WEAR AND FRICTION ON GIMBAL SEALANT

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May 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honor degree in

BACHELOR OF ENGINEERING (MANUFACTURING ENGINEERING WITH MANAGEMENT)

School of Mechanical Engineering

Engineering Campus

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DECLARATION

I, Illuni Islamiah Binti Ibrahim (125404) declare that this thesis and work presented in it my own and has been generated by me as the result of my own original research. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due refence to the literature and acknowledgement of collaboratives and discussions. The work was done under the guide of my supervisor Dr. Ramdziah Bt. MD Nasir.

Wear and Friction on Gimbal Sealant

Signed:

Date:

In my capacity are supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Signed:

Date:

ACKNOWLEDGEMENT

First and foremost, I would like to thank to the God for the good health and wellbeing that were necessary to complete the thesis successfully in order part of qualification my study in Degree on Manufacturing Engineering with Management at Universiti Sains Malaysia.

I have great pleasure in acknowledging my gratitude to my research supervisor Dr. Ramdziah MD Nasir of the Mechanical school at Universiti Sains Malaysia. Without her assistance and dedicated involvement every step of the research through the methodology, this thesis would have been accomplished. The door to DR. Ramdziah office was always open whenever I ran into trouble spot or had a question about my project and thesis. She consistently allowed this paper to my own work but steered me in the right direction whenever she thought I need her. Not forget to the DR. Mohamad Ikhwan Zaini Ridzwan for the for compiling the thesis schedule to all final year students as well as helping in contributing ideas and giving tips to complete the final year project.

I place record, my sincere thank you to Prof. Dr. Zainal Alimuddin Zainal Alauddin, Dean of Mechanical School in Universiti Sains Malaysia for given me an opportunity to run the final year project at the Mechanical School and finish my study in USM I also take this opportunity to express gratitude to all technician of the Mechanical School USM whose have help to guide me used the machine, gives an idea about my project and never stop to help me to solve the problems regarding my project since first semester until today.

Nobody has been more important to me in the pursuit of this project than the members of my family. I would like to thank my parents, Mr. Ibrahim Omar and Mrs. Aizam Mustapha whose love and guidance are with me in whatever I pursue. They are the ultimate role models. Thank also to my siblings especially my brother who always supporting me spiritually to finish my study. I would like to thanks to all my friends whose have pillar of support and helping me to finish the experiment and helping me during write the thesis. They always help me in the journey of my degree in USM. Thank a lot.

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ABSTRAK

Fenomena alam dari ekosistem laut boleh memberi kesan negatif terhadap semua jenis logam terutama dari segi kawalan kualiti dan penyelengaraan produk aplikasi dalam jangka hayat masa yang lama. Bagi aplikasi pengapan engsel dasarnya memberi tumpuan terhadap menstabilkan produk komponen dengan mengurangkan kesan getaran pada kawasan komponen tersebut terutama bagi pengangkutan laut dan darat. Bagi mengurangkan kesan getaran pada permukaan komponen, kajian kegagalan tribologi daripada segi kehausan dan geseran perlu dikenalpasti. Oleh itu, tujuan projek ini adalah untuk memberi cadangan jenis logam yang sesuai digunakan pada pengapan engsel bagi aplikasi di laut. Beberapa ujikaji perlu dijalankan bagi mengkaji kesan tindakbalas kehausan dan geseran pada logam yang berbeza. Lima jenis logam telah dipilih untuk dijadikan alat prosess ujikaji termasukklah aluminum tulen (kawalan), aluminum aloi, tembaga tulen, tembaga aloi dan kekuli lembut aloi. Process ujikaji telah dijalankan untuk mengukur tahap kehausan dan geseran mengunakan mesin pin-atas-cakera (POD), mesin profilometer, mesin ujian kekerasan Vickers dan mesin ujikaji universal (UTM). Tribo-filem telah dianalisa menggunakan mesin Scanning Electron Microscopy (SEM) untuk mengenalpasti kadar kehausan pada specimen dan mengenalpasti pencemaran unsur pada permukaan kawasan menggunakan perisian EDAX. Kesemua jenis logam telah didasarkan mengikut kadar kehausan terendah dan geseran sehingga kesan kegagalan tertinggi dan ia menunjukkan bahawa tembaga tulen berada pada kadar terendah diikuti dengan keluli lembut aloi dan kemudian aluminum aloi. Sementara itu, tembaga aloi menunjukkan kedudukan tertinggi bagi kesan hakisan dan geseran dan diikuti oleh spesimen aluminium tulen (kawalan). Oleh itu, tembaga padu dipilih sebagai logam yang paling sesuai untuk digunakan pada pengapan engsel dalam aplikasi laut.

ABSTRACT

The natural phenomena of marine ecosystem can cause negative effects to all types of metals especially in term of quality control and reliability of the long-term application product life cycle. Basically, for the gimbal sealant applications focus on stabilizing the product component by reducing the vibration at the component area especially for air and marine transportation. To minimize the vibration effect on the surface of component, the tribology failure analysis in term of wear and friction effect should be identified. Thus, the aim of this project to propose the metal that convenient to applied on the gimbal sealant in marine application. There are several tests must be conducted to measure the behavior of wear and friction effect for different types of metals. The five types of metals were chosen for the testing process that was used as a specimen sample include of pure aluminum (control), aluminum alloy, pure copper, brass alloy and mild steel alloy. The testing process were done by measuring the wear and friction using the pin-on-disc machine (POD), profilometer machine, Vickers hardness testing machine, and universal testing machine (UTM). The tribo-film was analyzed for all types of metals using scanning electron microscopy machine (SEM) to identify wear rate of the surface of the specimen and to identify the element contamination in the surface area by using EDX software. All five types of metals were ranked based on the lowest wear rate and friction to the higher failure effect and it shows that the pure copper is lowest ranked followed by the mild steel alloy and then the aluminum alloy. While, the brass alloy shows the highest ranked for the wear and friction effect and followed by pure aluminum (control) specimen. Thus, the pure copper was chosen as convenient metal to applied on the gimbal sealant in marine application.

CHAPTER 1 : INTRODUCTION

1.1 PROJECT BACKGROUND

Gimbal is defined as the device for suspending something, such as a ship's compass, so that it will remain level when its support is tripped. It basically used for stabilizing between two components joining together. The material is needed to fill the joint is known as sealant. Thus, the meaning of gimbal sealant can be concluded as the material used to support the stabilizing on joint of two joining components material by minimize the vibration on the application system which means can reduce the appearance of wear and friction on surface of material.

