WEAR AND FRICTION ON LOADED CONVEYOR BELT

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This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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LIST OF ABBREVIATIONS

SYMBOL	DESCRIPTION
NR	Natural rubber
NBR	Acrylonitrile butadiene rubber
SEM	Scanning electron microscope
SMRL	Standard Malaysia Rubber Grade L
SBR	Styrene-butadiene rubber
POD	Pin on disc
XNBR	Carboxylated acrylonitrile
CBS	N-cyclohexyl-2-benzothiazyl sulfonamide
BKF	rubber antioxidant 2246
MDR	Moving die rheometer
OHP	Overhead Heated Projection film
IRHD	International Rubber Hardness Degrees
SE	Secondary electron signal
COF	Coefficient of friction

ABSTRAK

Haus dan geseran telah dikenalpasti sebagai salah satu sebab utama yang memberi kesan kepada jangka hidup sistem tali pinggang penghantar. Keadaan ini mungkin menjadi sesuatu yang tidak diingini kerana ia mengakibatkan pelbagai kesan terhadap sistem itu sendiri. Terdapat pelbagai parameter yang menyebabkan masalah haus dan geseran ini. Contohnya, penyelenggaraan perkhidmatan, morfologi permukaan, bahan yang sistem tali pinggang penghantar bawa dan lain-lain. Untuk kajian penyelidikan ini, penyiasatan dan penyelidikan yang lebih terperincil tentang tingkah laku getah (80% getah butadiena acrylonitril,NBR dan 20% getah semulajadi,NR) dengan mempelbagaikan standard parameter seperti kesan parameter diameter trek haus, kelajuan putaran dan juga beban yang ditaggung telah dikaji. Selain itu, juga untuk mengenal pasti kombinasi optimum parameter yang digunakan semasa penggunaan sistem tali pinggang penghantar agar dapat mengoperasikan sistem tersebut dalam standard yang sesuai dan memperbaiki jangka hayat sistem ini. Untuk tujuan ini, satu reka bentuk eksperimen menggunakan mesin pin-atas-Cakera telah dijalankan untuk mendapatkan keputusan bagi tahap haus dan geseran sistem tali pinggang penghantar dengan menggunakan kaedah Taguchi. Spesimen telah disediakan dengan menggunakan mesin tekan panas dan menjalani beberapa ujian mekanikal seperti ujian tegangan, ujian memutuskan dan ujian kekerasan. Ujian Profilometry telah dilakukan untuk mengukur profil permukaan bagi mendapatkan nilai kekasaran. Tambahan pula, analisis imbasan mikroskop elektron (SEM) telah dilakukan untuk menganalisis struktur permukaan yang terlibat. Melalui imej yang telah didapati melalui imbasan mikroskop electron (SEM), mikrostruktur sampel dapat dikaji. Untuk kehilangan isipadu, nilai optimum untuk mendapatkan jumlah kehilangan yang paling rendah adalah dengan menggunakan kelajuan 50 rpm, beban 10 N dan diameter trek haus 50 mm. Sementara itu, kelajuan 100 rpm dengan beban 50 N dan 100 mm parameter diameter trek haus telah dikira untuk mendapatkan nilai minimum pekali geseran yang mungkin berdasarkan semua kombinasi pada eksperimen.

ABSTRACT

Wear and friction have been known as one of the major causes that affect the life time of conveyor belt system. It may become undesirable as it caused consequence of impact toward the system itself. There are various parameter that lead to this wear and friction problem. For instance service maintenance, surface morphology, material the belt convey and many more. For this research study, focused on investigation and make further research on wear behaviour of rubber compound (80% acrylonitrile butadiene rubber NBR and 20% natural rubber NR) by varying the influential parameter standard such as the effect of parameter of wear track diameter, sliding speed and also the load it's convey had been study. Then also to identify the optimum combination of parameter use during the usage of conveyor belt in order to run the conveyor in appropriate standard and improve the life span of the system. For this purpose, a simple design of experiment using Pin on disc machine are being done to get the result for wear and friction of the belt material by using Taguchi method. The specimen was fabricate by using hot press machine and undergo several mechanical testing such as tensile test, tear test and hardness test. Profilometry are done to measure surface's profile to quantify its roughness and waviness. On top of that, Scanning electron microscope (SEM) analysis is carried out to analyse the structure of the fractured surfaces. For the wear refer to volume loss, the optimum value to obtain the lowest amount is by using speed of 50 rpm, load of 10 N and wear track diameter of 50 mm. Meanwhile, speed of 100 rpm with load of 50 N and 100 mm of wear track diameter were calculated to obtain the minimum number of coefficient of friction possible. By having optimum configuration of parameter setting, the wear and friction during the application of conveyor belt system could be reduced in order to prolong its life time.

Chapter 1 : INTRODUCTION

1.1 Research Background

Based on the previous research paper they were study more about the effect of various surface at different normal load only for the composition of rubber (i.e. 80% on XNBR and 20% only on NR). It is a popular generalization that every composition of rubber will give different wear behavior results as influence by different parameter. Wear of rubber and its components is of great importance because rubber parts are widely used in different applications. Their use is limited by incomplete understanding of their abrasion wear resistance and the means by which this can be controlled and improved.

So it is important to investigate more on the effect of other parameter such as speed, loading and also wear track diameter. As this also have to be considered in order to discover the wear behavior in order to identify the optimum and early warning of conveyor belt failure. Based on the previous journal, it was stated that most often cause for procurement, maintenance, overhaul and restoration of conveyor belt overshadow the cost of the rest of the system[1].This shows that study on the influential parameter that lead to conveyor belt failure need to be focus more as it could improve the life time of conveyor belt thus reducing the maintenance cost.

