TRIBOLOGICAL STUDIES ON ALUMINIUM ALLOYS

A thesis submitted in partial fulfillment of the requirements for the degree

of

Bachelor of technology

In

Metallurgical and Materials Engineering

By

Vicky Vikram Das (107MM030)

&

Chandi Prasad Mohanty (107MM035)

Department of Metallurgical and Materials Engineering

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Under the guidance of

Dr.Subash Chandra Mishra

Department of Metallurgical and Materials Engineering

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the work in this project report entitled "TRIBOLOGICAL STUDIES ON ALUMINIUM ALLOYS" by Chandi Prasad Mohanty and Vicky Vikram Das has been carried out under my supervision and guidance, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Metallurgical and Materials Engineering, National Institute of Technology, Rourkela; is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, this work has not been submitted to any other university/institute for the award of any degree or diploma.

05/05/11

PLACE: Rourkela.

DATE: 05/05/2011

Dr. Subash Chandra Mishra

Professor

Department of Metallurgical and Materials Engineering

National Institute of Technology Rourkela, Orissa

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Chandi Prasad Mohanty

Place: Rourkela

Chandi Prasad Mohanty

Date: 05-05-2011

Vicky Vikram Das

Vicky Vikram Das

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ABSTRACT:

Aluminium alloys have extensive application in industries. The range of physical properties that can be imparted to them is remarkable.Addition of Silicon to Aluminium helps to increase their strength and wear resistance. Al-Si alloys are extensivelyused in industrial applications due to better tribological properties. In the present work, an attempt has been made to study the tribological properties of three Aluminium as-cast alloy samples i.e Al-7wt%Si, Al-10wt%Si and Al-14wt% Si. Wear tests were conducted using a pin-on-disc type wear testing machine (DUCOM wear and friction monitor) after metallographic examination followed by hardness measurement. The operational parameters that were varied were percentage Silicon content of the alloy, normal load, sliding velocity, sliding distance and lubrication. The wear was higher at increased velocity at increased normal load. Wear was found to be increasing with decreasing Silicon content. SEM characterisation was done. Interestingly, wear under lebricated condition was higher. The interaction of Silicon platelets at the Al-Si boundary might have been the possible reason.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND:

Aluminium (Al) is the second-most plentiful element on earth and it became an economic competitor in the engineering applications as early as the end of the 19th century. The emergence of three important industrial revolutions would, by demanding material characteristics consistent with the unique qualities of Aluminium and its alloys, greatly benefit growth in the production and use of the metal.

Among the most striking characteristics is its versatility. The range of physical properties that can be developed-from refined high-purity Al to the most complex alloys-is remarkable.

Aluminium and its alloys are extensively used as the materials in transportation (aerospace and automobiles), engine components and structural applications [1].Thus it becomes all the more vital to study the tribological characteristics of Aluminium and its alloys. Addition of Silicon to Aluminium gives high strength to weight ratio, low thermal expansion coefficient, and high wear resistance. These alloys also show improved strength and wear properties as the silicon content is increased beyond eutectic composition. Such properties warrant the use of these materials as structural components in automotive industries[2].The wear properties of three Aluminium alloy samples have been studied viz. Al-7wt% Si, Al-10%Si and Al-14%Si here.The principal wear mechanisms in these alloys and abrasive and sliding wear which have been dealt with in the later part of this work.

1.2 WHY ALUMINIUM ALLOYS

The properties of Aluminium and its alloys that make them the most economically attractive for a wide variety of applications are

(i) Light weight: Aluminium weighs roughly one-third as much as most of the common metals, but is one and a half times as heavy as Magnesium. It finds application to reduce weight of components and structures, particularly connected with transport, especially with aerospace

(ii) High Strength-to-weight ratio: High Strength-to-weight ratio saves a lot commercially, when dead weight is decreased and payload of transport is increased. This ratio is of particular significance in engineering designs where stiffness is involved. For example, stiffness for equal weights of similar beams are in ratio 1:2.9:8.2:18.9 for steel, Titanium, Aluminium and Magnesium respectively.

(iii) Ease of fabrication and machinability: It can be easily cast, rolled to any desired thickness (aluminium foils are so common), stamped, drawn, spun, forged and extruded to all shapes.

(iv) High resistance to atmospheric corrosion: When aluminium is exposed to air, a thin oxidised film forms on the surface, protecting the metal from corrosion. When scratched, the layer rapidly reforms retaining the protection. This feature is utilised in construction, buildings and household utensils .

(v) Resilience under static and dynamic loading: Aluminium products behave elastically under static and dynamic loading conditions, that is, they have the ability to resume both shape and size which is good when flexible strength is required.Mast and spars of racing yachts are designed to withstand the stress of the wind versus the waves.

(vi) Strength at low temperature: Brittle fracture problems do not occur with aluminium. As the temperature is reduced, aluminium alloys increase in strength without loss in quality, making them particularly suitable for low temperature applications[3].

1.3 Aluminium-Silicon Alloys :

1.3.1 Aluminium-Silicon Eutectic and hypoeutectic alloys:

Alloys with Silicon as a major alloying element are by far the most important commercial casting alloys, primarily because of their superior casting characteristics in comparison to other alloys. A wide range of physical and mechanical properties is afforded by these alloys.Binary aluminium-silicon alloys combine the advantages of high corrosion resistance, good weldability, and low specific gravity. Although castings of these alloys are somewhat more difficult to machine than the aluminium-copper or aluminium-magnesium alloys, all types of machining operations are routinely accomplished, usually using Tungsten carbide tools and appropriate coolants and lubricants.

Alloy 443 (5.3% Si) may be used for all casting processes for parts in which good ductility, good corrosion resistance, and pressure tightness are more important than strength. For die casting, alloys 413 and A 413 (12% Si) also have good corrosion resistance but are superior to alloy 443 in terms of castability and pressure tightness. Alloy A444 (7%Si-0.2% iron, maximum) also has good corrosion resistance and has especially high ductility when cast in permanent mold and heat treated to a T4 condition. This alloy has good impact resistance.

Alloys 413, 443 and 444 are important binary aluminium-silicon alloys. Another group of aluminium-silicon alloys however represents the workhorse aluminium foundry alloys. In this group, silicon provides good casting characteristics and copper imparts moderately high strength and improved machinability, at the expense of somewhat reduced ductility and lower corrosion resistance. Alloy 319(6% Si-3.5% copper) is a preferred general purpose alloy for sand foundries that may also be used in permanent mold casting.

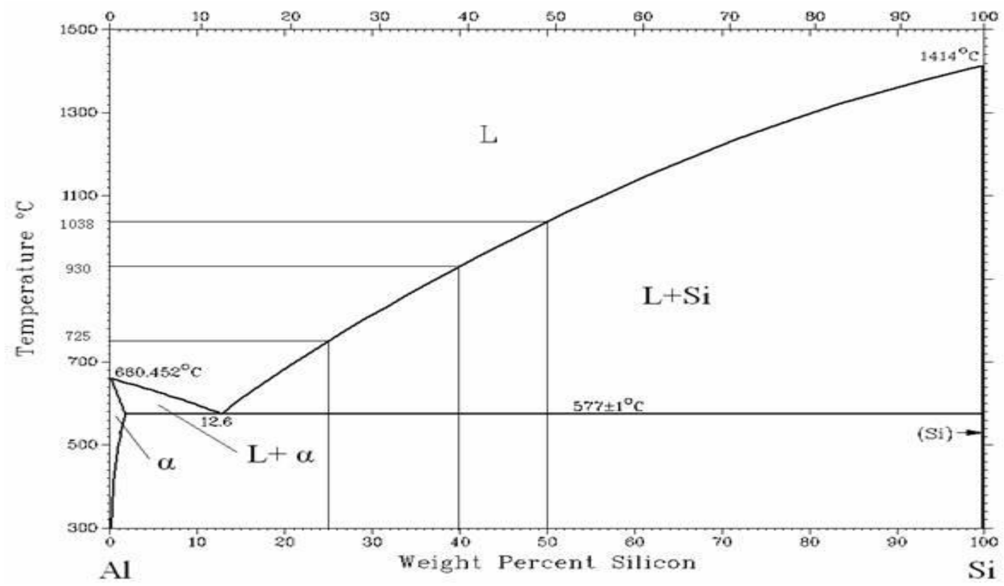


Figure 1.1 The Aluminium Silicon binary phase diagram . The eutectic occurs at 12.6 wt% Si

1.3.2 Hypereutectic aluminium-silicon alloys:

Aluminium silicon alloys with greater than 12% Silicon are called hypereutectic aluminium-silicon alloys. These have outstanding wear resistance, a lower thermal expansion coefficient, and very good casting characteristics. Such alloys have limited use because the presence of the extremely hard primary Silicon phase reduces tool life during machining.Also the special foundry characteristics and requirements of this alloy system, needed to properly control microstructure and casting soundness, are not clearly as well understood as are the characteristics of conventional hypoeutectic alloys.

These alloys have have outstanding fluidity and excellent machinability in terms of surface finish and chip characteristics. A typical example is 390 alloy (17%silicon-4.5% copper-0.5% magnesium) whose outstanding wear characteristics have caused a rapid growth in its use. It is used in small engines, pistons for air conditioning compressors, master brake cylinders, and pumps and other components in automatic transmission[4].

1.4 Wear

It is defined as a process of removal of material from one or both of two solid surfaces in solid contact. Wear is defined as “the damage to a solid surface, generally involving the progressive loss of material, due to relative motion between two moving surfaces[5]”. Such a process is complicated, involving time-dependent deformation, failure and removal of materials at the counterface. Research in this area is of vital importance from the economic point of view because it is a major problem and its direct cost is estimated to vary between 1% and 4 % of a nation’s Gross National Product.

1.4.1 Types of wear

Following are the various types of wear processes based on the types of wearing contacts.

(i) Single-phase wear: In which a solid moving relative to a sliding surface causes material to be removed from the surface. The relative motion for wear to occur may be sliding or rolling.
(ii) Multi-phase wear: In which wear, from a solid, liquid or gas acts as a carrier for a second phase that actually produces the wear[6].

1.4.2 Wear Mechanisms

Common types of wear mechanisms are as listed below

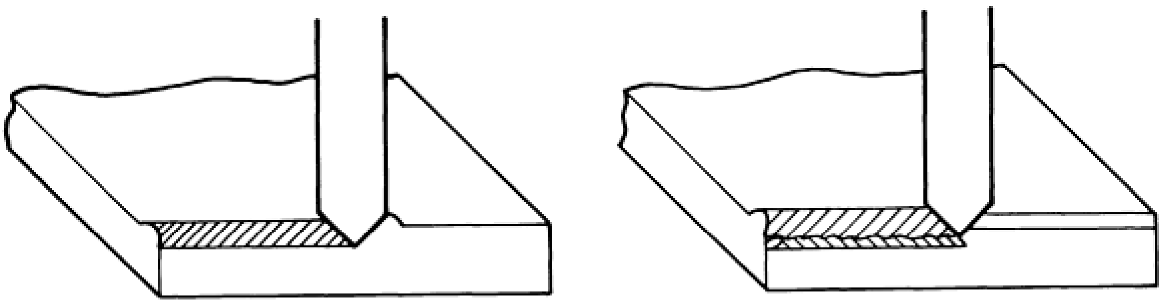
(i) Abrasive wear
(ii) Solid particle erosion
(iii) Sliding and adhesive wear
(iv) Fretting wear
(v) Corrosive wear
(vi) Impact wear

- **ABRASIVE WEAR:**

Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM (American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface. Wear, in turn, is defined as damage to a solid surface that generally involves progressive loss of material and is due to relative motion between that surface and a contacting substance or substances. The rate at which the surfaces abrade depends on the characteristics of each surface, the presence of abrasives between the first and second surfaces, the speed of contact, and other environmental conditions. In short, loss rates are not inherent to a material.

