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"Casting and rolling aluminium alloy"

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2023

بِسمِ اللّهِ الرَّحْمَنِ الرَّحِيمِ

((وَقُلِ اعْمَلُوا فَسَيَرَى اللّهُ عَمَلَكُمْ

وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ الَى

عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا

كُنتُمْ تَعْمَلُونَ))

صَدَقَ اللهُ العَلِيُّ العَظِيم

التوبة اية 105

الإهداء

الى بلدي العزيز موطن الانبياء والاوصياء وارض الخير والعطاء

الى الشهداء الابرار .

الى قدوتي الاولى، الى من رفعت راسي عاليا افتخارا به (ابي العزيز)

اطال الله في عمره .

الى نبع الحنان السامي ، الى من علمتني معنى الحياة (امي الحبيبة)

حفظها الله لنا .

الى زملائي ، اقدم لكم جميعا هذا المشروع المتواضع واسأل الله ان يمن

علينا بالنجاح الدائم والتوفيق.

مع التقدير.......

الشكر والتقدير ..

أتقدم بالشكر والتقدير الى استاذي الفاضل
الأستاذ مقداد الموسوي لكل ما قدمه لي من دعم وتوجيه وارشاد لأضهار
هذا العمل بهذه الصوره
فله مني اسمى عبارات التقدير والثناء

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CHAPTER ONE : INTRODUCTION

Introduction

1.1 General Review

Within the last few decades, there has been a tremendous increase in demand for lightweight materials, such as aluminum (Al), magnesium (Mg), and titanium (Ti), in the automotive and aerospace industries[1]. In recent years aluminium alloys are widely used in automotive industries. This is particularly due to the real need to weight saving for more reduction of fuel consumption. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. Surfaces of aluminium alloys have a brilliant luster in dry environment due to the formation of a shielding layer of aluminum oxide [1,2].

1.2 Properties of Aluminum alloys.

A wide range of physical and mechanical properties can be obtained from very pure aluminum. The different properties are:

1) Aluminum has a density of about 2.7g/cc which is one third (approximately) the value of steel.

2) Unlike steel, aluminum prevents progressive oxidation by formation of a protective oxide layer on its surface on exposure to air.

3) Aluminum alloys exhibit excellent electrical and thermal conductivities. The thermal conductivity of aluminum is twice that of copper (for the same weight of both materials used)[3].

1.3 Aluminum-Silicon alloy

Aluminum-Silicon alloys are of greater importance to engineering industries as they exhibit high strength to weight ratio, high wear resistance, low density, low coefficient of thermal expansion etc. Silicon imparts high fluidity and low shrinkage, which result in good castability and weldability.

Al-Si alloys are designated 4xxx alloys according to the Aluminium Association Wrought Alloy Designation System. The major features of the 4xxx series are:

a. Heat treatable

b. Good flow characteristics, medium strength

c. Easily joined, especially by brazing and soldering Al-Si is an important alloy for many commercial automotive applications (pistons, cylinder liners, etc.) duo to its unique properties. Al-Si casting alloy are the most versatile of all common foundry cast alloys in the production of pistons for automotive engineering[4] .

1.4. Objective of The Present Study

The present study aimed for contributing to a better understanding of the relationship between manufacturing processes, microstructure, and mechanical properties of Al-Si casting alloy, through the following :

- Preparation of Al-Si alloys of hyper eutectic compositions.
- Study of their microstructure and their mechanical properties.
- Manufacturing processes by rolling .
- Evaluate their wear behavior .