On top of that, this aspect was important to know because conveyor belt play an important role especially in industries. To knowledge on the level of wear behavior of conveyor belt ranging with wear and balance optimizing the parameter to get optimum usage of conveyor in order to reduce wear and also coefficient of friction.

Research on different parameter need to be emphasize more as in the application of conveyor especially in industries as it was used to provide continuous transport of bulk material from one point to another. So, balance optimization on the parameter settings which involve the speed of conveyor, the load that its convey and also the sliding distance that have to be set in order to make sure the conveyor belt system run efficiently and increase its lifespan.

1.2 Problem Statement

Acrylonitrile butadiene rubber (NBR) can be classified as one of the type of rubber that was used for conveyor belt fabrication. Based on previous study, researcher that study for composition of rubber (80% NBR and 20% NR) investigate on effect of various surface at different normal load only. Thus not providing much detail on wear behaviour as influence by different parameter such as speed, wear track diameter and loading which is important parameter for application on conveyer belt mechanisms that provide continuous transport of bulk material from one point to another. On top of that, parameter speed, wear track diameter, and load are the crucial influencer toward increasing the wear of conveyor belt system which cause consequence of problem such as increase downtime, increase cost of maintenance and also reduce the lifespan of the conveyor belt itself. Based on that, this parameter must be take into consideration in order to improve the lifespan of conveyor belt system.

1.3 Objective

- To investigate and make further research on wear behavior of rubber compound (80% NBR and 20% NR) by varying the influential parameter standard such as loading, speed and wear track diameter at a constant running time
- To identify the optimum combination of parameter use during the usage of conveyor belt in order to run the conveyor in appropriate standard and improve the life span of the system.

1.4 Scope of Research

The main focus of this research is to perform experiment and making analysis on wear and friction behaviour for the material belt conveyor. Basically, the material for testing will be fabricate at the material school and undergo several mechanical testing to identify its properties.

After that, the experiment are design and carried out using pin-on-disc tester machine with G-99 standard procedure which is the material will be tested with different parameter standard varies in wear track diameter, sliding speed and also the load with the constant running time. The result of wear and friction will be plotted into graph and we will see pattern for different parameter tested.

Then analysis also will be carried out by identify the surface structure after going through experiment by using Scanning Electron Microscope (SEM). Besides that, all the input data for different parameter, and the surface pattern after experiment will be analysed and have further discussion in term of rate of wear and friction.

Chapter 2 : LITERATURE REVIEW

Wear and friction in application of conveyor belt is a main concern. Many studies and research has been dedicated to investigate the wear behavior of conveyor belt that was influenced by different parameter. Experimental techniques are mostly used to analyze the wear behavior of the conveyor belt system subjected to vary parameter. An in-depth study of the literature published in this area is necessary to understand the approaches used to address the reliability concerns.

2.1 Mechanisms of Conveyor Belt

The basic idea of conveyor belt is basically a system which function to transport bulk material from of place to another place. It can transport different material based on its application. On top of that, it is widely used in industrial application such as mining, coal handling system in thermal power plant and many other project [2]. To suit its application it can be used either in horizontal transportation or in incline transportation so that the transportation are more convenient. Conveyor belt system consist of two or more pulley and a carrying medium (belt) that rotate around the pulley.

To emphasize more on the belt of the conveyor it consist of several layer which is the top layer, carcass, skim layer and then bottom layer. For the top layer the function are to cover the carcass and withstand the wear process while for bottom layer are also to cover the carcass and provide enough friction to drive the pulley. Usually the top layer consist of polymer based material like natural rubber (NR) or styrene-butadiene (SBR),while Ethylene Propylene Diene Monomer (EPDM) rubber or acrylonitrile butadiene rubber (NBR) is preferred in the case of exposure to heat and oil [2]. The main layer that provide strength and toughness for belt of conveyor are the carcass itself. Carcass is actually reinforcement inside of a conveyor belt. It can be nylon, fiber glass, cloth, polyester and etc. Refer to Fig. 2.1.

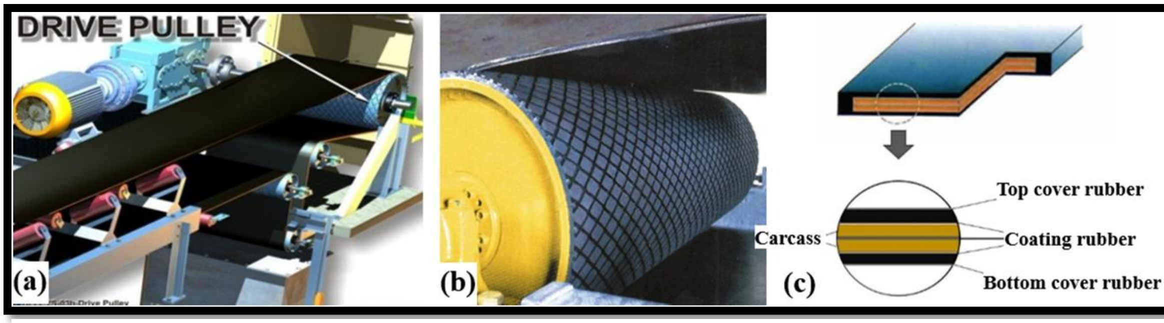

Figure 2.1: (a) conveyor belt system, (b) pulley with rubber lining, (c) schematic of belt structure

2.2 Tribology Concept of Rubber

The study and application of the principles of friction and wear was in the scope of tribology concept. The importance of tribology rises due to the fact that frictional and wear losses consume energy, which otherwise could be saved. On top of that, the concept of tribology of rubber refer to the science and technology for investigating the regularities of the emergence, change and developing of various tribological phenomena in rubber or rubber like material and their tribological application. Tribological phenomena are brought about by a combination of interaction between the interacting surface in the relative motion and environment.