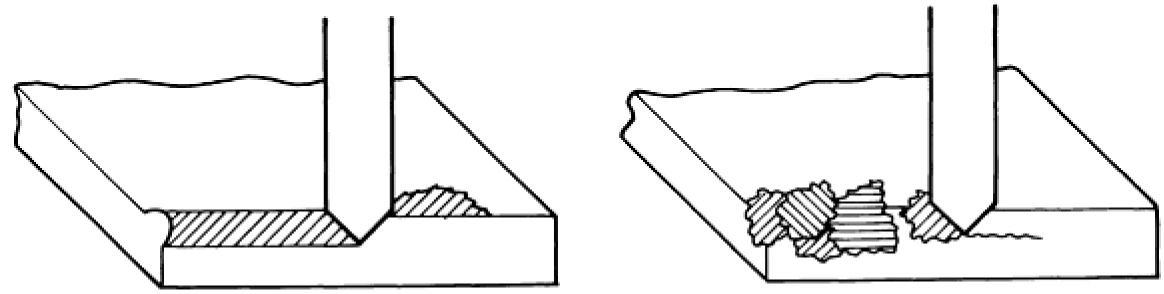
MECHANISMS PROPOSED

Many mechanisms have been proposed to explain how material removal during abrasion. These mechanisms include fracture, fatigue, and melting. Due to the complexity of abrasion process, no single mechanism completely accounts for all the loss. Figure 1.2 depicts some of the processes which are possible when a single abrasive tip slides accross a surface. They include plowing, wedge formation, cutting, microfatigue, and microcracking.



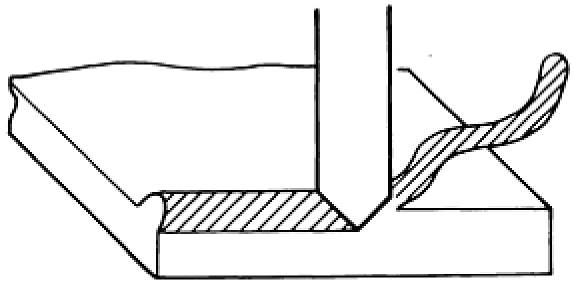
Plowing

Microfatigue



Wedge

Microcracking



Cutting

Fig1.2. Five processes of abrasive wear[7]

- **SOLID PARTICLE EROSION (SPE)**

It is the loss of material that results from repeated impact of small, solid particles. In some cases SPE is a useful phenomenon, as in sandblasting and high-speed abrasive waterjet cutting, but it is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves carrying particulate matter, and fluidized bed combustion (FBC) systems.

Solid particle erosion is to be expected whenever hard particles are entrained in a gas or liquid medium impinging on a solid at any significant velocity (greater than 1 m/s, or 3.3 ft/s). Manifestations of SPE in service usually include thinning of components, a macroscopic scooping appearance following the gas/particle flow field, surface roughening (ranging from polishing to severe roughening, depending on particle size and velocity), lack of the directional grooving characteristic of abrasion, and, in some but not all cases, the formation of ripple patterns on metals.

Solid particle erosion can occur in a gaseous or liquid medium containing solid particles. In both cases, particles can be accelerated or decelerated, and their directions of motion can be changed by the fluid. This is more significant in liquid media, and slurry erosion is generally treated as a different, though related, subject. In gaseous media, at least for particles larger than about 50 m, deflection of the particles by the gas stream can often be ignored in erosion tests.

The distinction between erosion and abrasion should be clarified, because the term erosion has often been used in connection with situations that might be better classed as abrasion. Solid particle erosion refers to a series of particles striking and rebounding from the surface, while abrasion results from the sliding of abrasive particles across a surface under the action of an externally applied force. The clearest distinction is that, in erosion, the force exerted by the particles on the material is due to their deceleration, while in abrasion it is externally applied and approximately constant[8].

- **SLIDING AND ADHESIVE WEAR**

It is a type of wear generated by the sliding of one solid surface against another. Erosion, cavitation, rolling contact, abrasion, oxidative wear, fretting, and corrosion are traditionally excluded from the class of "sliding" wear problems even though some sliding may take place in some of these types of wear. Apparently, sliding wear is a type of wear that is "left over" when all other types of wear have been identified under separate headings.

Although sliding wear and adhesive wear are not synonymous, Adhesive wear is as ambiguously defined as sliding wear. This phenomenon denotes a wearing action in which no specific agency can be identified as the cause of wear. Adhesive wear is said to occur if no abrasive substances are found, amplitude of sliding is greater than that in fretting and oxidation does not take place.

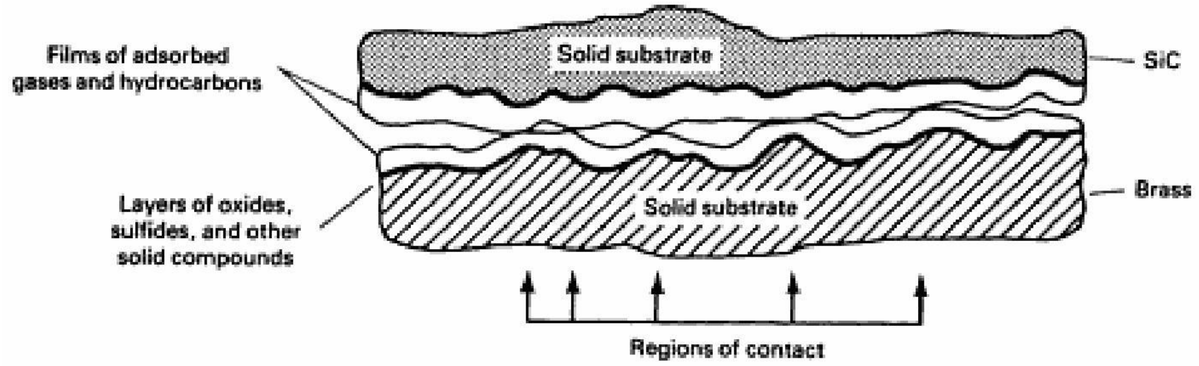


Fig 1.3 Schematic of a bond bridge produced when two solid surfaces are in contact with each other. It should be noted that when two rough surfaces are brought together, actual contact occurs only in a few isolated regions[9].

- **FRETTING WEAR**

Fretting can be defined as the “small-amplitude oscillatory movement that may occur between contacting surfaces, which are usually nominally at rest.” Production of oxide debris is one of the immediate consequences of this phenomenon. Hence, the terms “fretting wear” and “fretting corrosion” are applied to this process. The movement is due to external vibration. But in several cases, one of the members of the contact is subjected to a cyclic stress (fatigue). This gives rise to the initiation of fatigue cracks. This is called “ fretting fatigue” or “contact fatigue”[10].

- **CORROSIVE WEAR**

In case of corrosive wear, thin films are assumed to form through tribochemical reactions between contact surface materials and surrounding media, such as air or a liquid lubricant[11] and wear occurs through a combination of wear and corrosion can result in total material losses that are much greater than the additive effects of each process taken alone, which shows synergism between the two processes. Corrosion accompanies the wear process to some extent in all environments, except in inert atmospheres [12].

- **IMPACT WEAR**

It is defined as wear of a solid surface due to percussion. Percussion is a repetitive exposure to dynamic contact by another solid body. Several industries employ processes that lead to impact wear. Machine components, cams, and gears mate with a certain dynamic component. Typical applications occur in electromechanical printers; a prime example is that of typefaces, which are expected to hold definition, thus assuring high print quality, often for billions of cycles[13].

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The literature survey is carried out to study and evaluate the wear properties of Al-Si alloys. The various parameters such as Silicon content , applied load, sliding distance, effect of microstructure, etc have been studied. The work of researchers in this respect is been considered. Their conclusions are as follows:

Tuti Y. Alias and M.M Haque [14] have studied the wear behaviour of as-cast and heat treated Al-Si eutectic alloys. Wear tests on the alloys were performed on a pin on disk type wear testing apparatus and parameters were size and shape of the pin, load, speed and the material pairs.

Increase in the rotational speed of the disk leads to the increase in the mass loss of the as-cast and heat treated alloys. The wear rate is higher for as-cast samples. High speed leads to reduction in wear rate. The reduction is pronounced in heat treated samples. This is because during sliding, heat is developed and the material becomes softer and weaker. This heat might not affect the hardness of heat treated alloys due to their inherent characteristics.

Increase in the applied load leads to a high wear rate for both as-cast and heat treated alloys. But at higher loads, strain-hardening of the materials in contact increases, resulting in increase in the resistance to abrade or erode. At higher load, real surface area in contact is more which increases the gripping action and due to which wear rate slows down

At longer sliding distances, volumetric wear rate and specific wear rate are low. This was attributed to the fact that during sliding, heat develops due to friction which makes some of the adhered materials soften and loosen. As sliding goes on, these loosened particles are thrown away showing higher loss in weight. Heat treated alloys are not much affected due to their inherent characteristics due to heat treatment cycles whereas as cast alloys show higher weight loss.

S.A. Kori and T.M. Chandrashekharaiah[15] have studied the effect of grain refiner and or modifier on the wear behaviour of hypoeutectic (Al–0.2, 2, 3, 4, 5 and 7Si) and eutectic (Al–12Si) alloys using a Pin-On-Disc machine under dry sliding sliding conditions. It is important that Al-Si alloys solidify with fine equiaxed α-Al in hypoeutectic/fine primary Si particles in hypereutectic and fine eutectic Si. While the former can be achieved by a suitable grain refinement treatment/solidification processing the later can be achieved bya suitable grain modification. A fine grain size ensures good tribological properties.Al-Ti-B was used as grain refiner and Al-10%Sr was used as modifier.

Addition of grain refiner and modifier to Al-SI alloys resulted in less specific wear rate for these samples. An increase in sliding speed led to the decrease of specific wear rate both in the case of grain refined/modified and grain unrefined/unmodified alloys. This may be due to the fact that, at low sliding speeds, more time is available for the formation and growth of micro welds, which leads to increase in the force required to shear off the micro welds to maintain the relative motion, resulting in an increase in specific wear rate. Less specific wear rate was observed in grain refined/modified alloys under these conditions.

Addition of grain refiner and modifier led to decrease in wear rate at longer sliding distances. Grain refinement and modification led to increase in toughness and strength of the alloy. Increase in Silicon content leads to solid solution strengthening and precipitation hardening and a subsequent increase in the strength of the alloy. Addition of grain refiner and modifier leads to better mechanical properties.

G. Rajaram, S. Kumaran and T. Srinivas Rao[16] have studied the tensile and wear properties of Al-Si alloys fabricated by stir-casting technique at temperatures ranging from ambient to 350^0C. It is observed that the wear rate decreases with increasing temperature. This is because an oxide film is formed at high temperature which helps to avoid direct contact between alloy and the abrasive. Continuous sliding action removes this layer which facilitates direct contact of the alloy with the abrasive which results in decrement of wear rate at high temperature (~300^0C).

Another mechanism for this phenomenon has been suggested. At elevated temperatures, the agglomerated clusters of oxide formed due to tearing of oxide layers are subjected to thermal stresses and compaction by applied pressure and high temperature. At the same time sintering of the wear debris is also occurring resulting in solid smooth hard surfaces called “glazes”. These glaze layers protect the sliding surface and reduce the wear rate.