Gimbal sealant is widely used in any application of product especially for the air and marine transportation. It is small part for the component and most researchers does not focus to improve it. However, from the small basic part can give the large impact for the all the engineering design. Basic element of gimbal sealant is usually from metal. All metal elements have specific charges ion that can affect the physical properties for each metal. For the marine application, the corrosion is the main problems issues that give negative feedback to the metal. Corrosion can affect to the quality control of the gimbal sealant by reduce the stability of component part and reduce the strength to support the joining of two material. Corrosion can cause destructive attack of a material by reaction with environment known as atmospheric oxidation of metal. When the oxygen combined with metal, it will form the new layer called as oxidation layer[1]. This layer can be good and bad toward metal. However, for the gimbal sealant case, it is a bad situation and need to be avoided. There are two types of corrosion related with marine condition occur on the gimbal sealant which are electrochemical corrosion and anaerobic corrosion. The electrochemical corrosion occurs when metal and salt water (ocean) combine both together and the ion from the metal will dissolved into salt water conducted by electricity from friction of the ion charges called as electrochemical corrosion. During this situation, electrons from other compounds are attracted to the other metallic ions (gimbal sealant)[1][2].

The reliability concept is an important aspect for the engineering design process for improving the maintenance of component or systems. Ebeling (1997) defined reliability as "the probability that component or system will perform a required function for a given period used understated operation condition. It's the probability of non-failure over the time"[3]. Thus, the gimbal sealant is chosen for this experiment to maintain the reliability construction at the marine environment of ecosystem by maintaining the quality of the gimbal sealant from rust at the extended time. Although, the gimbal sealant is not the focal point amongst researchers mainly because it is a basic component, but it is still important to dominate the stabilizing between two joints of material[4]. Therefore, it shows that small basic component of gimbal sealant will give the large effect on the component of engineering part.

The material selection is the most important steps for process design of product. The consideration of placing the material, humidity, standard material properties, temperature, and product component should be considered[5]. Thus, this experiment is to determine the properties of the material that suitable for the gimbal sealant at the marine condition by minimize the wear and friction of the corrosion resistance and to increase long life cycles. Since it has a lot of the cases or accidents related with the maintenance problem effect from the material corrosion at marine application, thus the pure aluminum, aluminum alloy, pure copper, brass alloy and mild-steel alloy will be chosen as a part of experiment[5][6].

Tribology is an important aspect that needs to be focused in design and fabrication. It is important things to appreciate the impact of product performance and lifespan. Wear and friction is a part of tribology knowledge and must be focusing because it can cause the negative effect to the material of component. Study of mechanics of wear and friction was related with Newton's law motion. It was observed in several researchers that the variation of friction and load depend on interfacial condition such as normal load, geometry relative surface motion, sliding velocity, type of material, humidity and vibration[7][8].

For the marine application, the fretting and abrasive wear is the major factor that make the performance application become decreases. This defect will occur when corrosion reaction take place into surface of the structure material. Thus, by reducing the effect that can cause the reaction of corrosion on the material, one can minimize the wear and friction on the surface of the material. The best selection of material will give best benefit to the reliability of the components[9].

Thus, the aim of the experiment is to analyze the suitable metal in term of physical properties that can be applied on the gimbal sealant in marine application and to analyze the tribology behavior of wear and friction based on optimum parameter that can be applied. By minimize the wear and friction on the gimbal sealant could improve the quality and reliability of gimbal sealant applications. The wear and friction can be measured in a few steps that can achieve the standardizing of the methodology of engineering quality control[10]. All type of metal chosen because it is common metal that being used in variety of product and it easily to find it. Also, the alloy type is harder compared with other metal and it is the cheapest metal.

1.2 PROBLEM STATEMENT

Referring to the project discussed above, there are limited literature review focusing on the gimbal sealant in the marine application. This project is a very critical issues need to be solved. Although, it is a basic component but quiet critical effect on the joining of two components material to ensure the component can maintain their reliability of extended time. Thus, it also can affect to the quality of its applications. All machinery, instrument, and equipment with moving parts has a possibility of being damaged by a problem of tribology failure[8][11]. The tribology failure in term of wear and friction has received increasing attention as it has become evident that waste of resource resulting from high of wear and friction is greater than 6% of Gross National Product. The several tested to analyze wear and friction can help in understanding deficiencies in material properties and finding the solution for wear and friction on gimbal sealant by considering temperature and humidity during conduct the experiment since it affected to the properties behavior of different metal at a different orientation[12].

1.3 OBJECTIVE

The objectives of this project as are follows:

i. To investigate the tribology behavior in term of wear and friction on gimbal sealant with different types of metal in the marine application according to different parameter level.
ii. To suggest the suitable type of material which can be applied to the gimbal sealant for marine application.

1.4 SCOPE OF WORK

For the wear and friction testing, the five types of the specimen with different metal were fabricated for the experiment by using the CNC Lathe Machine and Milling Machine. The pin-on-disc machine was used to measure the wear and friction on the surface of the specimens. Result and data were recorded and compared on the discussion. The scanning electron microscope (SEM) is also used to analyze the wear surface and element contains the metal of the specimens by using EDAX TEAM software. The SEM machine was used before and after testing the pin-on-disc machine[13]. For this experiment, the profilometer machine also was used to measure the surface roughness of the specimens. This step can determine the wear rate of the different types of metal. The arithmetic average roughness (Ra) and Geometric average roughness (Rq) will be displayed as a value of the surface roughness of the specimen. The surface roughness of specimens after abrasion test were also studied using this method.-[14]. To support the result and discussion for the wear and friction test, the physical testing of the hardness value and tensile stress were done on all five types of specimens to prove the suitable metal can be applied on the gimbal sealant especially in marine application[15].

