EXPERIMENTAL INVESTIGATION OF FRICTION AND WEAR OF HEAT TREATED AISI 304 STAINLESS STEEL AGAINST EN-8 STAINLESS STEEL USING A MULTITRIBOTESTER AND EFFECT OF MICROSTRUCTURE ON WEAR BEHAVIOUR

SUBMITTED BY

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2016

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his Master of Engineering in Mechanical Engineering studies.

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We hereby recommend that the thesis prepared under our supervision by Santosh Kumar, examination roll number - M4MEC1606, entitled **“Experimental Investigation of Friction and Wear of Heat Treated AISI 304 Stainless Steel against En-8 Stainless Steel Using a Multitribotester and Effect of Microstructure on Wear Behaviour”** be accepted in partial fulfilment of the requirements for the Master of Engineering in Mechanical Engineering.

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The foregoing thesis entitled **"Experimental Investigation of Friction and Wear of Heat Treated AISI 304 Stainless Steel against En-8 Stainless Steel Using a Multitribotester and Effect of Microstructure on Wear Behaviour"** is hereby approved as credible study of an Engineering subject and presented in a manner satisfactory to warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval, the undersigned, do not endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it has been submitted.

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ABSTRACT

Dry sliding tribo-characteristics, that is, the nature of friction and associated wear in dry sliding condition of heat treated SS-304 stainless steel against EN-8 stainless steel has been studied in the present experimental work. Stainless steel specimens of SS-304 grade have been heated in muffle furnace in desired temperature and allowed to dwell for two hours. The heated specimen are then cooled in different medium namely in furnace, air and in cutting grade oil (grade 44) to obtain different heat treated conditions. The corresponding hardness has been measured in RB scale. Friction and wear characteristics have been studied using a multi tribo-tester (Ducom) in dry sliding condition against EN-8 stainless steel roller. Speed, load on job and duration of rolling have been considered as the experimental parameters. Mass loss of the samples before and after operation has been considered as the measure of wear in the present study. The data have been plotted and compared accordingly in case of five different heat treated samples against the same experimental parameters. The microstructure of a material can strongly influence the physical properties such as strength, toughness, ductility, hardness, corrosion resistance, wear resistance and so on. Here given different type of microstructure of a material, this shows that how influence, hardness and wear resistance. The microstructure of SS304 sample depends on such variables as the micro constituents elements present, their concentrations, and the heat treatment of the sample (i.e., the temperature, the heating time at temperature, and the rate of cooling to room temperature). Microstructure behaviours also affect the tribology properties such as wear. It has also been planned to extend the work, in future, with different other steels like mild steel, tool steel etc. and to compare the test result both in dry and lubricated conditions.

Key words: friction, wear, furnace cooling, air cooling, oil cooling, tribo-testing.

CHAPTER 1

1. INTRODUCTION

The study of friction, wear and associated lubrication in case of interacting surfaces in relative motion is the purview of tribology [1, 2].

The interactions taking place at the interface between two or more bodies under relative motion control the tribologiacal behaviour of the materials involved in such interaction. Progress of wear finally determines the useful life of a product and the quality as well. Hence the nature of friction, wear and their control plays an important role in different engineering operations [3].

For the reliability of the component it is utmost important to control the friction and wear in case of sliding contact. A fundamental knowledge base is thus helpful to achieve that control. Friction and wear are system dependent properties [3]. Though there are several research based models and formulations in this regard but majority of them are not suitable to predict the tribo logical behaviour in a particular case. Thus, iteration of friction and wear data through practical experimentation in a particular situation is very much important and need based activity. The present work has been carried out to compare the sliding friction and wear behaviour of different heat treated AISI-304 stainless steel against EN-8 stainless steel in dry condition. Our experiment shows that microstructure behaviour affects the wear rate and tribological properties.AISI type 304 stainless steel is an austenitic iron-nickel-chromium alloy and not heat-treatable for hardening purposes. However, this can be annealed and annealed 304 stainless steel has several use in industries like chemical, refrigeration, paper and food processing, beverage, screws, machinery parts, car headers and architecture and many more [15]. This may also be used for bellows, flexible metal hose, spinning, tubing and numerous other stainless applications. Study of friction and wear behaviour is thus important in the characterization of annealed AISI 304 stainless steel along with the evaluation of other mechanical properties.

Block-on-roller configuration of MultiTribotester “TR-25” (DUCOM, India) has been utilized for the purpose [16]. Normal load on the sample, sliding speed (rpm) of the wheel and duration of the test run have been considered as the design factor for the evaluation of tribo characteristics. The experiments have been conducted in dry condition, that is, without any lubricants in standard laboratory temperature and humidity conditions.

Stainless steel is a major component in industrial, commercial, and consumer products. Typical application of AISI 304 stainless steel includes but not limited to car headers, various machinery parts, screws, valves, lining of coal hopper, utensils, and marine applications and like others. This steel can’t be hardened by heat treatment process however can be heat treated for reliving stresses. In this paper attempts have been made to shed light on the friction and wear behaviour of AISI 304 stainless steel samples, heat treated to different grades, in dry and laboratory test conditions.

1.1 Stainless Steel

Stainless steel is an alloy of iron with a minimum of 10.5% Chromium and a small amount of carbon, plus some other elements in certain grades. Chromium produces a thin layer of oxide on the surface of the steel known as the 'passive layer'. This prevents any further corrosion of the surface. Increasing the amount of Chromium gives an increased resistance to corrosion.

Stainless steel also contains varying amounts of Carbon, Silicon and Manganese. Other elements such as Nickel and Molybdenum may be added to impart other useful properties such as enhanced formability, strength and increased corrosion résistance. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environments. For greater hardness and strength, more carbon is added. With proper heat treatment, these steels are used for such products as razor blades, cutlery and tools and as many other house-hold and engineering components.

1.2 Classification of Stainless Steels

There are many number of different systems currently used to designate stainless steel. Most commonly, the AISI system, used in USA is adopted. In the AISI system, austenitic grades are in the 200 and 300 series, martensitic and ferritic are in the 400 series. It is illustrates in given Figure1.1about the families of stainless steels.

1.2.1 300 Series- The most widely used austenite steel is the 304, also known as 18/8 for its composition of 18% chromium and 8% nickel. The second most common austenite steel is the 316 grade, also called marine grade stainless, used primarily for its increased resistance to corrosion. A typical composition of 18% chromium and 10% nickel, commonly known as 18/10 stainless, is often used in cutlery and high-quality cookware [30].

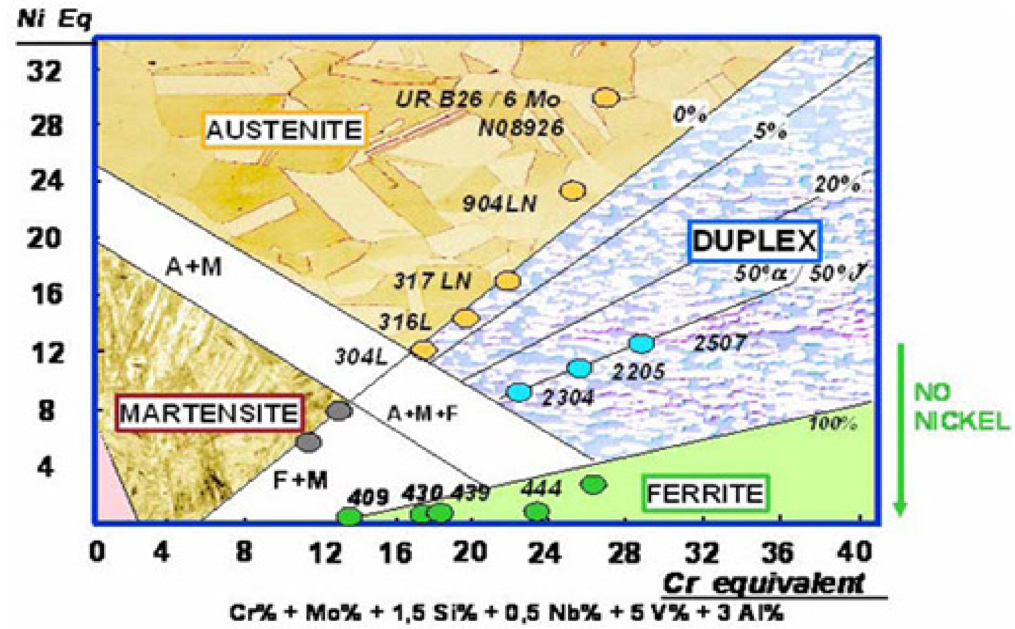


Figure1.1:- Families of stainless steel [33]

1.2.2Austenitic Stainless steels:-It is very common and most widely used type of stainless steels having carbon percentage upto 0.15%.It has FCC crystal structure and called γ-iron. They have an austenitic crystalline structure and contain a maximum of 0.15% carbon, a minimum of 16%-26% chromium and sufficient nickel(10-20%) and/or manganese to retain an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy. Austenite steels make up over 70% of total stainless steel production.

They have two series AISI 300-series and AISI 200-series. AISI 300- series include 301, 302, 303 Se, 304, 304L, 304 LN, 308, 309, 310, 316, 316 L, 316 LN, 321, 330, 347 etc, and contain chromium (16-26%) and nickel (10-22%). AISI 304 austenitic stainless steel is most widely used and also known as 18/8 for its composition of 18% chromium and 8% nickel. The second most common austenite steel is 316 grades which is also called marine grade stainless steel.

AISI 200-series include 202, 201, 205etc and they contain chromium, nickel and manganese (5- 18%).Decreasing nickel content and increasing manganese results in weak corrosion resistance. Austenitic steel 201 grades is hardenable through cold working. Type 202 steel is a general purpose stainless steel [28, 30, 33, 44&45].

1.3 Literature Review

In the context of the present work, a literature survey is made. This survey covers the interactions taking place at the interface between two or more bodies under relative motion control the tribological behaviour of the materials involved in such interaction.

Mohammad Asaduzzaman Chowdhury et al. [5]: Experiments are carried out when different types of pin such as aluminium, gun metal, copper and brass slide on SS 304 disc. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s relative humidity 70% and duration 30 min. Variations of friction coefficient with the duration of rubbing at different normal load and sliding velocity are investigated. Results show that friction coefficient varies with duration of rubbing, normal load and sliding velocity In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The obtained results reveal that friction coefficient decreases with the increase in normal load for all the tested pairs.

Mohammad Asaduzzaman Chowdhury et al. [6]: Stainless steel 202 (SS 202) sliding against mild steel are investigated experimentally using a pin on disc apparatus designed and fabricated. Experiments are carried out when smooth or rough SS 304 pin slides on SS 202 disc. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s, Surface condition-Dry and relative humidity 70%. Variations of friction coefficient with the duration of rubbing at different normal loads and sliding velocities are investigated. Results show that friction coefficient is influenced by duration of rubbing, normal load and sliding velocity. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The obtained results reveal that friction coefficient decreases with the increase in normal load for SS 202 mating with smooth or rough SS 304 counter-face.

S.A. Tukur et al.[23]: Austenitic Stainless steels are sensitized when exposed to elevated temperature range of 470-750°C causes carbide precipitations at grain boundaries. Carbide precipitation can have deleterious effects on the resistance to intergranular corrosion and reduces the tensile properties of stainless steels, specifically strength and toughness. This paper evaluates an optimum heat treatment strategy for solution annealing of AISI 304 stainless steel after sensitization. Standard tensile and Hardness test specimens were fabricated using precision Lathe Machine. These samples were subjected to various heat treatment sequences, consisting of Sensitization at 660°C, followed by air cooling and solution annealed at five different temperatures: 1010°C, 1050°C, 1090°C, 1140°C and 1190°C, followed by water quenching. Heat treated samples were then mechanically tested for Hardness and Tensile properties. The influence of heat treatment process and temperature on mechanical properties of as-received, sensitized and solution annealed 304 stainless steels were evaluated.

M.A. Chowdhury and D.M. Nuruzzaman [50]: Experiments are carried out when different types of disc materials such as stainless steel 314 (SS 314), stainless steel 202 (SS 202) and mild steel slide against stainless steel 314 (SS 314) pin. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s and relative humidity 70%. At different normal loads and sliding velocities, variations of friction coefficient with the duration of rubbing are investigated. The obtained results show that friction coefficient varies with duration of rubbing, normal load and sliding velocity. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The obtained results reveal that friction coefficient decreases with the increase in normal load for all the tested materials. It is also found that friction coefficient increases with the increase in sliding velocity for all the materials investigated. Moreover, wear rate increases with the increase in normal load and sliding velocity for SS 314, SS 202 and mild steel.

Ajay Sharma et al.[51]: The main focus of our research study is pin on disc tribometer, which is an advanced tribometer with precise measuring of friction and wear properties of combination of metals and lubricants under selected conditions of load, speed and temperature.

The main element of this tribometer are a pin sliding on the flat face of the disc in a vertical plane with provisions for controlling load, speed and oil temperature and for

measuring friction. This is the simplest form of tribometer used to measure wear and friction between two metals. This research relates to the various aspects (coefficient of friction, wear patter, lubrication testing, result graphs) obtained by pin on disc tribometer.

Aadarsh Mishra et al.[52] :A pin on disk sliding friction test was conducted on the titanium alloy (Ti-6Al-4V). Alloy disks were slid against the bearing ball composed of stainless steels at the speeds of 0.2 and 0.8 m/s. When the sliding speed is higher the coefficient of friction and wear rate are lower.

J. Qu et al.[53]: The tribology of titanium against various classes of counter face materials, pin-on-disk sliding friction and wear experiments were conducted on two different titanium alloys (Ti–6Al–4V and Ti–6Al–2Sn–4Zr–2Mo). Disks of these alloys were slid against fixed bearing balls composed of 440C stainless steel, silicon nitride, alumina, and polytetrafluoroethylene (PTFE) at two speeds: 0.3 and 1.0 m/s.

S. Senthur Prabu et al.[54]:the adhesive wear characteristics of crystalline polymer Polyacetal(Polyoxymethylene-POM) and semi-crystalline polymer such as Nylon 6, Nylon 66 (aliphatic polyamides) were investigated. Polymers considered for this study are potential candidate materials for rollers in hybrid chains in food processing industry, medical equipments etc. Sliding wear tests were carried out under dry conditions using a pin- on-disc (ASTM G99) arrangement. The wear tests were performed against a mild steel disc (HRB 67) at room temperature under various loads (60, 80&100N) and sliding speeds (1.8, 2.3& 2.8m/s).

M. A. Chowdhury et al.[55]: The present paper investigates experimentally the effect of sliding speed and normal load on friction and wear property of an aluminium disc sliding against stainless steel pin. To do so, a pin-on-disc apparatus was designed and fabricated. Experiments were carried out under normal load 10-20 N, speed 500-2500 rpm and relative humidity 70%. Results show that the friction coefficient decreases with the increase of sliding speed and normal load for aluminium. It is also found that the wear rates increase with the increase of sliding speed and normal load.

Dr. Mohammad Asaduzzaman Chowdhury et al.[56] : The present paper investigates friction coefficient of brass sliding against different steel counter faces. The effects of sliding velocity and relative humidity on friction coefficient of brass are investigated experimentally.

To do so, a pin-on-disc apparatus was designed and fabricated. Experiments are carried out when different types of steel pin such as mild steel (MS) and stainless steel 304 (SS 304) slide on brass disc under sliding velocity ranging from 20 to 100 cm/sec and relative humidity 60% and 80%. During experiment, normal load was kept constant at 10 N. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. Results show that friction coefficient decreases with the increase in sliding velocity and relative humidity. It is found that the magnitudes of friction coefficient are different for different mating pairs. It is also observed that at 60% relative humidity, the magnitudes of friction coefficient of brass-SS pair are higher than that of brass-MS pair. On the other hand, at 80% relative humidity, there is a little difference in the values of friction coefficient of brass-SS and brass- MS pairs.

Dewan Muhammad Nuruzzaman et al.[57]: In this research, friction and wear of copper and aluminium are investigated experimentally using a pin-on-disc apparatus. In the experiments, mild steel pin slides on copper or aluminium disc at different normal load conditions 10, 15, and 20 N. Experiments are also carried out at different sliding velocities 1, 1.5 and 2 m/s. The effects of duration of rubbing on the friction coefficient of copper and aluminium are investigated. Finally, as a comparison, it is found that friction coefficient and wear rate of copper are much lower than that of aluminium within the observed range of normal load and sliding velocity.

Vijay patidar et al.[58]: In the present paper experimentally investigate the effects of normal load and sliding speed on the friction coefficient and wear properties of an aluminium disc sliding against mild steel pin. To do so, a pin-on-disc apparatus was designed and fabricated.LM6 aluminium is most successful materials used for recent works in the industry. Metal LM6 aluminium significantly improved properties including hardness and wear resistance compared to alloys or any other metal. Friction and wear test is done by pin-on-disc method and the microscopic examination done by scanning electron microscope (SEM).The investigation results show that LM6 aluminium good tribological properties and used in automobile components for reliable, long life and high performance.

MohdShadab Khan et al. [59]: Wear is a continuous process in which material is degraded with every cycle. Scientists are busy in improving the wear resistance. Approximately 75%

failure in components or machine parts is due to wear. The present paper investigates experimentally the effect of orientation and normal load on Aluminium alloy and calculating weight loss due to wear. To do so, a multi-orientation pin-on-disc apparatus was designed and fabricated. Experiments were carried out under normal load 05-20 N, speed 2000 rpm. Results show that the with increasing load weight loss increases at all angular positions. The loss in weight is maximum at zero degree (horizontal position) and minimum at ninety degree (vertical position) for a particular load. Maximum wear occur when the test specimen is held at 0o angle minimum wear occur when the specimen is held at 90o angle for given applied load The circumferential distance travel is constant for all positions and for all load but still mass loss varies.

Mohammad A. Chowdhuryet al. [60]: Tribological characteristics of steel combinations are observed in this study using rotating tribometer. Experiments are done under different roughnesses of pin slides on stainless steel disc for different operating conditions certain trends are obtained between friction and rubbing durations. During experiment, it is found that there are significant relationship between friction coefficient and operating parameters. In fact, at initial stage friction coefficients of tested material are increased at a particular level with time and finally the friction becomes steady for remaining investigation period. Studies indicate that lower values of friction are obtained with higher loads for SS 202 slides against different roughnesses of mild steel counter face. Under similar conditions, higher values of frictions are found with higher values of sliding velocity. In addition to that, wear rates show higher values with higher load and velocity conditions. Tribological characteristics are varied for different roughnesses of pin materials under experimental ranges of two influencing parameters.

1.4 Application

- They have various applications in chemical, nuclear, power and other engineering industries.
- They have good wear resistance properties.
- The nature of friction, wear and their control plays an important role in different engineering operations.

- This can be annealed and annealed 304 stainless steel has several uses in industries like chemical, refrigeration, paper and food processing, beverage, screws, machinery parts, car headers and architecture and many more.

- This may also be used for bellows, flexible metal hose, spinning, tubing and numerous other stainless applications. Study of friction and wear behaviour is thus important in the characterization of annealed AISI 304 stainless steel along with the evaluation of other mechanical properties.
- Stainless steel is a major component in industrial, commercial, and consumer products. Typical application of AISI 304 stainless steel includes but not limited to car headers, various machinery parts, screws, valves, lining of coal hopper, utensils, marine applications and like others. This steel can't be hardened by heat treatment process however can be heat treated for reliving stresses.

1.5 Scope and Objective of the Present Work

Though the present work is concerned with Experimental Investigation of friction and Wear of Heat treated AISI 304 Stainless Steel against EN-8 stainless steel Using a MultiTribotester and effect of Microstructure Behaviour on Wear.

CHAPTER 2

2. THEORITICAL FRAME WORK

In this chapter some basic terminologies in connection with the present thesis work have been discussed at length for making the theoretical back bone of project.

2.1Tribology

The term tribology comes from “ tribos ” and “ ology ”, it is Greek word . “ tribos ” means“ rubbing” or “to rub” and ology means “the study of”[25].

Tribology is the study of science and engineering between two interacting surfaces in relative motion. It includes the field of study and application of the principles of friction, lubrication and wear. Tribology is a branch of mechanical engineering and materials science.

A tribometer is an instrument that measures tribological quantities, such as coefficient of friction, friction force, and wear, between two surfaces in contact [17-21, 28&29].

These records contain critically evaluated tribological data for a group of materials measured under specific tribological use or test conditions. The counter face material, the contact environment, and other parameters associated with the data are specified to the extent that such information was available in the original report. Blank spaces in the data records indicate data not available. Note carefully the conditions used when the data were obtained, since most materials are sensitive to changes in conditions. Note that the materials data in records of this type may not be complete in all cases because they depend on the original source.

A Multitribometer is an instrument that measures tribological quantities, such as coefficient of friction, friction force, and wear volume, between two surfaces in contact [46].

2.2 Tribometer

A tribometer is an instrument that measures tribological parameters such as coefficient of friction, frictional force and wear between two surfaces in contact and under relative motion [17-21, 28&29].The tribometers critically record and in some cases evaluate tribological data for a group of materials measured under specific test conditions. A multi tribometer is an instrument that measures tribological quantities such as coefficient of friction, frictional force, wear and working temperature between two surfaces in contact [46].

2.2.1 Types of Tribometers

Measurement of tribological parameters like friction and associated wear is done using an instrument known as 'tribometer'. Tribometers are often referred to by the specific contact arrangement they simulate or by the original equipment developer. Several arrangements are:

i. Four ball
ii. Pin on disc
iii. Block on ring
iv. Bouncing ball
v. Schwingungs- Reibungs- and Verschleisstest (SRV) test machine
vi. Twin disc

2.2.2 Type of Operation

i. Block on Roller operation
ii. Cylinder on Roller operation
iii. Ball on Roller operation
iv. Roller on Roller operation
v. Pin on plate
vi. Ball on plate

2.2.3 Fundamental Concepts of Tribology

- Friction and friction of coefficient are not a material property, it is a system property.
- Wear Rate or wear resistance depends on the wear mode, which is a function of the tribosystem [67].
- The amount of material receiving the load is not constant; it varies depending on the pressure, the roughness of the rubbing surface.
- The actual contacts of solids are discrete, and deformation takes place in material micro fragments to which the provisions of the classical theory of elasticity of the homogeneity and isotropy of the element the body do not apply.
- In the calculation of wear we evaluate the characteristic of the fracture process, in contrast to the calculations of strength which examine the conditions of non – failure of bodies.
- In friction the properties of materials change significantly, and it is very difficult to determine in advance the extent of this change and hence the new destruction conditions [70].

2.3 Friction

A simple tribometer is described by a hanging mass and a mass resting on a horizontal surface, connected to each other via a string and pulley. This arrangement is describe in figure2.1. The coefficient of friction, μ, when the system is stationary, is determined by increasing the hanging mass until the moment that the resting mass begins to slide. Then using the general equation for friction force:

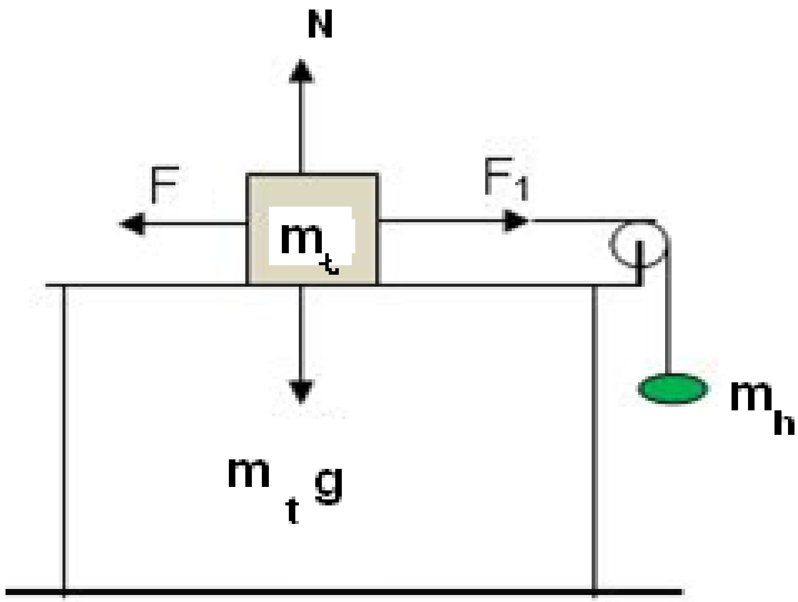


Figure 2.1: hanging mass a string and pulley arrangement [70].

Friction force is given by:

$$F=\mu N$$

Normal force is given by:

$$N=m_t g$$

Where, N the normal force, is equal to the weight (mass x gravity) of the sitting mass (m_t) and F, the loading force, is equal to the weight (mass x gravity) of the hanging mass (m_h).The force F_1 that is applied to the object due to the weight supported by the string.

To determine the kinetic coefficient of friction (dynamic coefficient of friction, μ_k).The hanging mass is increased or decreased until the mass system moves at a constant speed. In both cases, the coefficient of friction is simplified to the ratio of the two masses:

$$\mu = m_H / m_T$$

This graph shows that static friction behavior is linear and after sometimes it showing it cross the limiting value ($F=\mu_s N$).Then Dynamic force comes in consider in sliding motion between two bodies. Dynamic force value decreasing due to decrease in dynamic coefficient of friction (μ_k). Static and dynamic friction behaviour shown by Graphic figure 2.2.

Where, Static coefficient of friction: μ_s and Dynamic coefficient of friction: μ_k

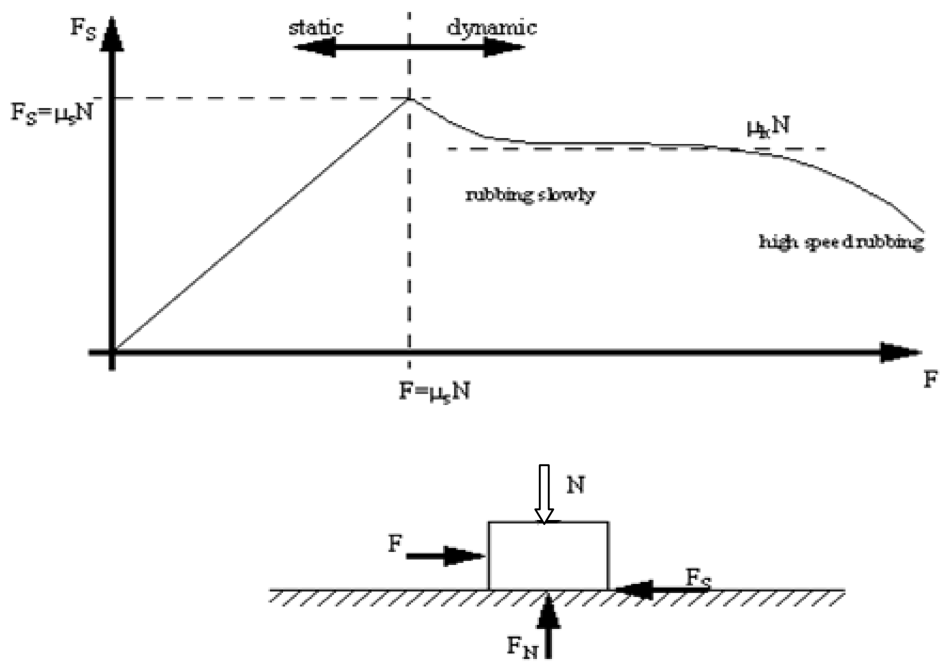


Figure 2.2: Static and dynamic friction behaviour [70]

The graph of applied load versus friction helps illustrate the nature of friction. Notice that while the force is static, the force increases linearly up to the limit.

After the object begins moving the force can be approximated with a constant value, using the dynamic coefficient of friction (μ_k).

Note that dynamic friction is shown to be lower than the maximum static friction.In most test applications using Tribometer, wear is measured by comparing the mass or surfaces of test specimens before and after testing. Equipment and methods used to examine the worn surfaces include optical microscopes, scanning electron microscopes, optical interferometer and mechanical roughness testers [46, 47& 62].