Dheerendra Kumar Dwivedi[17] has studied the effect of alloying elements on binary Al-17wt%Si alloy and multi-component (Al–17Si–0.8Ni–0.6Mg–1.2Cu–0.6Fe) cast alloy. A reduction in wear rate at high sliding speed was observed. This is due to the formation of an oxide layer on the sliding interface. Increase in the sliding speed leads to an increase in interface temperature. Rise in temperature increases the ability of soft Aluminium matrix to accommodate the hard and brittle Silicon. If temperature exceeds a certain critical value, thermal softening in the sub-surface region takes place which leads to large-scale plastic deformation.

Multi component alloys show better wear resistance because of increased solid solution strengthening, precipitation hardening and formation of intermetallic compounds in the presence of alloying elements. Formation of thermally stable intermetallic compounds and dispersion strengthening increase the wear resistance of multicomponent alloys. High hardness of these alloys is responsible for the low coefficient of friction during sliding due to easy fracture and deformation of asperities.

H. Torabian, J.B Pathak and S.N Tiwari[18] have studied the effects of alloy composition, sliding distance, sliding speed and load on the wear rate of Al-Si alloys.

The wear rate is strongly dependent on the applied load. It increases linearly with load in three distinct regions in all the alloys. Mild wear , Intermediate wear and Severe wear. Mild wear takes a longer duration and takes place under low loads. The intermediate wear and severe wear regions are distinguished from the mild region by higher rates of increase in the wear rate per unit weight.

It may be observed that the transition load at which change takes place from one region to another increases with increased Silicon content of the alloy. It is observed that wear rate initially decreases slightly with increasing sliding speed up to a certain value. Beyond this, there is a sharp rise in the wear rate, irrespective of the alloy composition. This value increases with increasing Silicon content.

The wear rate of the alloy is strongly dependent on the Silicon content of the alloy. The wear rate is found to decrease with increasing Silicon content. This effect is pronounced upto 15% Si in the alloy.Thus wear rates of hypereutectic alloys are better than those of hypoeutectic alloys.

A.S Anasayida, A.R Daud and M.J Ghazali[19] have studied the effect of addition of Cerium on the wear behaviour of as cast Al-4Si-4Mg alloys. Wear test results confirm that the wear rate decreases with the addition of Cerium in the alloy. The microstructures of the alloy samples reveal that Si in the as cast alloys is finely distributed in the interdendritic region. Silicon being harder than Aluminium increases the wear resistance of the alloys. Addition of Ce resulted in the formation of intermetallic phases like Al-Ce and Al-Si-Ce which leads to hardness and wear resistance.

The volume loss of the alloys increased with increasing load and sliding distance.With increase in Ce content, volume loss decreased. This was due to the strong bonding between intermetallic phases and the matrix. Wear mechanisms involved were oxidative wear, microcutting and delamination wear as shown by presence of oxides, microchips and delamination flakes. Cerium content upto 5% increased wear resistance.

D. Odabas and S.Su[20] worked on the comparison of reciprocating and continuous two body abrasive wear behaviour of solution-treated and age-hardened 2014 Al alloy. Reciprocating and continuous abrasive wear have been performed on solution treated 2014 Al alloys under similar conditions of load, speed, nominal area of contact and sliding distance. In order to compare the two body abrasive wear behaviour for two sliding modes. Pattern of wear is similar for both. But the average roughness in continuous wear is more than that of reciprocating. Because wear loss and abrasive wear coefficient in continuous wear is higher than that of reciprocating Sliding distance differences can explain this phenomena

Conclusions can be drawn as-

Difference in continuous and reciprocating wear.

- Wear loss is greater in the continuous wear.
- The abrasive wear coefficient is higher in the continuous wear.
- The values of average roughness of the worn surfaces are greater in reciprocating wear.

The above phenomenon is explaind by difference in sliding distance in both the cases and the greater amount of abrasion of the loose wear debris trapped between the contact surface of the pin and abrasive paper for much longer in the continuous wear mode.

Litian Hu, Jianmin Chun, Weimin Liu, Qunji Xue and Czeslaw Kajdas[21] have studied the wear and friction properties of Al-Si alloy against itself with the lubrication of pure ethyleneglycol, ethanolamine, ethylenediamine and triethylenetetramine.

Friction and wear tests showed that the friction coefficient for triethylenetetramine was lowest. Wear of the Al-Si alloy lubricated with ethyleneglycol was the largest whereas triethylenetetramine produced the best results. This has been explained on a molecular level. In amine like compounds, there are two electrons in the Nitrogen atom which are not bonded. Thus it is easy to interact with metals. In triethylenetetramine, though Nitrogen percentage is smaller than that in diamines, it exhibits better tribological behaviour. This has been explained by the fact that triethylenetetramine has a longer molecular chain. It also oxidises easily and the oxidation products interact with the Al-Si alloy. Oxidation products may include H_2NCH_2COOH and $–NHCH_2CH_2NH_2$. These products interact with the surface of the Al-Si alloy generated during sliding. It may also form some kind of a friction polymer

CHAPTER 3

EXPERIMENTAL DETAILS

3.1 Sample preparation:

Casting of the Al-Si alloys were done by pouring the molten alloy into a copper mould of dimension 1"x2"x3" . Grain modification was achieved by using sodium chloride. Cylindrical samples of diameter 10 mm each were machined from the as-cast Al-Si alloys. Test samples are prepared from these cast ingots after polishing. The microstructure of the samples are observed under an optical microscope, after etched with Keller's reagent.

3.2 Hardness test:

The hardness values of these samples were determined by using Vicker's Microhardness Tester with an applied load of 3 kgf.

3.3 Wear tests:

3.3.1 Abrasive wear test apparatus :

Test up used in the study of wear test is capable of creating reproducible abrasive wear situation accessing the abrasive wear resistance of the prepared samples. It consists of a pin on disc , loading panel and controller.

Fig3.1 DUCOM Wear and Friction Monitor used for the wear tests

All the test were carried out using a "Ducom friction and wear monitor" machine with both normal and lubricated condition. The normal condition has 50-60% relative humidity and a temperature of 28-32°C. The mass loss of the specimen after each test was estimated by measuring the height loss of the specimen due course of the experiment. The mass loss would be the heightloss multiplied by the area of cross section of the sample and the density of the sample. Care has been taken to clean up the sample before and after each test to prevent any form of corrosion on the surface. Abrasive paper of required grit size(220 µm optimised for the Al-Si sample) is cut into circular shape so as to fit in the ground steel disc and pasted on it with a proper adhesive ensuring no slide or detachment. The specimen was held steady and stationary with a holder of the apparatus and the required normal load was applied through lever mechanism. The sliding radius was kept at 80 mm for all tests concerned.

Parameter	unit	Minimum	Maximum
Wear disc	mm	100x6	---
Disc speed	RPM	10	800
Pin diameter	mm	2	10
Pin length	mm	10	50
Ball diameter	mm	10	---
Wear track dia	mm	10	80
Normal load	N	0	100
Frictional force	N	0	100

Table 3.1 Specifications of the DUCOM wear and friction monitor

3.3.2 Wear Parameters:

The variables involved in wear test are:

- % Si in the Al-Si alloy
- Normal load
- Sliding velocity
- Sliding distance
- Lubrication

Wear behaviour of the fabricated samples is combined affected by the above parameters. The effect of each individual parameter is studied in these experiments.

3.3.3 Wear measurement:

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, Δm in the specimen was obtained. We can calculate the mass loss by measuring the height loss (Δh) in each experiment, the area of cross section(A) of sample and the density (ρ) of the alloy by using the realtion

$\Delta m = \Delta h \times A \times \rho$

Cares have been taken after each test to avoid interaction of wear debris in the specimen. Wear rate which relates to the mass loss (Δm) and sliding distance (L) was calculated using the expression,

$$W = \Delta m/L$$

The friction force was measured for each pass and then averaged over the total number of passes for each wear test. The average value of co-efficient of friction, μ of composite was calculated from the expression,

$$\mu = F_f / F_n$$

where F_f is average friction force and F_n is applied load.

For characterization of the abrasive wear behaviour of the composite, the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied normal load. Often the inverse of specific wear rate expresses in terms of the volumetric wear rate as

$$W_s = W_v / V_s F_n$$

Where V_s is the sliding velocity.

3.3.4 Lubricated wear test:

In this case wear of samples were done in presence of some lubricating medium like engine oil of grade SAE 20W-40. The respective calculations can be done for this condition. The same operating conditions as in dry wear tests were applied except that a continuous flow of the lubricant was supplied to the alloy-abrasive paper interface.

CHAPTER 4

RESULTS AND DISCUSSION

4.1MICROSTRUCTURES OF THE AS CAST SAMPLES:

The micro structures of the as cast samples were seen under an optical microscope with 100x magnification

Fig 4.1a Fig 4.1b Fig4.1c

Fig 4.1 Optical microstructures of the as cast alloys a)Al-7wt%Si b)Al-10wt%Si and c)Al-14%Si

From the above figures it is found that, with increase in silicon percentage in the alloy, the microstructure is different for hypo-eutectic compositions than of the hyper-eutectic composition i.e. of Al-14%Si alloy.

4.2 HARDNESS :

Alloy composition	Hardness (H_V)
Al-7wt% Si	55.5
Al-10wt% Si	56.2
Al-14wt% Si	56.6

Table 4.1 showing Vicker's Hardness values for as cast alloys

Hardness is found to increase with increase in Silicon content of the alloy.

4.3 RESULTS OF WEAR TESTS:

The wear tests on the samples are carried out (considering the operating parameters of wear) i.e. by varying the sliding velocities, sliding distances, applied load and lubricant conditions. The effects of these parameters have been studied. Relationship between Cumulative Mass Loss (CML) with time, wear rate dependence of sliding distance etc. have been co-related.

4.3.1 **EFFECT OF NORMAL LOAD**

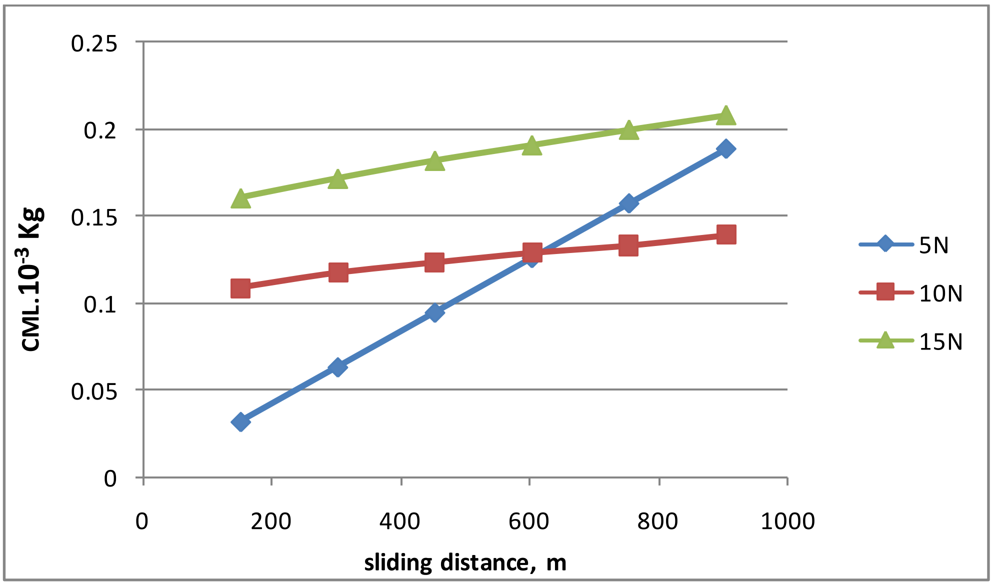


Fig. 4.3.1a Variation of Cumulative Mass Loss (CML) with sliding distance for Al-10wt% Si at 100rpm sliding speed