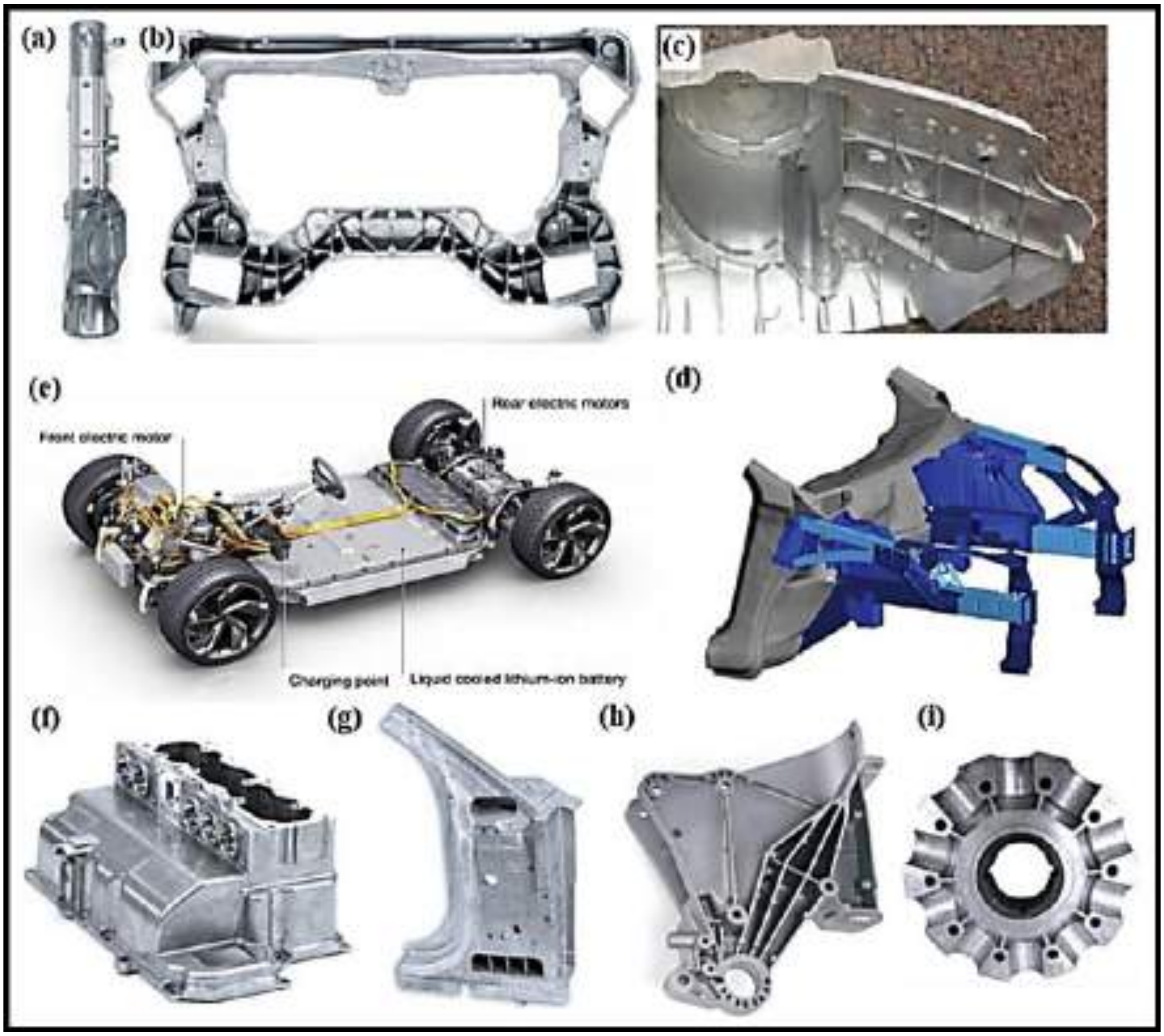

Figure 2. Automotive applications for Al-Si alloys, such as (a) steering column, (b) engine cradle [5], (c) shock tower [2], (d) front section [52], (e) Li-ion battery compartment for Audi e-tron [45], (f) upper safety housing for high-voltage heat plug connectors, (g) A-pillar, (h) truck cab tilting joint, and (i) ventilator hub [6].

CHAPTER TWO : THEORETICAL PART

Theoretical part

2.1 Introduction

Aluminum alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. In this chapter, we will discuss aluminum alloys, Classification, aluminum silicon, Phase Diagram, microstructure and rolling of AL alloys .

2.2 Classification of Aluminum Alloys

Aluminum alloys are usually classified into two main groups: casting compositions and formed compositions, each one of these groups are divided into two groups: heat treatable and non-heat treatable alloys[7].

2.2.1 Cast Aluminum Alloys

Cast aluminum alloys have relatively low melting temperatures when compared to steel and cast iron, they have a negligible solubility of gases except hydrogen, good fluidity and good surface finish. However, these alloys suffer from higher shrinkage (up to 7%) which occurs during cooling or solidification. Higher mechanical properties in these alloys can be achieved by controlling the level of impurities, grain size, and solidification parameters such as the cooling rate **[7] .** A system of four-digit numerical designation is used to identify aluminum and aluminum alloys in the form of castings and foundry ingots. The first digit indicates the alloy group according to the major alloying element as shown in table (1.1).**[8]** . The second two digits identify aluminum alloy or indicate the alloy purity the last digit indicates the product form: casting (designated by “0”) or ingot (designated by “1” or “2”depending on chemical composition limits**[9].**

Aluminum Alloy Groups Table (1.1): [8]

Alloy Series	Principal Alloying Element
1xxx	99.000% minimum Aluminum
2xxx	Copper (4%...4.6%)
3xxx	Silicon (5%...17%) with added copper and/or magnesium
4xxx	Silicon (5%...12%)
5xxx	Magnesium (4%...10%)
6xxx	Unused Series
7xxx	Zinc (6.2%...7.5%)
8xxx	Tin

2.2.2. Wrought Aluminum Alloys

Wrought aluminum alloys mean that the alloys have undergone certain working processes. Wrought alloys have been produced by thermo mechanically processing cast ingot into mill products such as billet, bar, plate sheet extrusions, rods and wires**[9].**

Table (1.2) shows the main classes of wrought aluminum alloys**[7]** . Like cast alloys, wrought alloys are also designated by a four-digit system. Both wrought and cast aluminum alloys are divided according to the specification of the alloying elements involved, into alloys which can be heat treated (in order to improve the mechanical properties) and alloys which cannot be heat treated. Heat-treatable alloys are those strengthened primarily by solution heat treatment or solution heat treatment and artificially aging (precipitation hardening) while Non-heat-treatable alloys are those which depend primarily on cold work for strengthening[**5,6]**

Table (1.2): Wrought Aluminum Alloy Groups **[8]**

Alloy Series	**Principal Alloying Element**
1xxx	99.000% Minimum Aluminum
2xxx	Copper (1.9%... 6.8%)
3xxx	Manganese (0.3%... 1.5%)
4xxx	Silicon (3.6%... 13.5%)
5xxx	Magnesium (0.5%... 5.5%)
6xxx	Magnesium and Silicon (Mg 0.4%... 1.5%, Si 0.2%... 1.7%)
7xxx	Zinc (1%... 8.2%)

2.3 Aluminum Silicone alloys

Al Si alloys are distinguished according to their major alloying elements. The 4xxx group contains silicon as the main alloying element for ease of casting. Silicon is good in metallic alloys. This is because it increases the fluidity of the melt, reduces the melting temperature, decreases the shrinkage during solidification and is very inexpensive as a raw material. Silicon also has a low density (2.34 g cm^{-3}), which may be an advantage in reducing the total weight of the cast component. Silicon has a very low solubility in aluminium; it therefore precipitates as virtually pure silicon, which is hard and hence improves the abrasion. Aluminium-silicon alloys form a eutectic at 12.6 wt% silicon, the eutectic temperature being 577°C. This denotes a typical composition for a casting alloy because it has the lowest possible melting temperature[10] .

2.3.1 **Phase Diagram**

Aluminium-Silicon system is a simple binary eutectic with limited solubility of aluminium in silicon and limited solubility of silicon in aluminium. There is only one invariant reaction in this diagram, namely $L \rightarrow \alpha + \beta$ (eutectic) In above equation, L is the liquid phase, α is predominantly aluminium, and β is predominantly silicon. It is now widely accepted that the eutectic reaction takes place at 577°C and at a silicon level of 12.6%.