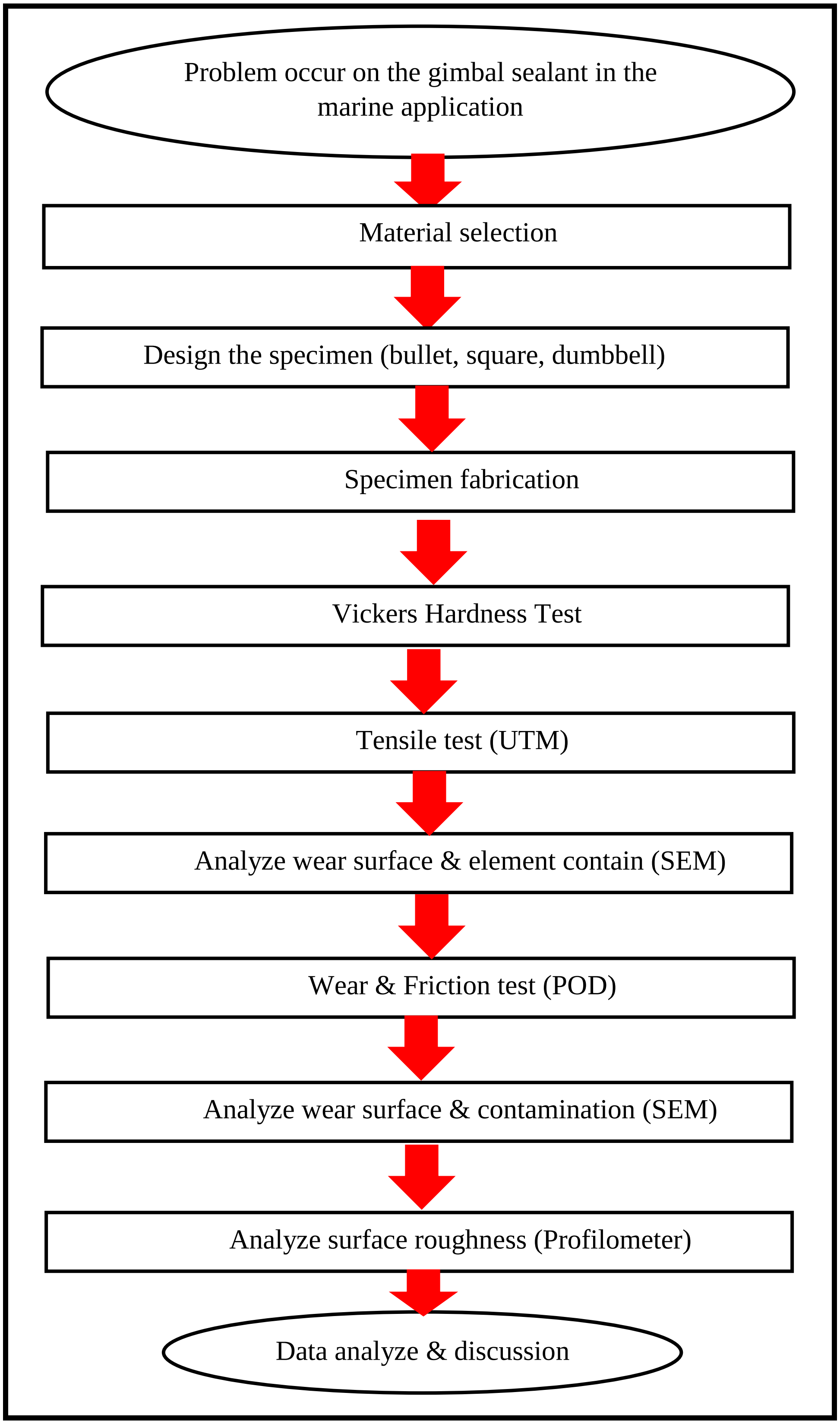


Figure 1-1:Process Flow for the wear and friction testing.

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION

In 2002, the U.S. Navy initiated its Littoral Combat Ship (LCS) Program to develop 55 fast, agile, focused-mission ships designed for operation in near-shore environments for missions such as clearing mines, tracking submarines, and humanitarian relief. The ships were intended to be affordable and easy to maintain over their lifespans{i}. The first ship delivered by Austal, suffered galvanic corrosion within one year of being built[16]. The Navy later found another ship, the USS Freedom, had a crack through its hull, and in November 2013, it was discovered that the same ship has experienced issues with its ship service diesel engines, a corroded cable and faulty air compressor[1]. Due to these design issues, the LCS program has changed its acquisition plan multiple times, and canceled contracts with both competing teams. Second disaster related with corrosion happen at the second busiest bridge in the nation, the San Francisco Bay Bridge carries 270,000 cars each day between Oakland and San Francisco. The bridge was first built in 1936. In 1989, a 6.9-magnitude earthquake hit the Bay Bridge, killing a motorist and causing part of the deck to buckle. A design was proposed for a new span, and after years of political and engineering debates, it was finally built alongside the old one to replace the damaged 2.2 miles that stretch east toward Oakland[17]{ii}.

However, the similar cases at San Francisco Bay Bridge also happen to Malaysia countries. On 6th June 2013 at time 7.00pm, the second bridge in Penang known as Jabatan Sultan Abdul Halim Shah connected between Batu Kawan, Seberang Perai with Batu Maung at Penang Island is collapse{iii}. The key of the accident is because of the failure frame work, wrong design and lack of maintenance structure such as wrong material, lack testing and so on. This accident might be traumatized mentally for people and loss of productivity on this project [19]. Before this, it accident is already done at the Penang Ferry Terminal. It was disaster on 31th July 1988 because of overloading that killing 32 people on this accident. This accident also because of structure failure in transportation infrastructure include crack deformation, corrosion, ground settlement, fatigue and fracture{iv}. Those catastrophes are caused by factors such as improper selection of material, overloading and natural climax. Both of two cases are very related with the humidity, temperature and stability of the construction. The material used for construction is the part of important things to improve maintenance and increase the reliability. Thus, it's shows that the corrosion effect is the common climax issues facing in the around of the marine application that should be focusing and must be solved it.

Alireza Bahadori state that, the selection of material will be influence on corrosion in order regarding of the other principle such as client preference, in-house experience and industry standard specification[18]. The author also explained about lubricant as the necessary tool that provided in design stage for a system. It functions as to minimize the corrosion hazard technically, economically and safely during the designed life of such a system[19].

Wear and Corrosion Behavior in Different Materials is well established that the mechanical, tribological and thermal properties of many metals can be proved by the controlled incorporation of interstitial elements, such as boron, nitrogen and carbon. Tungsten carbide, silicon carbide and silicon nitride are predicted to be among the most abrasion-resistant tool materials and more effective in resisting erosion[20]. This situation must be considerable attention to their high wear resistance and low friction coefficient. For the major of the wear tests is the scarce reproducibility of the experimental data. From UK inter-laboratory project state that a single pin-on-disk test on wear-resistant steels worn under fixed test conditions, Almond and Gee reported dispersion in the range of 57.2–75.4% for the wear data and a minimum reproducibility of 37% for the friction coefficient[21][22].

All failure analysis of engineering design because of the low of tribology knowledge in term of wear and friction analysis. To improve the quality and reliability of engineering design, a several tribology tested must be done to make sure that no failure analysis for engineering design. This test including of physical testing, tribology measurement and tribo-film analysis[12].

2.2 PHYSICAL TESTING

Physical tested is important method to determine what properties of they possess and its degree of material. This information is then used to choosing for gimbal sealant application.