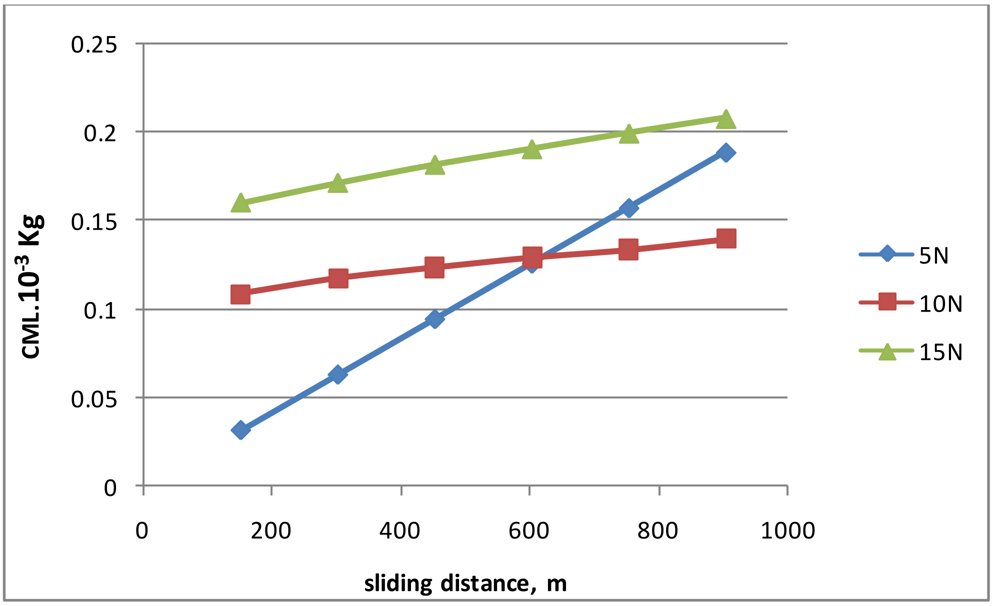


Fig.4.3.1b Wear rate against sliding distance for Al-10wt%Si at 0.837 m/s sliding speed

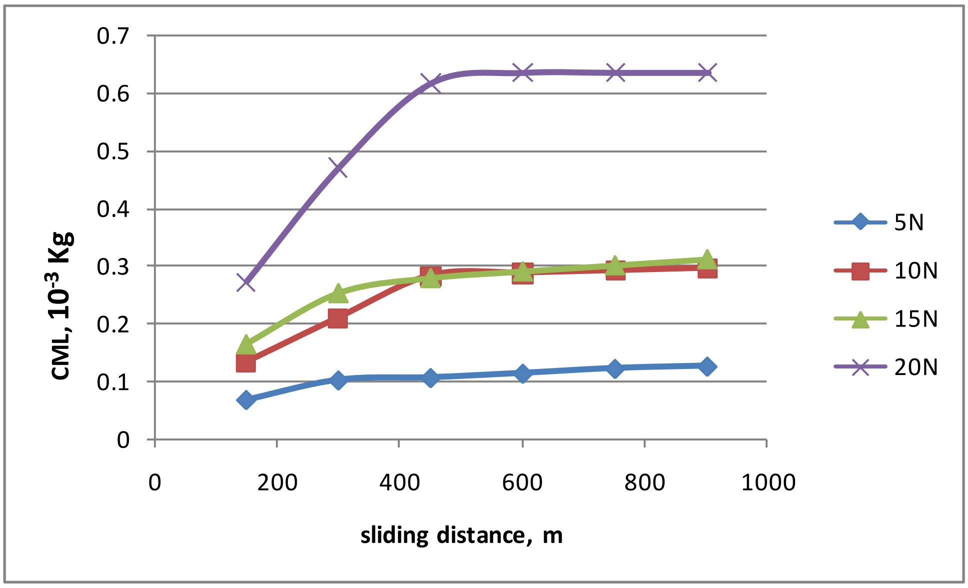


Fig. 4.3.1c CML against sliding distance for Al-7wt%Si at 0.837 m/s sliding speed

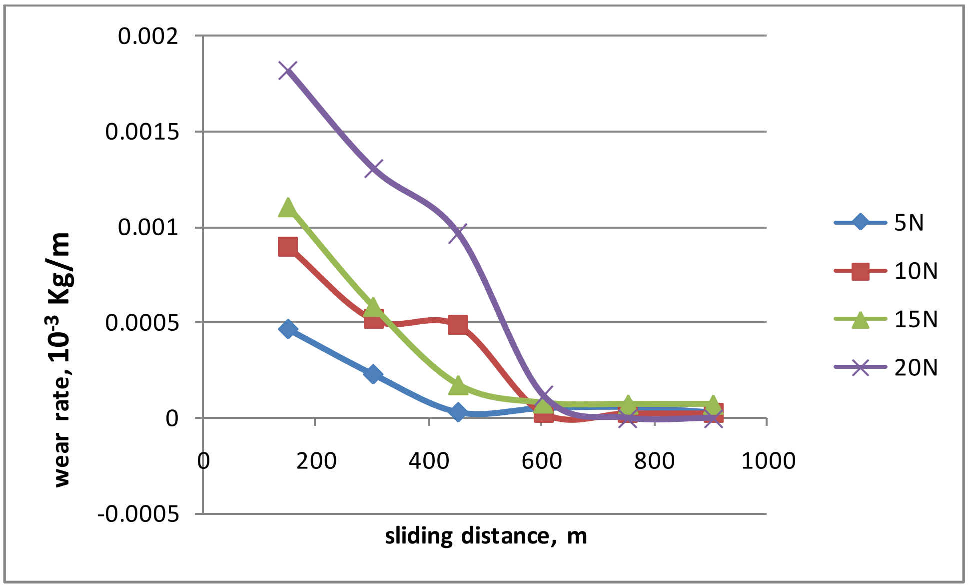


Fig.4.3.1d Wear rate against sliding distance for Al-7wt%Si at 0.837 m/s sliding speed.

From the above figures, it can be said that, (i) with increase in applied load wear rate increases and (ii) after a sliding distance of about 400 mts. Rate of wear attains a steady state.

4.3.2 **EFFECT OF SLIDING SPEED**

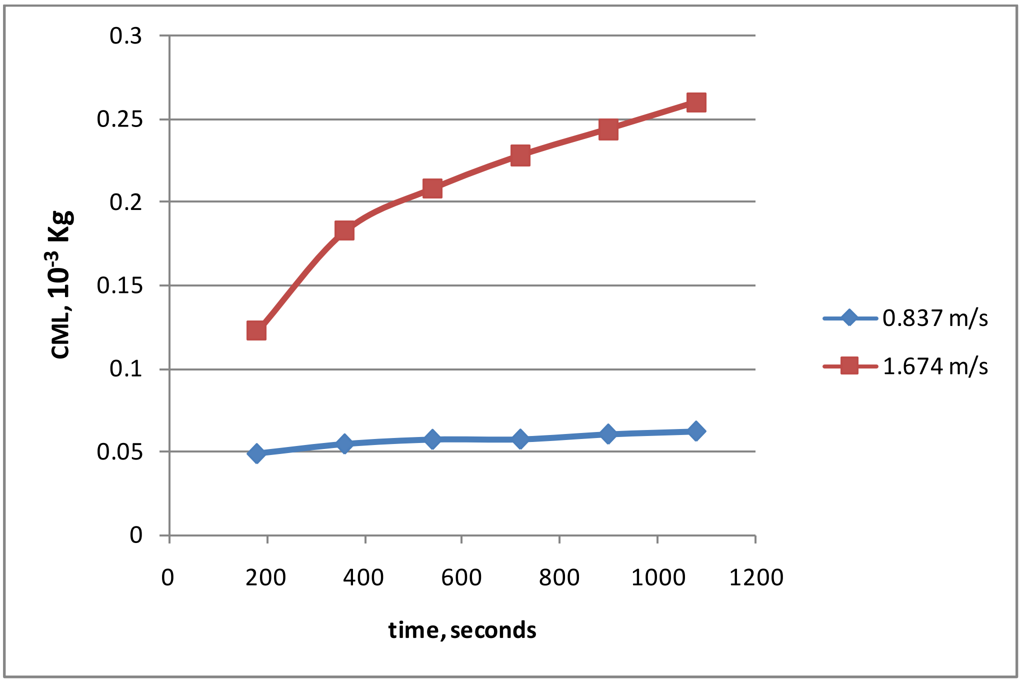


Fig 4.3.2a CML against time (seconds) for Al-10wt%Si at applied load of 5 Newton

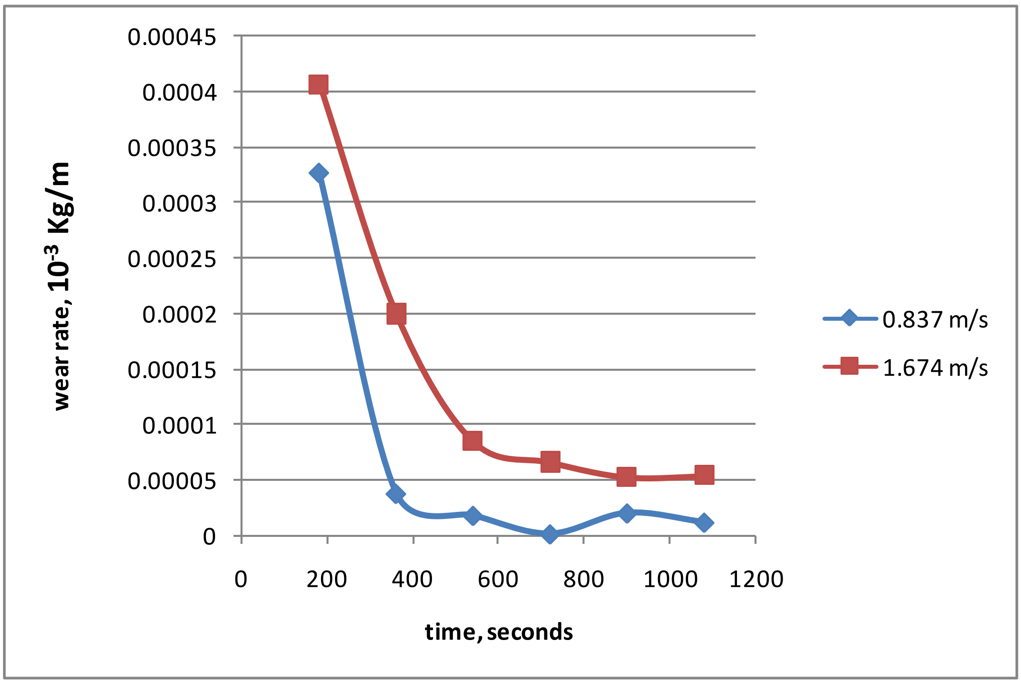


Fig 4.3.2b Wear rate against time (seconds) for AL-10wt%Si at applied load of 5 Newton