Friction is one the major concern when talking about wear in conveyor belt. Unfortunately, friction is not avoidable in any kind of moving parts like the conveyor. The friction occurs when any type of material have contact with the conveyor belt. The only difference are either the friction is high or not. The difference in the friction force exist in the system will highly influence the wear of the system since the friction will cause abrasion to the conveyor and in longer term, the conveyor will eventually failed. The friction between the conveyor and any other material will depends on various parameter. The main parameter are influenced by speed of contact, load force towards the conveyor and the surface roughness of the contact material.

From the aspect of wear and friction, tribotest is really important in order to studies the wear mechanism appearing in selected tribological application and to increase the fundamental and general understanding of how a material behaves in tribological applications [3]. The exposure of the material to the test under systematically varied loading conditions resulting in various type of wear mechanism involved. For each mechanism, the materials are characterized in terms of wear resistance, friction properties and typical types of surface damage, what may be called the tribological profile of the material.

One of the test which to investigate wear characteristics is using a pin on disc (POD) tribotester to stimulate the wear of the compound at dry contact condition subjected to the several experimental parameters. The results were then discussed by considering the damaging phenomena occurring at the sliding contact.

2.3 Type of Wear Mechanism Involve

Based on the previous journal, there are many type of wear involved in conveyor belt system such as abrasion wear, roll formation and fatigue wear. Abrasion wear are the effect of friction between sliding particle and rigid material and involved of tip sharp asperities. When there are in contact and moving it caused friction that removed small piece and remain small hole. In addition, when there are present of chemical it can result in corrosion to the material as it was being exposed because of the wear. In application of conveyor belt system abrasion wear usually happen between belt and pulley or between belt and our loading material. Basically abrasive wear can be differ in 2 in two type which is two-body abrasion or three-body abrasion as in Fig. 2.2. Two body abrasion involved between two surface while three body abrasion are when there are present of other foreign matter between two surface for example wear debris, lubricant, entrained particle, or even reactive particle [1]

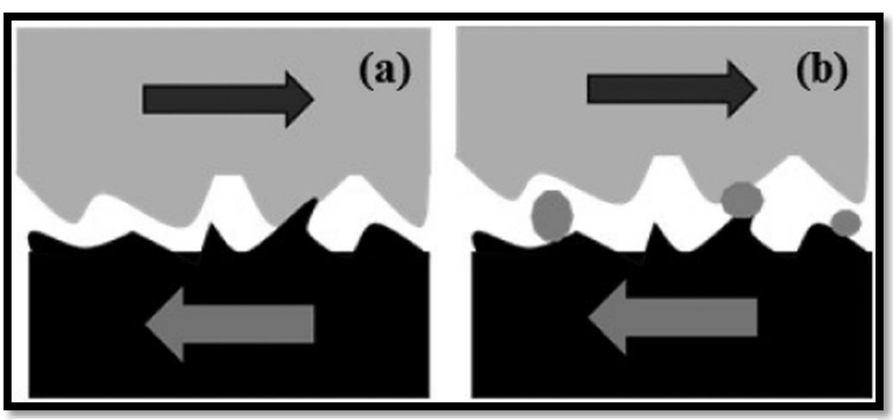

Figure 2.2: (a) two body abrasion, (b) three body abrasion

Fatigue wear is happen when there are contact between asperities and it was in repeated time with a higher stress. This can be caused as influence of loading. The applied stress which is refer to the load is continuous but the quality of being strength of that material cannot adapt to it as a result it will cause small hole and also crack that was generate below the surface. According to the journal at first the crack start at the beneath surface and then it will start to develop and joint with free surface and finally material separation [1] as shown in Fig. 2.3.

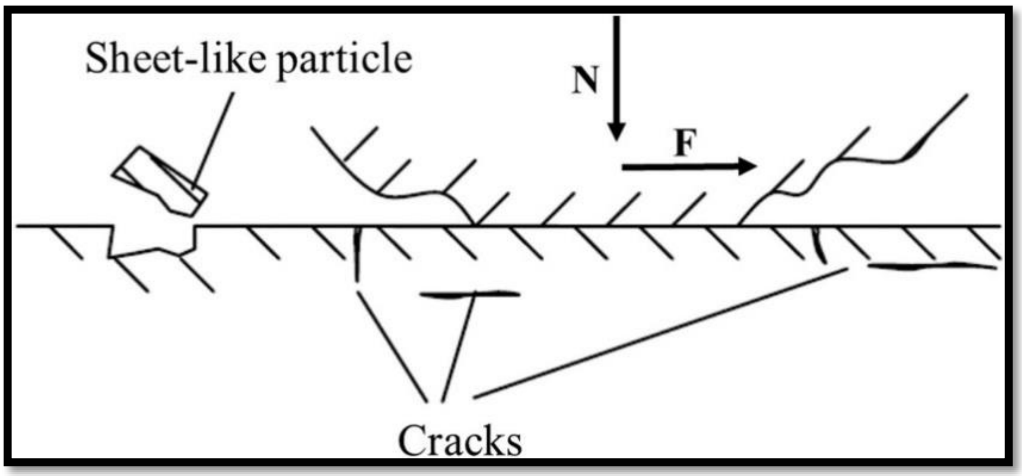

Figure 2.3: characteristic of surface fatigue wear model

Next, roll formation which is also known as Schallamach waves [1] Basically roll formation happen when tear strength of the rubber is low so it can’t resist adhesion. It happen when there are appearance of wave detachment on smooth surface of compressed rubber. The relative motion in the interface causes the waves of rubber due the low elastic modulus of rubber. Due to change of loading conditions along the length of waves with the further advancement of the abrader, the initial adhesion starts to release and the peak of the waves form curly shape.