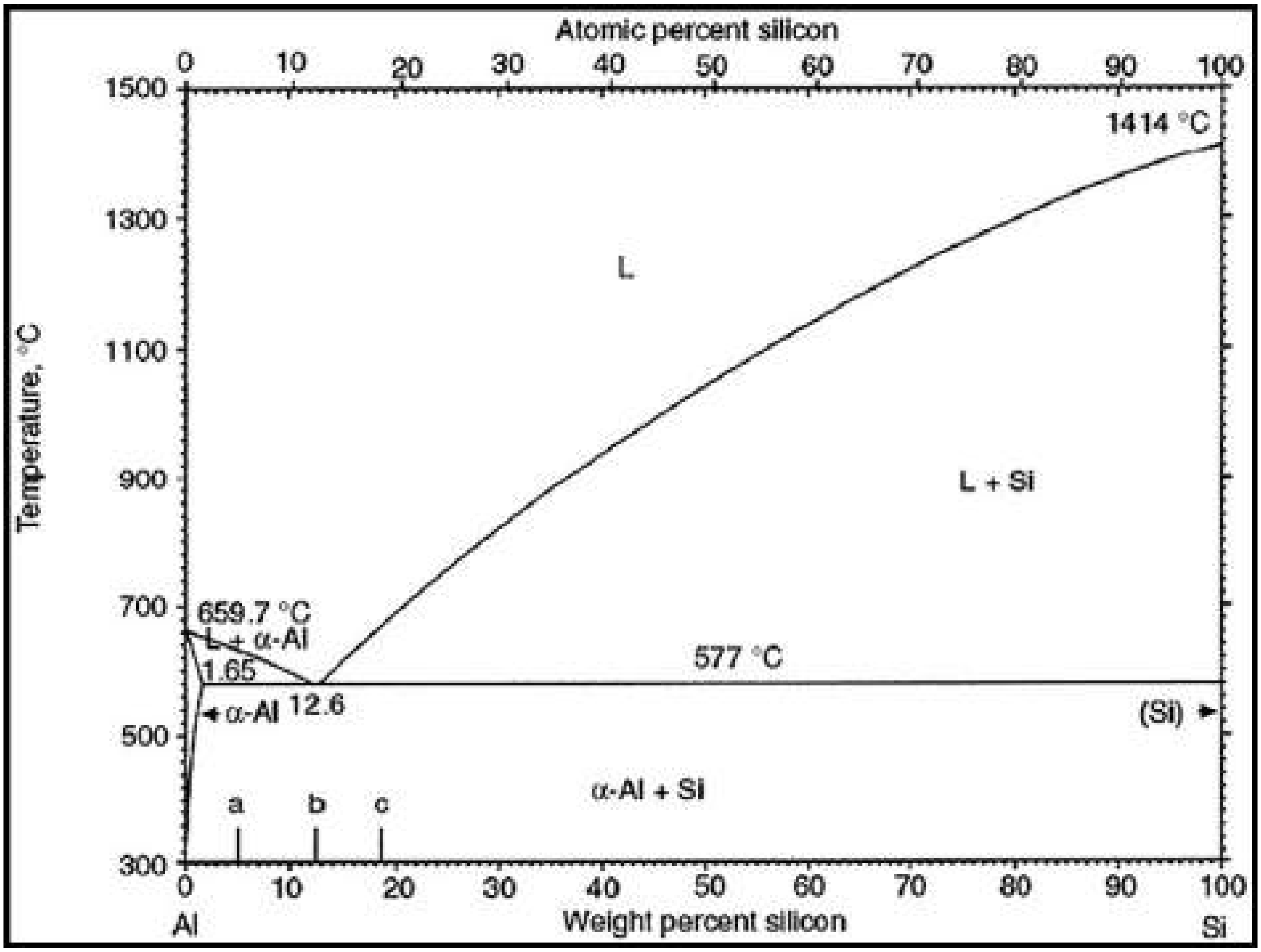

Fig. 2.1 Al-Si phase diagram[11]

Aluminum-Silicon (Al-Si) casting alloys are the most useful of all common foundry cast alloys in the fabrication of pistons for automotive engines. Depending on the Si concentration in weight percentage, the Al-Si alloy systems are divided into three major categories[7]:

i. Hypoeutectic (<12 wt % Si)

ii. Eutectic (12-13 wt % Si)

iii. Hypereutectic (14-25 wt % Si).

2.3.2 Microstructure

Binary Al-Si alloys, in the unmodified state, near to the eutectic composition exhibit acicular or lamellar eutectic silicon which is in the form of large plates with sharp sides and edges. Al-Si alloys containing more than about 12% Si exhibit a hypereutectic microstructure normally containing primary silicon phase in a eutectic matrix. Cast eutectic alloys with coarse acicular silicon show low strength and ductility because of the coarse plate-like nature of the Si phase that leads to premature crack initiation and fracture in tension. Similarly, the primary silicon in normal hypereutectic alloys is usually very coarse and imparts poor properties to these alloys[12]. Therefore, alloys with a predominantly eutectic structure must be modified to ensure adequate mechanical strength and ductility**.** According to Figure 2.4, upon solidification of aluminum–silicon alloys of composition generally less than 12% silicon (hypoeutectic) the first phase to form is aluminum. Considering an alloy containing 7% silicon on cooling form the liquid phase (Ts) the aluminum forms as small dendrites when the solidification temperature (Tl) is reached. The temperature difference Ts-Tl is the melt "superheat" or under cooling, which represents the driving force for solidification. Solidification does not occur at a single temperature but rather over a temperature range and will be completed at the eutectic temperature (Te)[13].