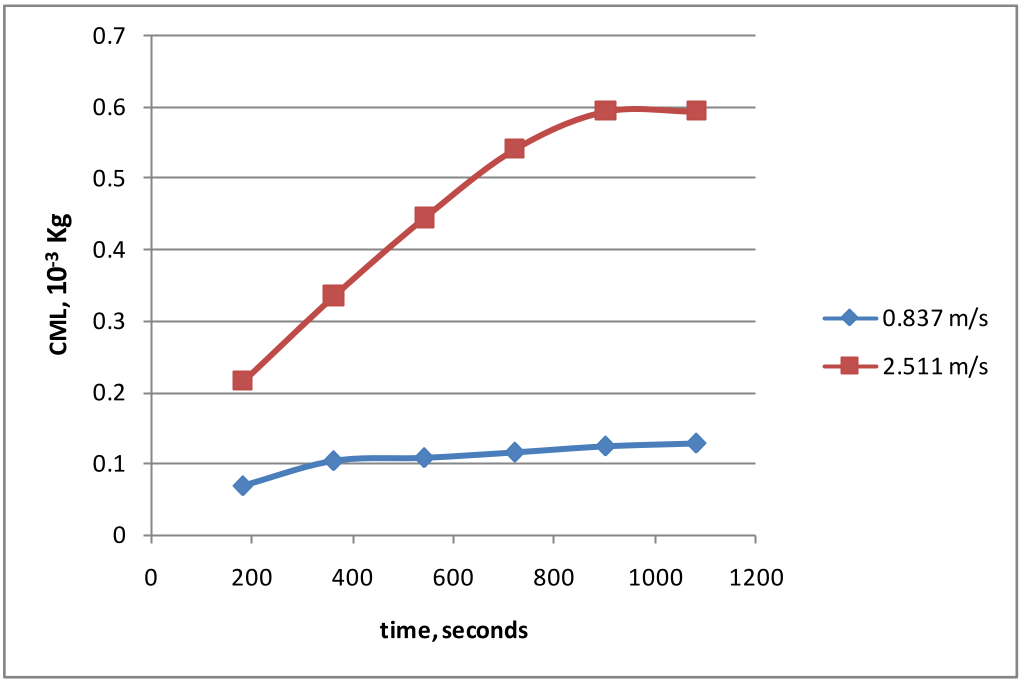


Fig 4.3.2c CML against time (seconds) for Al-14wt%Si at applied load of 5 Newton

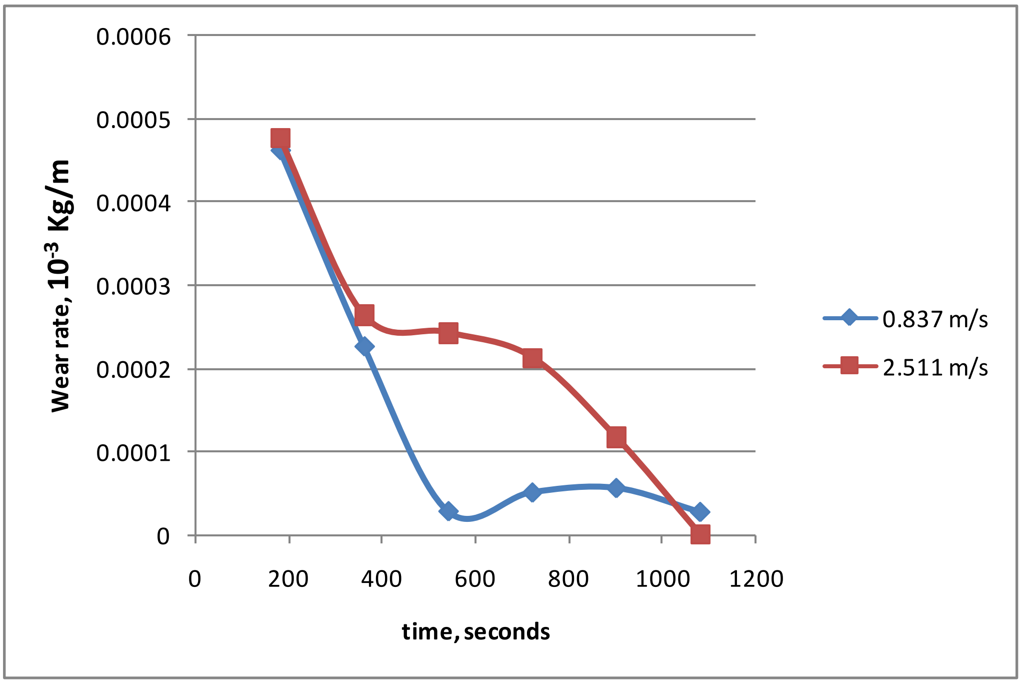


Fig 4.3.2d Wear rate against time(seconds) for Al-14wt%Si at applied load of 5 Newton.

The above figures implies that, cumulative mass loss initially increases but after a certain time it reduces and a steady state is attended in wear rate.

4.3.3 **EFFECT OF SILICON CONTENT**

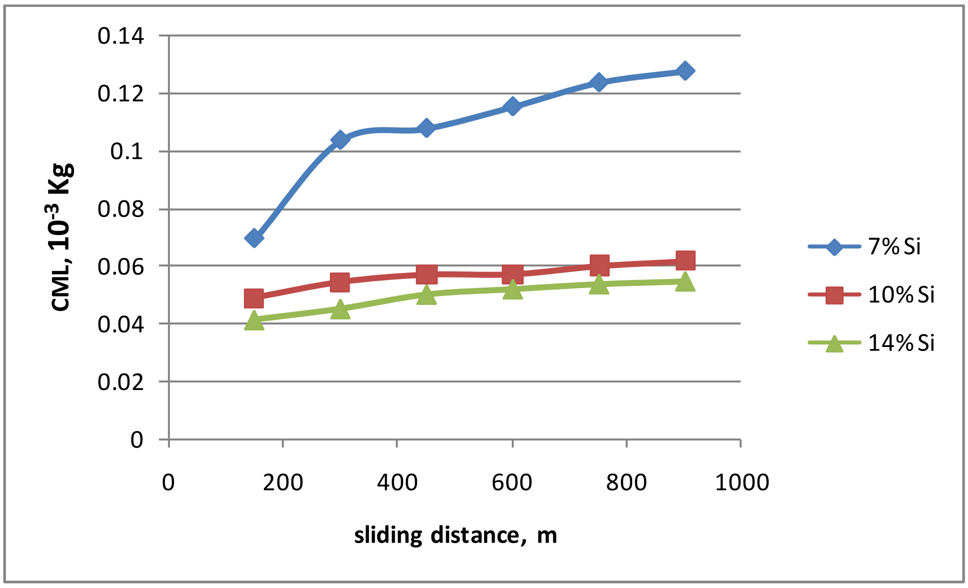


Fig 4.3.3a Variation of CML with sliding distance at sliding speed of 0.837 m/s and load 5 Newton

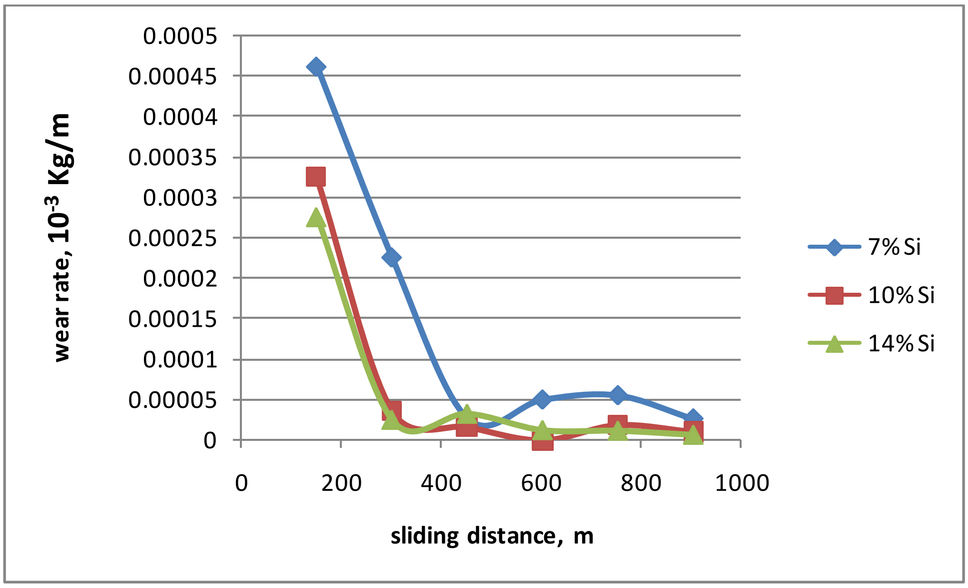


Fig 4.3.3b Variation of wear rate with sliding distance at a speed of 0.837 m/s and load 5 Newton.

These figures incorporate that, with increase in silicon content there is reduction in wear rate.

4.3.4 **EFFECT OF LUBRICANT**

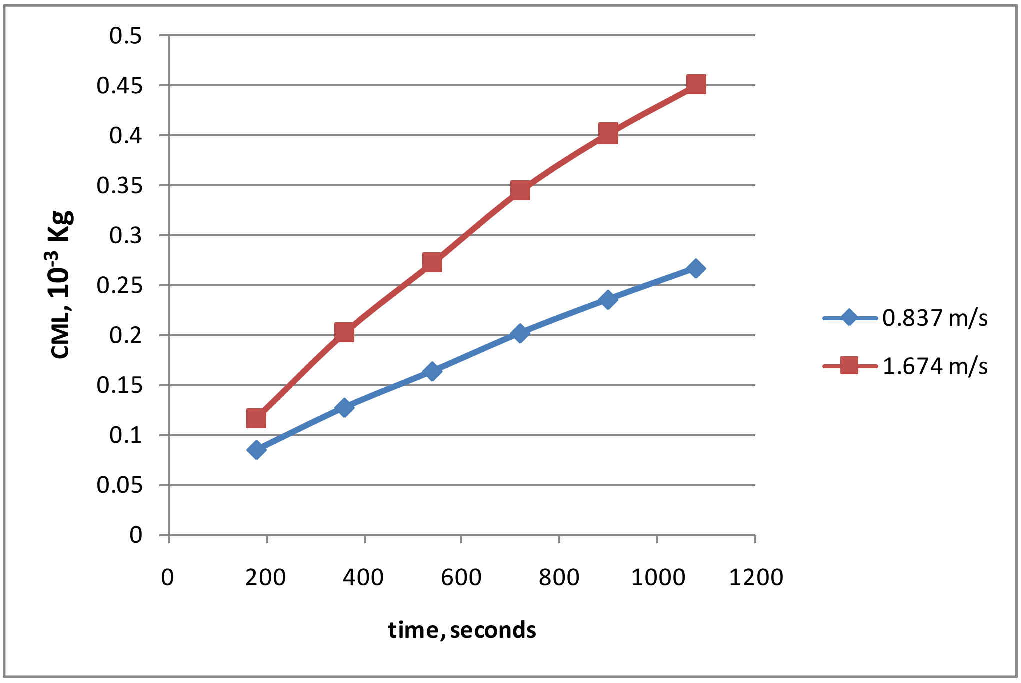


Fig.4.3.4a Variation of CML with time under 5 N load for Al-10wt%Si under lubricated condition