2.3.1Physical Characteristics of Surface Layer

The characteristics of surface layer metal and alloys have significant impact on many of the performance characteristics of the workpiece and particular on their wear resistance. The quality of the surface is a complex of the physical and mechanical properties of the surface layer such as roughness, microhardness, residual stresses etc. In the process of technological processing of surface layers as well as running in sliding on surface layer significantly change their structure and properties. Since the friction is due to process occurring in very thin surface layers. The friction force depends on the physic-mechanical properties of these days.

Which differ in their properties from the layers located at depth. The reason is that the binding forces of atoms in the surface layer are not symmetric ,and the atoms cannot occupy a position corresponding to the minimum value of energy within the material .The distortion of the structure of the surface layers show the process of friction under influence of deformation of these layers and temperature change[70].

2.3.1.1Deformed Layer

The metallurgical properties of the surface layer of a metal, alloy or a ceramic can vary markedly from the bulk of the material as a result of the forming process with which the material surface was prepared. For example, in grinding, lapping, machining, or polishing, the surface layers are plastically deformed with or without a temperature gradient and become highly strained. Residual stresses may be released of sufficient magnitude to affect dimensional stability.

The strained layer is called the deformed (or work hardened) layer and is an integral part of the material itself in the surface region. The deformed layer can also be produced during the friction process.

The amount of the deformed material present and the degree of deformation that occurs are functions of two factors: (1) the amount of work or energy that was put into the deformation process; and (2) the nature of the material. Some materials are much more prone to deformation and work hardening than are others. The deformed layer would be more severely strained near the surface. The thickness of the lightly and heavily deformed layers typically ranges from 1 to 10 and 10 to 100 μm, respectively.

We generally find smaller grains in the deformed zone from recrystallization of the grains. In addition, the individual crystallite or grains with interface rubbing can orient themselves at the surface. The properties of the deformed layers can be entirely different from the annealed bulk material. Likewise, their mechanical behavior is also influenced by the amount and the depth of deformation of the surface layers[25].

2.3.1.2Cause of Surface Roughness

Surface texture is the repetitive or random deviation from the nominal surface that forms the three-dimensional topography of the surface. Surface texture includes: (1) roughness (nano and microroughness); (2) waviness (macroroughness); (3) lay; and (4) flaws.Nano- and microroughness are formed by fluctuations in the surface of short wavelengths, characterized by hills (asperities) (local maxima) and valleys (local minima) of varying amplitudes and spacings, and these are large compared to molecular dimensions. Asperities are referred to as peaks in a profile (two dimensions) and summits in a surface map (three dimensions).Nano- and microroughness include those features intrinsic to the production process.These are considered to include traverse feed marks and other irregularities within the limits of the roughness sampling length. Waviness is the surface irregularity of longer wavelengths and is referred to as macroroughness. Waviness may result from such factors as machine or workpiece deflections, vibration, chatter, heat treatment, or warping strains.Waviness includes all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length.

Lay is the principal direction of the predominant surface pattern,ordinarily determined by the production method. Flaws are unintentional, unexpected, and unwanted interruptions in the texture. In addition, the surface may contain gross deviations from nominal shape of very long wavelength, which is known as error of form. They are not normally considered part of the surface texture. A question often asked is whether various geometrical features should be assessed together or separately. What features are included together depends on the applications[25&47].

2.4 Wear

Wear is basically removal (or displacement) of material from one body when subjected to contact and relative motion with another body [67].However, this is too simple explanation about wear. There are many complex mechanism and analysis about wear which will be discussed in the subsequent sections.

2.4.1 Primary Wear Modes:

1. Abrasive Wear, Scratching: The harder material scratches the softer material. Abrasion is the Microscopic forces of mechanical (includes elastic and plastic deformation).

2. Adhesive Wear: crystal structure, natural oxide formation all influence adhesive wear. Adhesion is the Microscopic forces of molecular. When objects touch – there are forces between them. (Includes electrostatic, Van der Waals, metallic bonds).

3. Fretting/Fretting Corrosion: Small adhesive pull-outs occur at the boundary. Often these oxidize, so sometimes called “fretting corrosion.

4. Erosive Wear, Cavitation, Impact: Dependency on particle size, shape, composition, angle of impingement, as well as ductility of “target”.

5.Rolling Contact Fatigue: Reversing sub-surface shear each time the roller or ball passes over the surface. Accumulation of these stresses leads to subsurface crack formation, usually at a microstructure in homogeneity. Cracks grow toward surface and particle spalls off

6.Tribo-Corrosion :Can happen with erosion or sliding wear

2.4.2Wear Analysis:

The Wear Coefficient, K

K → volume of material removed per unit load and sliding distance.

Units of k are: $mm^3/N\cdot m$

K can be used to predict component lifetimes, providing the tribosystem does not change wear modes. Duty cycle and directionality can influence wear Start-stop can be much more damaging than continuous motion .Unidirectional sliding is very different from reciprocating sliding. Friction and wear is a system property, it is not a material property [67].

A solid surface, or more exactly a solid–gas or solid–liquid interface, has a complex structure and complex properties dependent upon the nature of solids, the method of surface preparation, and the interaction between the surface and the environment. Properties of solid surfaces are crucial to surface interaction because surface properties affect real area of contact, friction, wear, and lubrication. In addition to tribological functions, surface properties are important in other applications, such as optical, electrical and thermal performance, painting, and appearance. Solid surfaces, irrespective of the method of formation, contain irregularities or deviations from the prescribed geometrical form. The surfaces contain irregularities of various orders ranging from shape deviations to irregularities of the order of interatomic distances. No machining method, however precise, can produce a molecularly flat surface on conventional materials. Even the smoothest surfaces, such as those obtained by cleavage of some crystals, contain irregularities the heights of which exceed the interatomic distances. For technological applications, both macro- and micro/nanotopography of the surfaces (surface texture) are important [25&47].

2.5 Lubrication

Lubrication is used in order to reduce the friction force of interaction the contact bodies.

The role of a lubricant is to:

- Reduce Friction
- Prevent / Minimize Wear
- Transport Debris away from Interface
- Provide Cooling [67]

2.6Test Material

Stainless steels are iron-base alloys; containing a minimum of 10- 20% Cr and some time with other alloying elements like Ni etc.

Stainless steels are classified mainly as

- Austenitic
- Ferrite
- Martensitic
- Duplex(50% Ferrite and 50% austenite)

Austenitic stainless steels have FCC crystal structure and they generally contain around 18% Cr and 8% Ni. They have various applications in chemical, nuclear, power and other engineering industries. They have high toughness, very good ductility and good corrosion resistance properties.

There are many grades of austenitic stainless steels, the most popular of which are 304 and 304L. Those Two account for about half of the total stainless steel production in the United States. Those are the two Grades we will address on this data sheet. Other grades include 316 316L, 317, 317L, 321, 347. Stainless Structural's can manufacture shapes in almost any of the austenitic grades, plus nickel, duplex and exotic Alloys. Austenitic (18-8) stainless steel alloys possess significant beneficial properties. They are strong, light, Ductile, aesthetically pleasing and readily available in a variety of forms. They resist corrosion and oxidation; fabricate and clean easily; and prevent contamination of products. They have also exhibited Good strength and toughness when exposed to cryogenic conditions.

Stainless Structural’s offers two variations of the 18-8 stainless steels:

- AISI 304 (S30400)
- AISI 304L (S30403)

Of the two types, 304 is the most widely used alloy, followed by 304L. 304L is typically used for welded Applications that must resist intergranular corrosion. The essential difference is in the carbon content, which is required to be lower in 304L than 304. These two grades are frequently supplied dual certified as304/304L. This means that the carbon content, which is expressed as a maximum in both grades, is incompliance with the maximum carbon content called for by each specification. In addition the due certified material meets the minimum mechanical properties, which are required to be higher in 304.

Therefore, the dual certification means the material is in full compliance with both specifications, providing the higher minimum strength requirements for one grade along with the better intergranular corrosion Resistance of the other[28,30,44&45].

2.6.1 Properties

This section outlines the chemical composition, physical and mechanical properties of SS304.Stainless Steel Chemical Composition Chart India and Technical Data Sheet AISI 304.

2.6.1.1 Chemical Composition

AISI SS-304 stainless steel has been selected as test material and EN-8 stainless steel (AISI 1040) as standard material of roller against which the test material will slide.

Chemical composition of AISI SS-304 stainless steel is given in table2.1.

Table 2.1: Chemical composition of AISI SS-304 stainless steel

C	**Si**	**Mn**	**P**	**S**	**Ni**	**Cr**	**Fe**
0.08	1.00	2.00	0.04	0.03	8.00-10.50	18.00-20.00	Balance

Chemical composition of EN-8 stainless steel is given in table2.2.

Table 2.2: Chemical composition of EN-8 stainless steel

C	**Mn**	**Si**	**S**	**P**
0.36-0.44	0.60-1.00	0.10-0.30	0.05 max.	0.05 max.

EN-8 stainless steel has been surface hardened to withstand wear and is used as a standard roller in the tribo tester. The hardness can be 50-55 HRC after surface hardening operation. The hardness of the roller material in this experiment is 55 HRC.

2.6.1.2 Physical Properties

The physical properties of austenitic stainless steel alloys are given below.

The following are accepted general physical properties of austenitic stainless steel alloys:

- Density - 0.285 lb/in3 (7.90 g/cm3)
- Melting Range - 2550 - 2590°F (1399 - 1421°C)
- Modulus of Elasticity - 29 Mpsi (200 GPa) - (In Tension)

2.6.1.3 Mechanical Properties

The mechanical properties of austenitic stainless steel alloys are as noted below.

In accordance with ASTM A240 and ASME SA-240

Minimum Mechanical Properties SS304 is given in table 2.3.

Table 2.3: Minimum Mechanical Properties

Property	Minimum Mechanical Properties SS304
0.2% Offset Yield Strength: psi MPa	30,000 205
Ultimate Tensile Strength: psi MPa	75,000 515
Percent Elongation in 2 in. or 51 mm	40.0
Hardness, Max.: Brinell RB	201 92

2.6.2 The Effects of the Alloying Elements

The microstructure of a material can strongly influence the physical properties such as strength, toughness, ductility, hardness, corrosion resistance, wear resistance and so on. The microstructure of an alloy depends on such variables as the alloying elements present, their concentrations, and the heat treatment of the alloy (i.e., the temperature, the heating time at temperature, and the rate of cooling to room temperature) [35].The alloying elements each have a specific effect on the properties of the steel. It is the combined effect of all the alloying elements and, to some extent, the impurities that determine the property profile of a certain steel grade. In order to understand why different grades have different compositions a brief overview of the alloying elements and their effects on the structure and properties may be helpful. The effects of the alloying elements on some of the important materials properties will be discussed in more detail in the subsequent sections. It should also be noted that the effect of the alloying elements differs in some aspects between the hardenable and the non-hardenable stainless steels.

- Chromium (Cr)

This is the most important alloying element in stainless steels. It is this element that gives the stainless steels their basic corrosion resistance. The corrosion resistance increases with increasing chromium content. It also increases the resistance to oxidation at high temperatures. Chromium promotes a ferritic structure.

- Nickel (Ni)

The main reason for the nickel addition is to promote an austenitic structure. Nickel generally increases ductility

and toughness. It also reduces the corrosion rate and is thus advantageous in acid environments. In precipitation

hardening steels nickel is also used to form the intermetallic compounds that are used to increase the strength.

- Molybdenum (Mo)

Molybdenum substantially increases the resistance to both general and localised corrosion. It increases the mechanical strength somewhat and strongly promotes a ferritic structure. Molybdenum also promotes the formation secondary phases in ferritic, ferritic-austenitic and austenitic steels. In martensitic steels it will increase the hardness at higher tempering temperatures due to its effect on the carbide precipitation.

- Manganese (Mn)

Manganese is generally used in stainless steels in order to improve hot ductility. Its effect on the ferrite/austenite balance varies with temperature: at low temperature manganese is a austenite stabiliser but at high temperatures it will stabilise ferrite. Manganese increases the solubility of nitrogen and is used to obtain high nitrogen contents in austenitic steels.

- Silicon (Si)

Silicon increases the resistance to oxidation, both at high temperatures and in strongly oxidising solutions at lower temperatures. It promotes a ferritic structure.

- Carbon (C)

Carbon is a strong austenite former and strongly promotes an austenitic structure. It also substantially increases the mechanical strength. Carbon reduces the resistance to intergranular corrosion. In ferritic stainless steels carbon will strongly reduce both toughness and corrosion resistance. In the martensitic and martensitic-austenitic steels carbon increases hardness and strength. In the martensitic steels an increase in hardness and strength is generally accompanied by a decrease in toughness and in this way carbon reduces the toughness of these steels.

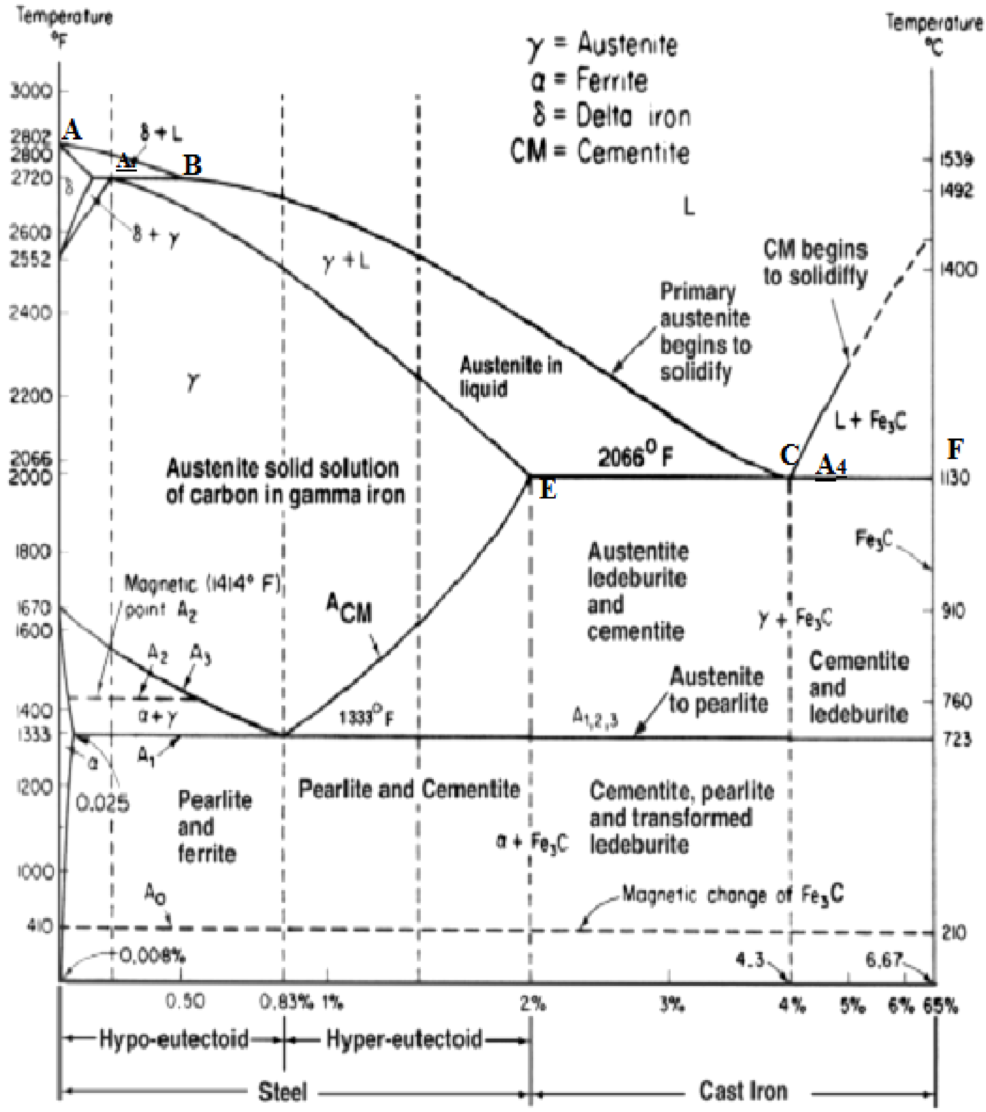
- Sulphur (S)

Sulphur is added to certain stainless steels, the free-machining grades, in order to increase the machinability. At the levels present in these grades sulphur will substantially reduce corrosion resistance, ductility and fabrication properties, such as weldability and formability.

In addition the due certified material meets the minimum mechanical properties, which are required to be higher in 304[28, 30, 40-45]

2.6.3Heat Treatment

Heat treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical) [21, 37-40&48]. The iron-carbon constitution diagram of heat treatment has been shown in Figure. 2.3.



Iron Carbon Constitutional diagram

Figure. 2.3 Iron Carbon Constitutional Diagram [21]

Critical temperatures:

A=arrest means arrest

A_0= a subcritical temperature ($<A_1$) = Curie temperature of cementite=210°C

A_1=Lower critical temperature=eutectoid temperature=727°C= this is known as Lower critical temperature line for steel. This line signifies the transformation of Pearlite into Austenite upon heating of eutectoid steel.

A_2=Curie temperature of ferrite=768/770°C= this is known as Curie temperature line. This line signifies the transformation of Magnetic to Non-magnetic. On which take place in iron carbon alloy on heating. Where carbon content has no affect on Curie temperature in iron carbon alloy.

A_3=upper critical temperature=$\gamma+\alpha$ /γ phase field boundary

=composition dependent=910-727°C= this is known as upper critical line for Hypo-eutectoid steel. This line signifies the transformation of ferrite into Austenite upon heating of hypo-eutectoid steel.

A_4=Eutectic temperature=1147°C

A_5=Peritectic temperature=1495°C

A_{cm}=γ/γ+cementite phase field boundary=composition dependent =727-1147°C [48] = this is known as upper critical line for Hyper-eutectoid steel. This line signifies the transformation of cementite into Austenite upon heating of hyper-eutectoid steel.

The complete iron-carbon phase or constitutional diagram represents the relationship between temperatures, compositions, and structures of all phases are formed by iron and carbon under conditions of equilibrium. So it is very slow cooling process. A portion of this diagram for alloys ranging up to 6.7 percent of carbon is reproduced in Figure2.3; the upper limit of carbon in cast iron is usually not in excess of 5 percent. The left-hand boundary of the diagram represents pure iron, and the right-hand boundary represents the compound iron carbide, Fe_3C, commonly called cementite. The alloy containing 4.3 percent of carbon, called the eutectic alloy of iron and cementite.

And freezes at a constant temperature as indicated by the point C. This temperature is 2,065 °F (1130°C), considerably below the freezing point of pure iron.

Carbon has an important effect upon the transformation temperatures (critical points) of iron. It raises the A_4 temperature and lowers the A_3. This effect on the A_3 temperature is very important in the heat treatment of carbon and alloy structural steels, while that on the A_4 is important role in the heat treatment of certain high alloy steels, particularly of the stainless types. It is possible for solid iron to absorb or dissolve carbon, the amount being dependent upon the crystal structure of the iron and the temperature.

The body-centered (alpha or delta) iron can dissolve but little carbon, whereas the face-centered (gamma) iron can dissolve a considerable amount, the maximum being about 2.0 percent at 2,065°F(1130°C), ((Figure2.3). This solid solution of carbon in gamma iron is termed austenite. The solid solution of carbon in delta iron is termed delta ferrite, and the solid solution of carbon in alpha iron is termed alpha ferrite, or, more simply, ferrite. The mechanism of solidification of iron carbon alloys, especially those containing less than about 0.6 percent of carbon, is rather complicated and is of no importance in the heat treatment of carbon steels and cast irons. It is sufficient to know that all iron-carbon alloys containing less than 2.0 percent of carbon (that is, steel) will, immediately or soon after solidification is complete, consist of the single phase austenite. Cast irons will consist of two phases immediately after solidification—austenite and cementite (Fe_3C). Under some conditions this cementite formed on cooling through the temperature horizontal *ECF* will decompose partly or completely into austenite and graphite (carbon) [21].

Micro constituents vs. Cooling Rate

- Spheroidite:

i. Spherical “globs” of Fe_3C in Ferrite

ii. If tempered for a long time, Fe_3C forms “spheres” and grows inside Ferrite.

iii. Very soft, easy to machine

- Pearlite: Layers of α ferrite and Fe_3C:It is defined as eutectoid mixture of ferrite and cementite.
    - Course Pearlite
    - Fine Pearlite

- Bainite:

i. 200 – 500 °C Transformation

ii. Upper (550-350°C)-Rods of Fe_3C

iii. Lower (350-250°C)-Fe_3C Precipitates in Plates of Ferrite

iv. It is still Ferrite and Cementite! It's just acicular.

- Ledeburite: It is defined as eutectic mixture of austenite and cementite.

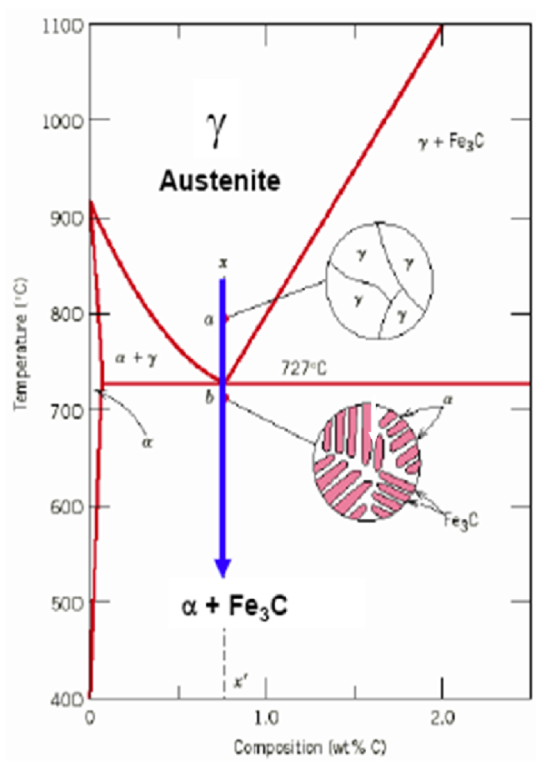
Theoretically, iron must be alloyed with a minimum of 0.03 percent of carbon before the first minute traces of pearlite can be formed on cooling. If the steel is held at a temperature just below A_1(either during cooling or heating), the carbide in the Pearlite tends to coalesce into globules or spheroids. This phenomenon, known as spheroidization, will be discussed subsequently. Hypoeutectoid steels (less than 0.80% of carbon), when slowly cooled from temperatures The microstructures of slowly cooled hypoeutectoid steels thus consist of mixtures of ferrite and pearlite. The lower the carbon content, the higher is the temperature at which ferrite begins to precipitate and the greater is the amount in the final structure.

Hypoeutectoid steels (less than 0.80% of carbon), when slowly cooled from temperatures above the A_3, begin to precipitate ferrite when the A_3 line is reached. As the temperature drops from the A_3 to A_1, the precipitation of ferrite increases progressively and the amount of the remaining austenite decreases progressively, its carbon content being increased. At the A_1 temperature the remaining austenite reaches eutectoid composition (0.80% of carbon) and, upon further cooling, transforms completely into pearlite.

The microstructures of slowly cooled hypoeutectoid steels thus consist of mixtures of ferrite and pearlite .The lower the carbon content, the higher is the temperature at which ferrite begins to precipitate and the greater is the amount in the final structure[21&37-40].

Figure 2.4 shows that Eutectoid reaction which tells about different microstructure formation in different percentage of carbon and temperature.

EUTECTOID REACTION (PEARLITE FORMATION)



- Austenite precipitates **Fe_3C** at Eutectoid Transformation Temperature (727°C).

$$\gamma \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \alpha + Fe_3C$$

- When cooled slowly, forms Pearlite, which is a micro-contituent made of ferrite (α) and Cementite (**Fe_3C**), looks like Mother of Pearl.

Figure2.4: Eutectoid reaction [48]

Figure 2.5 shows that hypo-eutectoid reaction which tells about different microstructure formation in different percentage of carbon and temperature.

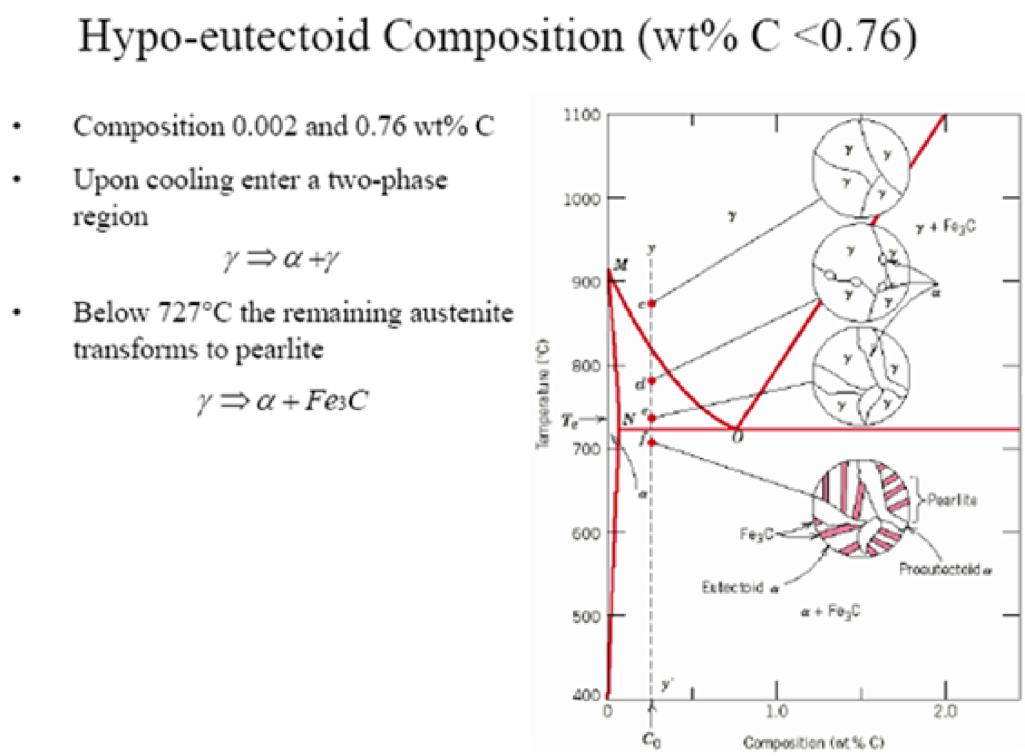


Figure2.5: Hypoeutectoid Reaction [48]

2.6.3.1Heat Treatment Quenching Medium:

(1)Annealing:

Quenching Medium: Furnace

- Full Annealing: Increase Ductility and Toughness
- Process Annealing: Stress relieving
- Spherodise annealing: Machinability increase
- Diffusion Annealing: To homogenize the chemistry of material

(2)Normalising:

Quenching media: Air

Produce hard surface and tough core.

(3) Quenching media: Water

Vapour blanket forms. This is reason for heat transfer decreases due to which Non uniform cooling occurs.

(4) Quenching media: Oil

Vapour blanket is not formed. This is reason for uniform heat transfer due to which uniform cooling occurs.

2.6.3.2 Objectives of Heat Treatment (Heat Treatment Processes)

The major objectives are

- to increase strength, harness and wear resistance (bulk hardening, surface hardening)
- to increase ductility and softness (tempering, recrystallization annealing)
- to increase toughness (tempering, recrystallization annealing)
- to obtain fine grain size (recrystallization annealing, full annealing, normalizing)
- to remove internal stresses induced by differential deformation by cold working, non-uniform cooling from high temperature during casting and welding (stress relief annealing)
- to improve machinability(full annealing and normalizing)
- to improve cutting properties of tool steels (hardening and tempering)
- to improve surface properties (surface hardening, corrosion resistance-stabilizing treatment and high temperature resistance-precipitation hardening, surface treatment)
- to improve electrical properties (recrystallization, tempering, age hardening)
- to improve magnetic properties (hardening, phase transformation)[21].