2.2.1 Vickers Hardness Test

Vickers hardness test has a similar principle with Brinell test except for indicator of a diamond pyramid with square based. The angle between the faces of a pyramid was 136 ^{o} as shown in Figure 2-0-1 the Vickers Hardness Number (VHN) of materials is obtained by dividing the applied force, F in Kgf, by the surface of the pyramidal depression yielding the relationship with the average length of diagonals, d in mm. Vickers Hardness test was chosen because it consists of high precision resolution microscope to visualize and measure indication using magnifications up to 600x typically. Thus, it's measurement was less inaccuracy[23]. The calculation of the hardness value was represented in Equation 2-1 as follow:

$$VHN = \frac{1.8544F}{d^2} \quad \textbf{(2-}\boldsymbol{1}\textbf{)}$$

Whereas value of d can be determine based on Equation 2-2:

$$\mathrm{d} = \frac{d_1 + d_2}{2} \quad \textbf{(2-}\boldsymbol{2}\textbf{)}$$

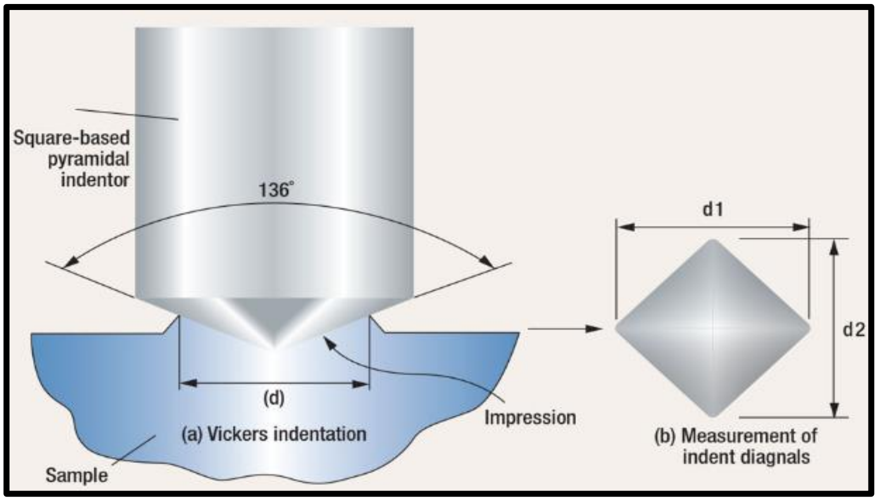
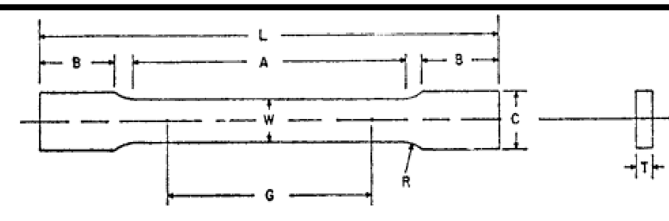


Figure 2-1: The illustration image of Vickers test where (a) Vickers indentation and (b) Measurement of indent diagonals.

2.2.2 Tensile Test

Tensile test measured by applying a pulling force to a sample. The universal testing machine (UTM) was used for this test. This machine has a set of jaws which function to place the sample in the machine and then pulled apart the jaws until material breaks. The tensile test was measured by the elongation of the material[24]. This testing was referring E8/E8M test method for tension testing of metallic material shown in Figure 2-2[11].



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gage length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

Figure 2-2: Dimension of specimen for tensile test refer ASTM E8.

2.3 TRIBOLOGY MEASUREMENT

Tribology measurement is the testing to determine the effect of the wear and friction of the material surface by using a pin-on-disc machine and profilometer machine to identify the presence of wear and friction. Some calculation was needed to prove the testing.

2.3.1 Taguchi Method

Taguchi method is one of the important tools based on performing an evaluation to test the sensitivity of set response variables (independent or variable) by considering experiments in "orthogonal array" with the aim to attain the optimum setting of a control parameter. It can minimize the balanced of experiments. Orthogonal array represented the requisite number of experiments design technique. The purpose to apply this method to help in the data analysis and prediction for optimum result. There have three specific classifications formulate for signal-noise ratio related to a design of experiment including of small-the-better, larger-the-better and nominal-the-better. The quality characteristic of experiments by minimization of wear larger-the-better needed for this experiment[25].

2.3.2 Wear Resistance Measurement

Research conducted by D.M. Kennedy and Hashmi reported that pin-on-disc machine were most widely used for the wear test process. The wear rates of the pin-on-disc were obtained by measuring their weight loss[26]. The test was carried out under four various of normal load applied to the contacts. other important load was used to compared and validate result obtained. The 30 minutes of time interval was chosen to run the machine because wear and friction stabilize before 30 minutes. The average value of coefficient of friction (COF) and wear rate was taken. Figure 2-3 represent the schematic view of pin-on-disc setup[27].

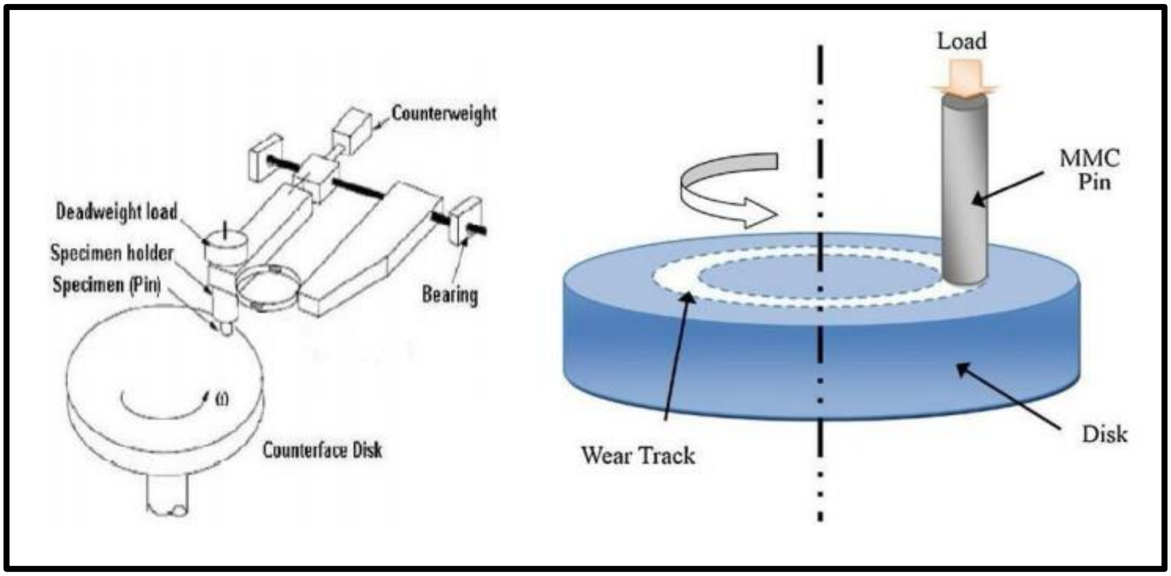


Figure 2-3: Schematic view for pin on disc apparatus.

