INVESTIGATION OF MECHANICAL PROPERTIES OF ENHANCED Al 6013 ALLOY FOR AIRCRAFT APPLICATION

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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LIST OF ABBREVIATIONS

S.No	SYMBOLS/ ABBREVIATIONS	DESCRIPTION
1.	ASTM	American Society for Testing and Materials
2.	TIG	Tungsten Inert Gas
3.	MIG	Metal Inert Gas
4.	UTM	Universal Testing Machine
5.	HBW	Hardness Brinell Wolfram Carbide
6.	Al	Aluminium
7.	T	Heat Treating Temper Code
8.	kN	kilo Newton
9.	MPa	Mega Pascal
10.	GPa	Giga Pascal
11.	mm	millimeter
12.	kg	kilogram
13.	Mg	Magnesium
14.	Si	Silicon
15.	Cu	Copper

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Al 6XXX alloys often find its extensive applications in aerospace, aircraft and shipping industries owing to their superior mechanical properties such as high strength to weight ratio, lower density and in addition to that, they possess excellent formability and corrosion resistance.

The objective of this project was to document the influence of Magnesium on the tensile strength, hardness, impact resistance and microstructure of modified Al 6013 alloy. The current study involves manufacturing Al 6013 samples with 2% and 4% Mg using stir casting method.

Micro structural analysis performed using optical microscope indicated the homogeneity of the manufactured specimen. Yield Strength and Ultimate Tensile Strength showed elevation after % wt of Mg was improved when the tensile test was conducted on the UTS Machine. Brinell Hardness Test aided in the inference of enhanced hardness with increment in % Mg content. Izod Impact Test was conducted to study the impact toughness of the modified specimens.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION TO ALUMINIUM ALLOYS AND THEIR MODIFICATION

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1.1 PREFACE

The most important classes of metallic materials in aircraft and spacecraft applications are Al alloys, Ti alloys, Mg alloys, steels and Ni super alloys. A provision of overview of recent advancements where the developmental course and history of the above mentioned materials have been listed which has been helpful in highlighting current problems and adding perspectives related to metals for aeronautical and aerospace applications.

1.2 ALUMINIUM ALLOYS IN AEROSPACE INDUSTRY

Aluminium is one of the most abundant metals in the world, contributing in significant ways to any industry it is involved in. Aluminum and its alloys have an intricate combination of qualities that make them one of the most versatile, cost-effective, and appealing metallic materials for a wide range of applications, from soft, highly ductile wrapping foil to the most demanding engineering applications. In terms of structural metals, aluminium alloys are second only to steels.

Aluminum possesses a meagre density of 2.7 g/cm^3, which is about one-third that of steel (7.83 g/cm^3). Such light weight, combined with the great strength of specific aluminium alloys, allows for the design and building of strong, lightweight structures that are especially beneficial for anything that moves, including spacecraft and aircraft.

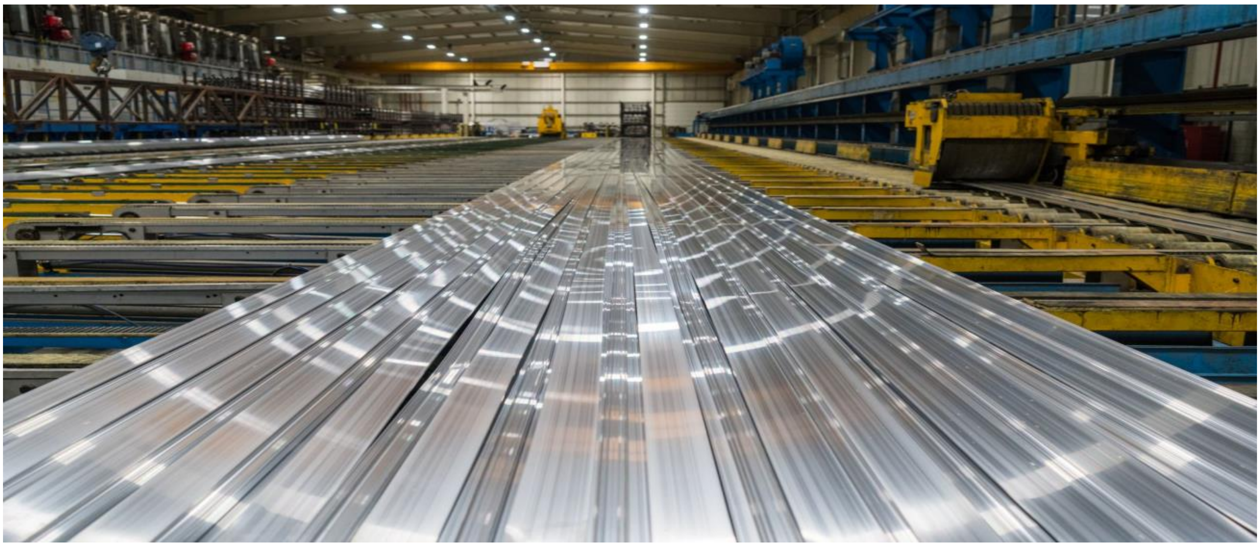


Figure 1.1 Cold Worked Al Alloy[1]

Starting in 19th century with frames in Airships designed by Count Ferdinand Zeppelin to being used in almost all important components in every nook and corner of the modern aircraft, ranging from fuselages to the smallest lug, Aluminium has made its imminent mark throughout the aviation sector.

For more than half a century, Aluminium was a material that dominated the aircraft and defense industries having high strength, superior ductility, excellent wear and corrosion resistance, better formability while being lightweight, cheaper and easily available. Some commonly used Al alloys in aircraft include 2024 (wing and fuselage structures), 6061 (light homemade aircrafts), 7050 (wing skins) and 2219 (external fuel tanks in space shuttles). [1]

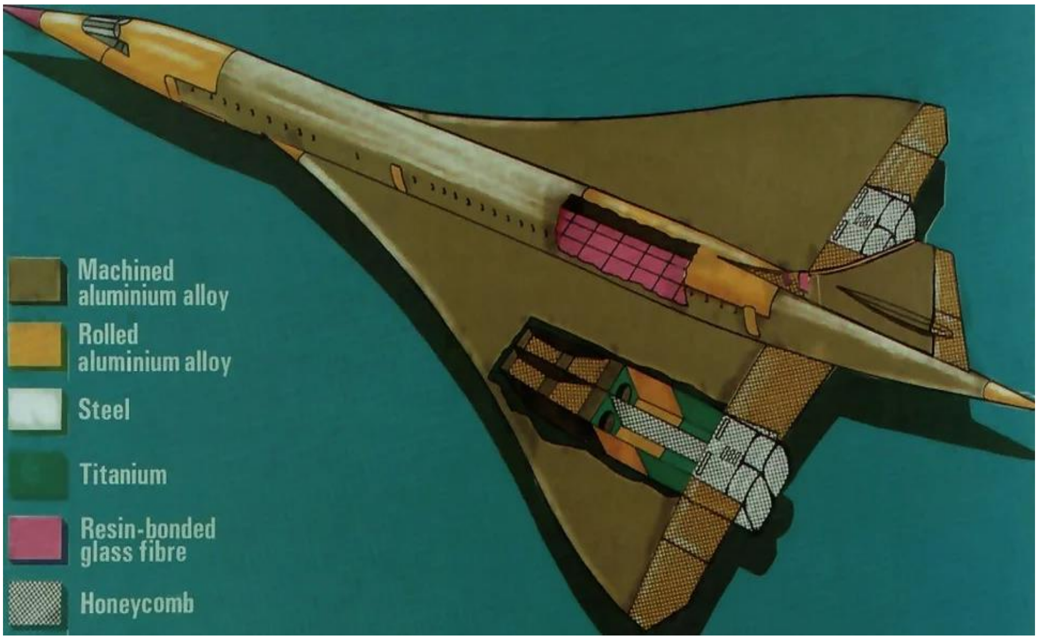


Figure 1.2 Overview of Al alloys application in Concorde aircraft [2]

This dominance is continually being challenged by the ever-growing research and development of organic resin composites while providing superior properties desirable in the aerospace and aircraft sector which has inevitably pushed the Al industry to innovate. In the recent years, focused research has been dedicated towards the development of a brand new generation of materials with the motivation to improve the service life of structural components in aircraft and also contributing to improved fuel efficiency, load capability and flight range. The strong competition in aircraft and defense sector is completely concentrated on the reduction in operating cost with increased payload capacity. Even though the major driving force for commercial aviation is the reduction in weight and the reduced fuel consumption that comes alongside it, there should be an accompanied guaranteed improvement in strength, fatigue life, wear behavior, corrosion resistance and impact toughness.[3]

1.3 ALLOY CLASSIFICATION

In order to provide simplicity and ease of understanding, aluminum alloys have been categorized into two parts: wrought compositions and cast compositions (Fig. 1.3). A large percentage of alloys respond to thermal treatment depending on the solubility of the phase in which it exists. Some of these treatments include quenching, precipitation, age hardening and solution heat treatment. In casting or wrought alloys, these kind of alloys are defined as as heat treatable. Numerous wrought compositions are reliant on work hardening by means of mechanical reduction. Such alloys are described as work hardening.

