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CHARACTERIZATION OF THE MECHANICAL PROPERTIES OF RECYCLED GGG-40 CAST IRON CHIPS REINFORCED AlMg1SiCu ALUMINUM CHIPS COMPOSITE

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BAHIR DAR UNIVERSITY

COLLEGE OF SCIENCE

DEPARTMENT OF MATERIAL SCIENCE AND ENGINEERING

CHARACTERIZATION OF THE MECHANICAL PROPERTIES OF RECYCLED GGG-40 CAST IRON CHIPS REINFORCED AlMg1SiCu ALUMINUM CHIPS COMPOSITE

By

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Characterization of the mechanical properties of recycled GGG-40 cast iron chips reinforced AlMg1SiCu aluminum chips composite

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A thesis submitted to the Department of Materials Science and Engineering in partial fulfillment of the requirements for the degree of Masters of Science in Materials Science and Engineering College of Science Bahir Dar University

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Declaration

I, the undersigned, declare that the work which is being presented in this thesis entitled "**Characterization of the Mechanical Properties of Recycled GGG-40 Cast Iron Chips Reinforced AlMg1SiCu Aluminum Chips Composites**", is a reliable record of my own work in fulfillment of the requirements for the degree of Masters of Science in Materials Science and Engineering under the supervision of Dr. Maru Dessie, in College of science at Bahir Dar University, Ethiopia.

Name of the student ___________________________ Signature _____________

Date of submission: ________________

Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

Advisor's Name: ______________________

Advisor's Signature: ___________________

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Abstract

Metal matrix composites are undoubtedly a group of advanced engineering materials. Compared to unreinforced matrix material, they are characterized by increase strength, greater stiffness, increase wear resistance, better mechanical properties and dimensional stability at elevated temperatures as well as lower density.

This paper deals with the mechanical properties of recycled GGG-40 cast iron chips reinforced AlMg1SiCu aluminum chip composites. Thus, composition type is aluminum metal matrix composites (AMMC) is fabricated by stir casting method. The composites were fabricated with various volume percentage levels as aluminum reinforced with (0, 5, 10 &15%) of GGG-40 cast iron chips. Fabricated composites specimens were prepared according to ASTM standard size to study. The improvement of GGG-40 cast iron chips reinforcement on mechanical properties of aluminum alloy composites were analyzed in this study. The microstructure studies were also carried out. It is observed that increasing the GGG-40 cast iron chips content within the aluminum matrix results in significant increasing in ductility, hardness, ultimate tensile strength up to 10% reinforcements. The addition of GGG-40 cast iron chips greater than 10% conversely decreased the hardness, ultimate tensile strength of the composites and porosity increased due to density difference between the composite.

Key words: AlMg1SiCu aluminum alloy, GGG-40 cast iron, reinforcement, metal matrix material.

Table of content

Contents Page

List of figures

List of tables

Abbreviations

AMMC	Aluminum Metal Matrix Composite
AMC	Aluminum Matrix Composite
DRMMC	Discontinuously Reinforced Metal Matrix Composites
ASTM	American Society for Testing and Materials
ASTME	American Society of Tool and Manufacturing Engineers
CMC	Ceramic Matrix Composites
CTE	Coefficient of Thermal Expansion
UP	Unsaturated Polyester
MMC	Metal Matrix Composite
PMC	Polymer Matrix Composites
YS	Yield Stress
UTS	Ultimate Tensile Stress
PVC	Polyvinyl Chloride
SG	Spheroidal Graphite
SGI	Spheroidal Graphite Iron
GCI	Grey Cast Iron
SGCI	Spheroidal Graphite Cast Iron
CGI	Compacted Graphite Iron
DI	Ductile Iron
DCI	Ductile Cast Iron
BHN	Brinell Hardness Number
RHN	Rockwell Hardness Number
ANSI	American National Standards Institute
UTM	Universal Testing Machine
HB	Hardness
P/M Al	Powder Metallurgy of Aluminum
SiCp	Structure and Interpretation of Computer Programs

Symbols

μm	Micrometer
mm	Millimeter
Al	Aluminum
Mg	Magnesium
Si	Silicon
Cu	Copper
Fe	Iron
Pb	Lead
Mo	Molybdenum
C	Carbon
V	Vanadium
P	Phosphorous
Cr	Chromium
Mn	Manganese
S	Sulfur
Zn	Zinc
B	Boron
SiC	Silicon carbide
Al_2O_3	Alumina
Ɛ	Strain
A_0	Original cross-sectional area
A_f	Final cross-sectional area
σ	Stress
°C	Degree centigrade
°F	Degree Fahrenheit
AlN	Aluminum nitride
TiC	Titanium carbide
Ti	Titanium
Ni	Nickel
TiB_2	Titanium diboride

Chapter 1

Introduction

1.1 Back ground

Composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct within the finished structure [1-3]. Composite materials have a wide range of applications compared to metals because of their light weight, high strength to weight ratio, good fatigue resistance, corrosion resistance [2, 4-11]. Composite materials can be classified into three groups on the basis of matrix material. They are:

- Metal matrix composites (MMC)
- Ceramic matrix composites (CMC)
- Polymer matrix composites (PMC)

The advantages of MMC compared to polymer matrix composites lie in their retention of strength and stiffness at elevated temperature, good abrasion and creep resistance properties. Mostly in MMC aluminum is used as matric metal due to easy availability, high strength to weight ratio, easy machinability, durability, ductility, recyclability and malleability [2-5, 10, 12]. Aluminum is 100% recyclable without downgrading of its quality. The re-melting of aluminum requires little energy only about 5% of the energy required to produce the primary metal initially is needed in the recycling process [28, 29, 23]. Pure aluminum has some limitations like low strength, hardness, toughness, and elongation. Thus, aluminum alloys are used to enhance the properties of aluminum [34].

When using aluminum alloy and metals for product parts it has been machined to the required dimension at this time scraps and chips are produced as waste after machining operation. The waste materials are reutilized by returning them in to smelters. However, during melting processes of materials for recycling, many metals are lost due to oxidation [2]. Recycling of iron and other metals require separating the ferrous and non-ferrous metal chips to improve its quality [5]. However, current manufacturing companies either put these wastes in landfills, or casting without separation [3].

Stir casting (vortex technique) is commercially a low-cost method to fabricate aluminum metal matrix composites (AMMCs). Its advantages lie in its simplicity, flexibility, and applicability to large volume production. This process is the most economical of all the available routes for AMMCs production, and it allows very large-sized components to be fabricated. To achieve the stir casting methods, the following parameters are considered [4, 6]:

(i) No adverse chemical reaction between the reinforcement material and matrix alloy
(ii) No or very low porosity in the cast AMMCs
(iii) Wettability between the two main phases, and
(iv) Achieving a uniform distribution of the reinforcement material.

In recent study the recycling of metallic chips such as aluminum chips, steel chips, and bronze chips has been carried out. Most of these studies have been focused on sintering and hot/cold extrusion processes. Also, the effect of chip size on the mechanical properties and microstructure have been investigated using different chips. Steel chips and Ti-6Al-4V chips have been used to produce metal matrix composite (MMCs). However, the mechanical properties of spheroidal cast iron chips (GGG-40) reinforced AlMg1SiCu aluminum chip composites have not been investigated and reported. Hence, in this study, GGG-40 cast iron chips and AlMg1SiCu aluminum chip were mixed with different contents. GGG-40 is a ductile iron grade of Germany standard, which is equal to QT400, ASTM A536 60-40-18, 60-40-15, FCD400, GS400-12, FGS400-12, 400/17, 420/12, 400-12, 400-18 and SG38, SG40.

1.2 Motivation

For most aluminum foundries, reusing aluminum chips and scraps as raw material for melting stocks is perhaps the best option as waste management policy in what concerns to economic and technical aspects. In-house recycling of aluminum machining chips presents some significant benefits over other recycling solutions, such as reduction on buying costs of raw material, elimination of chips transport costs; simplified waste management system; high cost/benefit ratio. And cast iron chips are thrown as waste product but these chips can be recycled to strengthen aluminum alloy as reinforcement material.

Aluminum chips is a low density product (0.25 kg/dm^3) which makes them inconvenient for handling and transportation, and their surface area is relatively large to the volume, and their surfaces are usually covered with oxides, oil emulsion and machining fluid, which is not good for recycling by re-melting approach without cleaning, separating and compressing the chips. Directing melting such a product lead to several problems like [21, 22]:

1. Economic aspects: very low metal recovery rate and high energy consumption;
2. Environmental aspects: high smoke and gases generation;

3. Quality aspects: low quality of the final product (non-metallic inclusions, gas porosities, poor mechanical properties).

1.3 Significance of the Study

The significance of this study is:

1. To find an alternating material for aluminum alloy and synthetic of aluminum metal matrix composites.
2. To recycle the waste aluminum alloy chips and cast iron chips composite effectively.
3. To reduce environmental factor.
4. To find an alternative material which is cheap in cost and have easy syntesis method.
5. To find material which have good mechanical strength and light weight.

1.4 Objectives

The main objective of this thesis is to characterize the mechanical properties of recycled GGG-40 cast iron chips reinforced AlMg1SiCu aluminum chip composites.

1.4.1 Specific objectives

The specific objectives are:

- To recycle effectively waste GGG-40 cast iron chips and AlMg1SiCu aluminum chip composite.
- To fabricate sample of AlMg1SiCu aluminum chip and cast-iron chips composite by stir casting method.
- To prepare standard test specimens according to ASTM standard.
- To study the toughness, hardness, tensile strength and microstructure for different composition of GGG-40 cast iron chips and AlMg1SiCu aluminum.
- To investigate less weight material than cast iron.
- To investigate better strength material than recycled AlMg1SiCu aluminum chips.

1.5 Scope of the research

The research has been considered to use the locally machined aluminum chips as a matrix element and cast-iron chips as reinforcement and its specimens have been prepared in four different compositions (0%, 5%, 10% and 15% of GGG-40 cast iron) by starting from 0% up to possible mixing in 5% increment in our capacity and up to change in properties. The reinforcement material is taken from the machined cast iron chips and it is cleaned, separated and crushed up to 70-100 µm and heated up to 150 ºC and it is mixed in to melted aluminum alloy by stir casting method. The hardness, tensile, microstructure tests is studied for each composition.

1.6 Problem statement

Light weigh, tough and high strength is a demand of today's technology. Composite material is lighter and stronger with compare to pure metal. Composite material is based on the metal matrix or reinforcement. This need is fulfilling by aluminum metal matrix based composite material. So recycled GGG-40 cast iron chips reinforced AlMg1SiCu aluminum chip composites can give high strength to weight ratio. Adding of cast iron on aluminum alloy can increase its strength due to high strength of cast iron.

Recently chips are recycled by simple casting without cleaning, separating and compacting thus cast iron and aluminum chips have a high specific volume and a low density that makes the re-melting more difficult and with a low yield. For this reason, compacting with a cold press or briquetting to increase the density of chips for transportation and melting capacity, clean with methyl alcohol and water to remove coolants, dirt’s and oil, and sieve to separate ferrous and non-ferrous metal improve quality of chips. Thus makes possible a more effective melting process and make cost effective. In addition to developing a lightweight material, waste recycling enhances the improvement of quality of environment.

1.7 Methodology

The methodology used to complete the research is as follows:

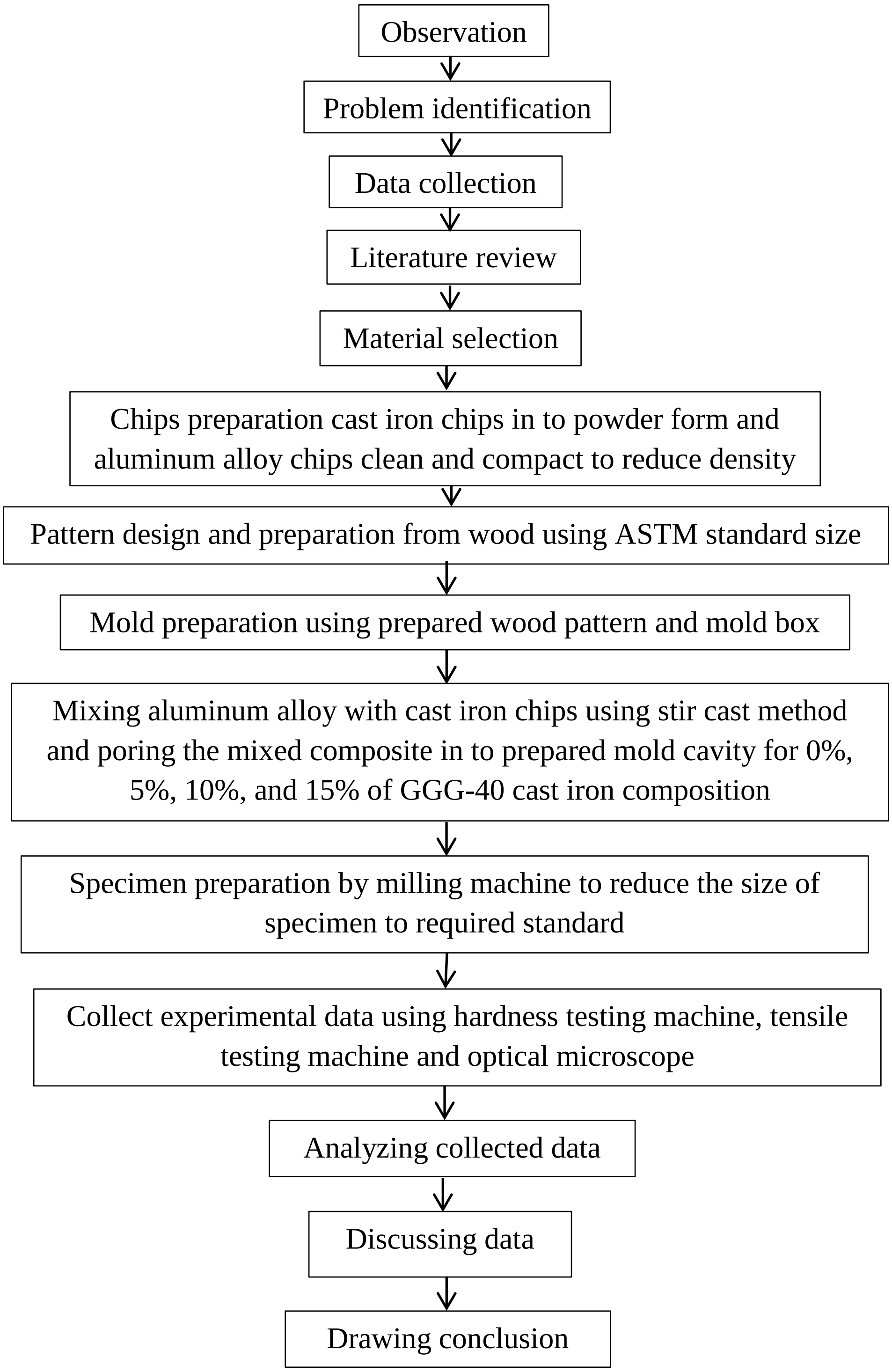


Figure 1.1 Methodology of the thesis.

Chapter 2

Literature Review

2.1. Composite materials

Composite material is a combination of two or more materials having significantly different physical and chemical properties that when combined produce a material with characteristics different from the individual. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents. Favorable properties of composites materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc. [11- 14, 23].

Composites are most successful materials used for recent works in the industry. Metal composites possess significantly improved properties including high tensile strength, toughness, hardness, low density and good wear resistance compared to alloys or any other metal. There has been an increasing interest in composites containing low density and low-cost reinforcements [13-17].

2.1.1 Classification of composites materials

(a) On the basis of matrix:

1. Metal matrix composites (MMC): MMC are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase [12, 13].

2. Ceramic matrix composites (CMC): CMC are composed of a ceramic matrix and imbedded fibers of other ceramic material (dispersed phase) [12, 13].

3. Polymer matrix composites (PMC): PMC are composed of a matrix from thermoset (unsaturated polyester (UP), epoxy) or thermoplastic (PVC, nylon, polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase) [12, 13].

(b) On the basis of material structure:

1. Particulate composites: particulate composites consist of a matrix reinforced by a dispersed phase in form of particles [12, 13].
a. Composites with random orientation of particles.
b. Composites with preferred orientation of particles.

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

2. Fibrous composites: short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers.
a. Composites with random orientation of fibers.
b. Composites with preferred orientation of fibers.

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

a. Unidirectional orientation of fibers.
b. Bidirectional orientation of fibers.
c. Laminate composites

The composite material in this work is ductile (nodular, graphite) cast iron and aluminum alloy from the classification of composite materials it is MMC materials based on matrix and particulate composites based on material structure.