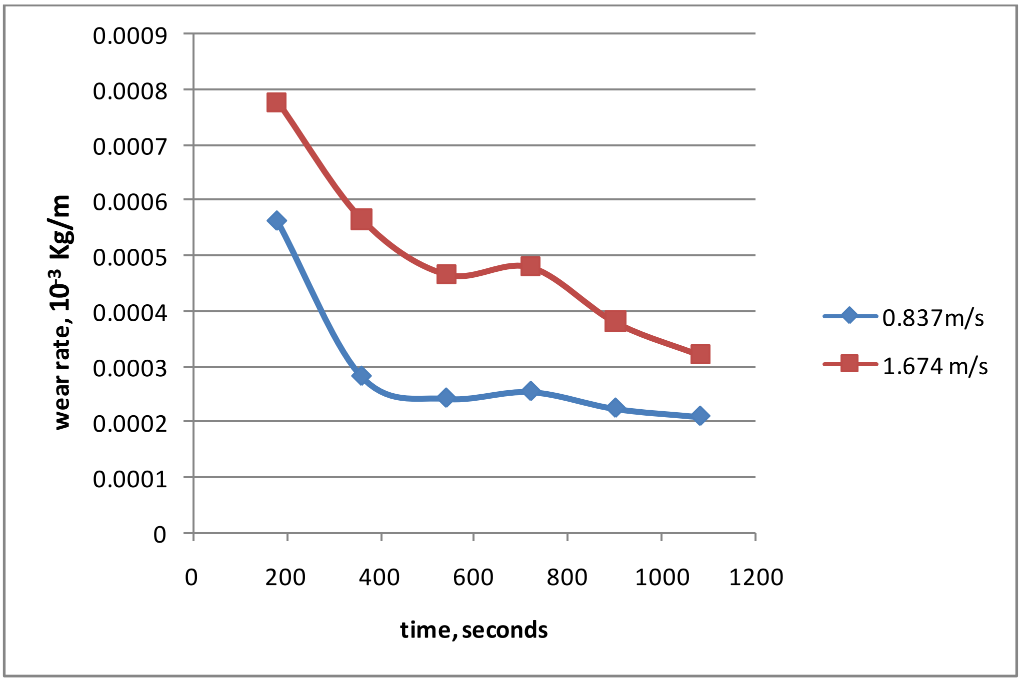


Fig 4.3.4b Variation of wear rate with time under 5 N load for Al-10wt%Si under lubricated condition

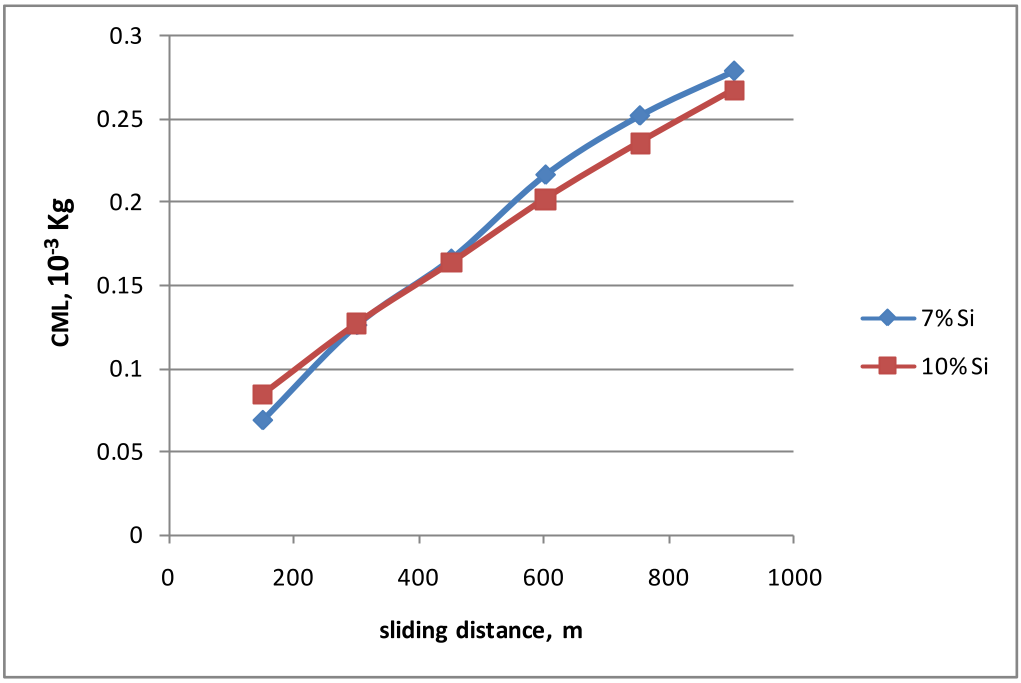


Fig 4.3.4c Variation of CML with sliding distance under a load of 5Newton and speed of 0.837 m/s for different Si contents in lubricated condition

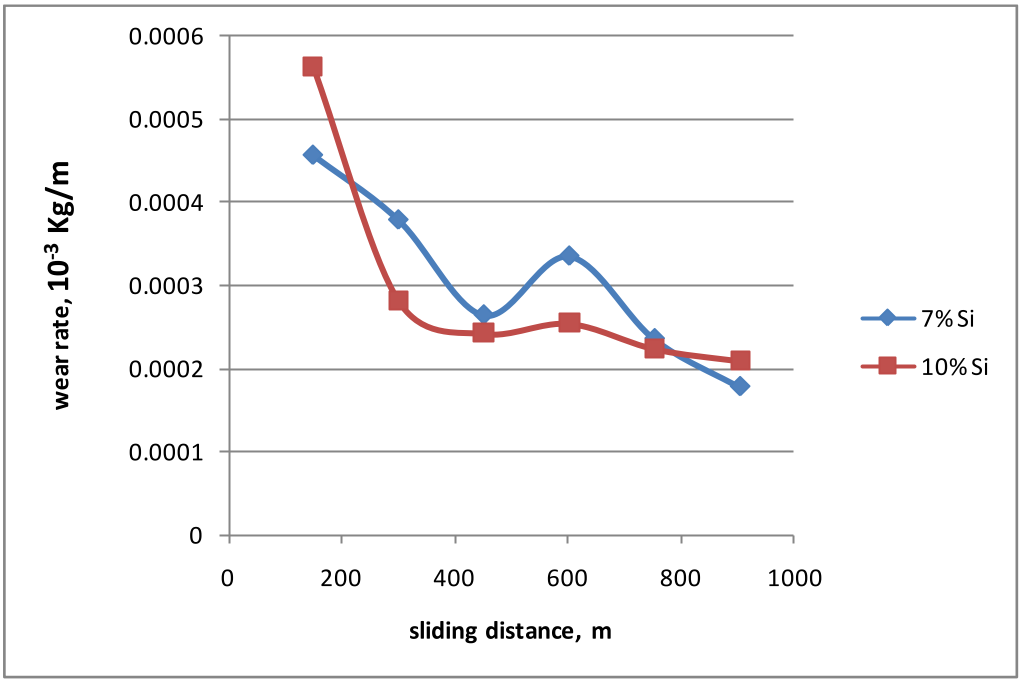


Fig4.3.4d Variation of wear rate with sliding distance under a load of 5Newton and speed of 0.837 m/s for different Si contents in lubricated condition

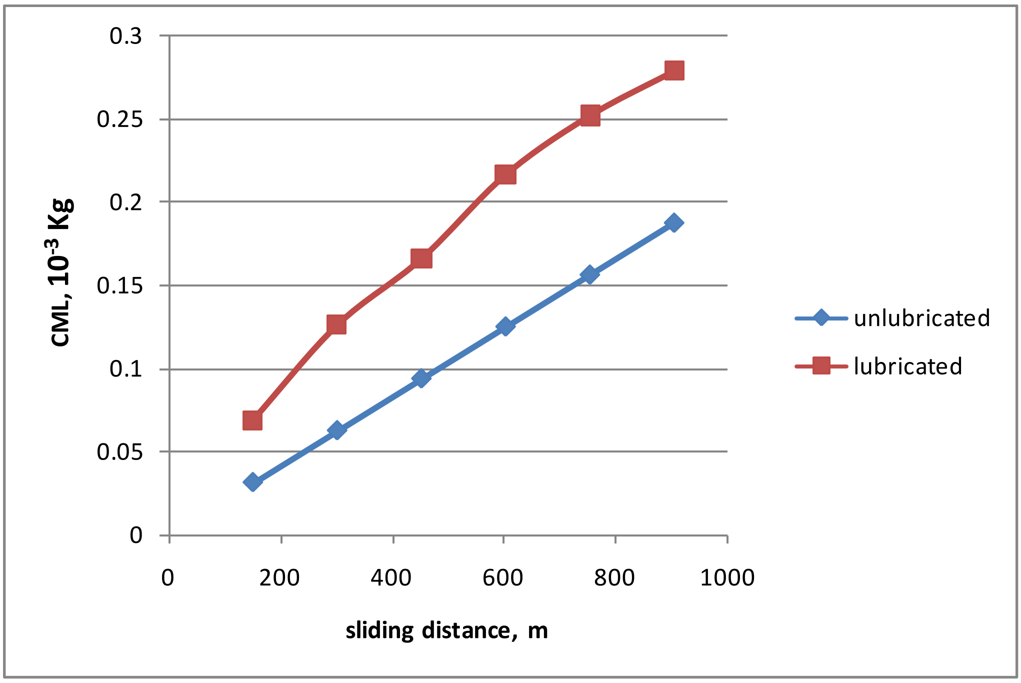


Fig 4.3.4e Variation of CML with sliding distance under a load of 5Newton and speed of 0.837 m/s for Al-7wt%Si alloy

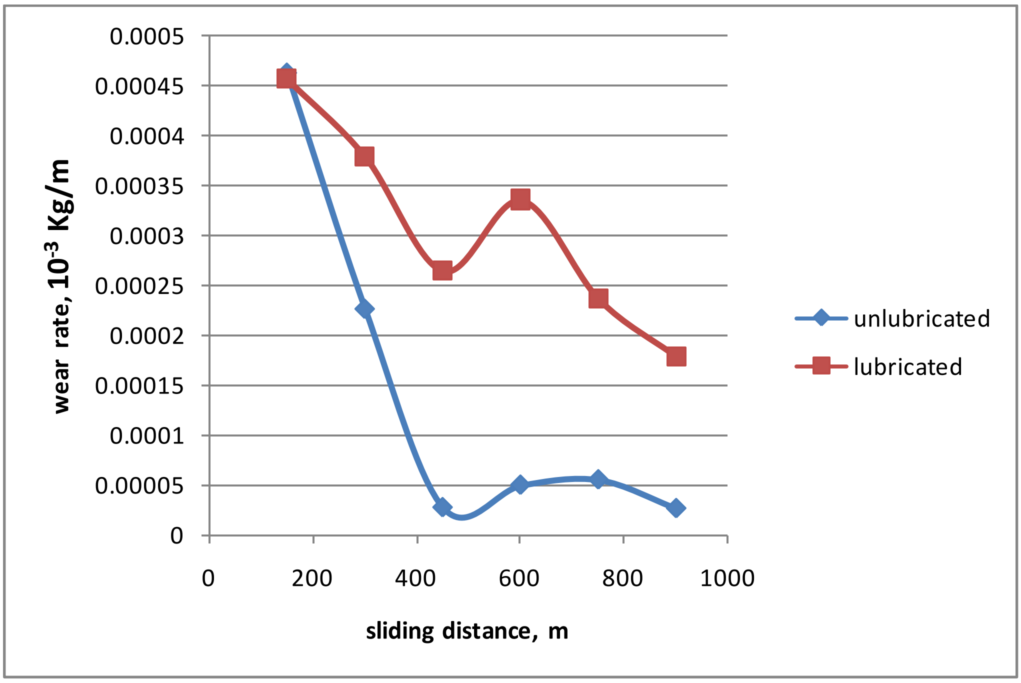


Fig 4.3.4f Variation of wear rate with sliding distance under a load of 5Newton and speed of 0.837 m/s for Al-7wt%Si alloy