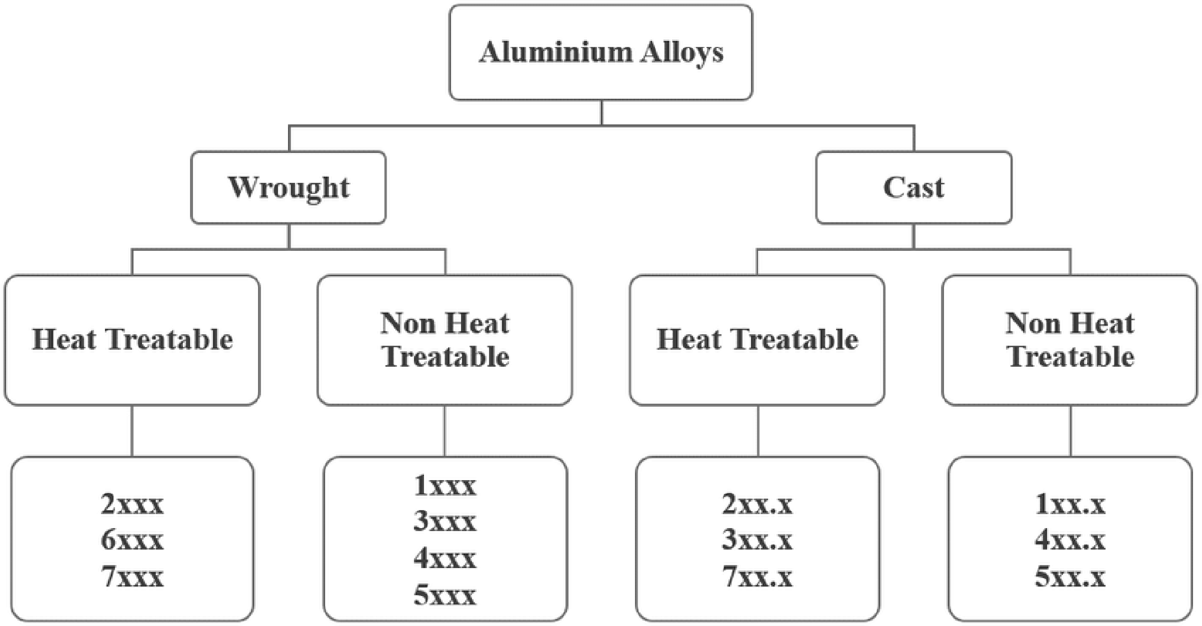


Figure 1.3 Classification of Al alloys [4]

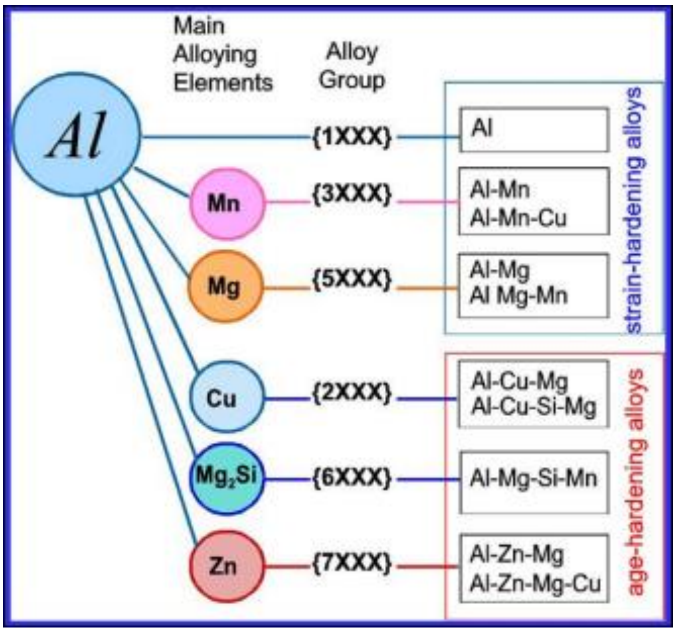


Figure 1.4 Flowchart of major constituents for a given Al alloy series number[4]

The USA mainly considers The Aluminum Association System for use. The system used for identification of alloys implements various nomenclatures for wrought and cast alloys, and for ease, it sub-divides alloys into families. The wrought and cast aluminums have unique systems that help in identification (Fig. 1.4); the wrought alloys with a system of 4-digits and the casting alloys with 3-digit and 1-decimal place system. The first digit denotes the major elements for alloying, augmented to the aluminum alloy, common for both alloy types. In wrought alloys, the second single digit, when not 0, represents an adjustment in that specific alloy, while the third and fourth digits are random integers provided to identify a specific alloy in that particular series. In casting alloys, the second and third digits are random integers given to identify a specific alloy in the series. The digit following the decimal place provides information on whether the alloy is a casting (.0) or an ingot (.1 or .2). An uppercase prefix denotes a revision to the specific alloy.[4]

1.4 NEED FOR ALLOY MODIFICATION

Throughout the history of aluminium, new alloy development has been crucial in developing numerous novel commercial applications. In the 1970s, alloys with high thermal conductivity and exceptional resistance to engine coolants were produced. This combination allowed for the production of heat exchangers that were both cheaper and lighter than standard copper equivalents. Automotive, aerospace, desalination of sea water, renewable energy, and maritime uses, as well as several civil engineering and industrial applications, have all recently seen new alloy advances.[5]

It is also important to emphasize studious research on the effects of enhancement/modification of small quantities of all of the major constituents in a chosen alloy series in order to truly derive a direct cause and effect relationship and the inter-compositional outcomes, which would prove to provide invaluable data. The usage of such an experimental research methodology can further contribute to the production of highly desirable materials in a variety of fields pertaining to science and engineering.

1.5 OBJECTIVE OF THE PROJECT

Al 6013 is a material that is capable of superior properties when one of its major macro- constituent's composition is systematically varied. The aim of the study is to analyze the effect on the mechanical properties of Al 6013 when the proportion of Mg is carefully altered.

1.6 SCOPE OF THE PROJECT

The scope of this project is to fabricate the Al 6013 alloy with Magnesium as the enhancing material through stir casting method for manufacturing. The specimen is cut into required dimensions for the Tensile Test, Brinell Hardness Test and Izod Impact Test and their characteristics are observed.

1.7 SUMMARY

Basic introduction and the history and applications of Al alloys in aircraft industry have been discussed elaborately in this Chapter and the various classifications of Al alloys have also been explained extensively with pictorial representations. The research methodology of the project is also disclosed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a detailed overview of previously conducted research and experiments related to alloy composition modification and the resultant beneficial effects brought about by each major alloying element in Al 6XXX series alloys ie. Copper, Magnesium and Silicon. The justification for the choice of 6-series Al alloy is also presented elaborately. With the aim of adding precision to the project, a thorough study has been carried out on the following research papers as reference.

2.2 LITERATURE REVIEW

Kaneko *et al.* performed a comparative analysis of various mechanical properties namely yield strength, ultimate tensile strength, corrosion resistance, aging behaviour, formability in addition to the costs incurred in manufacturing and production risk, between Al 6013-T6 alloy and Al 2024-T3 clad sheets while discussing practical reasons for the replacement and widespread implementation of latter with the former in the US Navy's P7-A antisubmarine warfare patrol airplane. It provided the following essential background information on Al 6013 alloy.

Al 6013 is an alloy composed majorly of Al-Mg-Cu-Si. It was found to be implemented in fuselage skin, formers and ribs, pressure bulkhead skin, leading and trailing edges, door skins, flap skins, dorsal fin, wing/nacelle fairings and nacelle skins and stiffeners and numerous other parts such as door skins, dorsal fin and trailing edge panels replacing clad 2024 alloy. Since 6013 alloy forms naturally in T4 temper, and can be simply aged to T6 temper, the manufacturing costs can be reduced drastically. The inherent chemical composition of Al 6013 allowed it to be 3% less dense than alclad 2024, therefore when used to substitute conventional materials provided the opportunity for structural weight and fuel consumption reduction. It was found from the static design properties test of various Aluminium alloys that 6013-T6 had a 20% strength advantage in compression buckling over clad 2024-T3/T42. Al 6013 exhibits yield strengths 25% greater than 6061-T6 and 12% higher than alclad 2024-T3 in sheet gauges. It was also seen that the former alloy was naturally corrosion resistant and hence could be used unclad. Al 6013’s toughness stayed intact up to a temperature of 250°F. Owing to its superior formability, it did not require heat treatment. This reduced the possibility of surface defects such as Lueder lines and orange peel effect thereby causing an improvement in its aerodynamic performance. Al 6013 was weldable by Gas tungsten arc (TIG), Gas metal arc (MIG) and resistance welding method. Al 6013 was resistant to stress corrosion cracking and exfoliation. It also proved to be superior to alclad 2024 and 7075 in pitting and intergranular corrosion during long term exposure testing.

Rajesh Purohit *et al.* carried out a study on the effect of increasing Mg content on the mechanical and wear properties of LM6 Al alloy comparing the modified alloy. The major constituents of this alloy are Al and Si with small amounts of Cu, Mn, Mg, Si, Zn, Fe, Ni, Pb and Sn. The primary effect of Si in the alloy was to produce good casting characteristics and increased fluidity. The Mg content in the alloy was increased to 1.18%. The Young's Modulus of the new specimen was measured to be 3.039 GPa. Mg addition caused the reduction of Ultimate tensile strength from 230 MPa to 217 MPa resulting in a 5.65% decrease in the quantity while the elongation was unaffected and well within the original range of 2-5%. Addition of Mg resulted in lower ductility. The average BHN of the specimen was found out to be 98.25 which was 70.87% increment from the original value of 57.5. Mg addition improved the hardness of the alloy.