2.1.2 Metal matrix composites (MMC)

Metal matrix composites are composed of a metallic matrix (Al, Mg, Fe, Cu etc.) and a dispersed ceramic (oxide, carbides) or metallic phase (Pb, Mo, W etc.). Ceramic reinforcement may be silicon carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc, whereas metallic reinforcement may be tungsten, beryllium, graphite etc [12-23]. MMCs are used for space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications. From a material point of view, when compared to polymer matrix composites, the advantages of MMCs lie in their retention of strength and stiffness at elevated temperature, good abrasion and creep resistance properties. Most MMCs are still in the development stage or the early stages of production and are not so widely established as polymer matrix composites [16].

The biggest disadvantages of MMCs are their high costs of fabrication, which has placed limitations on their actual applications [14, 17]. There are also advantages in some of the physical attributes of MMCs such as no significant moisture absorption properties, non-inflammability, low electrical and thermal conductivities and resistance to most radiations. MMCs have existed for the past 30 years and a wide range of MMCs have been studied [12, 19]. Compared to monolithic metals, MMCs have [16]: higher strength-to-density ratios, higher stiffness-to-density ratios, better fatigue resistance, better elevated temperature properties, higher strength, lower creep rate, lower coefficients of thermal expansion and better wear resistance.

The advantages of MMCs over the polymer matrix composites are [16]:

1. Higher temperature capability,
2. Fire resistance,
3. Higher transverse stiffness and strength,
4. No moisture absorption,
5. Higher electrical and thermal conductivities,
6. Better radiation resistance,
7. No out gassing,
8. Fabric ability of whisker and particulate-reinforced MMCs with conventional metalworking equipment.

2.1.2.1 Aluminum metal matrix composite

Aluminum is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the earth's solid surface [4, 21, 34]. Due to easy availability, high strength to weight ratio, easy machinability, durability, ductility and malleability aluminum is chosen as matrix material [4].

2.2 Materials for Matrix

According to K.K Chawla (2012), the common matrix materials for MMCs are aluminum and aluminum alloys, titanium and titanium alloys, magnesium and its alloys, cobalt, silver, nickel and niobium. For this paper aluminum and its alloys are used as matrix. Aluminum alloys because of their low density and excellent strength, toughness, and corrosion resistance, have been used extensively in the automotive and aerospace fields. Of special mention are Al-Cu-Mg and Al-Zn-Mg-Cu alloys, which are very important precipitation-hard able alloys. Criteria for the selection of matrix and reinforcement materials are [12, 19, 21]:

1. Compatibility
2. Thermal properties
3. Fabrication method
4. Application
5. Cost
6. Properties
7. Recycling

Metals are essential constituent for fabrication of MMC and choice of matrix material depends upon strength, temperature of application, density, cost requirement, easy availability and ease of processing. The 6xxx series of Al-Mg- Si alloys are widely used as medium strength structural alloys having the advantage of good weld ability, corrosion resistance and immunity to stress corrosion cracking [16, 18, 21, 24]. A typical 6xxx type of aluminum alloy that could be used as a matrix for the composites is the 6061 alloy.

The characteristics of AA6061 are like lower density, lower melting point, and ease of processing, high thermal conductivity, low coefficient of thermal expansion, good wear resistance, high temperature strength, easy availability and low cost influence the choice of matrix material [18, 25]. Aluminum is 100% recyclable with no downgrading of its qualities. The re-melting of aluminum requires little energy: only about 5% of the energy required to produce the primary metal initially is needed in the recycling process [26-29]. Pure aluminum has also some limits according to properties so to enhance aluminum properties aluminum alloys are used [8-10, 34]. Due to this recycled aluminum alloy is used to fabricate the aluminum alloy composite.

In metal industries waste and scrap metals that remain after manufacturing processing are chip and discards. These waste materials are reutilized by returning them to smelters. However, during melting processes of materials for recycling, many metals are lost due to occurring oxidation and costs of labor, energy and environmental protection expenditures [2, 5-7, 29]. Recycling of iron and other metals requires separating the ferrous and non-ferrous metal chips to improve their quality. However, currently there is a lack of separating these ferrous and non-ferrous metal chips to fulfill the needs of the manufacturing industry.

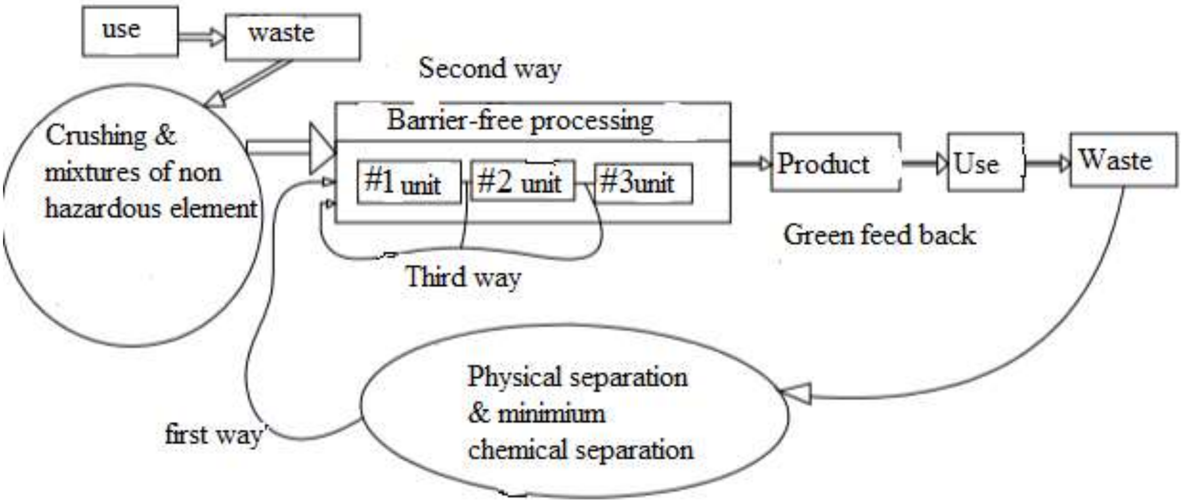


Figure 2.1 Material recycling process [5].

Due to easy availability, high strength to weight ratio, easy machinability, durability, ductility and malleability aluminum is chosen as matrix material [12, 14].

2.2.1 Advantages of aluminum

A. Light weight, strong and long-lasting**:** aluminum is a very light metal with a specific weight of 2.7 gm/cm^3, about a third that of steel. Its strength can be adapted to the application required by modifying the composition of its alloys [12, 28, 29, 34].

B. Highly corrosion resistant**:** aluminum naturally generates a protective oxide coating and is highly corrosion resistant [34].

C. Excellent heat and electricity conductor**:** aluminum is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminum the most commonly used material in major power transmission lines [34].

D. Good reflective properties**:** aluminum is a good reflector of visible light as well as heat, and that together with its low weight makes it an ideal material for reflectors, for example, light fittings or rescue blankets [34].

E. Very ductile**:** aluminum is ductile and has a low melting point and density. In a molten condition it can be processed in a number of ways [34].

F. Completely impermeable and odorless**:** aluminum foil, even when it is rolled to only 0.007 mm thickness, is still completely impermeable and let's neither light aroma nor taste substances out [34].

G. Totally recyclable: aluminum is 100 percent recyclable with no downgrading of its qualities [34].

2.3. Reinforcement materials of metal matrix composite

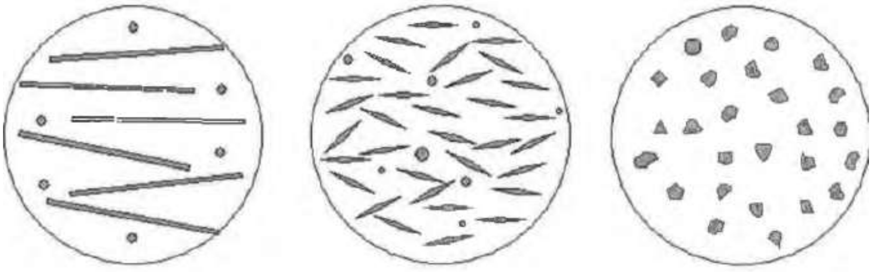
The correct selection of reinforcement type, geometry or shape is important in order to obtain the best combination of properties at relatively low cost. For instance, the use of spherical reinforcements instead of angular reinforcements could be advantageous in certain components [12]. When selecting the reinforcement materials, the following aspect must be considered:

1. Shape-continuous fiber, chopped fiber, whiskers, spherical or irregular particles, or flakes
2. Size - diameter and aspect ratio
3. Surface morphology-smooth or corrugated and rough
4. Surface defects - voids
5. Inherent properties - such as strength, moduli and density
6. Chemical compatibility with the matrix

In terms of size and shape, the reinforcement material may be sub divided into three major categories [12, 21].

1. Continuous fibers
2. Whiskers
3. Particles or platelet:

The reinforcing elements are schematically represented in figure 2.2:



(a) Monofilaments (b) Whiskers (c) Particulate

Figure 2.2 Schematic diagrams of different kinds of reinforcing elements [12].

a. Monofilaments (Continuous fiber)

Continuous fibers exhibit highest strength when they are oriented unidirectional, but the composite then has low strength in the direction perpendicular to the fiber orientation. carbon(C), boron (B), silicon carbide (SiC) and alumina (Al_2O_3) are the most researched continuous reinforcements [12].

The density of carbon fiber is the lowest; accordingly, it can offer significant weight savings. Boron fibers show the greatest strength in comparison with other fibers; however, the cost of these fibers is very high [21].

b. Whiskers

Numerous materials, including metal, oxides, carbides, halide and organic compounds have been prepared under controlled conditions into the form of whiskers. Whisker based composites are costlier than particle based ones, but in general they offer higher strength than particle based composites. Whisker reinforced composites offers the potential for enhanced properties, but suffer from whisker breakage and damage during secondary fabrication [12].

c. Particles

Particles are the most common and cheapest reinforcement. This type of reinforcement material produces discontinuous reinforced composites with isotropic properties another advantage is that conventional fabrication methods may be used to produce a wide range of product forms, making them relatively inexpensive compared to composites that are reinforced with continuous fiber or filaments. The useful temperature ranges of particle reinforced aluminum based composite is 20-150°C and because of their relatively low cost, these materials are likely to find extensive applications [12, 21]. Thus spheroidal graphite is one of discourteous or particle reinforced material which is from types of cast iron material, ductile cast iron it has particulate structure shown in figure 2.3.

Reinforcements for metal matrix composites have a manifold demand profile, which is determined by production and processing and by the matrix system of the composite material. The following demands are generally applicable [21]:

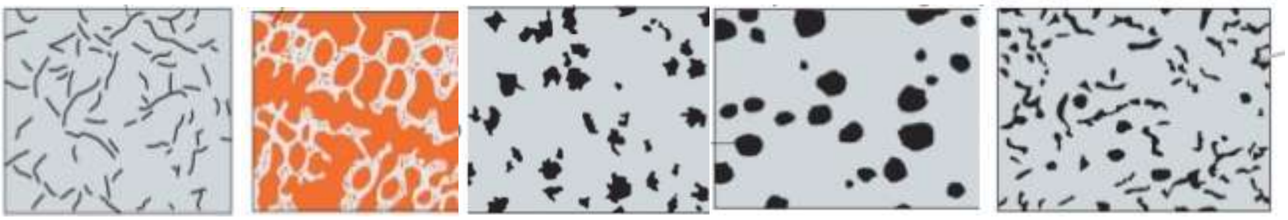
a) mechanical compatibility
b) chemical compatibility,
c) thermal stability,
d) high young’s modulus,
e) high compression and tensile strength,
f) good process ability,
g) economic efficiency

2.3.1 Cast iron

Cast iron is a group of iron-carbon alloys with carbon content greater than 2%. Its usefulness derives from its relatively low melting temperature as compared to steel. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through, grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks, and ductile cast iron has spherical graphite "nodules" which stop the crack from further progressing [33].

Depending on chemical composition, cooling rate and amount of insulates that are used cast iron can be as shown in the figure 2.3:

a. Gray iron,
b. White iron,
c. Malleable iron,
d. Ductile iron,
e. Compacted graphite iron



(a) Gray iron (b) White iron (c) Malleable iron (d) Ductile iron (e) Compacted graphite iron

Figure 2.3 Classifications of cast iron [33].

Nodular (spheroidal graphite) cast iron is also called ductile iron. The graphite is present as tiny balls or spheroids. Because the spheroids interrupt the matrix much less than graphite flakes, nodular cast iron has higher strength and toughness than gray cast iron. The formation of nodules or spheroids occurs when eutectic graphite separates from the molten iron during solidification [31].

Spheroidal graphite (SG) cast iron has excellent toughness; it has higher elongation and is used widely, for example, in crankshafts. Unlike malleable iron, nodular iron is produced directly from the melt and does not require heat treatment. Magnesium or cerium is added to the ladle just before casting. The matrix can be ferrite, pearlite, or austenite. The quality of SG iron is excellent, and X-ray quality castings are regularly produced [31-33].

2.3.1.1 Ductile cast iron & factors affecting its properties

Cast iron due to its easy cast ability and numerous advantages where strength has the main priority, gained its importance in many industries. Cast irons are iron carbon alloys with carbon percent ranging from 2.11-6.67 [31] and illustrated in figure 2.4. Microstructure consists of flake graphite embedded in ferrite/pearlite matrix. But flake graphite act like cracks in the iron matrix [31].

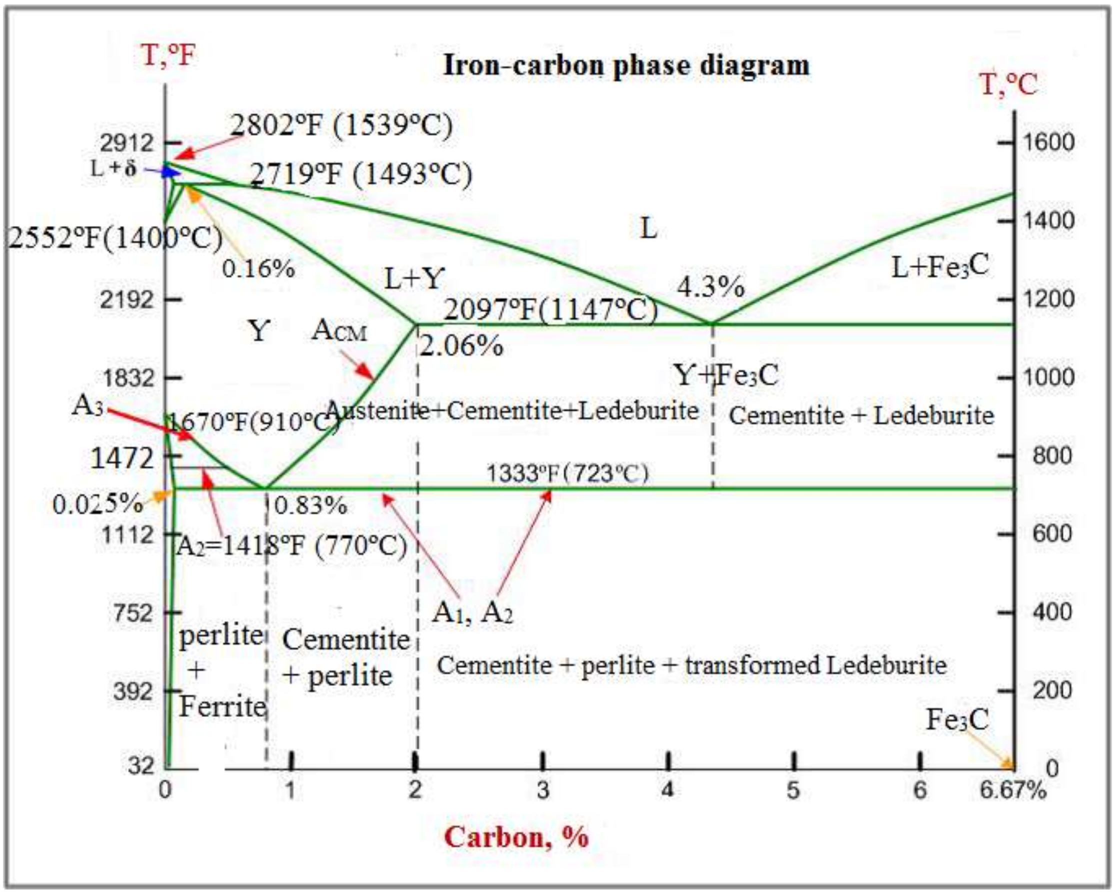


Figure 2.4 Iron carbide phase diagrams [31].