2.7 Microstructure

Some elements extend the γ-loop in the iron–carbon equilibrium diagram, e.g. nickel and manganese. When sufficient alloying element is added, it is possible to preserve the face-centred cubic (FCC) austenite at room temperature, either in a stable or metastable condition. Chromium added alone to plain carbon steel tends to close the γ-loop and favour the formation of ferrite. However, when chromium is added to a steel-containing nickel it retards the kinetics of the $\gamma \rightarrow \alpha$ transformation, thus making it easier to retain austenite at room temperature. The presence of chromium greatly improves the corrosion resistance of the steel by forming a very thin stable oxide film on the surface, so that stainless steels are now the most widely- used materials in a wide range of corrosive environments both at room and elevated temperatures. Added to this, austenitic steels are readily fabricated and do not undergo a ductile/brittle transition which causes so many problems in ferritic steels. This has ensured that they have become a most important group of construction steels, often in very demanding environments. Nevertheless, there are also some important ferritic stainless steels [30]. The microstructure of an alloy depends on such variables as the alloying elements present, their concentrations, and the heat treatment of the alloy (i.e., the temperature, the heating time at temperature, and the rate of cooling to room temperature)[35].

Generally, Austenite forms inside the grain boundary. Polished sample held at austenitisation temperature. Grooves develop at the prior austenite grain boundaries due to the balancing of surface tensions at grain junctions with the free surface [48].Photographic view given in figure 2.6(a)

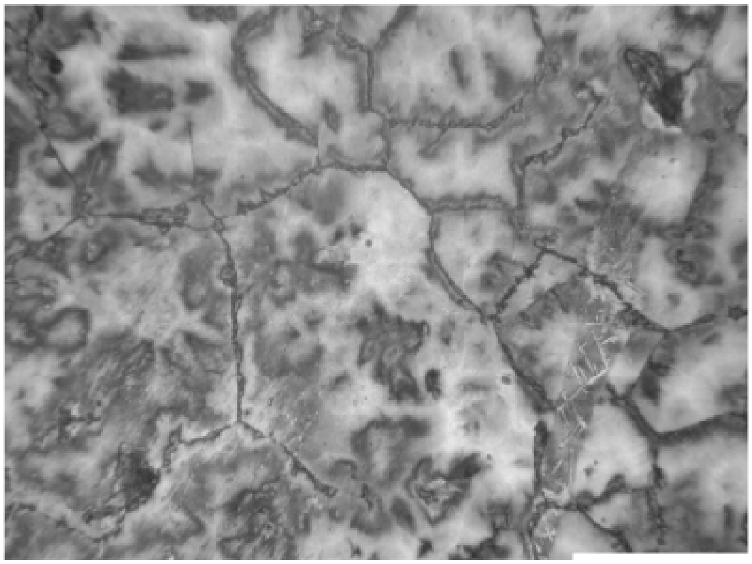


Figure2.6 (a)**:** Polished sample held at austenitisation temperature. Grooves develop at the prior austenite grain boundaries due to the balancing of surface tensions at grain junctions with the free surface [48].

Generally, Allotriomophic Ferrite forms at the grain boundary and some dark idiomorphic ferrite inside the grain boundary. Schematic diagram of grain boundary Allotriomophic (marked by a form different from the normal or expected because of development in special circumstances- not having their own regular shape) ferrite, and intragranular dimorphic (occurring in or representing two distinct forms) ferrite given in figure 2.6(b) [48].

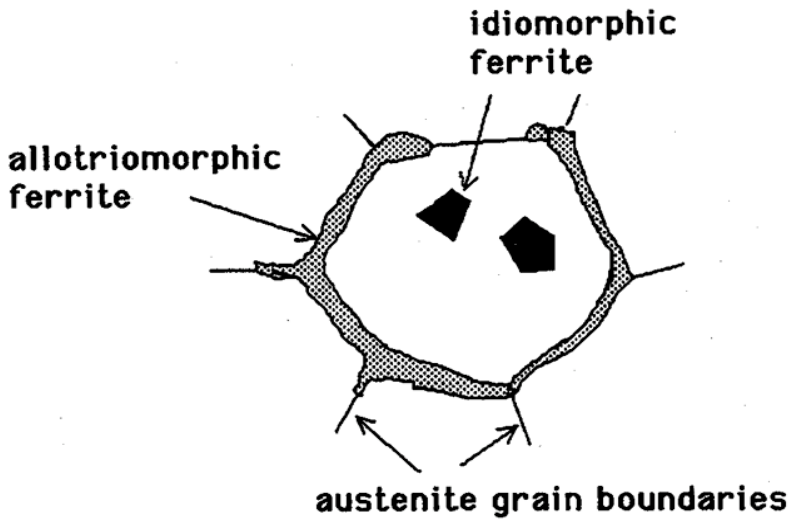


Figure2.6 (b): Schematic diagram of grain boundary Allotriomophic ferrite, and intragranular dimorphic ferrite [48].

It is well known that AISI 304 can also undergo a martensitic transformation under cyclic loading conditions and the increase in martensite fraction with increasing number of cycles at different temperature [63].

2.7.1Ferrite

Ferrite, also known as α-ferrite (α-Fe) or alpha iron, is a solid solution of limited amounts of carbon in iron with a body-centered cubic (B.C.C) crystal structure. It is this crystalline structure which gives steel and cast iron their magnetic properties, and is the classic example of a ferromagnetic material.

In pure iron, ferrite is stable below 910 °C (1,670 °F). Above this temperature the face-centred cubic form of iron, austenite (gamma-iron) is stable. Above 1,390 °C (2,530 °F), up to the melting point at 1,539 °C (2,802 °F), the body-centred cubic crystal structure is again the more stable form, as delta-ferrite (δ-Fe). Ferrite above the critical temperature A_2 (Curie temperature) of 771 °C (1,044 K; 1,420 °F), where it is paramagnetic rather than ferromagnetic.

The term is beta ferrite or beta iron (β-Fe). The term beta iron is not any longer used because it is crystallographically identical to, and its phase field contiguous with, α-Fe.

α-ferrite (α-Fe) : It is defined as interstitial solution of carbon in alpha iron. Which is pure form of iron having bcc structure with average no of atom is equal to two (2) & magnatic in character upto 768 °C during heating.

Gamma ferrite (γ-Fe): It is defined as interstitial solution of carbon in gamma iron (γ-Fe). Which is pure form of iron having fcc structure with average no of atom is equal to four (4) &Non magnatic in character.

Delta-ferrite (δ-Fe): It is defined as interstitial solution of carbon in gamma iron. Which is pure form of iron having bcc structure with average no of atom is equal to two (2) &Non magnatic in character.

2.7.2Martensite

Martensite is formed in carbon steels by the rapid cooling (quenching) of austenite at such a high rate that carbon atoms do not have time to diffuse out of the crystal structure in large enough quantities to form cementite (Fe_3C). As a result, the face-centred cubic austenite transforms to a highly strained body-centred tetragonal form of ferrite that is supersaturated with carbon. The shear deformations that result produce large numbers of dislocations, which is a primary strengthening mechanism of steels. The highest hardness of pearlitic steel is 400 Brinell whereas martensite can achieve 700 Brinell.

- Martensite:

i. Rapid Cooling

ii. Diffusionless transformation of FCC to BCT (more volume)

iii. Lenticular structure

iv. Very hard & very brittle.

Martensite needs to be tempered to get better ductility. This happens when Fe_3C is allowed to precipitate from the super cooled Martensite [48].This is shown in figure 2.6(c)

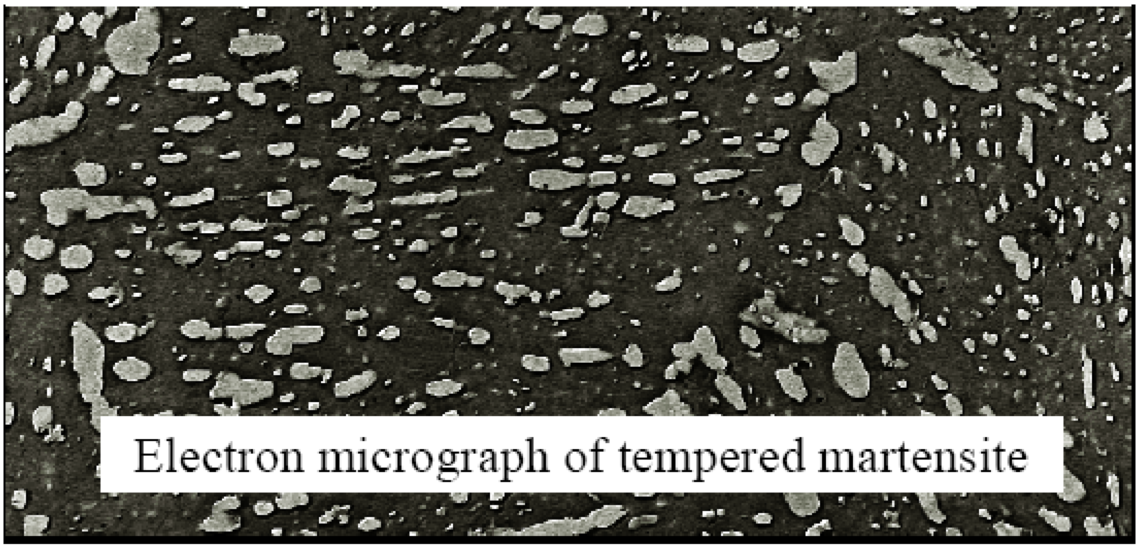


Figure2.6(c): Electron micrograph of tempered martensite [48]

2.7.3Austenite

Austenite is originally used to describe an iron-carbon alloy, in which the iron was in the face-centred-cubic (gamma-iron) form. It is now a term used for all iron alloys with a basis of gamma-iron. Austenite in iron-carbon alloys is generally only evident above 723°C, and below 1500°C, depending on carbon content. However, it can be retained to room temperature by alloy additions such as nickel or manganese [37-40].

2.7.4Iron Carbide or Cementite (Fe_3C): The body-centered (alpha or delta) iron can dissolve with little carbon. It is defined as interstitial compound of iron and carbon having the maximum carbon solubility of 6.67 percent in it.

2.8 Hardness

Hardness is the property of trial that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Measurement of Hardness: Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure. Hardness of materials has probably long been assessed by resistance to scratching or cutting impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry [34, 65&66].

2.8.1 Measurement of Hardness

There are three general types of hardness measurements:

1) Scratch hardness

   - The ability of material to scratch on one another

2) Indentation hardness

• Major important engineering interest for metals.

• Different types: Brinell, Meyer, Vickers, Rockwell hardness tests.

3) Rebound or dynamic hardness

• The indentor is dropped onto the metal surface and the hardness is expressed as the energy of impact.

2.8.2 Hardness Measurement Instruments

Hardness of materials has been assessed by resistance to scratching or cutting impression and measure by instruments such as Brinell, Vickers, and Rockwell.

2.8.2.1Brinell Hardness

• J.A. Brinell introduced the first standardised indentation-hardness test in 1900. The Brinell hardness test consists in indenting the metal surface with a 10-mm diameter steel ball at a load range of 500-3000kg, depending of hardness of particular materials.

The load is applied for a standard time (~30 s), and the diameter of the indentation is measured. Average value of two readings of the diameter of the indentation at right angle. The Brinell hardness number (BHN or HB) is expressed as the load P divided by surface area of the indentation. Brinell indentation is shown in figure2.7.

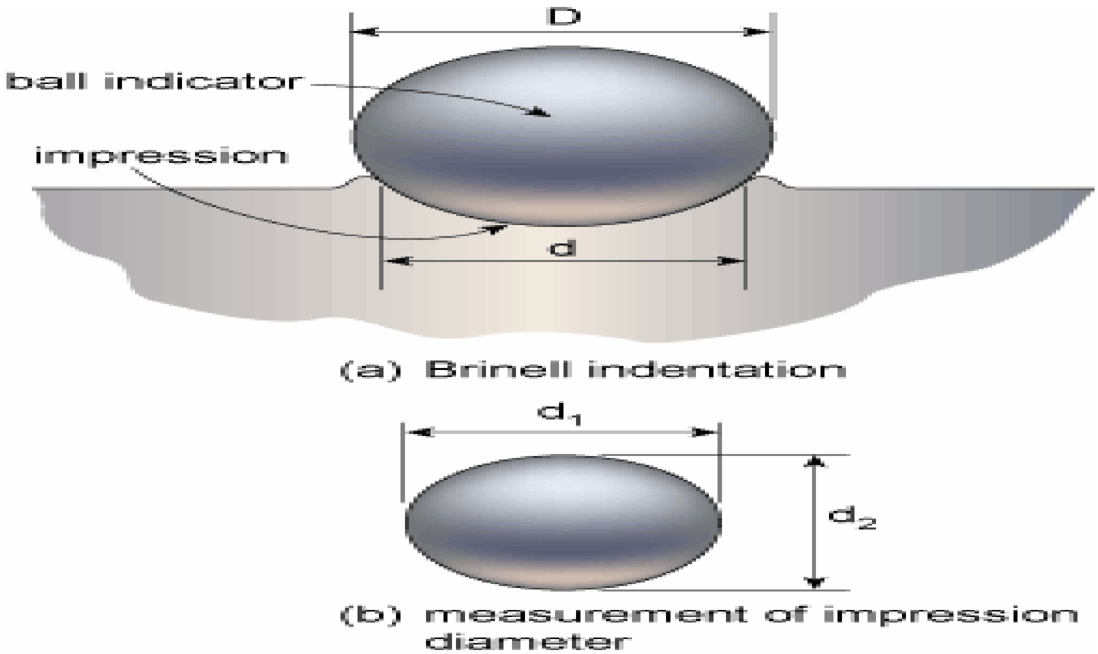


Figure2.7: Brinell indentation [65]

2.8.2.1.1 Advantages and disadvantages of Brinell hardness test

- Large indentation averages out local heterogeneities of microstructure.
- Different loads are used to cover a wide range of hardness of commercial metals.
- Brinell hardness test is less influenced by surface scratches and roughness than other hardness tests.

2.8.2.1.2 Limitations

• The test has limitations on small specimens or in critically stressed parts where indentation could be a possible site of failure [65&66].

2.8.2.2Rockwell Hardness Tester

The most widely used hardness test in the world and generally accepted due to

(1) Its speed

(2) Freedom from personal error.

(3) Ability to distinguish small hardness difference.

(4) Small size of indentation.

The hardness is measured according to the depth of indentation, under a constant load.Hardness of the heat treated samples has been measured in a Rockwell hardness tester. Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Rockwell 'B' scale has been used for this purpose. Indentations have been made on all the specimens with a 1/16″ steel ball indenter under a load of 100 Kgf. The Rockwell Hardness test is probably the most commonly performed hardness test. It is easy to perform and the hardness number is obtained directly from the testing machine. The hardness number, which is read directly from a dial or digital scale on the testing machine, is inversely related to the additional penetration caused by application of the major load. There are numerous variations of the Rockwell Hardness test involving different penetrators and loads. A 120^o diamond cone indenter with a slightly rounded point is used for testing very hard materials. Most materials are tested using hardened steel ball indenters. Steel indenters include 1/16, 1/8, 1/4, and 1/2 inch diameters. Major loads can be 60, 100 or 150 kg. (Superficial hardness tests use lower load values).

2.8.3.2.1 Rockwell hardness instruction

(1)Cleaned and well seated indenter and anvil.

(2)Surface which is clean and dry, smooth and free from oxide.

(3) Flat surface, which is perpendicular to the indenter.

(4) Cylindrical surface gives low readings, depending on the curvature.

(5)Thickness should be 10 times higher that the depth of the indenter.

(6) The spacing between the indentations should be 3 or 5 times the diameter of the indentation.

(8) Loading speed should be standardised.

Different type of Indenter, Load use for different applications in given in table2.4.

Table2.4: Different type of Indenter, Load use for Different Applications

Scale Symbol	Indenter	Major Load, kgf(1kgf=9.81N)	Dial Figure	Typical Applications or use on sample
A	Diamond	60	Black	Case Carburized surface Cemented carbides, thin steel, and shallow case-hardened steel
B	1/16" ball	100	Red	Unhardened steel etc. in rolled drawn or cast metal, Copper alloys, soft steels, aluminum alloys, malleable iron
C	Diamond	150	Black	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardened steel, and other materials harder than HRB 100
D	Diamond	100	Black	Thin steel and medium case-hardened steel and pearlitic malleable iron
E	1/8" ball	100	Red	Cast iron, aluminum and magnesium alloys, bearing metals
F	1/16" ball	60	Red	Annealed copper alloys, thin soft sheet metals
G	1/16" ball	150	Red	Phosphor bronze, beryllium copper, malleable irons. Upper limit is HRG 92, to avoid possible flattening of ball.
H	1/8" ball	60	Red	Aluminum, zinc, lead
K	1/8" ball	150	Red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not give anvil effect.plasticmaterial,Bakelite,vulcanized Fiber, nylon, polystyrene, flexiglass.
L	1/4" ball	60	Red	
M	1/4" ball	100	Red	
P	1/4" ball	150	Red	
R	1/2" ball	60	Red	

Most Rockwell hardness tests are performed on either the Rockwell B or C scales. The B scale utilizes a 1/16 inch diameter penetrator and a 100 kg major load while the C scale uses a conical diamond penetrator and a 150 kg major load [34, 65&66].

2.8.2.3 Vickers Hardness

• Vickers hardness test uses square-base diamond pyramid as the indenter with the included angle between opposite faces of the pyramid of 136^{o}.

• The Vickers hardness number (VHN) is defined as the load divided by the surface area of the indentation.

• Vickers hardness test uses the Loads ranging from 1-120 kgf, applied for between 10 and 15seconds.

• Provide a fairly wide acceptance for research work because it provides a continuous scale of hardness, for a given load.

2.8.2.3.1Impressions Made By Vickers Hardness

• A perfect square indentation made with a perfect diamond pyramid indenter would be a square.

• The pincushion indentation is the result of sinking in of the metal around the flat faces of the pyramid. This gives an overestimate of the diagonal length (observed in annealed metals).

• The barrel-shaped indentation is found in cold-worked metals, resulting from ridging or piling up of the metal around the faces of the indenter. Produce a low value of contact area giving too high value.

Types of diamond-pyramid indentation:

(a) Perfect Indentation

(b) Pincushion indentation due to sinking in.

(c) Barrelled indentation due to ridging [34, 65&66].

Different Types of diamond-pyramid indentation given in figure2.8 (a): Perfect Indentation, figure2.8 (b) Pincushion indentation due to sinking in, figure2.8 (c) Barrelled indentation due to ridging.

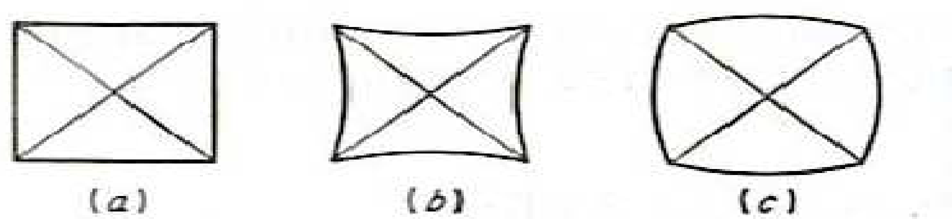


Figure2.8 (a), (b), (c): Impressions made by Vickers hardness [66]

Types of diamond-pyramid indentation given in figure2.8:

(a) Perfect Indentation

(b) Pincushion indentation due to sinking in.

(c) Barrelled indentation due to ridging [34, 65&66].

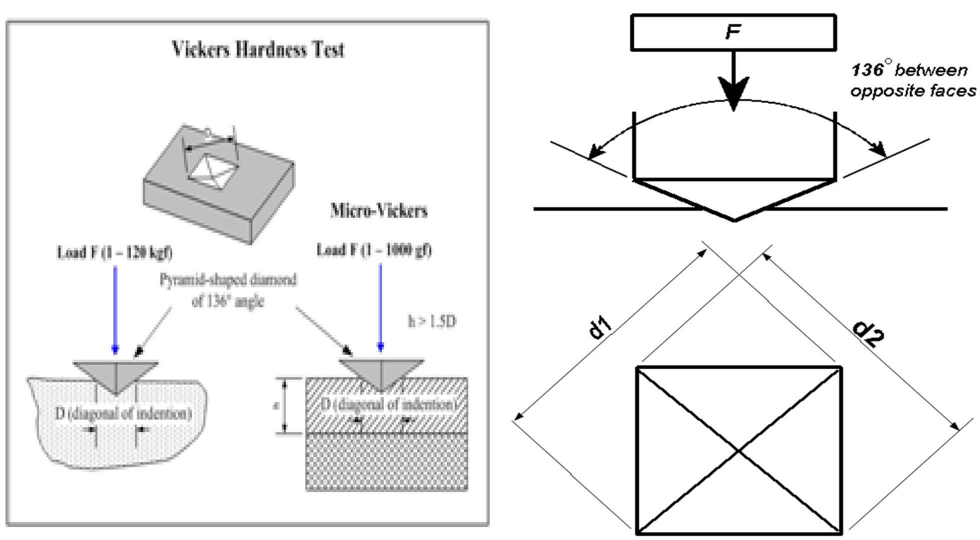
2.9 Microhardness

Determination of hardness over very small areas or point that is molecular matrix for example individual constituents, phases, requires hardness testing machines in micron scales.

2.9.1Theory

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 Kgf given in figure2.9. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the Kgf load by the square mm area of indentation.

Photographic view of Micro Vickers hardness test and Vickers Load set up in figure2.9 (a) and figure2.9 (b).



(a) **(b)**

Figure 2.9: (a) Micro Vickers hardness test, Figure 2.9: (b) Vickers Load set up

F = Load in Kgf

d = Arithmetic mean of the two diagonals, d1 and d2 in mm

HV = Vickers hardness

Vickers hardness measurement by this formulation:

$$HV = \frac{2F sin 136^0/2}{d^2}$$

$HV = 1.854\frac{F}{d^2}$ Approximately

Photographic view of Vickers Indenter given in figure 2.9(c).

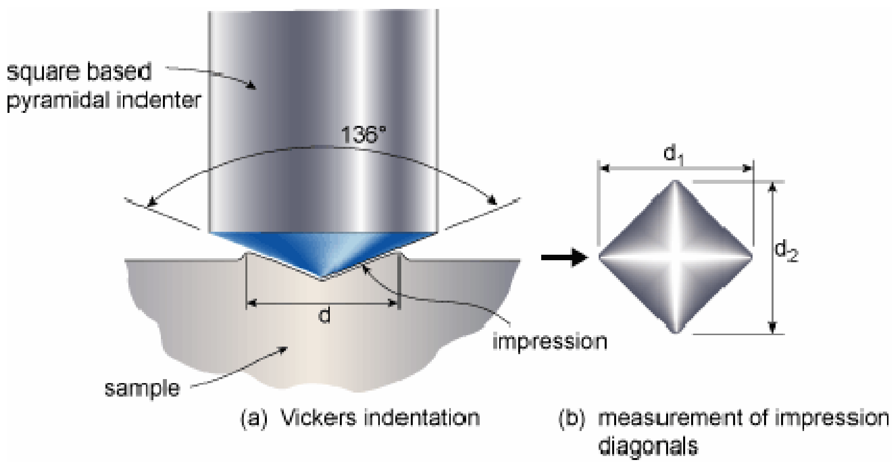


Figure 2.9(c): Vickers Indenter

Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines [34 65&66].

2.10 Ferrite Measurement

Measurement of Percentage of the ferrite content by using the Feritscope. This calculation require for understanding about wear rate of experimental sample.

2.10.1Feritscope

The Feritscope measures according to the magnetic induction method. A magnetic field generated by a coil begins to interact with the magnetic portions of the specimen. The changes in the magnetic field induce a voltage proportional to the ferrite contenting a second coil. This voltage is then evaluated. All magnetic portions in the otherwise non-magnetic structure are measured, i e., in addition to delta ferrite and other ferritic portions also strain-induced martensite.

It is easy to measure the ferrite content accurately when using the Feritoscope FMP30. Upon probe placement on the surface of the specimen, the reading is displayed automatically and stored in the instrument.

The determination of the delta ferrite on base material by the magnetic method was carried out at the Feritoscope FM

2.10.2Measurement Advantage

• Fast measurement and data storage

• Automatic measurement acquisition upon probe placement or through “external trigger”

• Enabled or disabled acoustic signal

• Overwriting of erroneous measurements or previously stored readings

• Selectable tolerance limits

• Measurement data presentation as an analog bar with display of specification limits

• Continuous display: Continuous display of threading when probe is placed on the specimen storing with externally triggered measurement acquisition.

• Outlier rejection functions for the automatic elimination of erroneous measurements [61].

CHAPTER 3

3. EXPERIMENTAL WORK

Various experiments have been conducted on the test materials as mentioned earlier. This chapter includes the detailed discussions on the experiments. All the experiments have been conducted in the laboratories of Mechanical Engineering department (Production Engineering specialization) as well as partially in the department of Metallurgy and Material Science of the Jadavpur University, Kolkata.

3.1Heat Treatment

Heat treatments of the samples have been done in an electric muffle furnace. Microprocessor controlled brand N´R electric muffle furnace [N.R. Scientific Kolkata make] has the dimension of 10″×5″×5″, with a maximum temperature limit of 1100°C. It is not out of place to mention here that stainless steel type SS-304 is non-harden able by heat treatment, that is, can't be hardened though heat treatment as no phase changes occur on heating and subsequent cooling. However, softening is possible. Several research studies [(8-13) and references therein, 14, 22-27] have discussed several ways of softening processes. Based on the feasibility of studies this paper has selected some basic heat treatment operations. These are discussed in the following sub-section.

3.1.1Sensitization

Samples are heated at 660°C and allowed to dwell for 30 minutes at that temperature inside the furnace. Then cooling has been done in an open environment, that is, air cooling.

3.1.2 Annealing

Some samples have been heated from room temperature to 950°C and allowed to dwell for 2 hours at that temperature inside the furnace. After the operation the furnace has been switched off and the samples have been allowed to cool inside the furnace, that is, furnace cooling.

3.1.3 Normalizing

Some test specimens have been heated from room temperature of approximately 25°C up to a temperature of 950℃ and allowed to dwell at that temperature for 2 hours (soaking time). Rate of increment of temperature has been selected as10° per minute for all the cases. At the end of the operation specimens have been taken out of the furnace and allowed to cool in open air to attain room temperature.

3.1.4 Quenching

Sudden cooling is known as quenching. This has been accomplished by dipping the heated samples in an oil bath maintained at room temperature. Samples have been heated up to a temperature of 950°C with a dwelling time of 2 hours as before and then dipped immediately inside an oil bath maintained at room temperature. Cutting grade oil (grade 44) has been used as the quenching medium in this case.

3.1.5 Solution Annealing

Solution annealing of SS-304 dissolves any precipitated carbide phase at high temperature. Some sensitized samples are reheated at temperature of 1040°C with a soaking time of 30 minutes and then allowed to cool rapidly in water maintained at room temperature. This is, however, completely opposite to martensitic steels where this type of heat treatment would harden the steel instead of softening [37].

3.1.2Muffle Furnace: Muffle furnace is used for Heat Treatment of the SS 304 samples in the present work. The photographic view of the Muffle furnace is given in figure 3.1.Major specifications are given here under in the Table3.1.

Figure 3.1: photographic view of Muffle furnace

Working parameter:

Room Temperature=26^0c

Heating up to =950^0c

Duration time = 2 hours

Pv = Furnace Temperature

Sv= Controller Temperature

Specification of furnace:

Table3.1Specification of Muffle furnace

Brand	Dimension	Temperature	Make
N´R Muffle Furnace	10″×5″×5″	Maximum =1100°C Working =1000° C	N.R Scientific, Kolkata, West Bengal.