Girisha *et al.* discussed the mechanical and microstructural properties of Al-4Cu alloy when the quantity of Mg is increased from 0.5-2% in the intervals of 0.5%. The Cu content in the alloy was kept constant while changing the Cu/Mg ratio in the order 4:2, 4:1.5, 4:1, 4:0.5. The microstructure analysis was performed on heated and ascast samples

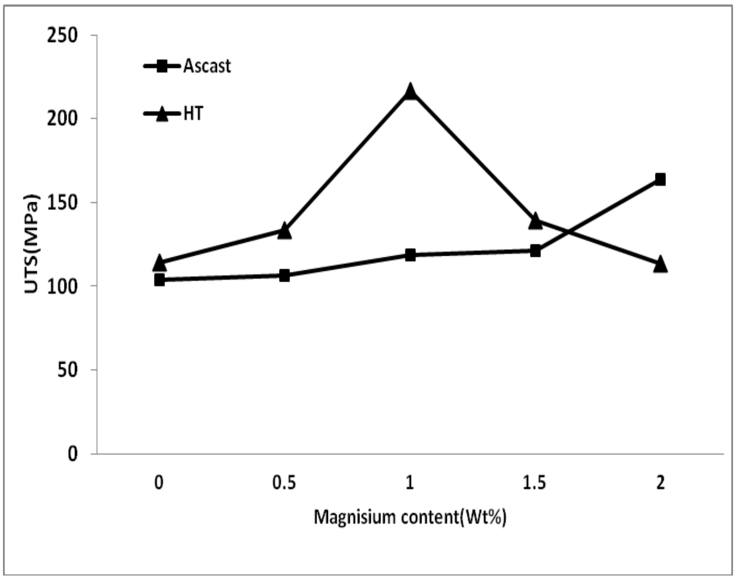


Figure 2.1 Graph of UTS with respect to % Mg

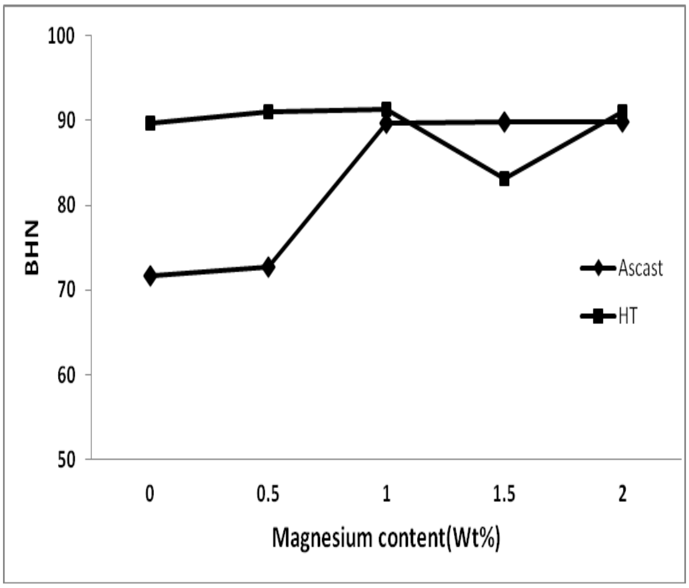
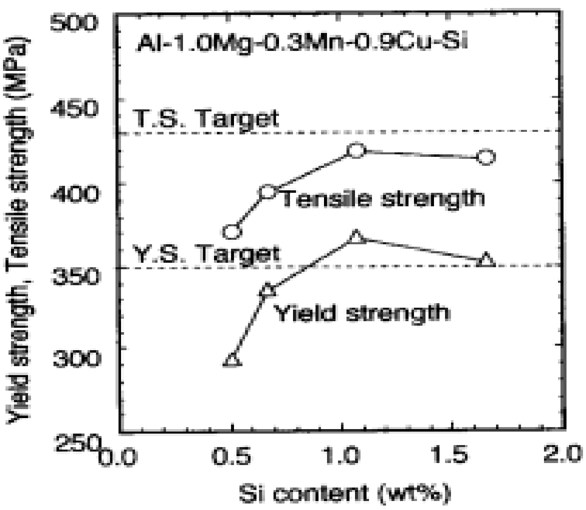


Figure 2.2 Graph of BHN with respect to % Mg

As shown in Fig. 2.1 and 2.2 above that the increment in the amount of Mg in ascast condition from 0-2% increased the Ultimate Tensile Strength linearly by almost 58%. Similarly, the Brinell's Hardness Number also increased in a linear fashion by 24%. But both the parameters showed a steep change in value at around 1% Mg content in the heat-treated sample, which indicated that heat treatment nullified the enhancing effects on the mechanical properties due to Mg.

Yoshida *et al.* involved producing a new alloy pertaining to remain under 6XXX series Al alloys to compete with the properties of Al 2024-T3 and Al 6013-T6 alloys in aircraft applications. The quantity of Cu and Si were varied from 0.5 to 2% independently of each other in steps of 0.5% and the results were obtained. The basis for the study was on the fact that even though Al 6XXX series alloys possessed lower strength, they exhibit better formability and corrosion resistance with lower density.



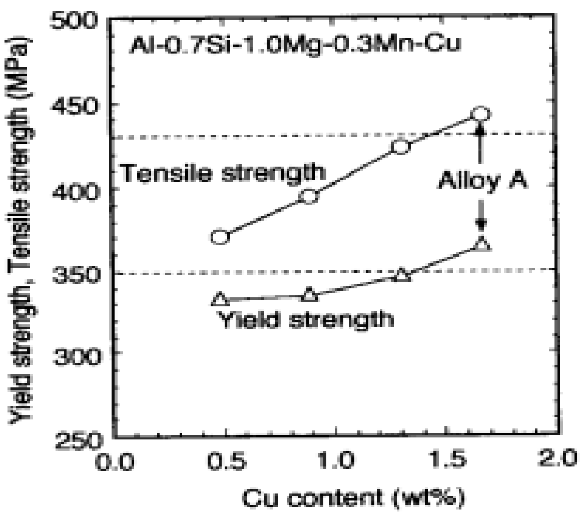


Fig 2.3 & 2.4 Graphs indicating changes in Yield and Tensile Strength with respect to %Si and Cu content respectively

From the above graphs shown in Fig, it can be inferred that using 1% Si and 2% Cu will maximize the beneficial effect on the mechanical properties of Al 6XXX alloy.

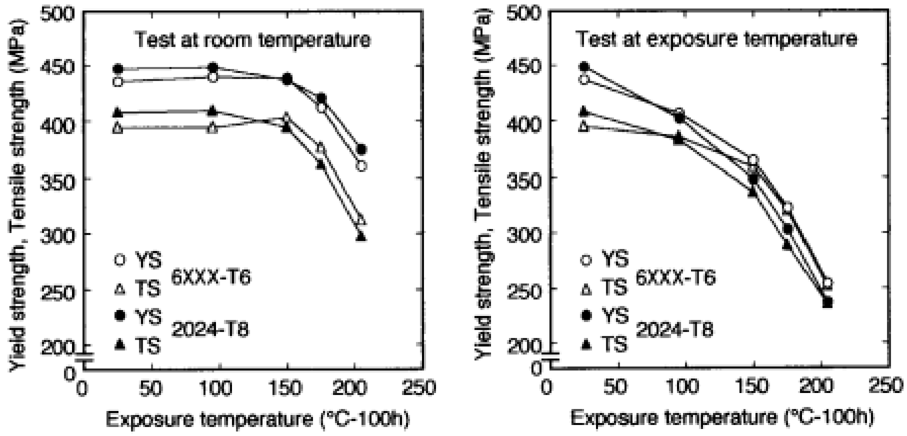


Figure 2.5 & 2.6 Graphs indicating change in strength in accordance with room and exposure temperature respectively

The new alloy consisted of 1.64% Cu, 1.01% Mg and 0.75% Si. The Yield Strength of this alloy was 60 MPa greater than that of 2024-T3 alloy. From Fig 2.5 & 2.6, it is clear that the new alloy possesses greater strength at elevated temperatures than 2024-T8 alloy. The basic methodology used in this paper provided quantitative insights on further research on the above-mentioned alloy series.

2.3 RESEARCH GAPS IN LITERATURE REVIEW

The effects of Magnesium content on the present Aluminum alloys for any application have not been studied extensively, which might potentially lead to a substantial result. Even though Al 6013 alloy showcases the desirable characteristics which deem to be favorable for their employment in aircraft industry, only a few existing research has focused on the said alloy. The effect of Mg content on the impact toughness/strength on Al 6XXX alloys with aircraft application has not been studied in the present literature.

2.4 SUMMARY

From the literature review, it is clear that Al 6013 alloy even though possessing lower strength, it has the potential for strength improvement when the amount of Mg in the specimen is carefully altered while retaining the advantageous characteristics such as corrosion and wear resistance, formability and ease of manufacturing. Although, such an increase in Mg content brings about a decrease in ductility which occurs as a disadvantage. It can be concluded that Al 6013 shows promising results despite its drawbacks and can easily provide drastic advantages to the current modern aircrafts.

CHAPTER 3
METHODOLOGY

3.1 PROBLEM DESCRIPTION

To improve the overall static mechanical properties namely, Yield Strength, Ultimate Tensile Strength, Hardness and Impact Resistance through the addition of Mg to Al 6013 alloy in steps of 2% till 4% in order to increase the material's suitability for aircraft application.

