DEVELOPMENT OF DUAL CONDITION PIN-ON-DISC WEAR TESTING MACHINE

BY

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PhD/SEET/2014/534

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MINNA, NIGERIA

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY(PhD) IN MECHANICAL ENGINEERING (INDUSTRIAL AND PRODUCTION ENGINEERING OPTION)

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ABSTRACT

Determination of surface wear of engineering materials was carried out using Pin-on-disc wear testing machine. Wear is a dynamic and complex process which involves not only surface and material properties but operating conditions as well. The wearing of surfaces may lead to extra cost of maintenance or manufacturing process. The present study developed dual condition Pin-on-disc wear testing machine with which both dry and lubricated surface contact of engineering material can be determined. The surface wear of Aluminium 6061, Bronze and Brass pins were investigated. The performance test was carried out based on varying loads, timeand speeds. The study determined pin wear rate, wear resistance and specific wear rate of the pins. The various pins were subjected to different performance test at constant sliding speed of 0.158m/s and 0.1975 m/s and at forces of 5N, 8N and 10N respectively. During experimental testing the pins were removed after 300 seconds and the final volume of each pin determined.The study indicated that Aluminium 6061 pin of 4mm diameter under dry surfaces at speed of 0.158m/s and applied force of 8N had highest wearing rate of 0.2129 mm^3/m as compared to 6mm diameter pin used. The wear test for Bronze pin at constant speedof 0.158m/shad the lowest wearing rate of 0.0394mm^3/m with a pin diameter of 6mm under applied force of 5N. The wearing rate per second under applied force of 5N and at sliding speed of 0.158m/s of 6mm diameter pin during lubricated condition include 20.5$\mu mm^3/ms$, 8.2 $\mu mm^3/ms$ and 11 $\mu mm^3/ms$ for Aluminium 6061, Bronze and Brass respectively. The lubricated surface reduces wear to 54%. Bronze has 59.32 % lower wear rate per second in compare to Aluminium 6061 and Brass using the pin-on-disc developed by this study. This indicated that wear resistance increases in the order of Bronze, Brass and least occurred in Aluminium 6061 pin. The specific wear rate of 6mm diameter pin with lubricated surface has least wearing rate at sliding speed of 0.158m/s and sliding distance of 568.8m. The results ofspecific wear rate for Brass pin, Aluminium 6061 pin and Bronze pin were$0.3172 \times 10^{-3}$$mm^3$/Nm, $0.5901 \times 10^{-3}$$mm^3$/Nm and$0.2428 \times 10^{-3}$$mm^3$/Nm. In conclusion, engineering surface with good lubricating surface and higher surface area in contact have reduce wear rate. The study contributes to indigenous technology development in both Machine Design and Tribology.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The study of wear, friction and lubricationare encompassed by the term Tribology. The word 'Tribology' is derived from the Greek word *Tribos*, which means rubbing or attrition. Tribology is a study of friction, wear and lubrication between two interacting surfaces in relative motion and of relative subjects and practices (John, 2008). The present study focuses on wear behaviour of engineering materials in which four broad general classes are known. They are adhesive wear, surface fatigue wear, abrasive wear and chemical/corrosion wear (Stolarski, 2000). Wear is among the most significant factors in processing of engineering materials (Kalpakjian and Schmid, 2009). Stolarski (2000) defined wear as loss of material fromcontacting bodies in relative motion. It is controlled by the properties ofthe material, the environmental operating conditions and the geometryof the contacting bodies. The wear mechanisms are in two groups. The firstdominated by the mechanical behaviour of materials, and the second defined by the chemical nature of the materials.

Kalpakjian and Schmid (2009) stated that wear is an undesired cumulative change in dimensions caused by thegradual removal of discrete particles from contacting surfaces in motion, due predominantlyto mechanical action. Also, corrosion often interacts with thewear process to change the character of the surfaces of wear particles through reaction withthe environment. Wear is, in fact, not a single process but a number of different processesthat may take place by themselves or in combination. Based on this understanding, Dalgobind and Anjani (2013) classified wear in to five major subcategories and they include: adhesive, abrasive, corrosive, surface fatigue and deformation wears. This agreed with classes of wear mentioned by Stolarski (2000). John (2008) understood that wear is the progressive loss of substance from the surface of a solid body caused by mechanical action that involves the contact and relative motion with a solid, liquid or gaseous counter-body. The wear always hampered the positive benefit of engineering material and reduces the life cycle of the material (Kutz, 2006).

The engineering material experiences wear when subjected to variables such as temperature, force, velocity, external material and harsh environment like more acidic or basic condition.The complexity of the wear process may be better appreciated by recognising the involved variables. These variables are hardness, toughness, ductility, modulus of elasticity, yield strength, fatigue properties, and structure and composition of the mating surfaces, contact geometry, contact pressure, temperature, stress distribution, coefficient of friction, sliding distance, relative velocity, surface finish, lubricants, contaminants, and ambient atmosphere at the wearing interface (Kutz, 2006).

There will be engineering material surface damage or removal of material from one or both side of solid surfaces in a sliding, rolling or impact motion relative to one another by this aforementioned variable (John, 2008). The wear condition has surface interactions in different region base on relative speed on the surface contact. This result to transfer of heat during contact surface, it leads to loses as a wear particle. However, Lim and Ashby (2005) opined that wear of engineering material resulted from corrosive, adhesive/abrasive or frictional, fatigue and impact surfaces.

The wear on the surface is tested usingdual condition pin-on-disc machine to assess erosive surface of material from its main source. It is simply achieved by measuring workability of engineering material used in frictional state. There is need to perform mechanical tests condition or experimental condition based on available data.This will be critical if a material subjected to wear testfailed the quality test or engineering materials test. In engineering material test there is need for load or force that acts as impact on the defined materialsin use (Williams, 2006). According to Kutz (2006) pin-on-disc wear tests is done using application of load mountedon a pin in direct surface contact on a rotating disc. The surface contact will be on rotating disc at constant speed to obtain weight loss. The loss can be continually measured to determine wear rate of pin material. This method helps in characterising coefficient of friction and its applied force, and also wearing rate that exist between materials in surface contact.

This present study includes design, fabrication and performance analysis test as a concept of development of reliable dual machine. The design and fabrication process of the machine wasdeveloped through indigenous process by instituting a dual process instead on single pin condition. Altenburg *et al.* (2006) stated the development of this kind of machine in under-developed country such as Nigeria will boost trends of technology advancement.

1.2 Statement of the Problem

Wear is a dynamic and complex process which involves not only surface and material properties but operating conditions as well. The wears in engineering material include wearing of bolts and nuts experienced by machines and equipment used in workshop. In manufacturing process whenever there is dull drill bits, there is need for regrinding the drill bit for sharpening. The worn cutting tools can also be changed or replaced or repaired in this situation. The underground or buried pipelines that transport fluid may be subjected to wear due to corrosion (Kalpakjian and Schmid, 2009). Based on this, it is important to develop a machine that can test the surface wear of engineering material.

The wearing surfaces may lead to extra cost of maintenance and production. It also causes time consuming activities during reworking process. Most of the existing techniques for wear measurement are carried out on assumption. Based on this background, the present study addresses these challenges in terms of periodic measurement of the material with accurate digital liquid crystal display screen, sensor gauge and the machine perform at high speed of operation,which allows for faster and dynamic measurements of wear components. This gives better accuracy of the readings in the wearing process and wearing environment.

1.3 Aim of the Study

The study aims to develop a dual condition pin-on-disc wear testing machine that can be used to determine surface wear of engineering material in a laboratory.

1.4 Objectives of the Study

The objectives of this study include:

i. Design and fabrication of dual condition pin-on-disc wear testing machine capable of determiningwear on pin surface.
ii. Assembly of the pin-on-disc wear testing machine.
iii. Develop monitoring device that will continuously measure the pin length reduction.
iv. Carrying out performance testing analysis to determine surface wear behaviour and determine specific rate of wear of the pinbeing subjected to variable parameters such as load, time and speed.

1.5 Justification and Significance of the Study

Industries and institutions in Nigerialack locally fabricated wear testing equipment for carrying out wear testing research. Most available types that are used are foreign wear testing machines. Engineering field of wear surface research adopts foreign made wear machines which are expensive and not readily available to the researchers. For this reason, the present study developed dual condition machine for testing surface wearing behaviour of material. This was manufactured with components and available materials sourced locally in Nigeria. The machineischeaper and readily available for studying surface wear of engineering material. In addition, this improves productivity, quality control, good manufacturing practice and also spurs national economic growth. This is the most important reason that justifies the development of wear testing machine.

The significance of this study include developed pin-on disc wear testing machine, which will be useful for graduates or students who study engineering related courses such as, machine design, manufacturing/production engineering and material engineering course in university. The design and fabrication concept will aid student to design similar machines in the university. This can be adopted as wear testing machine in engineering laboratory of Mechanical Engineering of Federal University of Technology on completion. The study points out wear parameters that affects engineering materials and this can be used for studying reliability and failure analysis of such materials by the students. With the developed machine, the identification of wear regions, behaviour, processes, or estimation of degree of wear will become possible.

However, it is not easy to access foreign type of the machine by researchers on reliability and failure to analyse the effect of surface wears on engineering materials. This resulted in high cost of importation of such machine from manufacturers abroad.

This study will be beneficent to researchers on related concept by adopting the similar approach for machine design and wear analysis. The society at large will benefited from technological know-how acquired by this study through application of the outcome of the study. This is due to adoption of local innovation technology concept. This can be used as one of tool for boosting Nigeria economy. Thus, the development of dual condition pin-on-disc wear testing machine will create improvement in development and sustainable of local technology concept.

1.6 Scope of the Study

The scope of the present study is to: design, fabricate, assembly and carrying out performance evaluation test on dual condition pin-on-disc wear testing machine. The dual condition pin-on-disc wear testing machine was developed locally. The design analysis for the production was based on machine design concept. The computer aided design for designing the machine prototype was Pro-E software. The variable parameters of wear behaviour considered include speed, time and load by this study. However, the wear results were compared to other wear performance testing of other authors report.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pin-on-Disc Wear Tester

Wear test using pin-on-disc is a method for characterising frictional force and its coefficient and rate of wearbetween contact surface (Abdul *et al.*, 2015).Design of pin-on-disc wear testing machine is being carried out through application of constant normal load on contacting surface with rotating disc at constant speed (Nassar and Nassar, 2011). The weight loss is measured to determine expected rate of wear for different material for comparative test analysis. The performance analysis if based on different materials can be quantified using defined value of resistance of wear rate of the materials. This study also adopts comparative analysis of resistance of wear rate of engineering material such as aluminium, bronze and brass. The experimental test may also consider volume lost to determine rate of wear of the engineering material under consideration.

Abdul *et al.*(2015) opined that pin wear tester is necessary to development of new and improved cost-saving applications in engineering design. For instance, design of frictional and wearing forces of the materials in contact. The purpose of pin wear tester research is to minimise or eliminate losses obtainable from wear and friction of engineering material surface. This means engineering surface requires proper design to reduce immediate wear when in use. In this note, Figure 2.1 shows the wear testing machine developed by Nassar and Nassar, (2011). It was designed with load frame and installed electric motor and the control sensor. The study was to improve on local content of wear testing machine.

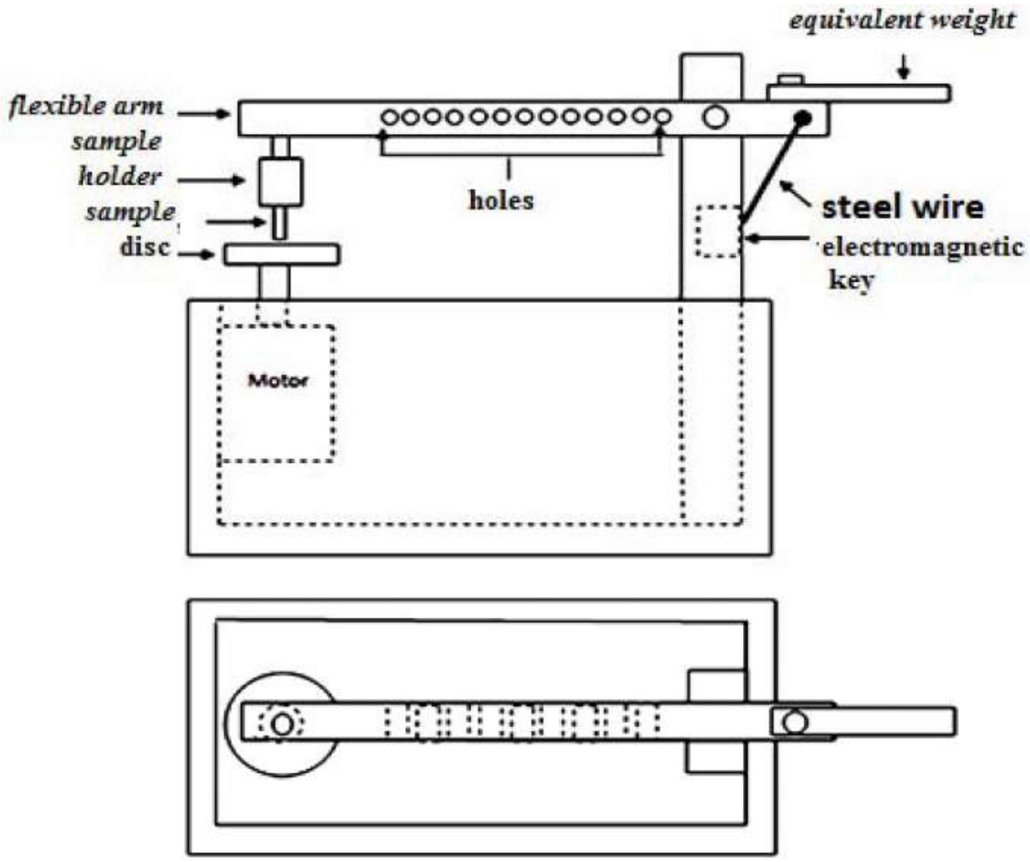

Figure 2.1: Wear Testing Machine (Nassar and Nassar, 2011)

,The flexible wear is determined using electromagnetic key that worked as brake for stopping experiment. There is digital timer for timing and loads vary with size of required load to be used for the testing. The mass of the load may ranges from 10 to 500 gm when carrying out the experimental analysis of wear testing.

El-Mahallawi and Shash (2017) considered effect on wear on dry surfaces. Different number of experiment wasconducted by using a pin-on-disc machine using wear and friction monitor TR-20 model. The pin was held against the counter face of a rotating disc(EN31 steel disc) with wear track diameter of 60 mm. This provides an insight on how to design a good pin on disc wear testing machine. The present study adopted the rotating disc using steel with diameter 100mm and thickness of 8mm. This was according to ASTM-G99 that requires rotating disc which must be within 165mm by diameter and 8mm of thickness size (ASTM, 2000). The pin required to be loadedagainst the disc through a dead weight loading system. El-Mahallawi and Shash (2017) conducted wear test for allspecimens under the normal loads of 20N, 40N and asliding velocity of 2 and 4 m/s.This complies with ASTM load requirement 5 to 200N and sliding speed of 0.5 to 10m/s and the present study will sticks to this condition. Wear tests require the pin samples' diameter of3 to 12 mm and length of 25mm to 30mm (ASTM, 2000).

2.2 Surface Engineering

Surface engineering is an application for modifying engineering material surfaces to enhance performanceand also to reduce corrosion and resistance of wear rate (Carlsson, 2005). Whenever material surface is subjected to engineering operation, there is tendency of materials degradation which includes wearing, cracking and fracture.

The objectives of Tribology is to regulate magnitude of frictional force from the experimental analysis that may be derived from process parameter such assurface finish and material properties, temperature, sliding velocity and lubrication (Kumar and Sen, 2014).In manufacturing processes, the surfaces of tools,dies, and workpieces are subjected to the following (Kalpakjian and Schmid, 2009):

i. force and contact pressure, which rangesfrom very low values to multiples of the yield stress of the work pieces material
ii. relative speed, from very low to very high
iii. temperature, which ranges from ambient to melting

In addition to selection of appropriate materials and controlling process parameters that can be adopted for reducing friction and wear is application of lubricant/metalworking fluids.

2.3 Wears of Engineering Material

CallisterJr. and Rethwisch (2010) classified solid materials into three forms such as metals,and polymers and ceramics. This study concentrates on wears of solid metalssuch as iron,lead, zinc, aluminium, copper and nickel based on alloying elements concentration used in mechanical system. The wearing of surface is commonly a cause of failure of engineering materials which is resulted from undesirable process. The surface wear leads to loss of human lives especially when a vehicle loss control and leads to accident as a result brake failure. The brake pad has wear surface in that regard. It also leads to economic losses and interference, loss of availability of products and services in engineering industry (Juhani *et al*, 2006).Wear is a process of removal of material from one or both oftwo solid surfaces in solid state contact (Callister Jr. and Rethwisch, 2010).Gupta (2009) defined wear as undesirable deterioration or removal ofmaterial from its surface. Wear also refers to progressive loss or removal of material from one or both the surfaces in contact as the result of relative motion between two surfaces (Kumar and Sen, 2014).

Wear is being considered as one of most influential factor that causes short life cycle of material due to frictional loss of surface wear of two bodies in contact. This can be experienced by two solid surfaces are in contact. According to Callister Jr and Rethwisch (2010) wear is the erosion of material from a solid surface by the action of another solid. The study of the processes of wear is part of thediscipline of Tribology.

The causes of wears and the behaviour of materials may be known, prevention of wears as a failure may benoteasily guarantee. The usual causes are improper materials selection and processing and inadequate design of the component or its misuse. Wear occurs in structural parts during service and regular inspection and repair or replacement is critical to safe design (Callister Jr. and Rethwisch, 2010).There are four principal wear processes including surface fatigue, adhesive wear, abrasive wear and corrosive wear (Callister Jr and Rethwisch, 2010). However, wear can be categorisedas follows(Kumar and Sen, 2014):

i. Abrasive wearing. It is either caused by low or high stress that occurs when material is removed by contact with hard particles. The wear particles may be located at thepoint of two materials surface or existing as loose particles between two material surfaces. This type of wear can be obtained from machining, grinding, polishing or lapping materials. It can also occur between two materials in which one is harder and other softer and harder cut-off the soft one. Figure 2.2 shows abrasive wear, according to Kumar and Sen (2014) when the two materials in contact and thus, grinding occurs in the process as the one of the material surface is fixed relative to other material surface. There may be lapping of surfaces and abrasive wear will occur with series of indentations or scratch.

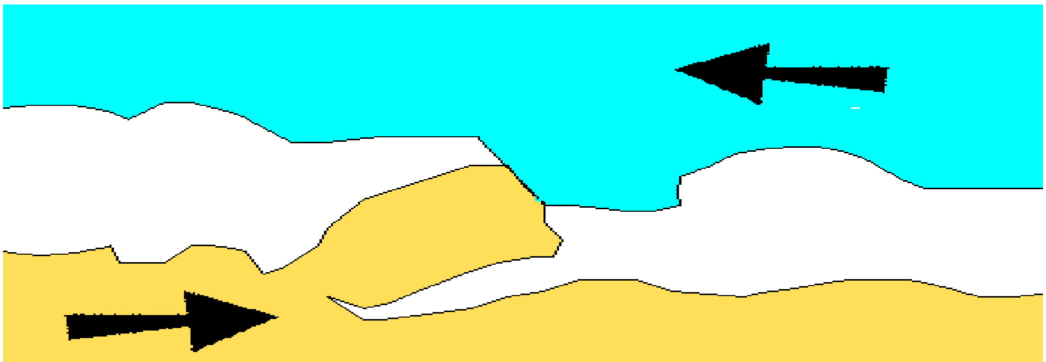

Figure 2.2: Abrasive wear (Kumar and Sen, 2014)

ii. Erosion includes cavitation, solid and fluid impingement: this wear is due to mechanical interaction between a surface and a fluid, a multi-component fluid, or impinging liquid or solid particles. Figure 2.3 shows a typical illustration of erosional wear.

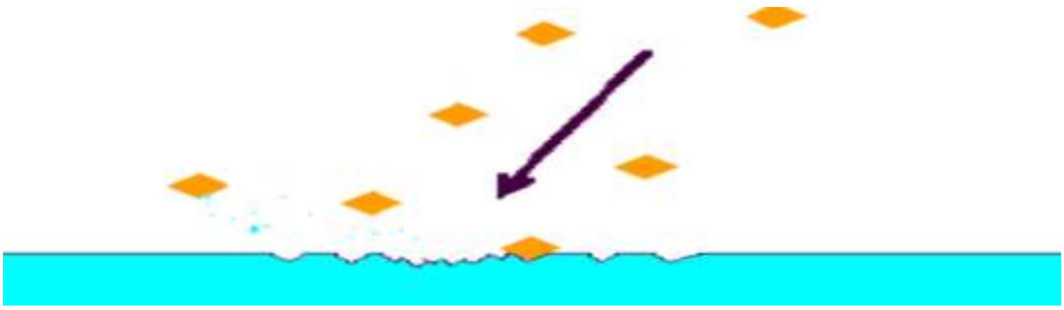

Figure 2.3: Erosional wear (Kumar and Sen, 2014)

iii. Corrosion include surface wearing due to environmental condition

iv. Adhesion wear is resulted from seizure and galling; fretting or oxidative wear: The fretting may also be called corrosive wear in which corrosive damages occurs at engineering material contact surfaces. This damage is induced under load and in presence of continuous relative motion by induced force. This occurs if two solid surfaces slide on each other by pre-determine force. For instance, the surface projections of plastically deformed material which welded together can result to local pressure. The sliding continues with surface projections on the second surface with wearing particles. The future wear of surfaces can be illustrated using intimate contact with each other. Figure 2.4 showed that surfaces are held apart by lubricating films and oxide films will reduce adhesion or surface wear.

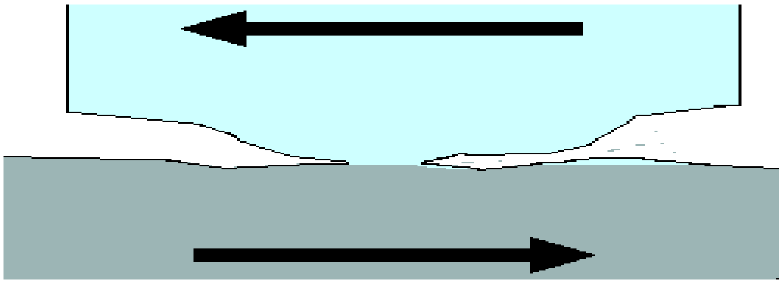

Figure 2.4: Adhesive Wear (Kumar and Sen, 2014)

v. Surface fatigue includes pitting, impact and Brinelling fatigue: Surface fatigue wear a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. The surface fatigue is the progressive and localised structural damage that occurs when a material is subjected to cyclic loading on its surface. Fatigue life is influenced by a variety of factors, such as temperature, surface finish, presenceof oxidising or inert chemicals, residual stresses and contact (fretting). The maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material as shown in Figure 2.5.

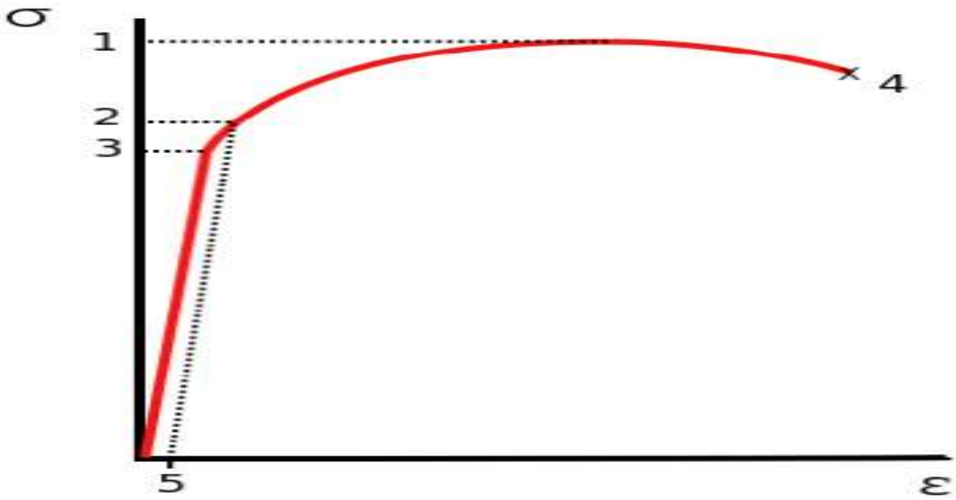

Figure 2.5: Stress and Strain Curve (El-Mahallawi and Shash, 2017)

The y-axis is applied stress while x-axis is the possible elongation (strain) due to applied force along the length of the engineering material. In Figure 2.5, notation include

1: ultimate strength

2: yield strength

3: proportional limit stress

4: rupture

5: offset strain (0.002)

2.4 Methods of Wear Testing

Wear testing is a method for assessing erosion or sideways displacement of materialfrom its “derivative” and original position on a solid surface performed by the action ofanother surface (Nassar and Nassar, 2011). Wear testing is a measure of workability of material inuse and behaviour of such material in frictional state is requirement of engineering design analysis. This shows that carrying out mechanical testing of engineering material either simulation or experimental condition will help to understand its nature when in use as engineering material (Nassar and Nassar, 2011). The nature or behaviour may be strength, elongation, ductility and resistance towards failure will help understanding selection and quality of the material. The selection of available wear characteristics is essential to quality control and manufacturingpractices in industry. Selection of suitable wear test is important due to the following (Kennedy and Hashmi, 1998):

i. Ensuring testing of material property being satisfied with defined standard such as ASTM
ii. Checking the condition of the material by considering bulk or volume analysis of the material
iii. Checking the condition of the material satisfied ASTM strength standard such as ultimate strength and yield strength.
iv. To determine effect of abrasive wear as a result of heat on surface in contact
v. To investigate impact of abrasive wear on the surface in contact
vi. To understand the atmospheric condition such as relative humidity on the surface in contact during engineering operation
vii. To understand effect of environment on the material, the environmental effect can acidic environment or basic environment.
viii. Testing of the wear must be carried out on specified time
ix. Testing material under wearing condition must be appropriate components for machine part

The method of wear analysis can be adopted for mechanical quality control system. Such system of engineering materials worked with quality control parameter that include thickness, porosity, adhesion, strength, hardness, ductility,chemical composition, stress and resistance of wear rateof a given material (Maik, 2018). However, wear test include (Kennedy and Hashmi, 1998):

i. The non-destructive tests include visual, penetrant dies,magnetic particle and acoustic techniques.
ii. Machining tests subject cutting tools to many wear parameters, including impact and shock, abrasion, adhesion and hot corrosion.

iii. Testing of wear in lab can also incorporate other testing parameters which include hardness, impact, and corrosive resistance test.

Wear testing experiment may be conducted by varying parameters such as:

i. Load or force
ii. Speed
iii. Distance or thickness or diameter

2.5 ASTM G99 Procedure for Rotating Wear Testing

The study of engineering material wear requires simulation to control effect of different and performance measures and analysis of engineering material. This will lead to production of quality product. The use standardized test methods such as American Society for Testing and Materials (ASTM) and theInternational Organization for Standardization (ISO) is also measure of engineering material performance (Murray, 2013). ASTM and ISO are known standard of engineering performance in the world with standards that prescribe testing of the engineering with defined analysis and report (Budynas and Nisbet, 2011).

Carrying out performance analysis of weartester on either ball or pin on disc Tribometer must be satisfied with American Society for Testing and Materials (ASTM) G99 or G133 standard specification. The test is carried out as follows (ASTM, 2000):

i. Mounting of reference sampleon a rotating disc
ii. Contacting the surface of a pin by applying load
iii. Evaluation of rate of wearofthe ball or pin on the contacted surface

2.5.1 Rotates Wear Test Method

The testing using ball or pin for evaluation test proves advantageous for ensuring reproducibility and quality. Allowing pin of different materials subjected to wear testing allows user to obtain affordable materials such as (Murray, 2013):

i. Rounded pins through coated tools allows for depositing of uniform coatings of thickness and materialtypes. It will also help reliability of material through coating deposited.
ii. The data is necessary for evaluating performance in stress analysis due to load mounted on the load during experimental period.
iii. It forms basis of comparative to other material

Murray (2013) identifies the use of Nanovea Tribometer a pin on disc wear tester is a precision rate of wear tester in which stainless steel andtungsten carbide ball tip form a base on wear rotating machine. The test on Nanovea Tribometer must be carried based on ASTM G99 for determine rate of wear of tungsten carbide ball. It was known that tungsten carbide ball has poor wearing rate in comparison to steel ball because rate of wearis 100 times lower to tungsten carbide ball. Test parameters include load, dry and wet condition which can be simulatedfor real-life applications. This study used pinof aluminium 6061, copper alloy (brass) and copper alloy (bronze) in carrying out performance analysis of the developed dual condition pin-on-disc tester.

2.5.2 Testing Procedure of Rotate Wear Test (ASTM G99) Method

The test sample requires be calibrated and cleaning before the testing and also by aligning pinto the axis of disc rotation Li, (2012) as shown in Figure 2.6. Flat or sphere surface shaped indenter require to load by testing the engineering material sample. However, the indenter is mounted directly on stiff lever for this purpose.

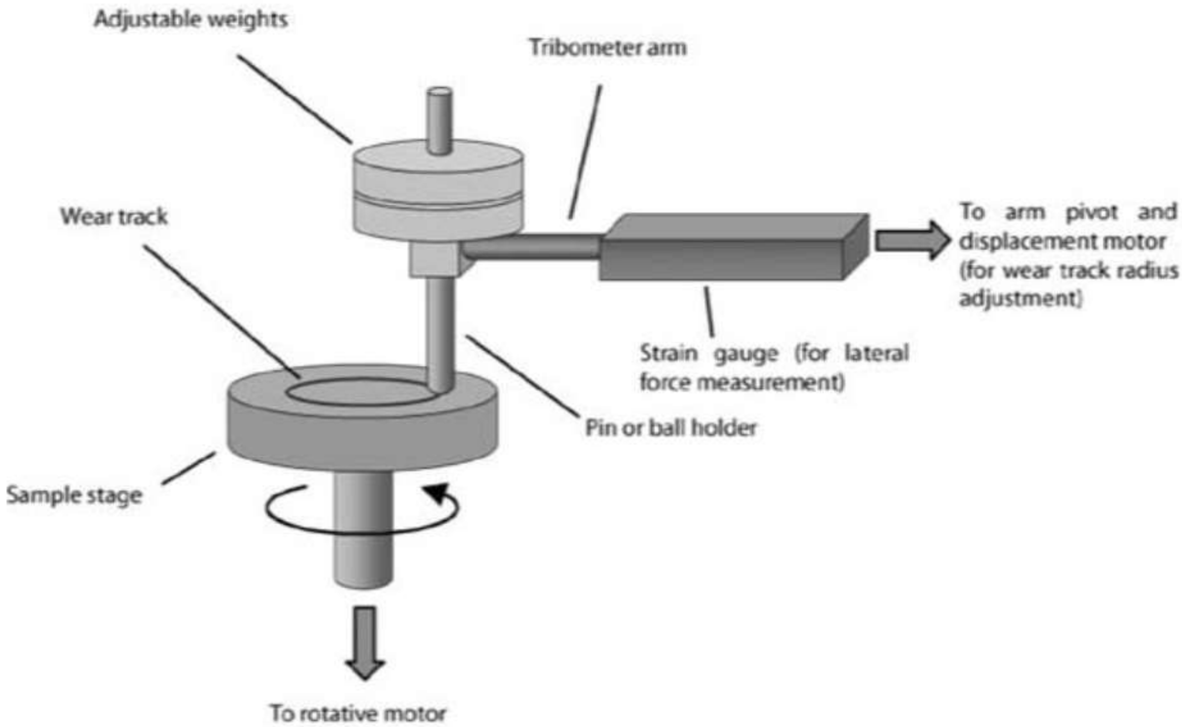

Figure 2.6: Pin-on-Disc Wear Tester (Murray, 2013)

The principle of Pin-on-Disc Tribometer is as follow according to Murray (2013):

i. Loading of precise weight on flat, pin or sphere
ii. Stiff elastic arm ensures fixed contact point to allow stability of the pin position on frictional track
iii. Determination of deflected elastic arm by knowing thechange in torque
iv. Determination of frictional coefficient of the material used
v. Determination of volume loss of the material
vi. Determination of wear coefficients for the pin and disc material

It is simple method that helps in studying frictional and wearing behaviour of engineering materialwith or without lubrication application. Therefore, it requires testing parameters such as: speed, time of occurrence, frequency, force, temperature, humidity this can be applied in real-life situation. This simple method facilitates study of frictional wear behaviourof engineering material (Mell and Begin, 2010).

