ASTM E10. The Rockwell scale is the hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload.

Figure 4.19: Hardness Specimen

Figure 4.20: Brinell hardness Testing Machine and Brinell Microscope

4.3.4 Tensile Test

Two vises apply tension to a specimen by pulling at it, stretching the specimen until it fractures. The maximum stress it withstands before fracturing is its ultimate tensile strength.

Ultimate tensile strength (UTS) often shortened to tensile strength (TS), ultimate strength, or Ftu within equations, is the capacity of a material or structure to withstand loads tending to elongate, as opposed to compressive strength, which withstands loads tending to reduce size. In other words, tensile strength resists tension (being pulled apart), whereas compressive strength resists compression (being pushed together). Ultimate tensile strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking. In the study of strength of materials, tensile strength, compressive strength, and shear strength can be analyzed independently.

Some materials break very sharply, without plastic deformation, in what is called a brittle failure. Others, which are more ductile, including most metals, experience some plastic deformation and possibly necking before fracture.

The UTS is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress–strain curve (see point 1 on the engineering stress–strain diagrams below) is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material.

Tensile strengths are rarely used in the design of ductile members, but they are important in brittle members. They are tabulated for common materials such as alloys, composite materials, ceramics, plastics, and wood.

Tensile strength can be defined for liquids as well as solids under certain conditions. For example, when a tree draws water from its roots to its upper leaves by transpiration, the column of water is pulled upwards from the top by the cohesion of the water in the xylem, and this force is transmitted down the column by its tensile strength. Air pressure, osmotic pressure, and capillary tension also plays a small part in a tree's ability to draw up water, but this alone would only be sufficient to push the column of water to a height of less than ten meters, and trees can grow much higher than that (over 100 m).

Tensile strength is defined as a stress, which is measured as force per unit area. For some non-homogeneous materials (or for assembled components) it can be reported just as a force or as a force per unit width. In the International System of Units (SI), the unit is the pascal (Pa) (or a multiple thereof, often megapascals (MPa), using the SI prefix *mega*); or, equivalently to pascals, newton's per square meter (N/m^2). A United States customary unit is pounds per square inch (lb/in^2 or psi), or kilo-pounds per square inch (ksi, or sometimes kpsi), which is equal to 1000 psi; kilo-pounds per square inch are commonly used in one country (US), when measuring tensile strengths.