3.2 METHODOLOGY

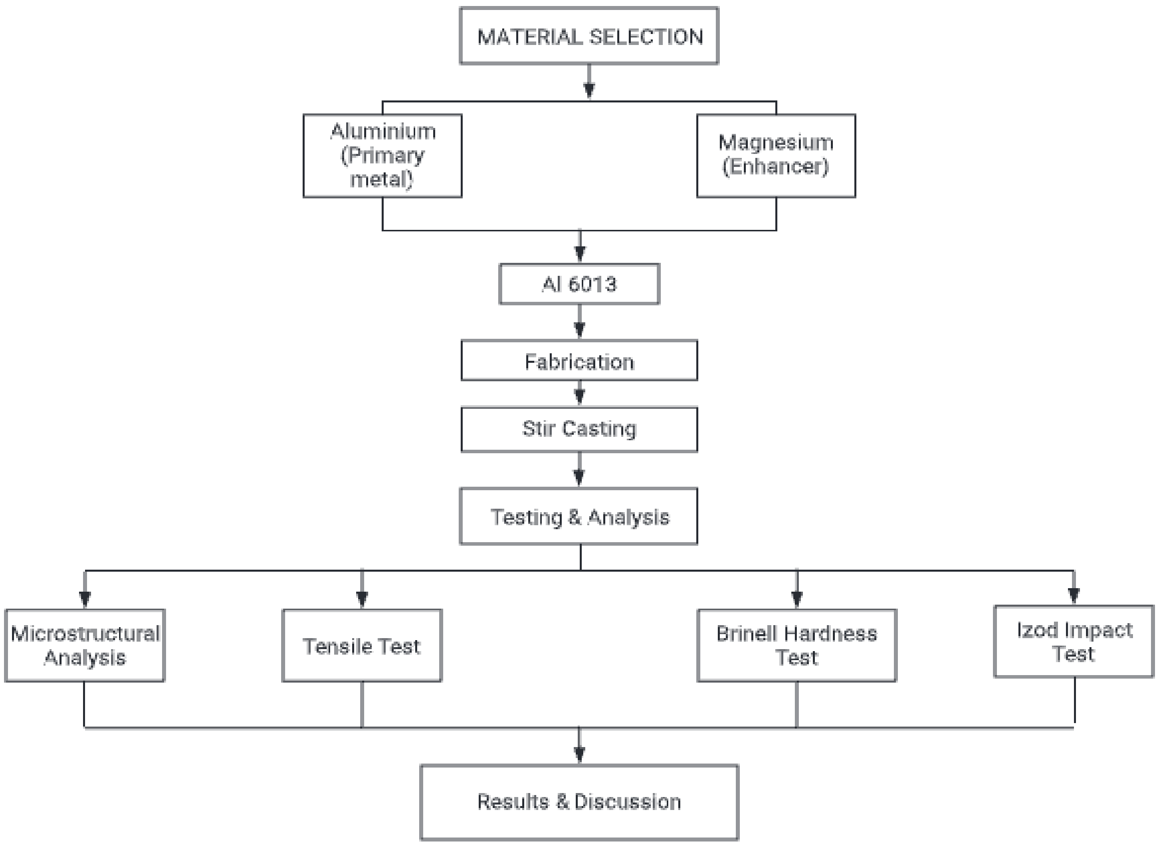


Figure 3.1 Flowchart indicating the use of methodology

The first step of the project involves the selection of suitable base metal that exhibits desirable strength, hardness, impact toughness, corrosion and wear resistance properties to employed in the aviation industry. Aluminium was selected as the base metal. The next step was to choose the right enhancing material with additional major constituents. Magnesium was selected as the enhancer while the other major elements included Copper, Silicon, Manganese and Iron.

This was followed by finding an Aluminium alloy series that matched the predetermined characteristics as well as contained all the major components selected for the alloy. Al 6013 alloy matched all the requirements and hence was chosen as the material considered for improvement. By means of stir casting method, two samples- Al 6013-2.0 Mg and Al 6013- 4.0 Mg were taken in an ingot and casted at 950°C and cooled down at room temperature. Heat treatment was not considered since it caused a negative effect on the strength enhancement of the material. Microstructural analysis was performed in order to analyze the grain structure and quality of the samples manufactured. Tensile test (UTM), Brinell Hardness Test and Izod Impact Test were performed to measure the variation in Yield And Ultimate Tensile Strength, Hardness and Impact toughness of both the specimens. The results were consolidated and discussed.

3.3 Al-Mg PHASE DIAGRAM

The aluminum-magnesium-based alloys are among the most important industrial materials for use in aero plane constructions, primarily because of their weight-saving qualities. In order to highlight the relevance of understanding the various phases involved during alloying, as well as the phase relationships, is extremely crucial.

Aluminum-Magnesium phase diagram is a binary system consisting of liquid, β-solid solution with hexagonal crystal structure, γ -solid solution with the α-Mn structure type, R phase with rhombohedral structure at 42 at. percent Mg, Al solid solution with a maximum solubility of 18.9 at. percent Mg at 723 K, and Mg solid solution with a maximum solubility of 11.8 at. percent Al at 710 K. When the relative atomic radius of Al and Mg are taken into consideration, the ratio of the Al radius to the Mg radius is 1.12. According to [6] this fundamentally implies a high mutual solid solubility.

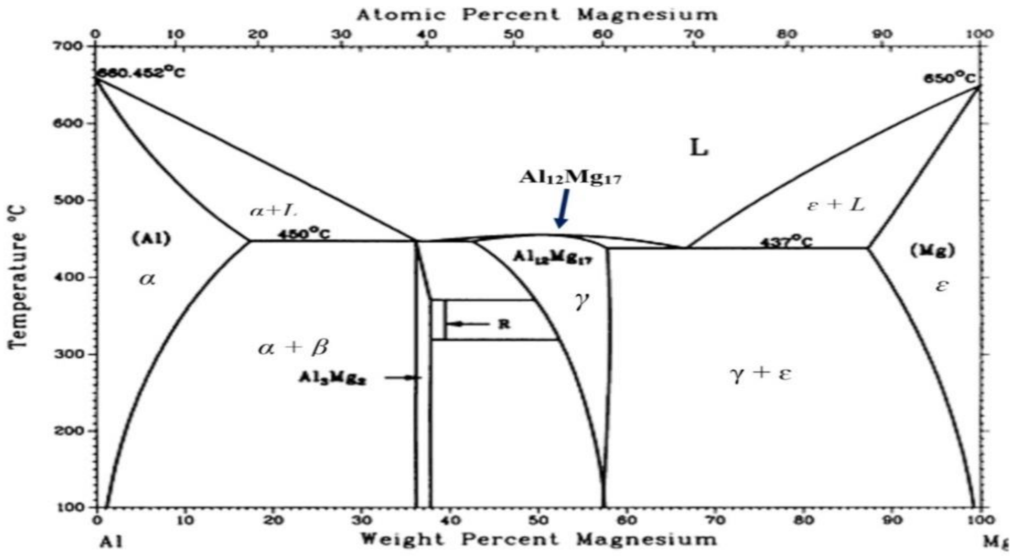


Figure 3.2 Al-Mg Phase Diagram [7]

Having 2 percent Mg content places it comfortably inside the α-Al phase region (with Al acting as the solvent and Mg acting as the solute in the solid phase) for temperatures ranging from 413 K to 903 K. With 4 percent Mg, the range is between 513 K and 843 K, like with the other percent.

When the Mg content of the alloy is increased in small increments of 0.5 percent, there are no significant variations in the phase of the alloy created throughout a wide range of temperatures. As a result, in order to investigate the mechanical consequences of Mg addition on a macroscopic scale, this research seeks to increase Mg percent by two percentage points at a time.

Furthermore, an increase in Mg concentration above 4 percent is not considered since there is a phase transition into the α+β and α+L regions in the above-mentioned temperature ranges, making the addition of Mg undesirable.

3.4 SUMMARY

The basic methodology of the project was discussed and the various phases involved were also explained briefly in chronological order. The phase diagram between Aluminium and Magnesium was employed to provide clarity on the specific reason as to why 2% and 4% Mg were chosen for the addition to Al 6013 alloy as an enhancement.

CHAPTER 4
MATERIALS

4.1 INTRODUCTION

The following materials were selected for fabricating the newly modified alloy.

- Aluminium (Base metal)
- Magnesium (Enhancer)
- Copper
- Silicon

4.2 ALUMINIUM

The advantages of choosing Aluminium as the primary base metal for aircraft applications have been discussed extensively in detail in Chapter 1, Section 1.2.

4.3 MAGNESIUM

Magnesium (Mg) is a chemical element with the atomic number 12 and the symbol Mg. It's a gleaming grey solid with many of the same physical and chemical properties as the other (five) alkaline earth metals. Almost all Aluminium alloys contain Magnesium in it. The liberated metal emits a distinctive brightly shining-white light. The metal is now predominantly produced through electrolysis of magnesium salts extracted from brine and is mostly utilised as a component in aluminum-magnesium alloys, sometimes known as magnalium or magnelium. Magnesium has a lower density than aluminium, and the resulting alloy is appreciated for its lightness and strength.

Table 4.1 Chemical Properties of Mg

Material	Formula	Atomic Mass	Density (g/cc)	Melting Point (°C)	Boiling Point (°C)
Magnesium	Mg	24.305 u	1.738	650	1091

Low specific gravity and a high strength-to-weight ratio are two of magnesium's advantages. As a result, the material is suitable for a wide range of applications in the automotive, aerospace, industrial, electrical, biomedical, and commercial sectors. Magnesium is chosen as the enhancer for this project since Mg has a very low density which can contribute to reduction in structural load and instead be used to carry more fuel and payload or can contribute to the beneficial decrement in fuel consumption for a given aircraft weight.

4.4 SILICON

Silicon is an element in the periodic table with the atomic number 14 and the symbol Si. It is a tetravalent metalloid and semiconductor that is a hard, brittle crystalline solid with a blue-grey metallic sheen. It belongs to the periodic table's group 14. It has a low reactivity. The majority of silicon is utilised commercially without separation process, and the natural minerals are often processed relatively little. Clays, silica sand, and stone are used in industrial construction.

Table 4.2 Chemical Properties of Si

Material	Formula	Atomic Mass	Density (g/cc)	Melting Point (°C)	Boiling Point (°C)
Silicon	Si	28.085 u	2.33	1414	3265

A collection of ultralight, great strength aluminium alloys developed through an aluminum–silicon combination is known as Silumin. Generally, Aluminium alloys that contain Silicon are highly corrosion resistant, hence promoting its employment even in humid conditions. Adding Silicon to Aluminum reduces the viscosity of the liquid, which, combined with its low cost (because the extraction of both components is comparatively cheap), makes it an excellent cast alloy.

4.5 COPPER

Copper, abbreviated as Cu, is a chemical element. It's a ductile, malleable metal with exceptional electrical and thermal conductivity. A freshly exposed pure copper surface is pinkish-orange in hue. Copper is among the few materials that may be found in an useful metallic state in nature.