2.4 Composition of Rubber Compound

Based on the previous journal it was study on effect of wear behaviour against various surface at different normal load. The specimen that are being use are rubber that are varies on different composition. But the main focus are for the composition of rubber which is 80% carboxylate acrylonitrile (XNBR) and 20% natural rubber (NR). Carboxyl groups is important as reactions characteristic of the carboxylic functional group might be employed to crosslink the polymer chains or attach them to other molecules or surfaces. The XNBR provide high tensile strength, tough, abrasion resistant and good physical properties at high temperatures. It's generally exhibits poor hysteresis properties and reduced cold temperature flexibility while NR is known to exhibit numerous outstanding properties. The reason why composition 80% acrylonitrile butadiene rubber (NBR) and 20% natural rubber (NR) are being investigate are because compared to others which is composition 20%-80% and 50%-50%,this one give better performance. It can be referred as MC-1 [4] as typically shown in Tables 2.1 and 2.2.

Table 2.1: Different composition of rubber compound

Sl. No.	Ingredients	Sample No. (wt. in wt.%)		
		MC-1	MC-2	MC-3
1	Carboxylated nitrile rubber (XNBR)	80	50	20
2	NR	20	50	80
3	Carbon black	40	40	40
4	Stearic acid	2	2	2
5	Elasto-710	2	2	2
6	HQ	1	1	1
7	Sulfur	2	2	2
8	CBS	0.7	0.7	0.7
9	ZnO	5	5	5

Table 2.2: Physical properties of rubber compound

Cure characteristics	MC-1	MC-2	MC-3
Scorch time (min)	1	3	3
Optimum cure time (min)	21	8	10
Specific gravity	1.15	1.18	1.21
Hardness (Shore A)	75	70	64
Tensile strength (MPa)	8.27	3.91	1.38
Tear strength (N/mm)	42.07	22.70	58.30
Elongation at break (%)	119.2	171.6	76.80
200% Modulus (MPa)	6.25	2.64	2.22

Nitrile rubber is a synthetic rubber manufactured from a copolymer of acrylonitrile and butadiene. It can be referred to as NBR rubber, Buna-N and nitrile butadiene rubber. On top of that, their specific properties are resistance to non-polar solvents, fats, oils and motor fuel. It is ideal for the feed mill industry and raw materials intake such as sunflower seeds, fish meal, tapioca and etc. Furthermore, resistance to oil can be beneficial for lubrication as oil and grease are the most common lubricating agent. Grease is composed of oil and a thickening agent to obtain its consistency, while the oil is what actually lubricates. This could be help in maintaining the system. Besides that, for resistance to fat could be help in improve the stretching of conveyor belt itself. This was good as oil and fat can effect on the performance and life expectancy of a conveyor belt because it penetrates into the rubber causing it to swell and distort, often resulting in serious operational problems.

The essential part of produced NBR is used for production of sealings, tubes and different supports for auto industry, for oil and engine fuel transport equipment, then for machinery and pump they are used at coating of printing machinery surfaces, at production of oil-proof conveyor belts and others products requesting resistance to oils.

2.5 Method for design of experiment (Taguchi method)

Basically, experimental design is a process in which we observe and analyses the result as the change of the parameter that could affect the performance of a system. The parameter that could influence the system includes controllable or uncontrollable. In order to identify the consequence of changes, large number of experiment have to be carried out. As refer to that, taguchi method is one of the method that proposed to design the experimental analysis by using orthogonal array in order to obtain optimum result by performing minimum number of experiment. By applying this, efficient testing of the main effects of the parameter can be studied, which in advance can also saving more time, money and resources instead of performing a full factorial designed experiment.[5] The parameter are level first. Each column in the array represents a factor of parameter, while each row represents an individual trial specifying the level of each factor.[6] The result are then transformed into signal-to-noise (S/N) ratio based on the characteristic needed which indicates the degree of the predictable performance. There are three standard types of S/N ratios depending on the desired performance response which are lower the better, nominal the best and higher the better. [7] For lower the better characteristic the formulation are:

$$\boxed{\eta = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y^2 i \right)} \qquad \text{Eq (2.1)}$$

Where, n is sample size and y is volume loss in that run. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance.[8] As result, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings.[9]

Chapter 3 : METHODOLOGY

Basically the methodology of the overall project can be referred below in Fig. 3.1. The detail of each process will be discussed.

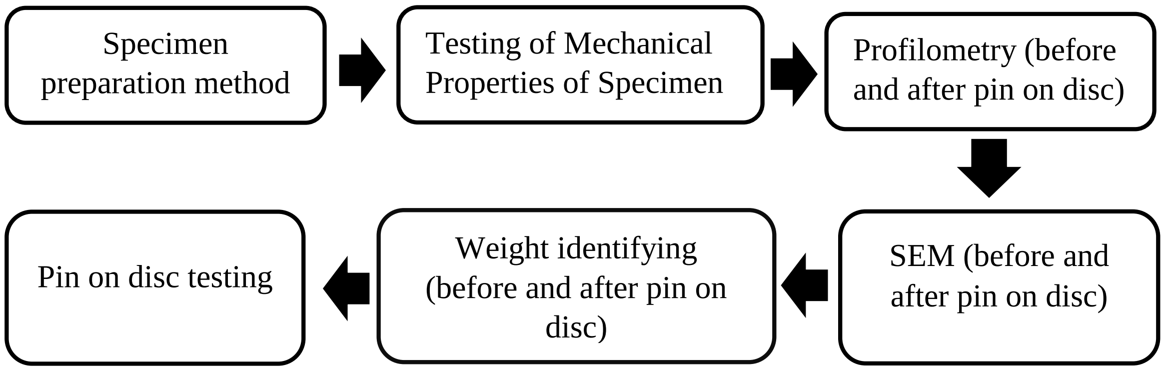

Figure 3.1: Flow chart of the work

3.1 Specimen Preparation Method

The preparation of specimen was done at Material School Engineering as all the requirement are available there. The fabrication process undergo 3 major steps which are mixing and compounding process, curing process and also rubber shaping process. Based on that, for mixing and compounding process the composition of rubber compound can be referred to Table 3.1 below:

Table 3.1: composition of rubber compound

Ingredient	Sample no (wt. in wt. %)
Nitrile butadiene rubber (NBR)	80
Natural rubber (NR)	20
Carbon black N330 (filler)	40
Stearic acid (activator)	2
Processing oil	2
BKF (antioxidant)	1
Sulphur (vulcanization agent)	2
CBS (rubber accelerator)	0.7
ZnO (activator)	5

For the ingredient, the natural rubber that was used are Standard Malaysia Rubber Grade L (SMRL), filler carbon black are type N330 which suitable for industrial compound, rubber antioxidant 2246 (BKF) and N-cyclohexyl-2-benzothiazyl sulfonamide (CBS). At the first step, the compounding ingredient was weighted using Sartorius weight balance model based on the composition given as shown in Fig. 3.2. The weight need to change from w t. in wt. % to gram. The formulation is as shown in Eq. 3.1:

$$\boxed{\frac{Wt.\,in\,wt.\%}{Total\ Wt.\,in\,wt.\%} = \frac{weight\ in\ g}{our\ total\ weight\ compound\ in\ g}} \qquad \text{Eq (3.1)}$$

All the rubber compound are prepared using two roll rubber mixing mill machine type XK-160 (refer to Fig. 3.3) with a mixing sequence in Table 3.2:

Table 3.2: mixing sequence for two roll mill process

No	**Step of mixing**	**Duration (min)**	**Cumulative (min)**
1	Natural rubber (NR)	1	1
2	Synthetic rubber (NBR)	2	3
3	Activator(zinc oxide)	2	5
4	Activator(stearic acid)	2	7
5	Filler(carbon black N330) + processing oil	10	17
6	Accelerator (CBS)	3	20
7	Antioxidant (BKF)	3	23
8	Curing agent (Sulphur)	2	25

Please ensure your hand should not pass the yellow safety guard when you drop the rubber sample. The rubber compound was make to about 2.5 mm sheet and was kept in a freezer for at least 24 hour before further test in order to prevent crosslink formation and to allow chain relaxation.

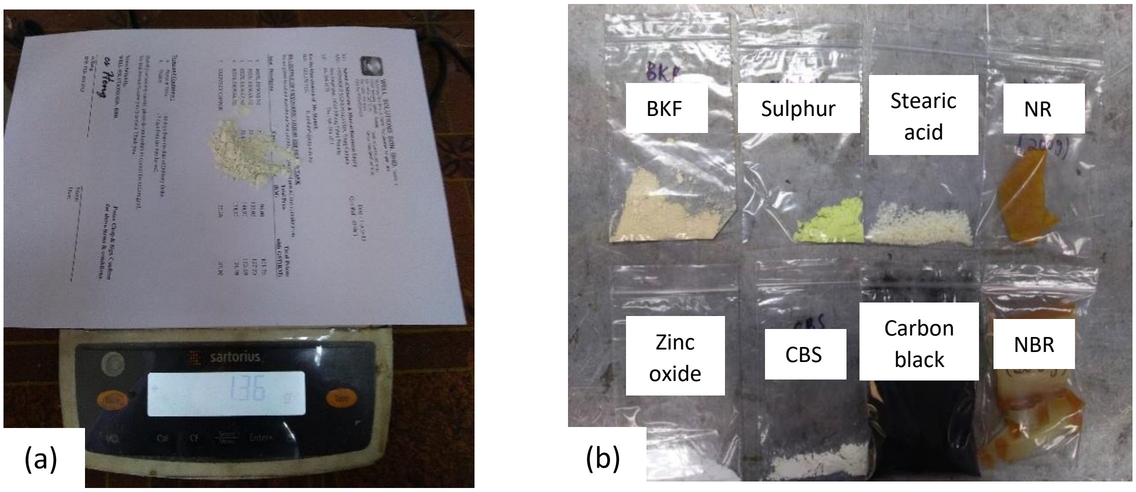

Figure 3.2: (a) weighting process using weight balance model Sartorius (b) all ingredient for rubber compound

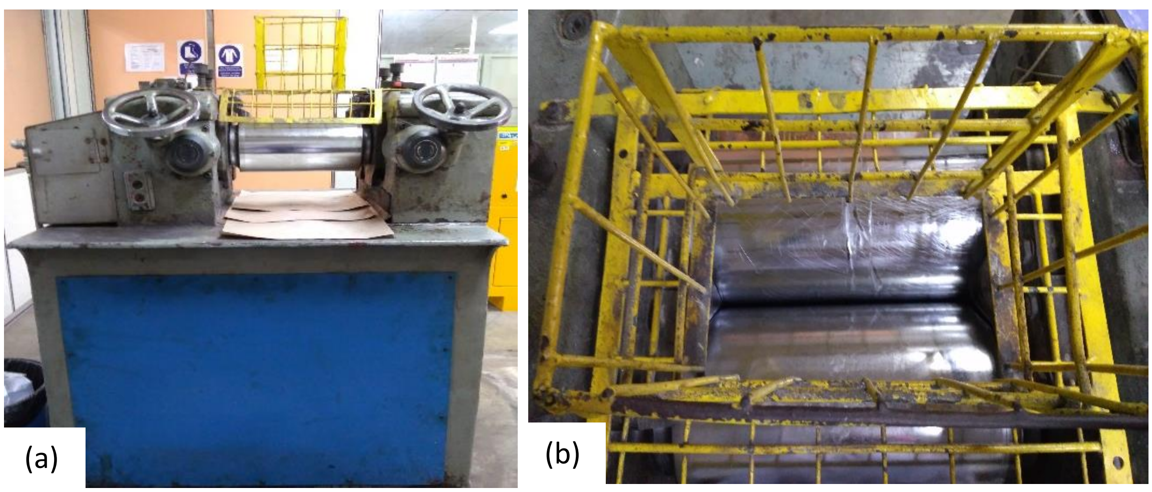

Figure 3.3: (a) Two roll rubber mixing mill machine type XK-160 (b) Position of roll mill and yellow safety guard