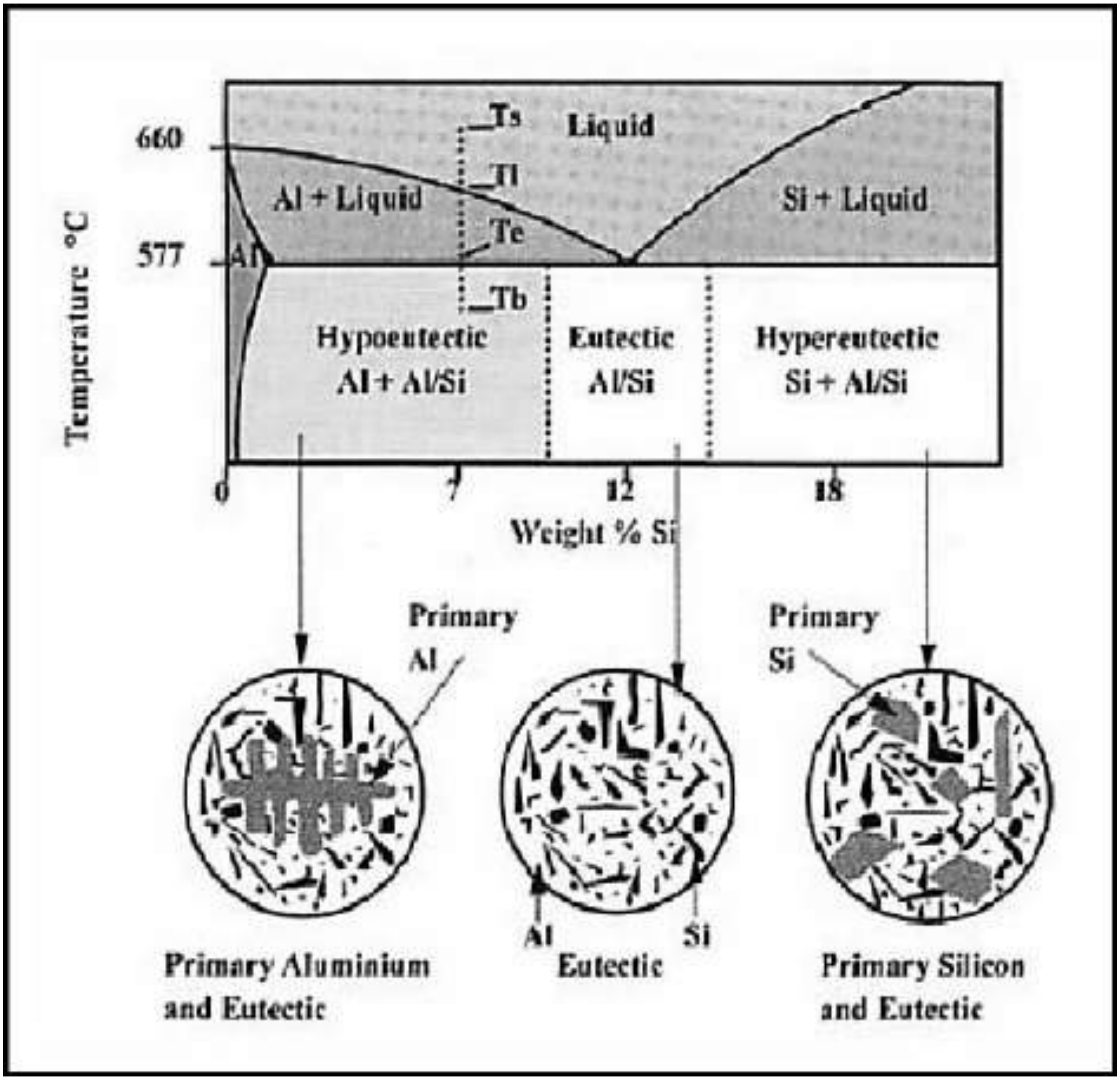

Figure 2.4: Aluminum – silicon phase diagram and microstructures [13].

2.4 Rolling of aluminium

Rolling of aluminum alloy is a process of reducing the thickness of flat aluminum sheets or plates by passing them through a series of rollers. The rollers exert compressive forces on the aluminum, causing it to become thinner and longer. The rolling process can be either cold or hot, depending on the desired outcome and the type of alloy being used. Hot rolling is usually used to produce thicker plates, while cold rolling is used for thinner sheets. Through this process, aluminum alloys can be produced in variety of forms, including sheets, foils, plates, strips, and bars with different dimensions and surface finishes.[14]

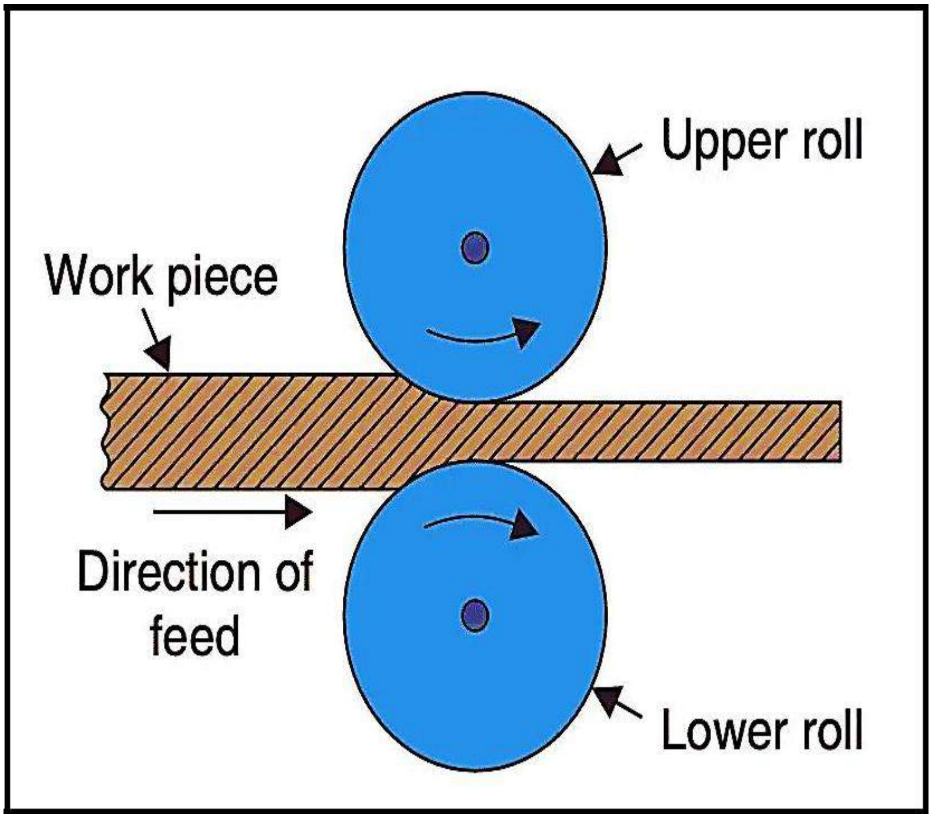

Figure 2.5: Rolling process

2.5 Effects of rolling parameter on the properties of Al-Si

The rolling parameters, including temperature, rolling speed, and reduction ratio, significantly affect the microstructure and properties of Al-Si alloys during the rolling process.

A)Temperature: The rolling temperature affects the recrystallization behavior, grain size, and texture of the aluminum alloy. At high temperatures, the crystals tend to recrystallize, causing the grain size to become coarser. On the other hand, rolling at lower temperatures can refine the grain size and potentially improve the strength of the material.

B)**Rolling Speed**: The speed of the rollers during the rolling process can affect the deformation behavior and grain size of the aluminum alloy. As the rolling speed increases, the deformation rate also increases, which can lead to an increase in micro strain and a decrease in the grain size. However, excessively high rolling speeds can cause the material to crack or break.

C)Reduction Ratio: The reduction ratio is the amount of reduction in thickness of the aluminum alloy during a single pass of rolling. A higher reduction ratio can lead to higher deformation and therefore greater grain refinement. However, excessively high reductions can lead to defects in the material. A lower reduction ratio can induce a more uniform deformation and prevent the formation of defects. The combination of these rolling parameters can be optimized to achieve the desired microstructure and mechanical properties for a particular application. For example, higher rolling temperatures and speeds may be required to produce thicker sheets or plates, while lower temperatures and speeds may be required for thin foils or sheets. A reduction ratio that balances grain refinement with defect formation can also be determined based on the desired final properties of the material.]15]

CHAPTER THREE: EXPERIMENTAL PART

Experimental Part

3.1. Introduction

This chapter gives a clear feature on the experimental work, and describes all the conditions under which the tests were carried out..

3.2. Program of the Present Study

Figure (3.1) shows the summary of the overall program used in the present work.