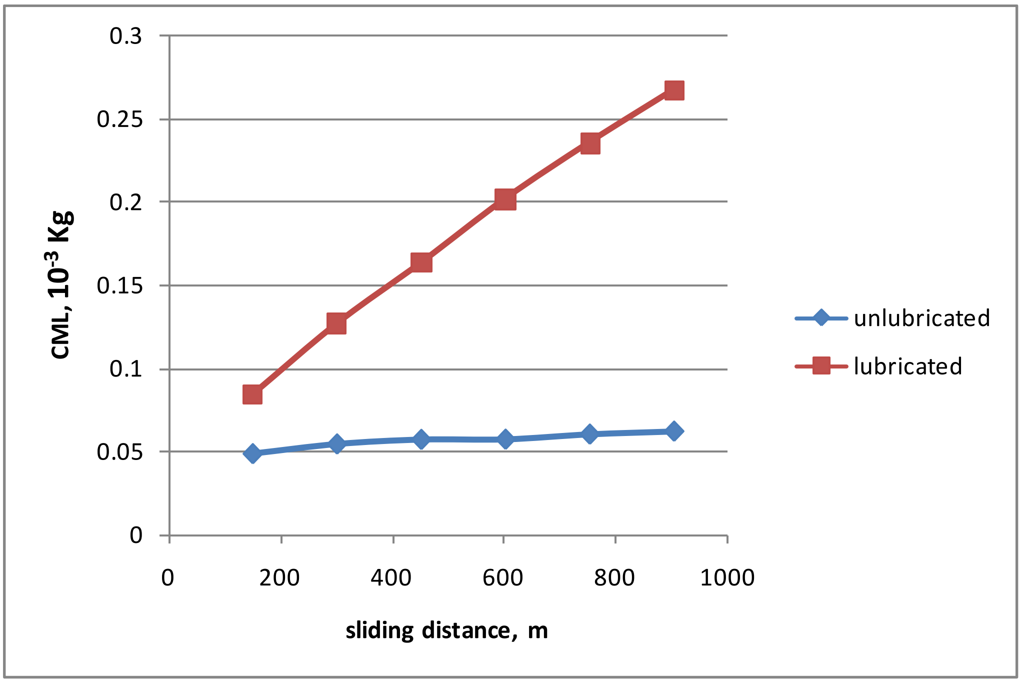


Fig 4.3.4g Variation of CML with sliding distance under a load of 5Newton and speed of 0.837 m/s for Al-10wt%Si alloy

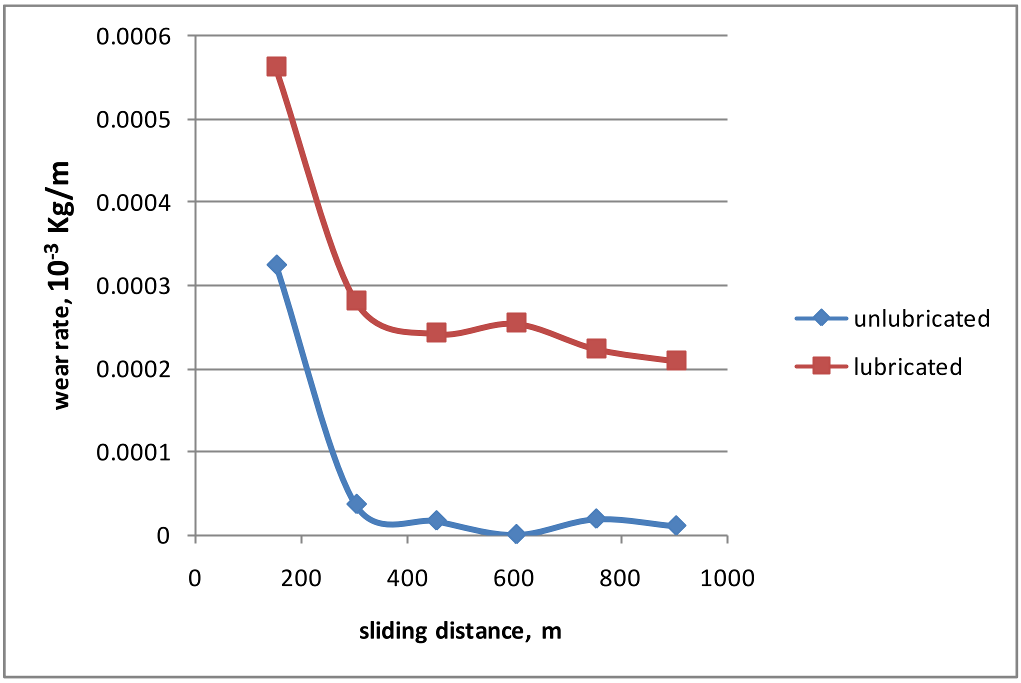


Fig 4.3.4h Variation of wear rate with sliding distance under a load of 5Newton and speed of 0.837 m/s for Al-10wt%Si alloy

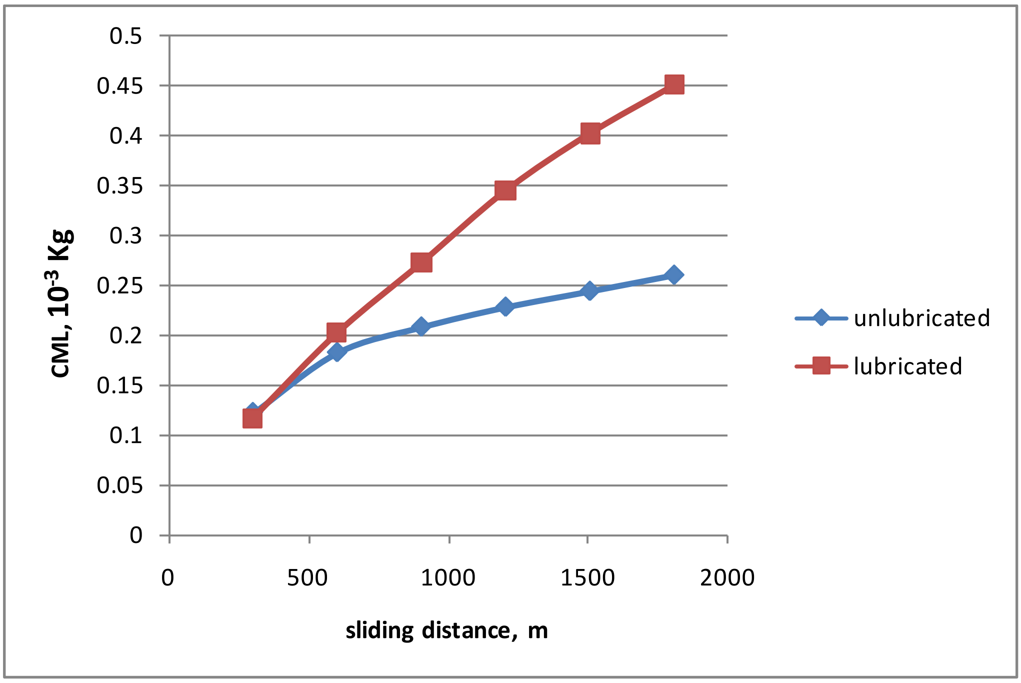


Fig 4.3.4i Variation of CML with sliding distance under a load of 5Newton and speed of 1.674 m/s for Al-10wt%Si alloy

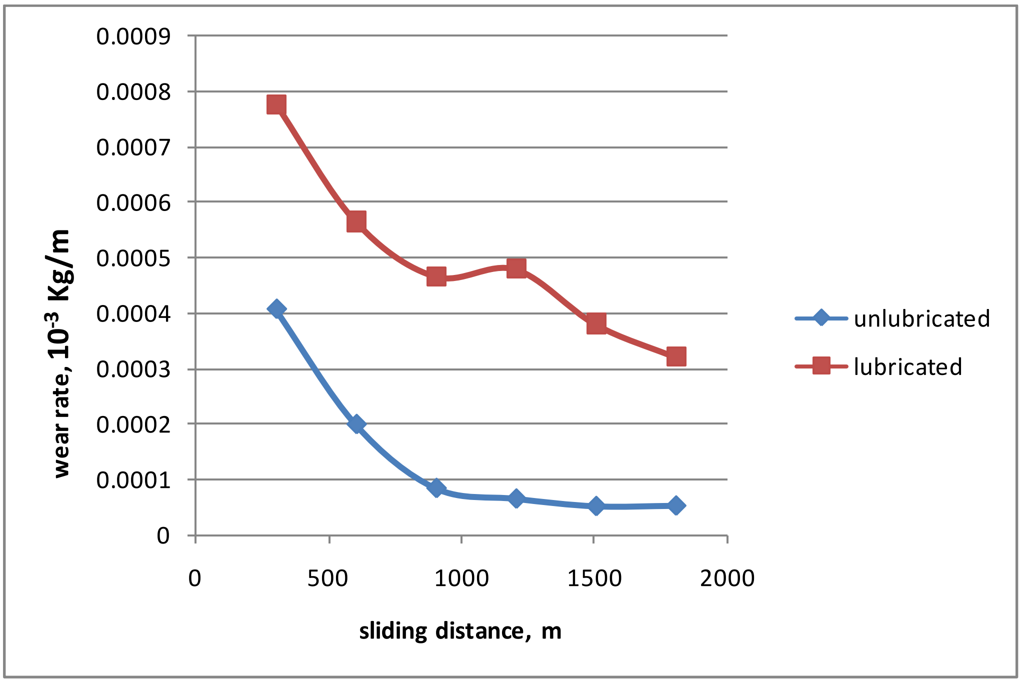


Fig 4.3.4j Variation of wear rate with sliding distance under a load of 5Newton and speed of 1.674 m/s for Al-10wt%Si alloy.

The effect of environmental conditions (i.e. dry and lubricated) on wear behaviour is represented in the figures 4.3.4a to 4.3.4j. It can be said that, the mass loss of the material is higher in case of the samples abraded with SAE 20W-40 grade engine oil than that of the dry abrasive test condition. It may be due to the fact that, the lubricants have filled the micro voids of the fibre dusts which have filled (the void spaces) with lubricant and hence caused the enhanced wear rate. However, this attains a steady state after a sliding distance of 1000 meters beyond.

4.4 SCANNING ELECTRON MICROSCOPY

The scanning electron micrographs for the worn surfaces in both unlubricated and lubricated conditions are obtained at magnifications of 1500x and 500x. The micrographs of the samples at unlubricated conditions are shown in fig. 4.4(a,b), 4.4(e,f) and 4.4(I,j) respectively for Al-7%, Al-10% and Al-14%Si alloys. And rest figures are for lubricated conditions, for the same sequences of the compositions.

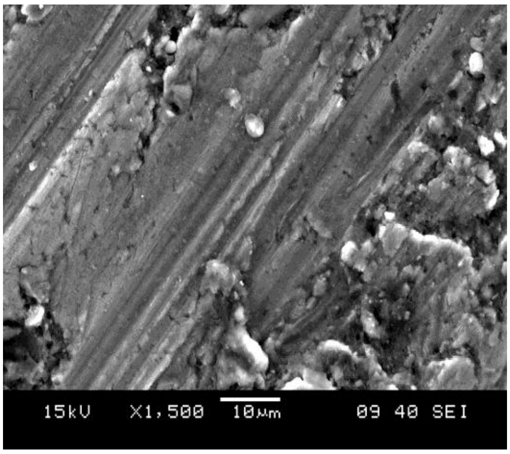


Fig4.4a

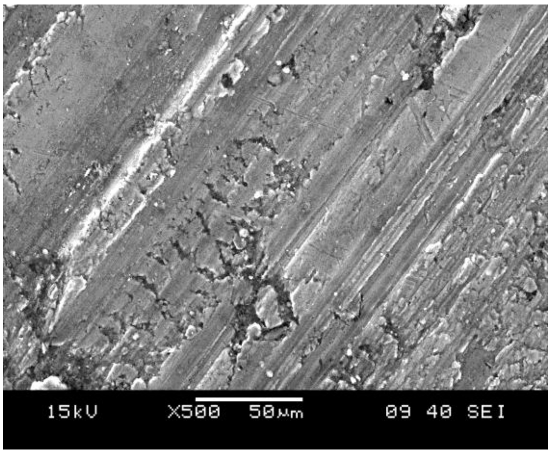


Fig4.4b

The micrographs of Al-7wt% Si samples tested in lubricated condition are shown below.