Curing process is defined as toughening or hardening polymer material by cross-linking of polymer chains that also known as vulcanization. The purpose of this process are to determine maximum optimum cure time (t_{90}) by using Rheometer Monsanto Model MDR 2000 machine (refer Fig. 3.4) which MDR refer to moving die rheometer. This method are based on ASTM D2084 which is Standard Test Method for Rubber Property, Vulcanization Using Oscillating Disk Cure Meter. The sheeted rubber was taking out from freezer one hour before the curing process. Then, 4 gram sheeted rubber was put in between Overhead Heated Projection film (OHP) and then was placed in between heated top and lower die cavity and closed it. The cavity was maintained at vulcanization or cure temperature, 150°C. The pressure was set to 50 Psi. The result of optimum cure time can be referred from rheograph produced after 30 minute.

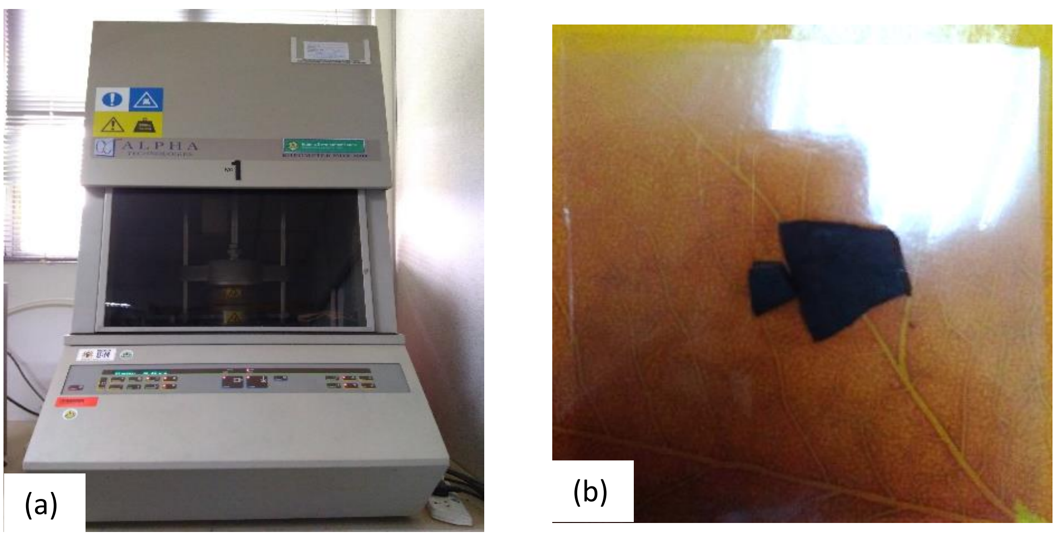

Figure 3.4: Curing process: (a) Rheometer Mosanto Model MDR 2000 machine (b) 4gram of rubber between OHP film

Rubber vulcanization or shaping process is a process of transforming the rubber compound to more durable material. The purpose of this process is to prepare a test piece for physical testing which are tensile and tear and specimen for experiment. Basically compression molding was used to perform this process by using hot press 120 T machine. The process begin with a piece of uncured rubber being weighted to specific mass based on type of mold and was place directly into the rubber mold cavity. The compound was held in the mold under high pressure, 1000 psi and temperature, 150 °C to activate the cure system in the compound. Rubber is vulcanized. Table 3.3 shows the test perform, parameter setting and the mold use for the process:

Table 3.3: Parameter setting and mold use for each testing

TESTING	PARAMETER SETTING	MOULD
Tensile test and tear test	• Temperature : 150 °C • Time : cure time (T90) 11.12 m.m = 667.2 s • Weight of rubber : 35 g • Thickness of mold : 2 mm	
Specimen for wear and friction experiment	• Temperature : 150 °C • Time : cure time (T90) + 5 min 11.12 m.m + 5 min = 967.2 s • Weight of rubber : 125 g • Thickness of mold : 9.2 mm	

3.2 Testing of Mechanical Properties

3.2.1 Tensile Strength Test

One of the important common measured properties of rubber compound is tensile strength as it can ensure quality control of the compound itself. The tensile strength help determine the effectiveness and behavior of a material when a stretching force acts on it and are done to determine the maximum strength or load that the material can withstand. By taking into consideration of this properties, it can allow designers to predict how the compound will behave in their intended applications. To get the standardize test result, first of all the test specimen was prepared by cutting the flat sheet rubber compound manually to dumbbell shape using dumbbell cutter. The size of the specimens were prepared as shown in Fig. 3.5 and gauge length was 30 mm.The reason of having dumbbell shape is to create a breakage prone area on the specimen so if the breakage occur other than that area, the test declared as fail. Then, the average thickness of the five specimens are recorded which could not be less than 1.5 mm and not more than 3mm (1) by using Mitutoyo Dial Thickness Gage 0-10mm with 0.01mm resolution. The process of testing involves placing and gripped the specimen in between the jaws at the Tensometer (Instron) machine (Fig 3.6). Make sure to adjust the specimen so that it will be strained uniformly along its length. After that, start to apply tension to it by moving the jaws in opposite direction until it breaks. The tensile strength of the rubber compound was measured with a computerized Tensometer (Instron) 3366 in accordance with the ISO 37, ASTM D412, BS 903: Part A2 and DIN53504. [10] ASTM D412 standard which is Standard Test Method for Vulcanized Rubber and Thermoplastic Elastomer Tension. The machine crosshead speed are at 500mm/min and conducted at 27°C of room temperature. The graph of stress against strain for all specimens was obtained and average value was recorded.