With this failure, there lead to the invention of ductile iron which consists of nodular graphite that acts like crack arresters. The versatility and high performance of ductile iron at low cost are main reasons for their approach to aerospace and aeronautical industries. Ductile iron offers high ductility with elongations more than 18% and tensile strength exceeding 825 MPa. The applications of ductile iron include trucks, agricultural tractors and oil well pumps. In wind power industry ductile iron is used for hubs and structural parts like machine frames [39]. This is also suitable for complex shapes and high loads [32, 33, 39].

There are many materials used for casting, but graphitic casts are one of the most common. Their wide range of properties is given by the structural state of the metal matrix, shape, size and distribution of graphite. Generally, heat treatment processes are determined by the graphite morphology. While there are no restrictions to annealing processes applied to cast iron, treatment processes with higher heating and cooling rates and significant thermal and structural tensions, can be applied only to some types of cast iron and casts of simple shapes [32, 33, 39].

2.3.1.2 Conventional ductile iron

Ductile iron (DI) provides best combination of overall properties mainly in the mechanical properties. The mechanical properties of DI depend on the microstructure which contains spheroidal graphite and metallic matrix. The metallic matrix changes with varying different parameters such as cooling rate during solidification, chemical composition and solid state heat treatments. Ferrite, pearlite or combination of both can be obtained in as cast condition and matrix like marten site, pearlite, bainite (ausferrite) can be attained by employing suitable heat treatments. In as cast condition microstructure consists of spherical graphite nodules embedded in pearlite/ ferrite matrix [31, 32].

2.3.1.3 Properties of conventional ductile iron

Ductile iron is essentially a family of materials with ample variety of properties that gives adequate results in distinct engineering requirements. Matrix structure is enhanced by using different heat treatments. Ductile iron has good mechanical properties above grey cast iron. The comparative properties of cast iron are shown on table 2.1.

Table 2.1 Comparative properties of cast irons [31].

Properties	Grey cast iron (GCI)	CGI	Ductile cast iron (DCI)
Tensile strength (MPa)	250	450	750
Young's modulus (GPa)	105	145	160
Fatigue resistance (MPa)	110	200	250
Heat conductivity (W/mK)	48	37	28
Hardness (HB)	179-202	217-241	217-255
Relative damping capacity	1.0	0.35	0.22

2.3.1.4 Family of ductile iron

The rapid growth of the ductile iron industry and the high annual utilization of ductile iron castings are testimonials to the outstanding mechanical properties, quality and economics of ductile iron castings. The automobile and agricultural implement industries are major users of ductile iron castings. The properties of ductile iron are considered basically in terms of matrix phases which govern the relative range of properties. With a high percentage of graphite nodules present in the structure, mechanical properties are determined by the ductile iron matrix. The importance of matrix in controlling mechanical properties is emphasized by the use of matrix names to designate the following types of ductile iron [31, 39].

2.3.1.5 Ferritic ductile iron

Spheroidal graphite in a ferritic matrix provides an iron with good ductility and impact resistance and with a tensile and yield strength equivalent to low carbon steel. Ferritic ductile iron can be produced as-cast but may be given an annealing heat treatment to assure maximum ductility and low temperature toughness. The structure of ferritic ductile iron consists of pearlitic and ferritic, with the ferritic generally surrounding the graphite nodules in “bulls eye” arrangement. The percent of ferrite in the ferritic ductile iron can be expected to range from 60-85%. This depends upon the melt chemistry, section thickness and cooling rate [39].

Microstructure consists of graphite nodules surrounded by ferrite matrix (figure 2.5). It provides iron good ductility and impact resistance with good tensile strengths and yield strengths equivalent to low carbon steels. These are produced in as cast conditions by using ferrite stabilizers but given annealing heat treatment to assure maximum ductility at low temperatures [31, 39].

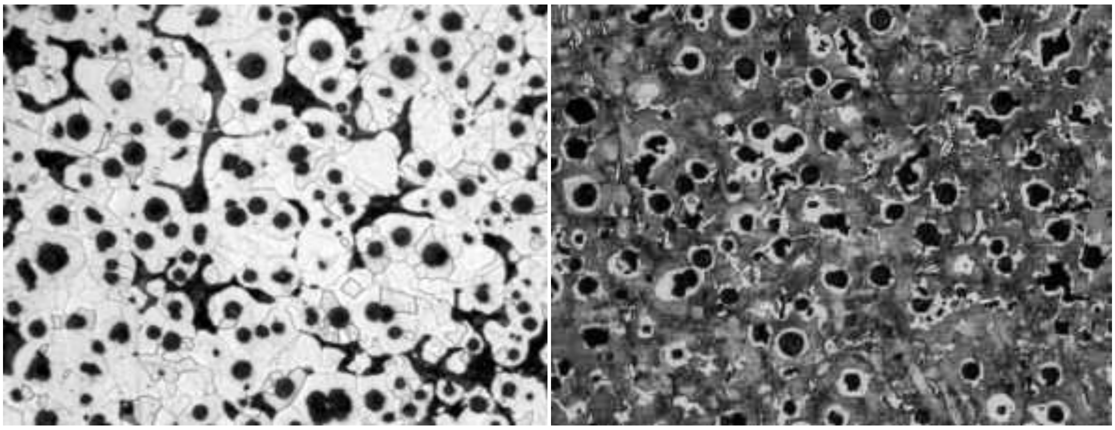

(a) (b)

Figure 2.5 Microstructure of ductile cast iron [39]: (a) Ferritic ductile iron, (b) Pearlitic ductile iron.

2.3.1.6 Ferritic/ pearlitic ductile iron

These are the most common grades of ductile iron produced in as cast condition. Microstructure consists of graphite nodules embedded in ferritic/pearlitic matrix. These acquire intermediate properties between ferritic and perlitic grades with low production costs and good machinability [31].

2.3.1.7 Pearlitic ductile iron

Microstructure consists of graphite nodules embedded in the pearlitic matrix (figure 2.5). Pearlite results in good wear resistance, high strength, moderate impact resistant and ductility. Their machinability and physical properties are superior to steels [31, 32, and 33].

Table 2.2 Chemical composition of the fundamental material (weight %), spheroidal graphite cast iron (SGCI) [32].

Chemical element	C	Si	Mn	P	S	Cr	Cu	Ni	V	Mg
Content of the element (weight %)	3.6	2.83	0.97	0.04	0.021	0.08	0.93	0.74	0.042	0.041

Generally ductile cast iron is cast iron in which the graphite is present as tiny balls in metallic matrix. Ductile cast iron is also known as nodular iron, spheroidal graphite iron, and spherulitic iron. This type of cast iron has increased strength and ductility when compared with a similar structure of gray cast iron [33, 38]. Ductile cast iron has excellent mechanical as well as technological properties together with relatively low price. Ductile iron is specifically useful in many automotive components. Other major industrial applications include off-highway diesel trucks, class 8 trucks, agricultural tractors, oil well pumps, fully machined piston for large marine diesel engine, bevel wheel, hydraulic clutch on diesel engine for heavy vehicle and Fittings overhead electric transmission lines [38].

AKM Asik Iqbal and D.M. Nuruzzama (2016**)** together have reviewed the effect of the reinforcement on the mechanical properties of aluminum matrix composite and summarized that the composite material developed by adding reinforcement in to the metallic matrix has improved mechanical properties such as tensile strength, stiffness, specific strength, wear resistance, creep and fatigue properties as compared to the matrix materials. The increase in reinforcement ratio and diminish in reinforcement particle size meaningfully develops the mechanical and fatigue properties of AMCs.

2.4 Metal matrix composites (MMC) fabrication method

Manufacturing techniques affect the microstructure, the distribution of the reinforcing materials and interfacial bond condition between reinforcing phase and matrix. These techniques have to ensure uniform distribution of the reinforcing material in the matrix and formation of good bond between matrix and reinforcing material, to obtain MMCs with optimum properties (J. Hashim et al., 1999). There are several fabrication techniques available to manufacture different MMC. Depending on the choice of matrix and reinforcement material and on the type of reinforcement, the fabrication techniques can vary considerably. According to the matrix materials processing phase, fabrication methods can be divided into three types [20].

1. Solid phase processes: diffusion bonding, hot rolling, extrusion, drawing, explosive welding, powder metallurgy (PM) route, pneumatic impaction.
2. Liquid phase fabrication method: stir casting, liquid metal infiltration, spray co-deposition and
3. Semi-solid fabrication process: squeeze casting, compo casting, pressure casting.

2.4.2 Solid state fabrication of MMCS

2.4.2.1 Powder metallurgy

Fabrication of AMCs via powder metallurgy includes uniform mixing of reinforcement with metal alloy and blending of powders; degassing the solidified product in vacuum and sintered under high temperature conditions [20]. Powder metallurgy route can exploit the nanoparticles and grain boundaries strengthening capability [20]. This method is cost effective for producing complex parts at very close dimensional tolerances, with minimum scrap and not suitable for mass production due to high cost of powder [20].

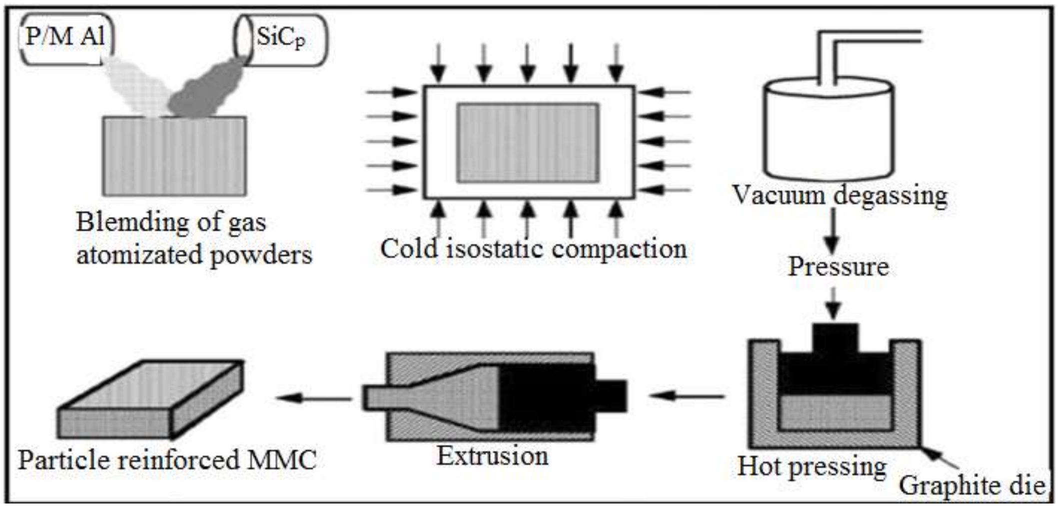
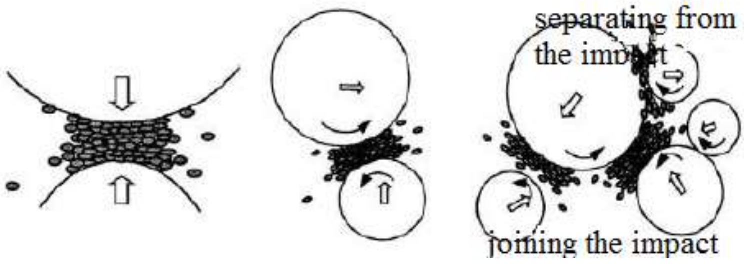


Figure 2.6 Schematic of typical powder metallurgy processing scheme [20].

2.4.2.2 High energy ball milling

High energy ball milling utilizes high energy impacts, high frequency from balls to repeatedly forge powder particles together and trapped between colliding balls and inner surface of the vial which causes repeated deformation, re-welding, fragmentation of premixed powders to form dispersed particles in grain refined matrix [20]. This method consume time for achieving required properties of composites and milling of powder require inert atmosphere which is difficult to maintain therefore method is not suitable for mass [20].



(a)Head-on impact (b) oblique impact (c) Multi-ball impact

Figure 2.7 Schematic diagrams showing the different forms of impact in which powder particles are trapped between balls which might occur during high-energy ball milling [20].

2.4.2.3 Ultrasonic probe assisted method

Traditional fabrication methods cannot be used for mass production and net shape fabrication of complex structural components without post processing. Ultrasonic probe assisted method is very effective in dispersing nano-sized particles in the metal matrix. The process generally requires resistance heating furnace for melting metal, nanoparticle feeding mechanism, inert gas envelope for protection and an ultrasonic system. The ultrasonic processing system consists of an ultrasonic probe, a transducer and power source [20].

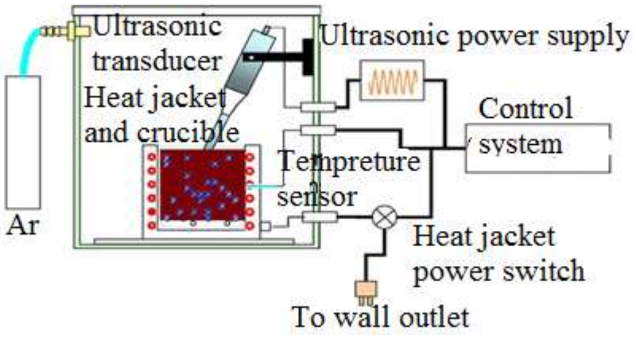


Figure 2.8 Schematic of ultrasonic solidification processing [20].

2.4.2.4 Diffusion bonding

Diffusion bonding is a solid state processing technique which is commonly used to produce mono filament reinforced AMCs. Inter diffusion of atoms between clean metallic surfaces which is in contact at an elevated temperature leads to bonding due to the inter diffusion of atoms across the surfaces of particulates and metal [20, 21].

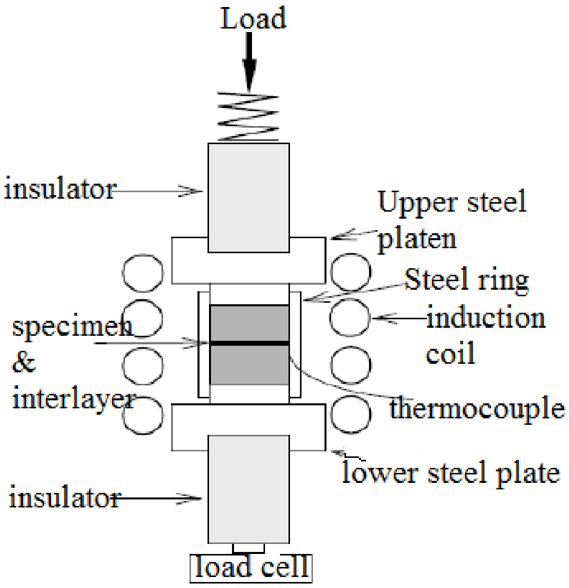


Figure 2.9 Diffusion bonding process [20].

2.4.3 Liquid state fabrication of MMCs

In the liquid casting technique, the particulates are mechanically well distributed over the liquid metal before casting and solidification. These methods are typically cost effective [20]. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [20] and allows very large sized components to be fabricated. The cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth [23].

2.4.3.1 Stir casting method

Stir casting is currently the most popular commercial method of producing aluminum-based composites stir casting of MMCs was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders [20, 21]. Fabrication of aluminum and it’s alloys based casting composite materials via stir casting is one of the prominent and economical technique for development and processing of MMCs and widely used for applications that require high production volumes and low cost [20, 23].

Stir casting is a liquid state method of composite materials fabrication, in which dispersed phase is mixed with a molten metal-matrix by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods. The term stir-casting is the process of stirring molten metals are used for continuous stirring particles into metal alloy to melt and immediately pour into the sand mold then cooled and allow to solidify [14]. In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement [15, 17].

Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical (compared to other methods, stir casting as little as one third to one tenth for mass production [18, 19, 22] for that reason, stir casting is currently the most popular commercial method of producing aluminum-based composites. The major merit of stir casting is its applicability to large quantity production. Process of the stir casting is shown in figure 2.10:

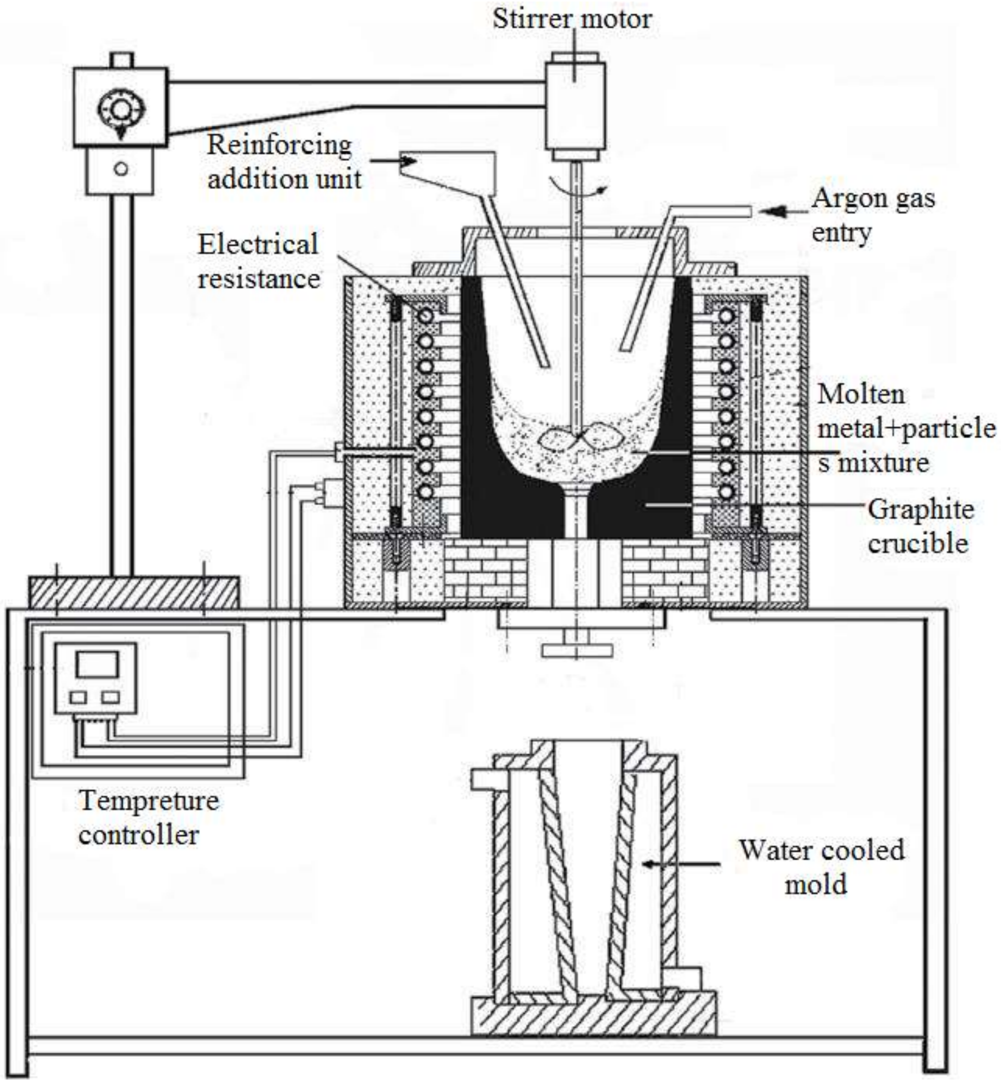


Figure 2.10 Stir casting machine equipped with inert gas source [20, 22].

2.4.3.1.1 Process parameter of stir casting

For manufacturing of composite material by stir casting knowledge of its operating parameter are very essential. As there is various process parameters if they properly controlled can lead to the improved characteristic in composite material. The important parameters during the process are [16-21]:

A. Stirring speed: stirring speed is the important process parameter as stirring is necessary to help in promoting wettability i.e. bonding between matrix & reinforcement. Stirring speed will directly control the flow pattern of the molten metal. Parallel flow will not promote good reinforcement mixing with the matrix. Hence flow pattern should be controlled turbulence flow. In this project I kept speed from 250-300 rpm. As solidifying rate is faster it will increase the percentage of wettability [8].

B. Stirring temperature: it is an important process parameter. It is related to the melting temperature of matrix i.e. aluminum. Aluminum generally melts at 650˚C. The processing temperature is mainly influence the viscosity of Al matrix. The change of viscosity influences the particle distribution in the matrix. It also accelerates the chemical reaction because of matrix and reinforcement [20].

C. Reinforcement preheats temperature: reinforcement was preheated at a specified 300-400˚C temperature 30 minute in order to remove moisture or any other gases present within reinforcement. The preheating also promotes the wettability of reinforcement with matrix.

D. Stirring time: stirring promotes uniform distribution of the particles in the liquid and to create perfect interface bond between reinforcement and matrix. The stirring time between matrix and reinforcement is considered as important factor in the processing of composite.

E. Preheated temperature of mould: in casting porosity is the prime defect. In order to avoid these preheating the permanent mould is good solution. While pouring molten metal keep the pouring rate constant to avoid bubble formation

F. Powder feed rate: to have a good quality of casting the feed rate of powder particles must be uniform. If it is non-uniform it promotes clustering of particles at some places which in turn enhances the porosity defect and inclusion defect, so the feed rate of particles must be uniform.

G. Blade angle design of stirrer: the blade angle and number of blades are prominent factor which decides the flow pattern of the liquid metal at the time of stirring.

2.4.3.2 Compo casting

Wettability and distribution of nanosize reinforcement is the key challenge in stir casting because very fine particles are having more surface energy and surface area resulting in agglomeration of reinforcement particles. Compo casting can mechanically entrap the semisolid slurry and reinforcing particles, prevent their gravity segregation and reduce their agglomeration [18, 20, 29]. Reduction in particle size to nanoscale results in greater improvement in ductility of compo-cast product compare to stir casting. In Compo-casting the particles are incorporated at semi-solid temperature of the alloy [20].

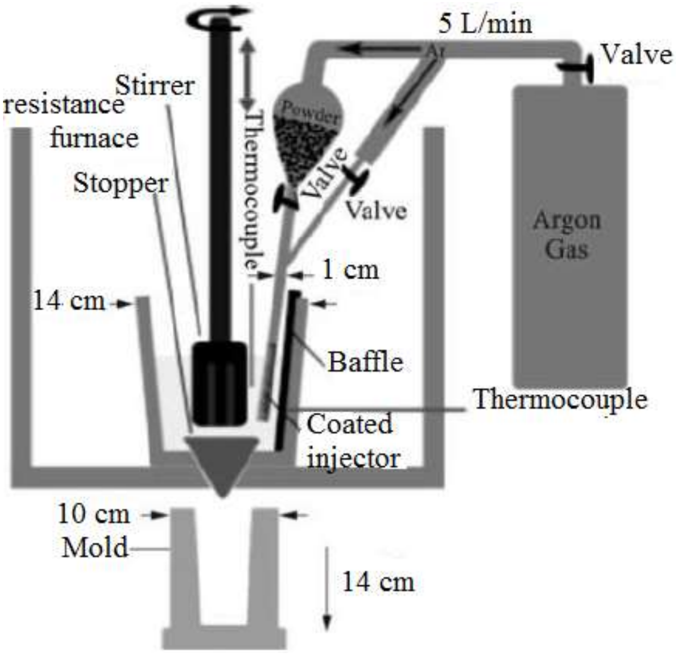
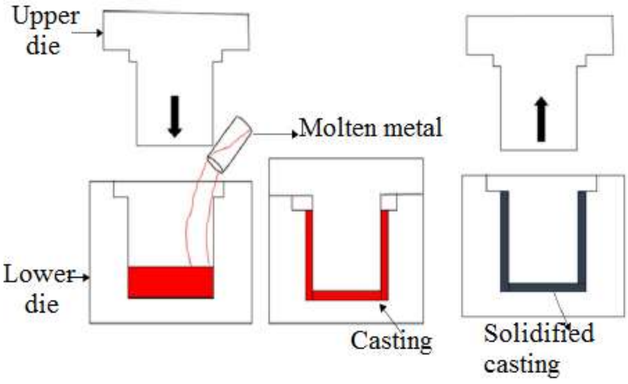


Figure 2.11 Experimental set-ups of compo casting used by Amirkhanlou [20].

2.4.3.3 Squeeze casting

Squeeze casting technique is a liquid phase fabrication method of AMCs in which metal solidifies under pressure within closed die halves, using a movable mould part for applying pressure on the molten metal and force it to penetrate into a preformed dispersed phase, placed in the lower fixed mould part [33]. Squeeze casting fabricated components have superior weld ability, heat treatability, high degree of surface finish and dimensional accuracy [20].



(a) (b) (c)

Figure 2.12 Schematic diagrams illustrating the sequence of steps involved in squeeze casting [20]:

(a) Molten metal poured into the pre-heated die, (b) application of squeeze pressure and (c) solidified casting.

2.4.3.4 Spray forming

Fabrication of composite by spray forming process involves melting of an alloy in a furnace, forcing the melt through a small orifice, passing a stream of compressed inert gas, injecting reinforcement through the jet and breaking the liquid metal into fine semi solid droplets. It is difficult to attain uniform distribution of reinforcements into the metal matrix by this method but the composites formed by spray deposition process are not very expensive [20].

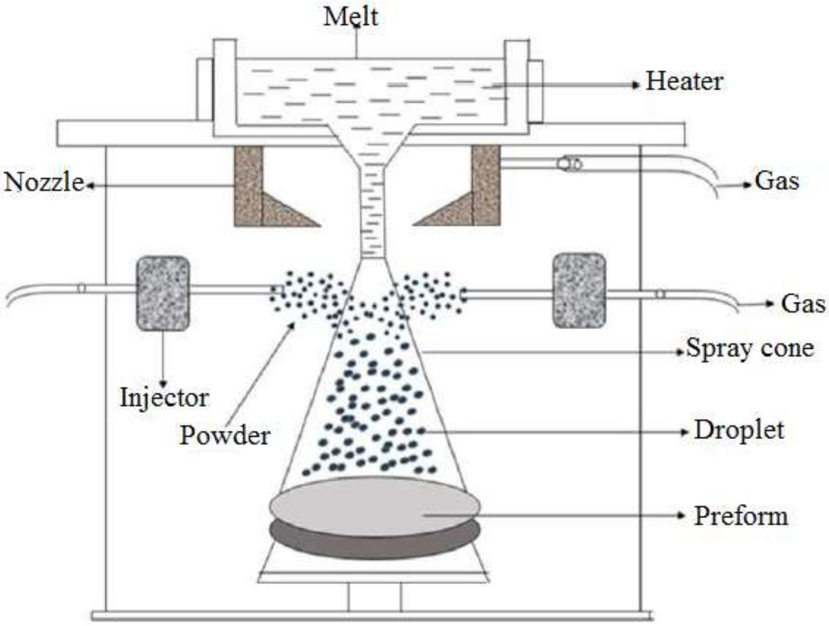


Figure 2.13 Schematic diagram of spray forming process [20].

2.4.3.5 In-situ synthesis

In-situ synthesis is a process wherein the reinforcements are formed in the matrix by controlled metallurgical reactions with various reinforcement ceramic particles SiC, AlN and TiC [20]. It is difficult to disperse the reinforcing particles uniformly in metal melts due to the low wettability with the melt. It requires the higher reaction time temperature and longer holding time, which is greatly, increases the cost of production and process requires that the reaction system be carefully screened [20].

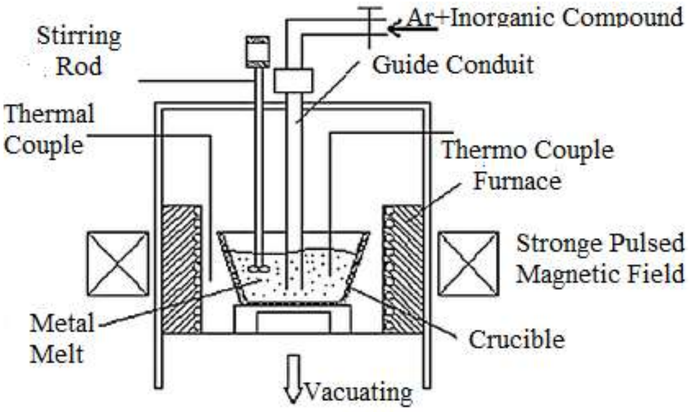


Figure 2.14 Schematic diagrams of in-situ direct reaction synthesis apparatus [20].

2.4.3.6 Liquid metal infiltration

It is a forced infiltration method of liquid phase fabrication of AMCs and begins with a ceramic preform of the desired shape and accomplished by the application of a pressure of inert gas. The pressure required for combining matrix and reinforcement is a function of the friction effects due to viscosity of the molten matrix as it fills the ceramic preform. Wetting of the ceramic preform depends on: alloy composition, ceramic preform material, ceramic surface, interfacial reactions, atmosphere, temperature and time [20].

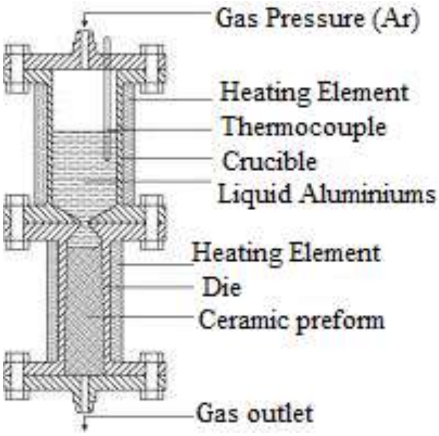


Figure 2.15 Schematic representative of the infiltration system [20].

2.4.4 Comparisons among fabrication techniques of MMCS

Table 2.3 Comparison among liquid state fabrication of MMCS [17- 23].

Method	Cost	Application	Comments
Stir casting	Least Expensive	Applicable to large quantity production. Commercial method of producing aluminum based composites.	Depends on material properties and process parameters. Suitable for particulate reinforcement in AMC
Compo casting	Low	Widely used in automotive and aerospace industries.	Suitable for discontinuous fibers, especially particulate reinforcement.
Squeeze casting	medium	Widely used in automotive industry for producing pistons, connecting rods, rocker arms, cylinder heads; suitable for manufacturing complex objects.	Generally applicable for any type of reinforcement and may be used for large scale manufacturing
Spray casting	medium	Used to produce friction materials, electrical brushes and contacts, cutting and grinding tools.	Particulate reinforcement used; full density materials can be produced
In-situ (reactive) processing	Expensive	Automotive applications.	Homogeneous distribution of the reinforcing particles.
Liquid-metal infiltration	Low/Medium	Used to produce structural shapes such as rods, tubes, beams with maximum properties in a uniaxial direction.	Filaments of reinforcement used.

Table 2. 4 Comparison among solid state fabrication of MMCS [17-23]:

Methods	Cost	Application	Comment
Powder metallurgy	Medium	For producing small objects (especially round), bolts, pistons, valves, high-strength and heat-resistant materials.	Both matrix and reinforcements used in powder form; best for particulate reinforcement; since no melting is involved, no reaction zone develops, showing high strength composite.
Ultrasonic assisted casting	Expensive	Used for net shape fabrication of complex structural components, applicable for mass production.	Nearly uniform distribution and good dispersion of reinforcement particles.
Diffusion bonding	High	Used to make sheets, blades, vane shafts, structural components.	Handles foils or sheets of matrix and filaments of reinforcing element
Friction Stir welding	Moderate/ Expensive	In automotive and aerospace application.	Used as surface modification process. Increase in micro hardness of the surface, significant improvement in wear resistance.

A comparative study of different techniques for discontinuously reinforced metal matrix composites (DRMMC) production is given in table 2.5.

Table 2.5 shows a comparative evaluation of the different processes commonly used for discontinuously reinforced metal matrix composites (DRMMC) production [18].

Table 2.5 A comparative analysis of different technique used for fabrication of DRMMC [18]

Method	Range of shape and size	Range of volume fraction	Damage to reinforcement	Cost
Stir casting	wide range of shapes; larger size; up to 500 kg	up to 0.3	no damage	least expansive
Squeeze casting	limited by preform shape up to 2cm height	up to 0.5	severe damage	moderately expansive
Powder metallurgy	wide range; restricted size	-----------	reinforcement fracture	expansive
Spray casting	limited shape; large size	0.3-0.7	-------------	expansive
Lanxide technique	limited by pre-form shape. Restricted size	-------------	----------------	expansive

Among the variety of manufacturing processes available for discontinuous metal matrix composite, stir casting is generally accepted as a particularly promising route, because of low cost. Its advantages lie in its simplicity, flexibility and applicability to the large quantity production [16, 17, 19]. This semi solid metallurgy technique is the most economical of all available routes for MMC production. It allows very large sized components to be fabricated, and is able to sustain high productivity rates. The cost of preparing composite materials using a casting method is about one third to one half that of competing methods [18].