A first simple model of adhesive wear states that the volume of worn material removed (volume loss) V_ω because of tribology intersection is directly proportional to the load F_n and the total sliding distance, L. However, since less wear is observed when the hardness of the softner member of the tribological couple increases, V_ω can also regard as inversely proportional to the hardness, H of the material being worn away. Equation 2-3 shows the of Archard's law[28].

$$V_\omega = \mathrm{K}\frac{F_n \, \mathrm{L}}{H} \tag{2-3}$$

Where K is referred as wear coefficient. For the volume loss, V_ω at average of weight loss ΔW inversely proportional with the density of material, ρ shown in Equation 2-4.

$$V_\omega = \frac{\Delta \mathrm{W}}{\rho} \tag{2-4}$$

For the sliding distance, L at constant velocity, V it is become Equation 2-5.

$$\mathrm{L} = \mathrm{Vt} \tag{2-5}$$

Where t is sliding time. For the value of velocity, V the radius of track, r (mm) directly proportional with speed of disc ω (rad/s) shown in Equation 2-6.

$$V = r \times \omega \quad or \quad \mathrm{V = r \times RPM \times 0.10742} \tag{2-6}$$

2.3.2 Coefficient of Friction (COF) Measurement

Friction is a force resisting relative motion and may occur at the interface between two or more bodies. The concept of coefficient of friction (COF) was introduce by Leonardo da Vinci and it's defined according to Equation 2-7.

$$\mu = \frac{F_f}{F_N} \tag{2-7}$$

Where F_f represented as friction force and F_N is applied normal load. The magnitude of COF was determined by the properties of the surfaces. There have two types of COF which is static and dynamic. For the pin-on-disc test, the dynamic (kinetic) of COF was applied based on the ratio of friction force during sliding that applied to the load[29][30].

2.3.3 Surface Roughness Measurement

Profilometer machine was used to measure the actual topography of a surface. This method of measuring surface roughness to pass a mechanical or optical stylus probe across the surface and measure its surface profile. This technic has been developed to very sophisticated level and can achieve surprisingly high precision[31]. However, there have limited set the finite radius of the tip of the probe. The roughness parameter most commonly used in the arithmetic mean Equation 2-8 of the absolute value of the height measured from the centerline shown in Figure 2-4 the simple mathematical model was defined the surface height variation $\delta \mathrm{h}_i$ measured from the mean surface level[32][14]:

$$R_a = \frac{1}{N} \sum_{i=1}^{N} |\delta \mathrm{h}_i| \tag{2-8}$$

An alternative measurement of the average variation in the surface is the root-mean-square roughness. It defined as Equation 2-9.

$$\sigma_R = \left[\frac{1}{N}\sum_{i=1}^{N}\delta h_i^2\right]^{1/2} \quad \textbf{(2-9)}$$

There was obviously relationship between Ra and σ_R shown in Equation 2-10. However, it depends on the statistical distribution height present in any given cases.

$$\sigma_R = 1.11R_a \quad \textbf{(2-10)}$$

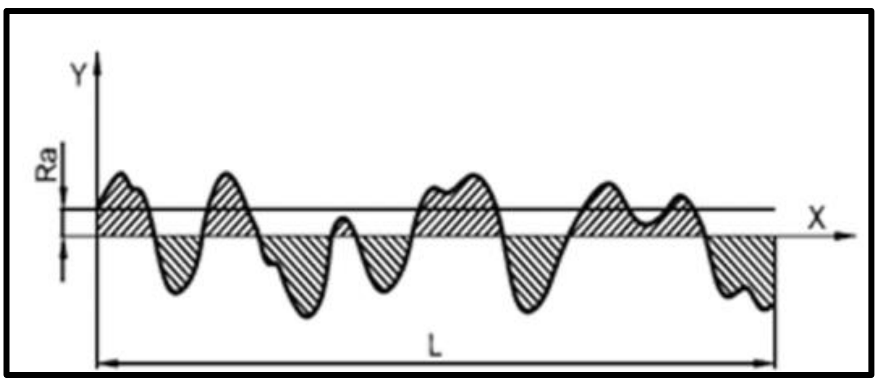


Figure 2-4: Definition of Ra

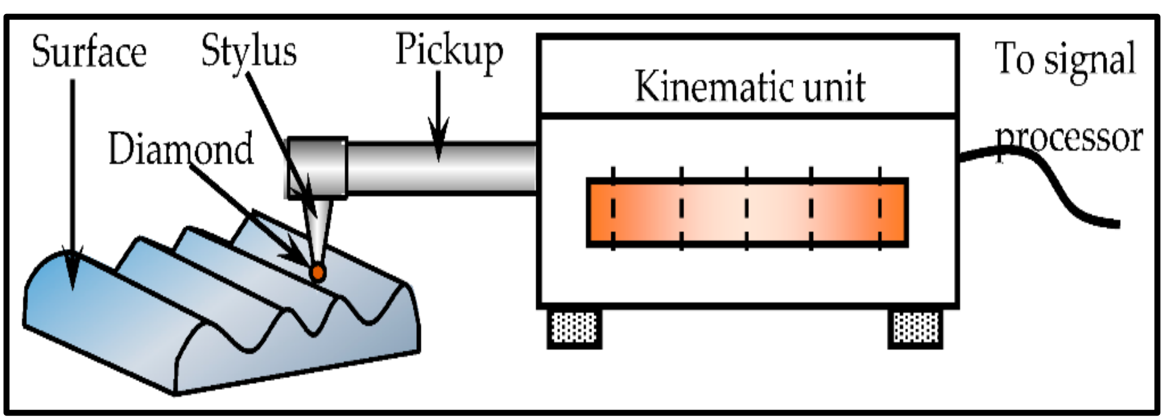


Figure 2-5: Schematic view of profilometer apparatus.

2.4 TRIBO-FILM ANALYSIS

Tribo-film analysis can be significant as the analytical review need to be analyzed the surface of wear and commonly the SEM machine has been used the measured the surface of wear and contamination of the sample.

2.4.1 Wear Surface Analysis

Scanning Electron Microscopy (SEM) is one of the most important machines for tribology wear analysis. It used to characterize all kind of materials, including biological samples. The SEM electron beam will be generated the scanned of sample and emission generated by the beam was detected. SEM was used after the wear test applied to the sample of material. It used to analyze the scar of wear appeared at the surface of the sample[33].

2.4.2 Element Contamination Analysis

The additional information about wear sample cab be obtained with analytical of metal EDAX has led the way in the development and supply of element analysis instrumentation based on the method of the energy-dispersive (X-ray) spectrometry (EDS). The EDS utilizes the simple information about electron transitions deep within an atom. This instrument can provide information of type and quantity of the element present refer ASTM E1508. This instrument was attached to a scanning electron microscopy (SEM) where electrons are used as the primary energy source to excite the X-ray spectra[21].

CHAPTER 3 : METHODOLOGY

3.1 INTRODUCTION

There are several types of testing has been conducted to identify the physical behavior of the five types of metal and to analyze the tribology failure in term of wear and friction on gimbal sealant in the marine application. All method and steps are referring from the other researcher to identify the tribology failure in few types of mechanical application. There are several steps that must be followed to identify the wear and friction on gimbal sealant.