2.5.3 Testing Parameters

The following parameters may be considered during the test (ASTM, 2000):

i. Load in kilogramme to determine force in wearing surface
ii. Velocity in meter per second to determine relative sliding speed between contacting surfaces
iii. Distance in meter to determine sliding distance
iv. Temperature in degree Celsius to determine temperature at point of wear
v. Atmospheric condition such a relative humidity in contact surface

2.6 Prevention of Wear's Failure in Engineering Material

Prevention of wears can be reduced during manufacturing process or when wear failure is discovered using following technique. Failure is said to occur in a system, equipment or machine when it can no longer perform the function it was intended for under the designed condition and environment (David, 2007). David (2007) refers to failure as a state or condition of not meeting a desirable or intended objective, and may be viewed as the opposite of compliance. In other words, it is non-conformity which may include product failure, failure of utility, quality system failure, market complaints and deviation. Scutti (2000) defines failure to be a breakdown or decline in the performance of something, or an occasion when something stops working adequately. Scutti (2000) summarised failure as when materials fell short of what is required or expected in its performance. Failure could occur at the start of the equipment (product) life due to manufacturing or material defects. This type of failure is said to be functional failure.

However, when a failure occurred after using the equipment (product) to use over a period of time it is known as reliability failure (Slack 2001). This is may be as result of wearing and friction between contact object such as belt, gear and bearings.

2.6.1 Failure Mode and Effect Analysis (FMEA) Technique

FMEA is a systematic method of identifying and preventing system, product and process problems before they occur. It is focused on preventing problems, enhancing safety, and increasing customer satisfaction (Nannikar*et al.*, 2012). Ideally, FMEA's are conducted in the product design or process development stages, although conducting an FMEA on existing products or processes may also yield benefits. FMEA includes review of the following:

i. Steps involve in the process
ii. Failure modes
iii. Failure causes
iv. Failure effects

Nannikar*et al.* (2012) stated that FMEA is a tool that allows the following:

i. Prevent system, product/material and process problems before they occur
ii. Reduce costs by identifying system, product and process improvements early in the development cycle
iii. Create more robust processes
iv. Prioritize actions that decrease risk of failure
v. Evaluate the system, design, and processes from a new vantage point

FMEA is required because of following reason:

i. Improvement of material/product life cycle

ii. Total quality management system of the material/product

iii. Adoption of fault tree analysis, process analysis technique and design of experiments (DOE)

The general failure rate curve also known as ‘Bath-tub Curve’ is as shown in Figure 2.8.

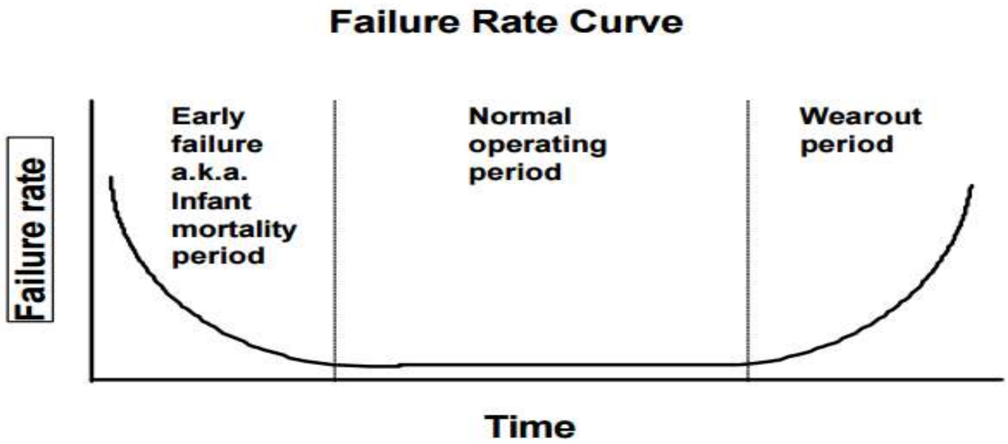

Figure 2.8: The ‘Bath-tub Curve’ (Slack, 2001)

According to Slack (2001) the infant mortality period or early failure is usually a short period, with initial high but decreasing failure rate. This may be due to defective parts, defects in materials, damages in handling during transportation, out of manufacturing tolerance. These factors show their effects early in life, leading to early failure. This situation could be corrected by improvement in design, careful materials selection and enhanced production quality control. It is therefore pertinent to know the cause of such failures in systems, process, equipment or plant. This will help to avoid such occurrence in the future and save cost, time and resources in terms of man-hour loss, down time, customer dissatisfaction and so on. The process of finding the cause of these failures involves investigation.The graph of failure rate due to lack of maintenance over time is shown in Figure 2.8 which showed that failure rate on y-axis and time on x axis and it can be grouped into three regions (Bose *et al.*, 2013).

i. Infant mortality period: progressively rate of failure
ii. Normal operating Period: constant failure rate
iii. Wear out Period: incremental stage of failure rate

According to United States National Aeronautics and Space Administration-NASA, (2000) investigating the cause of failure should not be approached with the approach of an inexperience sailor who saw the tip of the iceberg without realizing that it only represents a minute portion of the iceberg. Therefore, failure investigation is the process of collecting and analysing data through inspection, interview and examination to determine the cause of a failure. Failure investigation helps to prevent recurrence because failures are cost to company (e.g. insurance paid for permanent injury or death) and they can have adverse impact on the consumers if go undetected. In some cases, it may lead to accident causing injury to personnel which can be temporary or permanent injury if not death. However, failure investigation includes:

i. To identify the cause and take corrective actions
ii. To identify other similar situations and take preventive actions
iii. Continuous improvement
iv. Regulatory requirement.

2.6.2 The Application of Lubrication in Contact Surface

Kyunghyun (2010) states that material used for infrastructure and equipment requires essential services to improve sustainability in their life cycle. To achieve better sustainability of machines lubricant is applied for improving life cycle of machine. However, it is necessary to evaluate sustainability period or life cycle of lubricant before applying or using it on certain applied material. According to Kyunghyun (2010) life cycle modelling of any given material refers to both environmental life cycle assessment and cost analysis. The life cycle assessment helps to achieve better environmental and social impacts. The use of green composite to design a product must be based on specific needs with greater function. The design product may be checked technologically through available technology. The functions of a metalworking fluid/lubricant are to (Kalpakjian and Schmid, 2009):

i. Reduce friction, thus reducing force and energy requirements and any rise in temperature
ii. Reduce wear, thus reducing seizure and galling.
iii. Improve material flow in tools, dies, and moulds
iv. Act as a thermal barrier between the workpiece and its tool and die surfaces, thus preventing workpiece cooling in hot-working processes
v. Act as a release or parting agent-a substance that helps in the removal or ejection of parts from dies and moulds

2.6.3Heat Treatment

This application of heat treatment is applicable during manufacturing process and this reduces wear of engineering material (Uhuami, 2013). Vader (2002) stressed that various heat treatment include conventional or nonconventional. The conventional heat treatment are annealing, normalising, hardening and tempering. The nonconventional heat treatments are such as patenting, precipitation aging, special and surfacing. They include hardening, annealing, tempering and quenching.

2.7 Empirical Studies

Nassar and Nassar (2011) worked on design and fabrication of a wear testing machine in which locally sourced materialswereadopted for its fabrication process. This present study also adopts the same by sourcing for locally available material such as medium carbon steel for fabricating rotating disc and non-elastic rope that connects the load through fulcrum when pin was subjected to wear. Nassar and Nassar (2011) study established design and calculation for selection and fabrication of materials used and however the present study adopts similar approach.

Nassar and Nassar (2011) carried out the performance evaluation of the fabricated machine against a standard wear machine. It was performedusing statistical methods and result showedfabricated machine was 97% effective and testify the quality of fabricated wear testing machine. Using the fabricated machine rate of wear decreases from 49.4 to 29 Newton in 120 second.This serves as study guide in which the present study follows.

Abdo and Zaier (2012)study on novel pin-on-disc machine tester. It was developed to provide means for testing vibration samples using amplitudes andfrequencies of vibration. This is in order for investigating effect of vibration amplitude on machine with control features and sensors. The tested pin materialincludeglass fibre, reinforced plastic (GFRP), rubber, mild steel and polytetrafluoroethylene (PTFE). The test pin samples such as aluminium alloy, copper alloy brass and copper alloy (bronze). However, the study presented byAbdo and Zaier (2012) was used as one of the guide in developing present dual condition pin on-disc machine. Abdo and Zaier (2012)observedthat vibration amplitude depends on the type of material type. The study concluded that the rate of stick-slip amplitude reduction is in relationship with amplitude and frequency of vibration of the material being used.

Assessment of resistance of wear rate of coated and uncoated materials using test equipment for slidingwear, erosion, impact and dynamic wear tests was carried out by Kennedy and Hashmi (1998). The study indicated most engineering material experienced complex wear conditions as a result of process wear over time. Kennedy and Hashmi (1998) coated samplesof material under dynamic wear tests of combined impact abrasion.The impact actions adopt abrasion, adhesion, and fretting wear with shock loading, fatigue and gauging loading. It was understood that wear isserious in that direction of 1-D and it was observed for either bulk material or coatings material. However, thincoatings require greater care in wear tests in order toavoid penetration, which requires lighter loads andshorter test durations. The study shows that surface roughness also influencesthe tribologicalperformance of a mechanical system. This guides the present study on how to adopt test rig for carrying wearing mechanical system or materials.

Pavkovic*et al.* (2013) investigated on design of normal force control system for a pin-on-disc tribometer including active and passive suppression of verticalvibrations. This study based its design on a computer-controlled pin-on-discTribometer. It characterises frictional pairs of material in contact. The effectiveness ofvibrations damping of such material is verified with aid this method. This study guide present on implementing of sliding pairs which is subjected to load suspension in the present study and which is done experimentally.

Venkatesh*et al.* (2015) investigated that wear analysis on silicon carbide coated high speed steel (HSS) pin on stainless steel disc substrate. Venkatesh*et al.* (2015) understood that wear reduces cutting life time of tool materials by investigating its influence on silicon carbide Nano-coating on the HSS tool material. Rate of wear, volume loss and stress are performance parameter adopted for this work and it is considered base on temperature variation. The coefficient of friction values of the tool material was determined and also energy dispersive analysis by X-ray (EDAX) and scanning electronmicroscope (SEM) were used as characterisation methods. The study uses this ideology by using medium carbon steel in design the disc used for testing the wear of the engineering material. The material considered for testing wear is softer than material used for designing the disc in this study. The disc is hard carbon steel while testing wear alloy of aluminium, magnesium and brass materials.

Venkatesh*et al.* (2015) used coated and uncoatedpins of length of 6mm diameter and 50mm in length are measured. The parameters used were speed in rpm and load of 1kg, to generate values of coefficient of friction within period of 1 minute to 15 minutes. Venkatesh *et al.* (2015) stated rate of wear in coating material is lesser in comparing to coated pin.The present study adopts the same as coated material from industry, and they are aluminium alloy, bronze and brass.

The study carried out by Abdul *et al.* (2015) on design and development of pin disc wear tester. It was designed and fabricated as cost effective wear tester that can be used in metallurgy research field. The benefit of Abdul *et al.* (2015) is understanding principle of surface wear in engineering material through varying speed as process parameter with aid of sensor called light dimmer controller. The wear analysis of the pin was done using finite element analysis (FEA) software. There are two experimental of pin wear tester which is laboratory test and component simulation test.The analysis was carried out by two type of pin material and they are mild steel and aluminium. In the present study two experimental set up was also considered as testing of developed dual condition of pin on disc.Abdul *et al.* (2015) observed that the pin length differences show that the aluminium had less friction effect compare with mild steel.The result data show that the aluminium is more effect of friction compare than mild steel. This is because the aluminium is more elastic in comparing to steel.Abdul *et al.* (2015)

concludes that aluminium can be used intricate shapes that steel cannot to be adopted for. Steel is tougher and resilient but cannot be pushed into dimensional limits as aluminium without failure or cracking. It was understood that aluminium does not rust easily hence it can be applied without coating but carbon steel requirescoating in damping environment.

Li (2012) modelled a Finite Element Analysis (FEA) of tribometer's pin and disc interaction using developed bench scale tribometer for mimicking the friction and wearconditions on the rake face of a metal cutting tool. The tribometer was developed by the McMaster ManufacturingResearch Institute (MMRI)Ontario for testing purpose. It provides insight into theperformance of cutting tools operating under high stress and high temperaturemachining conditions. It saves test material costs, reduces machine downtime fortesting, increases the number of test replicates and effectively adds a reliabletesting tool to characterize metal cutting operations. Li (2012) investigated into the stress distribution, temperature profile andindentation pattern in order to verify the ability of the device. And also for capturing the machining environment and to gain a better understanding of thefriction effects and wears conditions. The investigation used finite elementanalysis to simulate the MMRI's tribometer with the FEA results compared to theexperimental results. This data was then used to tune the operating conditions ofthe tribometer to improve its ability to simulate the machining environment.

It was understood that FEA results match theexperimental results in a good states. This validated the equation used to calculate the coefficient of friction (COF) for MMRI tribometer.FEA model results agree with the experimental results, once aCOF is experimentally obtained from the MMRI tribometer. This could be then inputted into the FEA model to check the indentation diameter and reaction torque. The FEA model is able to generate detailed stress, strain andtemperature distribution as well as indentation profile at the contact surface during different process. The study of Li (2012) give an insight on how to mimicking frictional force and wear in engineering material surface and this present will not model frictional force and wear using software. It only developed the dual condition pin on disc for testing frictional force and wear that can affect the surface of engineering when applied as components mechanical system such as gear, brake, bearing and piston.

Kumi (2011) worked on the development and evaluation of abrasive wear testerfor determine ploughshare rate of wear when applied in agricultural sector. However, this assumption led to Kumi (2011) for developing abrasive wear test machines which is not available in Ghana.The developed machine components include power transmission system and arm-subassemblies, circular soil bin, support frame. The machine tested using soil obtained from Mampong, Akuse, Akatsi, Kwame Nkrumah University of Science and Technology, Wenchi, and Ho in Ghana with different variation of soil sample. The result showed therate of wear of ploughshare when applied in Akatsi and Ho soil with high percentage moisture resulted to increased values of wear on ploughshare while others showed reversed version of the value. The soils pH values were acidic and this causes influences of ploughshare wear. The present study differsthough, consideration of corrosive nature of soil under which ploughshare was applied is related to present study by applying wet condition into pin to understand the nature of rate of wear in the pin material used.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used in carrying out the experimental analysis include:

i. Pins of 25mm long and diameters of 4mm and 6mm. The pin materials are of aluminium alloy (Al 6061), bronze and brass

Aluminium Alloy 6061 Composition (SEDI, 2011)

Aluminium alloy 6061 Component	Weight %
Percentage of Aluminium	96.20
Percentage of Magnesium	1.20
Percentage of Silicon	0.75
Percentage of Iron	0.70
Percentage of Copper	0.40
Percentage of Zinc	0.25
Percentage of Titanium	0.16
Percentage of Manganese	0.14
Percentage of Chromium	0.20

Specification for Aluminium 6061 (SEDI, 2011)

Specification	Unit
Elasticity Modulus (GPa)	70
Density (kg/m^3)	2700
Thermal conductivity (W/mK)	173
Melting Temperature (^oC)	585
Poisson Ratio (υ)	0.33
Tensile strength MPa	125
Yield strength MPa	55
0.2% Proof strength MPa	100

Bronze Composition (SEDI, 2011)

Bronze Component	Weight %
Percentage of Copper	88
Percentage of Tin	9.5
Percentage of Silicon	0.75
Percentage of Aluminium	1.0
Percentage of Arsenic	0.25
Percentage of Zinc	0.25
Percentage of Nickel	0.15
Percentage of Manganese	0.10

Specification for Bronze (SEDI, 2011)

Specification	Unit
Elasticity Modulus (GPa)	70
Density (kg/m^3)	2700
Thermal conductivity (W/mK)	173
Melting Temperature (^oC)	585
Poisson Ratio (υ)	0.33
Tensile strength MPa	125

Brass Composition (SEDI, 2011)

Brass Component	Weight %
Percentage of Copper	66
Percentage of Zinc	33.5
Percentage of Silicon	0.15
Percentage of Titanium	0.14
Percentage of Manganese	0.11
Percentage of Chromium	0.10

Specification for Brass (SEDI, 2011)

Specification	Unit
Elasticity Modulus (GPa)	70
Density (kg/m^3)	8430
Thermal conductivity (W/mK)	173
Melting Temperature (^oC)	930
Poisson Ratio (υ)	0.35
Tensile strength MPa	360
Yield strength MPa	140
0.2% Proof strength MPa	68

ii. Disc size of diameter size 170mm, thickness of 10mm and surface wear track radius of 50mm and 40mm respectively.

iii. Applied force of 5N, 8N and 10N using laboratory dead weight of 0.51kg, 0.82kg and 1kg

iv. Gear oil as anti-wear additives oil (Monograde SAE 80)

3.2 Equipment

The following are the plates of pins and testing equipment used for carrying out the research.

Plate I: Aluminium 6061 Pins

Plate II: Bronze Pins

Plate III: Brass Pins

3.2 Methods

3.2.1 Design method and analysis

3.2.1.1 Shaft Shear Stress Analysis

The shaft shear stress is designed based on Guest' theory known as law of maximum shear stress, (MSS) theory and it is given by (Budynas and Nisbet, 2011).

$$\tau_m = \frac{1}{2}\sqrt{{\sigma_b}^2 + 4\tau^2} \quad (3.1)$$

$$\sigma_b = \frac{32M}{\pi d^3} \quad (3.2)$$

$$\tau = \frac{16T}{\pi d^3} \quad (3.3)$$

Where:

τ_m = Maximum shear stress in N/m^2

τ = Mean shear stress in N/m^2

σ_b = Bending stress in N/m^2

M =Bending moment in Nm

d =Solid diameter in m

T = Torque in Nm

By substituting equations (3.2) and (3.3) into equation (3.1) gives:

$$\tau_m = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + 4\left(\frac{16T}{\pi d^3}\right)^2} = \frac{1}{2}\sqrt{\frac{32^2M^2 + 4(16T)^2}{(\pi d^3)^2}} = \frac{1}{2}\sqrt{\frac{2^{10}M^2 + 2^{10}T^2}{(\pi d^3)^2}}$$

$$\tau_m = \frac{2^5}{2\pi d^3}\sqrt{(M^2 + T^2)} = \frac{16}{\pi d^3}\sqrt{M^2 + T^2}$$

Divide both sides by $\frac{\pi d^3}{16}$ gives:

$$\tau_m\left(\frac{\pi d^3}{16}\right) = \sqrt{M^2 + T^2}$$

(3.4a)

Khurmi and Gupta (2012) expressed that $T_e$is the equivalent twisting moment of a shaft given as

$$T_e = \sqrt{M^2 + T^2} \qquad (3.4b)$$

This results as maximum shear stress (MSS):

$$T_e = \tau_m\left(\frac{\pi d^3}{16}\right)(3.5)$$

Equation 3.5 is the equivalent twisting moment acting on shaft that rotates the disc as shown in Figure 3.1.

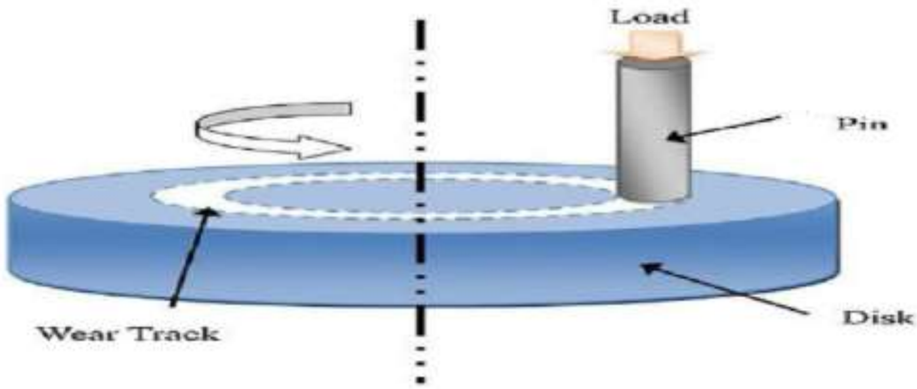

Figure 3.1: Pin on disc wearing set-up

Khurmi and Gupta (2005) stated that American Society of Mechanical Engineers (ASME) code for designing transmission shaft includes permissible working stress of 112 MPa and maximum permissible shear stress is 56 MPa. This is recommended for shaft without keyways which is adopted by this study. The shaft used in this design was non-key shaft and recommended design stress is maximum 75 percent of calculated stress as allowable stress (Nassar and Nassar, 2011). However,the factor of safety (FOS) for designing the shaft is given as (Khurmi and Gupta, 2005).

$$FOS = 0.5\sigma_y/\tau_m \quad (3.6)$$

Where:

σ_y =Yield stressat yield point (N/m^2)

The following components are used for designing the wear testing machine and they include electric motor, shaft diameter, fibre rope and pulley arm.

3.2.1.2 Electric motor

The strength of the shaft depends on maximum torque (T_m)which can be transmitted through electric motor and this is given as(Harris and Piersol, 2002):

$$T_m = P_m/\omega \tag{3.7}$$

$$T_m = \alpha T_a \tag{3.8}$$

$$\omega = 2\pi N/60 \tag{3.9}$$

Where:

$\alpha =$ Multiplicative factor

$T_a =$ Allowable torque in Nm

$\omega =$ Angular velocity (rad/s)

$N =$ Number of revolution

$P_m =$ Maximum power

The horse power (HP) of the electric motor is determined as (Harris and Piersol, 2002):

$$HP = \omega/2\pi \tag{3.10}$$

3.2.1.3 Shaft diameter

The shaft diameter is determined as (Budynas and Nisbet, 2011).

$$T_m = \frac{\pi d^3}{16}\tau_m \tag{3.11}$$

$$d = \sqrt[3]{\frac{16T_e}{\pi\tau_m}} \tag{3.12}$$

This is the required diameter of the shaft that helps in rotating the disc mounted on the developed wear testing machine.

3.2.1.4 Pulley arm and Groove

The pulley arm design is based on assumption that weight of the pulley block is small as compared to the weight of load to be lifted and this is neglected (Khurmi, 2012). This is analysed mathematically through velocity ratio (VR) which is given by (Khurmi, 2012):

$VR = 2^n$ (3.13)

$VR = y/x$ (3.14)

Equating equations (3.13) and (3.14) gives:

$$2^n = \frac{y}{x}$$

$y\ = 2^n x$ (3.15)

Where:

$n =$ Number of pulley

$y =$ Distance moved by the effort (P) in lifting load (W) in m

$x =$ Distance moved by the lifting load (W) in m

Let, Mechanical advantage, $MA = W/P$ (3.16)

Efficiency (η) is the ratio of output (O) and input (I) of the design pulley

$\eta = O/I$ (3.17)

If, $O = Wx$ (3.18)

$I = Py$(3.19)

Substitution of equations (3.18) and (3.19) into equation (3.17) gives:

$\eta = Wx/Py$ (3.20)

$$\eta = (W/P) \times (x/y)$$

$$\eta = (W/P) \div (y/x)$$

$\eta = MA/VR\ \times 100\%$(3.21)

Where:

η =Efficiency of the design pulley

Power transmitted by the pulley is (Khurmi and Gupta, 2005).

$P_p = (T_1 - T_2)v$ (3.22)

Where:

$P_p =$ Power transmitted by the pulley in Watt

T_1 = Tension in the tight side in Newton

T_2 = Tension in the slack side in Newton

v = Velocity of the rope in m/s

The velocity is given by (Khurmi and Gupta, 2005).

$$v = \frac{\pi d_p N_r}{60} \quad (3.23)$$

Where:

d_p =Driving pulley diameter in m

N_r =Required number of turns to be completed by the rope

3.2.1.5 Fibre Rope

The rope is open type and the angle of contact between rope and pulley groove is (Khurmi and Gupta, 2005).

$$\theta = (180^\circ - 2\alpha)\pi/180 \quad \text{in rad} \quad (3.24)$$

$$\alpha = \sin^{-1}\left(\frac{r_1 - r_2}{x}\right) \quad (3.25)$$

Where:

r_1 =Radius of driving pulley in m

r_2 =Radius of driven pulley in m

x =distance between the pulley driving and driven pulley in m

The ratio of driving tensions in the rope is (Khurmi and Gupta, 2005):

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu\theta cosec\beta \quad (3.26)$$

Where:

β =0.5 of the groove angle of the pulley in degree

μ =Coefficient of friction between the rope and pulley groove

3.2.2 Design calculations

3.2.2.1 Shaft Analysis

Factor of safety (FOS_u) annealed type of carbon steel material is 4 at ultimate strength condition (σ_u) and this was the material used for the shaft (Khurmi and Gupta, 2005; Budynas and Nisbet, 2011).

$$FOS_u = 4$$

σ_u =341 MPa

σ_y =220 MPa

Therefore, it means 1 factor of safety required strength of 85.25MPa;thus, strength of 220MPa requires 2.58 as factor of safety (FOS). The present study applied equations (3.1 to 3.6) as follows:

$$FOS = 0.5\sigma_y/\tau_m$$

$$2.58 = \frac{0.5(220)}{\tau_m} = \frac{110}{\tau_m}$$

$\tau_m = \frac{110}{2.58} = 42.64$ MPa

The shear stress (τ_y)atpoint of yield or failure is determined as (Khurmi and Gupta, 2005):

$$FOS = \tau_y/\tau_m$$

$\tau_y = 2.58\times42.64 = 110$ MPa

This is the shear stress at yield point and this stress will cause bending in the shaft which is a failure).

This agrees with equation (3.6):$FOS = 0.5\sigma_y/\tau_m$

$0.5\sigma_y = 2.58\times42.64 = 110$ MPa

This is the shear stress at yield point in a simple tension test which is equal to half of the yield stress in tension (Khurmi and Gupta, 2005). However, this proved that failure or yield will occur in the shaft when the maximum shear stress (τ_m) equals to the shear stress at yield point in a simple tension test analysis. For prevention of failure, Khurmi and Gupta (2005) stated that only 0.6 of yield stress at point of yield and 0.3 of shear stress at point of yield is considered for a safe design. Therefore:

Stress at point of yield/bending stress $(\sigma_b) = 0.5\sigma_y = 110$ MPa

Working stress or allowable stress $(\sigma_a) = 0.6 \times 110 = 66$ MPa

Working shear stress or allowable shear stress $(\tau) = 0.3 \times 110 = 33$MPa

Let:

Weight of the rotating disc in N $\left(W_{pm}\right) = 25kg \times 9.81\ m/s^2$ =245.25N

Shaft diameter, d = 0.12m

The maximum area of pin $\left(A_p\right) = 2\pi r^2 + ld = 2 \times \pi(0.006)^2 + 0.25 \times 0.12 =$ 0.003226m^2

The study designed for 10% of total weight of the mounted disc and pin on the shaft in Newton $(W_t) = 0.1W_{pm}$ =24.525N

Therefore, the maximum mass of fixedpulley load in kg (m_t) =24.525/9.81= 2.5kg

Acting distance of disc's weight on the shaft $(L) = 0.4$m

Therefore, maximum bending moment, $M = W_t L$ =24.525×0.4 = 9.81 Nm

Maximum shear stress, (MSS):

$$(2\tau_m)^2 = {\sigma_b}^2 + 4\tau^2$$

$$(2 \times 42.64)^2 = {\sigma_b}^2 + 4\tau^2$$

$$(85.28)^2 - 4(33)^2 = {\sigma_b}^2$$

$$7272.6784 - 4356 = {\sigma_b}^2$$

$\sigma_b = \sqrt{2}916.6784 = 54$ MPa

This is the stress that will lead to bending in the shaft

$$\sigma_b = \frac{32M}{\pi d^3} = \frac{32 \times 9.81}{\pi d^3} = \frac{313.92}{\pi d^3}$$

$$d = \sqrt[3]{\frac{313.92}{\pi \times 54}} = \sqrt[3]{\frac{313.92}{169.6 \times 10^6}}$$

$d = \sqrt[3]{1.85 \times 10^{-6}}$ =0.0123m = 12.27mm

This is the shaft diameter with length of 0.4m stated as acting distance of moment from point of references.

Torque, $T = \tau \times \pi d^3$

T =33$\times \pi(0.0123)^3$

T = 0.0001929Nm

This is the maximum torque that can be generated on the shaft.

$$T_e = \sqrt{M^2 + T^2}$$

$T_e = \sqrt{9.81^2 + 0.0001929^2}$= 96.23 Nm

3.2.1.2 Electric motor

From equations 3.7 to 3.10:

The power rating, P_m = 0.507 HP $\cong$ 380W

$$P_m = T_e \omega$$

$\omega = 380/96.23$ = 3.95 rad/s

3.2.1.3 Pulley arm

From equations 3.13 to 3.23:

$$n = 4$$

$$VR = 2^4 = 16$$

$$16 = y/x$$

Let, $y = 1.25$m

$$x = \frac{1.25}{16} = 0.078m$$

Maximum weight of the pulley load in N $(W_{pm}) = W$ =245.25N

Let, maximum weight of effort $(P) = 0.75W_{pm}$ = 24.525× 0.75= 18.39 N

Mechanical advantage, $MA = \frac{W}{P} = \frac{245.25}{18.39} = 13.33$

$$\eta = MA/VR \times 100\%$$

$$\eta = \frac{13.33}{16} \times 100\% = 83.3\%$$

3.2.1.4 Fibre rope

From equations 3.24 to 3.26:

$$\alpha = \sin^{-1}\left(\frac{r_1 - r_2}{x}\right)$$

$r_2 = 8.5mm = 0.0085$ m

$$x = 1m$$

Let, $r_1 = 1.2r_2 = 1.2 \times 0.0085 = .0102$ m

$$\alpha = \sin^{-1}\left(\frac{1 - 0.0085}{1}\right) = \sin^{-1}(.09915) = 0.175^{\circ}$$

$$\theta = (180^{\circ} - 2\alpha)\pi/180$$

$$\theta = (180^{\circ} - 2 \times 0.175)\pi/180$$

$\theta = 3.13$ rad

3.2.3 Computer Aid Design

The software used for the CAD modelling was Pro-engineer software. Pro Engineer software is a computer graphics system for modelling various mechanical designs and for performing related design and manufacturing operations. This study uses a 3D solid modelling system as the core, and applies it on the assembly of the dual condition pin-on-disc wear testing machine. The 3D components weremodelled, assembled and data exchanged with Para solid import and export. These include:

i. Rotating disc
ii. Experimental container
iii. Pin holder
iv. Pipe mechanism
v. Pulley
vi. Pulley arm
vii. Supporting base
viii. The assembly of the machine

3.2.4 Experimental Procedure

3.2.4.1 Sliding wear testing

The dry sliding wear tests are conducted for three different pin materials using the developed wear test machine. The pin materials are brass, bronze and aluminium alloy. Each pin material is 25mm of height with diameters of 4mm and 6mm respectively. The steps include (ASTM G99, 2003):

i. The surfaces of the pin samples was cleaned by emery paper (grit size 320 Fine),
ii. The surface of the disc was cleaned with acetone,
iii. The digital weighing scale was set to be zero,
iv. Each pin was held against the counter face of disc mounted on rotating shaft with wear track diameter of 100 mm,
v. Pulley load or dead weights used include 0.51 kg,0.82kg and 1kg. The experiment was carried out at constant nominal speed of 0.158 m/s and 0.1975m/s at interval of 5 minutes (300s) and

vi. The number of experiment carried out was average of 12 experiments on a pin material.

vii. The following parameter is determined based on Windarta*et al.,* 2011:

Volume loss in$V_l = Ah_l$(3.27)

Rate of wear in mm^3/m, $\omega = V_l/x_s$(3.28)

Resistance of wear rate in m/mm^3

$\omega_r = 1/\omega$(3.29)

Specific rate of wear in mm^3/Nm,$\omega_s = \omega/W_p$(3.30)

Where:

h_l= Height loss by the pin in m

x_s =Sliding distance in m

A = πr^2 = Cross section area in m^2

$W_p =$ Pulley weight

viii. Average value for the results of the parameters is shown for each pin material.

ix. The specific rate of wear of each material was compared

3.2.4.2 Wet wears testing

The same procedure as above was followed, however the difference was at step five of section 3.2.4.1,and gearoil was introduced into the experiment. This was possible through the use of pumping mechanism incorporated into developed machine.

3.3 Fabrication Procedure

The development of dual condition pin-on-disc wear testing machine was fabricated through following manufacturing processes:

i. Bending of required mild steel and angular bar into designed shape.

ii. There are four pulleys which were mounted and served as medium of weight insertion on the pin.

iii. The wet condition was possible by incorporating pumping mechanism that include electric motor (0.5 Horsepower) and hose pipe. This aids pumping the lubricant (gear oil) into surface disc during wet condition.

iv. The electric motors for pumping and rotating disc was placed at lower part of the standing support of developed machine while the pulley system is placed at the upper part of the machine.

v. The developed Pro-e design for the fabrication is attached in this thesis.

Plate IV below shown the Scanning Electron Microscope (SEM) for the wear track on the disc at dryand wet condition.