Chapter 3

Materials and Methods

3.1 Materials

AlMg1SiCu aluminum alloy chip is used as matrix metal and GGG-40 cast iron chips as reinforcement material. Methyl alcohol was used to clean the chips from impurities and cutting oils were used as lubricants and coolant. The chemical composition and other properties of AlMg1SiCu aluminum alloy and GGG-40 cast iron is shown in table 3.1 below. The material used for this study is shown in figure 3.1:

(a) (b)

Figure 3.1 Used material: (a) AlMg1SiCu aluminum alloy chips, (b) GGG-40 cast iron chips.

Aluminum alloys of the Al – Mg – Si and Al – Mg – Si – Cu system are used widely in the automotive industry, railroad transport, instrument making, and the building industry due to the combination of corrosion resistance, strength, and ductility. Most 6XXX alloys of the Al–Mg–Si–Cu system have an elevated quenching sensitivity affecting their mechanical and corrosive properties [36].

GGG-40 is the most common used nodular cast iron. Nodular cast iron has predominately a ferritic structure. Offers superior machinability combined with optimal impact, fatigue, electrical conductivity and magnetic permeability [32]. The chemical composition of spheroidal graphite cast iron (SGCI) is shown in table 3.1.

Table 3.1 Chemical composition of the fundamental material (weight %), spheroidal graphite cast iron (SGCI) [32].

Chemical element	C	Si	Mn	P	S	Cr	Cu	Ni	V	Mg
Content of the element (w.t %)	3.6	2.83	0.97	0.04	0.021	0.08	0.93	0.74	0.042	0.041

Table 3.2 Designation and chemical composition of aluminum alloy [36].

Group	Designation	Material composition in (w.t %)			
		Si	Cu	Mn	Mg
AlMg	AA6111	0.4	0.10	0.50	2.60-3.60
AlMg	AA5182	0.2	0.15	0.20-0.50	4.00-5.00
AlMgSi	AA6016	1.0-1.5	0.20	0.20	0.25-0.60
AlMg1Si(Cu)	AA6061	0.6-1.0	0.15-0.60	0.20-0.80	0.40-0.80
AlMgSi(Cu)	AA2036	0.5	2.20-3.0	0.10-0.40	0.30-0.60

From table 3.2 AA6061 is used as matrix material for the study since it has high percent composition of Si, Cu, Mn, Mg which make the composite with better mechanical strength. AlMg1SiCu aluminum alloys also have better mechanical properties than other. Its mechanical properties are show in the table 3.3 below.

Table 3.3 Mechanical properties of AA6061 aluminum alloy and nodular (graphite) cast-iron [41].

Property	Value for AlMg1SiCu aluminum alloy	Value for Nodular (spheroidal graphite) cast iron	Unit
Elastic modulus	6.9 e+04	2 e+05	MPa
Poisson's ratio	0.33	0.32	N/A
Shear modulus	2.7 e+04	7.7 e+04	MPa
Mass density	$2.7x10^3$	$7.1x10^3$	Kg/cm^3
Tensile strength	68.9	861.7	MPa
Yield strength	27.6	551.5	MPa
Thermal expansion coefficient	2.4e-005	1.1e-005	/K
Thermal conductivity	200	75	W/(m.K)
Specific heat	900	450	J/(Kg.K)

Source: Material properties from solid work software [41].

The AlMg1SiCu aluminum alloy and nodular (spheroidal graphite) cast iron shows a high difference in mechanical properties (see table 3.3). Whereas, when the two materials mixed together, the material shows better mechanical properties. AlMg1SiCu aluminum alloy has lower density, lower melting point, and ease of processing, high thermal conductivity, low coefficient of thermal expansion, good wear resistance, high temperature strength, easy availability and low cost influences the choice of the matrix materials.

3.2 Methods

In this thesis, fabrication and characterization of metal matrix composite material for mechanical properties tests has been selected. AlMg1SiCu aluminum alloy chip is chosen as a matrix metal and GGG-40 cast iron as reinforcement material were used for the production of the specimens. The methyl alcohol is used for cleaning chips. The other supporting materials are wood to prepare pattern, sand and sodium silicate for mold preparation. The equipment used are weighing balance, crusher, grinder, size measuring device, hydraulic press machine, optical microscope, hardness testing machine and universal testing machine (UTM). The composite is prepared by stir casting method and the specimens are prepared as per ASTM standards size. Hardness, microstructure and tensile tests are conducted on the specimens. The value of each property obtained for different composites were compared.

3.2.1 Experimental procedure

In this work stir casting technique is employed to fabricate the material, which is a liquid state metal in which a dispersed phase (reinforcement particulates) is mixed with a molten metal by means of stirring. At the beginning of the experiment, separating and size reduction processes by using a cutting device and sieve shaker were applied to aluminum and cast-iron chips which are remaining materials from metal machining process. Then, the sizes of the cast iron chips were reduced to grain sizes up to 100 μm. Aluminum alloy used as matrix material is mixed with 5-15 w.t % ratios by 5% increments of reinforcing phase cast iron chips powder by mechanical stirrer and so four different kinds of compositions are produced according to cast-iron w.t % contents for all test machines.

The degreased aluminum alloy chips were cold pressed into cylindrical compacts, more suitable for re-melting because of their higher density and lower volume. For the cold pressing a manually driven screw press was applied. The chips were charged in a hollow, slightly conical tool and repeatedly added and pressed until the tool was full. The pressed chips were then pressed out of the tool from the opposite site and melt it in to the furnace. After melted add heated GGG-40 cast-iron powder and mix by stirrer as shown in figure 3.2 (b).

(a) Casting (b) Mixing

Figure 3.2 Casting using furnace and mixing aluminum alloy with cast iron.

3.2.1.1 Chips preparation

Aluminum and cast-iron chips were prepared from waste of milling, drilling and lathe machine operations. Then, separating aluminum and cast-iron chips from coolant fluid and other ingredients by sieving and washing with methanol alcohol. Before the material compacted and crushed, it was dried up to 80 °C in order to minimize the size of chips for better compaction. Cold press machine was used to decrease the density of aluminum chips and crush the cast iron chips less than 100 μm in size. Finally, the compacted aluminum alloy chips are charged in to stir casting furnace, and then melt. The size of reducing order of reinforcement particle is shown in (Figure 4.3).

Figure 3.3 The size reduction of GGG-40 cast iron chips from 1 to 4.

3.2.1.2 Sample preparation

The fabricated specimens are tested for mechanical properties like hardness, toughness, tensile strength, and percent of elongation. By using different mechanical properties testing machines like universal tensile testing machine, rockwell hardness testing machine and optical microscope to characterize the mechanical properties. The percent of composition for specimen preparation is (0%, 5%, 10%, and 15% of GGG-40 cast iron) as shown in table 3.4.

Table 3.4 Percent of composition used for this experiment.

Specimen	Cast iron w.t (g)	Cast iron w.t %	Aluminum alloy w.t (g)	Aluminum alloy w.t %
Pure AlMg1SiCu	0	0	1000	100
AlMg1SiCu (95%) & GGG-40 (5%)	50	5	950	95
AlMg1SiCu (90%) & GGG-40 (10%)	100	10	900	90
AlMg1SiCu (85%) & GGG-40 (15%)	150	15	850	85

3.2.1.3 Hardness test specimen preparation

Hardness measurements were carried out on the matrix metal and composite samples by using standard rockwell hardness test machine. Rockwell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Standard specimen dimension for hardness test is shown in figure 3.4.

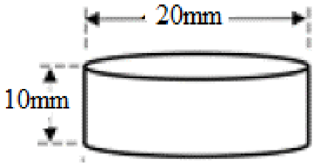
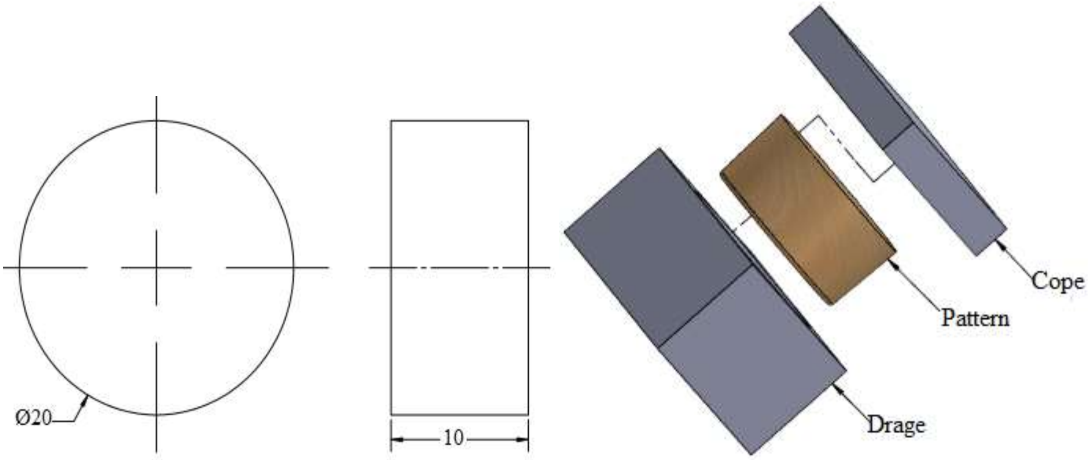


Figure 3.4 Hardness test specimen preparation according to ASTME18-05.

Using the above ASTME18-05 standard size first, the specimen is modeled by solid work software and prepared pattern from wood. The modeled and exploded part is shown in the figure 3.3.



(a) (b)

Figure 3.5 Hardness test specimen model: (a) Modeled hardness test sample pattern dimension in mm, (b) Mold preparation explode.

3.2.1.3 Tensile test and its specimen preparation

Tensile tests are performed for several reasons. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared.

The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. In addition, the material’s ductility, which is a measure of how much it can be deformed before fractures.

The most common testing machines are universal tester machine, which tests materials in tension, compression, or bending. The primary function is to create the stress-strain curve. Testing machines are either electromechanical or hydraulic. The principal difference is the method by which the load is applied. Electromechanical machines are based on a variable-speed electric motor, gear reduction system and one, two, or four screws that move the crosshead up or down. This motion loads the specimen in tension or compression.

The basic idea of a tensile test is to place a sample of a material between two fixtures called "grips" which clamp the material. The material has a known dimension, like length and cross-sectional area. We were begun to apply weight to the material gripped at one end while the other end was fixed. The weight was increased (often called the load or force) while at the same time the change in length of the sample was measured. The specimen was machined to get dog boned structure as per ASTME-8 standards. The test was carried out on a computerized UTM (TUE-C-600 Model).

The specimen is prepared first by modeling in software using ASTME standard size show in figure 3.6 (a). Then, using the modeled size prepare pattern from wood to form cavity in mold preparation show in figure 3.6 (b). After preparation of pattern prepare mold cavity using pattern, mold box and sand. The mixed aluminum and cast-iron composition is then poured in to the mold cavity up to the cavity filled. Finally machine the prepared sample in milling machine to reduce the size of specimen to ASTME standard size.

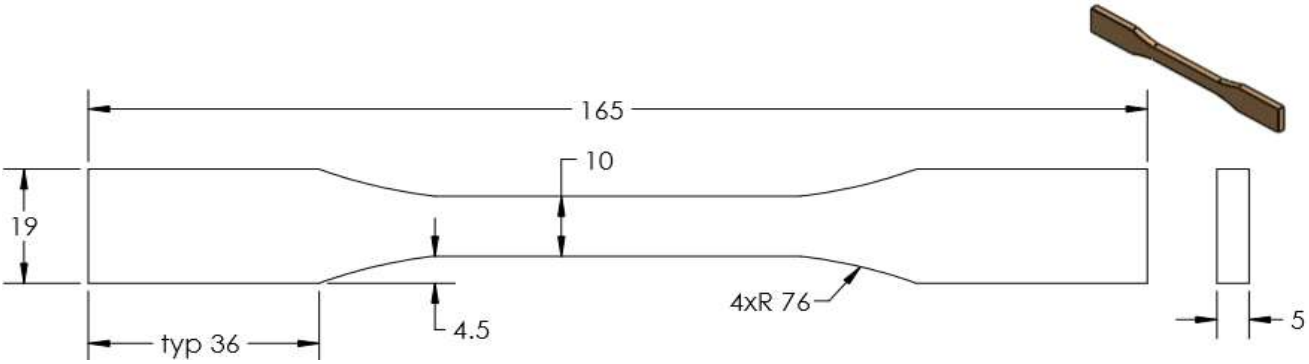


Figure 3.6 Tensile test Sample size and dimension in mm and prepared pattern from wood using ASTM D 638-02a, 2003 standard size.

Generally, the overall sample preparations are seen in the following figures starting from pattern preparation up to the prepared sample.

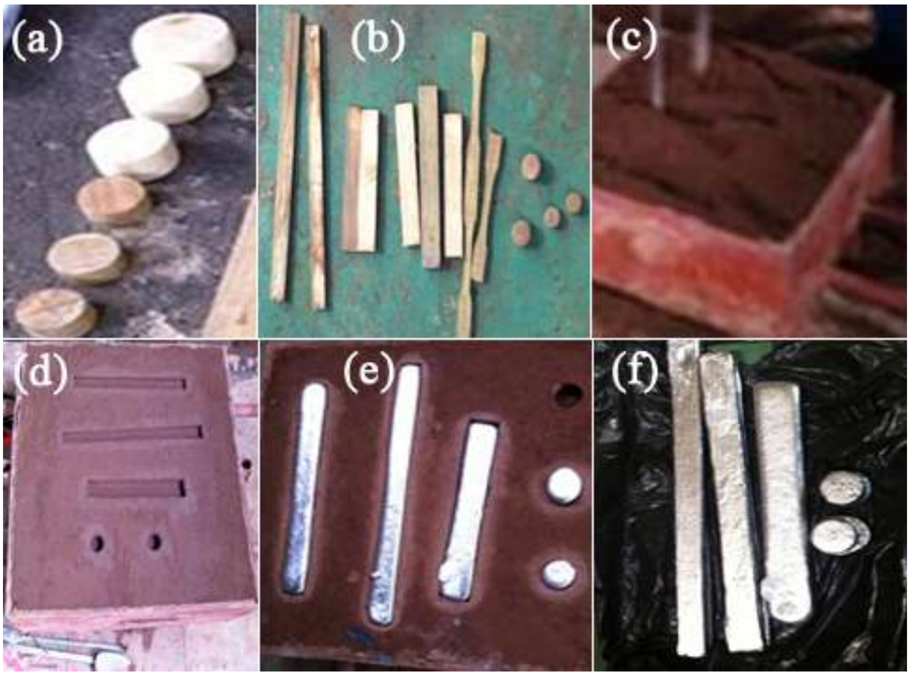


Figure 3. 7 Sample preparation methods: (a, b) pattern preparations from wood, (c, d) mold preparation from sand, (e, f) prepared sample for different tests.

Chapter 4

Results and Discussion

4.1 Hardness test

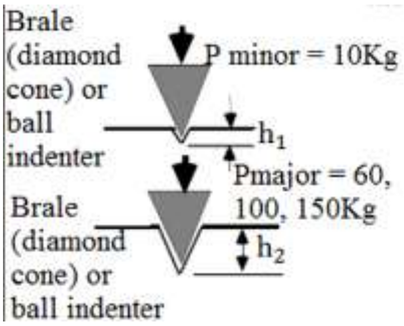
Hardness is the most important mechanical property of materials which is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch). Early hardness tests were based on natural minerals with a scale constructed solely on the ability of one material to scratch another that was softer.

4.1 Rockwell hardness Test

The rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load Fo (Figure 4.1) usually 10kg. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Figure 4.1). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (figure 4.1). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the rockwell hardness number [40].

Table 4.1 Rockwell hardness number and their scale.

Rockwell scale	**A**	**B**	**C**	**D**	**E**	**F**	**M**	**R**
Indenter	Brale (diamond)	1/16"	Brale (diamond)	Brale (diamond)	1/8" ball	1/8" ball	1/4" ball	1/2" ball
Major load (kg)	60	100	150	100	100	60	100	60



$$HRX = R_x = M - \frac{(h_2 - h_1)}{0.002} \ldots..1\ [40]$$

M = 100 for A, B, C and D scales

M = 130 for B, E, M, etc. scales

Figure 4.1 Rockwell Principles [40].

The hardness testing machine and their scale and application are in figure 4.2.