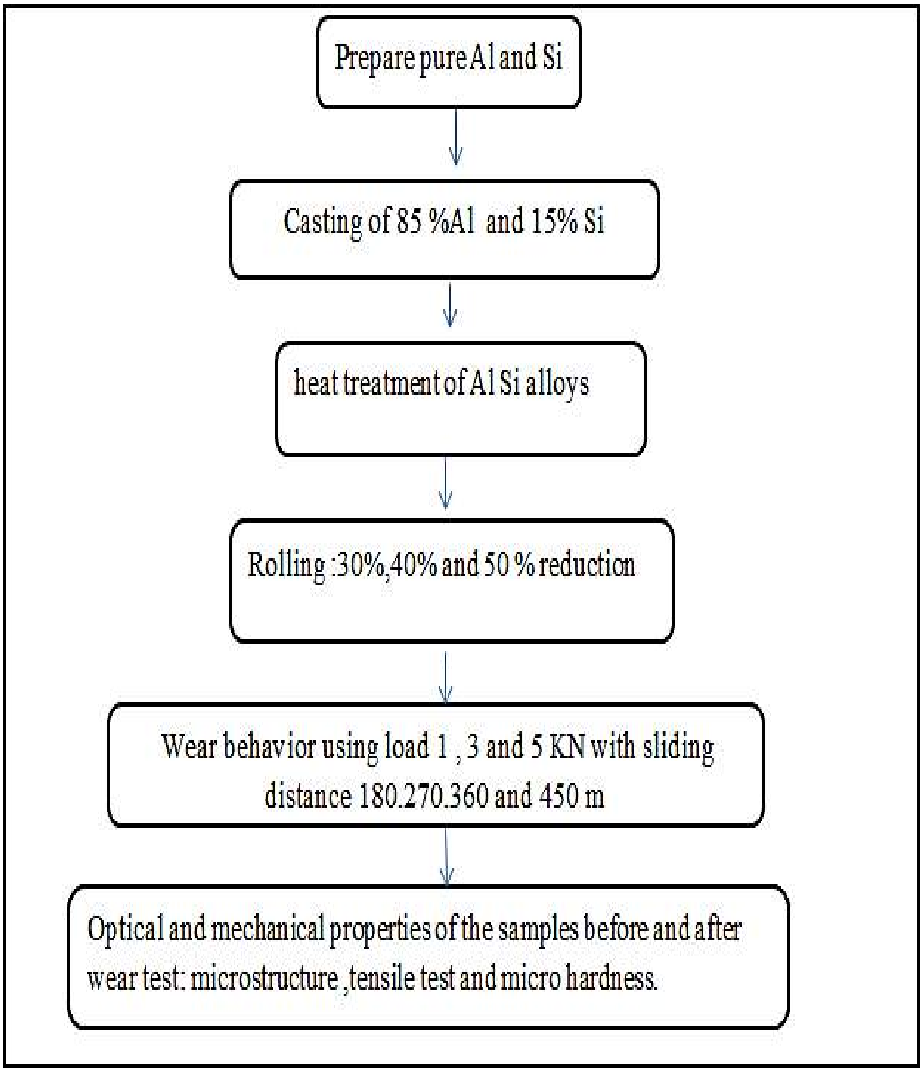

Figure 3.1 :Program of the Present Study

3.3 Preparation of the alloys

Al–Si alloys with varying Si percentage were prepared by melting commercially pure aluminum (99.7%) and commercially pure silicon (99.5%) in a graphite crucible in a high frequency induction furnace and the melt was held at 720 °C in order to attain homogeneous composition .The melt was stirred for 30s and held for 5 min and then poured into metal mold . The cast samples were of 300 mm length, 30 mm wide and 10 mm height.

Figure 3.2 Induction furnace ,metal mold and casting sample .

3.4 Rolling mill

The basic rolling mill consists of two opposing rolls, Rolling is the process of reducing the thickness or changing the cross section of a long work piece by compressive forces applied through a set of rolls, as shown in figure(),the

reduction ratio per pass was calculated by the equation

where h_0 and h_k are the plate’s thickness before and after each specific pass, respectively.

Figure 3.3 Rolling operations stages

3.5 Tensile test

Tensile properties of the alloys were analysed by carrying out test on Computer Controlled Electro Mechanical Universal Testing Machine (200KN). Tensile tests were carried out with a crosshead speed of 1mm/min. During the tests, the load elongation data is captured by induced software, whose data is used for further analysis. The figure 3.4 shows universial machine .

Figure 3.4:Computer Controlled Electro Mechanical Universal Testing Machine (200KN).

3.6 Light Optical Microscope (LOM)

Involved identification and measurement of the phases, shape and grain size are some characteristics of grain boundaries could be evaluated by optical microscope, it was professional metallurgical microscope with polarizing dark field reflected light, as shown in Figure (3.5).

Figure 3.5: Optical Microscope**.**

3.7. Micro-Hardness Measurements

Appropriate grinding and polishing were carried out before subjecting the specimens to the test. The test was carried out to the before and after rolling samples. The test was conducted at micro Vickers hardness device type (Digital Micro Vickers Hardness Tester TH 717) using a load of 100g for 10 sec with a square base diamond pyramid. The hardness was recorded as an average of three readings for each specimen. The Vickers hardness was determined by the following equation:

HV = 1.854 (F/D^2) Where: HV: Vickers micro hardness (kg/mm^2).

F: Applied load (kg).

D: The average diameter of the indentation (mm^2)

Figure 3.6: Vickers (HV1000) Micro-hardness Device.

3.8 Wear Test .

Specific wear rate was measured by using the pin on disc devise type (Pin on disk tribo meter model MT/60/H) shown in Figure 3.7 .The specific wear rates of the materials were obtained by W where W denotes specific wear rates in mm^3 /N, Δw is the weight loss measured in grams, ρ is the density of the worn material in g/mm^3, L is the sliding distance in meters and F is the load in N.

Figure 3.7:Pin on disk tribo meter

CHAPTER FOUR:

RESULT AND DISCUSSIONS

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the obtained results from this work and their discussion, which includes compositional analysis as well tensile test, macro hardness test, wear test on Al-Si alloys before and after rolling process were carried out.

4. **2 Reduction ratio**

The average reduction ratio per pass ,total reduction ratio of the sample and final thickness of samples are listed in below tables . Multi-pass rolling processes allow for precise control over the shape and dimensions of the rolled material. By applying multiple passes with controlled reductions in thickness, it can enhance the mechanical properties of the rolled material , surface roughness and reducing residual stresses by carefully controlling the deformation, temperature, and strain distribution during each pass, desired mechanical properties such as tensile strength, toughness, and ductility can be achieved.