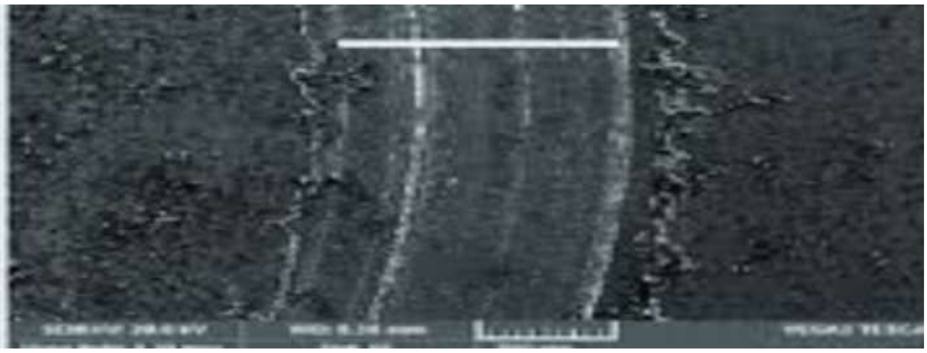

Plate IV SEM for the dry condition on pin-on-disc wear testing machine

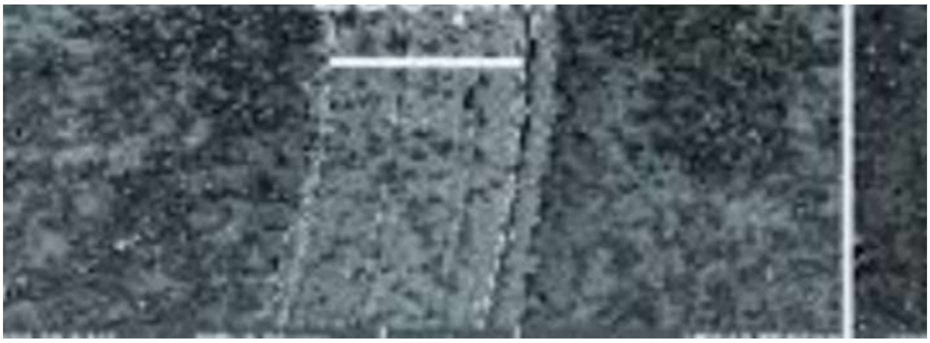

Plate V SEM for the wet condition on pin-on-disc wear testing machine

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The outcome of the experimental analysis of dual condition pin-on-disc wear testing machine is presented in this section. Figure 4.1 is the designed and developed dual condition pin-on-disc wear testing machine. The machine can determine rate of wear on pin's surface.

Figure 4.1: Dual Condition Pin-On-Disc Wear Testing Machine

The dual condition means the wear testing machine can operate under two conditions, dry and wet. The machine components are rotating disc, experimental container, pin holder, pumping (pipe) mechanism, pulley, pulley arm, supporting base, two electric motors and industrial lubricating oil tank. The wear testing is possible by inserting pin on the pin holder at variable time while loading the pulley mechanism on the machine. The pin is subjected to varying load, time and sliding distance during experimental stages that is employed for testing surface wear behaviour.

4.2 Aluminium 6061 Surface Wear Analysis (SWA)

The Aluminium 6061 pin of diameter 4mm and 6mm were subjected to wear analysis for both dry and wet surface wear testing condition. The effects of sliding speed and applied force on the pin were determined for estimating wear coefficient of Aluminium 6061. The testing of applied force 5N on pin diameter 4mm at sliding speed of 0.158m/s is shown in Table 4.1. The results are the average of two dry test of SWA of Aluminium 6061 pin diameter 4mm. The original pin was 25mm height measured using programmed micro controller with Ultra sonic sensor after required period of time. The height loss $h_l(mm)$ was determined by subtracting the original height from initial wear height. The experiment was repeated twice and average of the dry surface wear test parameter is determined and tabulated in Table 4.1.

The increase in both time $t(s)$ and sliding distance $x_s(m)$ lead to increases in pin volume loss $(V_l)$and decrease in rate of wear (ω). Table 4.1 showed that 4mm diameter of Aluminium 6061 subjected to 0.158 m/s had volume loss of 21.6204 mm^3, rate of wear of 0.1520mm^3/m, resistance of wear rate of 6.58 m/mm^3 and specific rate of wear of $3.04 \times 10^{-2}$$mm^3$/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N.

Table 4.1: Dry SWA of Aluminium 6061's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	1.52	19.1064	0.4031	2.48	8.06
600	94.8	1.61	20.2377	0.2135	4.68	4.27
900	142.2	1.72	21.6204	0.1520	6.58	3.04
1200	189.6	1.80	22.6260	0.1193	8.38	2.39
1500	237	1.83	23.0031	0.0971	10.30	1.94
1800	142.2	1.84	23.1288	0.0813	12.30	1.63
2100	331.8	1.85	23.2545	0.0701	14.27	1.40
2400	379.2	1.90	23.8830	0.0630	15.88	1.26
2700	426.6	1.94	24.3858	0.0572	17.49	1.14
3000	474	1.97	24.7629	0.0522	19.14	1.04
3300	521.4	2.10	26.3970	0.0506	19.75	1.01
3600	568.8	2.12	26.6484	0.0469	21.34	0.94

After experimental period of 3600s (1 hour) the pin volume loss was 26.6484mm^3, rate of wear of 0.0469 mm^3/m, resistance of wear rate of 21.34 m/mm^3 and specific rate of wear of $0.94\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.37% after 3600s. Table 4.2 shows the average of two dry test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.2: Dry SWA of Aluminium 6061's Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	1.76	22.1634	0.3741	2.67	7.48
600	118.50	1.87	23.4757	0.1981	5.05	3.96
900	177.75	2.00	25.0797	0.1411	7.09	2.82
1200	237.00	2.09	26.2462	0.1107	9.03	2.21
1500	296.25	2.12	26.6836	0.0901	11.10	1.80
1800	177.75	2.13	26.8294	0.0755	13.25	1.51
2100	414.75	2.15	26.9752	0.0650	15.38	1.30
2400	474.00	2.20	27.7043	0.0584	17.11	1.17
2700	533.25	2.25	28.2875	0.0530	18.85	1.06
3000	592.50	2.29	28.7250	0.0485	20.63	0.97
3300	651.75	2.44	30.6205	0.0470	21.28	0.94
3600	711.00	2.46	30.9121	0.0435	23.00	0.87

Table 4.2 showed that 4mm diameter of Aluminium 6061 pin subjected to 0.1975 m/s had volume loss of 25.0797 mm^3. The rate of wear was 0.1411mm^3/mm, resistance of wear rate was 7.09 mm/mm^3 and specific rate of wear was $2.82 \times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 30.9121mm^3, rate of wear of 0.0435mm^3/m, resistance of wear rate of 23 m/mm^3 and specific rate of wear of 0.87$\times 10^{-2}$ mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to

88.37% after 3600s. The average of two dry test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.3.

Table 4.3: Dry SWA of Aluminium 6061's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	47.4	2.13	26.7490	0.5643	1.7720	7.0541
600	94.8	2.25	28.3328	0.2989	3.3459	3.7359
900	142.2	2.41	30.2686	0.2129	4.6979	2.6607
1200	189.6	2.52	31.6764	0.1671	5.9855	2.0884
1500	237	2.56	32.2043	0.1359	7.3593	1.6985
1800	284.4	2.58	32.3803	0.1139	8.7831	1.4232
2100	331.8	2.59	32.5563	0.0981	10.1916	1.2265
2400	379.2	2.66	33.4362	0.0882	11.3410	1.1022
2700	426.6	2.72	34.1401	0.0800	12.4956	1.0004
3000	474	2.76	34.6681	0.0731	13.6725	0.9142
3300	521.4	2.94	36.9558	0.0709	14.1087	0.8860
3600	568.8	2.97	37.3078	0.0656	15.2462	0.8199

Table 4.3 showed that Aluminium pin diameter 6mm diameter was subjected to 0.158 m/s under applied force of 8N. The volume loss was 30.2686 mm^3, rate of wear was 0.2129 mm^3/m, resistance of wear rate was 4.6979m/mm^3 and specific rate of wear was 2.6607×10^{-2} mm^3/Nm after 900s with a sliding distance of 142.2 m. After

experimental period of 3600s (1 hour) the pin volume loss was 37.3078mm^3, rate of wear of 0.0656 mm^3/m, resistance of wear rate of 15.2462 m/mm^3 and specific rate of wear or wear coefficient of 0.8199×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.37% after 3600s. The average of two dry test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.4.

Table 4.4: Dry SWA of Aluminium 6061's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	2.25	28.2775	0.4773	2.0953	5.9657
600	118.50	2.38	29.9518	0.2528	3.9564	3.1595
900	177.75	2.55	31.9982	0.1800	5.5550	2.2502
1200	237.00	2.66	33.4865	0.1413	7.0775	1.7662
1500	296.25	2.71	34.0446	0.1149	8.7018	1.4365
1800	355.50	2.72	34.2306	0.0963	10.3854	1.2036
2100	414.75	2.74	34.4167	0.0830	12.0508	1.0373
2400	474.00	2.81	35.3468	0.0746	13.4100	0.9321
2700	533.25	2.87	36.0910	0.0677	14.7752	0.8460
3000	592.50	2.92	36.6491	0.0619	16.1668	0.7732
3300	651.75	3.11	39.0676	0.0599	16.6826	0.7493
3600	711.00	3.14	39.4396	0.0555	18.0276	0.6934

Aluminium pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.4 that volume loss was 31.9982 mm^3. The rate of wear was 0.18 mm^3/m, resistance of wear rate was 5.555 mm/mm^3 and specific rate of wear was $2.2502 \times 10^{-2}$$mm^3$/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 39.4396mm^3, rate of wear of 0.0555mm^3/m, resistance of wear rate of 18.0276 m/mm^3 and specific rate of wear of $0.6934 \times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Aluminium 6061 reduced to 88.37%.

The same experiment was carried out for 6mm diameter of the same pin and it was repeated twice and average of the dry surface wear analysis of required parameters which was determined and tabulated. Table 4.5 shows the average of two dry test of SWA of Aluminium pin diameter 4mm during the experiment. Table 4.5 showed that 4mm diameter of Aluminium subjected to 0.158 m/s had volume loss of 30.2889mm^3, rate of wear of 0.2130mm^3/m, resistance of wear rate of 4.6948m/mm^3 and specific rate of wear of $2.1300 \times 10^{-2}$$mm^3$/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 39.3378mm^3, rate of wear of 0.0692mm^3/m, resistance of wear rate of 14.4509m/mm^3 and specific rate of wear of $0.6920 \times 10^{-2}$$mm^3$/Nm and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear(ω) reduced to 87.39% after 3600s.

Table 4.5: Dry SWA of Aluminium Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	Mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	2.22	27.9010	0.5886	1.6989	5.8860
600	94.8	2.24	28.1523	0.2970	3.3670	2.9700
900	142.2	2.41	30.2889	0.2130	4.6948	2.1300
1200	189.6	2.48	31.1686	0.1643	6.0864	1.6430
1500	237	2.52	31.6714	0.1336	7.4850	1.3360
1800	284.4	2.70	33.9336	0.1193	8.3822	1.1930
2100	331.8	2.95	37.0756	0.1117	8.9526	1.1170
2400	379.2	3.10	38.9608	0.1027	9.7371	1.0270
2700	426.6	3.12	39.2122	0.0919	10.8814	0.9190
3000	474	3.12	39.2122	0.0827	12.0919	0.8270
3300	521.4	3.12	39.2122	0.0752	13.2979	0.7520
3600	568.8	3.13	39.3378	0.0692	14.4509	0.6920

Table 4.6 shows the average of two dry test of SWA of Aluminium pin diameter 4mm at sliding speed of 0.1975m/s under applied load of 10N.

Table 4.6: Dry SWA of Aluminium Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	2.26	28.404	0.4794	2.0859	4.794
600	118.50	2.40	30.163	0.2545	3.9293	2.545
900	177.75	2.56	32.174	0.1810	5.5249	1.810
1200	237	2.68	33.682	0.1421	7.0373	1.421
1500	296.25	2.74	34.436	0.1162	8.6059	1.162
1800	355.5	2.75	34.562	0.0972	10.2881	0.972
2100	414.75	2.77	34.813	0.0839	11.9190	0.839
2400	474	2.93	36.824	0.0777	12.8700	0.777
2700	533.25	2.95	37.076	0.0695	14.3885	0.695
3000	592.5	3.10	38.961	0.0658	15.1976	0.658
3300	651.75	3.10	38.961	0.0598	16.7224	0.598
3600	711	3.11	39.086	0.0550	18.1818	0.550

Table 4.6 showed that 4mm diameter of Alumium pin subjected to 0.1975 m/s had volume loss of 39.086mm^3. The rate of wear was 0.1810mm^3/mm, resistance of wear rate was 5.5249mm/mm^3 and specific rate of wear was 1.810×10^{-2} mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 39.086mm^3, rate of wear of 0.0550mm^3/m, resistance of wear rate of 18.1818m/mm^3 and specific rate of wear of 0.550×10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear (ω) reduced to

88.24% after 3600s.Table 4.7 shows the dry SWA of dry SWA of Aluminium 6061's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.7: Dry SWA of Aluminium 6061's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.61	17.1882	0.3626	2.7577	7.2524
600	94.8	0.64	18.2059	0.1920	5.2071	3.8409
900	142.2	0.69	19.4498	0.1368	7.3111	2.7355
1200	189.6	0.72	20.3544	0.1074	9.3149	2.1471
1500	237	0.73	20.6936	0.0873	11.4528	1.7463
1800	284.4	0.74	20.8067	0.0732	13.6687	1.4632
2100	331.8	0.74	20.9198	0.0630	15.8606	1.2610
2400	379.2	0.76	21.4852	0.0567	17.6494	1.1332
2700	426.6	0.78	21.9375	0.0514	19.4461	1.0285
3000	474	0.79	22.2768	0.0470	21.2778	0.9399
3300	521.4	0.84	23.7468	0.0455	21.9566	0.9109
3600	568.8	0.85	23.9730	0.0421	23.7267	0.8429

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 19.4498 mm^3, rate of wear of 0.1368 mm^3/m, resistance of wear rate of 7.3111 m/mm^3 and specific rate of wear of $2.7355 \times 10^{-2} mm^3/Nm$ in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 23.973 mm^3, rate of wear of 0.0421mm^3/m, resistance of wear rate of 23.7267m/mm^3 and specific rate of wear of 0.8429×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.39% after 3600s. Table 4.8 shows the average of two dry test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.8: Dry SWA of Aluminium 6061's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.85	23.9259	0.4038	2.4764	8.0763
600	118.50	0.90	25.3426	0.2139	4.6759	4.2772
900	177.75	0.96	27.0741	0.1523	6.5653	3.0463
1200	237.00	1.00	28.3333	0.1195	8.3647	2.3910
1500	296.25	1.02	28.8055	0.0972	10.2845	1.9447
1800	355.50	1.02	28.9630	0.0815	12.2743	1.6294
2100	414.75	1.03	29.1204	0.0702	14.2426	1.4042
2400	474.00	1.06	29.9074	0.0631	15.8489	1.2619
2700	533.25	1.08	30.5370	0.0573	17.4624	1.1453
3000	592.50	1.10	31.0092	0.0523	19.1072	1.0467
3300	651.75	1.17	33.0555	0.0507	19.7168	1.0144
3600	711.00	1.18	33.3704	0.0469	21.3063	0.9387

Table 4.8 showed that 6mm diameter of Aluminium 6061 pin subjected to 0.1975 m/s had volume loss of 27.0741 mm^3. The rate of wear was 0.1523 mm^3/mm, resistance of

wear rate was 6.5653 mm/mm^3 and specific rate of wear was 3.0463 $\times 10^{-2}$mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 33.3704mm^3, rate of wear of 0.0469 mm^3/m, resistance of wear rate of 21.3063 m/mm^3 and specific rate of wear of 0.9387$\times 10^{-2}$mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.39% after 3600s. The average of two dry test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.9.

Table 4.9 showed that Aluminium pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 27.2297 mm3, rate of wear was 0.1915 mm3/m, resistance of wear rate was 5.2222 m/mm3 and specific rate of wear was 2.3936 $\times 10^{-2}$mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 33.5621 mm^3, rate of wear of 0.0590 mm3/m, resistance of wear rate of 16.9477m/mm3 and specific rate of wear 0.7376$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Aluminium 6061 pin's rate of wear (ω) reduced to 88.39% after 3600s.

Table 4.9: Dry SWA of Aluminium 6061's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.85	24.0634	0.5077	1.9698	6.3458
600	94.8	0.90	25.4882	0.2689	3.7194	3.3608
900	142.2	0.96	27.2297	0.1915	5.2222	2.3936
1200	189.6	1.01	28.4962	0.1503	6.6535	1.8787
1500	237	1.02	28.9711	0.1222	8.1806	1.5280
1800	284.4	1.03	29.1294	0.1024	9.7633	1.2803
2100	331.8	1.04	29.2877	0.0883	11.3290	1.1034
2400	379.2	1.06	30.0793	0.0793	12.6067	0.9915
2700	426.6	1.09	30.7125	0.0720	13.8901	0.8999
3000	474	1.10	31.1875	0.0658	15.1984	0.8225
3300	521.4	1.18	33.2455	0.0638	15.6833	0.7970
3600	568.8	1.19	33.5621	0.0590	16.9477	0.7376

The average of two dry test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.10.

Table 4.10: Dry SWA of Aluminium 6061's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	59.25	0.90	25.4385	0.4293	2.3291	5.3668
600	118.50	0.95	26.9447	0.2274	4.3979	2.8423
900	177.75	1.02	28.7856	0.1619	6.1750	2.0243
1200	237.00	1.07	30.1245	0.1271	7.8673	1.5888
1500	296.25	1.08	30.6266	0.1034	9.6730	1.2923
1800	355.50	1.09	30.7939	0.0866	11.5445	1.0828
2100	414.75	1.10	30.9613	0.0747	13.3958	0.9331
2400	474.00	1.12	31.7981	0.0671	14.9066	0.8386
2700	533.25	1.15	32.4675	0.0609	16.4241	0.7611
3000	592.50	1.17	32.9696	0.0556	17.9711	0.6956
3300	651.75	1.24	35.1453	0.0539	18.5445	0.6741
3600	711.00	1.26	35.4800	0.0499	20.0395	0.6238

Aluminium pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.4, volume loss was 28.7856 mm^3. The rate of wear was 0.1619 mm^3/mm, resistance of wear rate was 6.1750 mm/mm^3 and specific rate of wear was $2.0243 \times 10^{-2} mm^3/Nm$, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of

3600s (1 hour) the pin volume loss was 35.48 mm^3, rate of wear of 0.0499 mm^3/m, resistance of wear rate of 20.0395m/mm^3 and specific rate of wear of 0.6238 $\times 10^{-2}$ mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Aluminium 6061 reduced to 88.38 %. Table 4.11 shows the average of two dry test of SWA of Aluminium pin diameter 6mm during the experiment. Table 4.11 showed that 6mm diameter of Aluminium subjected to 0.158 m/s had volume loss of 27.712mm^3, rate of wear of 0.195mm^3/m, resistance of wear rate of 5.128m/mm^3 and specific rate of wear of 1.950$\times 10^{-2}$mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N.

Table 4.11: Dry SWA of Aluminium Diameter 6mm at 0.158m/s (10N)

$\boldsymbol{t}$	$\boldsymbol{x_s}$	$\boldsymbol{h_l}$	$\boldsymbol{V_l}$	$\boldsymbol{\omega}$	$\boldsymbol{\omega_r}$	$\boldsymbol{\omega_s \times 10^{-2}}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.88	24.883	0.525	1.905	5.250
600	94.8	0.93	26.298	0.277	3.610	2.770
900	142.2	0.98	27.712	0.195	5.128	1.950
1200	189.6	1.02	28.844	0.152	6.579	1.520
1500	237	1.05	29.692	0.125	8.000	1.250
1800	284.4	1.06	29.975	0.105	9.524	1.050
2100	331.8	1.09	30.823	0.093	10.753	0.930
2400	379.2	1.11	31.389	0.083	12.048	0.830
2700	426.6	1.14	32.237	0.076	13.158	0.760
3000	474	1.14	32.237	0.068	14.706	0.680
3300	521.4	1.14	32.237	0.062	16.129	0.620
3600	568.8	1.15	32.520	0.057	17.544	0.370

After experimental period of 3600s (1 hour) the pin volume loss was 14.1237mm^3, rate of wear of 0.0248mm^3/m, resistance of wear rate of 40.2729m/mm^3 and specific rate of wear of 0.4966$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 87.38% after 3600s. Table 4.12 shows the average of two dry test of SWA of Aluminium pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.12: Dry SWA of Aluminium Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.95	26.864	0.4534	2.2025	4.534
600	118.50	0.98	27.712	0.2339	4.2753	2.339
900	177.75	1.05	29.692	0.1670	5.9880	1.670
1200	237	1.09	30.823	0.1301	7.6864	1.301
1500	296.25	1.12	31.671	0.1069	9.3545	1.069
1800	355.5	1.13	31.954	0.0899	11.1235	0.899
2100	414.75	1.16	32.802	0.0791	12.6422	0.791
2400	474	1.20	33.934	0.0716	13.9664	0.716
2700	533.25	1.20	33.934	0.0636	15.7233	0.639
3000	592.5	1.21	34.216	0.0577	17.3310	0.577
3300	651.75	1.25	35.348	0.0542	18.4502	0.542
3600	711	1.25	35.348	0.0497	20.1207	0.497

Table 4.12 showed that 4mm diameter of Aluminium pin subjected to 0.1975 m/s had volume loss of 35.348mm^3. The rate of wear was 0.1670mm^3/mm, resistance of wear rate was 5.9888mm/mm^3 and specific rate of wear was 1.9750×10^{-2}mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 35.348mm^3, rate of wear of 0.0497mm^3/m, resistance of wear rate of 20.1207m/mm^3 and specific rate of wear of 0.497×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear(ω) reduced to 87.44% after 3600s. Table 4.13 is the Aluminium pin diameter 4mm diameter under wet or lubricated condition at sliding speed of 0.158m/s through applied force of 5N.

Table 4.13: Wet SWA of Aluminium 6061's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	1.06	13.3745	0.2822	3.5441	5.6432
600	94.8	1.13	14.1664	0.1494	6.6919	2.9887
900	142.2	1.20	15.1343	0.1064	9.3959	2.1286
1200	189.6	1.26	15.8382	0.0835	11.9711	1.6707
1500	237	1.28	16.1022	0.0679	14.7185	1.3588
1800	284.4	1.29	16.1902	0.0569	17.5662	1.1385
2100	331.8	1.30	16.2782	0.0491	20.3832	0.9812
2400	379.2	1.33	16.7181	0.0441	22.6820	0.8818
2700	426.6	1.36	17.0701	0.0400	24.9911	0.8003
3000	474	1.38	17.3340	0.0366	27.3451	0.7314
3300	521.4	1.47	18.4779	0.0354	28.2175	0.7088
3600	568.8	1.48	18.6539	0.0328	30.4923	0.6559

Table 4.13 showed that 4mm diameter of Aluminium 6061 subjected to 0.158 m/s had volume loss of 15.1343 mm^3, rate of wear of 0.1064mm^3/m, resistance of wear rate of 9.3959m/mm^3 and specific rate of wear of 2.1286×10^{-2}mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 18.6539mm^3, rate of wear of 0.0328 mm^3/m, resistance of wear rate of 30.4923 m/mm^3 and specific rate of wear of 0.6559×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.38% after 3600s. Table 4.14 shows the average of two wet test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.14: Wet SWA of Aluminium 6061's Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	1.23	15.5144	0.2618	3.8190	5.2369
600	118.50	1.31	16.4330	0.1387	7.2111	2.7735
900	177.75	1.40	17.5558	0.0988	10.1249	1.9753
1200	237.00	1.46	18.3723	0.0775	12.8998	1.5504
1500	296.25	1.49	18.6785	0.0630	15.8605	1.2610
1800	355.50	1.49	18.7806	0.0528	18.9291	1.0566
2100	414.75	1.50	18.8827	0.0455	21.9646	0.9106
2400	474.00	1.54	19.3930	0.0409	24.4418	0.8183
2700	533.25	1.58	19.8013	0.0371	26.9301	0.7427
3000	592.50	1.60	20.1075	0.0339	29.4667	0.6787
3300	651.75	1.71	21.4344	0.0329	30.4068	0.6577
3600	711.00	1.72	21.6385	0.0304	32.8581	0.6087

Table 4.14 showed that 4mm diameter of Aluminium 6061 pin subjected to 0.1975 m/s had volume loss of 17.5558 mm^3. The rate of wear was 0.0988 mm^3/mm, resistance of wear rate was 10.1249 mm/mm^3 and specific rate of wear was 1.9753×10^{-2}mm^3/Nm

after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 21.6385mm^3, rate of wear of 0.0304 mm^3/m, resistance of wear rate of 32.8581 m/mm^3 and specific rate of wear of 0.6087 $\times 10^{-2}$mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.39% after 3600s. The average of two wet test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.15.

Table 4.15: Wet SWA of Aluminium 6061's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	1.49	18.7243	0.3950	2.5315	4.9378
600	94.8	1.58	19.8329	0.2092	4.7799	2.6151
900	142.2	1.69	21.1880	0.1490	6.7113	1.8625
1200	189.6	1.76	22.1735	0.1169	8.5508	1.4619
1500	237	1.79	22.5430	0.0951	10.5132	1.1890
1800	284.4	1.80	22.6662	0.0797	12.5473	0.9962
2100	331.8	1.81	22.7894	0.0687	14.5594	0.8586
2400	379.2	1.86	23.4053	0.0617	16.2014	0.7715
2700	426.6	1.90	23.8981	0.0560	17.8508	0.7002
3000	474	1.93	24.2676	0.0512	19.5322	0.6400
3300	521.4	2.06	25.8691	0.0496	20.1554	0.6202
3600	568.8	2.08	26.1154	0.0459	21.7802	0.5739

In Table 4.15, Aluminium pin diameter 6mm diameter was used and it is being subjected to 0.158 m/s under applied force of 8N. The volume loss was 21.1880 mm^3, rate of wear was 0.1490 mm^3/m, resistance of wear rate was 6.7113 m/mm^3 and specific rate of wear was 1.8625$\times 10^{-2}$mm^3/Nm after 900s with a sliding distance of

142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 26.1154mm^3, rate of wear of 0.0459 mm^3/m, resistance of wear rate of 21.7802 m/mm^3 and specific rate of wear of 0.5739×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.38% after 3600s. The average of two wet test of SWA of Aluminium 6061 pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.16.

Table 4.16: Wet SWA of Aluminium 6061's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	1.57	19.7942	0.3341	2.9933	4.1760
600	118.50	1.67	20.9663	0.1769	5.6519	2.2116
900	177.75	1.78	22.3987	0.1260	7.9357	1.5752
1200	237.00	1.86	23.4405	0.0989	10.1107	1.2363
1500	296.25	1.90	23.8312	0.0804	12.4312	1.0055
1800	355.50	1.91	23.9614	0.0674	14.8363	0.8425
2100	414.75	1.92	24.0917	0.0581	17.2155	0.7261
2400	474.00	1.97	24.7428	0.0522	19.1571	0.6525
2700	533.25	2.01	25.2637	0.0474	21.1074	0.5922
3000	592.50	2.04	25.6544	0.0433	23.0955	0.5412
3300	651.75	2.18	27.3473	0.0420	23.8323	0.5245
3600	711.00	2.20	27.6077	0.0388	25.7536	0.4854

Aluminium pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.16 that volume loss was 22.3987 mm^3. The rate of wear was 0.1260 mm^3/m, resistance of wear rate was 7.9357 m/mm^3 and specific rate of wear was 1.5752×10^{-2}mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 27.6077mm^3, rate of wear of 0.0388mm^3/m, resistance of wear rate of 25.7536m/mm^3 and specific rate of wear of 0.4854×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Aluminium 6061 reduced to 89.19%. Table 4.17 shows the average of two wet test of SWA of Aluminium pin diameter 4mm during the experiment.

Table 4.17: Wet SWA of Aluminium Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	1.50	18.850	0.3977	2.5145	3.977
600	94.8	1.61	20.234	0.2134	4.6860	2.134
900	142.2	1.66	20.863	0.1467	6.8166	1.467
1200	189.6	1.77	22.245	0.1173	8.5251	1.173
1500	237	1.80	22.622	0.0955	10.4712	0.955
1800	284.4	1.82	22.874	0.0802	12.4378	0.804
2100	331.8	1.83	22.999	0.0693	14.4300	0.693
2400	379.2	1.88	23.628	0.0623	16.0513	0.623
2700	426.6	1.90	23.879	0.0560	17.8571	0.560
3000	474	1.90	23.879	0.0504	19.8412	0.504
3300	521.4	1.90	23.879	0.0458	21.8341	0.458
3600	568.8	1.90	23.879	0.0420	23.8295	0.420

Table 4.17 showed that 4mm diameter of Brass subjected to 0.158 m/s had volume loss of 20.8630mm^3, rate of wear of 0.1467mm^3/m, resistance of wear rate of 6.8166m/mm^3 and specific rate of wear of 1.4670×10^{-2}mm^3/Nm after 900s. The pin has covered a

sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 23.879mm^3, rate of wear of 0.0420mm^3/m, resistance of wear rate of 23.8295m/mm^3 and specific rate of wear of 0.420×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 87.19% after 3600s. Table 4.18 shows the average of two wet test of SWA of Aluminium pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.18: Wet SWA of Aluminium Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	1.59	19.983	0.3373	2.9647	3.373
600	118.50	1.68	21.114	0.1782	5.6117	1.782
900	177.75	1.79	22.497	0.1266	7.8989	1.266
1200	237	1.88	23.628	0.0997	10.0301	0.997
1500	296.25	1.92	24.131	0.0815	12.2699	0.815
1800	355.5	1.93	24.256	0.0682	14.6628	0.682
2100	414.75	1.95	24.508	0.0591	16.9205	0.591
2400	474	1.98	24.885	0.0525	19.0476	0.525
2700	533.25	2.02	25.387	0.0476	21.0084	0.474
3000	592.5	2.03	25.513	0.0431	23.2019	0.431
3300	651.75	2.03	25.513	0.03914	25.5493	0.391
3600	711	2.03	25.513	0.0358	27.9330	0.358

Table 4.18 showed that 4mm diameter of Aluminium pin subjected to 0.1975 m/s had volume loss of 22.497mm^3. The rate of wear was 0.1266mm^3/mm, resistance of wear rate was 7.8989mm/mm^3 and specific rate of wear was 1.2660×10^{-2}mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 25.513mm^3, rate of wear of 0.0358mm^3/m, resistance of wear rate of 27.9330m/mm^3 and specific rate of wear of

0.358×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear(ω) reduced to 88.01% after 3600s. Table 4.19 shows wet SWA of Aluminium 6061's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.19: Wet SWA of Aluminium 6061's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.43	12.0317	0.2538	3.9396	5.0767
600	94.8	0.45	12.7441	0.1344	7.4387	2.6886
900	142.2	0.48	13.6148	0.0957	10.4445	1.9149
1200	189.6	0.50	14.2481	0.0751	13.3071	1.5030
1500	237	0.51	14.4855	0.0611	16.3611	1.2224
1800	284.4	0.52	14.5647	0.0512	19.5267	1.0242
2100	331.8	0.52	14.6439	0.0441	22.6580	0.8827
2400	379.2	0.53	15.0396	0.0397	25.2134	0.7932
2700	426.6	0.54	15.3563	0.0360	27.7802	0.7199
3000	474	0.55	15.5937	0.0329	30.3968	0.6580
3300	521.4	0.59	16.6228	0.0319	31.3666	0.6376
3600	568.8	0.59	16.7811	0.0295	33.8953	0.5901

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 13.6148 mm^3, rate of wear of 0.0957 mm^3/m, resistance of wear rate of 10.4445 m/mm^3 and specific rate of wear of 1.9149×10^{-2}mm^3/Nm in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 16.7811 mm^3, rate of wear of 0.0295mm^3/m, resistance of wear rate of 33.8953 m/mm^3 and specific rate of wear of 0.5901$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.38% after 3600s. Table 4.20 shows the average of two wet test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.20: Wet SWA of Aluminium 6061's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.59	16.7481	0.2827	3.5377	5.6534
600	118.50	0.63	17.7398	0.1497	6.6799	2.9941
900	177.75	0.67	18.9518	0.1066	9.3790	2.1324
1200	237.00	0.70	19.8333	0.0837	11.9496	1.6737
1500	296.25	0.71	20.1639	0.0681	14.6921	1.3613
1800	355.50	0.72	20.2741	0.0570	17.5347	1.1406
2100	414.75	0.72	20.3843	0.0491	20.3466	0.9830
2400	474.00	0.74	20.9352	0.0442	22.6413	0.8833
2700	533.25	0.76	21.3759	0.0401	24.9463	0.8017
3000	592.50	0.77	21.7065	0.0366	27.2960	0.7327
3300	651.75	0.82	23.1389	0.0355	28.1669	0.7101
3600	711.00	0.83	23.3593	0.0329	30.4376	0.6571

Table 4.20 showed that 6mm diameter of Aluminium 6061 pin subjected to 0.1975 m/s had volume loss of 18.9518 mm^3. The rate of wear was 0.1066 mm^3/mm, resistance of wear rate was 9.3790 mm/mm^3 and specific rate of wear was 2.1324 × 2mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 23.3593 mm^3, rate of wear of 0.0329 mm^3/m, resistance of wear rate of 30.4376 m/mm^3 and specific rate of wear of 0.6571 × 10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is

indicated that surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to 88.36% after 3600s. The average of two wet test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.21.