HARDNESS TESTER

DIFFERENT ROCKWELL HARDNESS SCALES

Scale No	Scale	Indentor	Load Kgs.	Dial	Application
1	A	Diamond	60	Black	Carbides, Thin Steel, Shallow Case-hardened Steel, Case-carburized surfaces.
2	B	1/16" Ball	100	Red	Aluminium Alloys, Copper Alloys, unhardened steel etc. in rolled, drawn, extruded or cast metal.
3	C	Diamond	150	Black	Hard Cast Irons, Pearlitic Malleable Iron, Steel, deep Case Hardened Steel, Titanium.
4	D	Diamond	100	Black	Pearlitic Malleable Iron, Thin steel & Medium case-hardened steel.
5	E	1/8" Ball	100	Red	Cast Iron, aluminium and magnesium alloys, bearing metal
6	F	1/16" Ball	60	Red	Thin soft sheet metals, annealed copper alloys.
7	G	1/16" Ball	150	Red	Copper-nickel-zinc and Cupro-nickel alloys, malleable irons.
8	H	1/8" Ball	60	Red	Lead, zinc, aluminium, magnesium alloys.
9	K	1/8" Ball	150	Red	Bearing metals, very soft or thin materials.
10	L	1/4" Ball	[illegible]	Red	Plastic materials : bakelite, vulcanised fibre
11	M	1/4" Ball	100	Red	Nylon, Polystyrene, Plexiglass
12	P	1/4" Ball	150	Red	
13	R	1/2" Ball	60	Red	Rigid sheet and plate materials used for electrical insulation are tested by M & L Scales
14	S	1/2" Ball	100	Red	When the "spring constant" or correction factor is included in the test procedure, only R Scale is used
15	V	1/2" Ball	150	Red	

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Figure 4.2 Rockwell hardness test machine and their scale.

The formulas used for calculating rockwell hardness values are as follows:

a) For regular rockwell hardness using spheroconical "Brale" indenter

$$\mathrm{HR[scale]} = 100 - \frac{\mathrm{h}}{0.002} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [40]$$

Where, scale is A, C, D and h is the depth penetrated in mm.

b) For regular rockwell hardness using a steel ball

$$\mathrm{HR[scale]} = 130 - \frac{\mathrm{h}}{0.002} \ldots\ldots\ldots\ldots\ldots\ldots.[40]$$

Where, scale is B, E, F, G etc. and h is in mm

c) For superficial rockwell hardness using either indenter

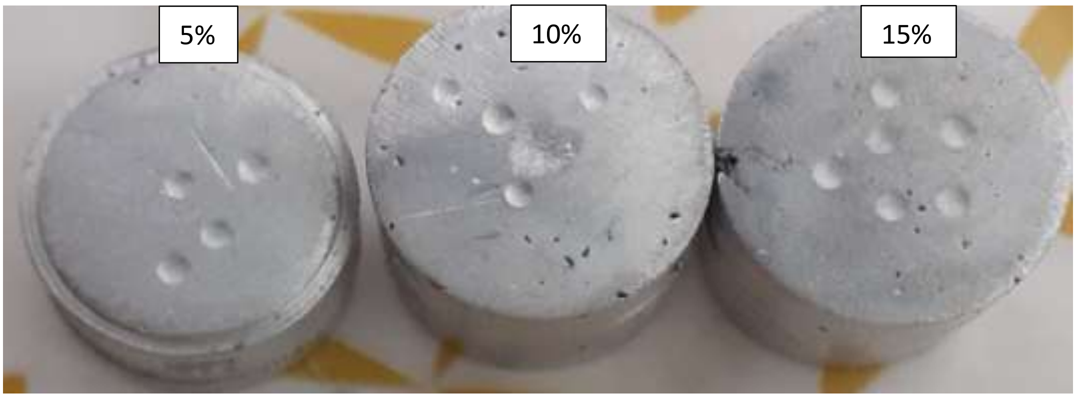
$$\mathrm{HR[(total\ load)scale]} = 130 - \frac{\mathrm{h}}{0.002} \ldots\ldots\ldots\ldots.[40]$$

Where, total load is 15, 30 or 45 kg and scale is N (for "Brale") or T (for 1/16" ball) and h is in mm. When performing a rockwell test the following procedures were used.

1. Putting gently the specimen in contact with the indenter,
2. Applying a preliminary (or minor) force (load) (of 10 kg for normal or 3 kg for superficial testing),
3. Automatically or manually zeroing the penetration measuring instrument or dial gage,
4. Applying gradually the total (or major) force (load) (100 kg,
5. Removing gently the total force (load) while leaving in place the preliminary one (so that the elastic deformation following the removal of final force (load) is recovered) and
6. Measuring the depth of penetration using the instrument.

Finally calculating the rockwell hardness number as the difference between a fixed value (100 for Brale 130 for ball) and showing it on a dial or on a digital display. The rockwell hardness number is therefore an expression of the depth penetrated by the indenter between the application of the preliminary force (load) (when the instrument is zeroed) and the removal of the total force (load), with the preliminary force (load) still in place (as shown in figure 4.1). The hardness test sample before and after testing is in figure 4.3.

(a) Hardness testing sample before test and machined.



(b) Hardness testing sample after hardness test.

Figure 4.3 Hardness tested sample for different % of GGG-40.

Table 4.2 Rockwell hardness test reading at different composition and trials.

Composition of the test	Rockwell hardness number or gauge reading (depth of penetration) in μm				
	Trial 1	Trial 2	Trial 3	Trial 4	Mean
Pure AlMg1SiCu	98.9	97.0	98.4	97.6	98.0
AlMg1SiCu (95%) & GGG-40 (5%)	63.0	64.0	62.0	62.5	62.9
AlMg1SiCu (90%) & GGG-40 (10%)	50.0	51.0	50.5	49.0	50.1
AlMg1SiCu (85%) & GGG-40 (15%)	69.0	69.5	71.5	70.0	70.0

Using the above depth of penetration h on table 4.2, the rockwell hardness value can be calculated using the equation for regular rockwell Hardness using a steel ball is calculated on the table 4.3.

$$HR[scale] = 130 - \frac{h}{0.002}$$

For example, HR scale of pure AlMg1SiCu for h = 98.9 μm = 0.0989 mm

$$HR[scale] = 130 - \frac{0.0989}{0.002} = 80.6$$

Using this example, the HR scale for all composition and trial is calculated on table 4.3.

Table 4.3 Rockwell hardness value at different composition and trials.

Composition of the test	Rockwell hardness (HR) = $130 - \frac{h}{0.002}$				
	Rockwell hardness trial 1	Rockwell hardness trial 2	Rockwell hardness trial 3	Rockwell hardness trial 4	Mean Rockwell hardness
Pure AlMg1SiCu	80.6	81.5	80.8	81.2	81.0
AlMg1SiCu (95%) & GGG 40 (5%)	98.5	98.0	99.0	98.8	98.6
AlMg1SiCu (90%) & GGG 40 (10%)	105.0	104.5	104.8	105.5	104.9
AlMg1SiCu (85%) & GGG 40 (15%)	95.5	95.3	94.3	95.0	95.0

Using the above recorded data the out put gragh of the rockwell hardness value is shown in figure 4.4 for different compositions and different trials.

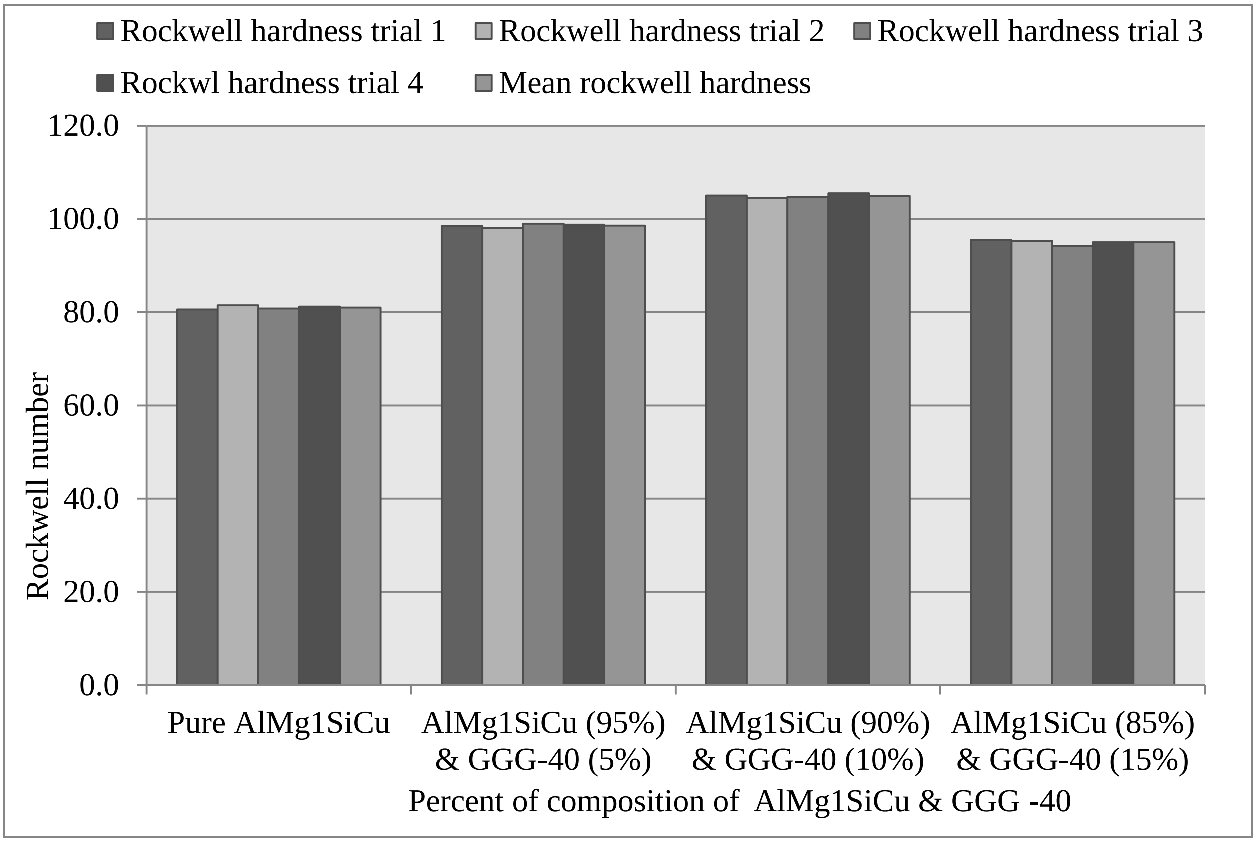


Figure 4.4 Rockwell hardness value for different composition and trial.

The mean rockwell hardness gragh is shown in figure 4.4.

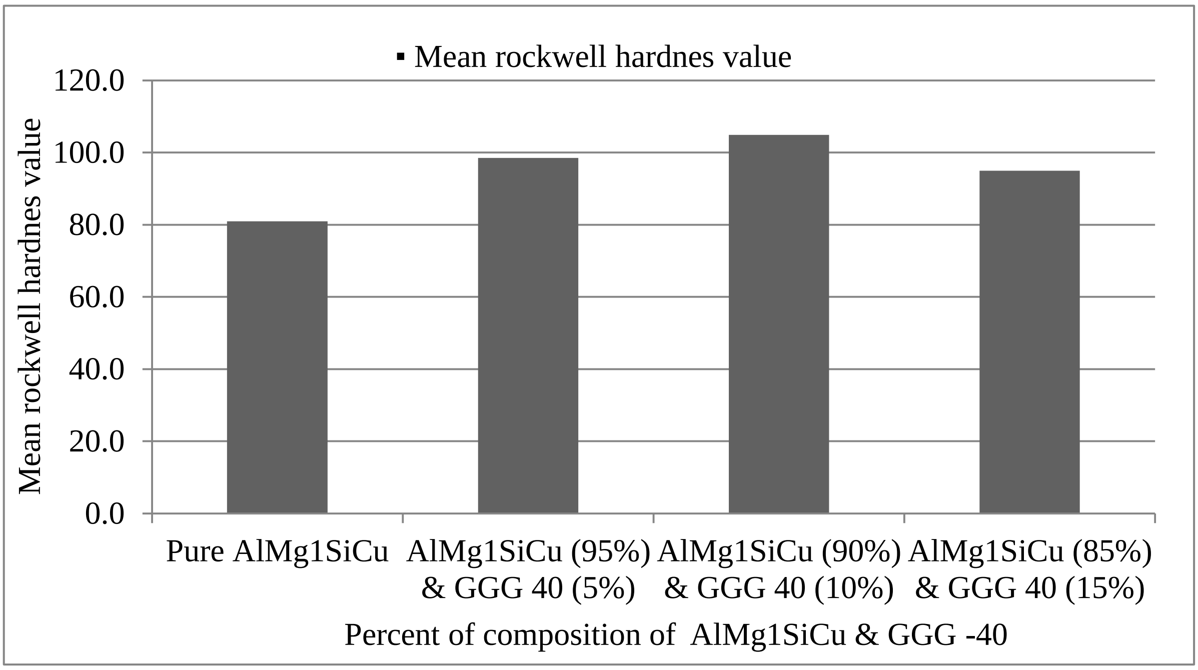


Figure 4.5 Average rockwell hardness value for different composition of AlMg1SiCu & GGG-40.

3.1.2 Brinell hardness test

For softer materials the load can be 100 kg or 150 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The brinell harness number is calculated by dividing the load applied by the surface area of the indentation. When the indenter is retracted two diameters of the impression, d_1 and d_2, are measured using a microscope with a calibrated graticule and then averaged as shown in figure 4.6 (b).

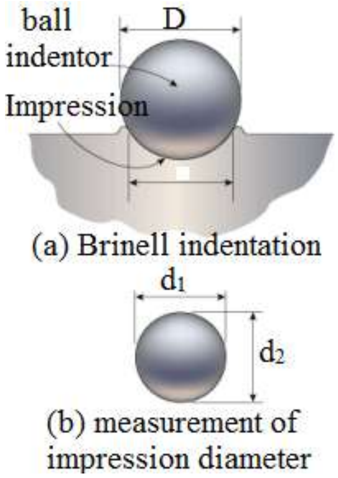
Table 4. 4 Common material, scale and types of indenter for brinell hardness test.

Scale	Type of indenter (dimension)	Initial load (Kg)	Major load (Kg)	Kind of material
A	cone, 120 degree	10	50	much harder such as carburized steel, cemented carbides
B	ball, 1.58 mm	10	100	soft steel, copper, aluminum, brass, gray cast iron
C	cone, 120 degree	10	150	spring steel, Ti, W, Va, etc.

$$\text{BHN} = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2\ [40]$$

Where:

P is the test load [kg]
D is the diameter of the ball [mm]
d is the average impression diameter of indentation [mm]



(a) Brinell indentation

(b) measurement of impression diameter

Figure 4.6 Brinell hardness test principle [40].

Brinell hardness Value is calculated using equation 2 and recorded data D = 1.5875 mm, P = 100 kg, and the d value is recorded for all percent of composition and shown on table 4.5.

For example, for pure AlMg1SiCu brinell hardness value:

$$\text{BHN} = \frac{100}{\frac{\pi * 1.5875}{2}\left[1.5875 - \sqrt{1.5875^2 - 1.280^2}\right]} = 97.1$$

For each value of d, the brinell hardness value is calculated and shown on table 4.5.

Table 4.5 Brinell hardness given, calculated and recorded data.