3.2 FABRICATION OF SPECIMENS

For the fabrication of specimen process, a few steps have been followed to make sure it fixes with testing machine. The accuracy of the specimen’s dimension must be considered to make sure the result of testing is valid.

3.2.1 Selection the Type of Metals

Five types of different metal were chosen for this experiment to analyze the behavior of metal and to measure wear and friction. To minimize the cost and save the time of the project, the existence of the metals in mechanical school was used. The pure copper 385-Annealed, aluminum alloy 6061-T6, brass alloy C-37700, and a mild-steel rod are being used to fabricate the bullet shape. While the pure aluminum 6061-O block is used for the control specimen to fabricate the square shape. All chemical composition represented in Table 3-1, 3-2, 3-3, 3-4 and 3-5 for each type of metal based on the EDAX TEAM EDS software of SEM machine. The metal plate of mild-steel 4043-Steel, aluminum alloy 6061-T6 and pure aluminum 6061-O is chosen to fabricate the dog bone shape with the thickness of 6 mm. The properties of material for five types of metals can referred in Appendix A.

Table 3-1: Chemical composition Pure aluminum (6061-O).

Element	CK	ZnL	MgK	AlK
Wt.%	12.95	4.81	1.83	80.41

Table 3-2: Chemical composition of Aluminum alloy (6061-T6).

Element	CK	OK	MgK	AlK
Wt.%	11.63	2.7	1.44	84.23

Table 3-3: Chemical composition of Pure copper (385-Annealed).

Element	CuL
Wt.%	100

Table 3-4: Chemical composition of Brass alloy(C-37700).

Element	CK	OK	CuL	ZnL
Wt.%	12.72	5.23	51.09	30.96

Table 3-5: Chemical composition of Mild-steel alloy (4043-Steel).

Element	CK	OK	FeL
Wt.%	28.27	11.73	59.99

3.2.2 Design Specimens using Solid Work Software

There are three types of specimens has been designed by using the SolidWorks software to make sure the dimension of each specimen is accurate. For the tensile test, the dog bone shape has been designed by referring the standard shape and dimension of ASTM E8 shown as Figure 3-3[11] {v}. The bullet and square shape has been designed for the wear and friction testing on the pin-on-disc machine. The square shape is designed for pure aluminum (control) specimen since it comes with block shape refer Figure 3-2. The other types metal is bullet shape refer Figure 3-1[17]. The size and dimension of each designed of specimen can be refer at Table 3-6.

Table 3-6: Diameter for three types of specimen design.

Shape of the specimen	**Dimension**
Bullet shape	Length: 40 mm Diameter: 12 mm
Square shape	Length: 40 mm Width: 12 mm Thickness: 40 mm
Dog bone shape	Overall length: 100 mm Reduce section length: 32 mm Grip section length: 30 mm Radius of fillet: 3 mm Overall width: 10 mm Grip width: 6 mm Thickness: 6 mm

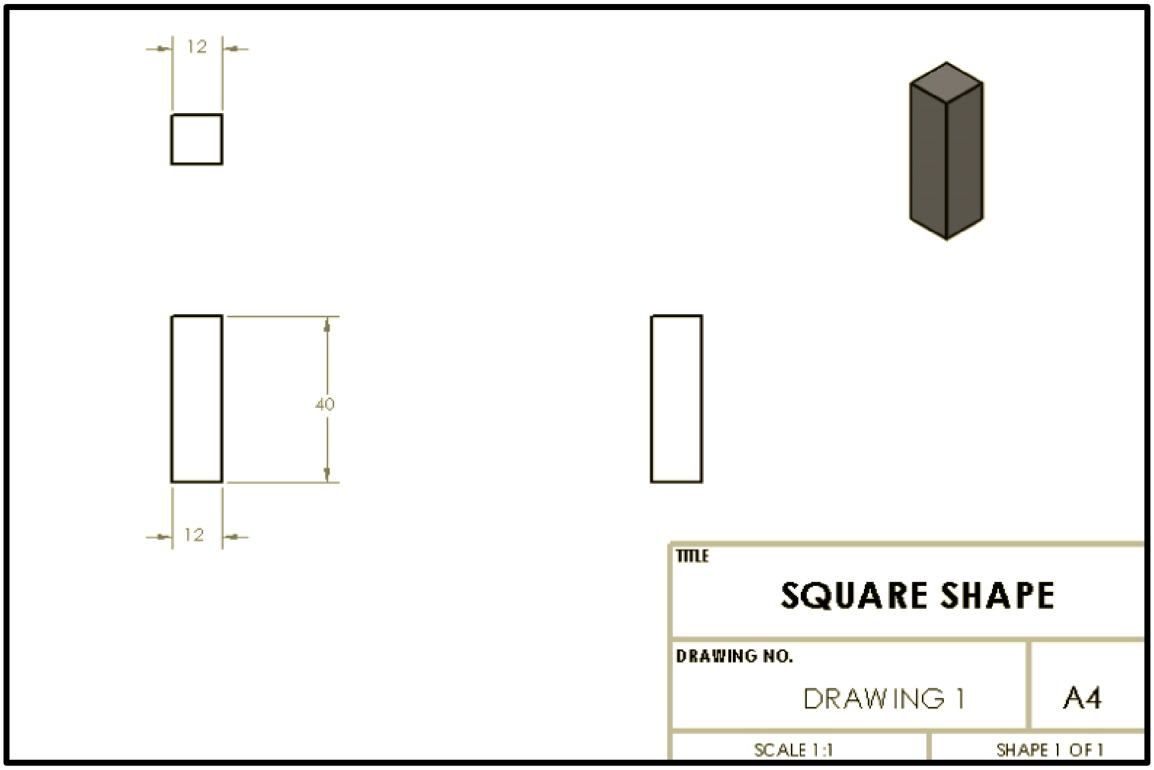


Figure 3-1: Square shape specimen design using Solid Work Software.