Table 4.21: Wet SWA of Aluminium 6061's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.60	16.8444	0.3554	2.8140	4.4421
600	94.8	0.63	17.8418	0.1882	5.3134	2.3526
900	142.2	0.67	19.0608	0.1340	7.4604	1.6755
1200	189.6	0.71	19.9473	0.1052	9.5050	1.3151
1500	237	0.72	20.2798	0.0856	11.6865	1.0696
1800	284.4	0.72	20.3906	0.0717	13.9476	0.8962
2100	331.8	0.73	20.5014	0.0618	16.1843	0.7724
2400	379.2	0.74	21.0555	0.0555	18.0095	0.6941
2700	426.6	0.76	21.4988	0.0504	19.8430	0.6299
3000	474	0.77	21.8312	0.0461	21.7120	0.5757
3300	521.4	0.82	23.2719	0.0446	22.4047	0.5579
3600	568.8	0.83	23.4935	0.0413	24.2110	0.5163

Table 4.21 showed that Aluminium pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 19.0608 mm^3, rate of wear was 0.134 mm^3/m, resistance of wear rate was 7.4604 m/mm^3 and specific rate of wear was 1.6755$\times 10^{-2}$$mm^3/Nm$ after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 23.4935 mm^3, rate of wear of 0.0413 mm^3/m, resistance of wear rate of 24.2110 m/mm^3 and specific rate of wear0.5163$\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Aluminium 6061 pin's rate of wear(ω) reduced to

88.38% after 3600s. The average of two wet test of SWA of Aluminium 6061 pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.22.

Table 4.22: Wet SWA of Aluminium 6061's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.63	17.8069	0.3005	3.3274	3.7567
600	118.50	0.67	18.8613	0.1592	6.2827	1.9896
900	177.75	0.71	20.1500	0.1134	8.8214	1.4170
1200	237.00	0.75	21.0872	0.0890	11.2391	1.1122
1500	296.25	0.76	21.4386	0.0724	13.8185	0.9046
1800	355.50	0.76	21.5558	0.0606	16.4921	0.7579
2100	414.75	0.77	21.6729	0.0523	19.1368	0.6532
2400	474.00	0.79	22.2587	0.0470	21.2951	0.5870
2700	533.25	0.80	22.7273	0.0426	23.4630	0.5328
3000	592.50	0.82	23.0787	0.0390	25.6730	0.4869
3300	651.75	0.87	24.6017	0.0377	26.4921	0.4718
3600	711.00	0.88	24.8360	0.0349	28.6278	0.4366

Aluminium pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.16, volume loss was 20.15 mm^3. The rate of wear was 0.1134mm^3/mm, resistance of wear rate was 8.8214 mm/mm^3 and specific rate of wear was 1.4170$\times 10^{-2}$$mm^3/Nm$, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 24.836 mm^3, rate of wear of 0.0349mm^3/m, resistance of wear rate of 28.6278 m/mm^3 and specific rate of wear of 0.4366 $\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Aluminium 6061 reduced to 88.39 %. Table 4.23 shows the average of two wet test of SWA of Aluminium pin diameter 6mm during the experiment.

Table 4.23: Wet SWA of Aluminium Diameter 6mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.63	17.815	0.3758	2.6610	3.758
600	94.8	0.65	18.381	0.1939	5.1573	1.939
900	142.2	0.68	19.229	0.1352	7.3964	1.352
1200	189.6	0.73	20.643	0.1089	9.1827	1.089
1500	237	0.74	20.926	0.0883	11.3250	0.883
1800	284.4	0.75	21.209	0.0746	13.4048	0.746
2100	331.8	0.75	21.209	0.0639	15.0495	0.639
2400	379.2	0.76	21.491	0.0566	17.6678	0.566
2700	426.6	0.78	22.057	0.0517	19.3424	0.517
3000	474	0.80	22.622	0.0477	20.9644	0.477
3300	521.4	0.83	23.471	0.0450	22.2222	0.450
3600	568.8	0.84	23.754	0.0418	23.9234	0.418

Table 4.23 showed that 4mm diameter of Aluminium subjected to 0.158 m/s had volume loss of 19.229mm^3, rate of wear of 0.1352mm^3/m, resistance of wear rate of 7.3964m/mm^3 and specific rate of wear of 1.353×10^{-2}mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 23.754mm^3, rate of wear of 0.0418mm^3/m, resistance of wear rate of 23.9234m/mm^3 and specific rate of wear of 0.4180×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear(ω) reduced to 87.68% after 3600s. Table 4.24 shows the average of two wet test of SWA of Aluminium pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.24: Wet SWA of Aluminium Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.64	18.098	0.3055	3.2733	3.055
600	118.50	0.68	19.229	0.1622	6.1652	1.622
900	177.75	0.73	20.643	0.1161	8.6133	1.161
1200	237	0.77	21.774	0.0919	10.8814	0.919
1500	296.25	0.77	21.774	0.0745	13.4228	0.745
1800	355.5	0.77	21.774	0.0612	16.3399	0.612
2100	414.75	0.78	22.057	0.0532	18.7970	0.532
2400	474	0.79	22.339	0.0471	21.2314	0.471
2700	533.25	0.82	23.188	0.0434	23.0415	0.434
3000	592.5	0.82	23.188	0.0392	25.5102	0.392
3300	651.75	0.87	24.602	0.0377	26.5252	0.377
3600	711	0.89	25.167	0.0354	28.2486	0.354

Table 4.24 showed that 6mm diameter of Aluminium pin subjected to 0.1975 m/s had volume loss of 20.643mm^3. The rate of wear was 0.1161mm^3/mm, resistance of wear rate was 8.6163mm/mm^3 and specific rate of wear was $1.1610 \times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 25.167mm^3, rate of wear of 0.0354mm^3/m, resistance of wear rate of 28.2486m/mm^3 and specific rate of wear of $0.354 \times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Aluminium pin's rate of wear(ω) reduced to 87.74% after 3600s.

4.2.1 Effect of Sliding Speed and Applied Force

The effect of constant sliding speed is considered on the Aluminium pin at varying applied force and varying diameter. Figures 4.1 and 4.2 illustrate the graph of rate of wear (mm^^{3}/m) and sliding distance (m).

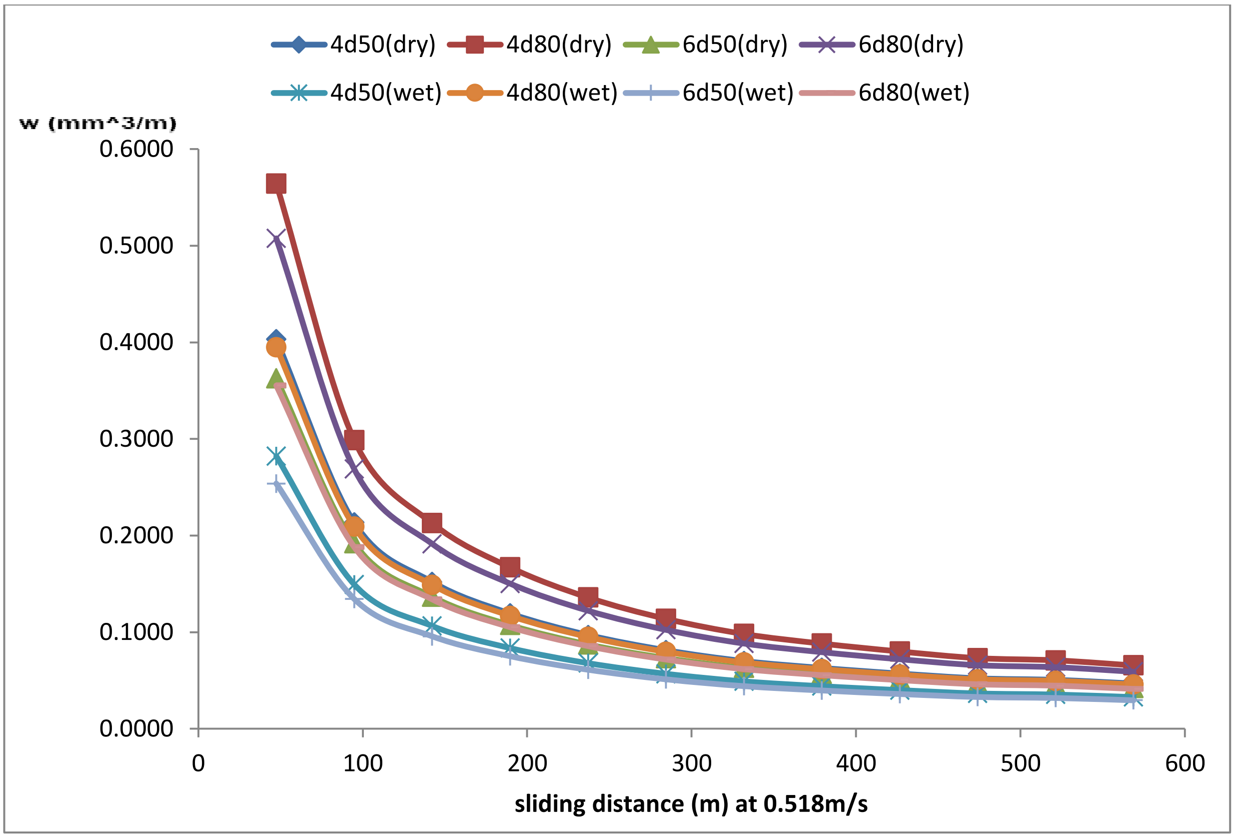

Figure 4.2: Effect of rate of wear on Aluminium 6061 Pin at sliding velocity of 0.158 m/s

Note: NdF(Condition)

Where: N: Is the first number indicated in the graph legend and it is either 4mm or 6mm

d: second in the graph legend and it is diameter

F: third in the graph legend and it is applied force of either 5N or 8N

Condition: Last in the graph legend and it is dry or wet condition.

It is shown in the graph of Figure 4.1 that sliding speed was 0.158m/s, the rate of wear was higher in Aluminium 6061 diameter 4mm pin “4d80(dry)” has 0.2129 mm^^{3}/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 142.2m covered at 900s and under the same condition the rate of wear was lower to 0.0957 mm^^{3}/m by Aluminium 6061 diameter 6mm pin “6d5(wet)”. This showed that the increase in pin contact surface area due to increase pin diameter under lesser applied force of 5N and lubricated surface will reduce rate of wear. The rate of wear was reduced to 55.05% condition.

Considering, Aluminium 6061 diameter 4mm pin “4d5(dry)” under applied force of 5N without lubricating surface at sliding distance of 142.2m at 900s. The rate of wear in this pin was 0.152 mm^^{3}/m and this reduced to 28.6% in comparing with 4d8(dry) above. In this case there is reduce force but the wear can be only being limited to 28.6% under this dry condition. If by changing the condition to lubricated surface of 4d8(dry) by 4d80(wet), the rate of wear of 4d8(wet) was 0.1490 mm^^{3}/m. This led to only 30.01% reduction of rate of wear and this means wearing at surface is reduced using lubricating oil and tends to reduce more if with increase in surface contact area.

The graph of Figure 4.2 has constant sliding speed of 0.1975m/s, the rate of wear was more higher in Aluminium 6061 diameter 4mm pin “4d8(dry)” with 0.18 mm^3/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 177.75m covered at 900s and under the same condition the rate of wear was lower to 0.0988 mm^3/mby Aluminium 6061 diameter 4mm pin “4d5(wet)”. This showed that the reduction of applied force to 5N on same diameter pin with lubricated surface will reduce rate of wear to 45.11% under same speed.

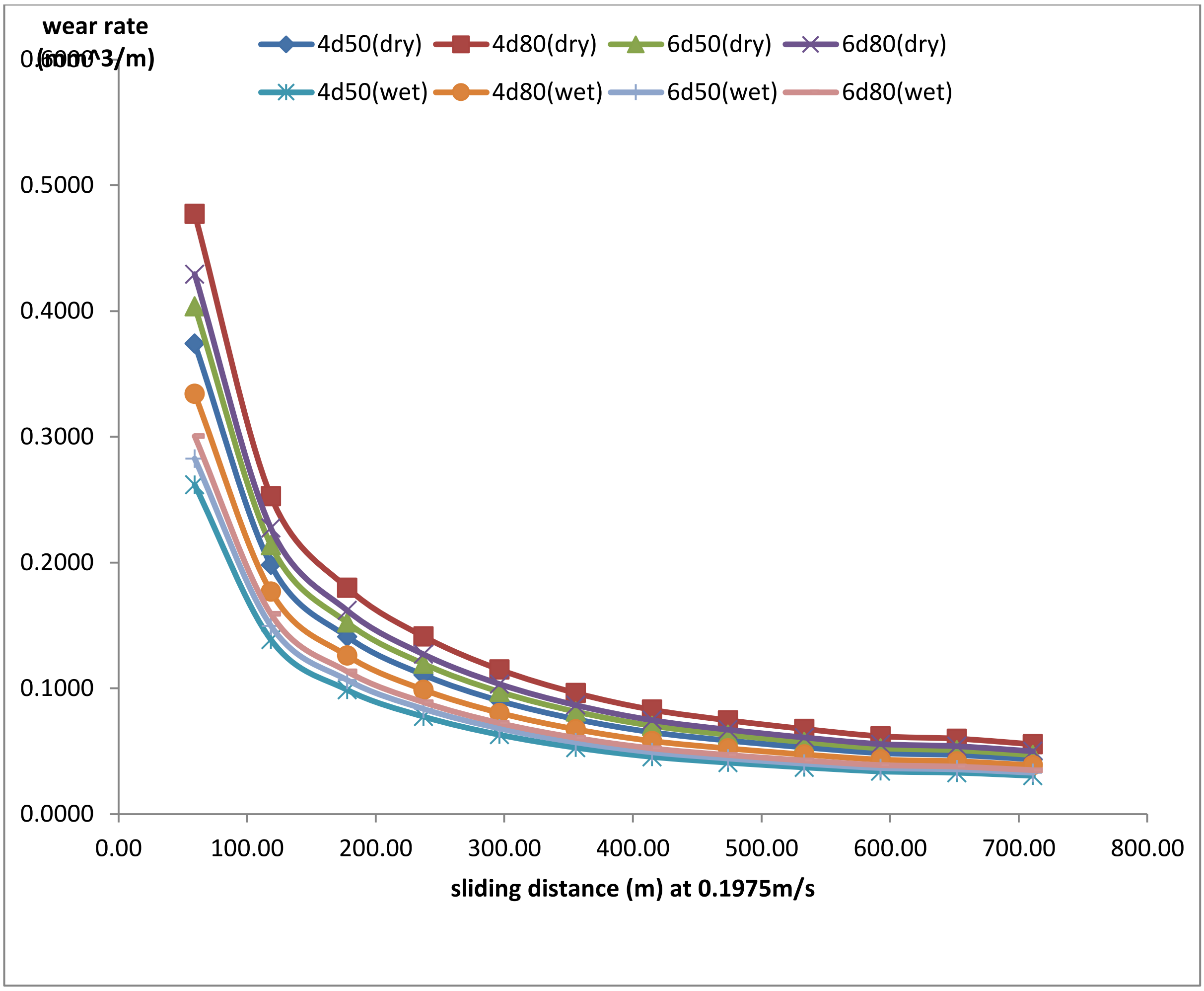

Figure 4.3: Effect of rate of wear on Aluminium 6061 Pin at sliding velocity of 0.1975 m/s

In comparing the rate of wear of 4d8(dry) by both sliding speed of 0.158m/s in Figure 4.1 and 0.1975m/s in Figure 4.2, it was understood that rate of wear reduce to 15.45% as result of increase in speed of the pin.

4.2.2 Specific rate of wear

Section 4.2.2 showed the effect of both sliding speed and applied force, thus Figure 4.3 illustrates Aluminium 6061 diameter 6mm pin "6d5(wet) specific rate of wear at 0.518m/s. The pin was considered it has lower rate of wear in comparing to other condition considered in section 4.2 above.

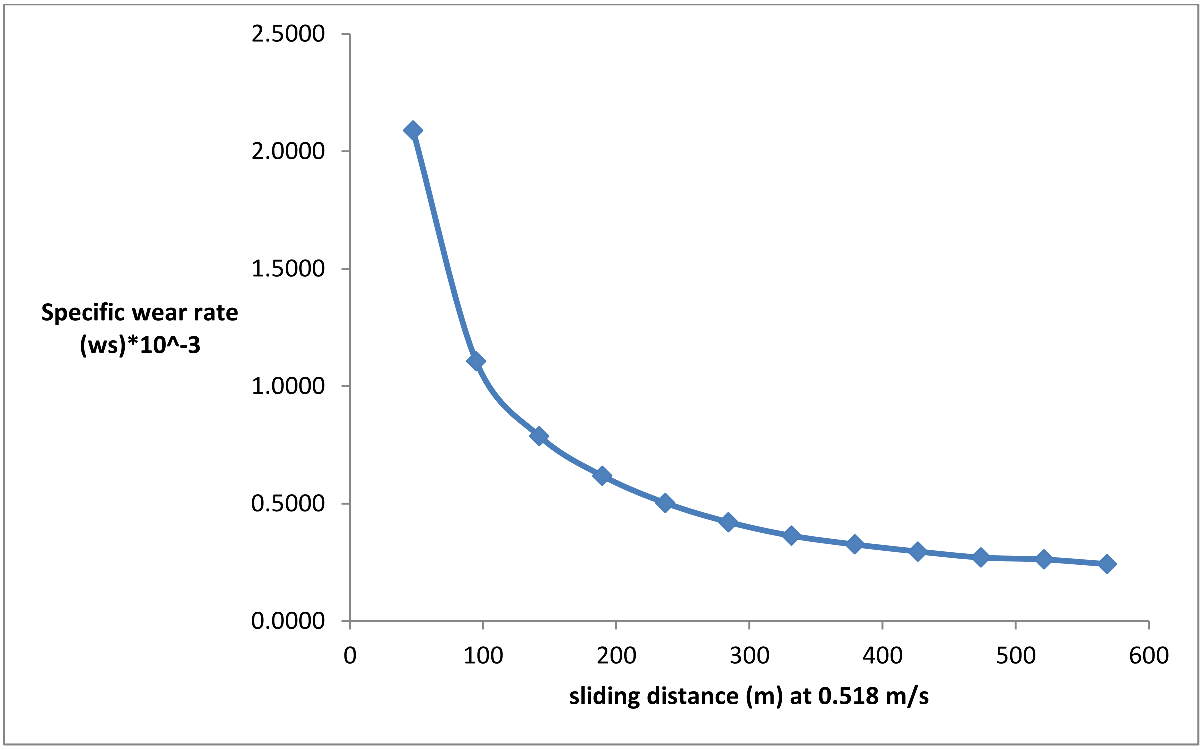

Figure 4.4: Specific rate of wear of Aluminium 6061

The specific rate of wear of Aluminium 6061 diameter 6mm pin with lubricated surface include 5.0767×10^{-2} mm^3/Nm, 1.9149×10^{-2} mm^3/Nm and $0.5901 \times 10^{-2} mm^3/Nm$ for 47.4m, 142.2m and 568.8m respectively. This means as sliding distance increase with decrease in specific wear of the pin.

4.3 Bronze surface Wear Analysis (SWA)

Bronze pin of both diameter 4mm and 6mm were subjected to wear analysis for both dry and wet surface wear testing condition. The effects of sliding speed and applied force on the pin were also determined. The testing of applied force 5N on pin diameter 4mm at sliding speed of 0.158m/s is shown in Table 4.25. Table 4.25 shows the average of two dry test of SWA of Bronze pin diameter 4mm during the experiment.

Table 4.25: Dry SWA of Bronze's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.61	7.6426	0.1612	6.2021	3.2247
600	94.8	0.64	8.0951	0.0854	11.7108	1.7078
900	142.2	0.69	8.6482	0.0608	16.4428	1.2163
1200	189.6	0.72	9.0504	0.0477	20.9494	0.9547
1500	237	0.73	9.2012	0.0388	25.7574	0.7765
1800	284.4	0.74	9.2515	0.0325	30.7409	0.6506
2100	331.8	0.74	9.3018	0.0280	35.6705	0.5607
2400	379.2	0.76	9.5532	0.0252	39.6935	0.5039
2700	426.6	0.78	9.7543	0.0229	43.7345	0.4573
3000	474	0.79	9.9052	0.0209	47.8538	0.4179
3300	521.4	0.84	10.5588	0.0203	49.3806	0.4050
3600	568.8	0.85	10.6594	0.0187	53.3616	0.3748

Table 4.25 showed that 4mm diameter of Bronze subjected to 0.158 m/s had volume loss of 8.6482 mm^3, rate of wear of 0.0608mm^3/m, resistance of wear rate of 16.4428 m/mm^3 and specific rate of wear of 1.2163$\times 10^{-2}$mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 10.6594 mm^3, rate of wear of 0.0187mm^3/m, resistance of wear rate of 53.3616m/mm^3 and specific rate of wear of 0.3748 $\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 5N.

It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.4 % after 3600s.

Table 4.26 shows the average of two dry test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.26: Dry SWA of Bronze's Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.71	8.8654	0.1496	6.6833	2.9925
600	118.50	0.75	9.3903	0.0792	12.6194	1.5849
900	177.75	0.80	10.0319	0.0564	17.7185	1.1288
1200	237.00	0.84	10.4985	0.0443	22.5747	0.8859
1500	296.25	0.85	10.6734	0.0360	27.7558	0.7206
1800	355.50	0.85	10.7318	0.0302	33.1260	0.6038
2100	414.75	0.86	10.7901	0.0260	38.4381	0.5203
2400	474.00	0.88	11.0817	0.0234	42.7732	0.4676
2700	533.25	0.90	11.3150	0.0212	47.1277	0.4244
3000	592.50	0.91	11.4900	0.0194	51.5666	0.3878
3300	651.75	0.97	12.2482	0.0188	53.2119	0.3759
3600	711.00	0.98	12.3649	0.0174	57.5017	0.3478

Table 4.26 showed that 4mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 10.0319 mm^3. The rate of wear was 0.0564mm^3/mm, resistance of wear rate was 17.7185mm/mm^3 and specific rate of wear was 1.1288$\times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 12.3649 mm^3, rate of wear of 0.0174mm^3/m, resistance of wear rate of 57.5017m/mm^3 and specific rate of wear of 0.3478 $\times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 5N. It

is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.37% after 3600s. The average of two dry test of SWA of Bronze pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.27.

Table 4.27: Dry SWA of Bronze's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.85	10.6996	0.2257	4.4301	2.8216
600	94.8	0.90	11.3331	0.1195	8.3649	1.4943
900	142.2	0.96	12.1074	0.0851	11.7449	1.0643
1200	189.6	1.01	12.6706	0.0668	14.9638	0.8353
1500	237	1.02	12.8817	0.0544	18.3981	0.6794
1800	284.4	1.03	12.9521	0.0455	21.9578	0.5693
2100	331.8	1.04	13.0225	0.0392	25.4789	0.4906
2400	379.2	1.06	13.3745	0.0353	28.3525	0.4409
2700	426.6	1.09	13.6560	0.0320	31.2389	0.4001
3000	474	1.10	13.8672	0.0293	34.1813	0.3657
3300	521.4	1.18	14.7823	0.0284	35.2719	0.3544
3600	568.8	1.19	14.9231	0.0262	38.1154	0.3280

Table 4.27 illustrated Bronze pin diameter 6mm diameter that was subjected to 0.158 m/s under applied force of 8N. The volume loss was 12.1074 mm^3, rate of wear was 0.0851 mm^3/m, resistance of wear rate was 11.7449m/mm^3 and specific rate of wear was 1.0643 $\times 10^{-2}$ mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 14.9231 mm^3, rate of wear of 0.0262 mm^3/m, resistance of wear rate of 38.1154 m/mm^3 and specific rate of wear of 0.3280 $\times 10^{-2}$ mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.39%

after 3600s. The average of two dry test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.28.

Table 4.28: Dry SWA of Bronze's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.90	11.3110	0.1909	5.2383	2.3863
600	118.50	0.95	11.9807	0.1011	9.8909	1.2638
900	177.75	1.02	12.7993	0.0720	13.8875	0.9001
1200	237.00	1.07	13.3946	0.0565	17.6937	0.7065
1500	296.25	1.08	13.6178	0.0460	21.7546	0.5746
1800	355.50	1.09	13.6922	0.0385	25.9636	0.4814
2100	414.75	1.10	13.7667	0.0332	30.1271	0.4149
2400	474.00	1.12	14.1387	0.0298	33.5249	0.3729
2700	533.25	1.15	14.4364	0.0271	36.9379	0.3384
3000	592.50	1.17	14.6596	0.0247	40.4171	0.3093
3300	651.75	1.24	15.6270	0.0240	41.7066	0.2997
3600	711.00	1.26	15.7759	0.0222	45.0689	0.2774

Bronze pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.28 that volume loss was 12.7993 mm^3. The rate of wear was 0.0720mm^3/mm, resistance of wear rate was 13.8875mm/mm^3 and specific rate of wear was 0.9001$\times 10^{-2}$mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 15.7759 mm^3, rate of wear of 0.0222mm^3/m, resistance of wear rate of 45.0689m/mm^3 and specific rate of wear of 0.2774$\times 10^{-2}$mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Bronze reduced to 88.37%. The same experiment was carried out for 6mm diameter to determine dry surface wear analysis of required parameters.

The average of two dry test of SWA of Bronze pin diameter 4mm at sliding speed of 0.158m/s under applied force of 10N is shown in Table 4.29.

Table 4.29: Dry SWA of Bronze's Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	47.4	0.86	10.8085	0.2280	4.3860	2.2800
600	94.8	0.92	11.5626	0.1220	8.1967	1.2200
900	142.2	0.98	12.3166	0.0866	11.5473	0.8660
1200	189.6	1.01	12.6706	0.0668	14.9638	0.6680
1500	237	1.02	12.8817	0.0544	18.3981	0.5440
1800	284.4	1.03	12.9521	0.0455	21.9578	0.4550
2100	331.8	1.04	13.0225	0.0392	25.4789	0.3920
2400	379.2	1.06	13.3745	0.0353	28.3525	0.3530
2700	426.6	1.09	13.6560	0.0320	31.2389	0.3200
3000	474	1.14	14.3275	0.0302	33.1126	0.3020
3300	521.4	1.18	14.8302	0.0284	35.2112	0.2840
3600	568.8	1.21	15.2073	0.0267	37.4531	0.2670

Table 4.29 illustrated Bronze pin diameter 6mm diameter that was subjected to 0.158 m/s under applied force of 10N. The volume loss was 12.3166 mm^3, rate of wear was 0.0866 mm^3/m, resistance of wear rate was 11.5473m/mm^3 and specific rate of wear was 8.6600 $\times 10^{-2}$ mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 15.2073 mm^3, rate of wear of 0.0267 mm^3/m, resistance of wear rate of 37.4531 m/mm^3 and specific rate of wear of 0.2670 $\times 10^{-2}$ mm^3/Nm and with sliding distance of 568.8m under applied

force of 10N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 87.89% after 3600s.

The average of two dry test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 10N is shown in Table 4.30.

Table 4.30: Dry SWA of Bronze's Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.91	11.4369	0.1930	5.1813	1.930
600	118.50	0.96	12.0653	0.1018	9.8232	1.018
900	177.75	1.04	13.0707	0.0735	13.6054	0.735
1200	237.00	1.08	13.5734	0.0573	17.4520	0.573
1500	296.25	1.09	13.6991	0.0462	21.6450	0.463
1800	355.50	1.11	13.9505	0.0392	25.5102	0.393
2100	414.75	1.13	14.2018	0.0342	29.2398	0.342
2400	474.00	1.15	14.4532	0.0305	32.7869	0.305
2700	533.25	1.16	14.5789	0.0273	36.6300	0.273
3000	592.50	1.18	14.8302	0.0250	40.0000	0.250
3300	651.75	1.26	15.8357	0.0243	41.1523	0.243
3600	711.00	1.26	15.8357	0.0223	44.8430	0.223

Bronze pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.28 that volume loss was 13.0707 mm^3. The rate of wear was 0.0735mm^3/mm, resistance of wear rate was 13.6054mm/mm^3 and specific rate of wear was 0.735$\times 10^{-2}$$mm^3/Nm$, sliding distance was 177.75m, applied force was 10N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 15.8357 mm^3, rate of wear of 0.0223mm^3/m, resistance of wear rate of 44.8430m/mm^3 and specific rate of wear of 0.2230 $\times$

10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 10N. This showed that on 3600s the pin rate of wear of Bronze reduced to 87.47%.

Table 4.31 shows the dry SWA of dry SWA of Bronze's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.31: Dry SWA of Bronze's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.24	6.8753	0.1450	6.8943	2.9010
600	94.8	0.26	7.2824	0.0768	13.0178	1.5364
900	142.2	0.28	7.7799	0.0547	18.2779	1.0942
1200	189.6	0.29	8.1418	0.0429	23.2873	0.8588
1500	237	0.29	8.2775	0.0349	28.6320	0.6985
1800	284.4	0.29	8.3227	0.0293	34.1717	0.5853
2100	331.8	0.30	8.3679	0.0252	39.6514	0.5044
2400	379.2	0.30	8.5941	0.0227	44.1234	0.4533
2700	426.6	0.31	8.7750	0.0206	48.6153	0.4114
3000	474	0.32	8.9107	0.0188	53.1945	0.3760
3300	521.4	0.34	9.4987	0.0182	54.8916	0.3644
3600	568.8	0.34	9.5892	0.0169	59.3168	0.3372

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 7.7799 mm^3, rate of wear of 0.0547 mm^3/m, resistance of wear rate of 18.2779m/mm^3 and specific rate of wear of 1.0942$\times 10^{-2}$mm^3/Nm in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 9.5892 mm^3, rate of wear of 0.0169mm^3/m, resistance of wear rate of 59.3168m/mm^3 and specific rate of wear of 0.3372$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.34% after 3600s.

Table 4.32 shows the average of two dry test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.32: Dry SWA of Bronze's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.34	9.5704	0.1615	6.1910	3.2305
600	118.50	0.36	10.1370	0.0855	11.6898	1.7109
900	177.75	0.38	10.8296	0.0609	16.4133	1.2185
1200	237.00	0.40	11.3333	0.0478	20.9118	0.9564
1500	296.25	0.41	11.5222	0.0389	25.7112	0.7779
1800	355.50	0.41	11.5852	0.0326	30.6858	0.6518
2100	414.75	0.41	11.6481	0.0281	35.6065	0.5617
2400	474.00	0.42	11.9630	0.0252	39.6223	0.5048
2700	533.25	0.43	12.2148	0.0229	43.6560	0.4581
3000	592.50	0.44	12.4037	0.0209	47.7680	0.4187
3300	651.75	0.47	13.2222	0.0203	49.2920	0.4057
3600	711.00	0.47	13.3481	0.0188	53.2658	0.3755

Table 4.32 showed that 6mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 10.8296 mm^3. The rate of wear was 0.0609 mm^3/mm, resistance of wear rate was 16.4133 mm/mm^3 and specific rate of wear was $1.2185\times 10^{-2} mm^3/Nm$ after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 13.3481mm^3, rate of wear of 0.0188 mm^3/m, resistance of wear rate of 53.2658m/mm^3 and specific rate of wear of $0.3755\times 10^{-2} mm^3/Nm$ and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.36% after 3600s.

The average of two dry test of SWA of Al-Bronze pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.33.

Table 4.33: Dry SWA of Bronze's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.34	9.6254	0.2031	4.9245	2.5383
600	94.8	0.36	10.1953	0.1075	9.2984	1.3443
900	142.2	0.39	10.8919	0.0766	13.0556	0.9574
1200	189.6	0.40	11.3985	0.0601	16.6338	0.7515
1500	237	0.41	11.5884	0.0489	20.4514	0.6112
1800	284.4	0.41	11.6518	0.0410	24.4083	0.5121
2100	331.8	0.41	11.7151	0.0353	28.3225	0.4413
2400	379.2	0.43	12.0317	0.0317	31.5167	0.3966
2700	426.6	0.43	12.2850	0.0288	34.7252	0.3600
3000	474	0.44	12.4750	0.0263	37.9960	0.3290
3300	521.4	0.47	13.2982	0.0255	39.2083	0.3188
3600	568.8	0.47	13.4249	0.0236	42.3692	0.2950

Table 4.33 showed that Aluminium pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 10.8919 mm^3, rate of wear was 0.0766mm^3/m, resistance of wear rate was 13.0556m/mm^3 and specific rate of wear was 0.9574$\times 10^{-2}$$mm^3$/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 13.4249 mm^3, rate of wear of 0.0236mm^3/m, resistance of wear rate of 42.3692 m/mm^3 and specific rate of wear0.2950 $\times$ 2mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.38% after 3600s.