Percent of Composition	P	d (mm)	d^2 (mm^2)	D (mm)	D^2 (mm^2)	$\sqrt{D^2 - d^2}$ (mm)	Brinell hardness value BHN $= \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$
Pure AlMg1SiCu	100 kg	1.280	1.6384	1.5875	2.5202	0.9390	97.1
AlMg1SiCu (95%) & GGG-40 (5%)		1.200	1.4400			1.0393	114.9
AlMg1SiCu (90%) & GGG-40 (10%)		1.101	1.2122			1.1437	141.9
AlMg1SiCu (85%) & GG-40 (15%)		1.220	1.4884			1.0158	110.2

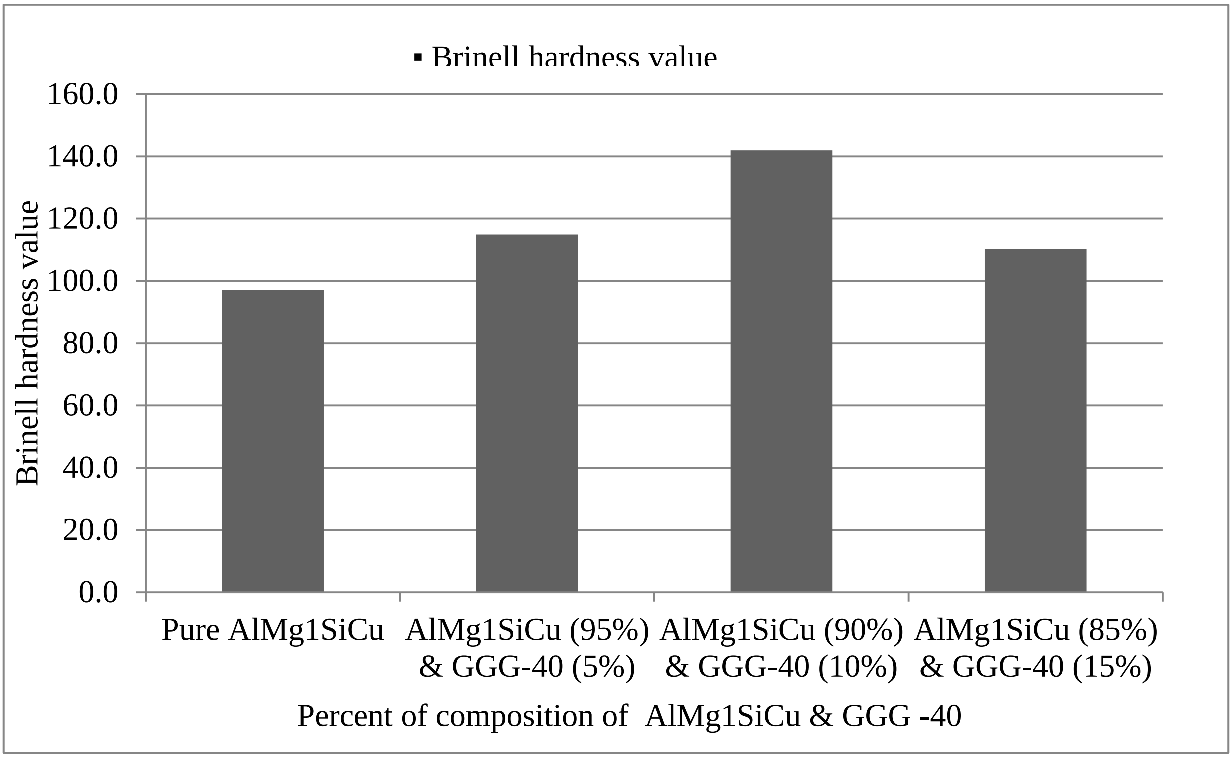


Figure 4.7 The graph of mean brinell hardness.

As observed from both rockwell and brinell hardness test report and practical experimentation. That is, the hardness of base metal AlMg1SiCu increases up to an optimum level on addition of GGG-40 reinforcement in particular weight fractions. But again, after a particular composition, there has been seen a decline or fall in the hardness of the material. Such as, the hardness of the metal increases up to 10% of GGG-40 reinforcement in the base metal AlMg1SiCu, but it is seen and observed that at 15% GGG-40 weight there is high decrement in hardness of the metal even though it is less than 5% GGG-40. Thus, it has been concluded that the hardness of AlMg1SiCu can be increased up to 10% GGG-40 addition by weight and is reported to be maximum at this composition. Beyond this, the hardness decreases of the metal due to density difference between the matrix and reinforce materials and high porosity occurs.

4.2 Tensile test

Experimental steps**:** Specimen is machined in the desired orientation and according to the standards size and dimension. Aluminum, steel or composite materials can be used as the specimen material mostly. Magnitude of the load is chosen with respect to the tensile strength of the material. Specimen is fit to the test machine. Maximum load is recorded during testing. After fracture of the material, final gage length and thickness is measured. The following are tensile property measuring criteria are:

a. *Engineering Stress* (σ): it is the ratio of applied force P and cross sectional area or force per area.

$$\sigma = \frac{\mathrm{P}}{\mathrm{Ao}} \text{ ……………………………………………………3 [44]}$$

Where, σ is engineering stress.

P is the external axial tensile load.

$A0$ is the original cross-sectional area.

b. *Engineering Strain* (Ɛ): it is defined as extension per unit length.

$$\mathcal{E} = \frac{\Delta L}{L0} = \frac{Lf-L0}{L0} \text{……………………………………………………….4 [44]}$$

Where, Ɛ is the engineering strain.

$L0$ is the original length of the specimen.

Lf is the final length of the specimen.

c. *Ultimate Tensile Strength* (σ_{UTS}): it is the maximum strength that material can withstand.

$$\sigma_{\mathrm{UTS}} = \frac{\mathrm{P_{max}}}{\mathrm{Ao}} \text{……………………………………………………5 [44]}$$

d. *Ductility*: it is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. Ductility can be described with the percent elongation or percent reduction in area [44].

$$\% = \frac{\mathrm{Lf-L0}}{\mathrm{L0}} * 100 \text{ (percent elongation)}$$

$$\% = \frac{\mathrm{Ao-Af}}{\mathrm{A0}} *100 \text{ (percent reduction in area)}$$

e. *Toughness*: it is combination of strength and ductility.

Dimension should be measured from the neck. The necessary data for calculations is recorded from table 4.5. Using the input data on computer: Types of specimen rectangular cross-section = Length × width × thickness = 100 x 20 × 4.5 mm.

The test is conducted at the same computer setting, machine feed rate, temperature and input data for all composition of specimen.

(a) Universal tensile testing machine (b) Tensile test specimen before test

(c) Tensile test specimen after test.

Figure 4.8 Universal tensile testing machine and prepared tensile test specimen for different % of GGG-40 cast iron.

A. Tensile test for pure AlMg1SiCu

Table 4.6 Recorded stress -strain data for pure AlMg1SiCu.

Force F [KN]	Stress S [N/mm^2]	strain Ɛ
0	0	0
0.31	0.99	0.01
0.87	2.77	0.02
1.42	4.52	0.03
1.87	4.77	0.035
2.01	4.81	0.036
2.55	5.19	0.04
3.26	5.95	0.045
4.11	6.4	0.05
4.2	8.12	0.07
4.75	10.38	0.08
4.55	10.3	0.09

Using the above recorded data, the result of stress strain curve for pure AlMg1SiCu is shown in figure 4.9:

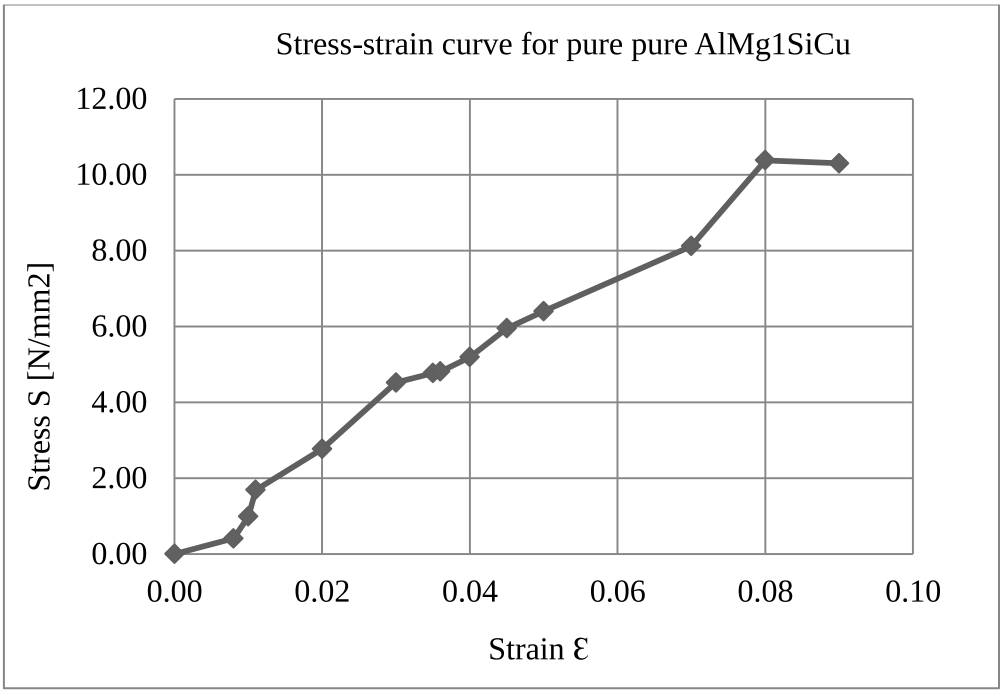


Figure 4.9 Stress -strain curve for pure AlMg1SiCu.

B. Tensile test for pure AlMg1SiCu (95%) & GGG-40 (5%)

Table 4.7 Recorded stress -strain data for AlMg1SiCu (95%) & GGG-40 (5%).

Force F [KN]	Stress S [N/mm²]	Strain Ɛ
0	0	0
0.01	0.3	0
0.11	0.45	0
0.24	0.76	0
0.5	1.59	0.01
1.01	3.21	0.02
1.54	4.9	0.03
2.27	7.23	0.05
3.29	10.47	0.07
4.35	13.85	0.09
4.98	15.85	0.098
4.8	15.8	0.1

Using the above recorded data, the result of stress strain curve for pure AlMg1SiCu (95%) & GGG-40 (5%) is shown in figure 4.10:

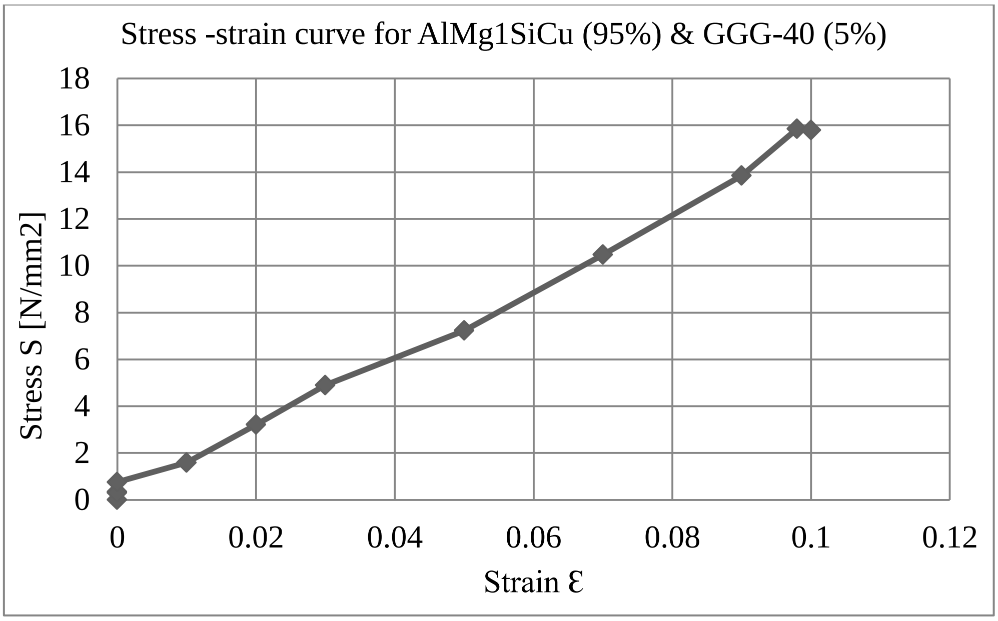


Figure 4.10 Stress -strain curve for AlMg1SiCu (95%) & GGG-40 (5%).

C. Tensile test for AlMg1SiCu (90%) & GGG-40 (10%)

Table 4.8 Recorded stress -strain data for AlMg1SiCu (90%) & GGG-40 (10%).

Force F [KN]	Stress S [N/mm²]	Strain Ɛ
0	0	0
0.05	0.16	0
0.15	0.48	0
0.16	0.51	0
0.35	1.11	0.01
0.49	1.56	0.015
0.74	2.36	0.02
1.49	4.74	0.03
2.92	9.29	0.06
4.4	14.01	0.09
5.48	17.44	0.1
5.4	17.4	0.11

Using the above recorded data, the result of stress strain curve for pure AlMg1SiCu (95%) & GGG-40 (5%) is shown in figure 4.11:

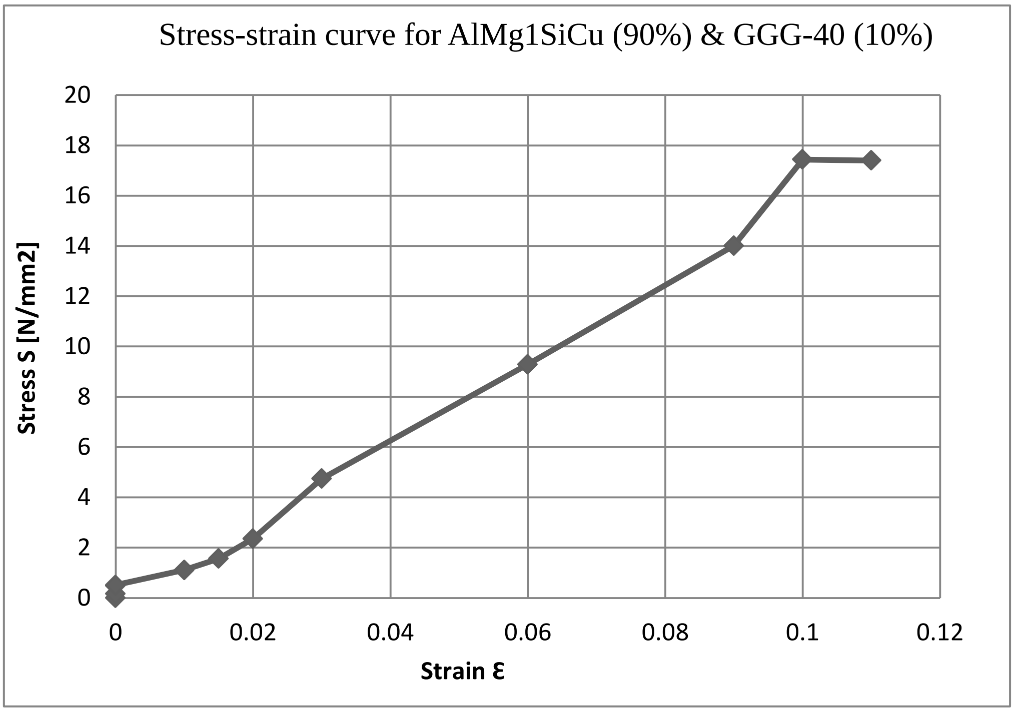


Figure 4.11 Stress -strain curve for AlMg1SiCu (90%) & GGG-40 (10%).

D. Tensile test for AlMg1SiCu (85%) & GGG-40 (15%)

Table 4. 9 Stress strain data for AlMg1SiCu (85%) & GGG-40 (15%) composition

Force F [KN]	Stress S [N/mm²]	Strain Ɛ
0	0.00	0.00
0.36	1.15	0.01
0.81	2.58	0.02
1.71	5.00	0.03
1.75	5.60	0.03
1.8	5.80	0.04

Using the above recorded data, the result of stress strain curve for AlMg1SiCu (85%) & GGG-40 (15%) composition is shown in figure 4.12:

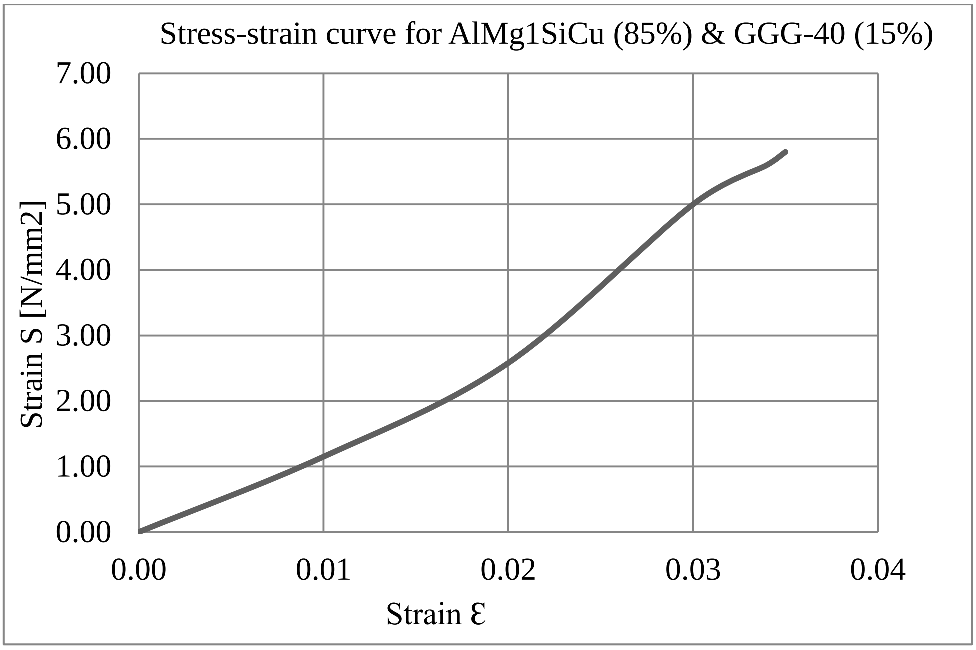


Figure 4.12 Stress -strain curve for AlMg1SiCu (85%) & GGG-40 (15%).