Table 4.3 Chemical Properties of Cu

Material	Formula	Atomic Mass	Density (g/cc)	Melting Point (°C)	Boiling Point (°C)
Copper	Cu	63.546 u	8.96	1084	2562

The copper boosts the strength of the Al alloy and makes precipitation hardening easier. Copper can diminish ductility and corrosion resistance when mixed with Aluminium. Aluminum-copper alloys have a higher propensity to solidification cracking; as a result, some of these alloys can be the most difficult to weld. Some of the highest strength heat treatable aluminium alloys are included in this group. Aerospace, military vehicles, and rocket fins are the most common applications of Al-Cu alloys.

4.6 SUMMARY

The various chemical elements and metals used in the fabrication process and the justifications for their use in the samples of Al 6013-2% Mg and Al 6013-4% Mg have been discussed elaborately in this chapter.

CHAPTER 5
FABRICATION OF THE ALLOY

5.1 INTRODUCTION

Fabrication of casting Aluminium alloys can be performed using several process. Some of these processes are listed below.

- Stir Casting
- Die Casting
- DC (Direct Chill Casting)

Stir casting is frequently seen as a very promising approach for the production of metal alloys, and it is currently being employed commercially in the manufacturing industry. Its advantages stem from its ease of use, versatility, and cost-effectiveness in large-scale manufacturing. Using stir casting to manufacture aluminum alloy is a low-cost method of producing aluminum alloy.

5.2 FABRICATION OF THE ALLOY SAMPLES USING STIR CASTING

Stir casting is one of the most common and widely used methods for forming materials (mostly metallic alloys and MMCs) by melting metals and pouring them into cavities for attaining castings of the desired shape. Liquid metallurgy is the other name for it.

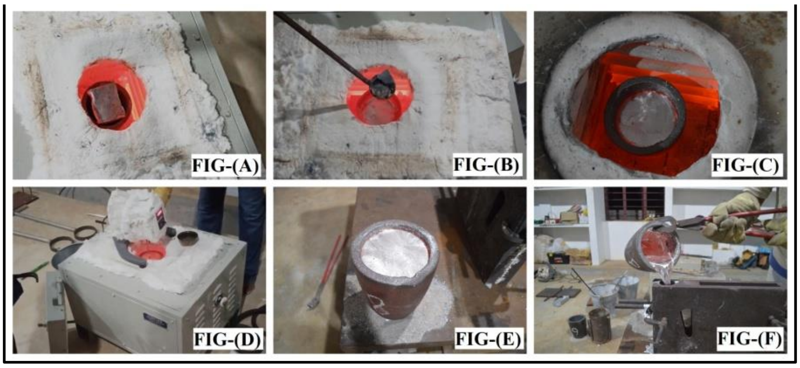


Figure 5.1: Figure-(5.1.A), Figure-(5.1.B), Figure-(5.1.C), Figure-(5.1.D), Figure-(5.1.E) and Figure-(5.1.F)

Aluminum 6013 alloys with different magnesium contents were created by melting aluminum bar with varying magnesium proportions in a graphite crucible at 800°C as shown in Figure 5.1.A, to achieve a homogeneous composition, and then cooling the alloys. After the addition of copper, zinc, iron, and silicone as shown in Figure 5.1.B, each melt was swirled for 15 minutes at a low temperature as shown in Figure 5.1.C and Figure 5.1.D.

The melting point is maintained at 920°C, and the degassing of the melt is accomplished with 1 percent solid hexa-chloromethane before being put into a graphite crucible as shown in Figure 5.1.E and 5.1.F. Table 5.1 illustrates the weight percentages of aluminum and magnesium utilized in the preparation of Al 6013-2.0 Mg alloys and Al 6013-4.0 Mg alloys, respectively.

Table 5.1: Composition of Al 6013 alloys (wt %)

Composition Wt%	**Al 6013-2.0Mg**	**Al 6013-4.0 Mg**
Aluminum (Al)	95.25	93.25
Magnesium (Mg)	2.00	4.00
Copper (Cu)	1.20	1.20
Zinc (Zn)	0.25	0.25
Iron (Fe)	0.30	0.30
Manganese (Mn)	0.60	0.60
Chromium (Cr)	0.20	0.20
Silicon (S)	0.20	0.20

Fig 5.2: Cast sample of Al-Mg-Cu-Si Alloys fabricated

Specimen 1: Alloy cast with Al 6013- 2.0 Mg & Specimen 2: Alloy cast with Al 6013- 4.0 Mg

5.3 MATERIALS AND EQUIPMENT USED FOR FABRICATION

- Stir Casting Setup
    1. Furnace
    2. Mechanical Stirrer
- Pure Al Ingot
- Mg, Cu, Si, Zn
- Graphite Crucible

5.4 SUMMARY

Various fabrication techniques used for casting alloys were listed. Advantages aiding in the selection of Stir casting method for alloy preparation were provided. Fabrication process was explained elaborately with pictorial representations. The chemical composition of the samples prepared were tabulated. The final product was also displayed in Figure 5.2.

CHAPTER 6
EXPERIMENTAL TESTS

6.1 INTRODUCTION

In this project four mechanical tests were carried out. The following tests were conducted on the samples of Al 6013-2% Mg and Al 6013-4% Mg to study the effect of varying Mg content on themechanical properties of the alloy.

The testing methods used for these specimens were:

- Tensile Test
- Brinell Hardness Test
- Izod Impact Test
- Microstructure Analysis

The specimens were cut and machined to dimensions specified for each test by the ASTM standard.

6.2 TESTING AND PROCEDURE

6.2.1 TENSILE TEST

For this test, the sample was crushed into fine powder by making sure it contains no impurities. The test was carried out by means of the UTM (Universal Testing Machine) each sample was places between the fixtures and the load was applied till the point of fracture. The provided temperature was in the range of 68 to 700˚C, in the intervals of 2˚C. The characteristics of the material are taken in the form of the plot between weight loss % with the change in temperature, called the TGA curve and also the derivative of this curve called as DTGA curve.

The following characteristics can be obtained from this test method.

- Yield Strength
- UTS
- Elongation
- Peak Load

Figure 6.1 Universal Testing Machine

6.2.2 BRINELL HARDNESS TEST

For this test, the samples were made according the ASTM standard E18. Each specimen was of the dimension 10×25mm.The samples were tested on a Brinell Hardness Testing machine with a tungsten carbide ball indenter of 2.5mm diameter. The dwell period was 30 seconds and the applied force was 60 kg. This test determines the Brinell Hardness Number of the material.

Figure 6.2 Brinell Hardness Testing Machine

6.2.3 IZOD IMPACT TEST

For this test, the samples were of the dimensions 75×10×10mm and a V notch of 2mm depth was machined at one third of the samples’ length, according to the ASTM standard D256 specified for the Izod Impact Test. The specimen was clamped with the notch facing the pendulum in a vertical cantilevered position and the energy carrying pendulum was allowed to strike the test piece. The energy absorbed by the specimen during fracture is obtained from the pointer. The impact toughness of the material was obtained through this test.

Figure 6.3 Izod Impact Testing Machine

6.2.4 MICROSTRUCTURAL ANALYSIS

For the microstructure analysis the samples into cylinders of dimension 10×20mm as per the ASTM standard E407, and were mechanically polished using standard metallographic procedures. The microstructure of the sample surface was examined using microstructural categorization investigations. This analysis was performed by means of an optical microscope and the samples' micrographs were obtained. Through this analysis the material composition of the specimen was examined and any casting defects present in the samples were identified.

Figure 6.4 Optical Microscope

6.3 SUMMARY

Various experimental tests that were chosen to be conducted were listed and their experimental procedures were explained elaborately.

CHAPTER 7
RESULTS AND DISCUSSION

7.1 INTRODUCTION

In this chapter, the results and graphs obtained from the all the four testing methods have been tabulated and compared.

- Tensile Test
- Brinell Hardness Test
- Izod Impact Test
- Microstructure Analysis

7.2 SPECIMEN DETAILS

The following table shows the ASTM standard followed for each test along theirspecimen dimensions.

Table 7.1: Table showing ASTM Standards and specimen dimensions for each test

S. NO	TEST NAME	ASTM STANDARD	SPECIMEN DIMENSION
1.	Tensile Test	B557	100 x 10 mm
2.	Brinell Hardness Test	E18	10 x 25 mm
3.	Izod Impact Test	D256	10 x 10 x 75 mm
4.	Microstructure Analysis	E407	10 x 20 mm

7.3 TENSILE TEST RESULTS

I. Results of Tensile Test conducted on 2 samples of Al 6013- 2.0 Mg

Table 7.2: The yield strength, ultimate tensile strength and the total elongation were calculated for different samples of Al 6013-2.0 Mg

S.No	Composition	Sample No.	Yield Strength (MPa)	UTS (MPa)	Elongation (%)	Peak Load (kN)
1	Al 6013- 2.0 Mg	Sample 1	152	171.1	4.0	4.523
2	Al 6013- 2.0 Mg	Sample 2	148	163	4.4	4.256

II. Stress vs Strain curve for Al 6013 – 2.0 Mg for Sample 1 & 2

Figures 7.1 and 7.2 show the stress-strain curve for the Samples 1 & 2 of Al 6013-2.0 Mg which indicates the proportionality limit, strain ranges in which elastic and plastic behaviour are exhibited and important important mechanical properties such as yield and ultimate tensile strength.