4.3 Microstructure

Specimens, with (20*20 mm), were cut from each samples. These specimens were flattened using SiC grinding papers having different roughness (180, 220, 320, 400, 600, 800, 1000, 1200 grit size). The water was used during grinding operation as a coolant in order to avoid temperature raising as a result of friction between the sample and the grinding papers. Then, the specimens were polished using diamond paste to produce flat, scratch free, mirror like surface. Grinding and polishing operations were done using polishing machine model (MP-2B grinder polisher).

Table 4.1 :Multi-pass rolling to 30% reduction ratio.

Pass number	Thickness average (mm)	Final thickness (mm)	Total reduction ratio (%)
1	7.045	6.905	30
2	6.905	6.755	
3	6.755	6.56	
4	6.56	6.385	
5	6.385	6.155	
6	6.155	5.98	
7	5.98	5.82	
8	5.82	5.675	
9	5.675	5.442	
10	5.442	5.126	
11	5.126	5.05	
12	5.05	4.897	

Table 4.2 : Multi-pass rolling to 40% reduction ratio

Pass number	**Thickness average (mm)**	**Final thickness (mm)**	**Total Reduction ratio (%)**
1	7.045	6.905	40
2	6.905	6.755	
3	6.755	6.56	
4	6.56	6.385	
5	6.385	6.155	
6	6.155	5.98	
7	5.98	5.82	
8	5.82	5.675	
9	5.675	5.442	
10	5.442	5.126	
11	5.126	5.05	
12	5.05	4.897	
13	4.897	4.81	
14	4.81	4.716	
15	4.716	4.643	
16	4.643	4.563	
17	4.563	4.476	
18	4.476	4.211	

Table 4.3: Multi-pass rolling to 50% reduction ratio

Pass number	**Thickness average (mm)**	**Final thickness (mm)**	**Total Reduction ratio (%)**
1	7.045	6.905	50
2	6.905	6.755	
3	6.755	6.56	
4	6.56	6.385	
5	6.385	6.155	
6	6.155	5.98	
7	5.98	5.82	
8	5.82	5.675	
9	5.675	5.442	
10	5.442	5.126	
11	5.126	5.05	
12	5.05	4.897	
13	4.897	4.81	
14	4.81	4.716	
15	4.716	4.643	
16	4.643	4.563	
17	4.563	4.476	
18	4.476	4.211	
18	4.221	3.990	
19	3.990	3.751	
20	3.751	3.551	

The specimens were etched by (0.5% HF, 99.5% Distilled $H2O$) for (15 second) at room temperature, then the specimens were washed with distilled water, and dried by electric dryer. An optical microscope with suitable magnification was used to capture the microstructure of each samples.

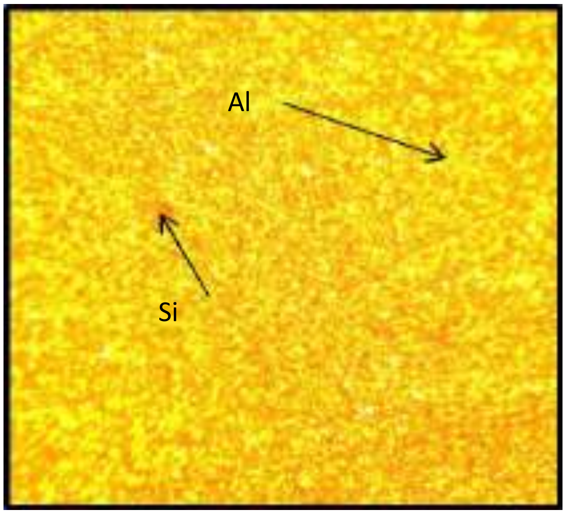

Fig 4.1 Microstructure of Al- Si sample 200X

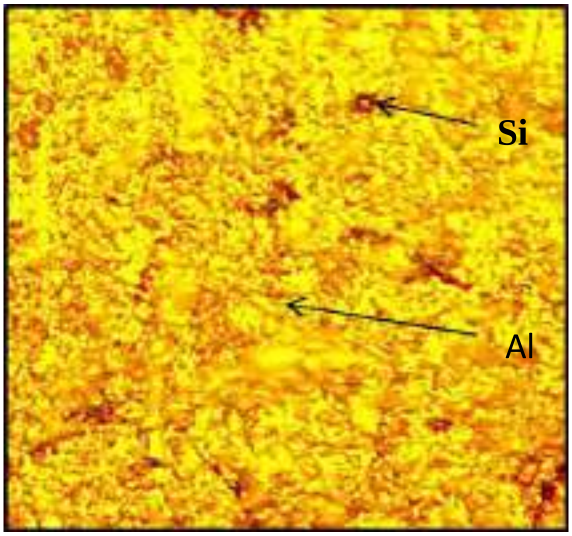

Fig 4.2 Microstructure of Al- Si sampl 600 X

4.4 Mechincal proprties

4.4.1 Tensile Test

From the load and elongation values, obtained from the universal testing machine, corresponding engineering stress and engineering strain were calculated and plotted to get stress vs. strain curves for different samples of Al casting and 50% reduction of Al Si casting :