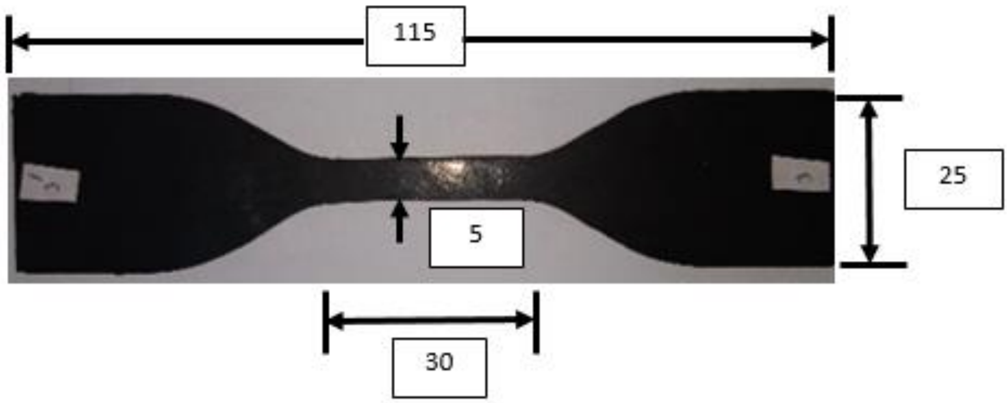

Figure 3.5: The size of tensile test specimens. All dimensions are in mm.

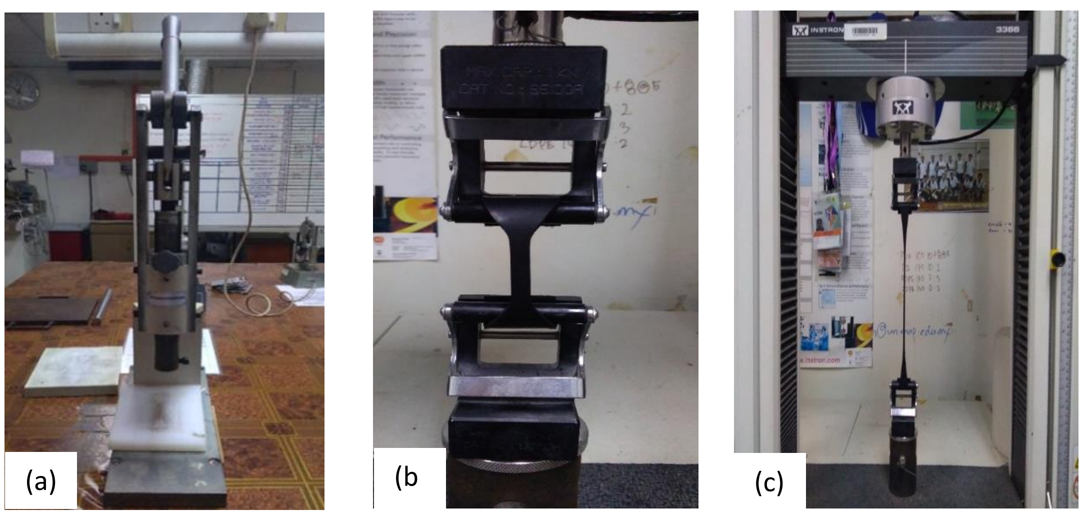

Figure 3.6: Tensile test: (a) dumbbell cutter that was used to cut the specimen (b) specimen grip on jaw (c) specimen when stretching force acts on it

3.2.2 Tear Strength Test

Vulcanized rubber often fail due to the generation and propagation of a special type of rupture called a tear. Due to this, tear strength test was conducted to measures the resistance of rubber compound to resists the growth of any cuts when under tension. The specimen was prepared and method for measurement are accordance to ISO 34, ISO 816, ASTM D624, and BS 903: PART A3, DIN 53507 and DIN 53515. [11] ASTM D624 are specialised for Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers. The testing specimens are prepare by cutting the rubber compound accordance to the standard shape which is type T or trousers shape in five specimens in order to get the average. The size of the specimen are shown in Fig. 3.7. For each of the specimen the thickness was recorded by using Mitutoyo Dial Thickness Gage 0-10mm with 0.01mm resolution. The process of testing involves placing and gripped the specimen in between the jaws at the Tensometer (Instron) 3366 machine. Make sure to adjust the specimen so that it will be strained uniformly along its length and then start to apply tension to it by moving the jaws in opposite direction at a constant rate of crosshead which is 500mm/min until the specimen is completely breaks. The tear strength of the rubber compound was measured with a computerized Tensometer (Instron) 3366 as refer in Fig. 3.8.