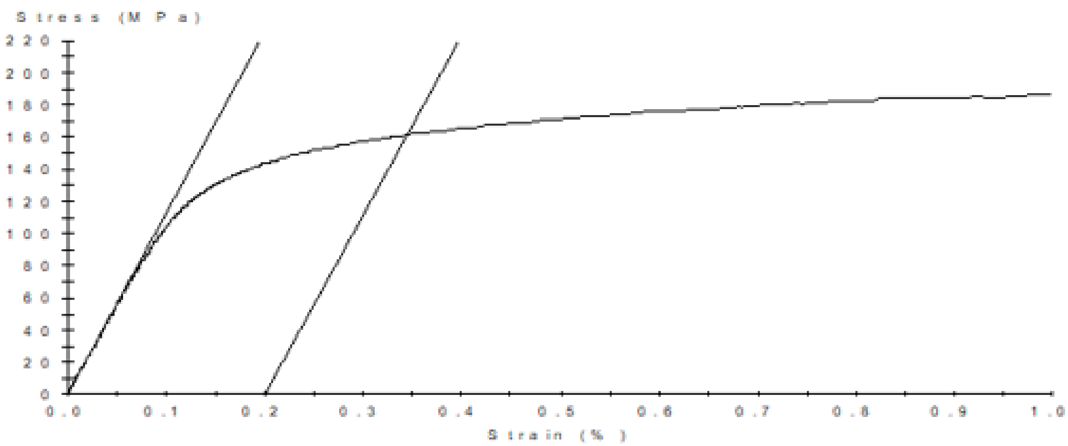


Figure 7.1 Al 6013 – 2.0 Mg- Sample 1

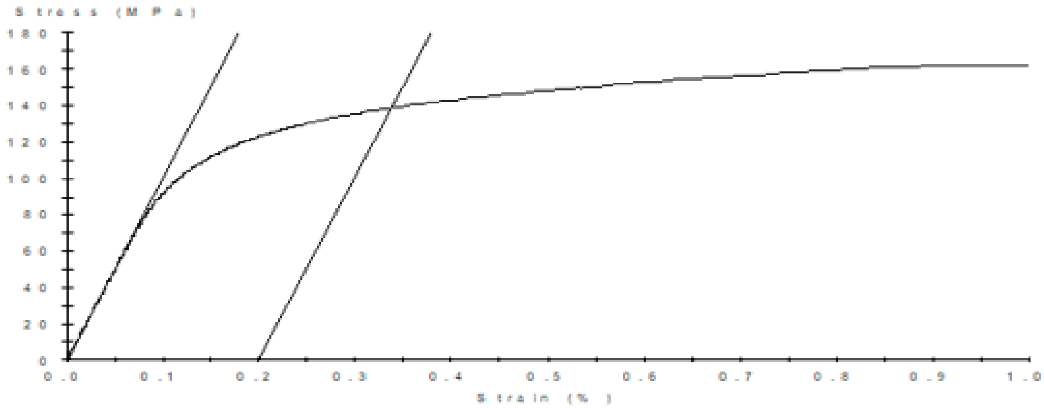


Figure 7.2 Al 6013 – 2.0 Mg- Sample 2

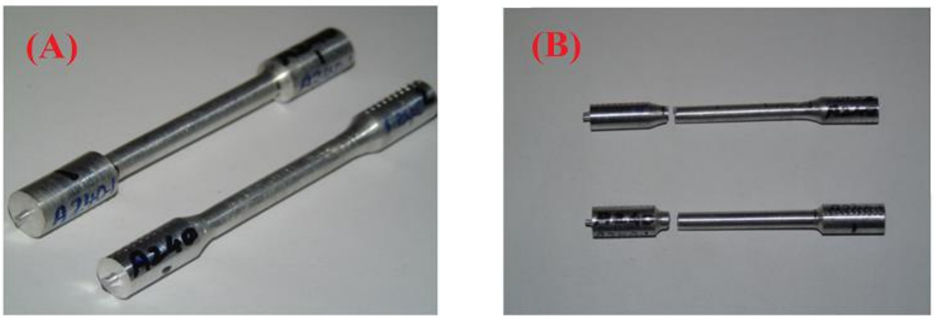


Fig 7.3: Fig (A) Tensile test specimen before tensile tests. Fig (B) Tensile test specimen after tensile test

III. Results of Tensile Test conducted on 2 Samples of Al 6013- 4.0 Mg

Table 7.3: The yield strength, Ultimate Tensile Strength and total elongation were calculated for different samples of Al 6013-4.0 Mg

S.No	**Composition**	**Sample No.**	**Yield Strength (MPa)**	**UTS (MPa)**	**Elongation (%)**	**Peak Load (kN)**
1	Al 6013 – 4.0 Mg	Sample 1	161.0	204	4.0	5.420
2	Al 6013 – 4.0 Mg	Sample 2	161.7	214	4.8	5.573

IV. Stress vs Strain curve for Al 6013 – 4.0 Mg for Sample 1 & 2

Figures 7.1 and 7.2 show the stress-strain curve for the Samples 1 & 2 of Al 6013-2.0 Mg which indicates the proportionality limit, strain ranges in which elastic and plastic behaviour are exhibited and important important mechanical properties such as yield and ultimate tensile strength. Yield strength was found by using 0.2% offset method.

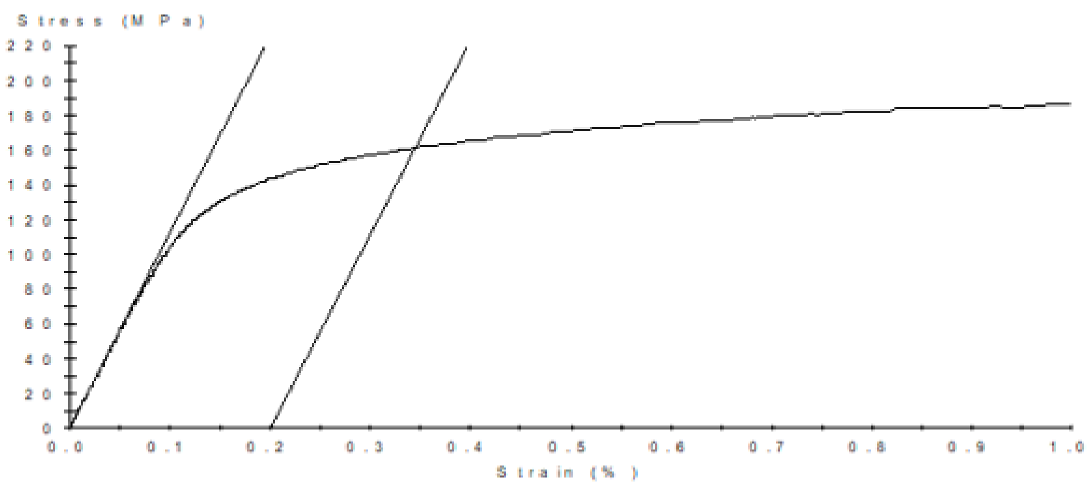


Figure 7.4 Al 6013 – 4.0 Mg- Sample 1

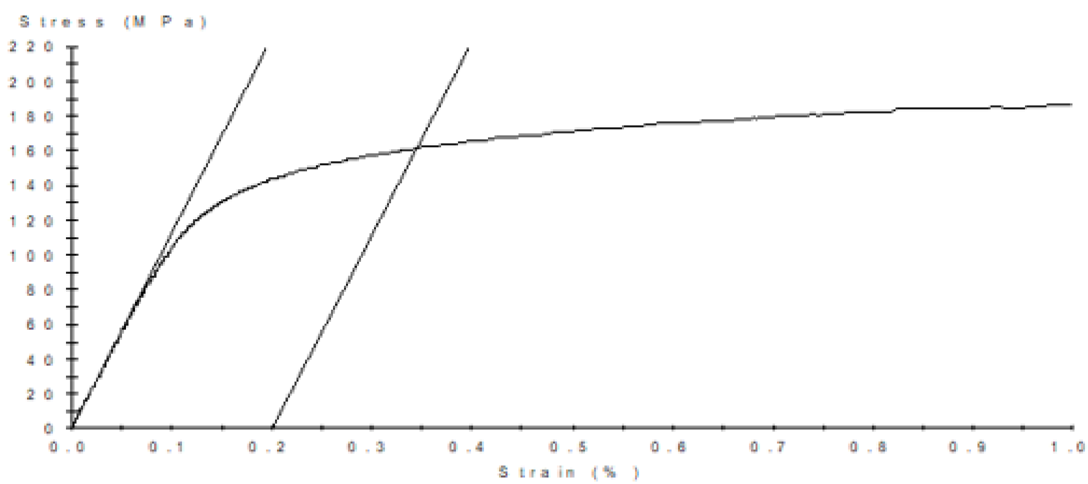


Figure 7.5 Al 6013 – 4.0 Mg- Sample 2

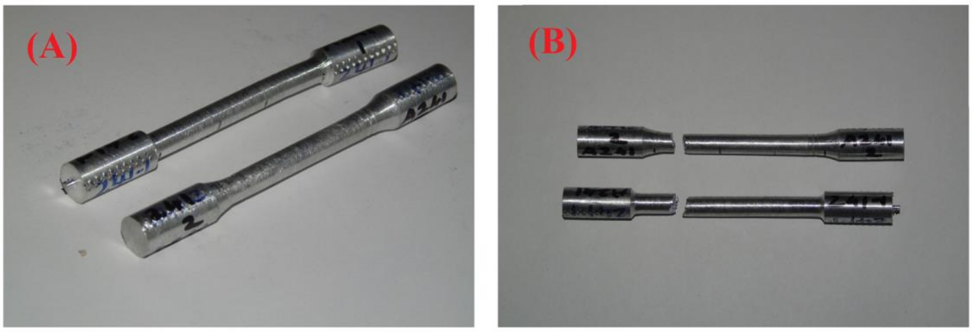


Fig 7.6: Fig (A) Tensile test specimen before tensile tests. Fig (B) Tensile test specimen after tensile test

V. Comparison Graphs

(i) Comparison of Yield Strength of Al 6061-O, Al 6061 – T4, Al 6013, Al 6013 –2.0 Mg and Al 6013 - 4.0 Mg

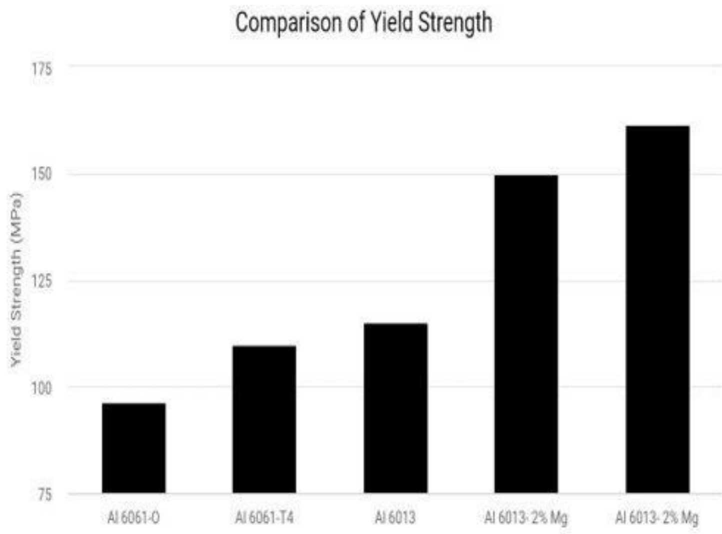


Figure 7.7 Comparison of Yield Strength of Al 6061-T0, Al 6061-T4, Al 6013-2.0Mg & Al 6013-4.0Mg

- When quantity of Mg present is increased from 1% to 2%, the Yield Strength improved by 30.43%.
- When quantity of Mg present is increased from 2% to 4%, the Yield Strength improved by 7.6%
- Al 6013 performed better as an alloy when compared to Al 6061-T0 and Al 6061-T4's strength
- Improvements in Mg to Al 6013 made the alloy superior to other alloys pertaining to the same series.
- Yield Strength results supports the usability of the new alloy for various applications.