The average of two dry test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.34.

Table 4.34: Dry SWA of Bronze's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.36	10.1754	0.1717	5.8229	2.1467
600	118.50	0.38	10.7779	0.0910	10.9947	1.1369
900	177.75	0.41	11.5143	0.0648	15.4374	0.8097
1200	237.00	0.43	12.0498	0.0508	19.6684	0.6355
1500	296.25	0.43	12.2506	0.0414	24.1824	0.5169
1800	355.50	0.44	12.3176	0.0346	28.8612	0.4331
2100	414.75	0.44	12.3845	0.0299	33.4894	0.3733
2400	474.00	0.45	12.7192	0.0268	37.2664	0.3354
2700	533.25	0.46	12.9870	0.0244	41.0603	0.3044
3000	592.50	0.47	13.1878	0.0223	44.9277	0.2782
3300	651.75	0.50	14.0581	0.0216	46.3612	0.2696
3600	711.00	0.50	14.1920	0.0200	50.0987	0.2495

Bronze pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.34, volume loss was 11.5143 mm^3. The rate of wear was 0.0648mm^3/mm, resistance of wear rate was 15.4374mm/mm^3 and specific rate of wear was $0.8097\times 10^{-2}$$mm^3/Nm$, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 14.1920 mm^3, rate of wear of 0.0200mm^3/m, resistance of wear rate of 50.0987m/mm^3 and specific rate of wear of 0.2495×10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Bronze reduced to 88.35%.

Table 4.35 shows the average of two dry test of SWA of Bronze pin diameter 6mm during the experiment.

Table 4.35: Dry SWA of Bronze`s Diameter 6mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.35	9.8973	0.2088	4.7893	2.088
600	94.8	0.37	10.4629	0.1104	9.0580	1.104
900	142.2	0.40	11.3112	0.0795	12.5786	0.795
1200	189.6	0.41	11.5940	0.0611	16.3666	0.611
1500	237	0.42	11.8768	0.0501	19.9601	0.501
1800	284.4	0.42	11.8768	0.0418	23.9234	0.418
2100	331.8	0.43	12.1595	0.0366	27.3224	0.366
2400	379.2	0.44	12.4423	0.0328	30.4878	0.328
2700	426.6	0.45	12.7251	0.0298	33.5570	0.298
3000	474	0.46	13.0079	0.0274	36.4964	0.274
3300	521.4	0.48	13.5734	0.0260	38.4615	0.260
3600	568.8	0.48	13.5734	0.0239	41.8410	0.239

Table 4.35 showed that 4mm diameter of Bronze subjected to 0.158 m/s had volume loss of 11.3112mm^3, rate of wear of 0.0795mm^3/m, resistance of wear rate of 12.5786m/mm^3 and specific rate of wear of 0.795$\times 10^{-2}$$mm^3/Nm$ after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 13.5734mm^3, rate of wear of 0.0239mm^3/m, resistance of wear rate of 41.8410m/mm^3 and specific rate of wear of 0.239$\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.28% after 3600s.

The average of two dry test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 10N is shown in Table 4.36.

Table 4.36: Dry SWA of Bronze's Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.37	10.4629	0.1766	5.6625	1.766
600	118.50	0.39	11.0284	0.0931	10.7411	0.931
900	177.75	0.42	11.8768	0.0668	14.9701	0.668
1200	237.00	0.43	12.1595	0.0513	19.4932	0.513
1500	296.25	0.44	12.4423	0.0420	23.8695	0.420
1800	355.50	0.45	12.7251	0.0358	27.9330	0.358
2100	414.75	0.47	13.2907	0.0320	31.2500	0.320
2400	474.00	0.48	13.5734	0.0286	34.9650	0.286
2700	533.25	0.50	14.1390	0.0265	37.7358	0.265
3000	592.50	0.51	14.4218	0.0243	41.1522	0.243
3300	651.75	0.51	14.4218	0.0221	45.2489	0.221
3600	711.00	0.51	14.4218	0.0203	49.2611	0.203

Bronze pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.36, volume loss was 11.8768 mm^3. The rate of wear was 0.0668mm^3/mm, resistance of wear rate was 14.9701mm/mm^3 and specific rate of wear was $0.668 \times 10^{-2}$$mm^3/Nm$, sliding distance was 177.75m, applied force was 10N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 14.4218 mm^3, rate of wear of 0.0203mm^3/m, resistance of wear rate of 49.2611m/mm^3 and specific rate of wear of $0.203 \times 10^{-2}$$mm^3/Nm$ and with sliding distance of 711m under applied force of 10N. This showed that on 3600s the pin rate of wear of Bronze reduced to 88.86%. Table 4.37 is the Bronze pin diameter 4mm diameter under wet or lubricated condition at sliding speed of 0.158m/s through applied force of 5N.

Table 4.37: Wet SWA of Bronze's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.44	5.5026	0.1161	8.6140	2.3218
600	94.8	0.46	5.8285	0.0615	16.2650	1.2296
900	142.2	0.50	6.2267	0.0438	22.8372	0.8758
1200	189.6	0.52	6.5163	0.0344	29.0963	0.6874
1500	237	0.53	6.6249	0.0280	35.7742	0.5591
1800	284.4	0.53	6.6611	0.0234	42.6957	0.4684
2100	331.8	0.53	6.6973	0.0202	49.5424	0.4037
2400	379.2	0.55	6.8783	0.0181	55.1299	0.3628
2700	426.6	0.56	7.0231	0.0165	60.7423	0.3293
3000	474	0.57	7.1317	0.0150	66.4637	0.3009
3300	521.4	0.60	7.6023	0.0146	68.5842	0.2916
3600	568.8	0.61	7.6747	0.0135	74.1133	0.2699

Table 4.37 showed that 4mm diameter of Bronze subjected to 0.158 m/s had volume loss of 6.2267mm^3, rate of wear of 0.0438mm^3/m, resistance of wear rate of 22.8372m/mm^3 and specific rate of wear of 0.8758$\times 10^{-2}$$mm^3/Nm$ after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 7.6747 mm^3, rate of wear of 0.0135mm^3/m, resistance of wear rate of 74.1133 m/mm^3 and specific rate of wear of 0.2699 $\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.37% after 3600s.

Table 4.38 shows the average of two wet test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.38: Wet SWA of Bronze's Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.51	6.3831	0.1077	9.2824	2.1546
600	118.50	0.54	6.7610	0.0571	17.5270	1.1411
900	177.75	0.57	7.2229	0.0406	24.6091	0.8127
1200	237.00	0.60	7.5589	0.0319	31.3538	0.6379
1500	296.25	0.61	7.6849	0.0259	38.5497	0.5188
1800	355.50	0.61	7.7269	0.0217	46.0083	0.4347
2100	414.75	0.62	7.7689	0.0187	53.3862	0.3746
2400	474.00	0.63	7.9788	0.0168	59.4072	0.3367
2700	533.25	0.65	8.1468	0.0153	65.4551	0.3056
3000	592.50	0.66	8.2728	0.0140	71.6203	0.2793
3300	651.75	0.70	8.8187	0.0135	73.9054	0.2706
3600	711.00	0.71	8.9027	0.0125	79.8634	0.2504

Table 4.38 showed that 4mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 7.2229mm^3. The rate of wear was 0.0406mm^3/mm, resistance of wear rate was 24.6091mm/mm^3 and specific rate of wear was 0.8127$\times 10^{-2}$$mm^3/Nm$ after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 8.9027mm^3, rate of wear of 0.0125mm^3/m, resistance of wear rate of 79.8634m/mm^3 and specific rate of wear of 0.2504$\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.39% after 3600s.

The average of two wet test of SWA of Bronze pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.39.

Table 4.39: Wet SWA of Bronze's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.61	7.7037	0.1625	6.1529	2.0316
600	94.8	0.65	8.1598	0.0861	11.6179	1.0759
900	142.2	0.69	8.7173	0.0613	16.3123	0.7663
1200	189.6	0.73	9.1228	0.0481	20.7831	0.6015
1500	237	0.74	9.2748	0.0391	25.5530	0.4892
1800	284.4	0.74	9.3255	0.0328	30.4969	0.4099
2100	331.8	0.75	9.3762	0.0283	35.3874	0.3532
2400	379.2	0.77	9.6296	0.0254	39.3785	0.3174
2700	426.6	0.78	9.8324	0.0230	43.3874	0.2881
3000	474	0.79	9.9844	0.0211	47.4741	0.2633
3300	521.4	0.85	10.6433	0.0204	48.9887	0.2552
3600	568.8	0.85	10.7446	0.0189	52.9380	0.2361

Table 4.39 indicated that Bronze pin diameter 6mm diameter was used and it is being subjected to 0.158 m/s under applied force of 8N. The volume loss was 8.7173mm^3, rate of wear was 0.0613mm^3/m, resistance of wear rate was 16.3123m/mm^3 and specific rate of wear was 0.7663$\times 10^{-2}$$mm^3$/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 10.7446 mm^3, rate of wear of 0.0189 mm^3/m, resistance of wear rate of 52.9380m/mm^3 and specific rate of wear of 0.2361$\times 10^{-2}$$mm^3$/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.37% after 3600s.

The average of two wet test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.40.

Table 4.40: Wet SWA of Bronze's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	59.25	0.65	8.1439	0.1374	7.2754	1.7181
600	118.50	0.69	8.6261	0.0728	13.7374	0.9099
900	177.75	0.73	9.2155	0.0518	19.2882	0.6481
1200	237.00	0.77	9.6441	0.0407	24.5746	0.5087
1500	296.25	0.78	9.8048	0.0331	30.2147	0.4137
1800	355.50	0.78	9.8584	0.0277	36.0605	0.3466
2100	414.75	0.79	9.9120	0.0239	41.8432	0.2987
2400	474.00	0.81	10.1799	0.0215	46.5624	0.2685
2700	533.25	0.83	10.3942	0.0195	51.3026	0.2437
3000	592.50	0.84	10.5549	0.0178	56.1349	0.2227
3300	651.75	0.90	11.2515	0.0173	57.9258	0.2158
3600	711.00	0.90	11.3586	0.0160	62.5957	0.1997

Bronze pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.40 that volume loss was 9.2155 mm^3. The rate of wear was 0.0518mm^3/mm, resistance of wear rate was 19.2882mm/mm^3 and specific rate of wear was 0.6481$\times 10^{-2}$$mm^3/Nm$, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 11.3586 mm^3, rate of wear of 0.0160mm^3/m, resistance of wear rate of 62.5957m/mm^3 and specific rate of wear of 0.1997 $\times 10^{-2}$ mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Bronze reduced to 88.36%.

The average of two wet test of SWA of Bronze pin diameter 4mm at sliding speed of 0.158m/s under applied force of 10N is shown in Table 4.41.

Table 4.41: Wet SWA of Bronze's Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.62	7.7922	0.1644	6.0828	1.644
600	94.8	0.66	8.2949	0.0875	11.4286	0.875
900	142.2	0.70	8.7976	0.0617	16.2075	0.617
1200	189.6	0.74	9.3003	0.0491	20.3666	0.491
1500	237	0.75	9.4260	0.0398	25.1256	0.398
1800	284.4	0.76	9.5517	0.0336	29.7619	0.336
2100	331.8	0.77	9.6912	0.0292	34.2466	0.292
2400	379.2	0.79	9.9287	0.0262	38.1679	0.262
2700	426.6	0.80	10.0544	0.0236	42.3729	0.236
3000	474	0.82	10.3058	0.0217	47.0829	0.217
3300	521.4	0.86	10.8085	0.0207	48.3092	0.207
3600	568.8	0.86	10.8085	0.0190	52.6316	0.190

Table 4.41 indicated that Bronze pin diameter 6mm diameter was used and it is being subjected to 0.158 m/s under applied force of 10N. The volume loss was $8.7976mm^3$, rate of wear was $0.0617mm^3/m$, resistance of wear rate was $16.2075m/mm^3$ and specific rate of wear was $0.617 \times 10^{-2} mm^3/Nm$ after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 10.8085 mm^3, rate of wear of 0.0190 mm^3/m, resistance of wear rate of $52.6316m/mm^3$ and specific rate of wear of $0.190 \times 10^{-2} mm^3/Nm$ and with sliding distance of 568.8m under applied force of 10N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.77% after 3600s.

Table 4.42 shows the average of two wet test of SWA of Bronze pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.42: Wet SWA of Bronze Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.66	8.2949	0.1399	7.1479	1.399
600	118.5	0.70	8.7976	0.0742	13.4771	0.742
900	177.75	0.74	9.3003	0.0523	19.1205	0.523
1200	237	0.79	9.9287	0.0419	23.8663	0.419
1500	296.25	0.79	9.9287	0.0335	29.8507	0.335
1800	355.5	0.80	10.0544	0.0283	35.3357	0.283
2100	414.75	0.82	10.3058	0.0248	40.3226	0.248
2400	474	0.85	10.6828	0.0225	44.4444	0.225
2700	533.25	0.86	10.8085	0.0203	49.2611	0.203
3000	592.5	0.87	10.9342	0.0185	54.0541	0.185
3300	651.75	0.91	11.4369	0.0175	57.1429	0.175
3600	711	0.91	11.4369	0.0160	62.5000	0.160

Table 4.42 showed that 4mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 9.3003mm^3. The rate of wear was 0.0523mm^3/mm, resistance of wear rate was 19.1205mm/mm^3 and specific rate of wear was 0.532$\times 10^{-2}$mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 11.4369mm^3, rate of wear of 0.0160mm^3/m, resistance of wear rate of 62.5000m/mm^3 and specific rate of wear of 0.160$\times 10^{-2}$mm^3/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.33% after 3600s.

Table 4.43 shows wet SWA of Bronze's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.43: Wet SWA of Bronze's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.18	4.9502	0.1044	9.5754	2.0887
600	94.8	0.19	5.2433	0.0553	18.0802	1.1062
900	142.2	0.20	5.6015	0.0394	25.3859	0.7878
1200	189.6	0.21	5.8621	0.0309	32.3435	0.6184
1500	237	0.21	5.9598	0.0251	39.7666	0.5029
1800	284.4	0.21	5.9923	0.0211	47.4606	0.4214
2100	331.8	0.21	6.0249	0.0182	55.0714	0.3632
2400	379.2	0.22	6.1877	0.0163	61.2825	0.3264
2700	426.6	0.22	6.3180	0.0148	67.5213	0.2962
3000	474	0.23	6.4157	0.0135	73.8812	0.2707
3300	521.4	0.24	6.8391	0.0131	76.2383	0.2623
3600	568.8	0.24	6.9042	0.0121	82.3845	0.2428

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 5.6015 mm^3, rate of wear of 0.0394 mm^3/m, resistance of wear rate of 25.3859 m/mm^3 and specific rate of wear of $0.7878\times 10^{-2}mm^3/Nm$ in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 6.9042 mm^3, rate of wear of $0.0121mm^3/m$, resistance of wear rate of 82.3845 m/mm^3 and specific rate of wear of $0.2428\times 10^{-2}mm^3/Nm$ and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Al-Bronze pin's rate of wear(ω) reduced to 88.41% after 3600s.

Table 4.44 shows the average of two wet test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.44: Wet SWA of Bronze's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	59.25	0.24	6.8907	0.1163	8.5986	2.3260
600	118.50	0.26	7.2987	0.0616	16.2358	1.2318
900	177.75	0.28	7.7973	0.0439	22.7963	0.8773
1200	237.00	0.29	8.1600	0.0344	29.0441	0.6886
1500	296.25	0.29	8.2960	0.0280	35.7100	0.5601
1800	355.50	0.30	8.3413	0.0235	42.6191	0.4693
2100	414.75	0.30	8.3867	0.0202	49.4535	0.4044
2400	474.00	0.30	8.6133	0.0182	55.0310	0.3634
2700	533.25	0.31	8.7947	0.0165	60.6334	0.3299
3000	592.50	0.32	8.9307	0.0151	66.3445	0.3015
3300	651.75	0.34	9.5200	0.0146	68.4612	0.2921
3600	711.00	0.34	9.6107	0.0135	73.9803	0.2703

Table 4.44 showed that 6mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 7.7973mm^3. The rate of wear was 0.0439mm^3/mm, resistance of wear rate was 22.7963 mm/mm^3 and specific rate of wear was $0.8773\times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 9.6107mm^3, rate of wear of 0.0135 mm^3/m, resistance of wear rate of 73.9803 m/mm^3 and specific rate of wear of 0.2703×10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.39% after 3600s.

The average of two wet test of SWA of Bronze pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.45.

Table 4.45: Wet SWA of Bronze's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.25	6.9303	0.1462	6.8396	1.8276
600	94.8	0.26	7.3406	0.0774	12.9145	0.9679
900	142.2	0.28	7.8421	0.0551	18.1328	0.6894
1200	189.6	0.29	8.2069	0.0433	23.1025	0.5411
1500	237	0.30	8.3437	0.0352	28.4047	0.4401
1800	284.4	0.30	8.3893	0.0295	33.9004	0.3687
2100	331.8	0.30	8.4349	0.0254	39.3367	0.3178
2400	379.2	0.31	8.6628	0.0228	43.7732	0.2856
2700	426.6	0.31	8.8452	0.0207	48.2295	0.2592
3000	474	0.32	8.9820	0.0189	52.7723	0.2369
3300	521.4	0.34	9.5747	0.0184	54.4560	0.2295
3600	568.8	0.34	9.6659	0.0170	58.8461	0.2124

Table 4.45 showed that Bronze pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 7.8421 mm^3, rate of wear was 0.0551mm^3/m, resistance of wear rate was 18.1328 m/mm^3 and specific rate of wear was 0.6894$\times 10^{-2}$mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 9.6659 mm^3, rate of wear of 0.0170mm^3/m, resistance of wear rate of 58.8461m/mm^3 and specific rate of wear of 0.2124 $\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.37% after 3600s.

The average of two wet test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.46.

Table 4.46: Wet SWA of Bronze's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.26	7.3263	0.1237	8.0873	1.5456
600	118.50	0.27	7.7601	0.0655	15.2705	0.8186
900	177.75	0.29	8.2903	0.0466	21.4408	0.5830
1200	237.00	0.31	8.6759	0.0366	27.3172	0.4576
1500	296.25	0.31	8.8205	0.0298	33.5867	0.3722
1800	355.50	0.31	8.8687	0.0249	40.0850	0.3118
2100	414.75	0.32	8.9169	0.0215	46.5130	0.2687
2400	474.00	0.32	9.1579	0.0193	51.7589	0.2415
2700	533.25	0.33	9.3506	0.0175	57.0281	0.2192
3000	592.50	0.34	9.4952	0.0160	62.3996	0.2003
3300	651.75	0.36	10.1218	0.0155	64.3905	0.1941
3600	711.00	0.36	10.2182	0.0144	69.5815	0.1796

Bronze pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.46, volume loss was 8.2903 mm^3. The rate of wear was 0.0466 mm^3/mm, resistance of wear rate was 21.4408 mm/mm^3 and specific rate of wear was 0.5830 $\times 10^{-2}$ mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 10.2182 mm^3, rate of wear of 0.0144mm^3/m, resistance of wear rate of 69.5815m/mm^3 and specific rate of wear of 0.1796$\times 10^{-2}$mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Bronze reduced to 88.36 %.

The average of two wet test of SWA of Bronze pin diameter 6mm at sliding speed of 0.158m/s under applied force of 10N is shown in Table 4.47.

Table 4.47: Wet SWA of Bronze's Diameter 6mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.28	7.9178	0.1670	5.9880	1.670
600	94.8	0.28	7.9178	0.0835	11.9760	0.835
900	142.2	0.29	8.2006	0.0577	17.3310	0.577
1200	189.6	0.30	8.4834	0.0447	22.3714	0.442
1500	237	0.31	8.7662	0.0370	27.0270	0.370
1800	284.4	0.31	8.7662	0.0308	32.4465	0.308
2100	331.8	0.32	9.0490	0.0273	36.6300	0.273
2400	379.2	0.33	9.3317	0.0246	40.6504	0.246
2700	426.6	0.34	9.6145	0.0225	44.4444	0.225
3000	474	0.34	9.6145	0.0203	49.2611	0.205
3300	521.4	0.34	9.6145	0.0184	54.3478	0.184
3600	568.8	0.35	9.8973	0.0174	57.4713	0.174

Table 4.47 showed that Bronze pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 10N. The volume loss was 8.2006 mm^3, rate of wear was 0.0577mm^3/m, resistance of wear rate was 17.3310 m/mm^3 and specific rate of wear was $0.577 \times 10^{-2} mm^3/Nm$ after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 9.8973 mm^3, rate of wear of 0.0174mm^3/m, resistance of wear rate of 57.4713m/mm^3 and specific rate of wear of $0.174 \times 10^{-2} mm^3/Nm$ and with sliding distance of 568.8m under applied force of 10N. The surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.97% after 3600s.

Table 4.48 shows the average of two wet test of SWA of Bronze pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.48: Wet SWA of Bronze Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	59.25	0.30	8.4834	0.1432	6.9832	1.432
600	118.5	0.31	8.7662	0.0739	13.5318	0.739
900	177.75	0.32	9.0489	0.0509	19.6464	0.509
1200	237	0.33	9.3317	0.0394	25.3807	0.394
1500	296.25	0.34	9.6145	0.0325	30.7692	0.325
1800	355.5	0.35	9.8973	0.0278	35.9712	0.278
2100	414.75	0.35	9.8973	0.0239	41.8410	0.239
2400	474	0.35	9.8973	0.0209	47.8469	0.209
2700	533.25	0.36	10.1801	0.0191	52.3560	0.191
3000	592.5	0.36	10.1801	0.0172	58.1395	0.172
3300	651.75	0.37	10.4629	0.0161	62.1118	0.161
3600	711	0.38	10.7456	0.0151	66.2252	0.151

Table 4.48 showed that 6mm diameter of Bronze pin subjected to 0.1975 m/s had volume loss of 9.0489mm^3. The rate of wear was 0.0509mm^3/mm, resistance of wear rate was 19.6464mm/mm^3 and specific rate of wear was $0.509 \times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 10.7456mm^3, rate of wear of 0.0151mm^3/m, resistance of wear rate of 66.2252m/mm^3 and specific rate of wear of $0.151\times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Bronze pin's rate of wear(ω) reduced to 88.24% after 3600s.

4.3.1 Effect of Sliding Speed and Applied Force

The constant sliding speed effect is considered on the Bronze pin at varying applied force and varying diameter. Figures 4.4 and 4.5 illustrate the graph of rate of wear (mm^3/m) and sliding distance (m) of Bronze pin.

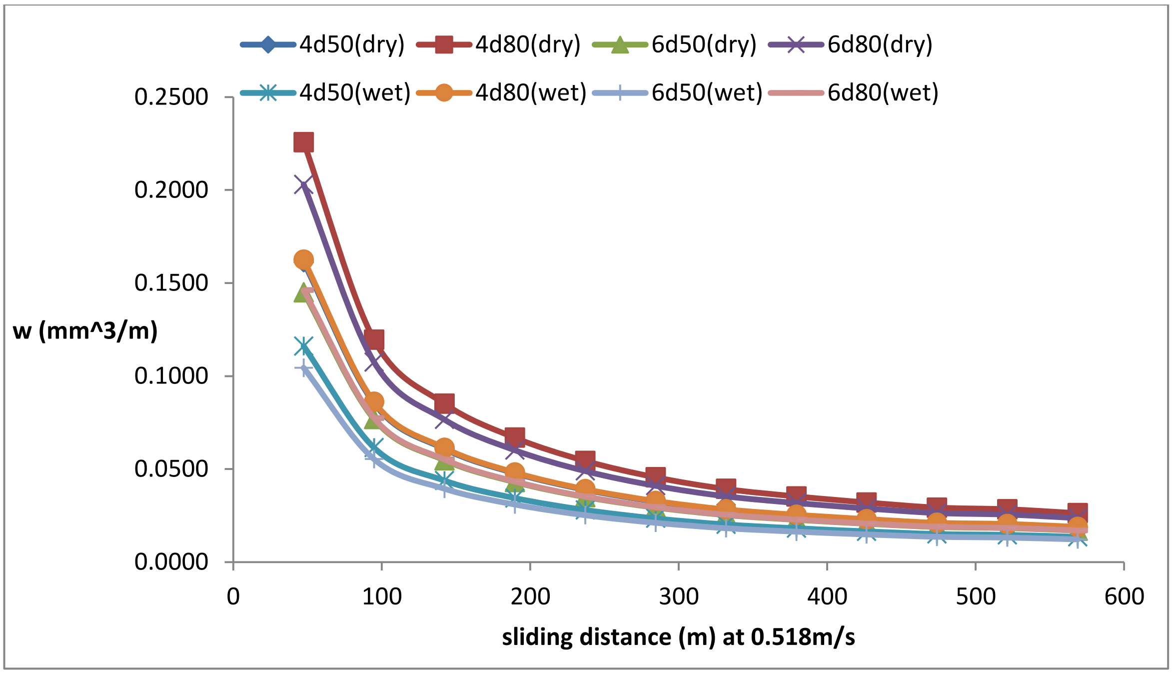

Figure 4.5: Effect of rate of wear on Bronze Pin at sliding velocity of 0.158 m/s

Note: NdF(Condition) remain as discussed in section 4.2.1

The graph of Figure 4.4 was in sliding speed of 0.158m/s, the rate of wear was higher in Bronze diameter 4mm pin “4d8(dry)” with 0.0851 mm^3/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 142.2m covered at 900s and under the same condition the rate of wear was lower to 0.0394 mm^3/m by Bronze diameter 6mm pin “6d5(wet)”. It was understood that increase in pin contact surface area due to increase pin diameter under lesser applied force of 5N and lubricated surface reduces rate of wear to 53.7% condition. There is instance of Bronze diameter 4mm pin “4d5(dry)” under applied force of 5N without lubricating surface at sliding distance of 142.2m at 900s. The rate of wear in this pin was 0.0608 mm^^{3}/m and this reduced to 28.55 % in comparing with 4d8(dry) above. This is a result of reduce force on dry condition. The situation of changing the condition to lubricated surface of 4d8(dry) by 4d8(wet), the rate of wear of 4d8(wet) was 0.0613 mm^3/m. This led to only 27.97 % reduction of rate of wear and this means wearing at surface is reduced using lubricating oil and tends to reduce more if there is increase in surface contact area. Figure 4.5 is on sliding speed of 0.1975m/s.

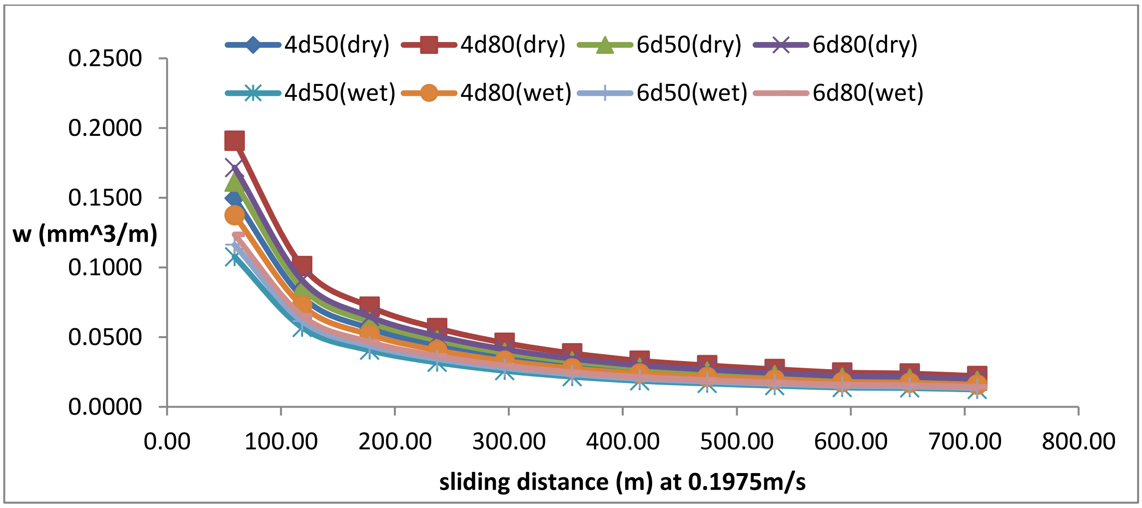

Figure 4.6: Effect of rate of wear on Bronze Pin at sliding velocity of 0.1975 m/s

The rate of wear was more higher in Bronze diameter 4mm pin "4d8(dry)" with 0.0702 mm^3/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 177.75m covered at 900s and under the same condition the rate of wear was lower to 0.0406 mm^3/m by Bronze diameter 4mm pin "4d5(wet)". This showed that the reduction of applied force to 5N on same diameter pin with lubricated surface will reduce rate of wear to 43.61 % under same speed. The comparison of rate of wear of 4d8(dry) by both sliding speed of 0.158m/s in Figure 4.4 and 0.1975 in Figure 4.5 it was understood that rate of wear reduce to 15.39 % as result of increase in speed of the pin.

4.3.2 Specific rate of wear

Figure 4.6 illustrates Bronze diameter 6mm pin "6d5(wet) specific rate of wear, this pin was selected as a result of lower rate of wear in comparing to other condition considered in section 4.3 above.

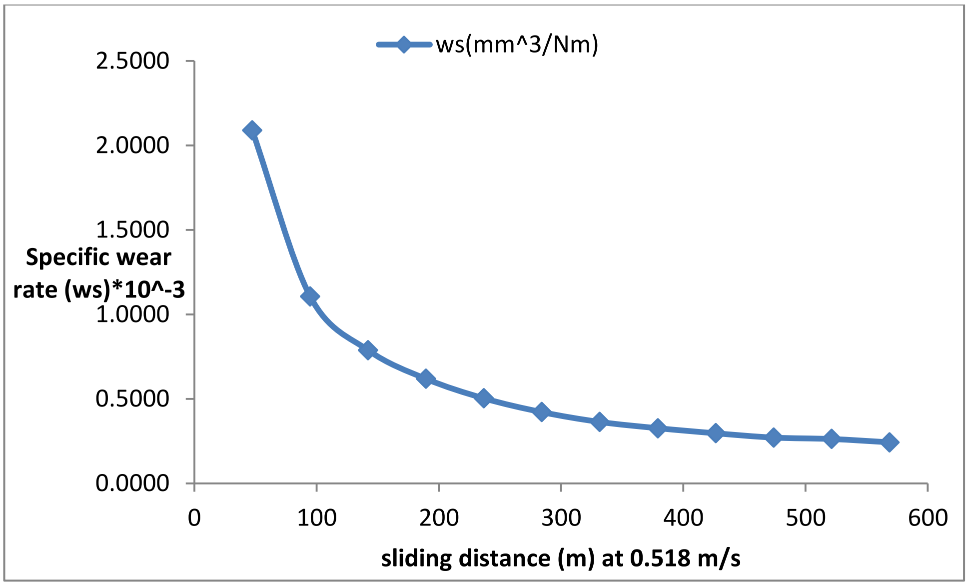

Figure 4.7: Specific rate of wear of Bronze

The specific rate of wear of Bronze diameter 6mm pin with lubricated surface include 2.0887 $\times 10^{-2}$ mm^3/Nm, 0.7878 $\times 10^{-2}$ mm^3/Nm and 0.2428 $\times 10^{-2}$ mm^3/Nm for 47.4m, 142.2m and 568.8m respectively. This means as sliding distance increase with decrease in specific wear of the pin.

4.4 Brass surface Wear Analysis (SWA)

The final experiment was conducted on another pin called brass "a copper alloy". The study considers the same diameter 4mm and 6mm for its wear analysis in both dry and wet surface wear testing analysis. The effects of sliding speed and applied force on the pin were also determined. The testing of applied force 5N on pin diameter 4mm at sliding speed of 0.158m/s is shown in Table 4.49. This shows the average of two dry test of SWA of Brass pin diameter 4mm during the experiment.

Table 4.49: Dry SWA of Brass's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.81	10.1264	0.2136	4.6808	4.2727
600	94.8	0.85	10.7260	0.1131	8.8384	2.2629
900	142.2	0.91	11.4588	0.0806	12.4097	1.6116
1200	189.6	0.95	11.9918	0.0632	15.8108	1.2650
1500	237	0.97	12.1916	0.0514	19.4395	1.0288
1800	284.4	0.98	12.2583	0.0431	23.2007	0.8620
2100	331.8	0.98	12.3249	0.0371	26.9211	0.7429
2400	379.2	1.01	12.6580	0.0334	29.9574	0.6676
2700	426.6	1.03	12.9245	0.0303	33.0071	0.6059
3000	474	1.04	13.1243	0.0277	36.1161	0.5538
3300	521.4	1.11	13.9904	0.0268	37.2684	0.5366
3600	568.8	1.12	14.1237	0.0248	40.2729	0.4966

Table 4.49 showed that 4mm diameter of Brass subjected to 0.158 m/s had volume loss of 11.4588 mm^3, rate of wear of 0.0806 mm^3/m, resistance of wear rate of 12.4097 m/mm^3 and specific rate of wear of 1.6116×10^{-2} mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 14.1237 mm^3, rate of wear of 0.0248 mm^3/m, resistance of wear rate of 40.2729 m/mm^3 and specific rate of wear of 0.4966×10^{-2} mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.38% after 3600s.