3.2Hardness Measurement

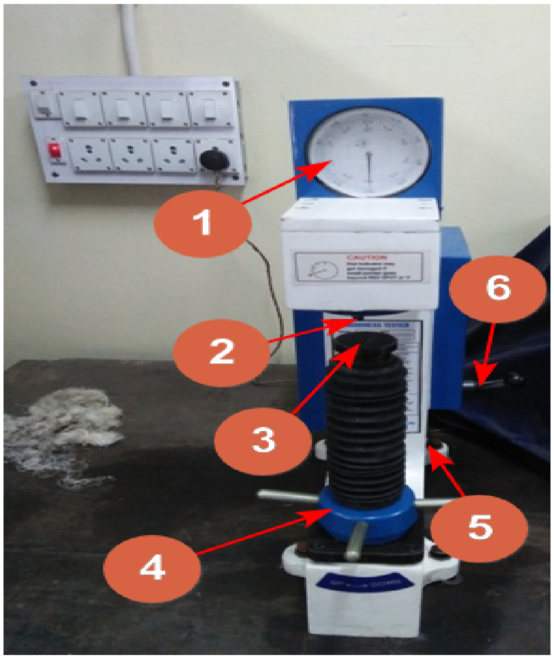
Hardness of materials has been calculated by resistance to scratching or cutting impression by using Rockwell hardness tester.

3.2.1 Rockwell Hardness Tester

Hardness of the heat treated samples has been measured in a Rockwell hardness tester.

Indentations have been made on all the specimens with a 1/16″ steel ball indenter under a load of 100 Kgf.

Photographic view of Rockwell hardness tester given in figure3.2 (a), Indenter and Anvil given in figure 3.2(b)& Indenter given in figure 3.2(c).



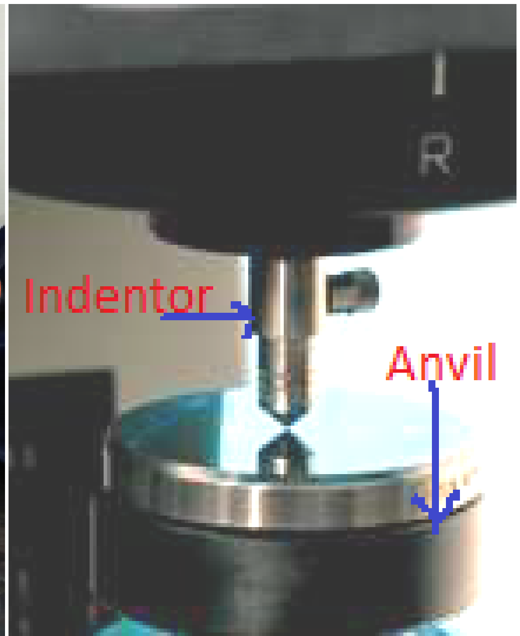


Figure 3.2(a): Rockwell hardness tester Figure 3.2(b): Indenter and Anvil

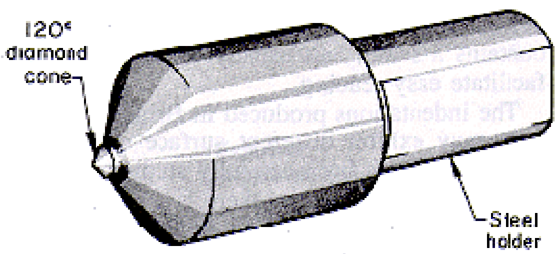


Figure 3.2(c): Indenter

3.2.2Rockwell Hardness Tester Parts:

(1.)Dial Gage

(2.) Indenter Holder

(2.) Anvil

(3.) Handle for up and down motion

(4.) Weights of Load Device

(5.) Crank Handle

3.2.3 Rockwell Hardness Tester Specification

Model: MRS

S.R NO: 2014/2260

Manufactured by: Meta Test Instrument (p) LTD.

Parameter:

Scale –B

Load- 100 kgf

Indentor-Diamond ball

Size-1/16″

3.3 Microhardness Measurement

Micro hardness of the samples has been measured in a micro hardness tester 'LM 248 AT' (LECO, serial no. XM8 116, Michigan). Included angle of the pyramid shaped diamond indentater is 136°. All the tests have been conducted at a magnification of 500X, test load of 100 gf and dwell time of 10 sec. Three indentations have been made at two different places on each sample and the average value is considered as the representative micro hardness. Figure3.3. shows the set up for micro hardness measurement.

Working Parameter:

Load = 100gf.

Magnification = x500.

Dwell time = 10 sec.

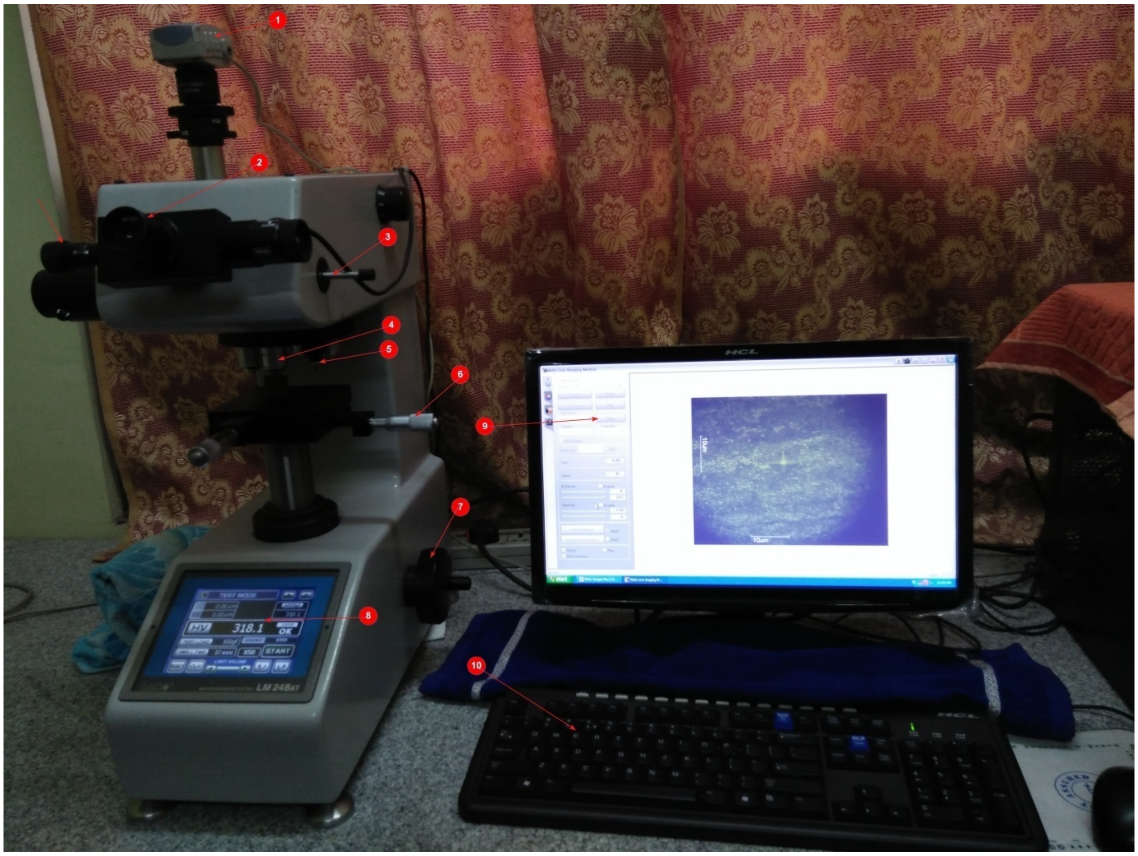


Figure3.3: Photographic view of Micro hardness tester ‘LM 248 AT’ (LECO, serial no. XM8 116, Michigan)

Micro hardness tester part:

1-Camera (just below Photo Tube)

2- Eyepieces (it has Dioptre Adjustment)

3-Seperating part between camera & Eyepieces

4- Objective lenses (just above Reverse Nosepiece or Nosepiece turret)

5-Indentor

6- Manual slider operation control

7- Coaxial focus

8-Display: output unit (Showing micro hardness and axis)

9-Monitor (output unit)

10-keyboard

Specification of micro-hardness tester is given in table 3.2.

Table 3.2 Specification of micro-hardness tester

Specification	**Value**
Model number	LM 248AT
Software	Amh 43
Zoom	10x – 50x
Indentation load	10 gf – 1 kgf

3.4Microscopic Observation

Many a times the physical properties and the mechanical behaviour, in particular, of a material depend on the microstructure. Microstructure is subject to direct microscopic observation using either optical or electron microscopes. In the present study a Trinocular microscope (Radical) has been used for the purpose. The surface of each sample has been polished using five grades of emery papers, courser to finer. Finally a felt polishing machine has been used to polish the surface with aqueous aluminium oxide (Al_2O_3) solution to give it a shinny, smooth and mirror like appearance. However, the surface roughness has not been measured in the present work. Standard Nital solution, a mixture of 3% nitric acid and 97% ethyl alcohol, has been used to etch the polished surface of the samples for microscopic observation as well as for the measurement of micro hardness.

3.4.1Preparation of a Specimen Microstructure

The specimen is ground on progressively finer SiC from 120 to 1000 grit, to produce a reasonably flat surface. It is then ground on the next finer paper such that the scratches produced are at right angles to those formed by the previous paper. When the scratches from the finer paper have been completely removed. This procedure is repeated through the range of papers available. We use four grade "EMERY" paper such as:

- coarse paper-1/0
- medium fine paper-2/0
- fine grade paper-3/0
- Very fine grade paper-4/0

We use four grade "EMERY" paper from coarse paper-(1/0) to Very finer grade paper-(4/0) progressively. we start polishing from coarse paper-(1/0) .It is then ground on the next finer paper (coarse finer paper-2/0)such that the scratches produced are at right angles to those formed by the previous paper. When the scratches from the finer paper (finer grade paper-3/0) have been completely removed. Then, we use Very fine grade paper-4/0 and getting surface is flat; in fact it needs to be optically flat, acting as a perfect mirror.

3.4.1.1 Polishing

it is essential that the surface is flat, in fact it needs to be optically flat, acting as a perfect mirror. Therefore, the specimen has to be "polished". This is done using rotating wheels covered with a cloth impregnated with a very fine abrasive compound, called felt cloth. We use aluminum oxide (Al_2O_3) solution in time to time for better surface finish and removing unwanted particle such as silicon carbide (SiC) and oil particle.

3.4.1.2 Solution of Nital etching: it is a mixture of nitric acid and alcohol commonly used for etching steels. It is especially suitable for revealing the micro structure of steels. Nitric acid is a strong oxidizer [69].Standard solution is prepared with 3% nitric acid and 97% ethyl alcohol.

The preparation of a specimen to reveal its microstructure involves.

- Sawing the section to be examined
- Mounting in resins (if sample is too small)
- Polishing using alumina powder on rotating wheel
- Etching in dilute acid (Nital for steel)
- Washing in Alcohol and drying

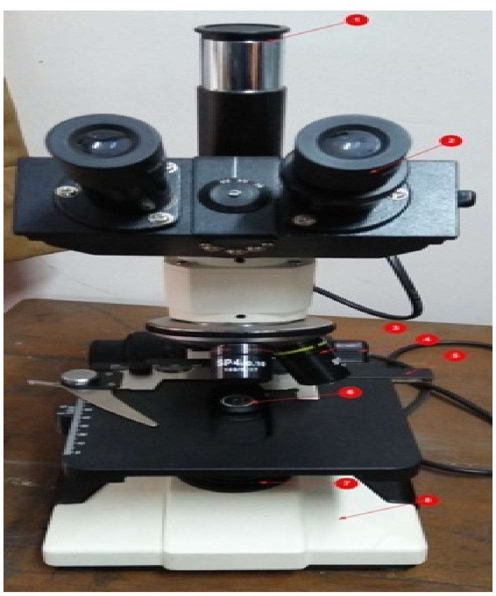
Typical magnifications used are between 50 x and 500x.

Our experimental microscopic magnifications range is 500x and 400x.

3.4.2 Microscope

Many times, the physical properties and, in particular, the mechanical behaviour of a material depends on the microstructure. Microstructure is subject to direct microscopic Observation, using Trinocular and optical microscopes.

Photographic view of the Trinocular microscope given in figure3.4 & Optical microscope figure 3.5.



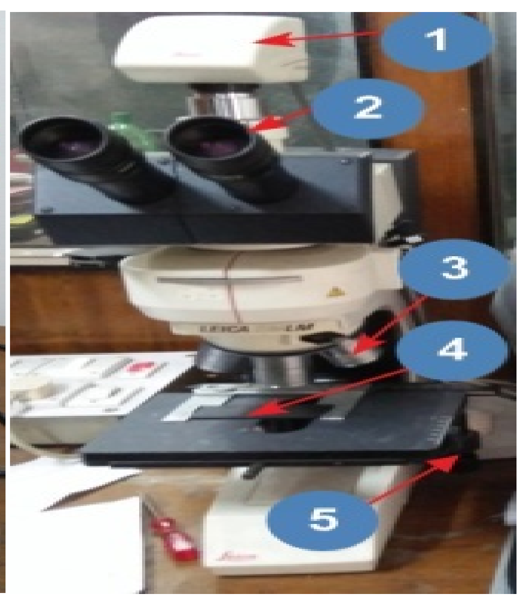


Figure 3.4: Trinocular Microscope (Radical)   Figure3.5: Optical Microscope

3.4.3 Trinocular Microscope (Radical) Part: Photographic view of the microscope given in figure 3.4:

1-Photo Tube

2-Eyepieces (it has Dioptres Adjustment)

3-Objective lenses (just above Reverse Nosepiece or Nosepiece turret)

4-Coaxial focus

5-Slider Path (just below Stage controls)

6-Led Lamp

7-Led lamp cover

8-Base

3.4.4 Optical Microscope Part: Photographic view of the microscope given in figure 3.5:

1-Camera (just below Photo Tube)

2- Eyepieces (it has Dioptres Adjustment)

3- Objective lenses (just above Reverse Nosepiece or Nosepiece turret)

4-Mechanical Stage

5- Stage controls

3.4.4.1Description:

1.) Eyepiece lens — magnifies the image from the objective. The standard size for relatively inexpensive microscopes is 23mm diameter, 18mm exit pupil, and 10 power. Some models also include other eyepiece powers like 16x or 20x. On models without a photo tube, the eyepiece lens may be replaced with a camera adapter for photo and video micrography. Eyepieces may be normal, wide-field, and/or extended-relief (longer viewing distance) for people with glasses.

2.) Nosepiece turret — the rotating part that holds the 3 or 4 objective lenses, making lens changes easy. Some of the better models have a "reverse nosepiece," which swing the unused objectives back under the frame arm, allowing easier access to the stage and specimens. They should *all* be made this way, as it is no more costly to do so. Having the objectives sticking out the front, in the way, is annoying, and is just a traditional hold-over from tilting microscopes that were used from the back.

3.) Objective lenses — the 3 or 4 lenses that directly observe and magnify the specimens on the slide. Various types are achromatic, plan-achromatic, plan-apochromatic, and phase-contrast. The quality of the objectives is the most important factor in the price and quality of the microscope.

4.) Stage — holds and manipulates the slide. In units with angled viewing, the stage (and thus the slide and sample) moves up and down for focusing, as opposed to the old straight-tube units where the stage was fixed and the entire optical assembly moved for focusing. Stages come in several types:

- Simple or plain — just a flat plane with a hole in it and leaf-spring clips to hold the slide down. The specimens in the sample are observed by pushing the slide around with the thumbs. Not suitable for higher magnifications. These appear in toy and entry-level educational microscopes.
- Simple, with add-on vernier slide holder — the leaf-spring clips of the simple stage are replaced with an add-on slide holder that uses finely-threaded shafts and knobs to move the slide around on the stage. They appear on mid-level educational microscopes, and will usually be called "mechanical" stages in the advertising. They should be called vernier slide holders, because that's what they are. The stage itself does not move x-y, just the slide.
- Mechanical Stage — sometimes called a double-layer stage, this type has two levels with rack-and-pinion gears and linear bearings between them, and the slide holder is built right into the stage. They are controlled by two coaxial knobs that extend downward from the right-rear corner of the stage, quite near the focus. Left and right movements are performed by moving the slide holder sideways on the stage.

Since moving around the sample is what we do the most, and the movements must be very fine and precise at high magnification, this type of stage is highly desirable and well worth a little extra cost.

5.) Focusing Knobs — these may be coaxial or separate, and they control the vertical position (z-axis) of the stage. Since they are the second-most used controls, they must be large, smooth-operating, on both sides, and without any annoying backlash. The focus knobs drive a pinion gear that drives a rack gear that attaches to the stage mount, which slides vertically in linear bearings within the frame. Coaxial focus uses a single rack-and-pinion, with a planetary reduction on the inner (fine) shaft. Separate course and fine focus use two rack-and-pinion setups, each with its own set of knobs. The fine focus rack has a very limited travel, and you frequently run out of range and have to re-center it then move the course focus a little, then fine focus again. The coaxial type is much more desirable, since it uses only one rack and you never run out of fine focus range until you hit the focus limit stop.

6.) Focus Limit Stop — usually just a fine-thread screw with a lock-nut, located right behind the stage. It is set to keep the user from ramming the sample into the longer (40x and 100x) objective lenses and damaging or breaking the slide, the cover slip, or the objective. This is very important, as the working distance between the long objectives and the cover slip is well under 0.5mm. Note that the 40x and 100x objectives will usually have a spring-loaded lens assembly, allowing the lens to retract a few millimetres and reduce the potential for lens damage, but any touching of the lens to the cover slip may force it down against the specimen, immobilizing or mashing live critters between the slide and the slip. The stop screw is set (then locked) by carefully focusing the 100x lens on a tiny speck of dust or single cell on the slide. This is about 0.10–0.15mm for most 100x objectives.

7.) Focus friction adjustment — usually a small lever or set-screw near the focus knob. It is adjusted tight enough to keep the stage from drifting downward during normal handling of the stage and sample. Models with coaxial focus usually do not have or need a focus friction, as the outer (coarse focus) shaft drives the inner (fine focus) shaft through a planetary bearing with a fairly high ratio and very thick grease, providing plenty of friction to keep the stage in position and maintain focus.

8.) Lamp Assembly — may be a simple mirror on very low-cost models (and most antiques), or may be an electric lamp with a dimmer control. The lamp itself may be tungsten, tungsten-halogen (longer life), fluorescent, or LED. By far the best, the modern white LED is cool, uses little power, lasts almost forever (≈50,000 hours), and best of all does not change colour as it is dimmed. The power requirements of LED are so low that some LED microscopes are battery-powered for field use. Halogen lights use 20–50 watts, put out a lot of heat that will cook our specimens, accelerate evaporation, melt plastic filters, and typically last about 1500 hours. Worst of all, they change colour, becoming reddish, when dimmed. Avoid halogen and go for the modern white LED—it really is worth the few extra dollars. Note that many modern microscopes are still being sold with halogen lamps, but they are gradually changing over to LED, making the halogen lamps obsolete.

9.) Base — the base should be stable and somewhat weighty, with vibration-isolating rubber feet. It usually houses the power supply, the lamp assembly, the fuse, the power switch, and dimmer control.

3.5Determination of Delta Ferrite

Determination of delta ferrite has been done on the base material by magneto inductive testing equipment ‘Fischer Feritscope FMP 30 (Finland)’ as shown in Figure 3.6.

3.5.1Feritscopic Observation

A Feritscope is used to measure the ferrite content in austenitic and duplex steel. Magnetic induction method is the basis of such measurement [12&13].

Photographic view of Feritscope FMP30 is given in figure3.6.

Figure3.6: Photographic view of Feritoscope FMP30

Proportions of delta ferrite, strain induced martensite and any other ferrite phases can be measured by this method Testing has been done on heat treated samples SS-304 stainless steel of size 20 mm × 20 mm × 8 mm. Ten readings have been taken in ten different places on the surface of each sample and the average value represents the corresponding reading. This test is based on the fact that the austenite is nonmagnetic and the delta ferrite is magnetic [64].

3.6Wear Test

Wear performed when Removal (or displacement) of material from one body when subjected to contact and relative motion with another body.

3.6.1. Friction and Wear Test

Friction and wear tests of the samples have been carried out in a multi tribo tester "TR-25" DUCOM (India), supported with Winducom 2006 software. Block-on-Roller configuration of the tester has been utilized for this purpose. The samples have been slid against EN-8 steel roller of 50mm diameter and hardness of 55HRB. Wear is measured in terms of displacements in microns with the help of a linear voltage resistance transducer in this set up [16]. All the tests have been carried out at an average room temperature of 25°C and humidity of approximately 85%-90%. All the samples have been cleaned thoroughly with acetone to remove any trace of oil, grease, dirt or dust. Based on different research studies [3 to 7 and references there in] rotational speed of the wheel (rpm), load on job (N) and duration of test run (sec) have been selected as the most important parameters for the wear test in the multi tribo tester. Weights of all the specimens have been measured before and after the wear test in an electronic analytical and precision balance (Sartorius BSA 223S, Germany; maximum range is 220 gm with a readability of 0.001gm). Difference of the two values indicates the weight loss of the specimen due to wear.

3.6.2Test Procedure

The main focus of our research study is pin on disc tribometer. The set up parameter of this Multi-Tribometer:

i. Speed : 375 rpm

ii. Load : 25 N

iii. Time : 1800 sec

Dead weights are placed on the loading platform which is attached at one end of a 1:5 ratio loading lever. A linear voltage resistance transducer is used for measuring wear in terms of wear depth. It is worth noting that, in general, wear is measured in terms of wear volume or mass loss. However, in the present case, wear is expressed in terms of displacement or wear depth. Hence, to ensure that the wear measurements are accurate, the wear depth results are compared with the weight loss of the specimens and almost linear relationship is observed between the two for the range of test parameters considered in the present study.

Photographic view of the Test setup Block-on-roller configuration of Multi Tribotester “TR-25” (DUCOM, India) ”Tribometer”given in figure 3.7:

Figure 3.7 : Test setupBlock-on-roller configuration of Multi Tribotester “TR-25” (DUCOM, India) ”Tribometer”

Photographic view of the figure 3.7(a): Multi Tribotester Lever Load Mechanism and Figure3.7 (b): Sample Holder, Sample. Roller Mechanism

Figure 3.7(a) : Multi Tribotester Lever Load Mechanism

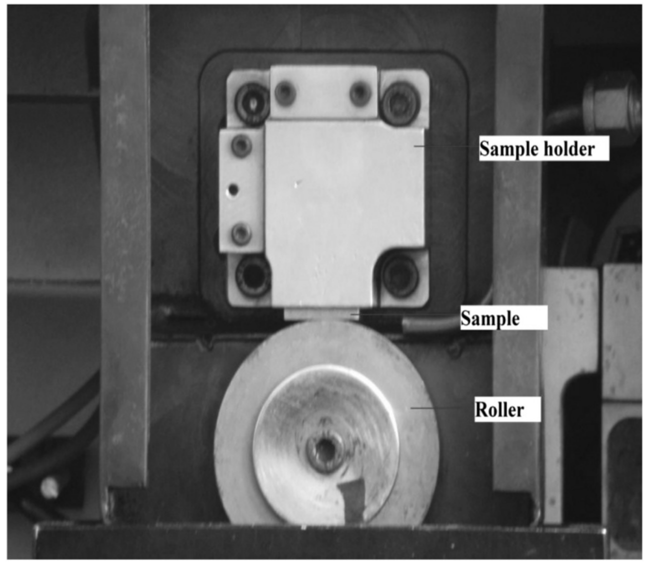


Figure3.7(b): Sample Holder, Sample. Roller Mechanism

Sample Dimension: SS-304 stainless steel samples of dimension 20 mm ×20 mm×8 mm have been procured for wear test. This dimension has been considered based on the requirement of the size of the specimen holder of the multi tribo-tester.

Photographic view of the Test setup Block-on-roller configuration of Multi Tribotester "TR-25" (DUCOM, India) "Tribometer" component given in figure :

1-Indicate workpiece or sample

2- Indicate sample Holder

3- Indicate Roller

4- Indicate Load (1/2 kg)

5- Indicate power suppleir (output unit)

6 - Indicate Central Processing Unit

7- Monitor(Display)

8-Keyboard(input unit)

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Hardness Values in HRB Scale

The hardness values in HRB scale have been indicated in Table 4.1.

Working parameter:

Scale –B

Load- 100 Kgf

Indentor-Diamond ball

Size-1/16″

Table 4.1: Hardness of the heat treated samples in HRB scale

Sample No.	Heat Treatment Type				
	Sensitized	**Furnace Cooled**	**Air Cooled**	**Oil Cooled**	**Solution Annealed**
I	67	53	54	51	49
II	68	53	55	51	50
Avg.	67.5	53	54.5	51	49.5

It has been observed from the data that hardness is maximum in case sensitized sample. This may be due to the carbide precipitation at the grain boundaries of the samples. Oil cooed and solution annealed specimens show almost equal hardness.

Hardness of air cooled, that is, normalized samples are slightly higher than that of annealed samples. It is not out of place to

mention here that in case of solution annealing treatment the samples have been cooled in water maintained at room temperature. This has been done to minimize exposure in the carbide precipitation region. However, in case of martensitic steels this type of rapid cooling will lead to the development of hardened surface.

Weight loss data of the samples due to wear after tribo testing are been given in Table 4.2.

Table 4.2: Weight loss of the specimens due to wear

Sample No.	**Weight Loss (w_1-w_2) in gm**				
	Sensitized	Furnace Cooled	Air Cooled	Oil Cooled	Solution Annealed
I	0.076	0.069	0.057	0.098	0.092
II	0.074	0.063	0.061	0.093	0.088
Avg.	0.075	0.066	0.059	0.096	0.090

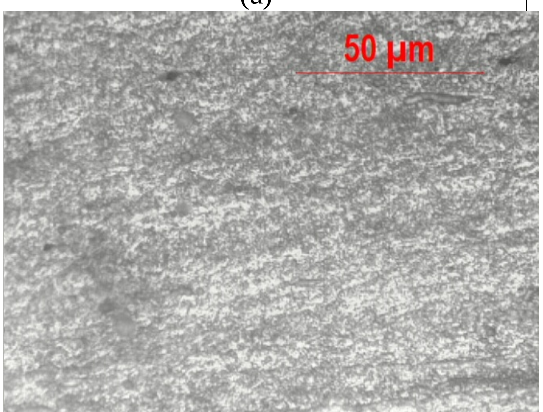
4.2Photographic View Microstructure of SS304 Heat Treated in 500x & 400x Resolution.

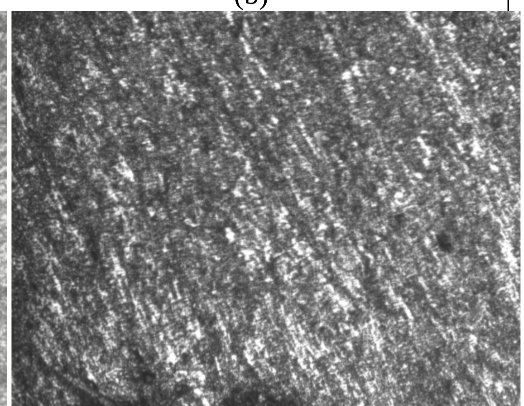
Here given different type of microstructure of a material, this shows that how influence, hardness and wear resistance. The microstructure of SS304 sample depends on such variables as the micro constituents elements present, their concentrations, and the heat treatment of the sample (i.e., the temperature, the heating time at temperature, and the rate of cooling to room temperature).

It is well known that AISI 304 can also undergo a martensitic transformation under cyclic loading conditions and the increase in martensite fraction with increasing number of cycles at different temperatures [63].

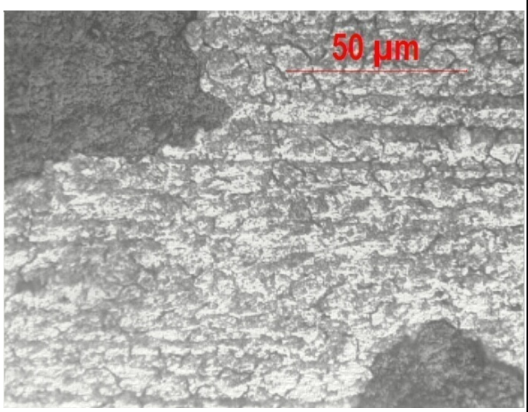
Micro hardness values of the heat treated samples at different matrix or region have been furnished in Table 4.4. The values of the micro hardness indicate the probable microstructures of the particular region. This is further supported by corresponding micrographs. The micrographs of all the heat treated samples at two magnifications namely 500 × and 400 × have been furnished in Figure. 4.1 (a) – (j).