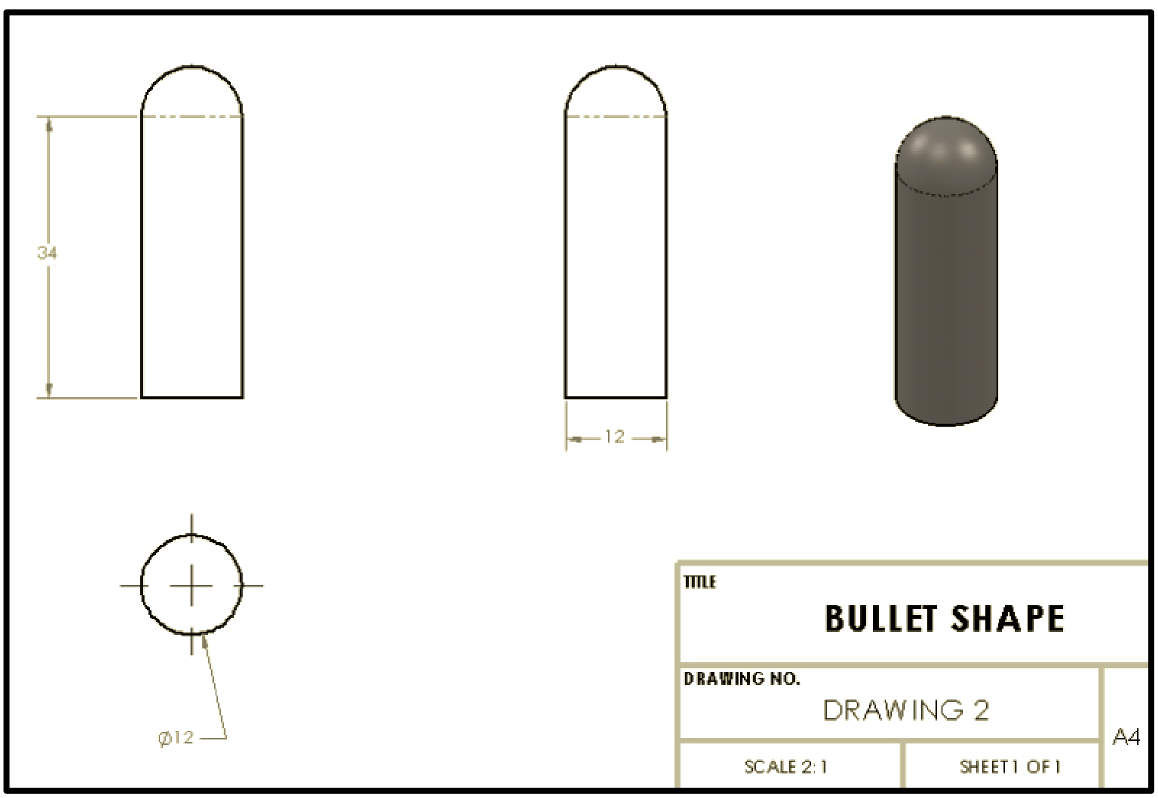


Figure 3-2: Bullet shape specimen design using Solid Work Software.

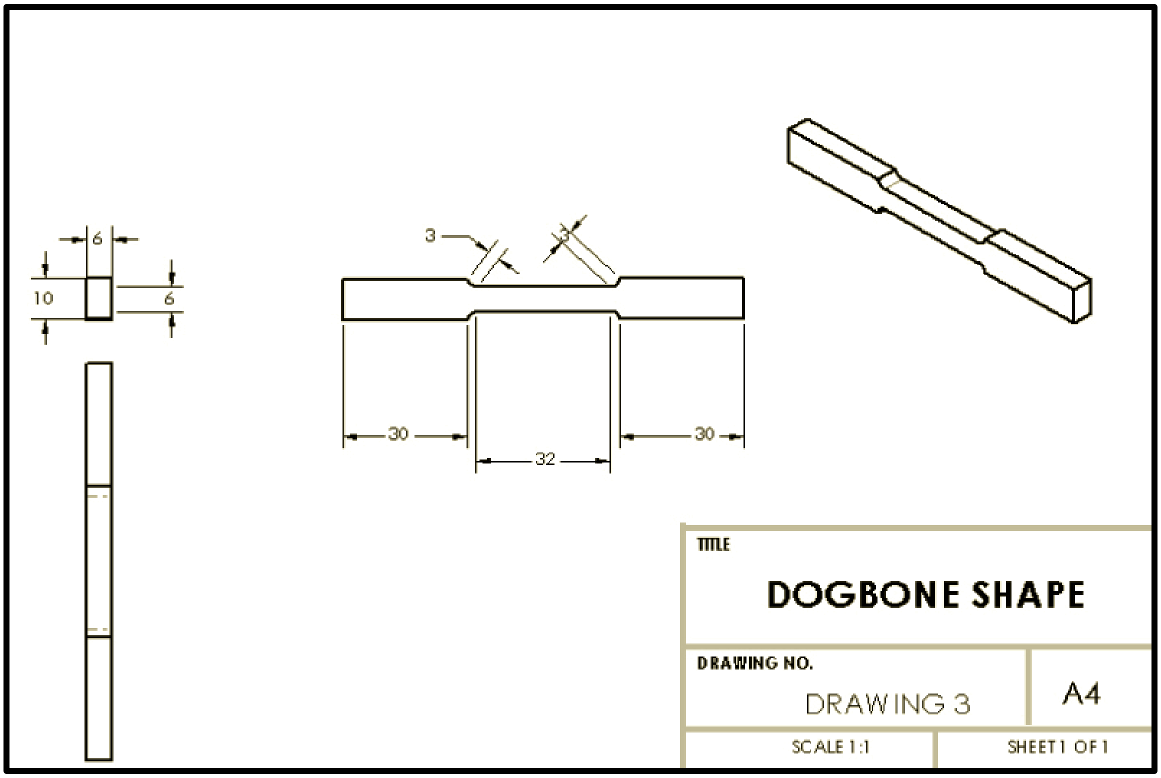


Figure 3-3: Dog bone shape specimen design using Solid Work Software.

3.2.1 Fabricate Specimens

The 300 mm of rod metal of pure copper, brass alloy and mild-steel were cut into four parts using the metal cutting hacksaw machine. All part of each metal was fabricated in bullet shape by using CNC Lathe machine (Okuma LB-15C) shown in Table 3-9(a). The specimen was tightly gripped into a chunk of the lathe and the coolant was open to hit the tip of the tool. This step is to avoid the heating process during running the machine which can damage the properties of the metal. Then, the dimension of the specimen will be set up into the programming of this machine and then run the machine. Make sure the door of the machine was closed for safety precaution to avoid the chip of metal waste leaps out from the machine. The similar steps were repeated for the other parts of rod each metal. However, the programming of the machine does not need to set up because it has a similar size for each part of metal. Then, cut the piece of each metal specimen into 40mm length using specimen cutter refer Table 3-9(b). The four pieces of bullet specimens were formed for each different type of metal as a backup of the specimens. Figure 3-4 show the bullet shape for four types of specimens.

For the square shape, the block of pure aluminum 6061-O being fabricated by using Universal Milling machine FEXAC refer Table 3-9(c). This machine is manually machine process. The size of the square shape specimen was measured and labeled. Ensure the machine is off prior to machining and it is at a suitable positioning. Run the machine so the tool will cut the block based on the required shape of the specimen. The personal protection equipment (PPE) must be used to avoid accident happened during conducting this machine. The square shape was produced as shown in Figure 3-4.

Figure 3-4: Specimens that being used to pin-on-disc machine.