Table 4.50 shows the average of two dry test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.50: Dry SWA of Brass Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.93	11.7466	0.1983	5.0440	3.9651
600	118.5	0.99	12.4421	0.1050	9.5241	2.0999
900	177.75	1.06	13.2922	0.0748	13.3725	1.4956
1200	237	1.11	13.9105	0.0587	17.0375	1.1739
1500	296.25	1.13	14.1423	0.0477	20.9478	0.9548
1800	355.5	1.13	14.2196	0.0400	25.0007	0.8000
2100	414.75	1.14	14.2969	0.0345	29.0099	0.6894
2400	474	1.17	14.6833	0.0310	32.2816	0.6195
2700	533.25	1.19	14.9924	0.0281	35.5680	0.5623
3000	592.5	1.21	15.2242	0.0257	38.9182	0.5139
3300	651.75	1.29	16.2289	0.0249	40.1599	0.4980
3600	711	1.30	16.3834	0.0230	43.3975	0.4609

Table 4.50 showed that 4mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 13.2922 mm^3. The rate of wear was 0.0748 mm^3/mm, resistance of wear rate was 13.3725 mm/mm^3 and specific rate of wear was $1.4956 \times 10^{-2} mm^3/Nm$ after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 16.3834mm^3, rate of wear of 0.0230 mm^3/m, resistance of wear rate of 43.3975m/mm^3 and specific rate of wear of $0.4609 \times 10^{-2} mm^3/Nm$ and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.4% after 3600s.

The average of two dry test of SWA of Brass pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.51.

Table 4.51: Dry SWA of Brass's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	1.13	14.1769	0.2991	3.3435	3.7386
600	94.8	1.19	15.0164	0.1584	6.3131	1.9800
900	142.2	1.28	16.0423	0.1128	8.8640	1.4102
1200	189.6	1.34	16.7885	0.0885	11.2935	1.1068
1500	237	1.36	17.0683	0.0720	13.8854	0.9002
1800	284.4	1.37	17.1616	0.0603	16.5719	0.7543
2100	331.8	1.37	17.2548	0.0520	19.2294	0.6500
2400	379.2	1.41	17.7212	0.0467	21.3981	0.5842
2700	426.6	1.44	18.0943	0.0424	23.5765	0.5302
3000	474	1.46	18.3741	0.0388	25.7972	0.4845
3300	521.4	1.56	19.5866	0.0376	26.6203	0.4696
3600	568.8	1.57	19.7731	0.0348	28.7663	0.4345

Table 4.51 illustrated Brass pin diameter 6mm diameter that was subjected to 0.158 m/s under applied force of 8N. The volume loss was 16.0423mm^3, rate of wear was 0.1128mm^3/m, resistance of wear rate was 8.8640 m/mm^3 and specific rate of wear was 1.4102 $\times 10^{-2}$ mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 19.7731 mm^3, rate of wear of 0.0348 mm^3/m, resistance of wear rate of 28.7663m/mm^3 and specific rate of wear of 0.4345$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 88.39% after 3600s.

The average of two dry test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.52.

Table 4.52: Dry SWA of Brass's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	1.19	14.9871	0.2529	3.9534	3.1618
600	118.5	1.26	15.8745	0.1340	7.4648	1.6745
900	177.75	1.35	16.9590	0.0954	10.4811	1.1926
1200	237	1.41	17.7478	0.0749	13.3537	0.9361
1500	296.25	1.44	18.0436	0.0609	16.4185	0.7613
1800	355.5	1.44	18.1422	0.0510	19.5952	0.6379
2100	414.75	1.45	18.2408	0.0440	22.7375	0.5498
2400	474	1.49	18.7338	0.0395	25.3018	0.4940
2700	533.25	1.52	19.1282	0.0359	27.8777	0.4484
3000	592.5	1.55	19.4240	0.0328	30.5035	0.4098
3300	651.75	1.65	20.7058	0.0318	31.4767	0.3971
3600	711	1.66	20.9030	0.0294	34.0142	0.3675

Brass pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.52 that volume loss was 16.9590mm^3. The rate of wear was 0.0954 mm^3/mm, resistance of wear rate was 10.4811 mm/mm^3 and specific rate of wear was 1.1926×10^{-2} mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 20.903 mm^3, rate of wear of 0.0294mm^3/m, resistance of wear rate of 34.0142 m/mm^3 and specific rate of wear of $0.3675\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Brass reduced to 89.56%. The same experiment was carried out for 6mm diameter to determine dry surface wear analysis of required parameters.

Table 4.53 shows the average of two dry test of SWA of Brass pin diameter 4mm during the experiment.

Table 4.53: Dry SWA of Brass`s Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	1.14	14.3275	0.3023	3.3079	3.023
600	94.8	1.19	14.9559	0.1578	6.3371	1.578
900	142.2	1.29	16.2127	0.1140	8.7719	1.140
1200	189.6	1.35	16.9668	0.0895	11.1732	0. 895
1500	237	1.37	17.2182	0.0727	13.7552	0.727
1800	284.4	1.38	17.3438	0.0609	16.4204	0.609
2100	331.8	1.39	17.4695	0.0527	18.9753	0.527
2400	379.2	1.42	17.8466	0.0471	21.2314	0.471
2700	426.6	1.45	18.2236	0.0427	23.4192	0.427
3000	474	1.46	18.3493	0.0387	25.8398	0.387
3300	521.4	1.57	19.7318	0.0378	26.4550	0.378
3600	568.8	1.57	19.7318	0.0347	28.1884	0.347

Table 4.53 showed that 4mm diameter of Brass subjected to 0.158 m/s had volume loss of 16.2127mm^3, rate of wear of 0.1140mm^3/m, resistance of wear rate of 8.7719m/mm^3 and specific rate of wear of 1.140$\times 10^{-2}$$mm^3/Nm$ after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 19.7318mm^3, rate of wear of 0.0347mm^3/m, resistance of wear rate of 28.1884m/mm^3 and specific rate of wear of 0.347$\times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 10N. It is

indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.79% after 3600s.

Table 4.54 shows the average of two dry test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.54: Dry SWA of Brass Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	1.20	15.0816	0.2545	3.9293	2.545
600	118.5	1.26	15.8357	0.1336	7.4850	1.336
900	177.75	1.36	17.0925	0.0962	10.3950	0.962
1200	237	1.42	17.8466	0.0753	13.2802	0.753
1500	296.25	1.45	18.2236	0.0613	16.3132	0.613
1800	355.5	1.45	18.2236	0.0513	19.4932	0.513
2100	414.75	1.46	18.3493	0.0442	22.6244	0.442
2400	474	1.50	18.8520	0.0398	25.1256	0.398
2700	533.25	1.53	19.2291	0.0361	27.7008	0.361
3000	592.5	1.56	19.6061	0.0331	30.2115	0.331
3300	651.75	1.66	20.8629	0.0320	31.2500	0.320
3600	711	1.67	20.9886	0.0295	33.8983	0.295

Table 4.54 showed that 4mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 17.0925mm^3. The rate of wear was 0.0962mm^3/mm, resistance of wear rate was 10.3950mm/mm^3 and specific rate of wear was $0.962\times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 20.9886mm^3, rate of wear of 0.0295mm^3/m, resistance of wear rate of 33.8983m/mm^3 and specific rate of wear of $0.295 \times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.24% after

3600s. The same experiment was carried out for 6mm diameter to determine dry surface wear analysis of required parameters.

Table 4.55 shows the dry SWA of dry SWA of Brass's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.55: Dry SWA of Brass's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	47.4	0.32	9.1097	0.1922	5.2032	3.8438
600	94.8	0.34	9.6491	0.1018	9.8247	2.0357
900	142.2	0.36	10.3084	0.0725	13.7946	1.4498
1200	189.6	0.38	10.7878	0.0569	17.5754	1.1380
1500	237	0.39	10.9676	0.0463	21.6090	0.9255
1800	284.4	0.39	11.0276	0.0388	25.7899	0.7755
2100	331.8	0.39	11.0875	0.0334	29.9256	0.6683
2400	379.2	0.40	11.3872	0.0300	33.3007	0.6006
2700	426.6	0.41	11.6269	0.0273	36.6908	0.5451
3000	474	0.42	11.8067	0.0249	40.1468	0.4982
3300	521.4	0.45	12.5858	0.0241	41.4276	0.4828
3600	568.8	0.45	12.7057	0.0223	44.7674	0.4468

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 10.3084 mm^3, rate of wear of 0.0725 mm^3/m, resistance of wear rate of 13.7946 m/mm^3 and specific rate of wear of $1.4498 \times 10^{-2} mm^3/Nm$ in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 12.7057mm^3, rate of wear of 0.0223 mm^3/m, resistance of wear rate of 44.7674 m/mm^3 and specific rate of wear of $0.4468\times 10^{-2} mm^3/Nm$ and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.40% after 3600s.

Table 4.56 shows the average of two dry test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.56: Dry SWA of Brass's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.45	12.6807	0.2140	4.6724	4.2804
600	118.5	0.48	13.4316	0.1133	8.8225	2.2669
900	177.75	0.51	14.3493	0.0807	12.3874	1.6145
1200	237	0.53	15.0167	0.0634	15.7825	1.2672
1500	296.25	0.54	15.2669	0.0515	19.4047	1.0307
1800	355.5	0.54	15.3504	0.0432	23.1591	0.8636
2100	414.75	0.55	15.4338	0.0372	26.8729	0.7442
2400	474	0.56	15.8509	0.0334	29.9036	0.6688
2700	533.25	0.57	16.1846	0.0304	32.9479	0.6070
3000	592.5	0.58	16.4349	0.0277	36.0513	0.5548
3300	651.75	0.62	17.5194	0.0269	37.2015	0.5376
3600	711	0.63	17.6863	0.0249	40.2006	0.4975

Table 4.56 showed that 6mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 14.3493mm^3. The rate of wear was 0.0807mm^3/mm, resistance of wear rate was 12.3874 mm/mm^3 and specific rate of wear was $1.6145 \times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 17.6863mm^3, rate of wear of 0.0249mm^3/m, resistance of wear rate of 40.2006 m/mm^3 and specific rate of wear of 0.4975×10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.41% after 3600s. The average of two dry test of SWA of Brass pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.57.

Table 4.57: Dry SWA of Brass's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.45	12.7536	0.2691	3.7166	3.3633
600	94.8	0.48	13.5088	0.1425	7.0177	1.7812
900	142.2	0.51	14.4317	0.1015	9.8533	1.2686
1200	189.6	0.53	15.1030	0.0797	12.5538	0.9957
1500	237	0.54	15.3547	0.0648	15.4350	0.8098
1800	284.4	0.55	15.4386	0.0543	18.4214	0.6786
2100	331.8	0.55	15.5225	0.0468	21.3754	0.5848
2400	379.2	0.56	15.9420	0.0420	23.7862	0.5255
2700	426.6	0.58	16.2776	0.0382	26.2077	0.4770
3000	474	0.58	16.5294	0.0349	28.6763	0.4359
3300	521.4	0.62	17.6201	0.0338	29.5912	0.4224
3600	568.8	0.63	17.7879	0.0313	31.9767	0.3909

Table 4.57 showed that Aluminium pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 14.4317mm^3, rate of wear was 0.1015 mm^3/m, resistance of wear rate was 9.8533 m/mm^3 and specific rate of wear was $1.2686 \times 10^{-2}$$mm^3/Nm$ after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 17.7879mm^3, rate of wear of 0.0313 mm^3/m, resistance of wear rate of 31.9767 m/mm^3 and specific rate of wear$0.3909 \times 10^{-2}$$mm^3/Nm$ and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 88.37% after 3600s.The average of two dry test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.58.

Table 4.58: Dry SWA of Brass's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.48	13.4824	0.2276	4.3946	2.8444
600	118.5	0.51	14.2807	0.1205	8.2979	1.5064
900	177.75	0.54	15.2564	0.0858	11.6509	1.0729
1200	237	0.56	15.9660	0.0674	14.8441	0.8421
1500	296.25	0.57	16.2321	0.0548	18.2509	0.6849
1800	355.5	0.58	16.3208	0.0459	21.7820	0.5739
2100	414.75	0.58	16.4095	0.0396	25.2750	0.4946
2400	474	0.60	16.8530	0.0356	28.1256	0.4444
2700	533.25	0.61	17.2078	0.0323	30.9889	0.4034
3000	592.5	0.62	17.4739	0.0295	33.9077	0.3686
3300	651.75	0.66	18.6270	0.0286	34.9896	0.3572
3600	711	0.67	18.8044	0.0264	37.8103	0.3306

Brass pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.58, volume loss was 15.2564 mm^3. The rate of wear was 0.0858 mm^3/mm, resistance of wear rate was 11.6509 mm/mm^3 and specific rate of wear was $1.0729 \times 10^{-2} mm^3/Nm$, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 18.8044mm^3, rate of wear of 0.0264 mm^3/m, resistance of wear rate of 37.8103 m/mm^3 and specific rate of wear of $0.3306 \times 10^{-2} mm^3/Nm$ and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Brass reduced to 88.40 %.

Table 4.59 shows the average of two dry test of SWA of Brass pin diameter 6mm during the experiment.

Table 4.59: Dry SWA of Brass Diameter 6mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.46	13.0079	0.2744	3.6443	2.744
600	94.8	0.49	13.8562	0.1462	6.8399	1.462
900	142.2	0.52	14.7046	0.1034	9.6712	1.034
1200	189.6	0.54	15.2701	0.0805	12.6224	0.805
1500	237	0.56	15.8357	0.0668	14.9701	0.668
1800	284.4	0.56	15.8357	0.0557	17.9533	0.557
2100	331.8	0.57	16.1185	0.0486	20.5761	0.486
2400	379.2	0.57	16.1185	0.0425	23.5294	0.425
2700	426.6	0.59	16.6840	0.0391	25.5754	0.391
3000	474	0.59	16.6840	0.0352	28.4091	0.352
3300	521.4	0.63	17.8151	0.0342	29.2398	0.342
3600	568.8	0.64	18.0979	0.0318	36.4465	0.318

Table 4.59 showed that 4mm diameter of Brass subjected to 0.158 m/s had volume loss of 14.7046mm^3, rate of wear of 0.1034mm^3/m, resistance of wear rate of 9.6712m/mm^3 and specific rate of wear of 1.034×10^{-2}mm^3/Nm after 900s. The pin has covered a sliding distance of 142.2 m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 18.0979mm^3, rate of wear of 0.0318mm^3/m, resistance of wear rate of 31.4465m/mm^3 and specific rate of wear of 0.318×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 89.78% after

3600s.Table 4.60 shows the average of two dry test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.60: Dry SWA of Brass Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.49	13.8562	0.2339	4.2753	2.339
600	118.5	0.52	14.7046	0.1241	8.0580	1.241
900	177.75	0.55	15.5529	0.0875	11.4286	0.875
1200	237	0.57	16.1185	0.0680	14.7059	0.680
1500	296.25	0.57	16.1185	0.0544	18.3824	0.544
1800	355.5	0.59	16.6840	0.0469	21.3219	0.469
2100	414.75	0.59	16.6840	0.0402	24.8756	0.402
2400	474	0.61	17.2496	0.0364	27.4725	0.364
2700	533.25	0.62	17.5324	0.0329	30.3951	0.329
3000	592.5	0.63	17.8151	0.0301	33.2226	0.301
3300	651.75	0.67	18.9463	0.0291	34.3643	0.291
3600	711	0.67	18.9465	0.0266	37.5939	0.266

Table 4.60 showed that 4mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 15.5529mm^3. The rate of wear was 0.0875mm^3/mm, resistance of wear rate was 11.4286mm/mm^3 and specific rate of wear was $0.875\times 10^{-2}$$mm^3$/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of 3600s (1 hour) the pin volume loss was 18.9465mm^3, rate of wear of 0.0266mm^3/m, resistance of wear rate of 37.5939m/mm^3 and specific rate of wear of $0.266 \times 10^{-2}$$mm^3$/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.41% after

3600s.Table 4.61 is the Brass pin diameter 4mm diameter under wet or lubricated condition at sliding speed of 0.158m/s through applied force of 5N.

Table 4.61: Wet SWA of Brass's Diameter 4mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	47.4	0.57	7.1897	0.1517	6.5927	3.0336
600	94.8	0.61	7.6154	0.0803	12.4484	1.6066
900	142.2	0.65	8.1358	0.0572	17.4784	1.1443
1200	189.6	0.68	8.5142	0.0449	22.2688	0.8981
1500	237	0.69	8.6561	0.0365	27.3796	0.7305
1800	284.4	0.69	8.7034	0.0306	32.6770	0.6121
2100	331.8	0.70	8.7507	0.0264	37.9171	0.5275
2400	379.2	0.71	8.9872	0.0237	42.1935	0.4740
2700	426.6	0.73	9.1764	0.0215	46.4889	0.4302
3000	474	0.74	9.3183	0.0197	50.8678	0.3932
3300	521.4	0.79	9.9332	0.0191	52.4907	0.3810
3600	568.8	0.80	10.0278	0.0176	56.7224	0.3526

Table 4.61 showed that 4mm diameter of Brass subjected to 0.158 m/s had volume loss of 8.1358 mm^3, rate of wear of 0.0572mm^3/m, resistance of wear rate of 17.4784 m/mm^3 and specific rate of wear of $1.1443 \times 10^{-2}$$mm^3/Nm$ after 900s. The pin has

covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 10.0278mm^3, rate of wear of 0.0176mm^3/m, resistance of wear rate of 56.7224m/mm^3 and specific rate of wear of 0.3526×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.40% after 3600s. Table 4.62 shows the average of two wet test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s.

Table 4.62: Wet SWA of Brass's Diameter 4mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.66	8.3401	0.1408	7.1042	2.8152
600	118.5	0.70	8.8339	0.0745	13.4142	1.4910
900	177.75	0.75	9.4375	0.0531	18.8345	1.0619
1200	237	0.79	9.8764	0.0417	23.9965	0.8335
1500	296.25	0.80	10.0410	0.0339	29.5039	0.6779
1800	355.5	0.80	10.0959	0.0284	35.2123	0.5680
2100	414.75	0.81	10.1508	0.0245	40.8589	0.4895
2400	474	0.83	10.4251	0.0220	45.4671	0.4399
2700	533.25	0.85	10.6446	0.0200	50.0958	0.3992
3000	592.5	0.86	10.8092	0.0182	54.8144	0.3649
3300	651.75	0.92	11.5225	0.0177	56.5632	0.3536
3600	711	0.93	11.6322	0.0164	61.1232	0.3272

Table 4.62 showed that 4mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 9.4375mm^3. The rate of wear was 0.0531 mm^3/mm, resistance of wear rate was 18.8345 mm/mm^3 and specific rate of wear was 1.0619×10^{-2}mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 11.6322 mm^3, rate of wear of 0.0164mm^3/m,

resistance of wear rate of 61.1232 m/mm^3 and specific rate of wear of 0.3272×10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.07 % after 3600s. The average of two wet test of SWA of Brass pin diameter 4mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.63.

Table 4.63: Wet SWA of Brass's Diameter 4mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.80	10.0656	0.2124	4.7091	2.6544
600	94.8	0.85	10.6616	0.1125	8.8917	1.4058
900	142.2	0.91	11.3901	0.0801	12.4846	1.0012
1200	189.6	0.95	11.9198	0.0629	15.9063	0.7859
1500	237	0.96	12.1185	0.0511	19.5569	0.6392
1800	284.4	0.97	12.1847	0.0428	23.3407	0.5355
2100	331.8	0.97	12.2509	0.0369	27.0836	0.4615
2400	379.2	1.00	12.5820	0.0332	30.1382	0.4148
2700	426.6	1.02	12.8469	0.0301	33.2064	0.3764
3000	474	1.04	13.0456	0.0275	36.3341	0.3440
3300	521.4	1.11	13.9065	0.0267	37.4933	0.3334
3600	568.8	1.12	14.0389	0.0247	40.5160	0.3085

Table 4.63 indicated that Brass pin diameter 6mm diameter was used and it is being subjected to 0.158 m/s under applied force of 8N. The volume loss was 11.3901 mm^3, rate of wear was 0.0801mm^3/m, resistance of wear rate was 12.4846 m/mm^3 and specific rate of wear was 1.0012×10^{-3}mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 14.0389mm^3, rate of wear of 0.0247mm^3/m, resistance of wear rate of 40.5160 m/mm^3 and specific rate of wear of 0.3085×10^{-2}mm^3/Nm and with sliding distance of 568.8m

under applied force of 8N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 88.37% after 3600s. The average of two wet test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.64.

Table 4.64: Wet SWA of Brass's Diameter 4mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/mm^3	mm^3/Nm
300	59.25	0.85	10.6408	0.1796	5.5682	2.2449
600	118.5	0.90	11.2709	0.0951	10.5138	1.1889
900	177.75	0.96	12.0409	0.0677	14.7622	0.8468
1200	237	1.00	12.6010	0.0532	18.8081	0.6646
1500	296.25	1.02	12.8110	0.0432	23.1247	0.5405
1800	355.5	1.02	12.8810	0.0362	27.5988	0.4529
2100	414.75	1.03	12.9510	0.0312	32.0246	0.3903
2400	474	1.06	13.3010	0.0281	35.6364	0.3508
2700	533.25	1.08	13.5810	0.0255	39.2643	0.3184
3000	592.5	1.10	13.7911	0.0233	42.9626	0.2910
3300	651.75	1.17	14.7011	0.0226	44.3333	0.2820
3600	711	1.18	14.8411	0.0209	47.9074	0.2609

Brass pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.64 that volume loss was

12.0409mm^3. The rate of wear was 0.0677 mm^3/mm, resistance of wear rate was 14.7622mm/mm^3 and specific rate of wear was 0.8468×10^{-2} mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 14.8411mm^3, rate of wear of 0.0209mm^3/m, resistance of wear rate of 47.9074m/mm^3 and specific rate of wear of 0.2609×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Brass reduced to 88.36%. The average of two wet test of SWA of Brass pin diameter 4mm at sliding speed of 0.158m/s under applied force of 10N is shown in Table 4.65.

Table 4.65: Wet SWA of Brass's Diameter 4mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.81	10.1800	0.2148	4.6555	2.148
600	94.8	0.86	10.8085	0.1140	8.7719	1.140
900	142.2	0.92	11.5626	0.0813	12.3001	0.813
1200	189.6	0.96	12.0623	0.0636	15.7232	0.636
1500	237	0.97	12.1907	0.0514	19.4553	0.514
1800	284.4	0.98	12.3166	0.0433	23.0947	0.433
2100	331.8	0.99	12.4423	0.0375	26,6667	0.375
2400	379.2	1.01	12.6937	0.0335	29.8507	0.335
2700	426.6	1.02	12.8194	0.0301	33.2226	0.301
3000	474	1.05	13.1964	0.0278	35.9712	0.278
3300	521.4	1.12	14.0762	0.0269	37.1747	0.269
3600	568.8	1.13	14.2018	0.0249	40.1606	0.249

Table 4.65 indicated that Brass pin diameter 6mm diameter was used and it is being subjected to 0.158 m/s under applied force of 10N. The volume loss was 11.5626 mm^3, rate of wear was 0.0813mm^3/m, resistance of wear rate was 12.3001 m/mm^3 and

specific rate of wear was 0.813$\times 10^{-3}$mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 14.2018mm^3, rate of wear of 0.0249mm^3/m, resistance of wear rate of 40.1606 m/mm^3 and specific rate of wear of 0.249$\times 10^{-2}$mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 90.37% after 3600s. The average of two wet test of SWA of Brass pin diameter 4mm at sliding speed of 0.1975m/s under applied force of 10N is shown in Table 4.66.

Table 4.66: Wet SWA of Brass's Diameter 4mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.86	10.8085	0.1824	5.4825	1.824
600	118.5	0.91	11.4369	0.0965	10.3627	0.965
900	177.75	0.96	12.0653	0.0679	14.7275	0.679
1200	237	1.01	12.6937	0.0536	18.6567	0.516
1500	296.25	1.02	12.8194	0.0433	23.0947	0.433
1800	355.5	1.03	12.9450	0.0364	27.4725	0.364
2100	414.75	1.05	13.1964	0.0318	31.4465	0.318
2400	474	1.07	13.4478	0.0284	35.2113	0.284
2700	533.25	1.08	13.5734	0.0255	39.2157	0.255
3000	592.5	1.11	13.9505	0.0235	42.5532	0.235
3300	651.75	1.19	14.9559	0.0229	43.6681	0.229
3600	711	1.19	14.9559	0.0210	47.6190	0.210

Brass pin 4mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed in Table 4.66 that volume loss was 12.0653mm^3. The rate of wear was 0.0679 mm^3/mm, resistance of wear rate was 14.7275mm/mm^3 and specific rate of wear was 0.679 $\times 10^{-2}$mm^3/Nm, sliding distance was 177.75m, applied force was 10N after this time frame. On experimental period of 3600s (1 hour) the pin volume loss was 14.9559mm^3, rate of wear of 0.0210mm^3/m, resistance of wear rate of 47.6190m/mm^3 and specific rate of wear of 0.210×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 10N. This showed that on 3600s the pin rate of wear of Brass reduced to 89.66%. Table 4.67 shows wet SWA of Brass's diameter 6mm at 0.158m/s under applied force of 5N.

Table 4.67: Wet SWA of Brass's Diameter 6mm at 0.158m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.23	6.4679	0.1365	7.3285	2.7291
600	94.8	0.24	6.8509	0.0723	13.8377	1.4453
900	142.2	0.26	7.3189	0.0515	19.4290	1.0294
1200	189.6	0.27	7.6594	0.0404	24.7540	0.8079
1500	237	0.28	7.7870	0.0329	30.4353	0.6571
1800	284.4	0.28	7.8296	0.0275	36.3238	0.5506
2100	331.8	0.28	7.8721	0.0237	42.1487	0.4745
2400	379.2	0.29	8.0849	0.0213	46.9024	0.4264
2700	426.6	0.29	8.2551	0.0194	51.6772	0.3870
3000	474	0.30	8.3827	0.0177	56.5447	0.3537
3300	521.4	0.32	8.9359	0.0171	58.3488	0.3428
3600	568.8	0.32	9.0210	0.0159	63.0527	0.3172

The pin diameter 6mm at sliding speed of 0.158 m/s experience volume loss of 7.3189 mm^3, rate of wear of 0.0515 mm^3/m, resistance of wear rate of 19.4290 m/mm^3 and specific rate of wear of 1.0294×10^{-2}mm^3/Nm in 900s. The pin has covered a sliding distance of 142.2 m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 9.021 mm^3, rate of wear of 0.0159mm^3/m, resistance of wear rate of 63.0527 m/mm^3 and specific rate of wear of 0.3172×10^{-2}mm^3/Nm and with sliding distance of 568.8m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.35% after 3600s. Table 4.68 shows the average of two wet test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.68: Wet SWA of Brass's Diameter 6mm at 0.1975m/s (5N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	$m/\ mm^3$	mm^3/Nm
300	59.25	0.32	9.0033	0.1520	6.5809	3.0391
600	118.5	0.34	9.5364	0.0805	12.4261	1.6095
900	177.75	0.36	10.1880	0.0573	17.4470	1.1463
1200	237	0.38	10.6618	0.0450	22.2288	0.8997
1500	296.25	0.38	10.8395	0.0366	27.3305	0.7318
1800	355.5	0.39	10.8988	0.0307	32.6184	0.6132
2100	414.75	0.39	10.9580	0.0264	37.8491	0.5284
2400	474	0.40	11.2542	0.0237	42.1178	0.4749
2700	533.25	0.41	11.4911	0.0215	46.4055	0.4310
3000	592.5	0.41	11.6688	0.0197	50.7765	0.3939
3300	651.75	0.44	12.4388	0.0191	52.3965	0.3817
3600	711	0.44	12.5573	0.0177	56.6206	0.3532

Table 4.68 showed that 6mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 10.1880 mm^3. The rate of wear was 0.0573mm^3/mm, resistance of wear rate was 17.4470mm/mm^3 and specific rate of wear was 1.1463×10^{-2} mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 5N. After experimental period of 3600s (1 hour) the pin volume loss was 12.5573mm^3, rate of wear of 0.0177mm^3/m, resistance of wear rate of 56.6206 m/mm^3 and specific rate of wear of 0.3532 $\times$

10^{-2} mm^3/Nm and with sliding distance of 711m under applied force of 5N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 86.36% after 3600s.

The average of two wet test of SWA of Brass pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.69.

Table 4.69: Wet SWA of Brass's Diameter 6mm at 0.158m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.32	9.0551	0.1910	5.2346	2.3879
600	94.8	0.34	9.5912	0.1012	9.8840	1.2647
900	142.2	0.36	10.2465	0.0721	13.8779	0.9007
1200	189.6	0.38	10.7231	0.0566	17.6814	0.7070
1500	237	0.39	10.9018	0.0460	21.7395	0.5750
1800	284.4	0.39	10.9614	0.0385	25.9456	0.4818
2100	331.8	0.39	11.0210	0.0332	30.1062	0.4152
2400	379.2	0.40	11.3188	0.0298	33.5017	0.3731
2700	426.6	0.41	11.5571	0.0271	36.9123	0.3386
3000	474	0.42	11.7358	0.0248	40.3891	0.3095
3300	521.4	0.44	12.5103	0.0240	41.6777	0.2999
3600	568.8	0.45	12.6294	0.0222	45.0376	0.2775

Table 4.69 showed that Brass pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 8N. The volume loss was 10.2465 mm^3, rate of wear was 0.0721 mm^3/m, resistance of wear rate was 13.8779 m/mm^3 and specific rate of wear was 0.9007 $\times 10^{-3}$mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 12.6294 mm^3, rate of

wear of 0.0222mm^3/m, resistance of wear rate of 45.0376 m/mm^3 and specific rate of wear of 0.2775$\times 10^{-3}$mm^3/Nm and with sliding distance of 568.8m under applied force of 8N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 88.38% after 3600s. The average of two wet test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s under applied force of 8N is shown in Table 4.70.

Table 4.70: Wet SWA of Brass's Diameter 6mm at 0.1975m/s (8N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.34	9.5725	0.1616	6.1896	2.0195
600	118.5	0.36	10.1393	0.0856	11.6872	1.0695
900	177.75	0.38	10.8320	0.0609	16.4097	0.7617
1200	237	0.40	11.3359	0.0478	20.9071	0.5979
1500	296.25	0.41	11.5248	0.0389	25.7055	0.4863
1800	355.5	0.41	11.5878	0.0326	30.6789	0.4074
2100	414.75	0.41	11.6507	0.0281	35.5986	0.3511
2400	474	0.42	11.9656	0.0252	39.6135	0.3155
2700	533.25	0.43	12.2175	0.0229	43.6463	0.2864
3000	592.5	0.44	12.4065	0.0209	47.7574	0.2617
3300	651.75	0.47	13.2252	0.0203	49.2811	0.2536
3600	711	0.47	13.3511	0.0188	53.2540	0.2347

Brass pin 6mm diameter is subjected to wear surface analysis at sliding speed of 0.1975 m/s and after 900s, the analysis showed that in Table 4.70, volume loss was 10.8320 mm^3. The rate of wear was 0.0609 mm^3/mm, resistance of wear rate was 16.4097 mm/mm^3 and specific rate of wear was 0.7617$\times 10^{-3}$mm^3/Nm, sliding distance was 177.75m, applied force was 8N after this time frame. On experimental period of 3600s

(1 hour) the pin volume loss was 13.3511mm^3, rate of wear of 0.0188 mm^3/m, resistance of wear rate of 53.2540m/mm^3 and specific rate of wear of 0.2347 × 10^{-3} mm^3/Nm and with sliding distance of 711m under applied force of 8N. This showed that on 3600s the pin rate of wear of Brass reduced to 88.37%. The average of two wet test of SWA of Brass pin diameter 6mm at sliding speed of 0.158m/s under applied force of 8N is shown in Table 4.71.