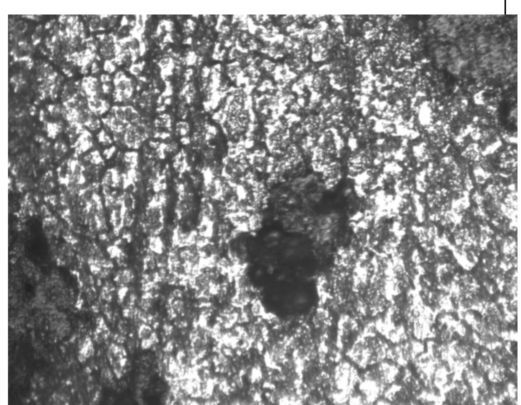
(a) (b)





(c) (d)





(e) (f)

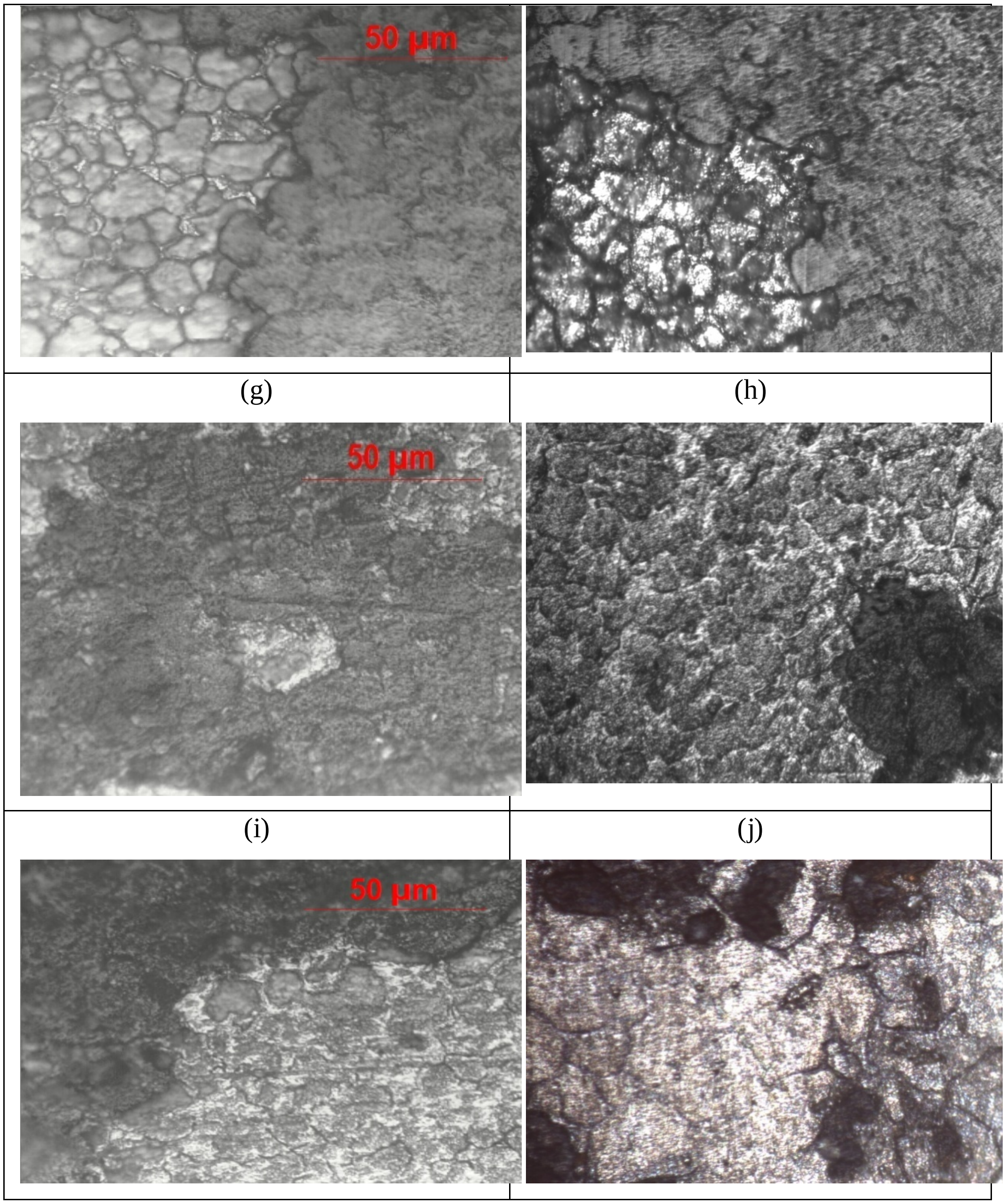


Figure 4.1 Micrographs of different heat treated SS-304 samples showing the microstructures of (a) sensitized sample at 500 × (b) sensitized sample at 400 × (c) air cooled sample at 500 × (d) air cooled sample at 400 × (e) furnace cooled sample at 500 × (f) furnace cooled sample at 400 × (g) oil quenched sample at 500 × (h) oil quenched at 400 × (i) solution annealed sample at 500 × and (j) solution annealed sample at 400 ×.

Micro hardness values have been observed in different zones or regions of the samples microstructures. There are three prominent matrix or zone in the microstructures namely white, black and mixture of white and black. From the micro hardness values in different matrix of different micrographs, as obtained after different heat treatments and tabulated in table 4.4, following analysis can be made:

Figure 4.1 (a) and 1(b) indicates the microstructures of sensitized sample where white and black matrix in both the figures indicates the formation of martensite. Mixture of martensite and carbide is present in the black matrix or region and some part contains ferrite, where as white matrix or region is austenite in case of air cooled samples as indicated in Figure 4.1(c) and (d) respectively. Microstructures of furnace cooled samples have been depicted in Figure. 4.1(e) and 4.1 (f). Figure 4.1(e) indicates that austenite has been transformed into ferrite and carbide (chromium carbide). White matrix in Figure 4.1(f) reveals the presence of austenite within grain boundary. On the grain boundary carbide deposition is prominent. Oil quenched sample shows the presence of ferrite as evidenced as black band in Figure4.1 (g). The entire black matrix here represents carbide. Figure 4.1(h) shows the existence of austenite (white), ferrite and carbide. In case of solution annealed samples the existence of austenite and formation of ferrite has been revealed from Figure 4.1 (i).

Figure 4.1 (j), on the other hand, indicates the formation of martensite inside the grain boundaries. It is needless to be mentioned that austenite already contains carbon.

4.3 Percentage Composition of Microstructures in Heat Treated Sample

Fischer Feritscope measures the bcc percentage in the heat treated samples. It may be possible δ-Ferrite or Martensite, both have bcc structure. We follow given Table4.3. Then, we found that approximately 1% δ-Ferrite. The Rest of Part of different sample contains austenite, carbide and Martensite (that is 99%). So we can say that Different types of heat treated SS-304 stainless steel contain mainly austenite (approximately 95%). So, Microstructure is:

1.) Austenite (95% approx.)

2.) Carbide(Remaining part)

3.) Martensite (Less than 1%)

4.) δ-Ferrite (Less than 1%)

Percentage of bcc phase as obtained from Fischer Feritscope is given in table4.3.

Table4.3: Percentage of bcc phase as obtained from Fischer Feritscope

Heat Treatment	% Reading Value of bcc phase										% Avg.(bcc Phase)
	1	2	3	4	5	6	7	8	9	10	
Sensitized	0.25	0.15	0.14	0.26	0.25	0.12	0.17	0.16	0.24	0.18	0.192
Annealed	0.67	0.75	0.68	0.58	0.72	0.88	0.70	0.51	0.63	0.65	0.676
Oil Quenched	0.61	0.51	0.55	0.60	0.49	0.61	0.43	0.59	0.45	0.58	0.542
Furnace Quenched	1.0	0.87	0.93	0.97	1.1	0.81	0.90	1.0	0.91	0.99	0.948
Air Quenched	0.51	0.53	0.51	0.71	0.78	0.59	0.80	0.53	0.71	0.64	0.631

Generally slow cooling process rate produces Ferrite and fast cooling process rate produces Matensite.Here Furnace cooling is slow process, due to which obtaining more time for formation δ-Ferrite or bcc structure.

Ferrite has less than 1% in heat treated sample, due to which not more effect on hardness of heat treated sample. So, hardness much affected by austenite, carbide and Martensite. Hardness is totally related to microhardness of Ferrite austenite, carbide and Martensite.

4.4Microhardness

Micro hardness of different heat treated samples are given here in the table

Where:

D_1 = X- axis.

D_2 = Y-axis.

Micro hardness at different matrix of different heat treated sample is given in table4.4

Table 4.4: Micro hardness at different matrix of different heat treated samples

Heat Treatment	Matrix Type	Microstructure	D_1 (µm)	D_2 (µm)	HV (H)	Avg. HV
Sensitized	White	Martensite	24.72µm	21.64µm	345.1	331.6
	White	Martensite	25.37µm	22.92µm	318.1	
	Black	Martensite	21.24µm	19.96µm	437.0	432.3
	Black	Martensite	20.37µm	21.28µm	427.6	
Solution Annealed	White	Austenite	30.48µm	32.16µm	189.0	202.1
	White	Austenite	29.87µm	29.87µm	215.2	
	Black	Ferrite	23.50µm	29.29µm	266.2	270.8
	Black	Ferrite	24.88µm	27.02µm	275.4	
Oil Quenched	White	Austenite	28.51µm	28.35µm	229.4	223.1
	White	Austenite	30.84µm	27.65µm	216.8	
	Black	Ferrite Band	26.66µm	25.45µm	273.2	273.2
	Black	Carbide(CrC)	16.28µm	14.04µm	806.9	806.9
Furnace Quenched	White	Carbide(CrC)	15.88µm	16.63µm	701.8	734.6
	White	Carbide(CrC)	15.16µm	15.93µm	767.4	
	Black	Ferrite	25.36µm	25.44µm	287.4	291.3
	Black	Ferrite	24.99µm	25.14µm	295.2	
Air Quenched	White	Austenite	29.54µm	29.30 µm	214.8	214.8
	White	Ferrite	26.14 µm	27.23 µm	257.8	257.8
	Black	Carbide(CrC)	16.55 µm	16.23 µm	690.3	690.3
	Black	Mixture of Martensite and carbide	20.54 µm	19.86 µm	454.4	454.4

Above table shows that very much amount of martensite is formed in sensitize heat treated sample, due to which more hardness is obtained in sensitized sample and less wear rate. Furnace quenched sample have more amount of carbide. So it has good value of hardness and very less amount of wear than Sensitized, Oil Quenched and Solution Annealed sample.

Air Quenched material have good hardness, because of it contains Austenite, Carbide (CrC) and Mixture of Martensite and carbide. So it has lesser amount of wear than all other heat treated sample.

Solution Annealed and Oil Quenched have lesser amount of hardness than Sensitized, furnace quenched and Air Quenched, because of it contains Ferrite and Austenite in maximum part of sample. So it has more wear than other three samples.

4.5 Tribological Properties Test

Tribological properties test determine the properties of friction and wear behaviour with respect to time.

4.5.1Tribological Properties Friction and Wear Variation with Time

Linear Regression Analysis: it is mathematical Technique of obtained the line of best fit between the dependent variable Y and some independent Variable X. The Relation between two variable X and Y can be represented by start line.

$$Y = a + bX$$

Where: $b = (n\times\sum XY - \sum X\times\sum Y) / (n\times\sum X^2 - (\sum X)^2)$

$a = (\sum Y - b\times \sum X) / n$

4.5.1.1 Sensitize sample

Coefficient of Friction (µ) Vs Time (in second) is given in table4.5.

Table4.5: Coefficient of Friction (µ) Vs Time (s)

Time (s)	Coefficient of Friction(µ)
300.141	0.164
599.954	0.202
899.907	0.118
1200.063	0.175
1499.938	0.188
1799.907	0.196

Coefficient of Friction (µ) Vs Time (s) graphical representation in figure4.2 (a)

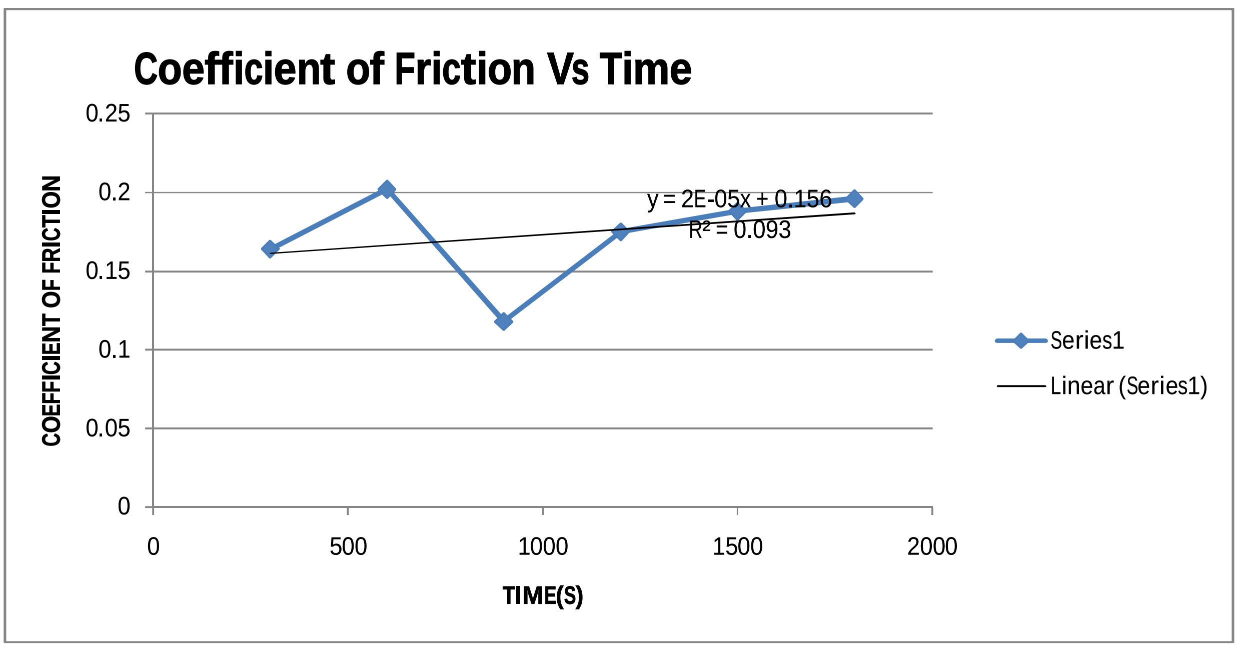


Figure4.2 (a): Coefficient of Friction (µ) Vs Time (s)

Linear Regression Line equation:

Y= 2E-05X + 0.156 i.e. Y= 0.00002X + 0.156

Correlation Coefficient or Validity coefficients:

For each model standardized coefficient, the relative independent contribution of the predictor variables and variance-explained statistics (R^2) are presented.

$R^2 = 0.093$

It is representation of the relationship of two variables.

Coefficient of Friction (μ) Vs Time in seconds: this figure represents the Coefficient of Friction (μ) zigzag behaviour with respect to time.

Wear (μm) Vs Time in seconds is given in table 4.6

Table4.6: Wear (μm) Vs Time (s)

Time (s)	**Wear(μm)**
300.141	86.152
599.954	94.262
899.907	107.793
1200.063	125.043
1499.938	151.501
1799.907	164.972

Wear (µm) Vs Time (in second) graphical representation in figure4.2 (b).

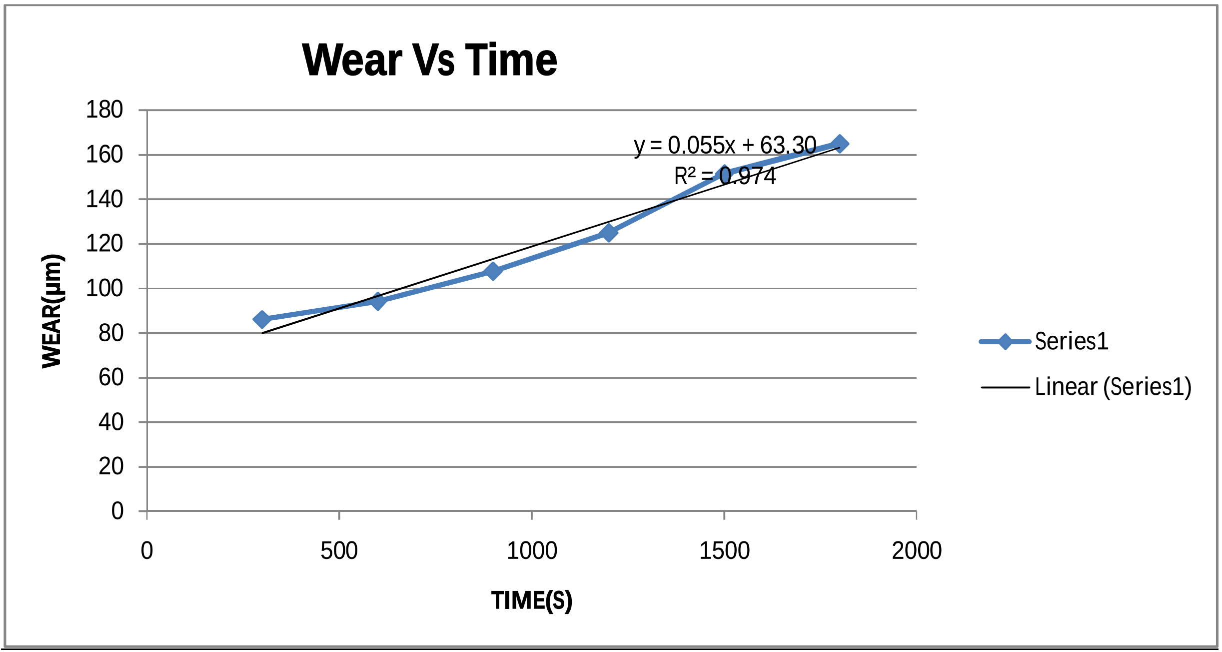


Figure4.2 (b): Wear (µm) Vs Time (s)

Linear Regression Line equation:

Y=0 .055X + 63.30

Correlation Coefficient or Validity coefficients:

$R^2 = 0.974$

Wear (µm) Vs Time in seconds: it shows almost linear behaviour.

The R-squared value confirms this. It is 0.093 in Figure4.2 (a) compared to 0.974 in Figure4.2 (b). Though we would need to take in to account information such as the number of data points collected to make an accurate statistical prediction as to how well the regression line represents the true relationship, we can generally say that Figure4.2 (b) represents a better representation of the relationship of two variables.

4.5.1.2. Solution Annealed sample

Coefficient of Friction (μ) Vs Time (in second) given in table4.7.

Table4.7: Coefficient of Friction (μ) Vs Time (s)

Time (s)	Coefficient of Friction(μ)
300.094	0.159
599.891	0.184
899.922	0.173
1199.891	0.197
1499.953	0.194
1800.109	0.199

Coefficient of Friction (μ) Vs Time (in second) graphical representation in figure4.3 (a).

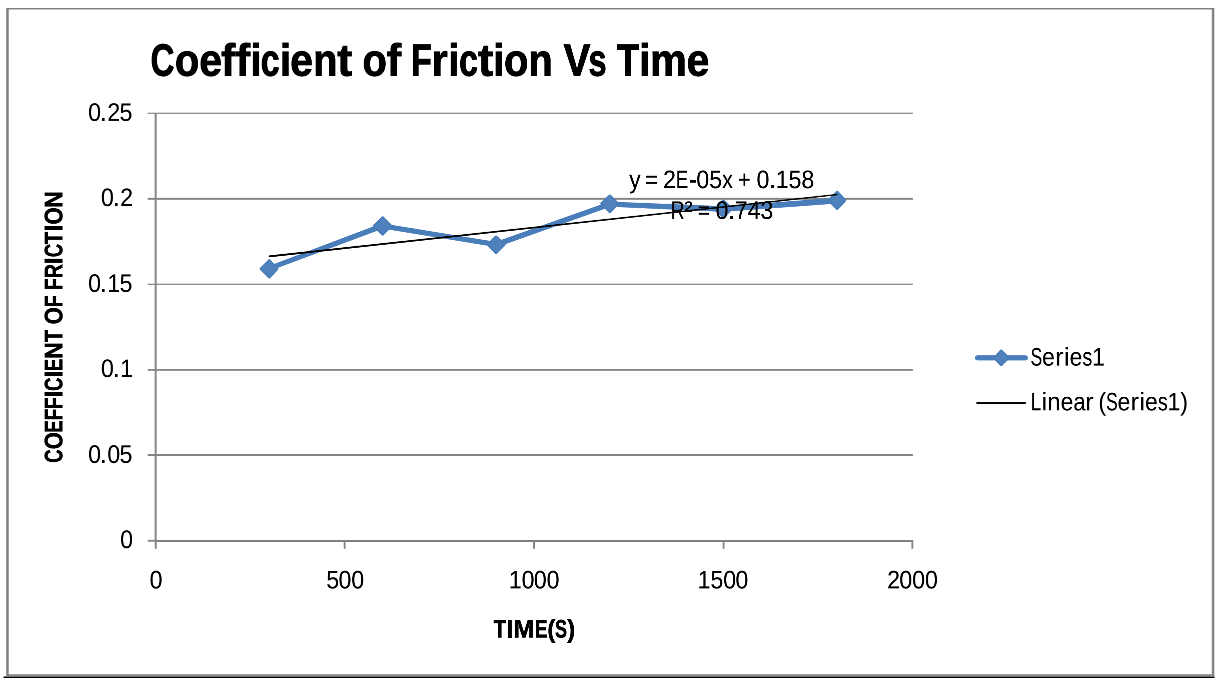


Figure4.3 (a): Coefficient of Friction (μ) Vs Time (in second)

Linear Regression Line equation:

Y= 2E-05X + 0.158 i.e. Y= 0.00002X + 0.158

Correlation Coefficient or Validity coefficients:

$R^2 = 0.743$

Wear (µm) Vs Time (in second) is given in table4.8

Table4.8: Wear (µm) Vs Time (s)

Time (s)	Wear(µm)
300.094	134.974
599.891	168.633
899.922	189.968
1199.891	199.537
1499.953	205.777
1800.109	210.34

Wear (µm) Vs Time (in second) graphical representation in figure4.3 (b).

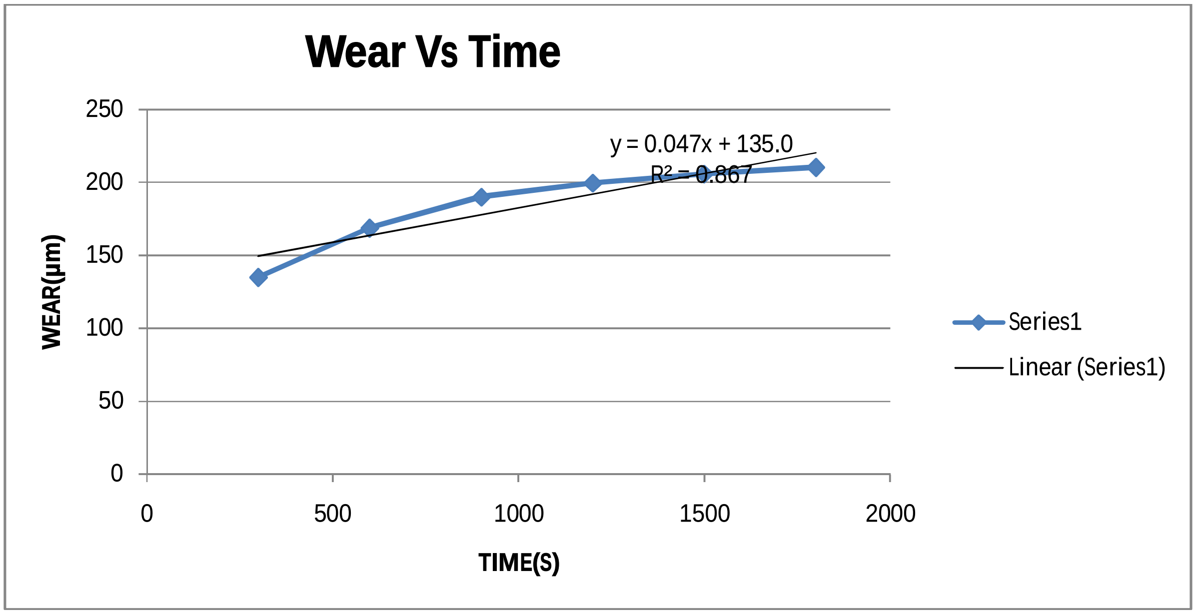


Figure4.3 (b): Wear (µm) Vs Time (in second)

Linear Regression Line equation:

Y=0 .047X + 135.0

Correlation Coefficient or Validity coefficients:

R^2 = 0.867

The R-squared value confirms this. It is 0.743 in Figure4.3 (a) compared to 0.867 in Figure4.3 (b). Though we would need to take in to account information such as the number of data points collected to make an accurate statistical prediction as to how well the regression line represents the true relationship, we can generally say that Figure4.3 (b) represents a better representation of the relationship of two variables.

4.5.1.3. Air cooled sample

Coefficient of Friction (μ) Vs Time in (second) is given in table4.9.

Table4.9: Coefficient of Friction (μ) Vs Time (s)

Time (s)	Coefficient of Friction(μ)
299.953	0.261
600.063	0.171
899.984	0.202
1200.078	0.158
1500.016	0.329
1800.031	0.286

Coefficient of Friction (μ) Vs Time (in second) graphical representation in figure4.4 (a).