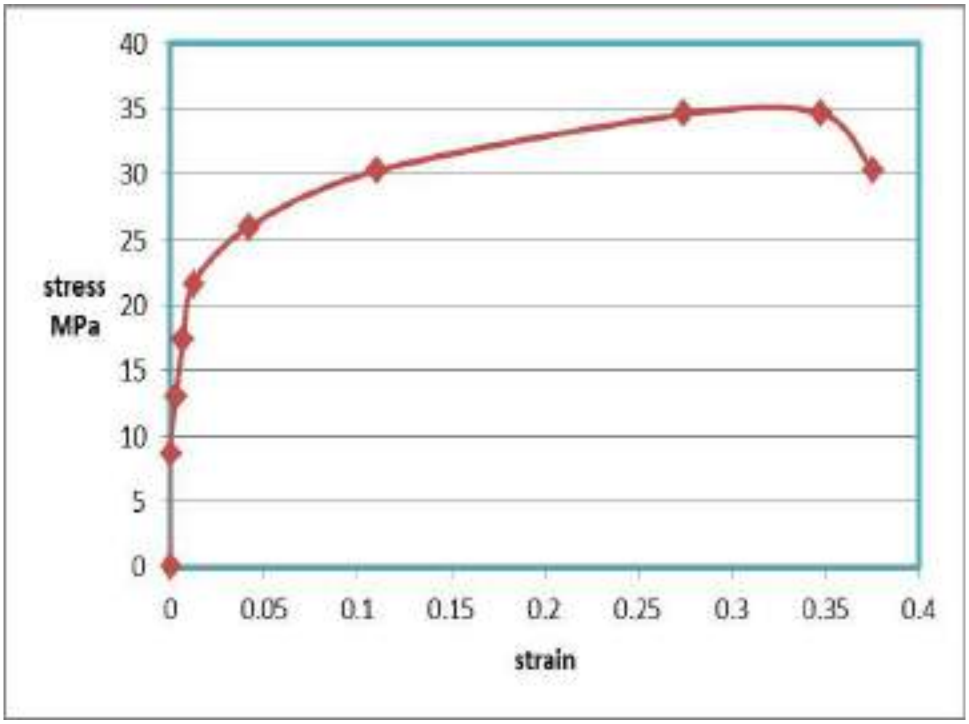

Figure 4.3 :Engineering stress – strain curve for Al casting samples

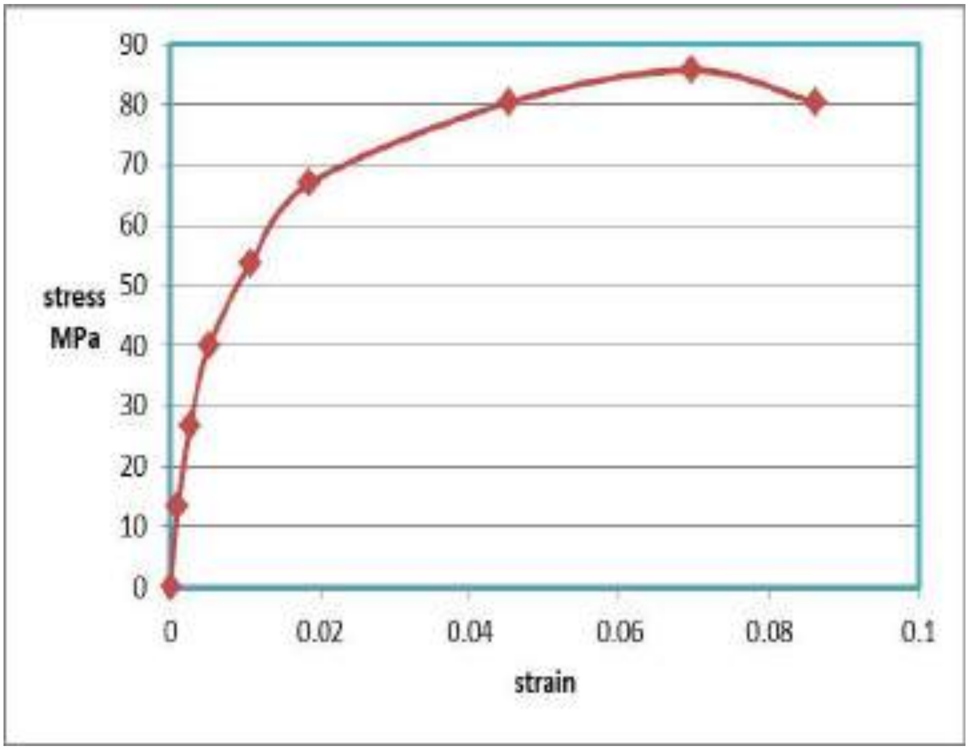

Figure 4.4: Engineering stress – strain curve for rolling Al Si samples

From Fig. 4.3 to Fig. 4.4, it can be observed that the curves are continuous when transition from elastic to plastic region takes place. Therefore, the yield strengths of the alloys are computed by 0.2% offset method, according to ASTM standard E8M[17] . it is observed that ultimate tensile strength and yield strength increases with rolling reduction of the sample .The reduction in cross-sectional area leads to an increase in dislocation density, which hinders the movement of dislocations and strengthens the material.; while it is reverse for the total elongation. This may be due increases the hardness of rolling Al-Si alloy.

The following table 4.4 shows the values of mechanical properties for Al Si, and rolling Al Si casting .

Table 4.4: mechanical properties for Al Si, and rolling Al Si casting .

	Ultimate tensile strength (MPa)	Yield stress (MPa)	Elongation (%)
Al Si	34.65	22.24	37.56
Rolling Al Si alloys	85.71	62.35	8.63

4.4.2 Micro hardness

The results of Vickers hardness test are shown in figure (), it is concluded that hardness (HV) is increased with increased rolling reduction ,where the reduction in grain size that occurs during rolling, along with the strain hardening effect, leads to a higher degree of lattice distortion within the metal. These changes contribute to an increase in the hardness of the material, making it more resistant to penetration

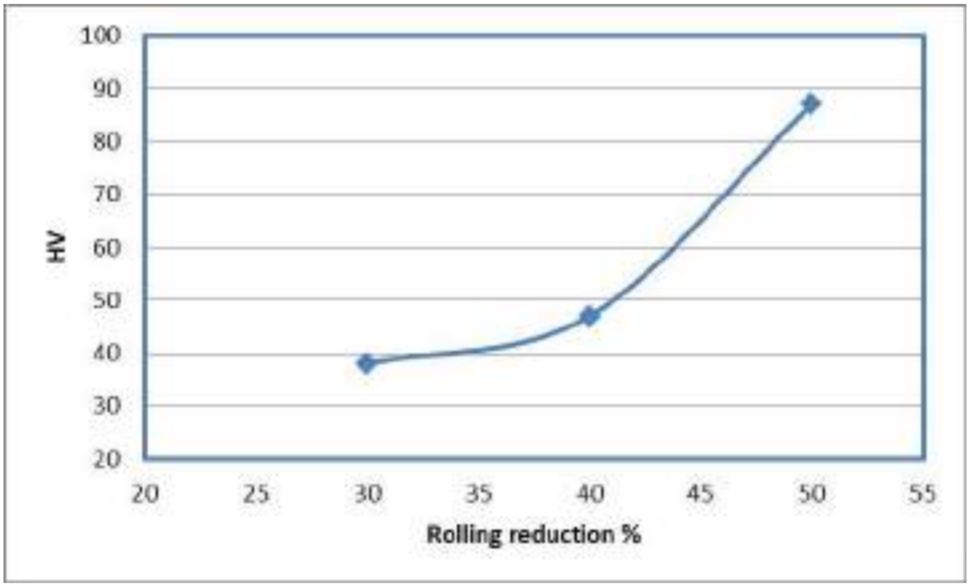

Figure 4.5: Rolling reduction% – micro hardness for rolling Al Si samples

4.5 Wear test

The results are obtained from the series of tests which is done by two parameters sliding distance(m), and load(KN) . The results of wear tests on all samples with varying loads (1, 3, 5 N) and sliding distance are illustrated in Figure 4.6, Figure 4.7 and Figure 4.8. It is noticed that the wear rate decreases when the percentage of rolling reduction increases due to increase the hardness of sample . With the increase in sliding speed, the interface temperature of the sample increases making it more soft and thus increases the wear rate.