E. Tensile test stress-strain curve comparison for all composition of AlMg1SiCu & GGG-40

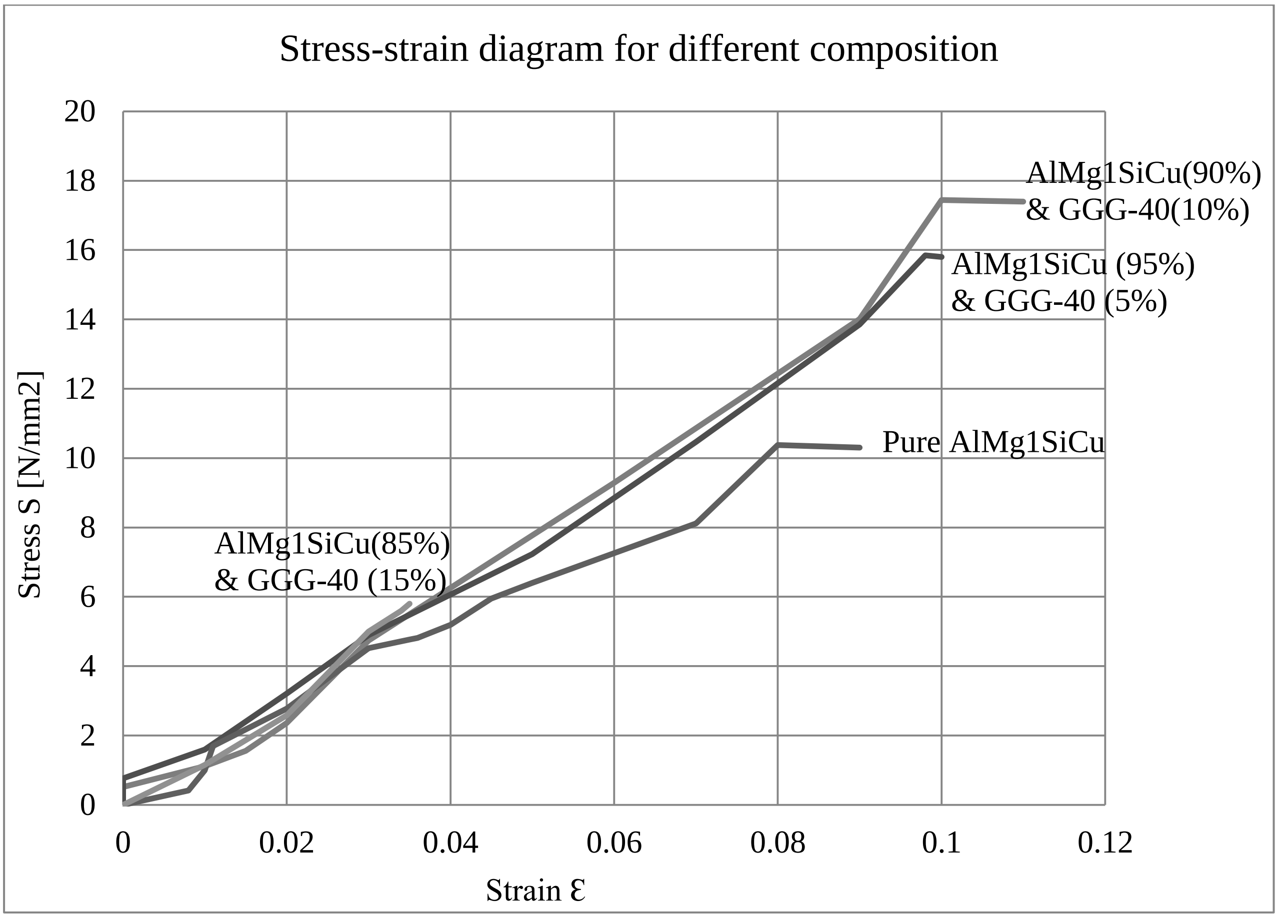


Figure 4.13 Stress-strain diagrams for different composition of AlMg1SiCu & GGG-40.

As shown in figure 4.13 the area of stress strain curve is increased as percent of GGG-40 cast iron increased up to 10% and decreased rapidly when % of GGG-40 cast iron greater than 10%. Thus, toughness is increased as percent of GGG-40 composition increased up to 10%, since this area is a measure of fracture toughness.

Using the above equation the final cross sectional area, A_f $[mm^2]$ = $W_f \times T_f$ = final width × final thickness of tensile test specimen, ultimate tensile strength, σ_{UTS} [MPa] $= \frac{P_{max}}{Ao}$ where, P_{Max} is recorded for each composition of specimen from universal testing machine and Ao = $W_o \times T_o$ = 4.5mm × 20 mm = 90 mm^2.

Table 4.10 Data which is entered, calculated and recorded on tensile test.

Details	Value of pure AlMg1SiCu	Value of AlMg1SiCu (95%) & GGG-40 (5%)	Value of AlMg1SiCu (90%) & GGG-40 (10%)	Value of AlMg1SiCu (85%) & GGG-40 (15%)
Initial length, L_o [mm]	100	100	100	100
Initial thickness, T_o[mm]	4.5	4.5	4.5	4.5
Maximum force, P_{max} [N]	4200	4980	5480	1710
Final length, L_f [mm]	101	102	103	100.5
Final thickness, T_f [mm]	4.2	4	3.8	4.4
Final Cross sectional area, A_f $[mm^2]$	84	80	76	88
Ultimate tensile strength, σ_{UTS} [MPa]	46.7	55.3	60.9	19.0
Fracture stress, σ_f [MPa]	10.3	15.8	17.4	5.8
% elongation = $\frac{Lf-L0}{L0} * 100$	1	2	3	0.5
% area of reduction = $\frac{Ao-Af}{A0} *100$	6.67	11.1	15.5	2.2

By observing the tensile test data and graph it can be seen that the ultimate tensile strength and percentage elongation increases up to 10% reinforcing GGG-40 cast iron chips as powder in aluminum alloy AlMg1SiCu. Furthermore, the ultimate tensile strength and toughness increases on increasing the GGG-40 cast iron reinforcement in the aluminum alloy, but would start to decrease after 10% reinforcing GGG-40 cast iron chips. Here, on adding GGG-40 cast iron by the variation of 5 % by weight to the aluminum alloy, it can be seen that the tensile strength and toughness increases up to the 10 % GGG-40 cast iron reinforcement with base metal but showed a fall/decrease in tensile strength when the reinforcement was made to 15 % by weight fraction instead of 10 %. The reason is that interfacial bond between GGG-40 cast iron particles and aluminum matrix is poor. Therefore, it can be observed and finally concluded that on adding or reinforcing 10 % GGG-40 cast iron by weight to AlMg1SiCu aluminum alloy would result in an impressive increase in the ultimate tensile strength, ductility and toughness.

4.3 Microstructure of different composition of AlMg1SiCu & GGG-40

Metallographic samples were selected from prepared tensile test specimen before testing. To see the difference in distribution of GGG-40 cast iron particles in the aluminum matrix, microstructure of samples was developed on optical microscope. Figure 4.15 shows Micrograph of GGG-40-AlMg1SiCu aluminum alloy samples for different weight fraction (5%, 10%, 15%, 20%) of GGG-40 particles. Optical micrographs showed reasonably uniform distribution of GGG-40 particles. The microscopic result for different composition of AlMg1SiCu aluminum alloy & GGG-40 cast iron test sample is shown in figure 4.14.

Figure 4.14 Using the prepared tensile test sample before test for microstructure examination

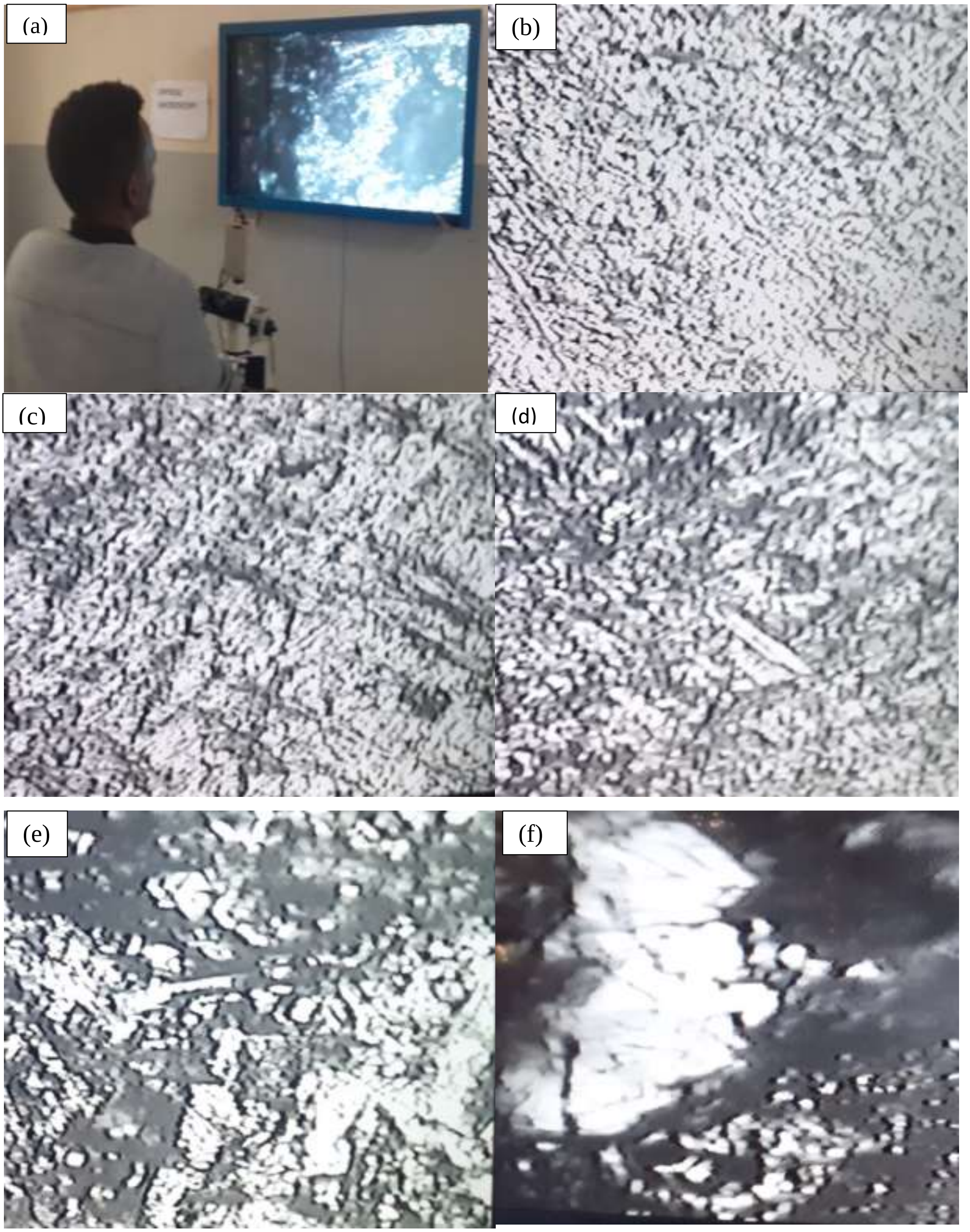


Figure 4.15 Microscopic image of different composite material: (a) operating the test, (b) micrograph of pure AlMg1SiCu, (c) micrograph of AlMg1SiCu (95%) & GGG-40 (5%), (d) micrograph of AlMg1SiCu (90%) & GGG-40 (10%), (e) micrograph of AlMg1SiCu (85%) & GGG-40 (15%), (f) micrograph of AlMg1SiCu (80%) & GGG-40 (20%).

As shown from figure 4.15 the microstructure of the AlMg1SiCu aluminum alloy and GGG-40 cast iron composition as the percent of composition increase the porosity and defect is increased when the percent of GGG-40 cast iron increase due to the manufacturing process effect and the size of the reinforcement powder and heating temperatures. A typical micrograph of AlMg1SiCu aluminum alloy and GGG-40 cast iron composites shows a reasonably even distribution of GGG-40 cast iron particles up to 10 % but it is rapidly increase the porosity when the percent of GGG-40 cast iron particle is greater than 10%. For instance, at 15 % and 20 % of GGG-40 cast iron there is high porous. It is to be noted that the GGG-40 cast iron particles was simply entrapped by the primary aluminum AlMg1SiCu during the solidification of the composite melt. It is also observed that porous sites were increased since the amount of entrapped decrease.

Porosity seems to increase with the increase of GGG-40 cast iron particles in the matrix. This is supported by the fact that when the volume fraction of GGG-40 cast iron particles increases, the tendency for them to agglomerate or clustering will increase. There are also air pockets between the particles, and these air pockets tend to become bigger when the GGG-40 cast iron particles content increases. As shown in figure 4.15 a void or pore is always surrounded by GGG-40 cast iron particle clusters.

Generally, the above result is the comparative study between reinforced and non-reinforced AlMg1SiCu aluminum alloy by GGG-40 cast iron chips the result have different properties than real properties of cast iron and aluminum alloy due to the manufacturing process and the testing machine problems.

Chapter 5

Conclusions and Recommendations

5.1 Conclusion

In this work, the tensile, hardness tests and microscopic result of AlMg1SiCu aluminum alloy with GGG-40 cast iron composite were studied. The sample were manufactured by stir casting method and tested according to ASTM standard size.

The tensile test, ultimate tensile strength increases on increasing the graphite reinforcement in the aluminum alloy, but start to decrease after 10% composition of GGG-40 cast iron composition. On adding or reinforcing 10 % GGG-40 cast iron by weight to AlMg1SiCu aluminum alloy would result in an impressive increase in the ultimate tensile strength, ductility and toughness.

Both rockwell and brinell hardness tests show the variation among the hardness of specimens with different compositions having the same behavior as of ultimate tensile strength. Thus, we conclude that the hardness of AlMg1SiCu increased up to the addition of 10% GGG-40 cast iron composition and maximum at this composition. Beyond this, hardness of the material decreases.

The microstructure result of the AlMg1SiCu aluminum alloy and GGG-40 cast iron composition shows that as the percent of composition increase the porosity is increased. A typical micrograph of AlMg1SiCu aluminum alloy and GGG-40 cast iron composites shows a reasonably even distribution of GGG-40 cast iron particles up to 10 % but it is rapidly increase the porosity when the percent of GGG-40 cast iron particle is greater than 10%. This is due to the tendency of the particles to agglomerating or clustering is increases.

Therefore, on adding or reinforcing 10% GGG-40 cast iron by weight to AlMg1SiCu aluminum alloy results an increase in the ultimate tensile strength, ductility, hardness and toughness.

5.2 Recommendations

The research has been considered to use the locally machined aluminum chips as a matrix element and cast iron chips as reinforcement and its spacemen have been prepared in four different compositions. The cast iron chips crushed up to 70-100 μm and heated up to 150 °c and it is mixed in to melted aluminum alloy by stir casting method and stirred by using modified hand drill bit. The characterization of mechanical properties of aluminum chips and cast iron chips composition at different composition have been studied by conducting hardness, old universal test tensile machine, microstructure tests using optical microscope. Thus are the limitations so in the future work the above limitation can be reworked and corrected by:

1. Using different mechanical test machine than this like modern tensile testing machine, Vikers hardness testing machine, XRD microstructure result, Wear testing machine, Fatigue testing machine and etc, to characterize the mechanical properties in better way.
2. Using modern automatic electric furnace for preparing sample to control temperatures of AlMg1SiCu aluminum alloy and GGG-40 cast-iron composite since they have different density and melting temperatures between them.
3. Using different chips extrusion machine and press machine to prepare the aluminum chips compressed or denser and use chips grinding machine to reduce the particle size of GGG-40 cast-iron particle to nanosize.

5.3 Recommended applications

AlMg1SiCu aluminum alloy and GGG-40 cast iron composite form a new class of aluminum alloy reinforced composites, which may find potential applications in:

a. Widely used in air craft, aerospace, automobiles, defense and various other fields.
b. Mostly for shafts, pistons, gears, gear housing, bearing house, engine block parts.
c. Automotive castings, truck parts.
d. Agricultural parts, various machinery casting parts, manhole covers, even for pump and valve parts.

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