Figure 4.21: Tensile Test Specimen

Figure 4.22: Tensile Testing Machine

CHAPTER 5

RESULT

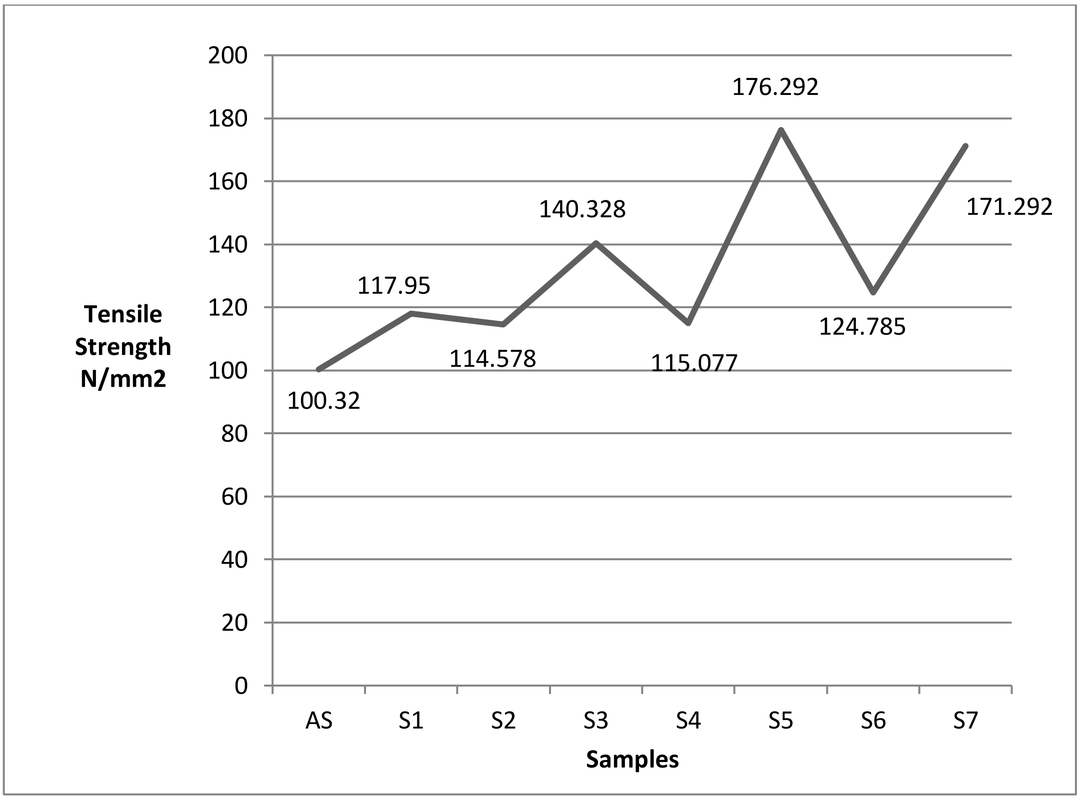
5.1 Cast Compositions

Casting	SIC 80 Microns%	SIC120 microns%	Modifier %	Refiner %
As cast	_	_	_	_
S1	_	_	2	2
S2	1	4	2	2
S3	2	3	2	2
S4	3	2	2	2
S5	4	1	2	2
S6	5	0	2	2
S7	0	5	2	2

Table 5.1 Casting Composition

5.2 TENSILE TEST

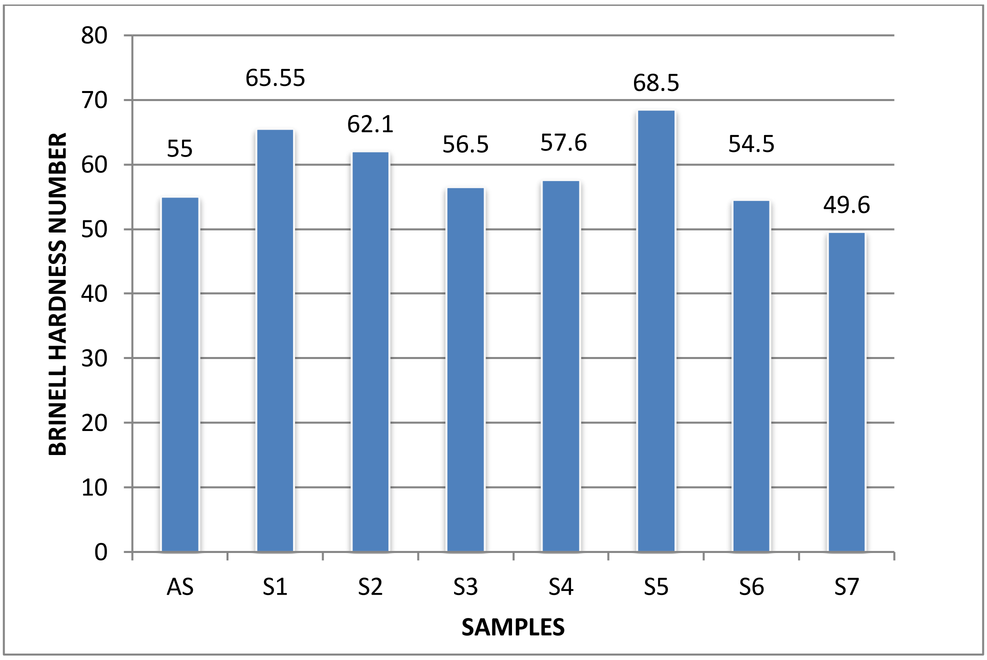
SAMPLES	AS	S1	S2	S3	S4	S5	S6	S7
Tensile Strength N/mm ^{2}	100.32	117.95	114.57	140.32	115.07	176.29	124.78	171.292



Result: Compared to all casting prepared, casting S5 with 4% silicon carbide of 80 microns and 1%120 microns gave the better tensile strength.