Table 4.71: Wet SWA of Brass's Diameter 6mm at 0.158m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	47.4	0.33	9.3317	0.1969	5.0787	1.969
600	94.8	0.34	9.6145	0.1014	9.8619	1.014
900	142.2	0.36	10.1801	0.0716	13.9664	0.716
1200	189.6	0.39	11.0284	0.0582	17.1821	0.582
1500	237	0.40	11.3112	0.0477	20.9644	0.477
1800	284.4	0.41	11.5940	0.0398	25.1256	0.398
2100	331.8	0.41	11.5940	0.0349	28.6532	0.349
2400	379.2	0.42	11.8768	0.0313	31.9489	0.313
2700	426.6	0.43	12.1595	0.0285	35.0877	0.285
3000	474	0.44	12.4423	0.0262	38.1679	0.262
3300	521.4	0.44	12.4423	0.0239	41.8410	0.239
3600	568.8	0.45	12.7251	0.0224	44.6429	0.224

Table 4.71 showed that Brass pin diameter 6mm diameter was used and it was subjected to 0.158 m/s under applied force of 10N. The volume loss was 10.1801 mm^3, rate of wear was 0.0716 mm^3/m, resistance of wear rate was 13.9664 m/mm^3 and specific rate of wear was 0.716 × 10^{-3}mm^3/Nm after 900s with a sliding distance of 142.2 m. After experimental period of 3600s (1 hour) the pin volume loss was 12.7251 mm^3, rate of

wear of 0.0224mm^3/m, resistance of wear rate of 44.6429 m/mm^3 and specific rate of wear of 0.224$\times 10^{-3}$mm^3/Nm and with sliding distance of 568.8m under applied force of 10N. The surface behaviour of Brass pin's rate of wear(ω) reduced to 89.69% after 3600s. Table 4.72 shows the average of two dry test of SWA of Brass pin diameter 6mm at sliding speed of 0.1975m/s.

Table 4.72: Wet SWA of Brass Diameter 6mm at 0.1975m/s (10N)

t	x_s	h_l	V_l	ω	ω_r	$\omega_s \times 10^{-2}$
(s)	m	mm	mm^3	mm^3/m	m/ mm^3	mm^3/Nm
300	59.25	0.35	9.8973	0.1670	5.9880	1.670
600	118.5	0.36	10.1801	0.0859	11.6414	0.859
900	177.75	0.38	10.7456	0.0605	16.5289	0.605
1200	237	0.42	11.8768	0.0501	19.9601	0.501
1500	296.25	0.42	11.8768	0.0401	24.9377	0.401
1800	355.5	0.43	12.1595	0.0342	29.2398	0.342
2100	414.75	0.44	12.4423	0.0299	33.4448	0.299
2400	474	0.44	12.4423	0.0262	38.1679	0.262
2700	533.25	0.44	12.4423	0.0233	42.9185	0.233
3000	592.5	0.45	12.7251	0.0215	46.5116	0.215
3300	651.75	0.49	13.8562	0.0213	46.9484	0.213
3600	711	0.49	13.8562	0.0195	51.2821	0.195

Table 4.72 showed that 4mm diameter of Brass pin subjected to 0.1975 m/s had volume loss of 10.7456mm^3. The rate of wear was 0.0605mm^3/mm, resistance of wear rate was 16.5289mm/mm^3 and specific rate of wear was 0.605$\times 10^{-2}$mm^3/Nm after 900s, within sliding distance of 177.75m under applied force of 10N. After experimental period of

3600s (1 hour) the pin volume loss was 13.8562mm^3, rate of wear of 0.0195mm^3/m, resistance of wear rate of 51.2821m/mm^3 and specific rate of wear of 0.195×10^{-2}mm^3/Nm and with sliding distance of 711m under applied force of 10N. It is indicated that surface behaviour of Brass pin's rate of wear(ω) reduced to 88.34% after 3600s.

4.4.1 Effect of Sliding Speed and Applied Force

The constant sliding speed effect is also considered on the Brass pin at varying applied force and varying diameter. Figures 4.7 and 4.8 illustrate the graph of rate of wear (mm^3/m) and sliding distance (m) of Brass pin.

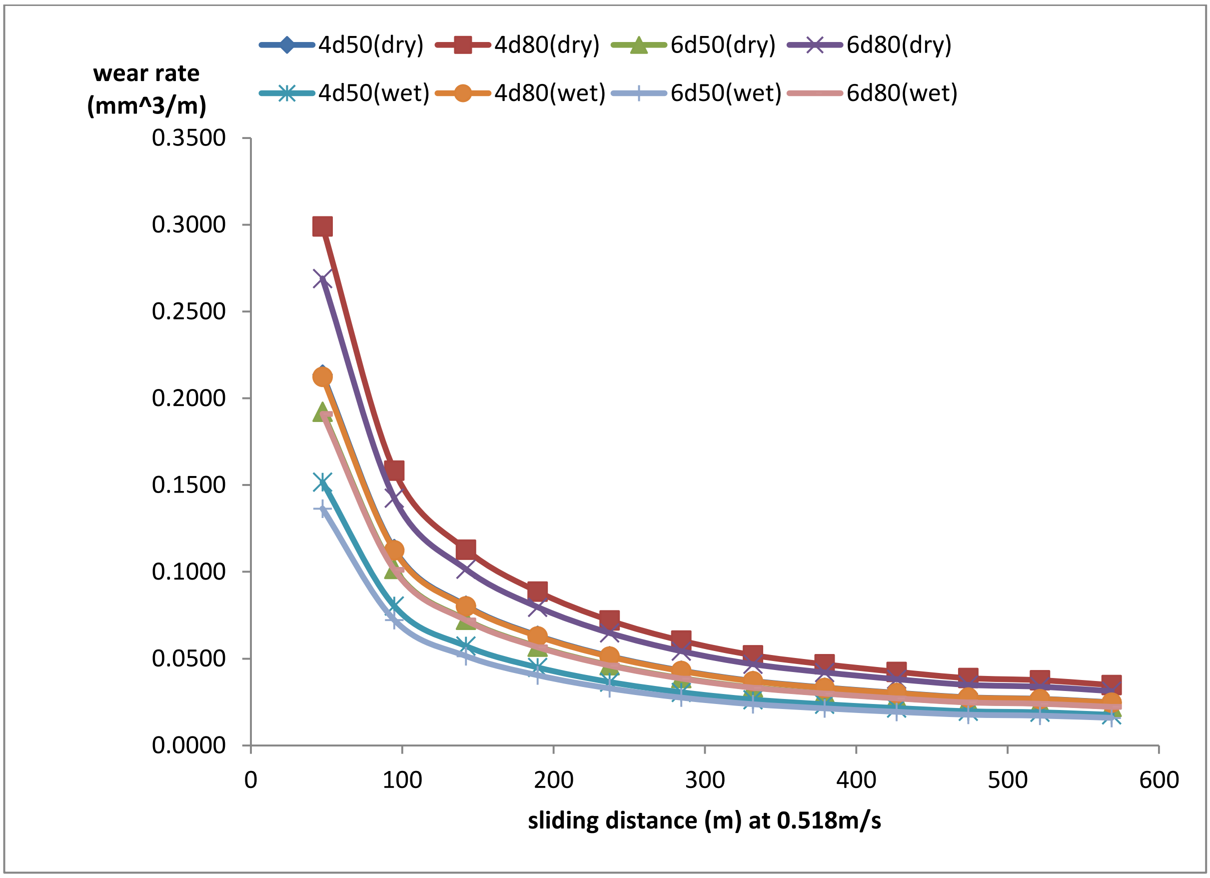

Figure 4.8: Effect of rate of wear on Brass Pin at sliding velocity of 0.158 m/s

Note: NdF(Condition) remain as discussed in section 4.2.1

The graph of Figure 4.7 was in sliding speed of 0.158m/s, the rate of wear was higher in Brass diameter 4mm pin “4d8(dry)” with 0.1128 mm^3/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 142.2m covered at 900s and under the same condition the rate of wear was lower to 0.0515 mm^3/m by Brass diameter 6mm pin “6d5(wet)”. It was understood that increase in pin contact surface area due to increase pin diameter under lesser applied force of 5N and lubricated surface reduces rate of wear to 54.34% condition.

There is instance of Brass diameter 4mm pin “4d5(dry)” under applied force of 5N without lubricating surface at sliding distance of 142.2m at 900s. The rate of wear in this pin was 0.0806 mm^3/m and this reduced to 28.55 % in comparing with 4d8(dry) above. This is a result of reduce force on dry condition. The situation of changing the condition to lubricated surface of 4d8(dry) by 4d8(wet), the rate of wear of 4d8(wet) was 0.0801 mm^3/m. This led to only 28.99% reduction of rate of wear and this means wearing at surface is reduced using lubricating oil and tends to reduce more if with increase in surface contact area. Figure 4.8 shows the effect of rate of wear on brass pin at sliding velocity of 0.1975m/s.

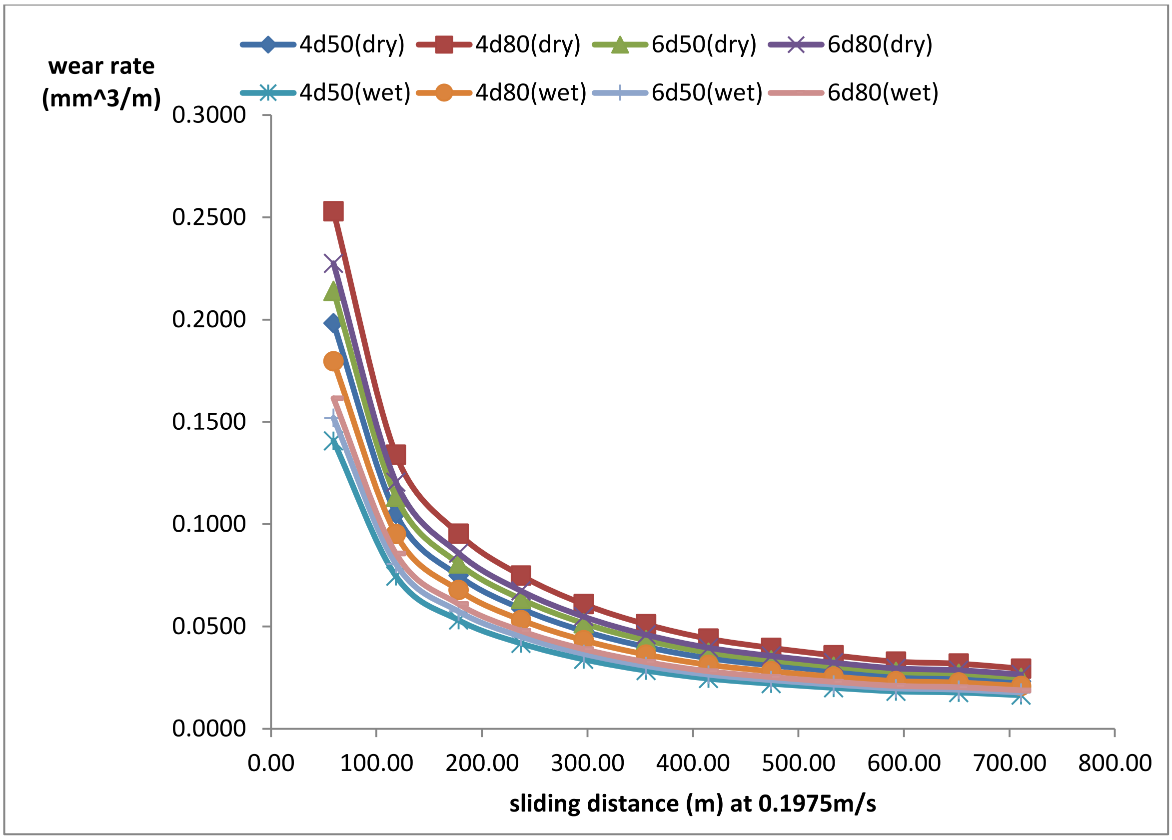

Figure 4.9: Effect of rate of wear on Brass Pin at sliding velocity of 0.1975 m/s

Figure 4.8 on sliding speed of 0.1975m/s, the rate of wear was more higher in Brass diameter 4mm pin "4d8(dry)" with 0.0954 mm^^{3}/m under applied force of 8N without lubricating surface or at dry condition. This occurred at sliding distance of 177.75m covered at 900s and under the same condition the rate of wear was lower to 0.0531 mm^3/m by Brass diameter 4mm pin "4d5(wet)". This showed that the reduction of applied force to 5N on same diameter pin with lubricated surface will reduce rate of wear to 44.34 % under same speed. The comparison of rate of wear of 4d8(dry) by both sliding speed of 0.158m/s in Figure 4.7 and 0.1975 in Figure 4.8 it was understood that rate of wearreduce to 15.43 % as result of increase in speed of the pin.

4.4.2 Specific rate of wear

Figure 4.9 is the Brass diameter 6mm pin “6d5(wet) specific rate of wear, this pin was selected as a result of lower rate of wear in comparing to other condition considered in section 4.4 above.

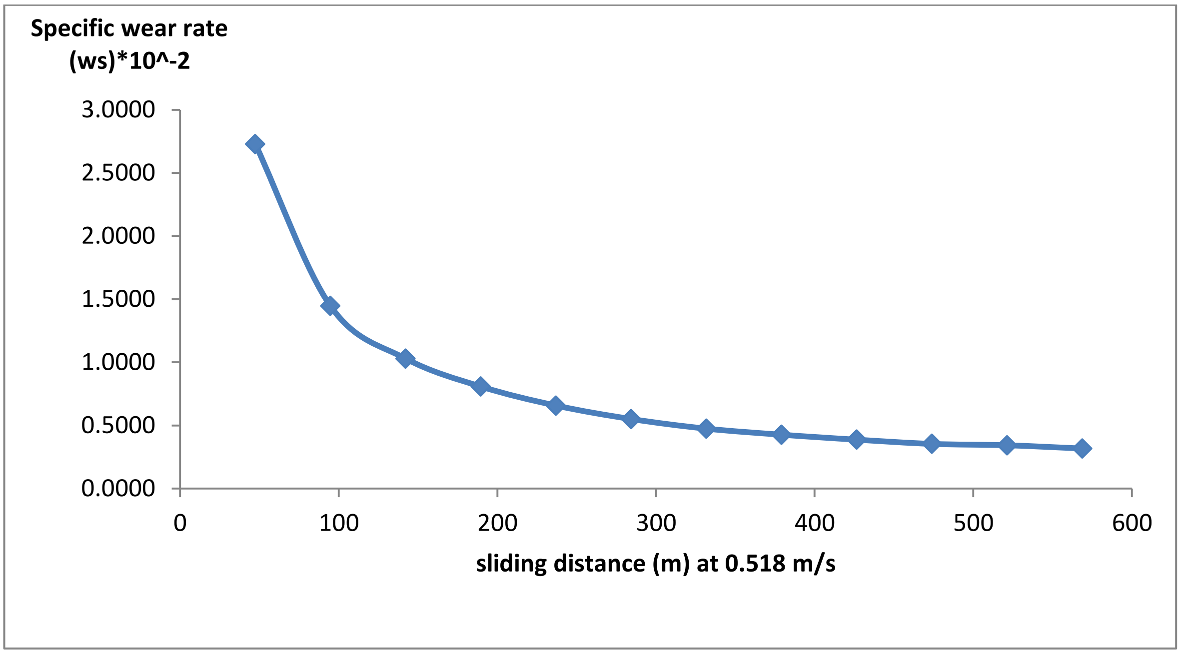

Figure 4.10: Specific rate of wear of Brass

The specific rate of wear of Al-Bronze diameter 6mm pin with lubricated surface at speed 0.518m/s include 2.7291×10^{-2} mm^3/Nm, 1.0294×10^{-2} mm^3/Nm and 0.3172×10^{-2} mm^3/Nm for 47.4m, 142.2m and 568.8m respectively. This means as sliding distance increase with decrease in specific wear of the pin.

4.5 Comparative Analysis of the three Pins

The study considers comparative analysis of Brass diameter 6mm pin “6d5(wet)” at 0.158m/s rate of wear and the result is plotted in Figure 4.10.

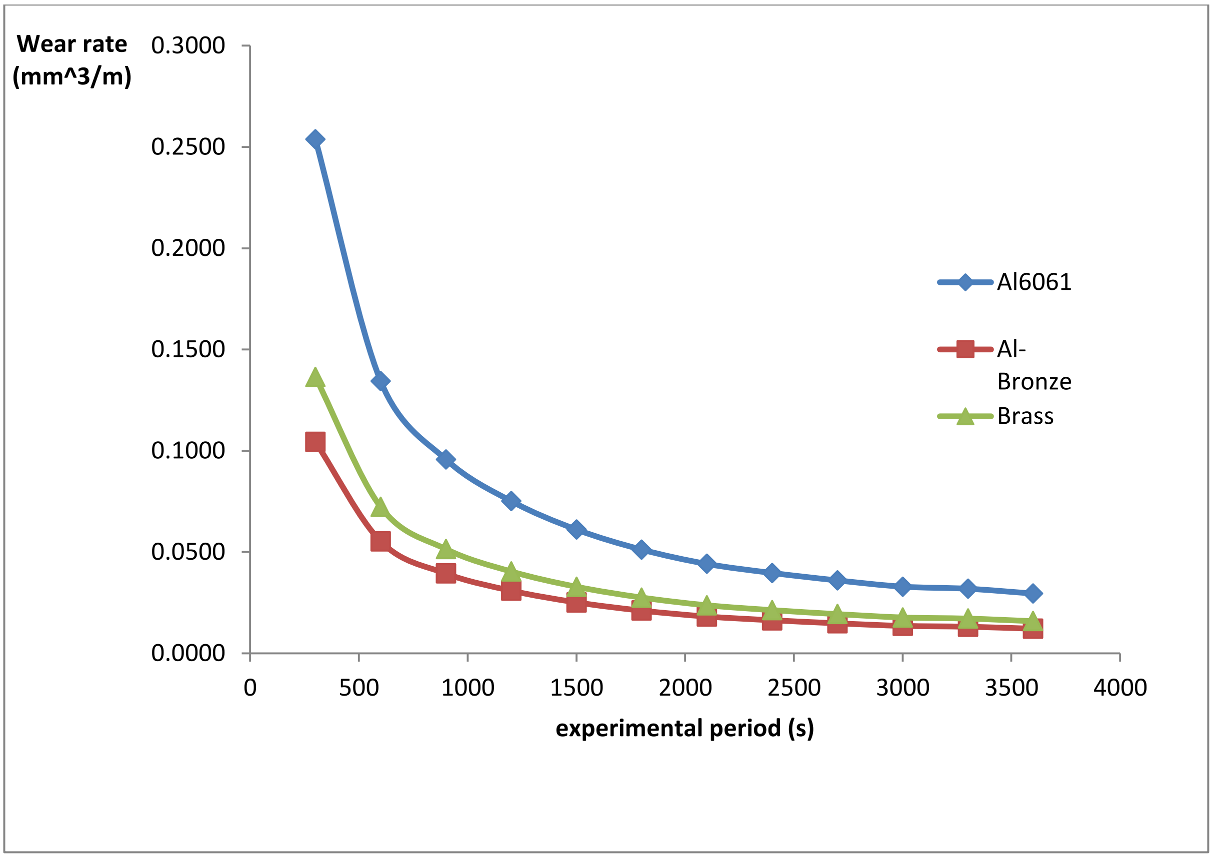

Figure 4.10: Rate of wear of pin 6 diameter under applied force 5N at 0.158m/s

Figure 4.10 showed that wearing experienced after one hour are such as 0.0295 mm^3/m in Aluminium 6061, 0.0120 mm^3/m in Bronze and 0.0159 mm^3/m in Brass after one hour. It was understood this occurred on the pin during lubricated condition when the pin is 6 diameters under applied force 5N and for the three pins, this condition has least of rate of wear.

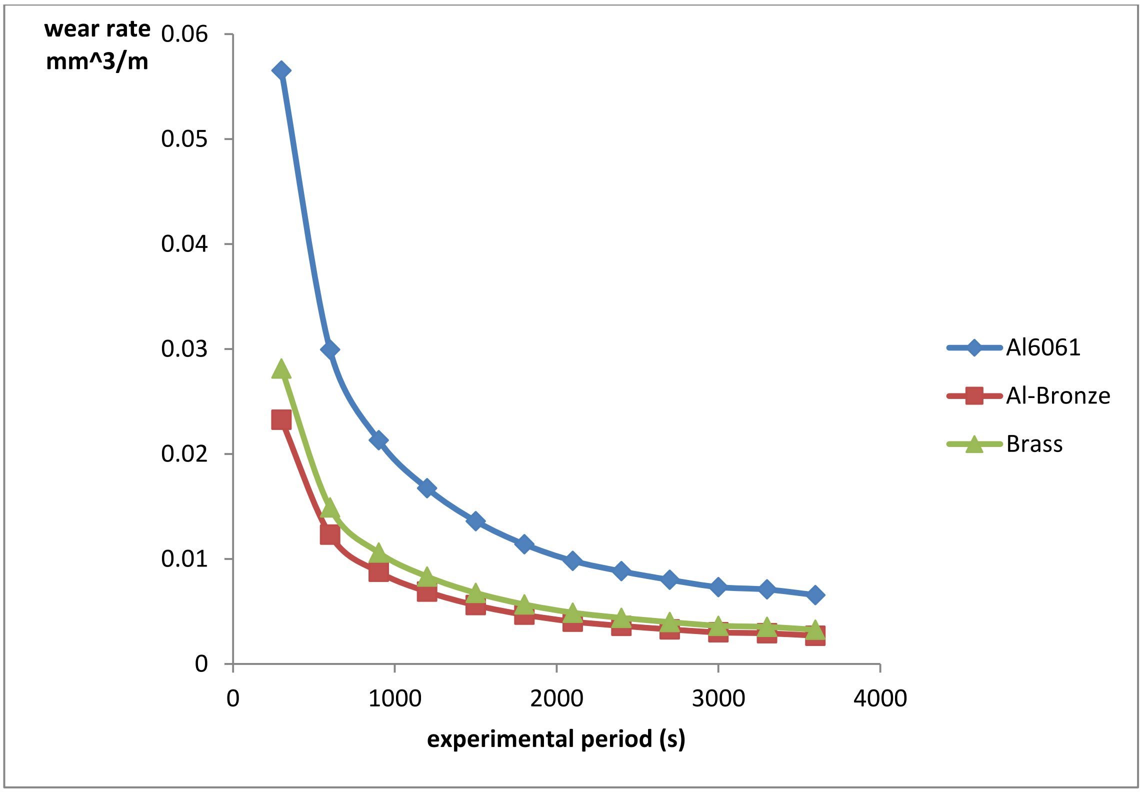

Figure 4.11: Rate of wear of pin 6 diameter under applied force 5N at 0.1975m/s

Bronze has lower rate of wear of 46.10% in comparing to Aluminium 6061 and also Brass has 59.32 % of lower rate of rate of wear using the pin on disc developed by this study. The average wearing rate per seconds for 6 diameter lubricated pin include 20.5$\mu mm^3/ms$, 8.2 $\mu mm^3/ms$ and 11 $\mu mm^3/ms$ for Aluminium 6061, Brass and Bronze respectively in Figure 4.10. Also the same occurred in Figure 4.11 wet pin 6 diameter lubricated under applied force of 5N at sliding speed 0.1975m/s and the result include pin include 0.05653 mm^3/m of Aluminium 6061, 0.02326 mm^3/m of Bronze and 0.02815 mm^3/m of Brass.

4.6 Discussions

The investigated pins underwent different performance testing such as constant sliding speed of 0.158m/s and 0.1975 m/s in which each speed was subjected to two different forces of 5N and 8N respectively. During the experiment the pins were measured with the aid of micro controller and programmed infra sensor (Transmitter and Receiver) mounted on the pin headset cap and monitor the readings through liquid crystal display unit. There are three pins which include Aluminium 6061, Bronze and Brass. The speed was determined from the disc wear track radius of 40mm and 50mm respectively. The angular velocity of the disc was 3.95 rad/s as stated in chapter three. The sliding speed is product of angular velocity and wear track radius which is 40 mm or 50mm, therefore sliding speeds were 0.158m/s and 0.1975 m/s. However, the sliding distance was determined as product of sliding speed and experimental period.

The effect of constant sliding speed on the Aluminium pin at varying applied force and varying diameter as in Figure 4.1 showed that rate of wear at sliding speed of 0.158m/s was 0.2129 mm^3/m. Thisoccurred in Aluminium 6061 diameter 4mm pin under applied force and without lubricating surface. At the same speed, sliding distance of 142.2m, 900s the lowest wearing rate was 0.0957 mm^3/m by Aluminium 6061 diameter 6mm pin under applied force of 5N. It was observed that increase in pin contact surface area, lower applied force and lubricated surface will reduce rate of wear. The same speed, same surface contact area but different condition such as dry or wet will also lead to lower wearing rate in lubricated in comparing to situation of different surface contact area. This situation occurred in Aluminium 6061 pin 4mm diameter under applied force of 8N and without lubricating surface and Aluminium 6061 pin 4mm diameter under applied force of 8N and with lubricating surface. In Figure 4.2, the condition of sliding speed of 0.1975m/s, sliding distance of 175.5, 900s, reducing of applied force and increase speed will reduce wear and such cases occur in Aluminium 6061 pin 4mm diameter under applied force of 8N with dry surfaces and Aluminium 6061 pin 4mm diameter under applied force of 5N. The study indicated that Aluminium 6061 pin 6mm diameter under lubricated surfaces and at 0.518m/s lowest possible wearing rate of 0.0957 mm^3/m.

The wear test parameters for effect of constant sliding speed on the Aluminium Bronze pin with varying force and diameter was plotted in Figures 4.4 and 4.5 respectively. Figure 4.4 illustrated showed that rate of wear at sliding speed of 0.158m/s, the highest rate of wear was 0.0851 mm^3/m which occurred with pin diameter 4mm under applied force of 8N and without lubricating surface. At the same speed, sliding distance of 142.2m, 900s the lowest wearing rate was 0.0394 mm^3/m by the pin diameter 6mm under applied force of 5N. This is a result of increase in pin contact surface area, lower applied force and lubricated surface in 6 diameter pin. Figure 4.5, indicated condition of sliding speed of 0.1975m/s, sliding distance of 175.5, 900s, in which pin 6mm diameter pin under lubricated surfaces and at 0.518m/s lowest possible wearing rate of 0.0406 mm^3/m.

The wear test for Bronze pin at constant speed, varying force and diameter was illustrated in Figures 4.7 and 4.5. Figure 4.7 illustrated showed that rate of wear at sliding speed of 0.158m/s, the highest rate of wear was 0.1128 mm^3/m in pin diameter 4mm under applied force of 8N and without lubricating surface. The lowest wearing rate was 0.0515 mm^3/m by the pin diameter 6mm under applied force of 5N. This is a result of increase in pin contact surface area, lower applied force and lubricated surface in 6 diameter pin. Figure 4.8, indicated condition of sliding speed of 0.1975m/s, sliding distance of 175.5, 900s, in which pin 6mm diameter pin under lubricated surfaces and at 0.518m/s lowest possible wearing rate of 0.0531 mm^3/m.

The wear is engineering failure leads to loss of materials during machine operation. This study agrees with Kumar *et al.,* (2018) that rate of wear is increased with the increase in the applied load at dry lubrication condition. Kumar *et al.,* (2018) observed that using of oil lubrication reduces wear up to 80% compared to dry lubrication state. This study observed average 54% reduction rate in dry to wet condition with lower applied force.

This study agrees with Venkatesh *et al.* (2015) that wear takes predominant role in reducing the cutting life time of tool materials.This present study investigated volume loss, rate of wear and speed. The study understand that increase speed will reduce wearing rate and cases occur in Aluminium 6061 pin 4mm diameter at speed of 0.518m/s and Aluminium 6061 pin 4mm diameter under applied force of at speed of 0.1975 m/s. The pin with higher speed has lower wearing rate. The study agrees with Venkatesh *et al.* (2015) the use of hard carbon steel while testing wear alloy of aluminium, magnesium and brass materials. The present study uses medium carbon steel for testing wear of Aluminium 6061, Aluminium Bronze and Brass respectively. The present work also in agreement with work of Venkatesh*et al.* (2015) that the weight of the pins of 6mm diameter and 50mm in length both coated and uncoated are measured. Then the pin is clamped with support, a disc was fixed on rotor which is coupled with motor via belt drive pulley. The present study used similar approach by uses rope drive pulley of 4 members in which disc was mounted for testing wear of the pin concerned.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study develops a dual operational pin-on-disc wear testing machine that could be used for the determination of surface wear on engineering material in a workshop. The machine uses dual condition both dry and wet or lubricated surface contact of disc and pins. It has capability of disc wear track of 40mm and 50mm, respectively. This was adopted for speed variation during experimental period. The wear parameters of Aluminium 6061,Bronze and Brass pins was investigated.

The performance testing analysis was carried out for surface wear behaviour of the pins. The pins were subjected to variable parameters such as applied force of 5N and 8N, at interval of 300s and sliding of 0.518m/s and 0.1975m/s. The results shows that increase in force will increase rate of wear at constant speed. The increase in speed will lead to reducing of rate of wear. The increase in surface area of contact and using lubricated surface will lead to wear reduction rate.

The wearing rate per second under applied force of 5N and at sliding speed of 0.518m/s in 6mm diameter pin during lubricated condition include 20.5$\mu mm^3/ms$, 8.2 $\mu mm^3/ms$ and 11 $\mu mm^3/ms$ for Aluminium 6061, Bronze and Brass respectively. The 6mm diameter showed lower rate of wear due to increase surface area in contact while lubricated surface reduces wear in the experiment to 54%. Bronze has 59.32 % of lower rate of rate of wear using the pin on disc fabricated by this study. This indicated that resistance of wear rate increases in the order of Aluminium Bronze, Brass and least occurred in Aluminium 6061 pin.

The specific rate of wear of 6mm diameter pin with lubricated surface has least wearing rate at sliding of 0.518 m/s and sliding distance of 568.8m. The Brass pin specific rate of wear was 0.3172×10^{-2}mm^3/Nm, Aluminium 6061 pin specific rate of wear was 0.5901×10^{-2} mm^3/Nm and Bronze pin specific rate of wear was 0.2428×10^{-2}mm^3/Nm. The sliding distance increases with decrease in specific wear of the pin.

5.2 Recommendations

The study recommended the following:

i. The bronze can replace brass during manufacturing process of products as a result of relative close range of resistance of wear rate
ii. The surface contact in engineering machine requires lubricant to minimise wears and failure in the machine
iii. The increase load on machine surface contact will lead to surface wear and the surface contact require to have increase surface contact area
iv. The machine surface contact requires to be well design with minimal speed requirement due to the increase in speed higher than minimal speed requirement will lead to wear

The following are considered as areas of concentration for further study:

i. Critical failure approach in coefficient of wear of selected engineering material
ii. Determination of resistance of wear rate of selected engineering material in both acidic and basic media.