(ii) Comparison of Ultimate Tensile Strength of Al 6061-O, Al 6061 – T4, Al 6013, Al 6013 –2.0 Mg and Al 6013 - 4.0 Mg

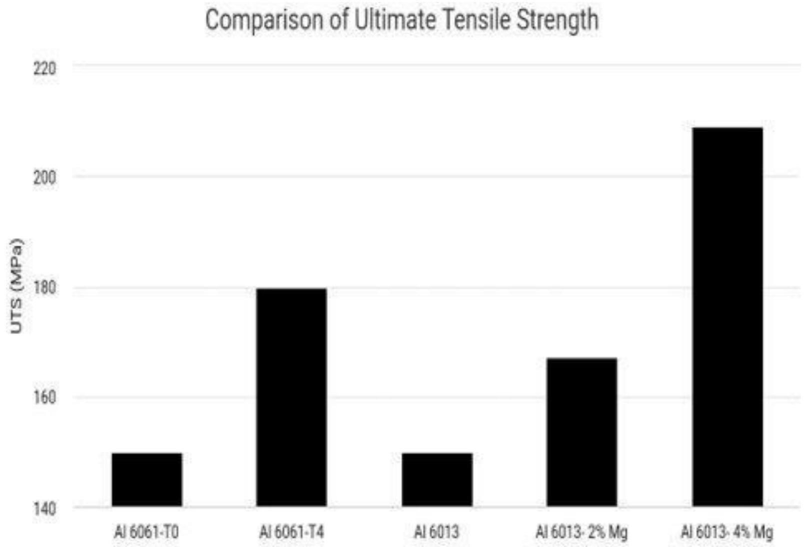


Fig 7.8 Comparison of Ultimate Tensile Strength of Al 6061-T0, Al 6061-T4, Al 6013 -2.0Mg & Al 6013 -4.0Mg

- When quantity of Mg present is increased from 1% to 2% the Ultimate Tensile Strengthwas enhanced by around 11.36%.
- When quantity of Mg present is increased from 2% to 4% the Ultimate Tensile Strengthwas enhanced by around 25%

(iii) Comparison of Peak Loads of Al 6013 – 2.0 Mg and Al 6013 - 4.0 Mg

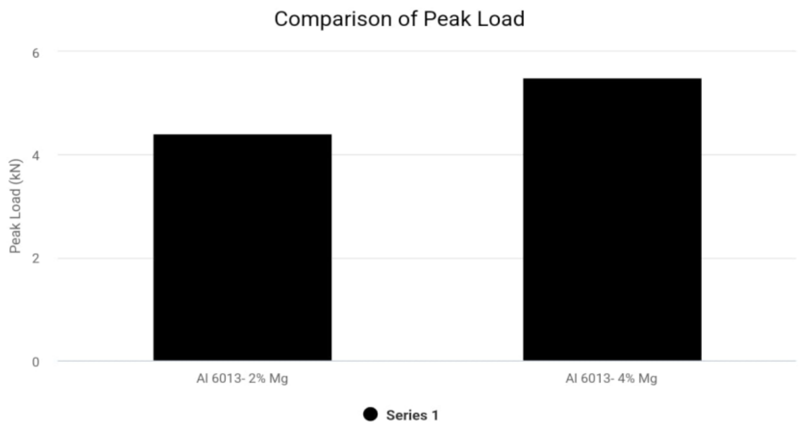


Figure 7.9 Comparison of Peak Load of Al 6013-2.0Mg & Al 6013 -4.0Mg

- When quantity of Mg present is increased from 2% to 4%, there was a 24.8% increase in the Peak Load that can be withstood.

7.4 BRINELL HARDNESS TEST RESULTS

I. Results of Brinell Hardness Test performed on Al 6013 – 2.0 Mg and Al 6013 – 4.0 Mg

Table 7.4 Brinell hardness number of Al-2.0Mg-1.2 Cu & Al-4.0Mg-1.2 Cu Alloys

S.No	Composition	Sample 1	Sample 2	Average HBW
1	Al 6013-2.0Mg	120.616	121.962	121.276
2	Al 6013-4.0Mg	124.13	124.527	124.328

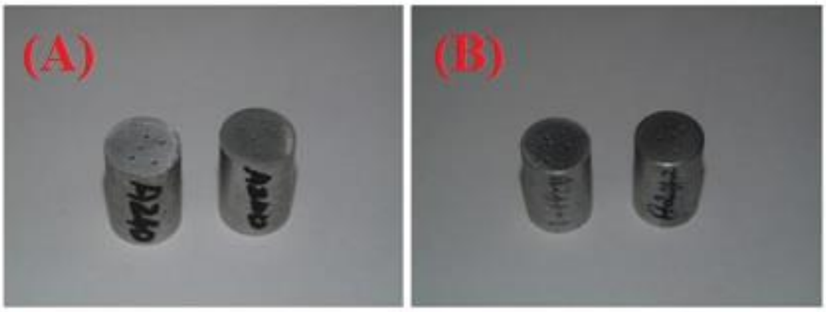


Figure 7.10: Hardness test specimen of Al 6013- 2 % Mg & Al 6013- 4 % Mg

As shown in Table 7.4 and Figure 7.10, 2 samples of both Al 6013 – 2.0 Mg and Al 6013 - 4.0 Mg were taken and checked for hardness and the average values of HBW were tabulated.

II. Comparison Graphs

This graph shows the comparison of Brinell Hardness Numbers of Al 6061-O, Al 6061– T4, Al 6013, Al 6013 – 2.0 Mg and Al 6013 - 4.0 Mg.

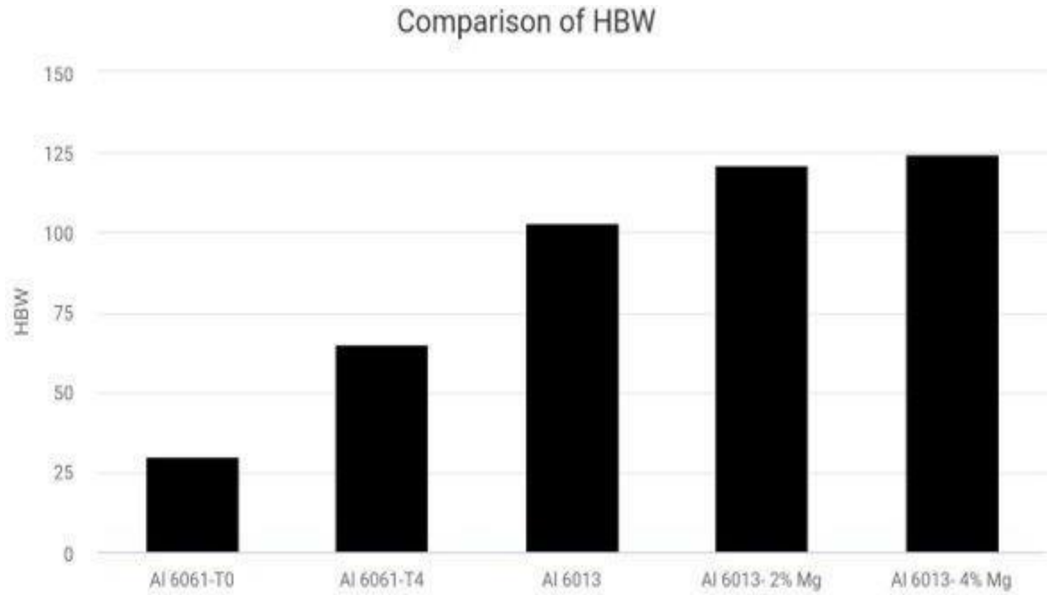


Figure 7.11 Comparison of Brinell hardness number of Al 6061-T0, Al 6061-T4, Al 6013 -2.0Mg & Al 6013 -4.0Mg

- The increment of Mg from 1% to 2% brought about increase in hardness by about 17.74%
- The increment of Mg from 2% to 4% brought about increase in hardness by almost 2.52%.