5.3 HARDNESS TEST

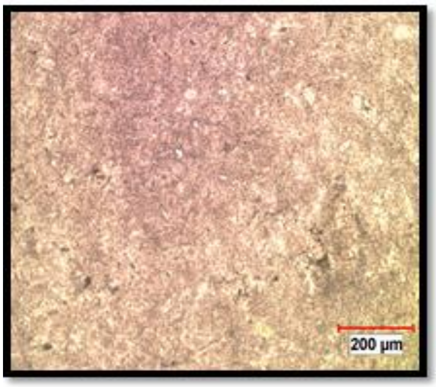
SAMPLES	AS	S1	S2	S3	S4	S5	S6	S7
BHN	55	65.5	62.1	56.5	57.6	68.5	54.5	49.6

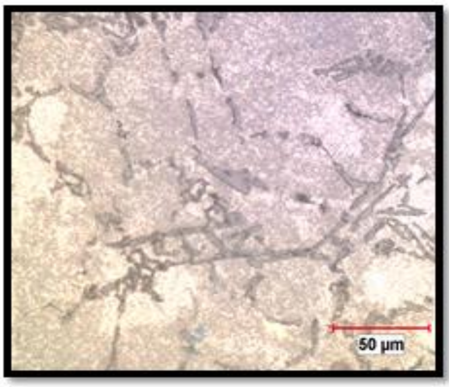


Result: compared to all specimen sample S5 with 4%of silicon carbide of 80% micron and 1% of 120 micron which gives the better hardness.