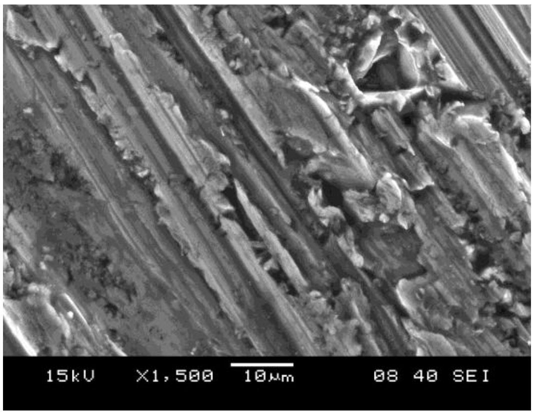


Fig 4.4c

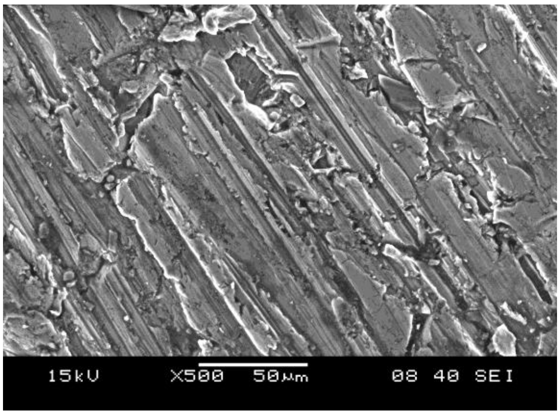


Fig 4.4d

The micrographs of Al-10wt% Si samples tested in unlubricated condition are shown below.

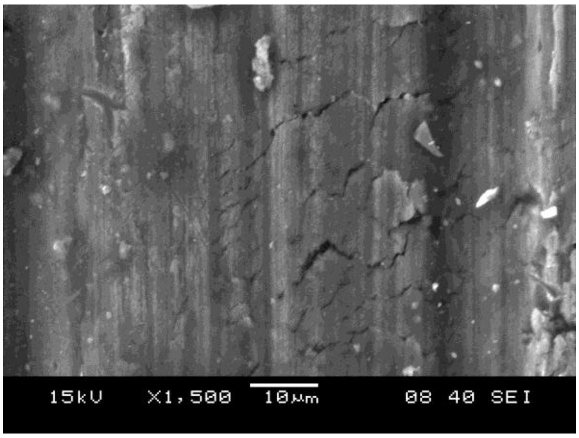


Fig 4.4e

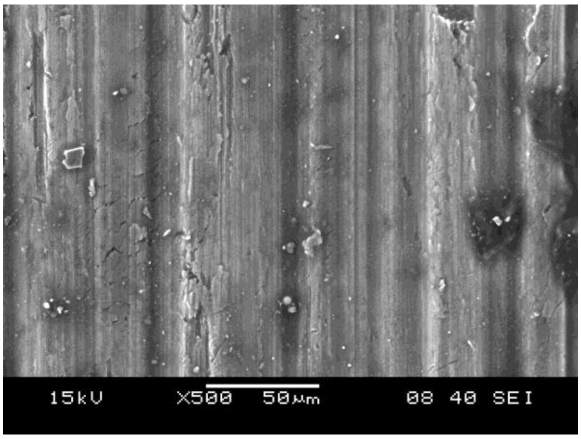


Fig 4.4f

The micrographs of Al-10wt% Si samples tested in lubricated condition are shown below

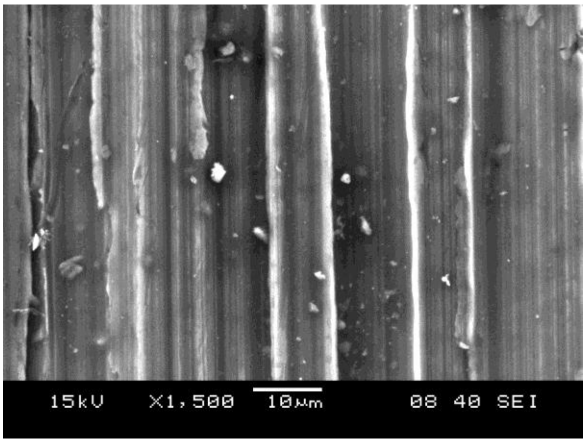


Fig 4.5g

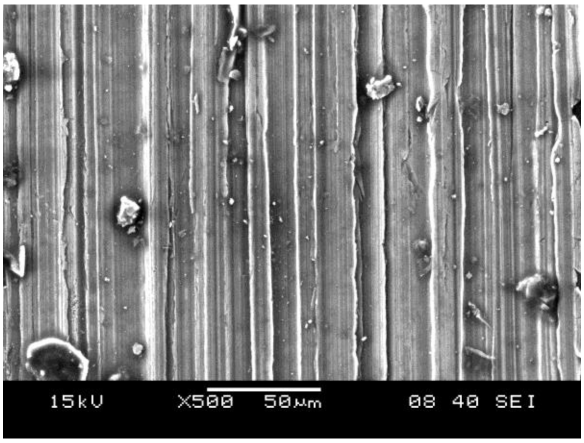


Fig 4.5h

The micrographs of Al-14wt% Si samples tested in unlubricated condition are shown below

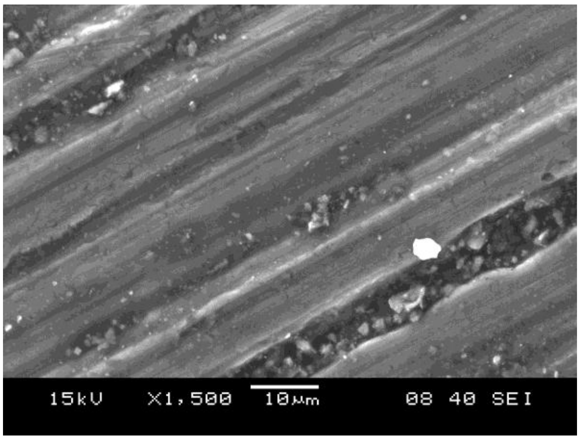


Fig 4.6i

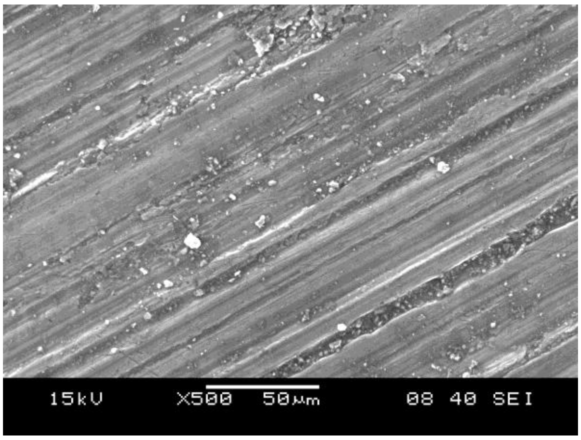


Fig 4.6j

The micrographs of Al-14wt% Si samples tested in lubricated condition are shown below

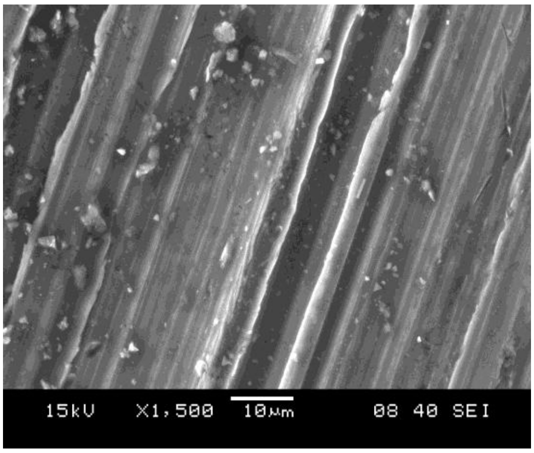


Fig 4.7k

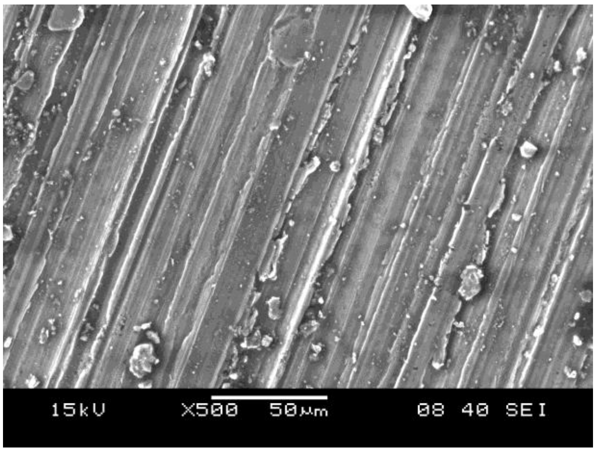


Fig 4.7l

The worn surface after dry sliding of Al-7wt% (fig 4.4a and 4.4b) shows deep well separated grooves. Cracks are also observed which are spread perpendicular to the sliding direction. Comparing it with the SEM of worn surface at lubricated condition (fig 4.4c and 4.4d), It is found that the grooves are along the sliding direction, but not many cracks are seen. However, crack propagation is seen along the same direction as sliding.

With increase in silicon content in the alloys that is 10% and 14% silicon, reveals different micrographs. For Al-10wt% Si, the worn surface shown(fig 4.4e, 4.4f and fig 4.4g,4.4h) for the sample tested in dry and lubricated conditions respectively. It can be observed that although deeper grooves/abrasive tracks are observed but are smooth in dry condition; and at lubricated condition the separation of groove line is reduced. This may be due to the fact that at dry condition the wear debris (of the material) might have flown off, but in lubricated condition some particles are embedded in the matrix which is the reason for deeper grooves.

In case of Al-14wt% Si (Fig 4.4i, 4.4j and Fig 4.4k, 4.4l) with increase in Si content hardness of the material has increased. Deeper grooves in dry sliding condition may be assigned to the abrasion of SiC particles that have forced the Silicon in platelet form, for which deeper grooves are produced. This can also be clarified at lubricated condition (fig4.4k and 4.4l), that debris and silicon platelets (i.e. pro-eutectic silicon) are observed along the direction of sliding and are obligated to deep crack lines.

CHAPTER 5

CONCLUSIONS

From this piece of experimentations following conclusions can be drawn.

1) Wear behaviour is dependent on applied load, sliding speed mainly. However, a steady state is attained after a sliding distance of about 1000 meters in all cases.

2) Wear is seen to increase at higher sliding speed and at higher applied load.

3) With increase in silicon percent, the CML and wear rate decreases

.

4) In case of lubricated condition the specimens shows higher amount of material loss i.e. higher wear rate, which is not clear at the moment. But is expected that, the precipitated silicon platelets have been easily removed from the material due to interaction at the inter boundary zone of Al-Si eutectic and silicon platelets (i.e. pro-eutectic silicon) and has enhanced the material loss.

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