7.5 IZOD IMPACT TEST RESULTS

I. Results of Izod Impact Test performed on 3 samples of Al 6013 – 2.0 Mg and 3 samples of Al 6013 – 4.0 Mg

Table 7.5 Impact Strength of Al 6013-2.0 Mg & Al 6013-4.0 Mg-1.2 Alloys

Composition		Energy Observed (J)	Impact Strength (J/mm^2)	Avg. Impact Strength(J/mm^2)
Al 6013-2.0Mg	Sample 1	6	0.075	0.08
	Sample 2	7	0.0875	
	Sample 3	6	0.075	
Al 6013-4.0Mg	Sample 1	10	0.125	0.11
	Sample 2	8	0.1	
	Sample 3	8	0.1	

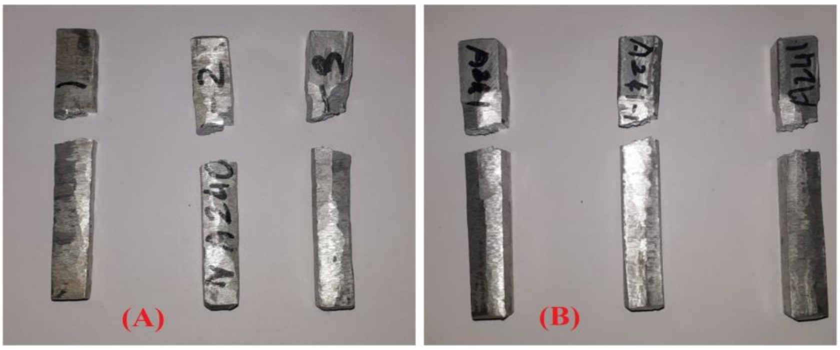


Fig 7.12 Figure (A) Al 6013 -2 % Mg sample specimen after testing, Figure (B) Al 6013 -4 % Mg sample specimen after testing

As shown in Figure 7.12 and Table 7.5, 3 samples each of Al 6013 – 2.0 Mg and Al 6013 - 4.0 Mg were taken and tested for impact toughness in an Izod Impact Testing Setup.

II. Comparison Graph

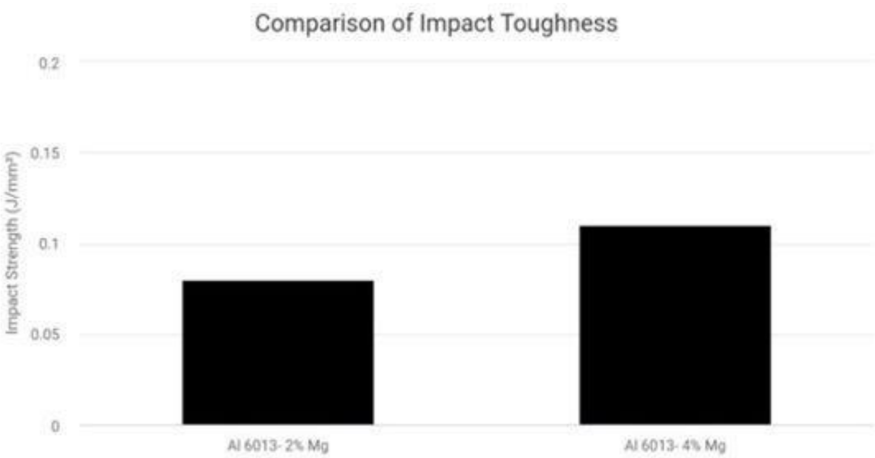
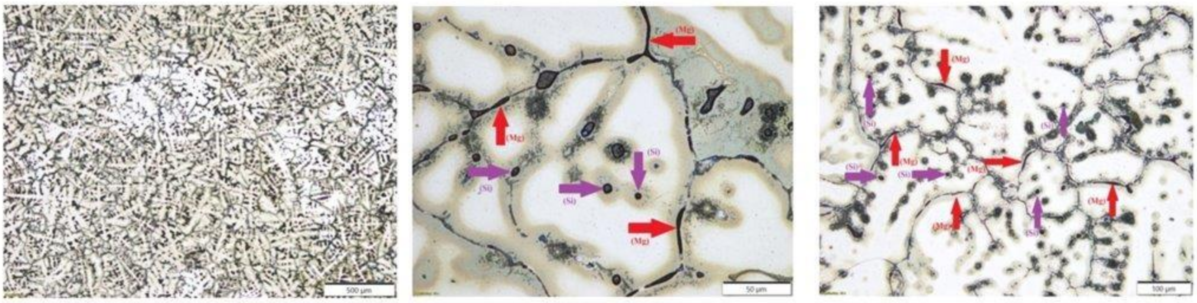


Fig 7.13 Comparison of Impact Toughness of Al 6013-2.0Mg & Al 6013-4.0Mg

- An increment of about 37.5% was observed in Impact Strength when Mg content was modified from 2% to 4%.

7.6 MICROSTRUCTURAL ANALYSIS

I. Micrograph showing the Grain Morphology of a Sample of Al 6013 – 2.0 Mg

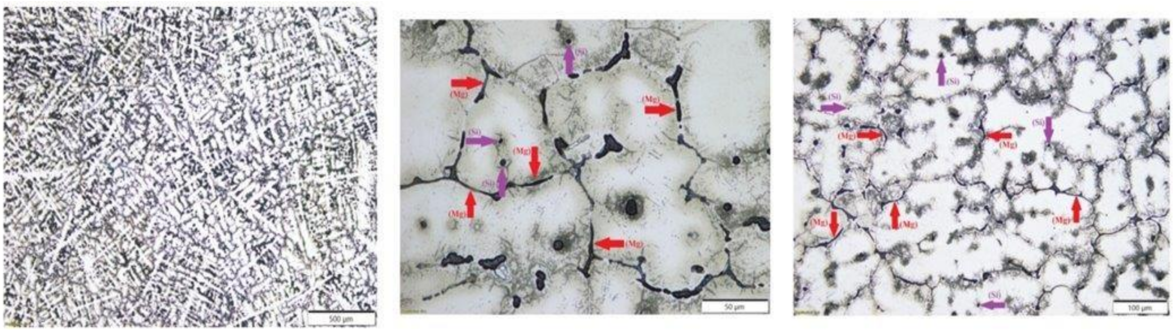


The red arrow denotes the magnesium grain & Purple arrow denotes the silicone grain present in the micrograph

Figure 7.14 Micrographs showing the grain morphology of Al 6013- 2.0Mg

- The microstructure of cast Al 6013-2.0% Mg alloy representing the grain morphology and metal distribution are shown in Figure 7.14.
- The micrographs clearly state minimal micro porosities in the casting. The distributions of alloying elements in the respective parent metal are uniform so the fusion between alloying elements and parent metal is good.
- The fine dispersion of Magnesium and Silicon through the cast is observed which reveals the homogeneity of the cast sample.

II. Micrograph showing the Grain Morphology of a Sample of Al 6013 – 4.0 Mg



The red arrow denotes the magnesium grain & Purple arrow denotes the silicone grain present in the micrograph

Figure 7.15 Micrographs showing the grain morphology of Al 6013- 4.0Mg

- The microstructure of cast Al 6013-4.0 Mg alloy representing the grain morphology and metal distribution are shown in Figure.
- The micrographs clearly state minimal micro porosities in the casting. The distributions of alloying elements in the respective parent metal are uniform so the fusion between alloying elements and parent metal is good.
- The fine dispersion of Magnesium and Silicon through the cast is observed which reveals the homogeneity of the cast sample.

7.7 SUMMARY

The results of Tensile Test, Brinell Hardness Test, Izod Impact Test and Microstructural Analysis were discussed and the sample specimens were also displayed. The comparative studies were represented in a bar graph.

CHAPTER 8
FUTURE ENHANCEMENTS

8.1 INTRODUCTION

This chapter provides insight on the work and further enhancements that can be implemented into the project in the future.

8.2 LIMITATIONS/CONSTRAINTS OF THE PROJECT

It was inferred from the experimental results of this project, that the addition of Mg to Al 6013 alloy caused the reduction in ductility/elongation of the material produced. It was also found from the literature review, that the heat treatment of the modified alloy brought about a nullifying effect on the beneficial strengthening of the material due to the increment in Mg content. Due to time and budgetary constraints, fatigue testing, creep testing, evaluation of strength at elevated temperatures, wear and corrosion resistance testing have been performed in the current study.

8.3 FUTURE ENHANCEMENTS

In order to have a deeper understanding on the micro-effects of Magnesium, the same set of procedures conducted in the current project will be carried out by adding Mg in steps of 0.5%, within the well defined α-Al phase (1-4%). In addition to this, literature review will be extended to the effects of Mg addition on the fatigue cycles, creep, wear and corrosion resistance and further conclusion will be derived.

After the collection of sufficient data, fatigue testing, creep testing, evaluation of strength at elevated temperatures, wear and corrosion resistance testing will be performed on the modified samples. Heat treatment of T6 and T8 and annealing will also be performed on one sample per specimen to record a conclusive effect of heat treatment on Mg addition.

All the above processes will also be repeated with Cu as the major macro-constituent that is modified in terms of % wt and the overall results from Mg and Cu addition on various mechanical and tribological properties will be further analyzed in order to evaluate the newly manufactured alloy's airworthiness.

8.4 SUMMARY

All the necessary works and enhancements and the future of this project which would lead to further beneficial studies have been dicussed in this chapter.

CONCLUSION

- The suitable range of Mg addition to Al 6XXX series was observed to be between 1.5-4% after which an undesirable phase transition was seen.

- From the microstructure of the prepared Al 6013-2.0 Mg & Al 6013-4.0 Mg, we can see the fusion of alloying element and Aluminum is good which reveals the homogeneity of the cast sample. The micrographs clearly state minimal microporosities in the casting.

- The results from the UTM revealed that the addition of Mg to Al 6013 alloy proved to be beneficial in the enhancement of yield strength, tensile strength and peak load.

- Mg augmentation displayed excellent hardness property when placed in juxtaposition with conventional Al 6XXX alloys with a decrease in ductility.

- Enrichment of Mg also presented betterment in Impact Toughness in the manufactured and modified cast Al 6013 alloy.

- In the range of Mg improvements considered, 4% Mg seems to be the most desirable in terms of strength, hardness and toughness.

- Further study of Al 6XXX alloys with respect to Cu and Mg content with extensive mechanical and tribological analysis was planned for the continuation of the project in the future.

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