5.4 MICROSTRUCTURE

Sample AS

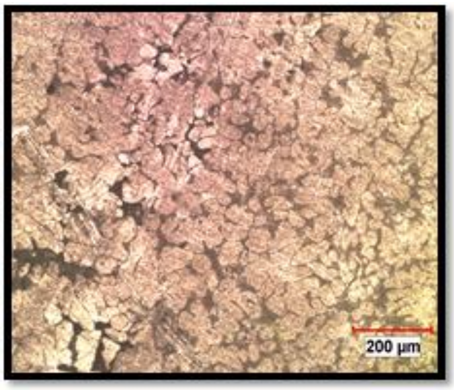


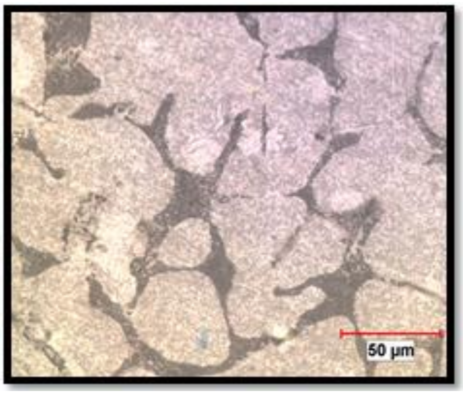


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 1

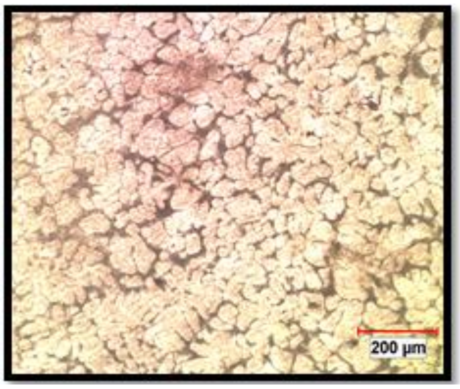


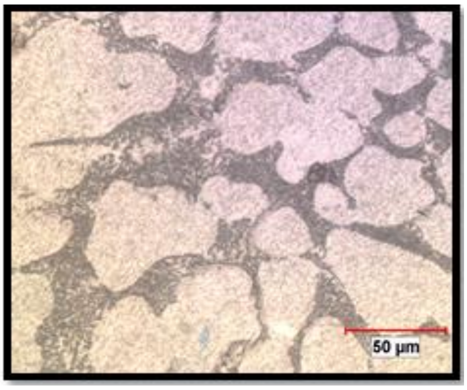


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 2

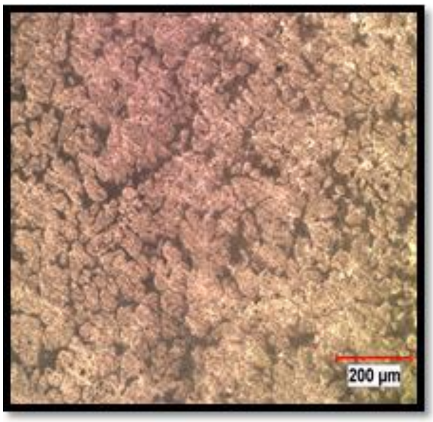


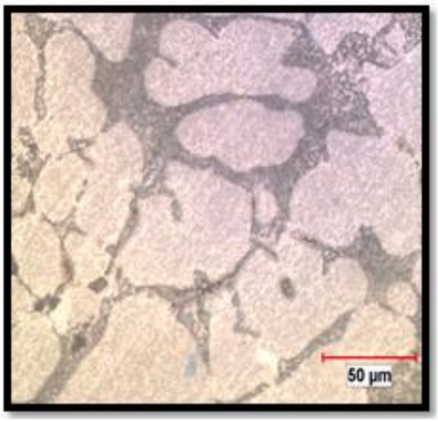


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of Aluminium solid solution.