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APPENDICES

APPENDIX I: COMPUTER AIDED DESIGN (CAD) OF WEAR TESTING MACHINE

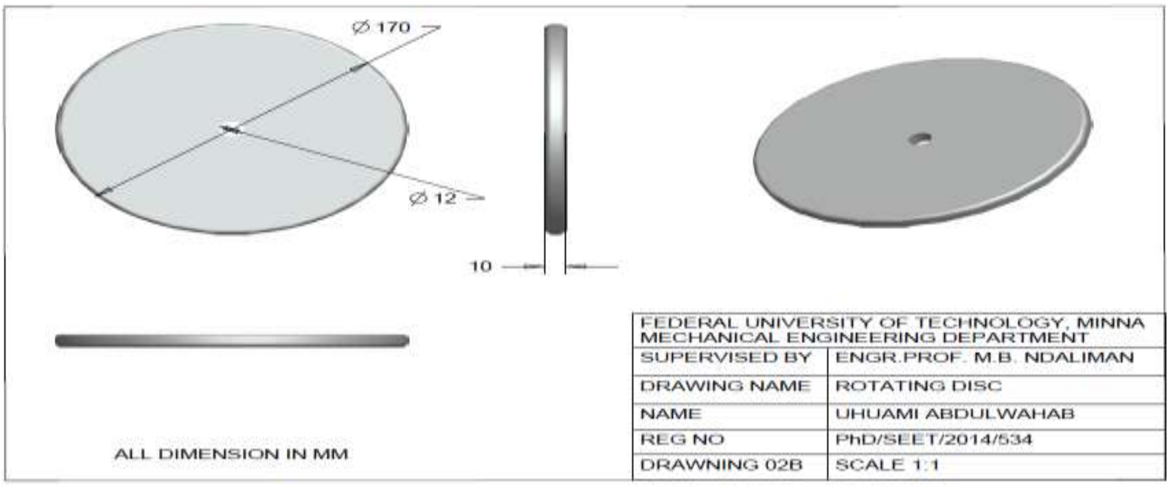
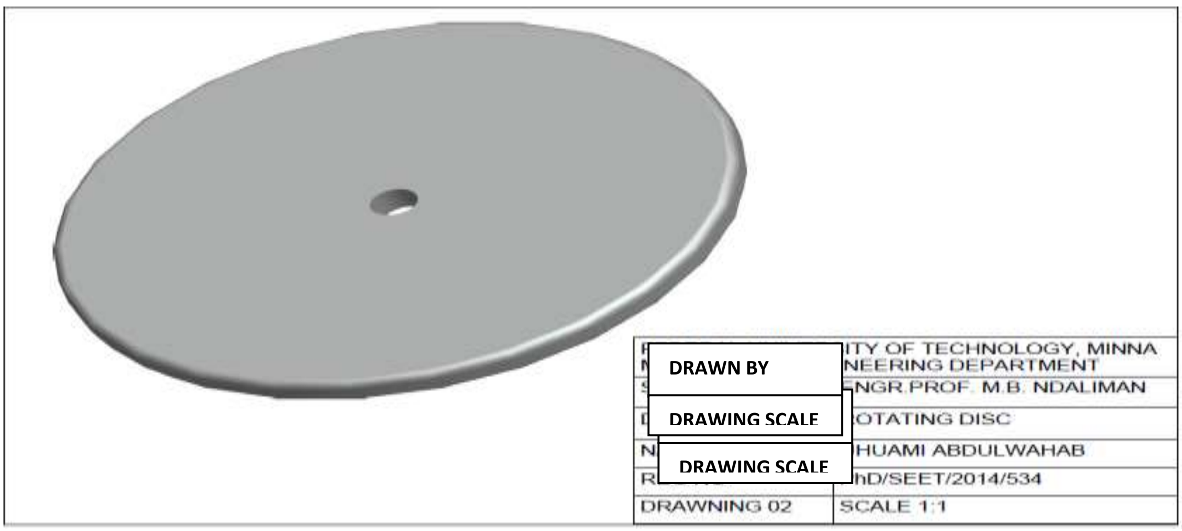


Figure 1: Rotating Disc



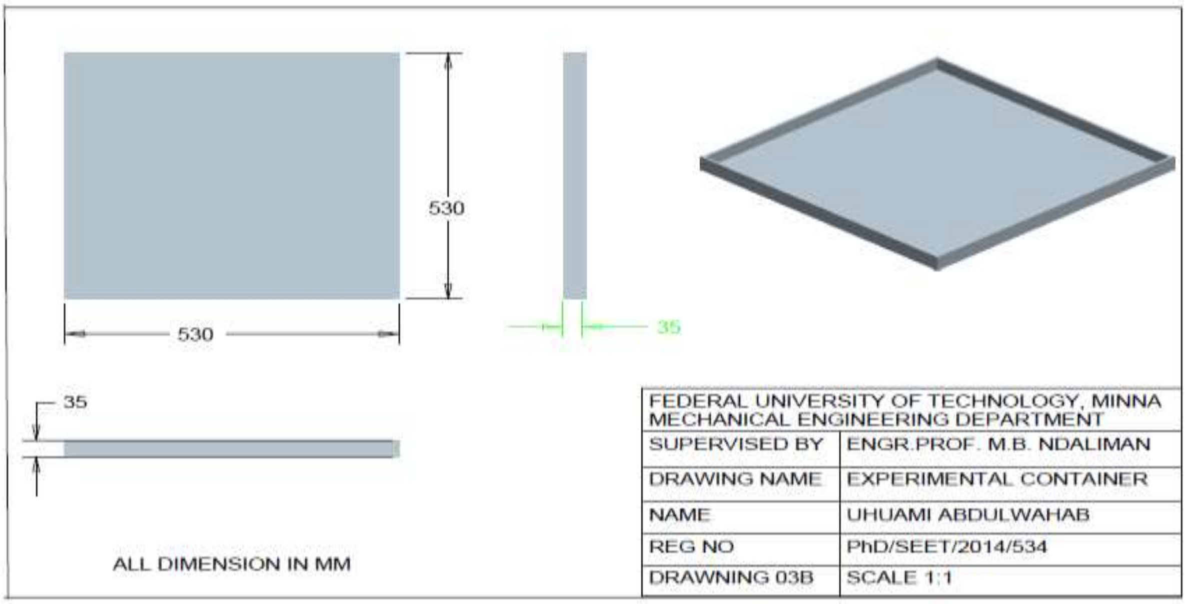
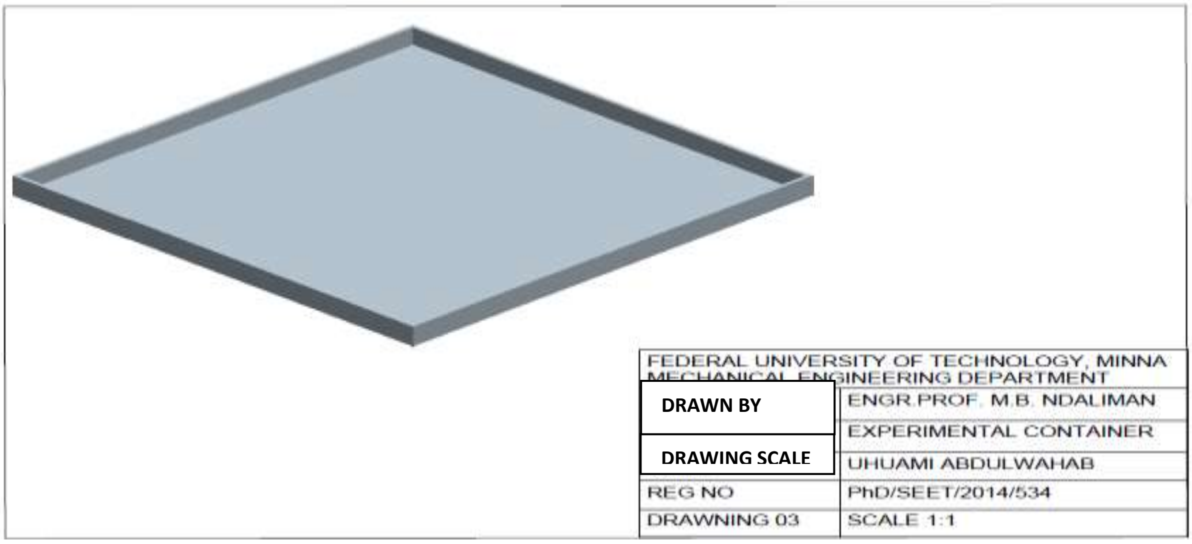


Figure 2: Experimental Container



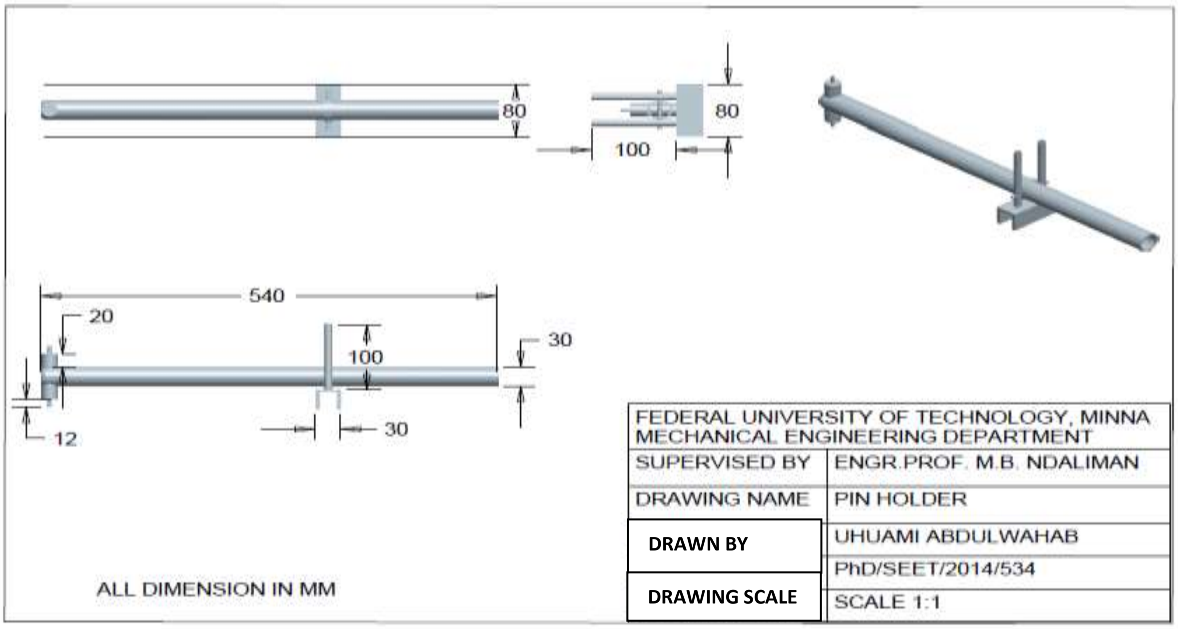
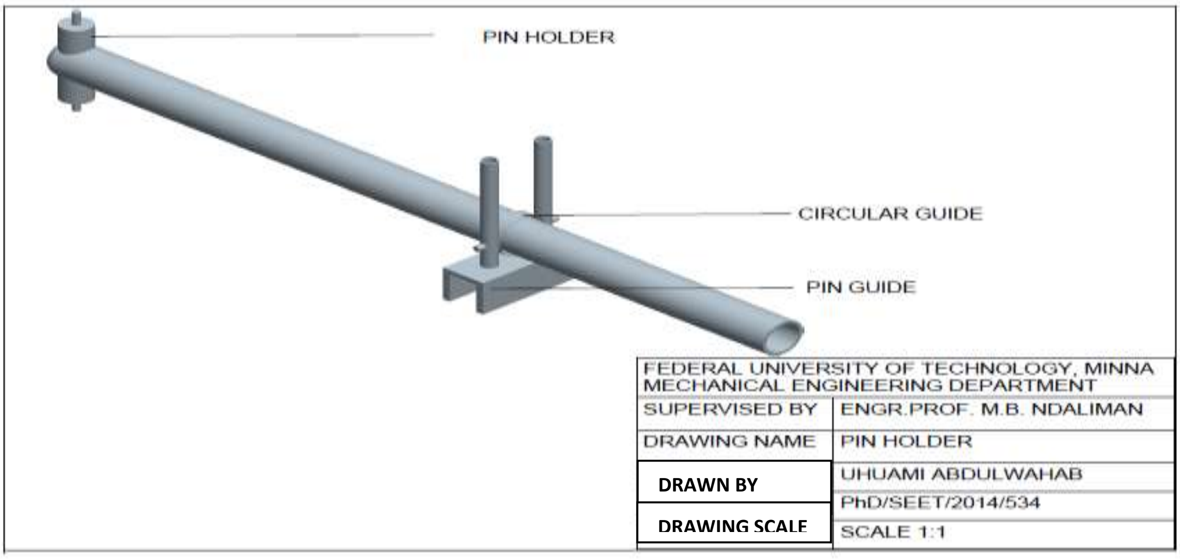


Figure 3: Pin Holder



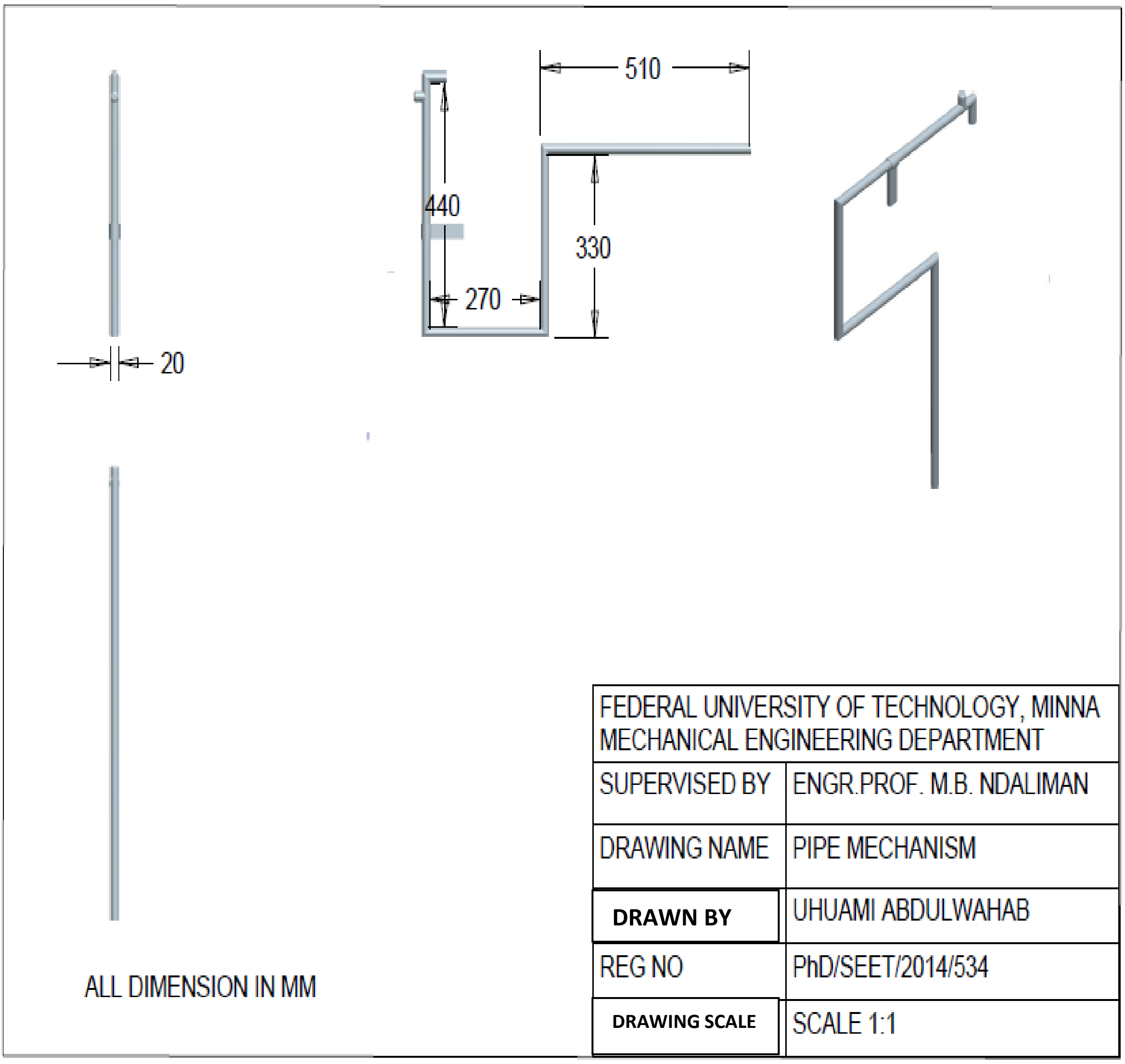


Figure 4: Pump (pipe) Mechanism

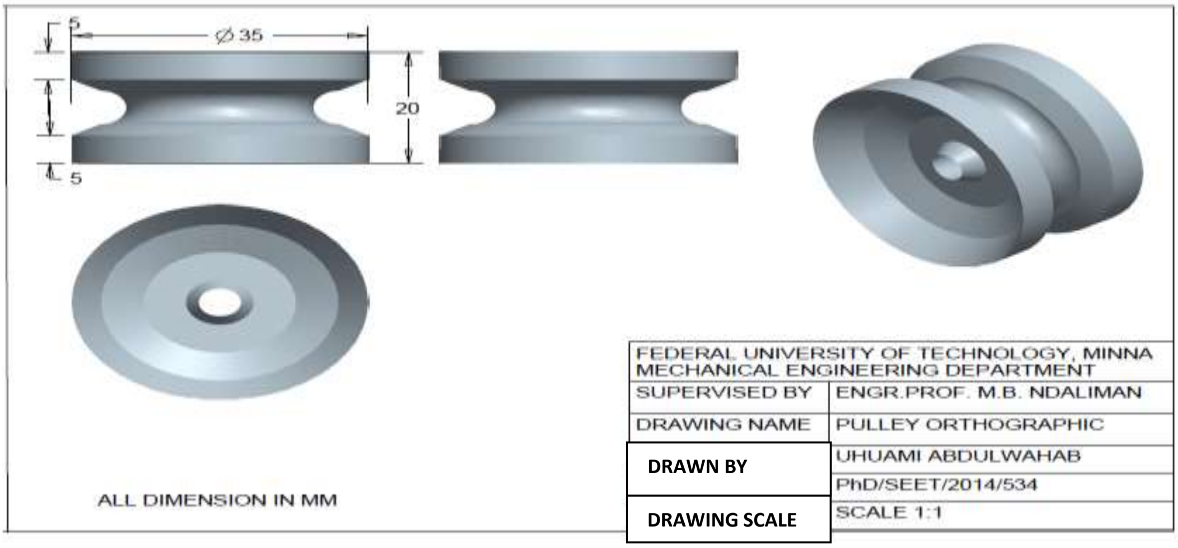
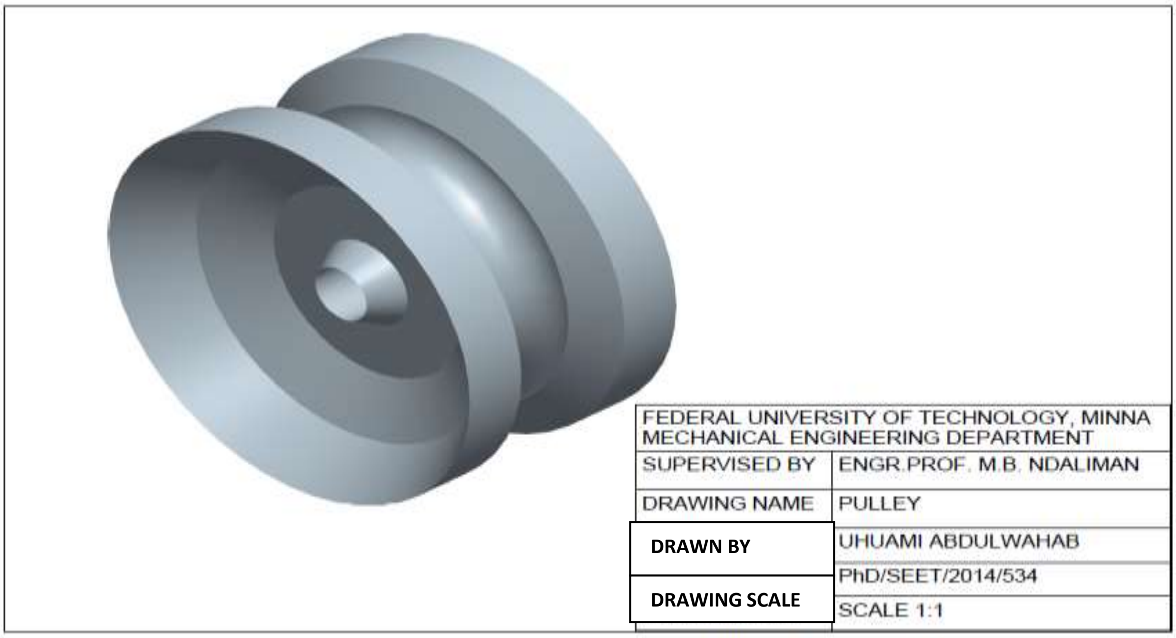
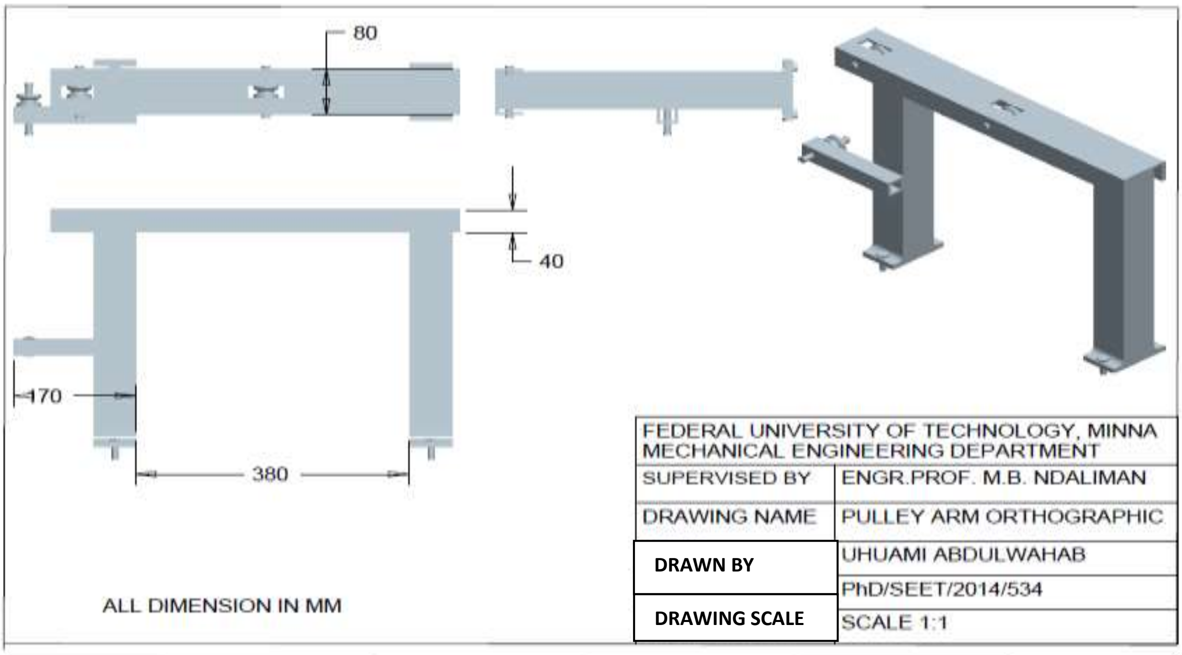


Figure 5: Pulley





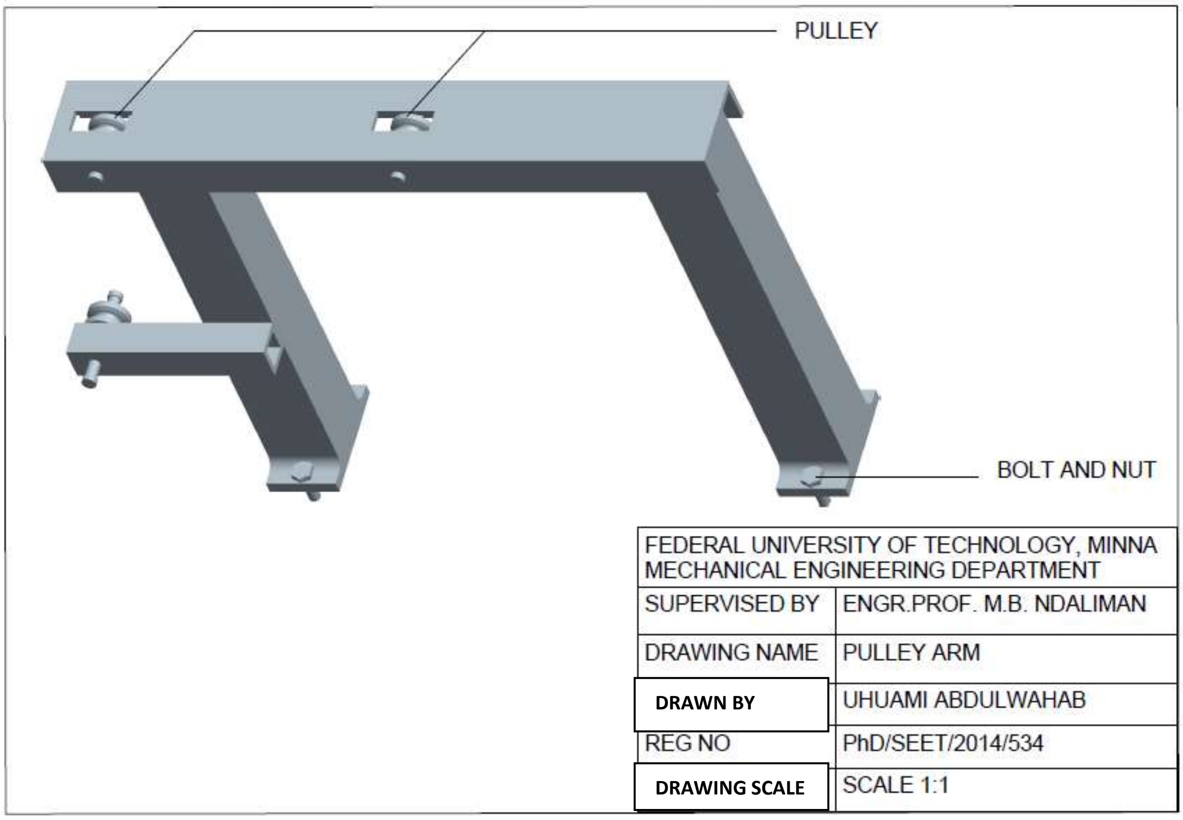


Figure 6: Pulley Arm

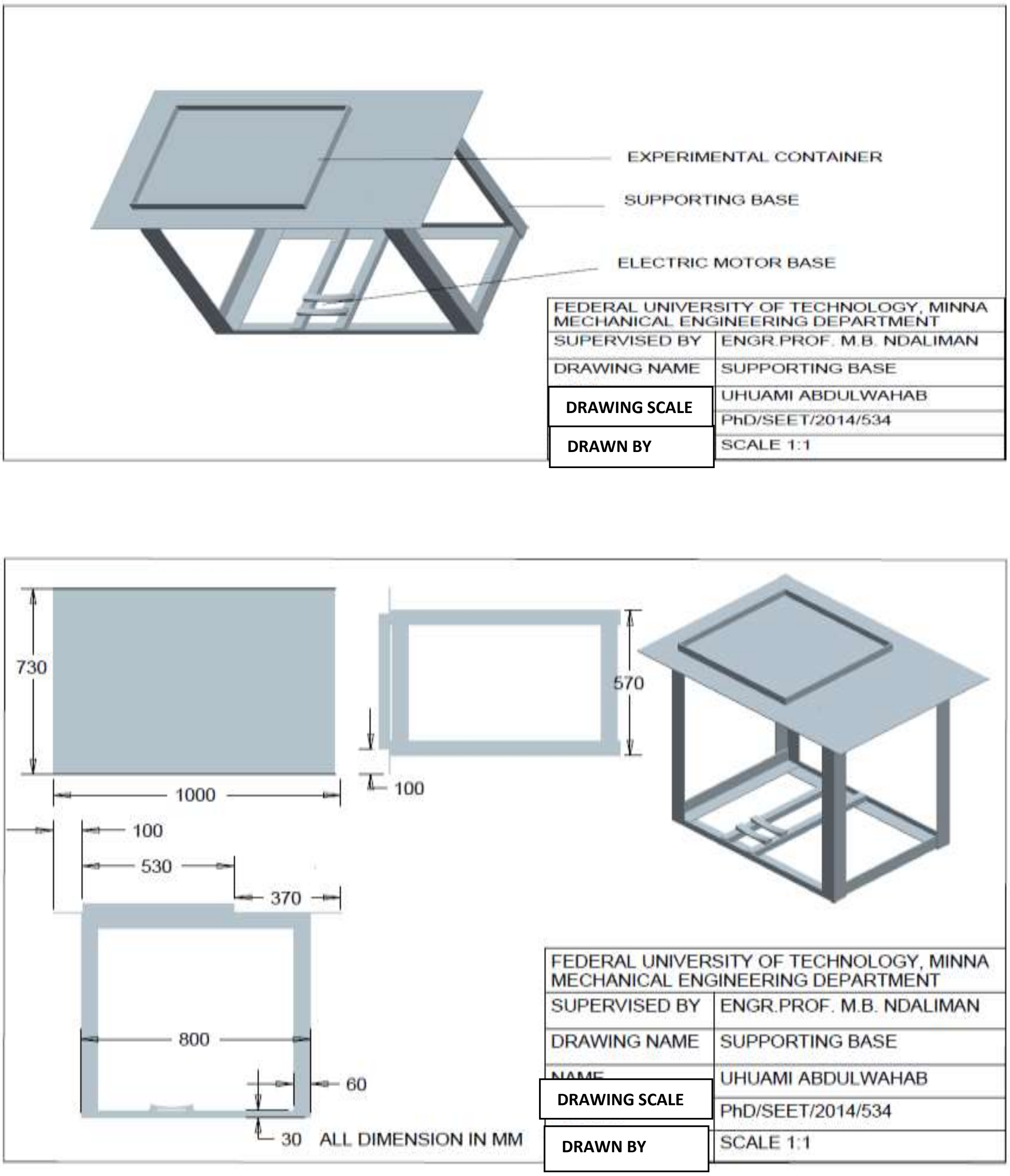
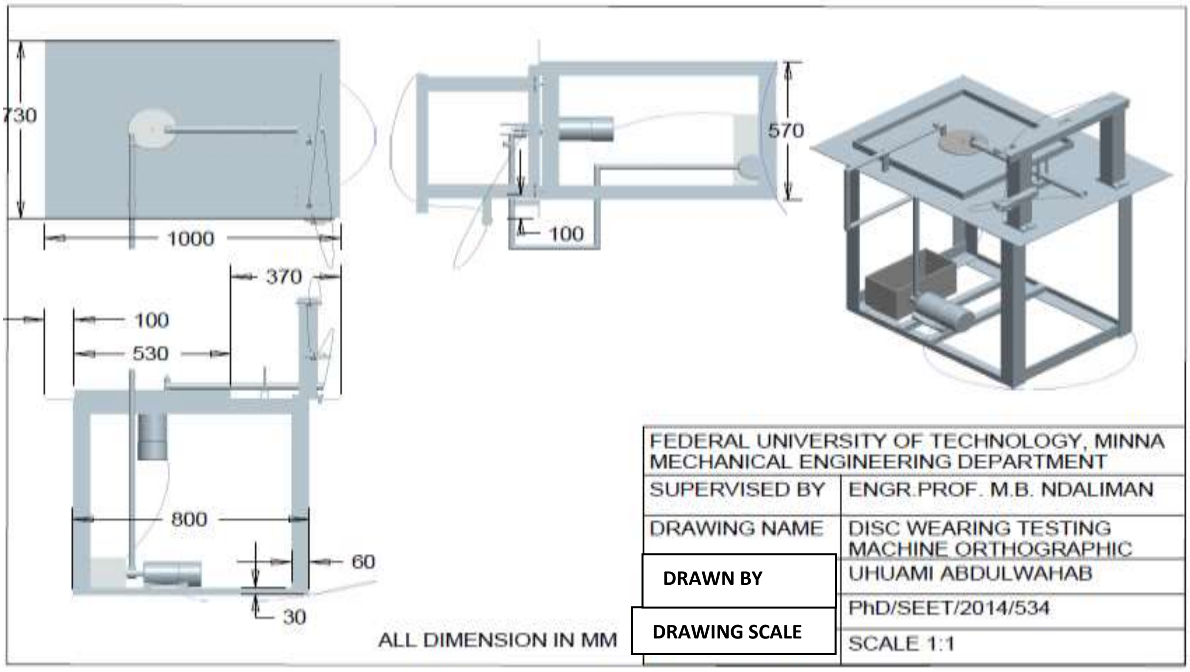


Figure 7: Supporting Base



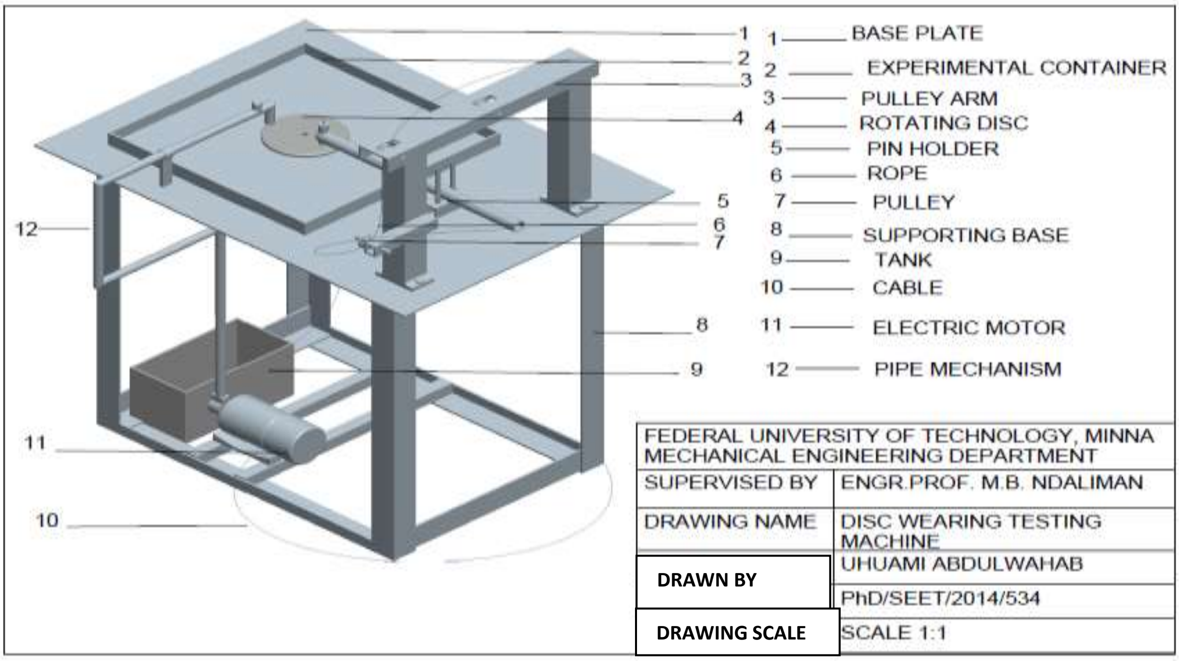


Figure 8: Pin on Disc Wear Testing Machine