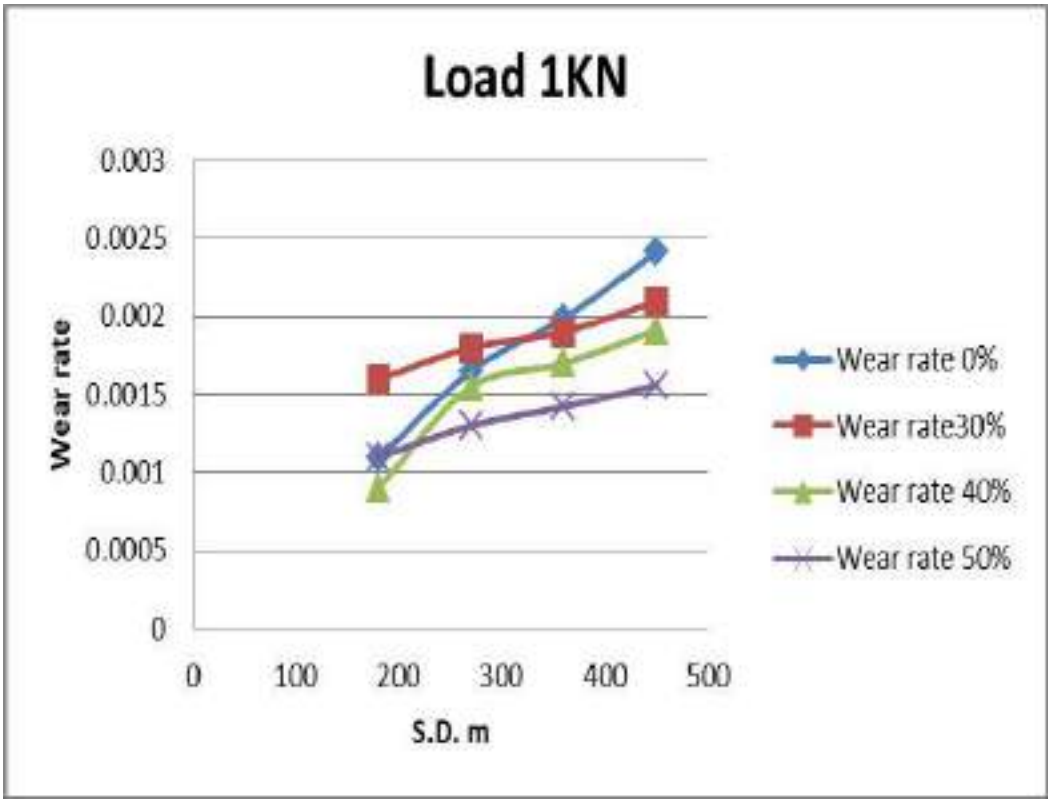

Figure 4.6 :Wear rate of Variation rolling reduction of Al-Si alloys with sliding distance.

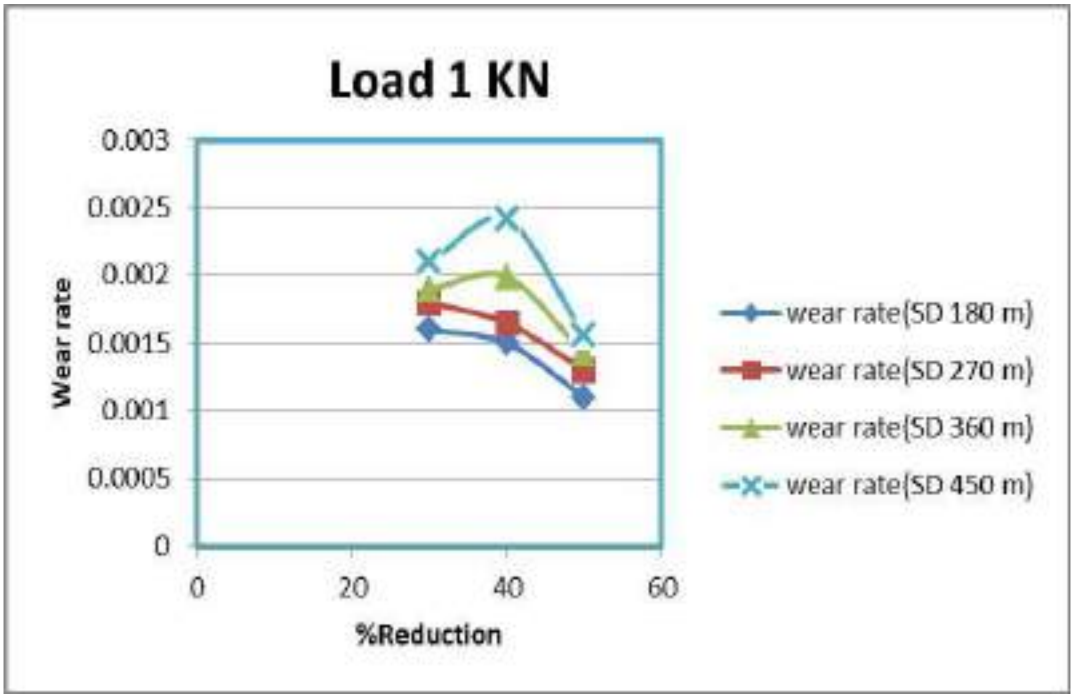

Figure 4.7 :Wear rate –rolling reduction of variation sliding distance of Al-Si alloys

Figure 4.8 :Wear rate- load of vartion rolling reduction of Al-Si alloys

It is noticed that the wear rate decreases when the percentage of rolling reduction increases due to increase the hardness of sample . With the increase in sliding speed, the interface temperature of the sample increases making it more soft and thus increases the wear rate.

CHAPTER FIVE : CONCLUSIONS

Conclusion

5.1 conclusion

The conclusions drawn from the conducted investigations are as follows:

1. The prepared aluminum-silicon alloys have homogenous distribution of silicon throughout the cast.
2. The value of hardness of the Al-Si increases with the increase in reduction ratio in rolling process.
4. Total elongation decreases with the increase in reduction ratio in rolling process in reduction ratio in rolling process
5. Specific wear rate of the Al-Si alloys increases with the increase in sliding distance and load applied
6. Specific wear rate of the Al-Si alloys decrease with the increase in reduction ratio in rolling process .

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