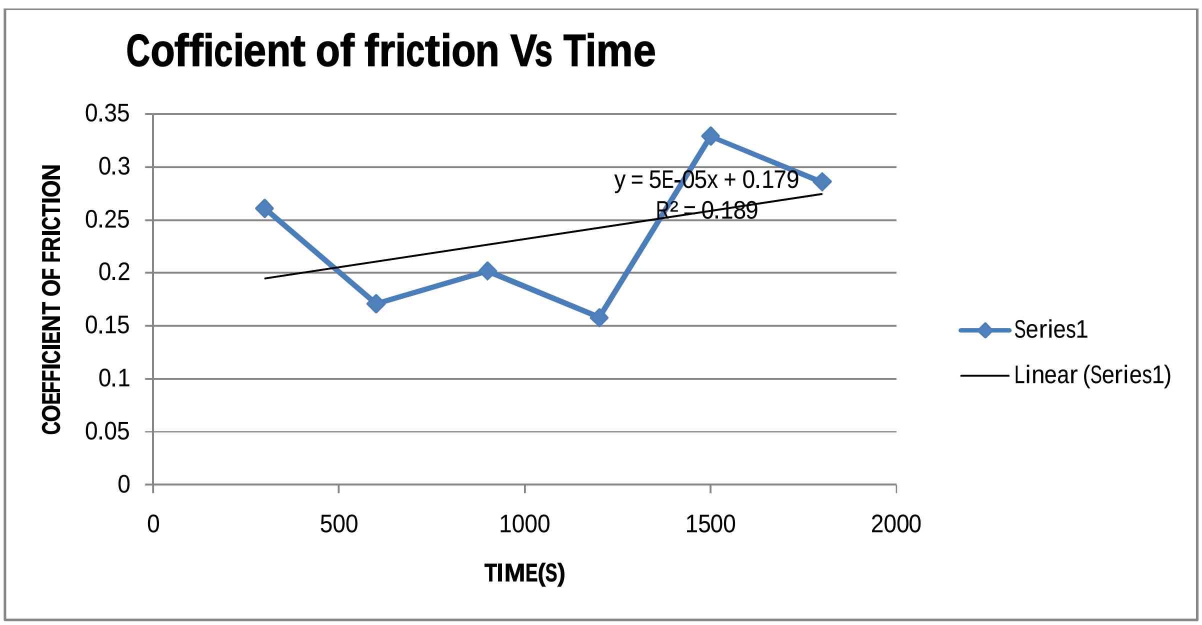


Figure4.4 (a): Coefficient of Friction (μ) Vs Time (in second)

Linear Regression Line equation:

Y= 5E-05X + 0.179 i.e. Y= 0.00005X + 0.179

Correlation Coefficient or Validity coefficients:

$R^2 = 0.189$

Wear (µm) Vs Time (in second) is given in table4.10

Table4.10: Wear (µm) Vs Time (s)

Time (s)	**Wear(µm)**
299.953	31.712
600.063	40.092
899.984	48.325
1200.078	60.933
1500.016	73.133
1800.031	91.218

Wear (µm) Vs Time (s) graphical representation in figure4.4 (b)

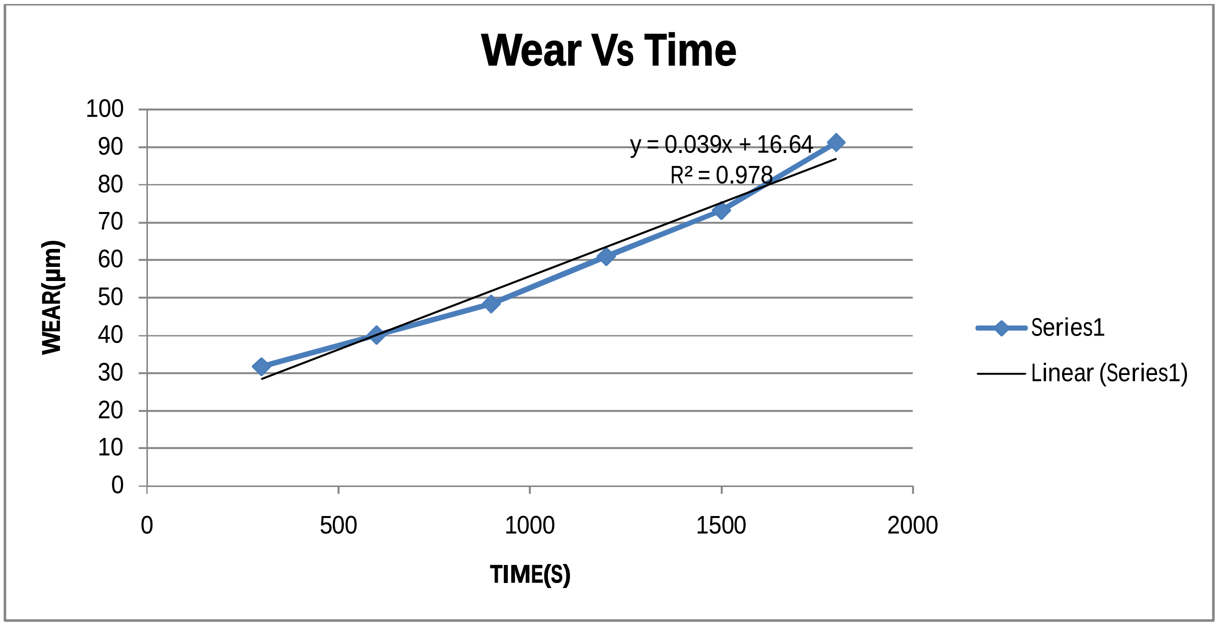


Figure4.4 (b): Wear (µm) Vs Time (s)

Linear Regression Line equation:

Y=0 .039X + 16.64

Correlation Coefficient or Validity coefficients:

$R^2 = 0.978$

The R-squared value confirms this. It is 0.189 in Figure4.4 (a) compared to 0.978 in Figure4.4 (b). Though we would need to take in to account information such as the number of data points collected to make an accurate statistical prediction as to how well the regression line represents the true relationship, we can generally say that Figure4.4 (b) represents a better representation of the relationship of two variables.

4.5.1.4. Furnace (Annealed) cooled sample

Coefficient of Friction (µ) Vs Time (in second) is given in table4.11.

Table4.11: Coefficient of Friction (µ) Vs Time (in second)

Time (s)	Coefficient of Friction(µ)
299.953	0.261
600.063	0.171
899.984	0.202
1200.078	0.158
1500.016	0.329
1800.031	0.286

Coefficient of Friction (µ) Vs Time (in second) graphical representation in figure4.5 (a)

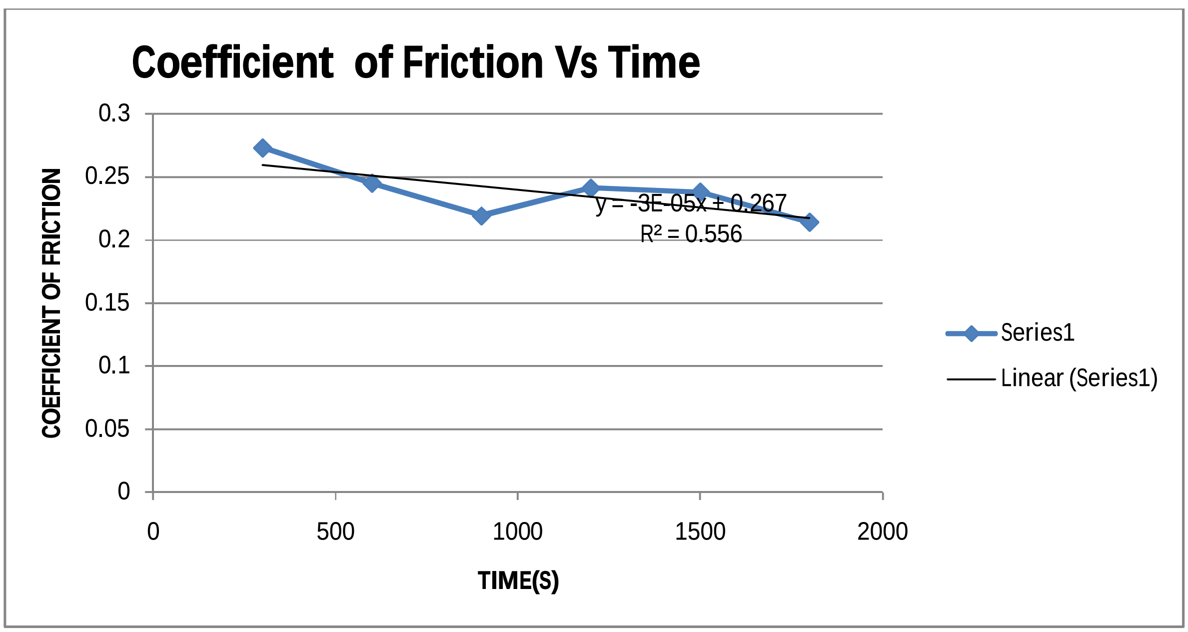


Figure4.5 (a): Coefficient of Friction (µ) Vs Time (in second)

Linear Regression Line equation:

Y= -3E-05X + 0.267 i.e. Y= -0.00003X + 0.267

Correlation Coefficient or Validity coefficients:

$R^2 = 0.556$

Wear (µm) Vs Time (in second) is given in table4.12.

Table4.12: Wear (µm) Vs Time (s)

Time (s)	Wear(µm)
300.219	111.040
600.953	117.157
900.250	116.397
1200.172	117.201
1500.234	120.968
1800.156	123.966

Wear (µm) Vs Time (in second) graphical representation in figure4.5 (b).

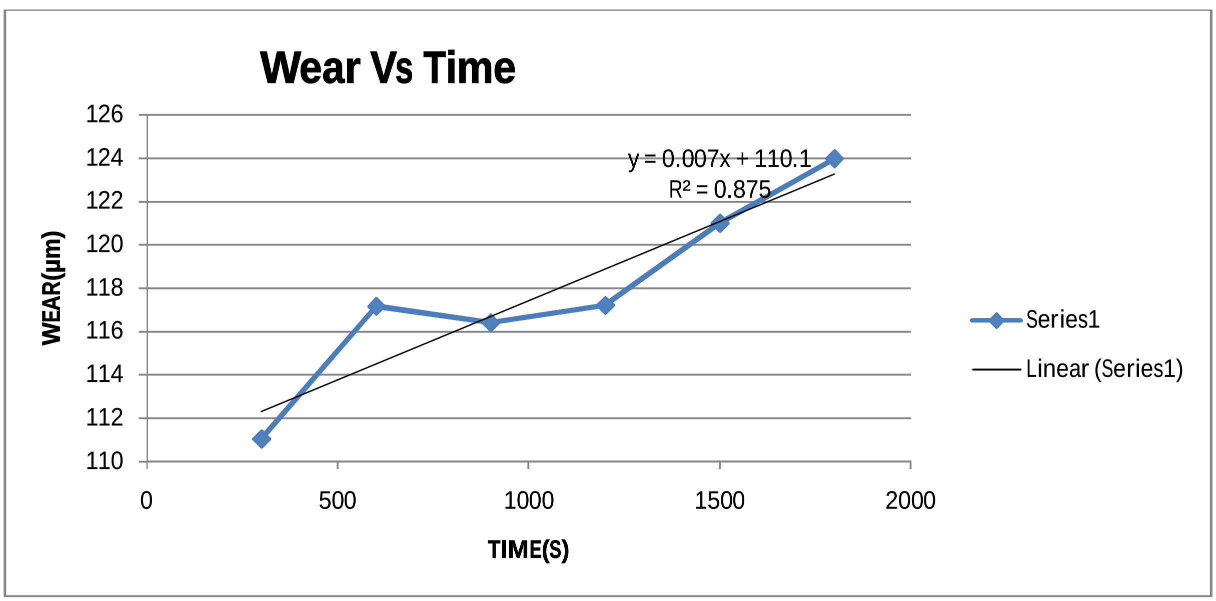


Figure4.5 (b): Wear (µm) Vs Time (s)

Linear Regression Line equation:

$Y=0.007X + 110.1$

Correlation Coefficient or Validity coefficients:

$R^2 = 0.875$

The R-squared value confirms this. It is 0.556 in Figure4.5 (a) compared to 0.875 in Figure4.5 (b). Though we would need to take in to account information such as the number of data points collected to make an accurate statistical prediction as to how well the regression line represents the true relationship, we can generally say that Figure4.5 (b) represents a better representation of the relationship of two variables.

4.5.1.5. Oil cooled sample

Coefficient of Friction (μ) Vs Time (in second) is given in table4.13.

Table4.13: Coefficient of Friction (μ) Vs Time (s)

Time (s)	**Coefficient of Friction(μ)**
299.969	0.204
599.907	0.217
900.094	0.207
1200.016	0.238
1499.922	0.154
1800.047	0.269

Coefficient of Friction (µ) Vs Time (s) graphical representation in figure4.6 (a).

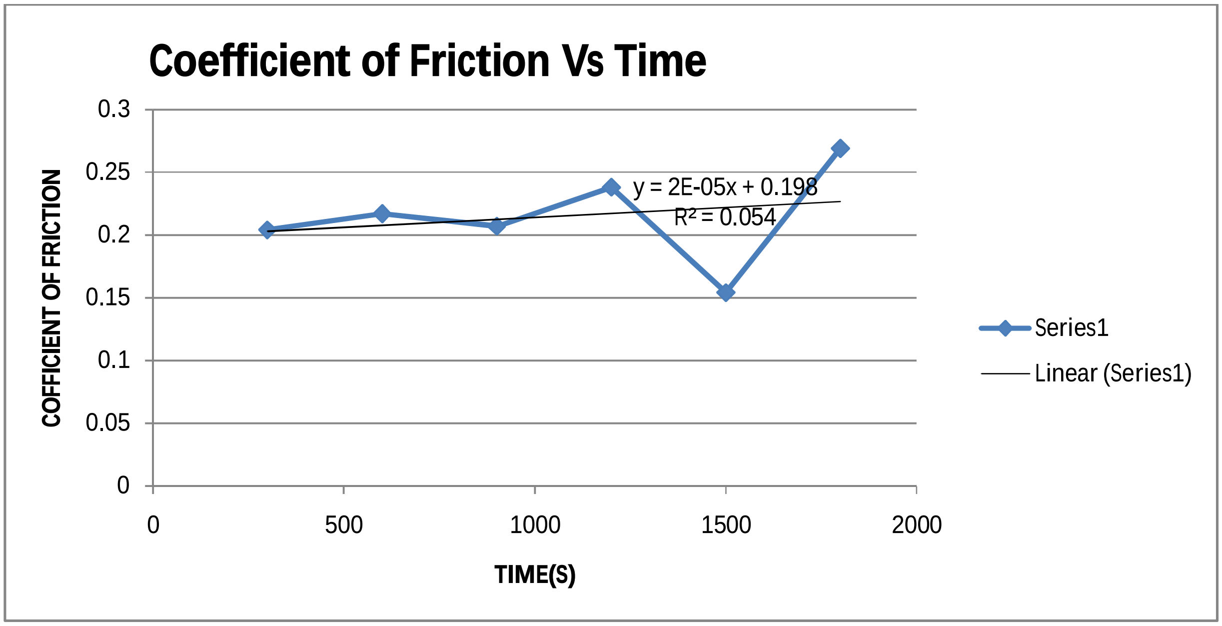


Figure4.6 (a): Coefficient of Friction (µ) Vs Time (s)

Linear Regression Line equation:

Y= 2E-05X + 0.198 i.e. Y= -0.00002X + 0.198

Correlation Coefficient or Validity coefficients:

R^2 = 0.054

Wear (µm) Vs Time (s) is given in table4.14.

Table4.14: Wear (µm) Vs Time (s)

Time (s)	Wear(µm)
299.969	139.965
599.907	177.901
900.094	204.43
1200.016	218.06
1499.922	224.054
1800.047	231.011

Wear (µm) Vs Time (s) graphical representation in figure4.6 (b).

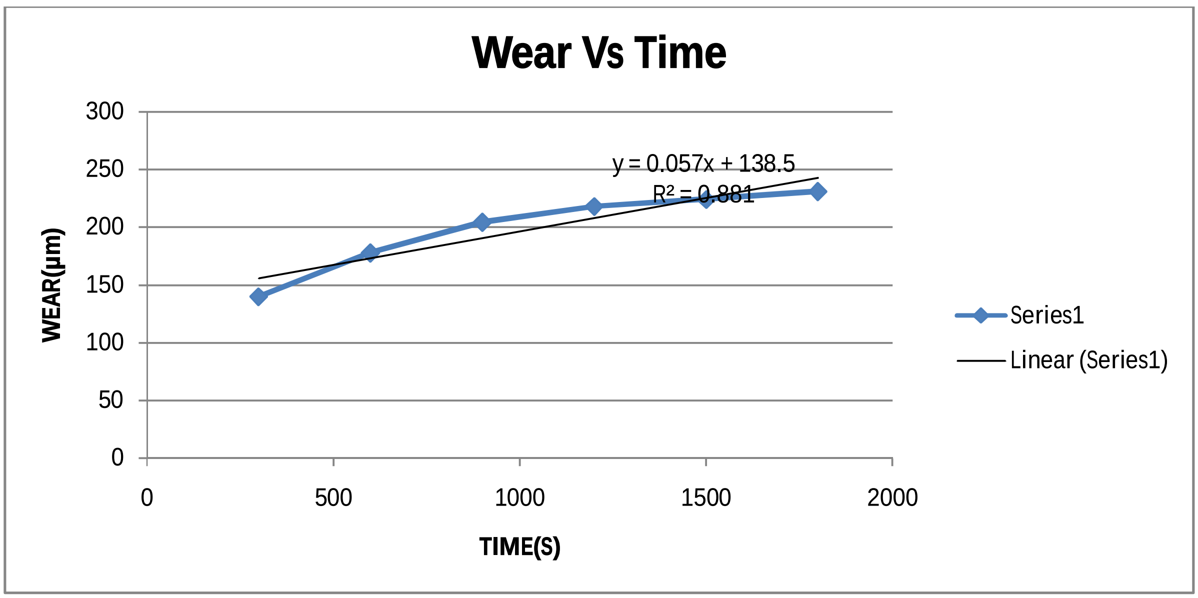


Figure4.6 (b): Wear (µm) Vs Time (s)

Linear Regression Line equation:

Y=0 .057X + 138.5

Correlation Coefficient or Validity coefficients:

$R^2 = 0.881$

The R-squared value confirms this. It is 0.054 in Figure4.6 (a) compared to 0.881 in Figure4.6 (b). Though we would need to take in to account information such as the number of data points collected to make an accurate statistical prediction as to how well the regression line represents the true relationship, we can generally say that Figure4.6 (b) represents a better representation of the relationship of two variables.

4.5.1.6Comparative Charts of Wear (Micron) against Time

Table 4.15 Wear (micron) of different heat treated samples in regular time intervals(s)

Heat Treatment	**Wear (micron) in different time intervals (s)**					
	300	600	900	1200	1500	1800
Sensitized	86.152	94.262	107.793	125.043	151.501	164.972
Annealed	111.040	117.157	116.397	117.201	120.968	123.966
Normalized	31.712	40.092	48.325	60.933	73.133	91.218
Oil quenched	139.965	177.901	204.43	218.06	224.054	231.011
Solution annealed	134.974	168.633	189.968	199.537	205.777	210.34

From Table 4.4 it has been revealed that normalized sample has good hardness owing to the presence of austenite, carbide (CrC) and mixture of martensite and carbide. So it has lesser amount of wear than all other heat treated samples. The wear follows almost a straight line path (Figure4.7). Sensitize samples contain higher amount of martensite.

Thus, more hardness is obtained in sensitized samples resulting less wear rate as is evidenced in Table 4.15. The wear is, however, gradually increasing with time (Figure4.7).

On the contrary, annealed samples have more amount of carbide. They also have good amount of hardness. Initial wear is somehow more than that of sensitized samples. But the wear is almost stable with time and follows a straight line path.

Comparative charts of wear (micron) against time given in figure 4.7

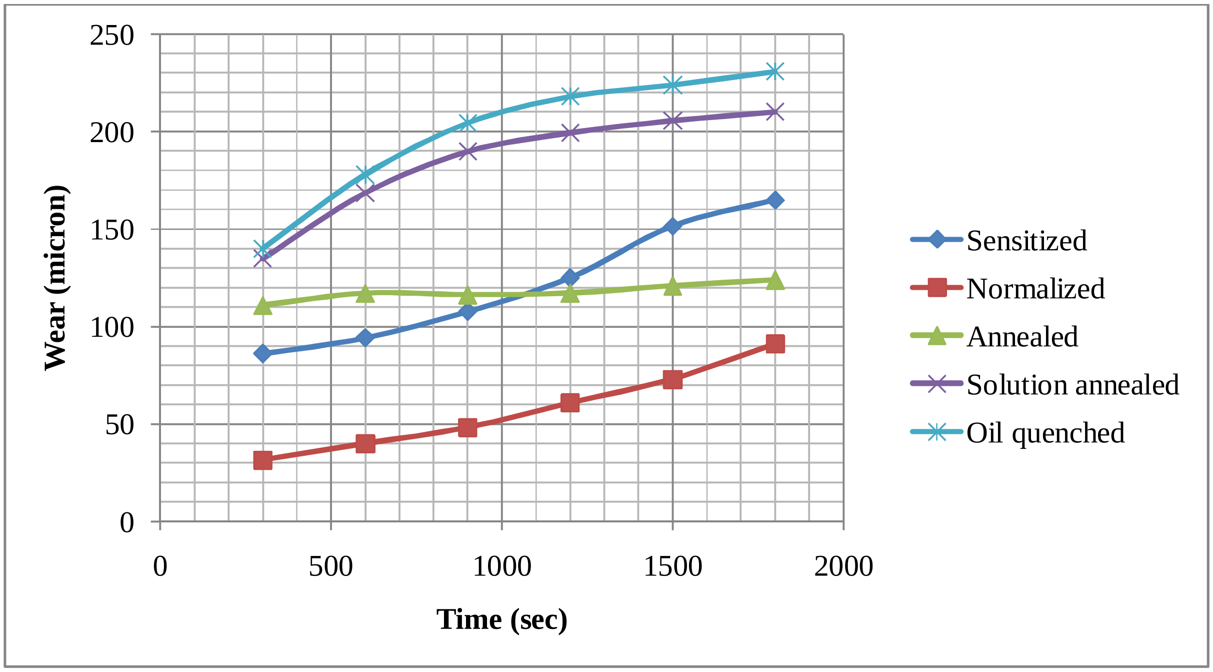


Figure 4.7 Comparative charts of wear (micron) against time.

Sensitized, annealed and normalized samples have less amount of wear than oil quenched and solution annealed samples as the hardness of oil quenched and solution annealed samples are far less than sensitized, annealed and normalized samples. Ferrite and austenite phases are prominent in majority of the portions of oil quenched and solution annealed samples. Though oil quenched sample contains carbide (CrC) but quite likely the percentage is very low. Hence, this sample has little resistance against wear.

Weight loss data (gm) of the worn samples have been given in Table 4.2. It has been revealed that the weight loss data and the wear (micron), as obtained directly from the Winducom 2006' software, are in good agreement. Thus, it is justified to consider the weight loss data as a measure of wear.

4.6 Comparative Curves of Frictional Force, Coefficient of Friction, Wear amongst Different Heat Treated Samples after Tribotesting in the Multi Tribo-Tester

Figures 4.8, 4.9 and 4.10 show some tribological characteristics like frictional force, coefficient of friction and wear of different samples after tribotesting in the multi tribo-tester.

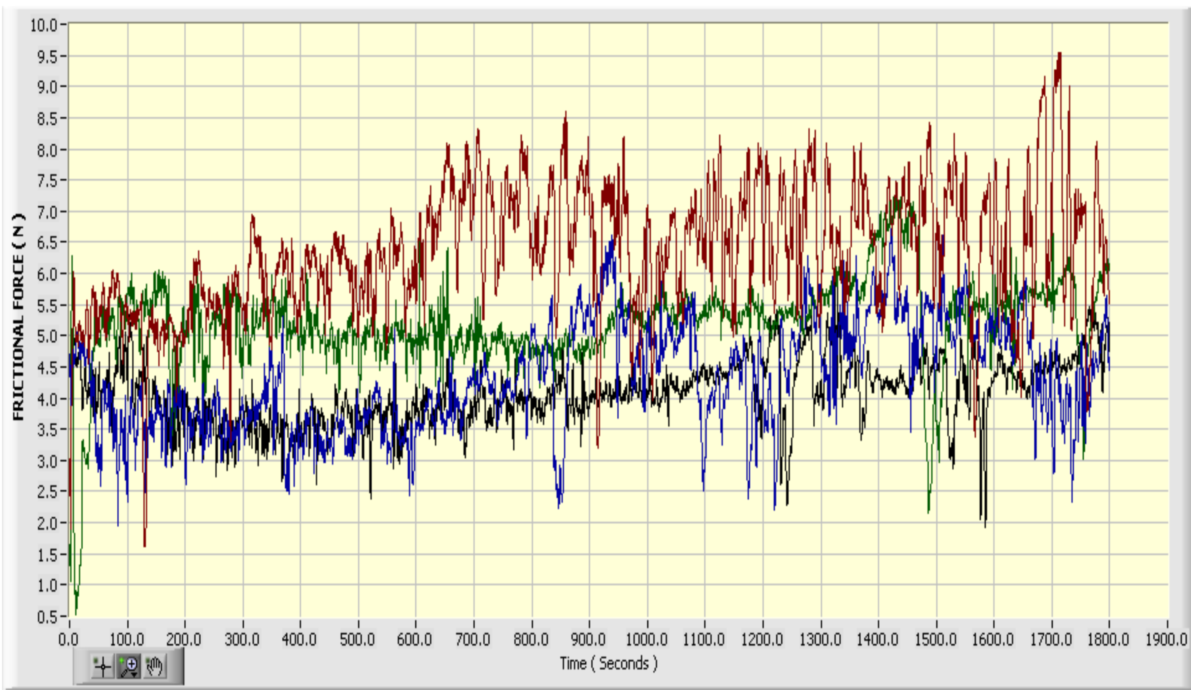


Figure 4.8: Comparative curves of frictional force amongst furnace

Cooled (maroon), air cooled (blue), oil quenched (green)

And solution annealed (black) samples.

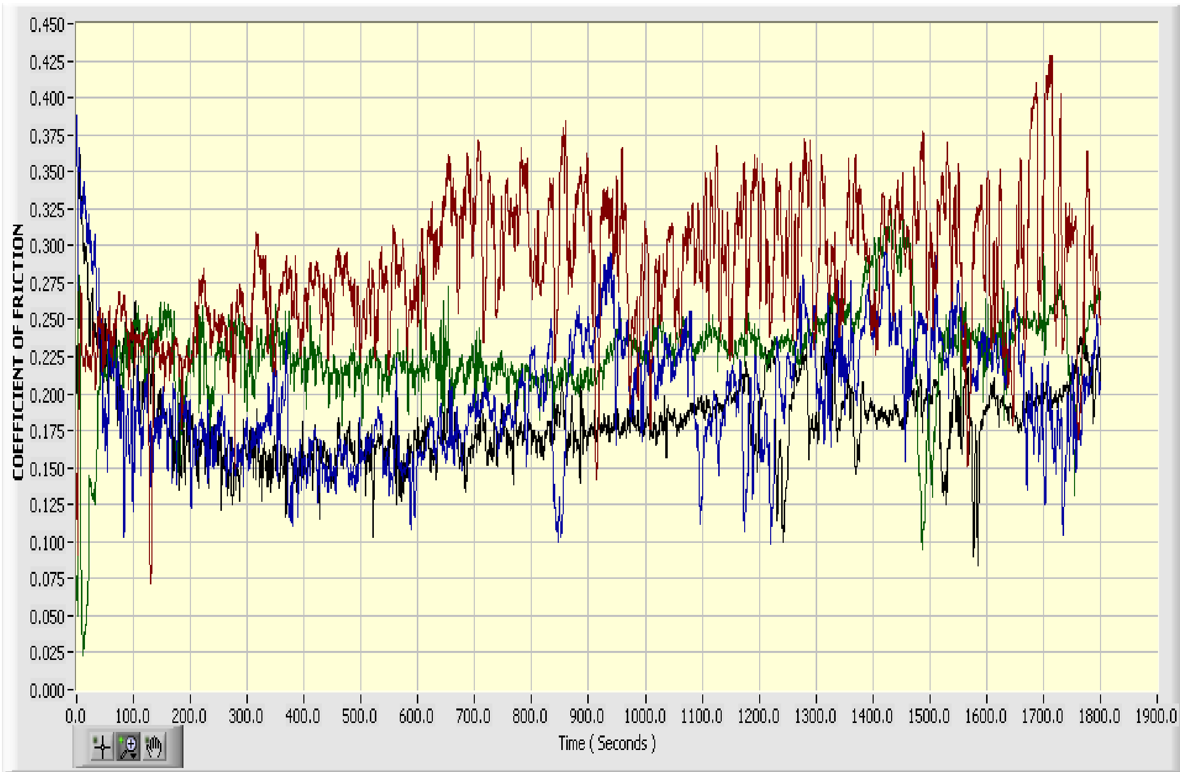


Figure 4.9: Comparative curves of coefficient of friction amongst Furnace cooled (maroon), air cooled (blue), oil quenched (Green) and solution annealed (black) samples.