Sample 3

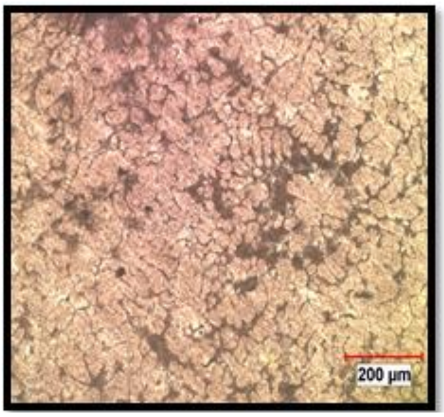


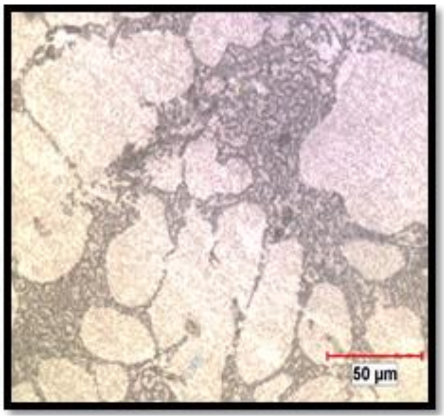


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 4

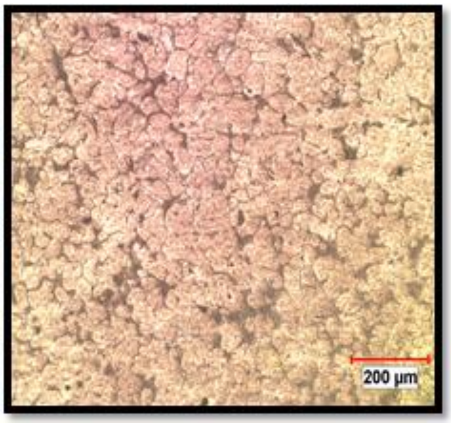


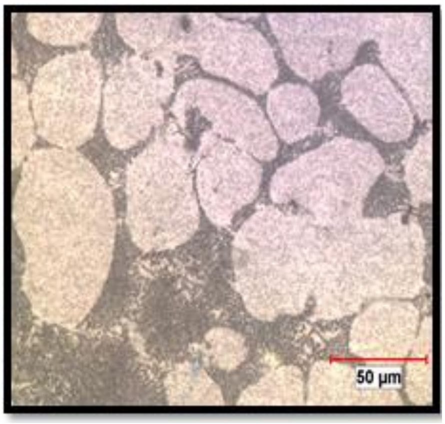


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 5

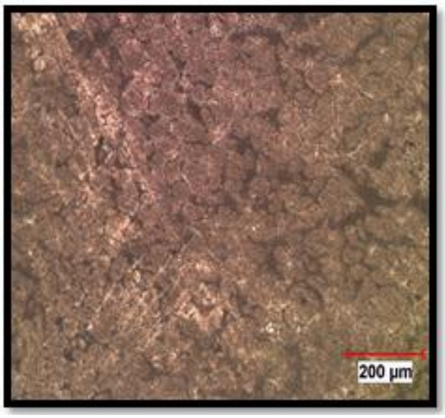


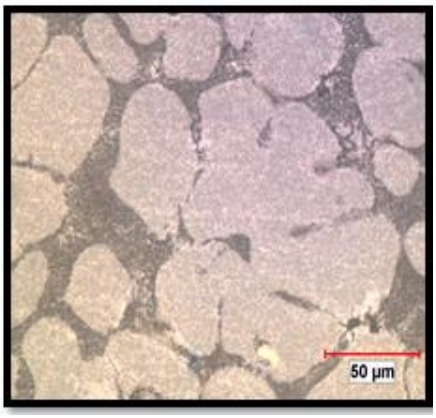


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 6

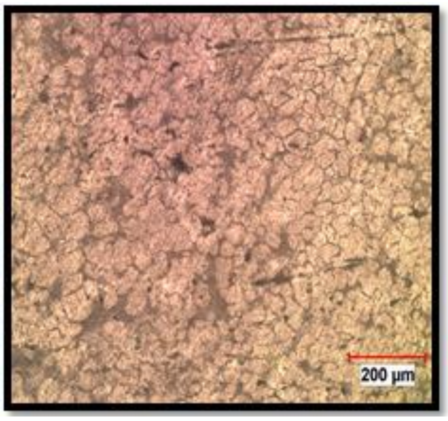


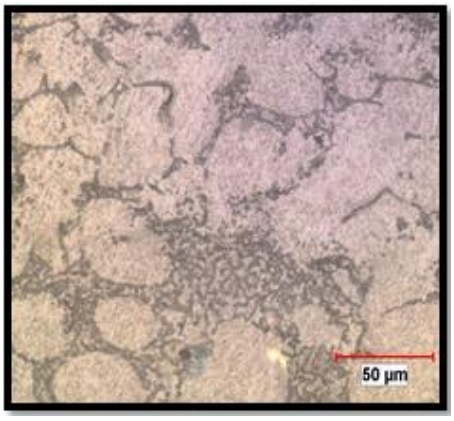


100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

Sample 7





100X **500X**

RESULT: - Microstructure consists of interdendritic precipitates in a matrix of aluminium solid solution.

CONCLUSION

From the studies conducted on A356 alloy based, Al-Sr grain refined and Al-Ti-B modified reinforced composite, the following conclusion have been drawn.

- Gravity die casting method is used to obtain homogeneous microstructure even after heat treatment of A356 alloy with Al-Sr as grain refiner and Al-Ti-B as modifier.
- Microstructure revels the uniform distribution of grain refiners in the aluminium solid structure
- Microstructure consists of interdendritic network of eutectic silicon matrix of aluminium solid solution. No segregation or porosity was seen in the section.
- Compared to all specimens prepared, Sample S5 with Silicon Carbide Size of 4% 80 microns, 1% of 120 Microns gave the better tensile strength.
- Sample S5 Showcases Better Hardness due to addition Silicon Carbide of 4% 80 Microns, 1% of 120 micron particle which improves the Hardness Properties.
- Hence, we can consider Sample S5 for the further scope of work due to its comparatively better properties than all the casts prepared.

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