For fabricating of the dog bone shape specimen, a plate size 100 mm x 120 mm with 6 mm of thickness was cut using hydraulic plate cutter machine for both aluminum alloy and mild-steel metal. The CNC precision Wire Cut EDM machine (Sodick-400AG) in Table 3-9(d) was used to fabricate the dog bone shape specimen for both aluminum alloy and mild-steel plate. For all samples, similar machining method was used. The plate was placed on the table of the workpiece of the machine. The SolidWorks design will transfer into the programming of the machine and the machine will be run automatically. Figure 3-5 shown the dog bone shape of the specimen for three types of metal.

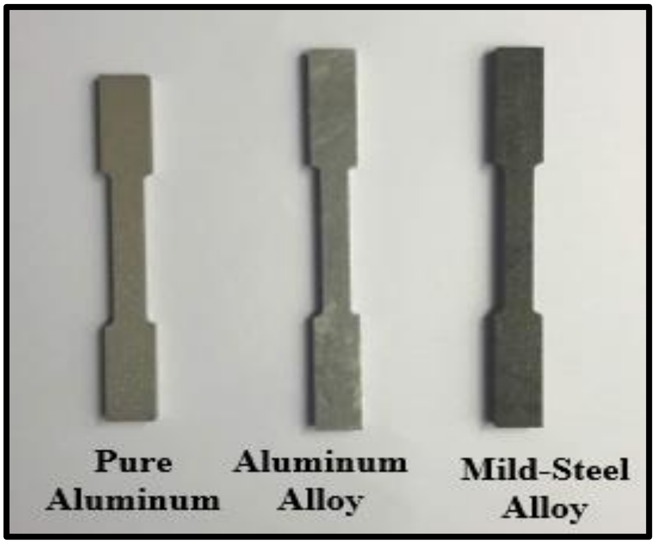


Figure 3-5: Dumbbell shape that being used at Universal Tensile Machine (UTM) for tensile test.

3.3 PHYSICAL TESTING

The physical testing is to verify the physical behavior for each of metal. This testing can help to improve the quality and reliability of the gimbal sealant, especially for the marine application by minimizing the effect of the corrosion at the surface of the metal. The physical testing including of hardness and tensile strength test.

3.3.1 Vickers Hardness Testing Machine

Vickers Hardness Testing machine in Table 3-9(e) was used to measure the value of hardness of the metal. Since the space machine to place the specimen is limited, the bullet shape and square shape of specimens were cut into 10 mm length of each metal. The microscope of the machine was adjusted until clearly see the microstructure on the surface of the specimens. The diamond tool is being used to measure the hardness of metal. 10kg of the weight load were applied on the each of specimen. The results of hardness value in VHN unit were taken at the control screen of the machine. The similar steps were repeated for each of the metal for three times to minimize the parallax error and to take the average value. This method was referring the ASTM E92 Standard Method of Vickers Hardness of Metallic Material[11].

3.3.2 Universal Testing Machine (UTM) Testing

Universal Tensile Machine (UTM) in Table 3-9(f) is used to determine the tensile stress of the metal referred in ASTM E8/E8M Standard Test Method for Tension Testing of Metallic Material{v}. The dog bone shape of specimen was prepared to measure the tensile strength of metals. The specific size such as thickness and length of the specimen were kept in into the software at the computer. The load rate of the machine was setup into 2mm/min. Then, the specimens were placed between the grip of the specimens. It functions to grip and pull the specimen during machine was monitored. The data and result appeared at the screen of the computer[11][24].

3.4 WEAR AND FRICTION MEASUREMENT

Wear and friction measurement can be tested using different processes. For this experiment, the pin-on-disc (POD) machine, Profilometer machine and scanning electron microscopy (SEM) machine were used to measure the wear and friction appeared on the surface of the specimens. SEM machine also can be used to detect the elemental composition inside the surface of specimen by using the EDAX software.

3.4.1 Pin on Disc Testing (POD) Machine

Pin on Disc Testing (POD) Machine (DUCOM) in Table 3-9(g) was used to measure wear and friction behavior refer ASTM G-99 Standard Method {vi}. The specific parameter must be verified before starting the testing. The parameters were applied load (N), the speed of disc rotated (rpm), and the diameter of the track (mm) were stated and leveling shown in Table 3-7. Then, the clean specimen was weighted using analytical balance weight before started run the machine. The software on the pin-on-disc was opened and must be connected to this machine. The disc of track was stuck with sandpaper (1000 grit size of SiC) by using double tape at the end of the sandpaper corner. The specimens were clamped at the sample holder and tight with Allen key[27]. The diameter of track was adjusted and the load at load was applied at the load cell. The parameter (speed, diameter track, and load) was set up on the program of the computer software. The specimen was run in 30 minutes. Then, the specimens were weighted again by using analytical balance weight in Table 3-9(j) to measure the weight loss. The result of the coefficient of friction (COF) and the weight loss was recorded for each metal. The same steps were repeated for the second until fifth level for each type of metals. All the value of data and result were taken to analyze in the discussion section[26].

Table 3-7: Level of parameter for pin-on-disc machine.

CODE VALUE	**INPUT PARAMETER**	**UNITS**	**LEVEL**				
			1	**2**	**3**	**4**	**5**
A	Load	Newton	5	10	15	20	25
B	Speed	rpm	100	200	300	400	500
C	Diameter track	mm	50	60	70	60	50

There have several conditions that must be consider during conducting the test. The condition state of the machine was recorded in the Table 3-8 shown as below:

Table 3-8: Specification of condition during conducting the tribology test.

Specification	
Date and Time	5^{th} February 2018, 9:50 AM
Time Sample Run	30 minutes
Temperature Disc	Room temperature
Temperature Specimen	Room Temperature
Humidity	71%
Sandpaper Type	SiC (1000 grit size)

3.4.2 Profilometer Testing Machine

The Profilometer Machine in Table 3-9(h) was used to measure the surface roughness of the specimens affected by tribology failure testing. The specimen was placed at below of the needle detector. The length of the specimen that being measure was set up at the machine. Also, the needle was set at origin position. the graph of surface roughness appeared on the screen of the machine. the value of Arithmetic average roughness (Ra) and Geometric average roughness (Rq) also showed on the machine screen[14].

3.4.3 Scanning Electron Microscopic (SEM) Machine

The Scanning Electron Microscope (SEM) Machine in Table 3-9(i) was used to analyze the wear surface on the specimen and to identify the contaminant element at the surface of the specimen. The specimen was put into specimen chamber and electron detector detect the presence of wear surface area by the help of the magnetic lens inside the SEM machine. Ensure the specimens does not move inside the specimen chamber, the double tape is used to stick between specimen and base[13][5]. A few magnifications of the lens were used to capture the wear surface on the specimen to make sure it can clearly see on the surface of the specimen. The element contains the specimen also was determined by using the EDEX TEM EDS software which comes out with SEM machines. Both steps are being used before and after applying the specimens into the pin-on-disc machine to compare the presence of the wear and to identify the contaminant in the surface of the specimens after running the testing[34].