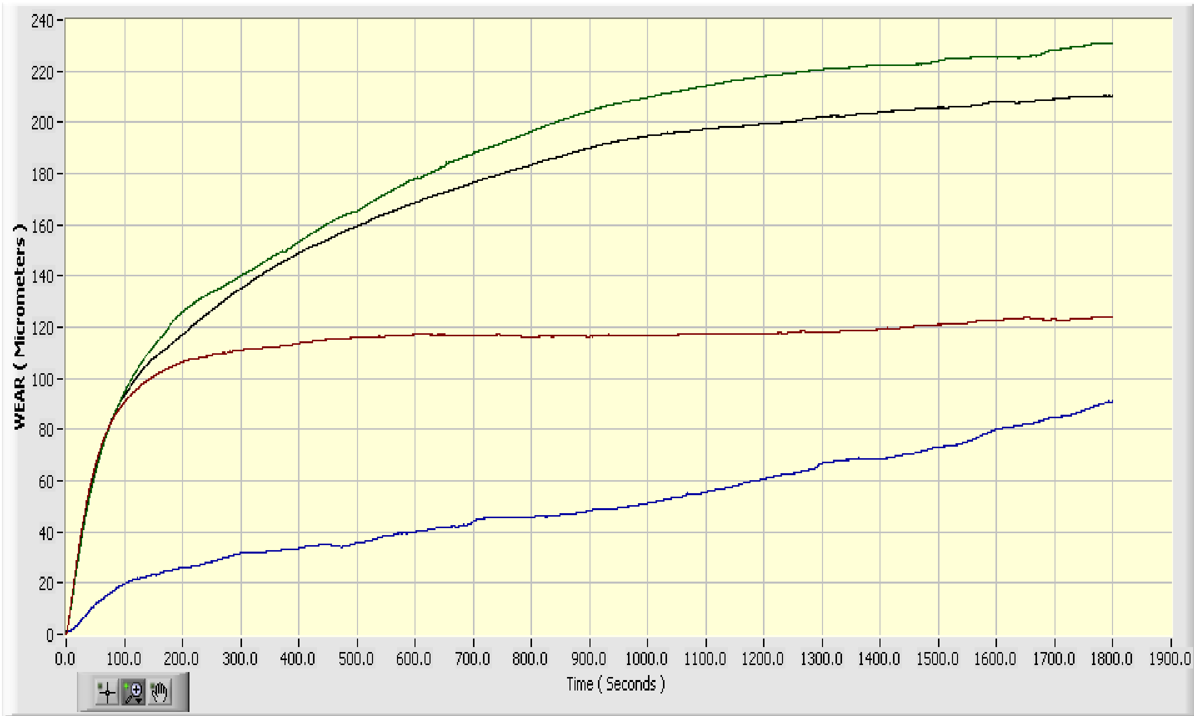


Figure 4.10: Comparative curves of wear amongst furnace cooled (Maroon), air cooled (blue), oil quenched (green) and Solution annealed (black) samples.

From Figure4.8 it has been revealed that the frictional force in case of normalized and solution annealed samples are almost same up to 800 sec of operation. The initial value 4.5N is slightly higher than 3.5N during the remaining part of operation within this time span of test run. However, the value jumped up to 6.5N in case of normalized sample during 950 sec and shows continuous ups and downs during the rest of the time. The curve of solution annealed sample shows little fluctuation throughout the test run. Both curves end almost equally at a value of 5N, solution annealed being slightly higher. Oil quenched sample shows a higher initial value of frictional force 6N and the curve maintains this trend almost throughout the experiment except in the interval of 1400 to 1500 sec.

The operation ends at 6N maintaining an overall average of 5.5N. Annealed (Furnace) sample, on the other hand, shows a comparatively high value of frictional force in the range of 600 to 1800 sec. maintaining an average of 7N where as the average up to first 600 sec. is 6N. Fluctuation throughout the operation in this case also is very high. Explanation of the above situations may be due to the variations in surface roughness conditions. In the present study measurements of the surface roughness have not been made. Fewer initial contacts have been made between the smooth counter surface and comparatively rough work piece. As the test goes on and material wears, the work surface becomes smoother. When two such smooth surfaces come in contact and one surface glide pasts the other, adhesion results.

Coefficient of friction (COF) is the ratio of frictional force to the applied load, that is, normal load on the job or work piece. In the present work a constant normal load on the job of 25 N has been used. Hence, COF will be proportional to the frictional force. All the COFs have been depicted in Figure4. 9 and are self explanatory.

Wear is considered as the progressive loss of material from the work surface. Softer material will wear out when slides against a harder counter surface. Figure4.10 depicts the comparative wear curves of four different samples. Furnace cooled specimen shows an average constant wear of 120 micron approximately after 500 sec. Wear becomes constant at a value of 120 micron between 1200 sec to 1550 sec of operation in case of this annealed sample. After 1800 sec the wear becomes 125 micron. Normalized, that is, air cooled samples show minimum initial wear. The wear of this type of specimen is gradually increasing in nature; however, final wear is maximum at a value of 90 micron after 1800 sec of operation. Wears of these two samples are comparatively low. This is also supported by the weight loss data in both the cases. Wear of both the oil quenched and solution annealed samples are high from the very inception of the operation and continue to maintain a gradually increasing trend throughout the entire time span of 1800 sec. The final wear of solution annealed and oil quenched samples are 210 and 230 microns respectively. Weight loss data of these two samples are also at par with this trend.

Comparison of the tribo characteristics of the heat treated samples with sensitized sample has not been made for obvious reason. However, the wear curve has been shown in Figure4.11. It is clear from the wear curve that the wear is very erratic all along and gradually increasing in trend.

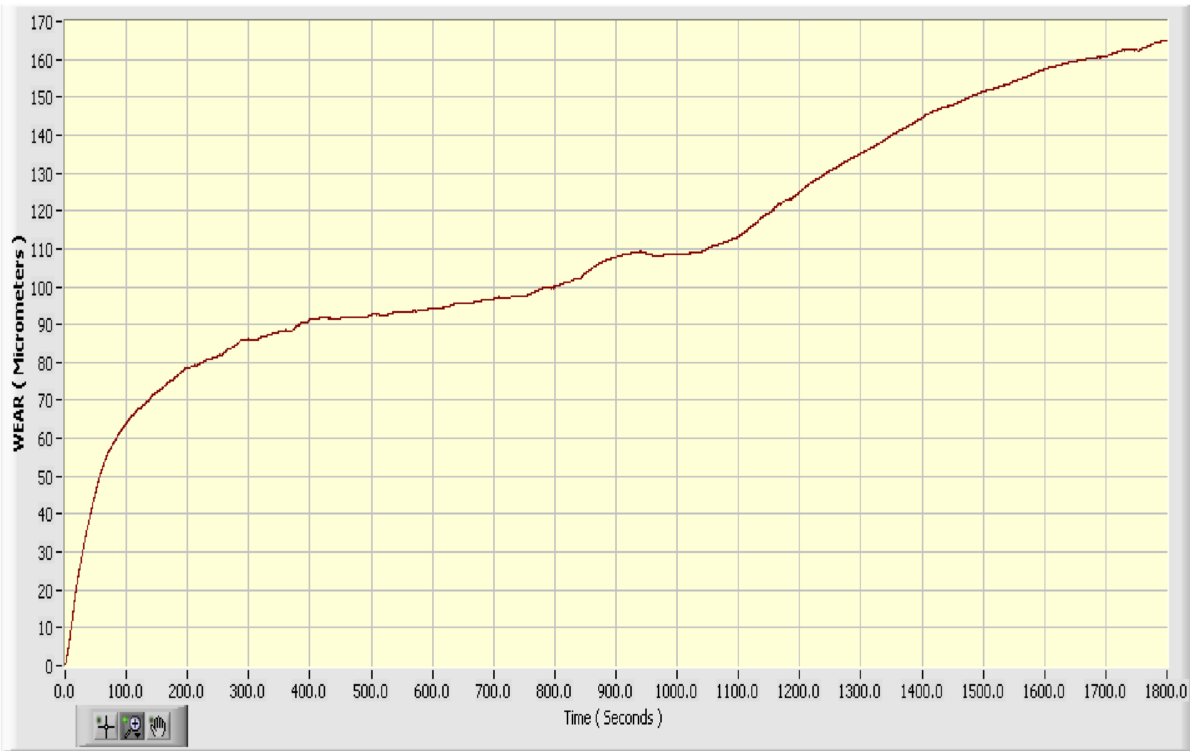


Figure4.11: Wear curve of sensitized sample

Comparing weight loss data and corresponding wear of the samples, it may be predicted that the wear of sensitized sample would be in between 125 to 200 micron. From the wear curve of the sensitized sample in Figure4.11 it has been revealed that the wear of the said sample is 165 micron.

CONCLUSION

The microstructure of a material can strongly influence the physical properties such as strength, toughness, ductility, hardness, corrosion resistance, wear resistance and so on.

By experimental tabular data and investigation of microstructure such as Ferrite Austenite, Martensite and Carbide (CrC) affect the hardness of heat treated sample and wear. Above Discussions show that Annealed and Oil Quenched sample have lesser amount of hardness than Sensitized, furnace quenched and Air Quenched, because of it contains % of Ferrite and Austenite in maximum part of sample. So they have more wear than other three samples. Air Quenched material have good hardness, because of it contains Austenite, Carbide (CrC) and Mixture of Martensite and carbide. So it have lesser amount of wear than all other heat treated sample. So microstructure behaviours also affect the tribology properties such as wear.

Heat treatment is a precise operation and needs much care and control of temperature monitoring. Maximum heat, dwelling time inside furnace and cooling media are all important parameters to be considered critically for the desired outcome. Heat treatments of different grades have been done on AISI 304 stainless steel samples which have been procured from the market. Heat treatment is a precise process and the commercial users often outsource this operation to be done by some professional. In this work attempts have been made to heat treat SS-304 samples using an ordinary, in-house electric muffle furnace. This is an attempt of knowledge enrichment in this field of study. Friction and wear characteristics depend on the hardness, speed, load, duration and other operating conditions. Hence, evaluation of such data for each individual tool-work piece combination is important and needs to be evaluated. Present experimental study reveals that the air cooled, that is, normalized sample is associated with lowest wear amongst other type of heat treated samples.

Prediction regarding wear of sensitized or other sample can be made from the weight loss data of the samples. In the present study prediction regarding wear of sensitized sample from the weight loss data perfectly matches with the experimental data.

The following conclusions are drawn in the above context:

- Some important heat treatments of AISI 304 stainless steel have been done utilizing in house facilities. This is a great value addition in conceptual learning process.
- Microstructures and corresponding micro hardness of different matrix has been appraised and evaluated accordingly.
- Presence of δ- ferrite and martensite, that is, bcc structure is less than 1% in all the heat treated samples.
- Normalized samples have minimum wear whereas oil quenched samples have maximum wear. Wear of normalized samples, though minimum, have a gradually increasing trend. Hence, the study should be conducted for an extended period of time to observe the nature of wear.
- Annealed samples show medium wear with a stable trend.
- Weight loss data has been considered as a good measure of wear.

FUTURE SCOPE OF WORK

(1) Use Different material of block and roller system mechanism, and The interactions taking place at the interface between two or more bodies under relative motion control the tribological behaviour of the materials involved in such interaction.

(2)Block-on-roller configuration of Multi Tribotester has been utilized for the purpose Of Different Normal load on the sample, Different sliding speed (rpm) of the wheel and duration of the test run have been considered as the design factor for the evaluation of tribo characteristics.

(3) We can optimize by taking different parameter such as speed, load &time .These values are optimise by optimization method and Multi-objective optimization is carried out to identify the optimal parametric combination.

(4) More elaborate study of microstructure characteristics, hardness test at different regions and its effect on tribological properties also provide scope of future work.

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APPENDIX

Air cooled data: A(Time),B(Load),C(Friction force),D(Temp.),E(Speed),F(Wear)

A	B	C	D	E	F	G
0.797;	18.997;	3.897;	27.775;	0.501;	0.583;	1.001;
1.047;	19.106;	3.779;	27.793;	0.515;	0.777;	1.016;
1.297;	19.193;	3.620;	27.814;	0.429;	0.971;	1.103;
1.547;	19.268;	3.469;	27.836;	5.673;	1.160;	1.057;
1.797;	19.348;	3.059;	27.851;	43.218;	1.110;	0.971;
99.172;	21.816;	6.659;	28.010;	381.184;	19.459;	1.551;
99.422;	21.809;	6.782;	28.010;	381.159;	19.442;	1.470;
99.672;	21.812;	6.521;	28.010;	381.141;	19.501;	1.597;
99.922;	21.805;	6.273;	28.011;	381.006;	19.524;	1.596;
100.172;	21.808;	6.169;	28.014;	381.023;	19.538;	1.687;
100.422;	21.784;	6.058;	28.021;	380.901;	19.598;	1.584;
100.672;	21.797;	6.189;	28.016;	380.953;	19.572;	1.700;
100.922;	21.797;	6.491;	28.019;	380.936;	19.716;	1.627;
199.078;	22.269;	4.422;	28.023;	381.443;	25.872;	2.279;
199.328;	22.268;	4.538;	28.025;	381.371;	25.841;	2.383;
199.578;	22.271;	4.563;	28.025;	381.427;	25.886;	2.280;
199.828;	22.270;	4.701;	28.025;	381.492;	25.835;	2.216;
200.078;	22.271;	4.816;	28.025;	381.582;	25.874;	2.133;
200.328;	22.265;	4.907;	28.025;	381.592;	25.857;	2.087;
200.578;	22.273;	4.966;	28.024;	381.634;	25.851;	2.055;
200.828;	22.266;	4.930;	28.023;	381.562;	25.880;	2.051;
299.219;	21.961;	5.672;	28.036;	381.816;	31.718;	2.240;
299.453;	21.960;	5.744;	28.034;	381.931;	31.696;	2.369;
299.703;	21.956;	5.701;	28.035;	382.005;	31.749;	2.469;
299.953;	21.955;	5.739;	28.036;	382.088;	31.712;	2.560;
300.203;	21.950;	5.731;	28.038;	381.986;	31.781;	2.527;
300.453;	21.948;	5.762;	28.038;	382.024;	31.764;	2.544;
300.703;	21.958;	5.812;	28.038;	381.916;	31.799;	2.443;
300.953;	21.964;	5.864;	28.037;	381.864;	31.803;	2.466;
399.344;	22.198;	5.761;	28.043;	382.044;	33.538;	2.781;
399.594;	22.208;	5.538;	28.044;	382.053;	33.591;	2.778;
399.844;	22.205;	5.320;	28.045;	382.096;	33.578;	2.823;
400.094;	22.214;	5.035;	28.046;	382.048;	33.620;	2.856;
400.344;	22.216;	4.770;	28.045;	382.068;	33.637;	2.852;
400.578;	22.230;	4.742;	28.045;	382.008;	33.633;	2.740;
400.828;	22.220;	4.647;	28.046;	381.997;	33.701;	2.850;
499.203;	22.328;	6.024;	28.062;	382.031;	35.662;	3.319;
499.453;	22.333;	6.056;	28.062;	381.993;	35.713;	3.203;
499.703;	22.338;	6.008;	28.063;	381.920;	35.689;	3.142;
499.953;	22.342;	5.873;	28.066;	381.988;	35.766;	3.145;

500.453;	22.354;	5.718;	28.062;	381.996;	35.776;	3.138;
500.703;	22.350;	5.766;	28.065;	381.854;	35.772;	3.200;
500.953;	22.360;	5.832;	28.063;	381.882;	35.777;	3.120;
599.063;	22.294;	3.589;	28.073;	382.050;	40.024;	3.027;
599.313;	22.296;	3.611;	28.074;	382.015;	39.998;	3.116;
599.563;	22.289;	3.620;	28.075;	382.015;	40.062;	3.037;
599.813;	22.291;	3.807;	28.074;	382.024;	40.039;	3.054;
600.063;	22.289;	3.806;	28.077;	382.012;	40.092;	3.129;
600.313;	22.287;	3.915;	28.076;	381.898;	40.088;	3.156;
600.563;	22.301;	4.028;	28.075;	381.885;	40.095;	3.048;
600.797;	22.302;	4.144;	28.074;	381.972;	40.123;	2.989;
699.172;	22.503;	2.880;	28.095;	382.442;	43.688;	3.059;
699.422;	22.602;	2.382;	28.178;	382.440;	43.922;	3.061;
699.672;	22.420;	2.956;	28.197;	382.431;	44.080;	3.172;
699.922;	22.387;	2.735;	28.170;	382.445;	44.031;	3.259;
700.172;	22.331;	2.584;	28.167;	382.472;	44.072;	3.319;
700.422;	22.330;	2.304;	28.164;	382.453;	44.139;	3.227;
700.672;	22.364;	2.017;	28.153;	382.383;	44.119;	3.279;
700.922;	22.353;	1.919;	28.149;	382.336;	44.209;	3.398;
799.141;	22.545;	4.759;	28.094;	382.387;	45.865;	3.440;
799.375;	22.557;	4.838;	28.095;	382.511;	45.812;	3.535;
799.625;	22.564;	4.899;	28.096;	382.490;	45.852;	3.579;
799.875;	22.561;	4.911;	28.096;	382.521;	45.831;	3.637;
800.125;	22.569;	4.890;	28.096;	382.450;	45.838;	3.705;
800.375;	22.557;	4.819;	28.097;	382.355;	45.858;	3.754;
800.625;	22.558;	4.962;	28.096;	382.407;	45.828;	3.601;
800.875;	22.557;	4.921;	28.096;	382.337;	45.865;	3.674;
899.234;	22.515;	4.096;	28.112;	382.320;	48.342;	3.320;
899.484;	22.515;	4.309;	28.111;	382.489;	48.323;	3.233;
899.734;	22.507;	4.415;	28.112;	382.395;	48.373;	3.315;
899.984;	22.496;	4.552;	28.111;	382.248;	48.325;	3.368;
900.234;	22.489;	4.627;	28.109;	382.324;	48.390;	3.363;
900.484;	22.490;	4.769;	28.109;	382.208;	48.361;	3.462;
900.734;	22.500;	4.861;	28.107;	382.144;	48.382;	3.403;
900.984;	22.500;	4.914;	28.107;	382.097;	48.408;	3.312;
999.078;	22.741;	6.170;	28.118;	382.686;	51.181;	3.249;
999.328;	22.752;	6.293;	28.117;	382.796;	51.148;	3.344;
999.578;	22.753;	6.259;	28.117;	382.816;	51.202;	3.425;
999.828;	22.749;	6.301;	28.118;	382.774;	51.177;	3.361;
1000.078;	22.758;	6.286;	28.116;	382.699;	51.211;	3.273;

1000.328;	22.759;	6.385;	28.117;	382.580;	51.200;	3.214;
1000.578;	22.765;	6.467;	28.118;	382.478;	51.201;	3.195;
1000.828;	22.766;	6.568;	28.117;	382.349;	51.236;	3.194;
1099.203;	22.607;	7.269;	28.132;	382.346;	55.567;	3.569;
1099.453;	22.621;	7.310;	28.133;	382.424;	55.586;	3.467;
1099.703;	22.610;	7.275;	28.133;	382.491;	55.608;	3.379;
1099.953;	22.619;	7.326;	28.133;	382.374;	55.587;	3.413;
1100.203;	22.610;	7.215;	28.133;	382.318;	55.641;	3.433;
1100.453;	22.609;	7.296;	28.134;	382.290;	55.619;	3.474;
1100.703;	22.608;	7.219;	28.133;	382.166;	55.668;	3.374;
1100.953;	22.596;	7.195;	28.134;	382.228;	55.652;	3.465;
1199.078;	22.424;	4.058;	28.148;	382.535;	60.838;	3.627;
1199.328;	22.425;	4.027;	28.149;	382.456;	60.834;	3.580;
1199.578;	22.419;	3.817;	28.148;	382.502;	60.897;	3.582;
1199.828;	22.418;	3.726;	28.149;	382.513;	60.856;	3.551;
1200.078;	22.419;	3.543;	28.150;	382.456;	60.933;	3.577;
1200.328;	22.410;	3.522;	28.150;	382.501;	60.916;	3.544;
1200.578;	22.412;	3.598;	28.150;	382.446;	60.952;	3.527;
1200.828;	22.404;	3.836;	28.150;	382.482;	60.914;	3.602;
1299.000;	22.433;	4.601;	28.148;	382.612;	66.701;	3.656;
1299.250;	22.413;	4.582;	28.154;	382.595;	66.729;	3.560;
1299.500;	22.413;	4.648;	28.159;	382.650;	66.735;	3.661;
1299.750;	22.388;	4.573;	28.161;	382.730;	66.800;	3.697;
1300.000;	22.405;	4.722;	28.157;	382.701;	66.761;	3.780;
1300.250;	22.411;	4.721;	28.162;	382.666;	66.829;	3.763;
1300.500;	22.417;	4.801;	28.161;	382.492;	66.802;	3.853;
1300.750;	22.425;	4.819;	28.160;	382.491;	66.853;	3.855;
1399.094;	22.576;	6.842;	28.183;	382.587;	68.454;	3.633;
1399.344;	22.582;	6.789;	28.185;	382.554;	68.488;	3.622;
1399.594;	22.575;	6.799;	28.184;	382.587;	68.478;	3.730;
1399.859;	22.583;	6.826;	28.185;	382.574;	68.471;	3.609;
1400.109;	22.574;	6.782;	28.184;	382.497;	68.507;	3.579;
1400.359;	22.579;	6.924;	28.183;	382.352;	68.478;	3.651;
1400.609;	22.580;	6.888;	28.184;	382.356;	68.525;	3.626;
1400.844;	22.577;	6.961;	28.185;	382.295;	68.488;	3.669;
1499.016;	22.466;	7.270;	28.191;	382.488;	73.105;	3.425;
1499.266;	22.473;	7.358;	28.190;	382.532;	73.083;	3.377;
1499.516;	22.473;	7.348;	28.192;	382.334;	73.131;	3.367;
1499.766;	22.475;	7.415;	28.190;	382.289;	73.080;	3.317;
1500.016;	22.477;	7.405;	28.189;	382.209;	73.133;	3.395;
1500.266;	22.474;	7.423;	28.190;	382.357;	73.104;	3.325;
1500.531;	22.483;	7.400;	28.190;	382.338;	73.111;	3.356;
1500.766;	22.478;	7.339;	28.189;	382.375;	73.136;	3.377;
1599.172;	22.387;	6.340;	28.208;	382.613;	79.957;	3.497;
1599.422;	22.391;	6.226;	28.208;	382.464;	80.025;	3.510;
1599.672;	22.389;	6.276;	28.208;	382.557;	80.009;	3.501;
1599.922;	22.401;	6.335;	28.209;	382.619;	80.063;	3.516;
1600.172;	22.404;	6.374;	28.209;	382.627;	80.048;	3.469;
1600.422;	22.414;	6.460;	28.210;	382.779;	80.069;	3.385;
1600.672;	22.405;	6.446;	28.208;	382.649;	80.098;	3.443;
1600.922;	22.417;	6.536;	28.210;	382.682;	80.075;	3.366;
1699.375;	22.486;	6.538;	28.222;	382.240;	84.802;	3.636;
1699.625;	22.478;	6.530;	28.223;	382.278;	84.840;	3.717;
1699.875;	22.485;	6.604;	28.221;	382.161;	84.788;	3.779;
1700.125;	22.482;	6.622;	28.221;	382.339;	84.837;	3.689;
1700.375;	22.482;	6.706;	28.220;	382.315;	84.805;	3.584;
1700.625;	22.486;	6.752;	28.220;	382.322;	84.830;	3.651;
1700.875;	22.482;	6.747;	28.220;	382.419;	84.827;	3.604;
1799.031;	22.626;	6.630;	28.228;	382.462;	91.084;	3.740;
1799.281;	22.612;	6.647;	28.228;	382.319;	91.090;	3.789;
1799.531;	22.601;	6.625;	28.225;	382.326;	91.140;	3.894;
1799.781;	22.586;	6.614;	28.225;	382.372;	91.117;	3.992;
1800.031;	22.567;	6.462;	28.228;	382.447;	91.218;	3.978;
1800.281;	22.562;	6.515;	28.228;	382.562;	91.196;	4.033;
1800.516;	22.543;	5.436;	28.228;	344.474;	91.528;	3.895;

Furnace cooled data: A(Time),B(Load),C(Friction force),D(Temp.),E(Speed),F(Wear)

A	B	C	D	E	F	G
0.484;	20.767;	3.029;	28.485;	0.764;	0.310;	-1.199;
0.734;	20.849;	2.754;	28.520;	0.765;	0.518;	-1.282;
0.984;	20.927;	2.516;	28.547;	0.768;	0.714;	-1.309;
1.234;	21.003;	2.322;	28.574;	0.658;	0.912;	-1.351;
1.484;	21.078;	1.912;	28.597;	38.487;	1.141;	-1.343;
1.734;	21.163;	2.130;	28.616;	72.653;	1.501;	-1.216;
1.984;	21.235;	2.539;	28.634;	103.379;	1.812;	-1.137;
99.140;	22.468;	5.467;	28.799;	378.923;	90.634;	-1.008;
99.390;	22.479;	5.493;	28.799;	379.071;	90.762;	-1.079;
99.640;	22.481;	5.513;	28.801;	379.097;	90.801;	-1.133;
99.890;	22.489;	5.467;	28.801;	379.198;	90.885;	-1.236;
100.140;	22.485;	5.422;	28.804;	379.273;	90.961;	-1.128;
100.390;	22.492;	5.468;	28.801;	379.280;	90.995;	-1.066;
100.640;	22.488;	5.377;	28.800;	379.186;	91.096;	-1.164;
100.890;	22.499;	5.453;	28.801;	379.230;	91.113;	-1.057;
199.047;	22.500;	4.957;	28.807;	379.071;	106.374;	-0.916;
199.297;	22.498;	4.897;	28.806;	379.162;	106.437;	-0.794;
199.547;	22.497;	4.946;	28.805;	379.156;	106.401;	-0.692;
199.797;	22.498;	4.892;	28.804;	379.307;	106.484;	-0.653;
200.047;	22.495;	4.913;	28.804;	379.297;	106.468;	-0.570;
200.297;	22.502;	4.899;	28.805;	379.219;	106.513;	-0.533;
200.547;	22.501;	4.959;	28.803;	379.194;	106.537;	-0.662;
200.797;	22.511;	5.002;	28.802;	379.259;	106.536;	-0.798;
299.234;	22.473;	5.324;	28.817;	379.349;	111.004;	-0.620;
299.484;	22.470;	5.452;	28.819;	379.297;	110.979;	-0.518;
299.734;	22.465;	5.464;	28.820;	379.322;	111.033;	-0.435;
299.969;	22.458;	5.509;	28.823;	379.356;	110.984;	-0.541;
300.219;	22.460;	5.435;	28.821;	379.367;	111.040;	-0.596;
300.469;	22.451;	5.410;	28.820;	379.264;	111.011;	-0.679;
300.719;	22.460;	5.432;	28.820;	379.413;	111.017;	-0.608;
300.969;	22.454;	5.434;	28.820;	379.358;	111.062;	-0.568;
399.109;	22.425;	5.559;	28.825;	379.624;	113.694;	-0.716;
399.359;	22.428;	5.649;	28.822;	379.584;	113.742;	-0.750;
399.609;	22.416;	5.739;	28.826;	379.639;	113.713;	-0.865;
399.859;	22.410;	5.789;	28.827;	379.495;	113.761;	-0.741;
400.109;	22.405;	5.826;	28.826;	379.543;	113.751;	-0.772;
400.359;	22.413;	5.917;	28.827;	379.398;	113.750;	-0.698;
400.609;	22.411;	5.925;	28.828;	379.329;	113.792;	-0.598;
400.859;	22.419;	6.045;	28.826;	379.422;	113.755;	-0.517;
499.031;	22.451;	4.978;	28.818;	379.328;	116.054;	-0.663;
499.281;	22.450;	4.978;	28.816;	379.363;	116.018;	-0.754;
499.531;	22.450;	5.025;	28.816;	379.302;	116.014;	-0.866;
499.781;	22.443;	5.139;	28.815;	379.336;	116.032;	-0.952;
500.031;	22.443;	5.206;	28.817;	379.395;	115.996;	-0.907;
500.281;	22.448;	5.218;	28.817;	379.292;	116.037;	-0.798;
500.531;	22.443;	5.257;	28.818;	379.331;	115.994;	-0.856;
500.781;	22.444;	5.195;	28.816;	379.197;	116.040;	-0.774;
599.187;	22.464;	5.865;	28.846;	379.172;	117.114;	-0.853;
599.437;	22.455;	5.656;	28.841;	379.161;	117.160;	-0.820;
599.703;	22.450;	5.640;	28.840;	379.117;	117.135;	-0.728;
599.937;	22.447;	5.528;	28.838;	379.181;	117.184;	-0.790;
600.187;	22.435;	5.639;	28.837;	379.264;	117.142;	-0.768;
600.437;	22.444;	5.617;	28.838;	379.190;	117.188;	-0.665;
600.687;	22.428;	5.572;	28.835;	379.322;	117.182;	-0.781;
600.953;	22.428;	5.605;	28.835;	379.261;	117.157;	-0.699;
699.156;	22.393;	7.144;	28.845;	379.427;	116.845;	-0.540;
699.406;	22.383;	6.986;	28.846;	379.465;	116.882;	-0.482;
699.656;	22.387;	7.063;	28.846;	379.539;	116.855;	-0.426;
699.906;	22.390;	6.940;	28.847;	379.449;	116.893;	-0.533;
700.156;	22.395;	7.045;	28.847;	379.561;	116.847;	-0.587;
700.406;	22.400;	7.063;	28.846;	379.598;	116.880;	-0.704;
700.656;	22.392;	7.125;	28.844;	379.473;	116.852;	-0.589;
700.906;	22.396;	7.186;	28.843;	379.453;	116.862;	-0.559;
799.062;	22.368;	6.418;	28.846;	379.349;	116.238;	-0.784;
799.312;	22.366;	6.494;	28.845;	379.426;	116.198;	-0.740;
799.547;	22.359;	6.486;	28.845;	379.425;	116.242;	-0.608;
799.812;	22.359;	6.384;	28.845;	379.407;	116.208;	-0.486;
800.062;	22.360;	6.249;	28.844;	379.506;	116.248;	-0.525;
800.812;	22.357;	6.066;	28.844;	379.543;	116.258;	-0.642;
899.234;	22.333;	7.282;	28.816;	379.668;	116.362;	-0.233;
899.500;	22.322;	7.179;	28.825;	379.630;	116.365;	-0.142;
899.734;	22.323;	7.157;	28.825;	379.577;	116.386;	-0.062;
899.984;	22.338;	7.247;	28.828;	379.473;	116.351;	-0.140;
900.250;	22.342;	7.172;	28.839;	379.524;	116.365;	-0.190;
900.500;	22.327;	7.000;	28.837;	379.505;	116.397;	-0.208;
900.750;	22.314;	6.880;	28.842;	379.464;	116.392;	-0.151;
900.984;	22.301;	6.835;	28.843;	379.531;	116.458;	-0.169;
999.219;	22.437;	7.027;	28.851;	379.291;	116.797;	-0.687;
999.469;	22.443;	7.096;	28.853;	379.322;	116.754;	-0.600;
999.719;	22.441;	7.038;	28.855;	379.430;	116.806;	-0.712;
999.969;	22.443;	6.966;	28.855;	379.405;	116.766;	-0.689;
1000.219;	22.452;	6.965;	28.855;	379.372;	116.783;	-0.730;
1000.469;	22.450;	6.937;	28.855;	379.279;	116.778;	-0.735;
1000.719;	22.457;	6.992;	28.855;	379.390;	116.763;	-0.737;
1000.969;	22.453;	6.916;	28.856;	379.344;	116.803;	-0.650;
1099.172;	22.387;	6.295;	28.854;	379.388;	117.375;	-0.547;
1099.422;	22.391;	6.215;	28.854;	379.323;	117.402;	-0.423;
1099.672;	22.387;	6.176;	28.855;	379.379;	117.378;	-0.530;
1099.922;	22.392;	6.220;	28.854;	379.317;	117.348;	-0.517;
1100.172;	22.383;	6.226;	28.854;	379.374;	117.389;	-0.545;
1100.422;	22.388;	6.284;	28.854;	379.342;	117.330;	-0.518;
1100.672;	22.394;	6.167;	28.854;	379.280;	117.384;	-0.537;
1100.922;	22.389;	6.138;	28.854;	379.389;	117.348;	-0.447;
1199.156;	22.361;	6.791;	28.861;	379.847;	117.153;	-0.539;
1199.406;	22.363;	6.687;	28.859;	379.790;	117.204;	-0.634;
1199.656;	22.367;	6.579;	28.859;	379.697;	117.161;	-0.506;
1199.906;	22.377;	6.363;	28.857;	379.537;	117.187;	-0.522;
1200.172;	22.384;	6.316;	28.858;	379.606;	117.201;	-0.466;
1200.406;	22.404;	6.239;	28.857;	379.512;	117.177;	-0.557;
1200.656;	22.410;	6.106;	28.860;	379.446;	117.239;	-0.665;
1200.906;	22.408;	6.032;	28.861;	379.492;	117.205;	-0.718;
1299.094;	22.384;	5.660;	28.857;	379.448;	118.226;	-0.086;
1299.344;	22.366;	5.697;	28.857;	379.530;	118.191;	-0.014;
1299.594;	22.364;	5.650;	28.859;	379.462;	118.228;	-0.074;
1299.844;	22.360;	5.632;	28.858;	379.460;	118.199;	-0.212;
1300.094;	22.359;	5.539;	28.857;	379.351;	118.200;	-0.232;
1300.344;	22.347;	5.375;	28.858;	379.326;	118.228;	-0.368;
1300.594;	22.349;	5.452;	28.857;	379.415;	118.181;	-0.428;
1300.844;	22.345;	5.565;	28.858;	379.345;	118.245;	-0.456;
1399.047;	22.422;	5.715;	28.867;	379.616;	119.148;	-0.540;
1399.297;	22.428;	5.585;	28.865;	379.599;	119.151;	-0.642;
1399.547;	22.413;	5.471;	28.865;	379.578;	119.155;	-0.512;
1399.797;	22.410;	5.477;	28.865;	379.643;	119.143;	-0.590;
1400.047;	22.399;	5.461;	28.866;	379.540;	119.188;	-0.470;
1400.297;	22.406;	5.647;	28.866;	379.404;	119.154;	-0.366;
1400.547;	22.412;	5.633;	28.865;	379.415;	119.207;	-0.441;
1400.797;	22.406;	5.667;	28.866;	379.549;	119.169;	-0.419;
1499.250;	22.391;	6.628;	28.878;	379.292;	120.987;	-0.668;
1499.484;	22.390;	6.593;	28.878;	379.284;	120.981;	-0.701;
1499.734;	22.379;	6.542;	28.879;	379.390;	121.001;	-0.670;
1499.984;	22.380;	6.632;	28.877;	379.513;	120.959;	-0.609;
1500.234;	22.369;	6.668;	28.875;	379.614;	120.986;	-0.485;
1500.484;	22.376;	6.887;	28.875;	379.643;	120.927;	-0.413;
1500.734;	22.379;	6.988;	28.870;	379.691;	120.974;	-0.418;
1500.984;	22.380;	7.050;	28.874;	379.685;	120.929;	-0.457;
1599.187;	22.377;	6.989;	28.872;	379.276;	122.639;	-0.788;
1599.437;	22.373;	7.072;	28.872;	379.171;	122.642;	-0.871;
1599.687;	22.385;	7.157;	28.871;	379.083;	122.621;	-0.932;
1599.937;	22.376;	7.116;	28.873;	379.154;	122.681;	-0.765;
1600.187;	22.375;	7.205;	28.874;	379.265;	122.651;	-0.780;
1600.437;	22.371;	7.326;	28.873;	379.357;	122.699;	-0.793;
1600.687;	22.367;	7.624;	28.872;	379.309;	122.669;	-0.768;
1600.937;	22.368;	7.708;	28.871;	379.319;	122.690;	-0.692;
1699.125;	22.343;	7.099;	28.867;	379.575;	123.025;	-0.260;

;

1700.625;	22.355;	6.943;	28.868;	379.442;	123.044;	-0.098;
1700.125;	22.349;	6.625;	28.868;	379.438;	123.065;	-0.084
1700.875;	22.356;	7.294;	28.867;	379.316;	123.003;	-0.229;
1799.156;	22.339;	5.634;	28.873;	379.272;	123.938;	-0.658;
1799.406;	22.340;	5.576;	28.874;	379.219;	123.933;	-0.735;
1799.656;	22.330;	5.542;	28.874;	379.223;	123.952;	-0.689;
1799.906;	22.327;	5.522;	28.874;	379.180;	123.920;	-0.722;
1800.156;	22.322;	5.398;	28.873;	379.145;	123.966;	-0.800;
1800.406;	22.317;	4.377;	28.874;	341.362;	123.764;	-0.811;

A(Time),B(Load),C(Friction force),D(Temp.),E(Speed),F(Wear)

Sensitize sample data

A	B	C	D	E	F	G
299.141;	22.432;	3.520;	23.066;	382.423;	86.119;	3.278;
299.391;	22.423;	3.515;	23.070;	382.358;	86.161;	3.362;
299.641;	22.429;	3.623;	23.073;	382.406;	86.144;	3.388;
299.891;	22.433;	3.656;	23.071;	382.508;	86.156;	3.273;
300.141;	22.432;	3.682;	23.068;	382.423;	86.152;	3.377;
300.391;	22.424;	3.702;	23.066;	382.368;	86.150;	3.267;
300.641;	22.435;	3.751;	23.060;	382.247;	86.153;	3.259;
300.891;	22.462;	3.838;	23.066;	382.283;	86.132;	3.204;
599.204;	22.942;	4.465;	23.079;	382.891;	94.250;	3.604;
599.454;	22.948;	4.636;	23.078;	382.941;	94.239;	3.623;
599.704;	22.947;	4.601;	23.079;	382.868;	94.265;	3.636;
599.954;	22.947;	4.641;	23.080;	382.885;	94.262;	3.611;
600.204;	22.945;	4.621;	23.081;	382.924;	94.284;	3.613;
600.454;	22.945;	4.596;	23.080;	382.879;	94.281;	3.539;
600.704;	22.950;	4.415;	23.081;	382.845;	94.302;	3.454;
600.954;	22.953;	4.249;	23.080;	382.679;	94.307;	3.411;
899.157;	23.032;	2.720;	23.099;	383.207;	107.750;	4.014;
899.407;	23.036;	2.684;	23.099;	383.105;	107.784;	3.943;
899.657;	23.032;	2.687;	23.099;	383.120;	107.781;	3.985;
899.907;	23.034;	2.709;	23.100;	383.070;	107.793;	3.955;
900.157;	23.030;	2.680;	23.099;	383.110;	107.812;	4.020;
900.407;	23.034;	2.721;	23.099;	383.051;	107.801;	3.927;
900.657;	23.034;	2.716;	23.098;	383.172;	107.841;	3.962;
900.907;	23.032;	2.757;	23.099;	383.247;	107.834;	4.096;
999.094;	23.059;	4.847;	23.114;	382.908;	108.620;	4.411;
999.344;	23.055;	4.901;	23.116;	382.961;	108.613;	4.479;
999.594;	23.047;	4.849;	23.116;	382.948;	108.604;	4.377;
999.844;	23.046;	4.900;	23.118;	382.975;	108.590;	4.464;
1000.094;	23.039;	4.790;	23.118;	382.883;	108.609;	4.323;
1000.344;	23.036;	4.791;	23.118;	382.815;	108.590;	4.235;
1000.594;	23.036;	4.727;	23.119;	382.869;	108.594;	4.218;
1000.844;	23.034;	4.404;	23.118;	383.005;	108.577;	4.277;
999.094;	23.059;	4.847;	23.114;	382.908;	108.620;	4.411;
999.344;	23.055;	4.901;	23.116;	382.961;	108.613;	4.479;
999.594;	23.047;	4.849;	23.116;	382.948;	108.604;	4.377;
999.844;	23.046;	4.900;	23.118;	382.975;	108.590;	4.464;
1000.094;	23.039;	4.790;	23.118;	382.883;	108.609;	4.323;
1000.344;	23.036;	4.791;	23.118;	382.815;	108.590;	4.235;
1000.594;	23.036;	4.727;	23.119;	382.869;	108.594;	4.218;
1000.844;	23.034;	4.404;	23.118;	383.005;	108.577;	4.277;
1499.188;	22.977;	4.345;	23.161;	383.515;	151.462;	4.128;
1499.438;	22.982;	4.359;	23.161;	383.597;	151.474;	4.036;
1499.688;	22.981;	4.353;	23.160;	383.690;	151.498;	4.090;
1499.938;	22.986;	4.322;	23.160;	383.725;	151.501;	3.999;
1500.188;	22.990;	4.193;	23.160;	383.652;	151.533;	4.088;
1500.438;	22.996;	4.259;	23.159;	383.705;	151.530;	4.035;
1500.688;	23.000;	4.275;	23.159;	383.848;	151.554;	3.953;
1500.938;	23.004;	4.395;	23.158;	383.845;	151.550;	4.025;
1799.407;	22.834;	4.491;	23.188;	383.577;	164.978;	4.392;
1799.657;	22.834;	4.485;	23.188;	383.518;	164.969;	4.307;
1799.907;	22.835;	4.478;	23.187;	383.665;	164.972;	4.299;
1800.157;	22.837;	4.411;	23.187;	383.557;	164.991;	4.220;
1800.407;	22.837;	3.945;	23.187;	345.445;	165.025;	4.155;

Annealed sample data

A	B	C	D	E	F	
299.094;	22.600;	3.543;	23.903;	382.907;	134.875;	2.092;
299.344;	22.599;	3.525;	23.904;	382.902;	134.873;	2.101;
299.594;	22.600;	3.606;	23.904;	382.866;	134.927;	2.000;
299.844;	22.600;	3.597;	23.906;	382.926;	134.961;	2.115;
300.094;	22.606;	3.611;	23.906;	382.878;	134.974;	2.022;
300.344;	22.607;	3.577;	23.906;	382.800;	135.046;	1.943;
300.594;	22.611;	3.604;	23.908;	382.941;	135.052;	1.932;
300.844;	22.611;	3.550;	23.908;	382.966;	135.127;	1.922;
599.141;	22.899;	4.017;	23.946;	383.825;	168.571;	2.667;
599.391;	22.902;	4.101;	23.946;	383.769;	168.585;	2.577;
599.641;	22.904;	4.126;	23.946;	383.786;	168.638;	2.709;
599.891;	22.904;	4.210;	23.946;	383.666;	168.633;	2.643;
600.141;	22.904;	4.136;	23.947;	383.657;	168.692;	2.738;
600.391;	22.902;	4.047;	23.947;	383.736;	168.679;	2.652;
600.641;	22.909;	4.057;	23.946;	383.787;	168.723;	2.624;
600.891;	22.907;	4.012;	23.946;	383.833;	168.718;	2.640;
899.172;	22.983;	3.984;	23.963;	383.984;	189.896;	3.007;
899.422;	22.980;	3.985;	23.964;	383.958;	189.950;	3.100;
899.672;	22.975;	3.995;	23.965;	383.917;	189.921;	3.188;
899.922;	22.978;	3.974;	23.962;	383.885;	189.968;	3.074;
900.172;	22.972;	3.984;	23.963;	383.841;	189.966;	2.961;
900.422;	22.981;	4.051;	23.964;	383.884;	189.997;	3.034;
900.672;	22.962;	4.009;	23.966;	383.865;	190.031;	3.106;
900.906;	22.962;	4.012;	23.965;	383.978;	190.042;	3.215;
1199.141;	22.868;	4.058;	23.990;	384.039;	199.523;	3.379;
1199.391;	22.862;	4.194;	23.987;	383.950;	199.505;	3.274;
1199.641;	22.869;	4.410;	23.988;	383.948;	199.501;	3.202;
1199.891;	22.868;	4.515;	23.990;	384.001;	199.537;	3.185;
1200.141;	22.876;	4.649;	23.990;	383.898;	199.517;	3.090;
1200.391;	22.882;	4.642;	23.989;	383.827;	199.548;	2.995;
1200.641;	22.884;	4.633;	23.990;	383.777;	199.523;	3.050;
1200.891;	22.877;	4.643;	23.992;	383.878;	199.552;	3.025;
1499.203;	22.896;	4.450;	24.017;	384.071;	205.763;	2.989;
1499.453;	22.890;	4.439;	24.017;	384.226;	205.756;	3.109;
1499.703;	22.896;	4.454;	24.018;	384.257;	205.750;	3.034;
1499.953;	22.893;	4.437;	24.018;	384.315;	205.777;	3.172;
1500.203;	22.894;	4.549;	24.018;	384.342;	205.750;	3.172;
1500.453;	22.898;	4.546;	24.017;	384.223;	205.783;	3.306;
1500.703;	22.898;	4.591;	24.018;	384.143;	205.750;	3.337;
1500.953;	22.902;	4.613;	24.018;	384.110;	205.780;	3.448;
1799.125;	22.827;	5.096;	24.046;	384.286;	210.331;	3.286;
1799.375;	22.830;	5.009;	24.047;	384.344;	210.293;	3.419;
1799.625;	22.840;	4.932;	24.047;	384.209;	210.334;	3.435;
1799.875;	22.841;	4.749;	24.046;	384.198;	210.334;	3.525;
1800.109;	22.849;	4.562;	24.046;	384.090;	210.340;	3.519;
1800.359;	22.842;	4.569;	24.048;	345.887;	210.388;	3.572;

Oil Sample data:

A	B	C	D	E	F	G
0.735;	21.442;	1.636;	22.945;	0.295;	0.768;	1.234;
0.985;	21.522;	1.406;	22.971;	0.190;	0.968;	1.324;
1.235;	21.603;	1.208;	22.996;	0.100;	1.171;	1.408;
1.485;	21.674;	1.068;	23.020;	0.064;	1.376;	1.493;
1.735;	21.740;	1.162;	23.040;	32.260;	1.588;	1.421;
1.985;	21.804;	2.255;	23.058;	66.948;	1.854;	1.301;
99.235;	23.142;	5.427;	23.249;	380.537;	94.211;	1.399;
99.485;	23.211;	5.658;	23.220;	380.468;	94.301;	1.476;
99.735;	23.197;	5.650;	23.227;	380.560;	94.376;	1.587;
99.985;	23.199;	5.697;	23.224;	380.480;	94.495;	1.530;
100.235;	23.214;	5.779;	23.217;	380.579;	94.546;	1.605;
100.485;	23.207;	5.747;	23.220;	380.504;	94.656;	1.526;
100.735;	23.204;	5.728;	23.224;	380.410;	94.792;	1.524;
100.985;	23.198;	5.773;	23.228;	380.448;	94.880;	1.467;
199.219;	23.111;	5.003;	23.266;	380.810;	125.713;	1.696;
199.469;	23.105;	4.952;	23.268;	380.898;	125.769;	1.796;
199.719;	23.111;	4.978;	23.269;	381.018;	125.810;	1.906;
199.969;	23.115;	4.991;	23.268;	380.997;	125.893;	1.960;
200.219;	23.114;	5.025;	23.267;	380.976;	125.910;	2.030;
200.469;	23.110;	4.970;	23.267;	380.770;	126.008;	2.061;
200.719;	23.114;	5.047;	23.270;	380.679;	126.017;	2.083;
200.969;	23.121;	5.136;	23.270;	380.709;	126.098;	1.949;
299.219;	23.006;	4.325;	23.279;	380.996;	139.891;	2.100;
299.469;	23.008;	4.469;	23.279;	381.031;	139.877;	2.061;
299.719;	23.012;	4.560;	23.276;	380.895;	139.957;	2.162;
299.969;	23.008;	4.694;	23.277;	380.972;	139.965;	2.079;
300.219;	23.015;	4.825;	23.277;	380.916;	140.013;	2.138;
300.469;	23.004;	4.886;	23.279;	380.797;	140.074;	2.218;
300.719;	23.006;	5.057;	23.278;	380.743;	140.090;	2.101;
300.969;	23.003;	5.034;	23.278;	380.828;	140.173;	2.114;
399.219;	22.977;	5.220;	23.282;	380.372;	153.106;	1.984;
399.469;	22.982;	5.301;	23.281;	380.364;	153.143;	1.993;
399.719;	22.976;	5.224;	23.282;	380.306;	153.209;	1.885;
399.969;	22.979;	5.238;	23.284;	380.446;	153.223;	1.876;
400.219;	22.977;	5.222;	23.283;	380.578;	153.310;	1.880;
400.469;	22.979;	5.299;	23.282;	380.507;	153.319;	1.893;
400.719;	22.981;	5.274;	23.281;	380.614;	153.390;	1.907;
400.969;	22.974;	5.235;	23.280;	380.634;	153.388;	1.823;
499.172;	23.060;	5.248;	23.280;	380.626;	165.126;	1.946;
499.422;	23.054;	5.180;	23.280;	380.677;	165.125;	1.827;
499.672;	23.054;	5.177;	23.281;	380.620;	165.180;	1.786;
499.922;	23.044;	5.126;	23.281;	380.757;	165.210;	1.842;
500.172;	23.045;	5.154;	23.283;	380.649;	165.248;	1.773;
500.422;	23.035;	5.021;	23.284;	380.558;	165.314;	1.695;
500.657;	23.031;	4.905;	23.284;	380.512;	165.286;	1.679;
500.907;	23.019;	4.581;	23.284;	380.618;	165.349;	1.806;
599.157;	22.906;	5.012;	23.287;	380.769;	177.816;	2.140;
599.407;	22.894;	4.990;	23.289;	380.781;	177.842;	2.164;
599.657;	22.899;	4.964;	23.291;	380.816;	177.901;	2.186;
599.907;	22.899;	4.980;	23.293;	380.708;	177.901;	2.288;
600.157;	22.895;	4.887;	23.299;	380.625;	177.979;	2.233;
600.407;	22.901;	4.962;	23.298;	380.622;	177.965;	2.318;
600.657;	22.898;	4.812;	23.296;	380.604;	178.013;	2.378;
600.907;	22.873;	4.626;	23.297;	380.634;	178.014;	2.391;
699.125;	22.904;	5.011;	23.338;	380.722;	187.726;	2.100;
699.375;	22.911;	5.001;	23.318;	380.752;	187.691;	2.046;
699.625;	22.883;	4.885;	23.340;	380.830;	187.801;	1.951;
699.891;	22.885;	4.774;	23.339;	380.869;	187.840;	1.981;
700.141;	22.821;	4.484;	23.358;	380.873;	187.901;	2.096;
700.391;	22.823;	4.205;	23.360;	380.765;	187.982;	2.064;
700.641;	22.844;	4.255;	23.338;	380.781;	187.907;	2.173;
700.875;	22.889;	4.463;	23.360;	380.882;	188.052;	2.253;
799.094;	22.874;	4.762;	23.310;	380.978;	196.335;	2.126;
799.344;	22.873;	4.736;	23.310;	380.928;	196.393;	2.211;
799.594;	22.874;	4.789;	23.310;	381.049;	196.374;	2.103;
799.844;	22.879;	4.855;	23.312;	381.031;	196.424;	2.029;
800.094;	22.877;	4.859;	23.312;	380.913;	196.449;	2.065;
899.844;	22.911;	4.687;	23.321;	380.367;	204.409;	1.702;
900.094;	22.915;	4.754;	23.322;	380.467;	204.430;	1.728;
1000.282;	22.946;	5.057;	23.324;	380.912;	209.737;	1.895;
1000.532;	22.948;	5.072;	23.323;	380.792;	209.706;	2.020;
1000.782;	22.951;	5.085;	23.324;	380.903;	209.749;	2.001;
1099.047;	22.910;	5.336;	23.327;	380.514;	214.182;	2.082;
1099.297;	22.912;	5.398;	23.326;	380.451;	214.174;	2.131;
1099.547;	22.911;	5.384;	23.327;	380.468;	214.219;	2.125;
1099.813;	22.909;	5.432;	23.326;	380.556;	214.183;	2.019;
1100.063;	22.908;	5.480;	23.328;	380.591;	214.236;	2.088;
1100.313;	22.904;	5.469;	23.327;	380.621;	214.200;	1.973;
1100.563;	22.909;	5.509;	23.327;	380.672;	214.224;	2.082;
1100.813;	22.903;	5.510;	23.327;	380.778;	214.247;	2.194;
1199.032;	22.854;	5.572;	23.336;	380.362;	218.063;	2.207;
1199.266;	22.846;	5.501;	23.335;	380.439;	218.033;	2.157;
1199.516;	22.848;	5.474;	23.336;	380.500;	218.046;	2.038;
1199.766;	22.841;	5.431;	23.335;	380.431;	218.075;	2.151;
1200.016;	22.846;	5.429;	23.335;	380.461;	218.060;	2.060;
1200.266;	22.845;	5.381;	23.335;	380.622;	218.099;	2.155;
1200.516;	22.846;	5.393;	23.335;	380.764;	218.084;	2.226;
1200.766;	22.844;	5.302;	23.337;	380.856;	218.131;	2.223;
1299.219;	22.832;	5.374;	23.341;	380.462;	220.699;	2.301;
1299.469;	22.827;	5.435;	23.341;	380.522;	220.686;	2.171;
1299.719;	22.821;	5.370;	23.342;	380.635;	220.731;	2.242;
1299.969;	22.811;	5.386;	23.343;	380.800;	220.692;	2.336;
1300.219;	22.807;	5.413;	23.341;	380.761;	220.726;	2.254;
1300.469;	22.798;	5.402;	23.342;	380.634;	220.713;	2.119;
1300.719;	22.800;	5.475;	23.342;	380.801;	220.719;	2.235;
1300.969;	22.791;	5.450;	23.344;	380.709;	220.758;	2.114;
1399.219;	22.892;	6.687;	23.342;	380.598;	222.429;	2.225;
1399.469;	22.883;	6.631;	23.341;	380.652;	222.471;	2.196;
1399.719;	22.884;	6.652;	23.341;	380.525;	222.439;	2.097;
1399.969;	22.885;	6.554;	23.342;	380.463;	222.480;	1.992;
1400.219;	22.878;	6.526;	23.344;	380.614;	222.468;	2.016;
1400.469;	22.882;	6.576;	23.344;	380.727;	222.500;	1.942;
1400.719;	22.878;	6.557;	23.345;	380.652;	222.477;	1.879;
1400.969;	22.885;	6.652;	23.346;	380.706;	222.474;	1.797;
1499.172;	22.910;	3.726;	23.347;	380.956;	223.948;	2.189;
1499.422;	22.909;	3.661;	23.348;	380.866;	224.019;	2.207;
1499.672;	22.910;	3.599;	23.349;	380.749;	223.999;	2.218;
1499.922;	22.914;	3.530;	23.349;	380.849;	224.054;	2.102;
1500.172;	22.911;	3.466;	23.349;	380.788;	224.074;	2.214;
1500.422;	22.914;	3.415;	23.350;	380.668;	224.078;	2.321;
1500.688;	22.914;	3.415;	23.351;	380.736;	224.139;	2.235;
1500.938;	22.911;	3.540;	23.352;	380.850;	224.115;	2.127;
1599.219;	22.707;	4.974;	23.347;	380.900;	225.637;	2.100;
1599.469;	22.710;	4.988;	23.333;	380.770;	225.567;	2.216;
1599.703;	22.724;	5.068;	23.316;	380.843;	225.504;	2.212;
1599.953;	22.771;	5.233;	23.289;	380.782;	225.445;	2.326;
1600.203;	22.738;	5.103;	23.289;	380.893;	225.400;	2.261;
1600.453;	22.743;	5.152;	23.290;	380.788;	225.447;	2.172;
1600.719;	22.683;	4.947;	23.311;	380.802;	225.481;	2.280;
1600.969;	22.663;	4.896;	23.292;	380.840;	225.431;	2.404;
1699.016;	22.851;	5.702;	23.379;	380.919;	228.404;	1.846;
1699.266;	22.829;	5.588;	23.386;	380.899;	228.447;	1.762;
1699.500;	22.805;	5.509;	23.390;	380.934;	228.451;	1.867;
1699.750;	22.828;	5.603;	23.382;	380.938;	228.482;	2.003;
1700.000;	22.872;	5.801;	23.372;	380.999;	228.422;	2.113;
1700.250;	22.965;	6.092;	23.384;	381.081;	228.499;	2.157;
1700.500;	22.988;	6.039;	23.403;	380.936;	228.554;	2.057;
1700.750;	23.008;	6.210;	23.365;	380.866;	228.504;	1.959;
1799.047;	22.912;	6.057;	23.377;	380.694;	231.034;	2.016;
1799.297;	22.913;	6.065;	23.376;	380.813;	230.993;	2.118;
1799.547;	22.915;	6.081;	23.374;	380.752;	231.019;	2.051;
1799.797;	22.910;	6.100;	23.373;	380.805;	230.981;	1.968;
1800.047;	22.911;	6.161;	23.375;	380.928;	231.011;	2.019;
1800.297;	22.900;	6.137;	23.375;	380.930;	230.995;	1.958;
1800.547;	22.894;	5.716;	23.376;	342.828;	231.037;	2.100;