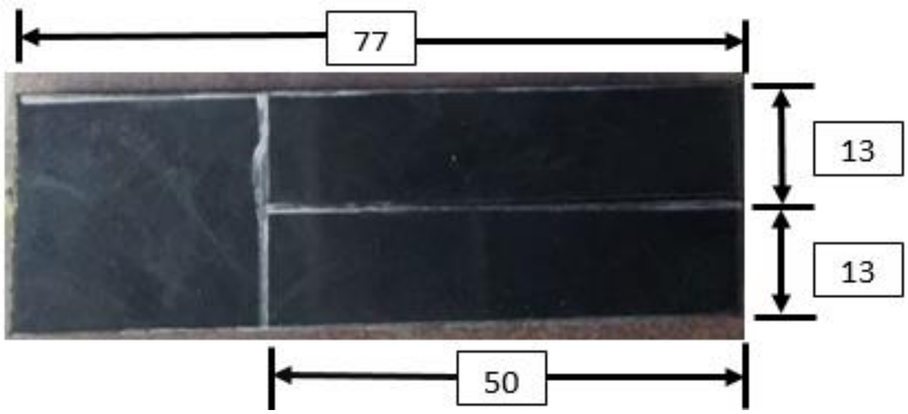

Figure 3.7: The size of tear specimens. All dimensions are in mm

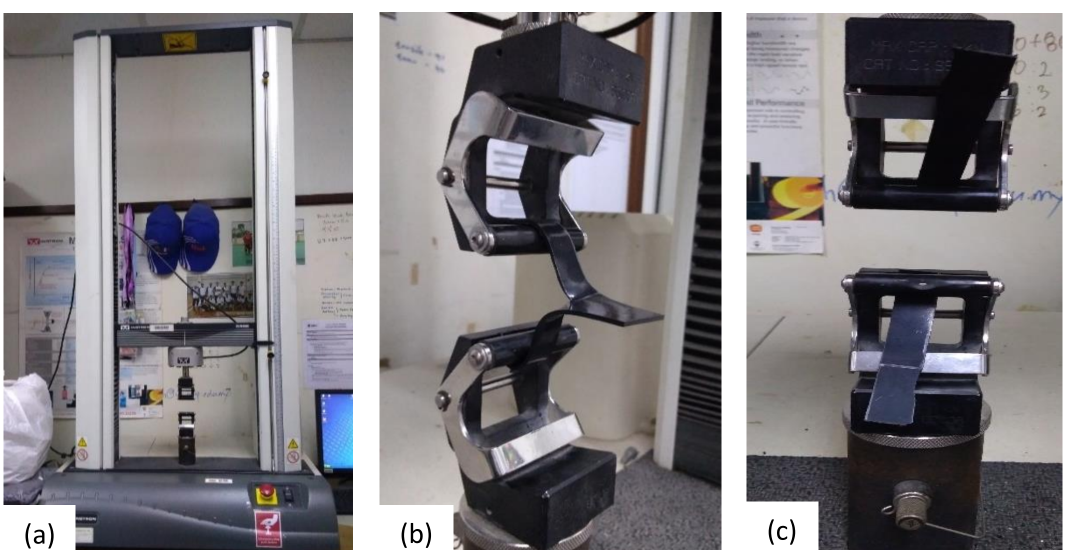

Figure 3.8: Tear test: (a) Tensometer (Instron) 3366 machine that was used (b) specimen grip on jaw (c) Specimen when stretching force acts on it.

3.2.3 Hardness Test

Hardness test is based on the penetration of a specific type of indentor when forced into the rubber compound. Teclock Durometer Hardness Tester model GS-706G was used to perform the hardness test. In this test shore A scaled was used. The International Rubber Hardness Degrees (IRHD) scale has a range of 0 to 100. Higher values indicate harder compound, lower values indicate softer compound. The test method was based on ASTM D2240 which is Standard Test Method for Rubber Property-Durometer Hardness. [12] The specimen is first placed on a hard flat surface. The indentor for the instrument is then pressed manually into the specimen and make sure the flat metal plate on the bottom is parallel to the surface. After that, the hardness reading was obtained. 3 specimens were tested and the average values recorded. Refer to Fig. 3.9

Figure 3.9: Teclock Durometer Hardness Tester model GS-706G that used to conduct hardness test

3.2.4 Density

Simple experiment were conducted to measure one of the rubber compound physical properties which is its density. Besides that, in order to change mass loss to volume loss, the density of the compound were needed. To get the density, a measuring cylinder were used with the sensitivity of 1 ml and also electronic balance. Rubber compound were first weighted to get its weight. Then, 40 ml water was pour into the measuring cylinder as its initial volume. Slowly drop the rubber compound and the final volume of water was recorded. Finally, the density was calculated based on the volume change and mass of the rubber compound as in equation below:

$$\boxed{\text{Density } (\mathrm{g}/cm^3) = \frac{mass(g)}{volume(ml)}} \qquad \text{Eq (3.2)}$$

3.3 Testing of Wear and Friction Properties of specimen

3.3.1 Wear and Friction Test

By performing wear and friction testing it can determine the performance of our rubber compound in applications where abrasive exposure will degrade our material's properties or surfaces over time. Pin on Disc tester (POD) refer Fig 3.10 was used to determine the wear and co-efficient of friction of the rubber compound with method for measurement are accordance to ASTM G 99 standard which is Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus. [13] The specimen was prepared by cutting the rubber to rectangular shape with size dimension as shown in Fig. 3.11. To begin the test, adjust the wear track diameter according to our setup by adjusting the sliding plate which can be range between 0-160 mm. Then, the specimen was inserted securely in its holder and make sure it is perpendicular contact to the disk surface. Specimen are tested under abrasive conditions that is by having sand paper with grade 2000 as the bottom disc surface. After that, add the mass to the system lever to develop the selected force pressing the specimen against the rotating disc. The wear measurement should be reported as the mass loss after the experiment had been tested. The specimen has high wear if the mass loss is higher and vice versa. This is cause by abrasion between the specimen testing and the surface of disc as the effect of different parameter standard. The material are being wearing away which will reduce the mass and damage the surface structure of the specimen. Besides that, to get accurate result the weight have was measured three times for each data and the average was calculated. The difference in initial and final weight gives the loss of material in turn wear rate of material. The specimen is weighed by using electronic balance.The wear rate that calculated from weight loss and can be expressed in term of volume loss by using the following Eq. 3.3:

$$\boxed{\text{volume loss } (\mathrm{mm}^3) = \frac{\text{mass loss (g)}}{\text{density } \left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right)} \times 1000} \qquad \text{Eq (3.3)}$$

Sliding distance was calculated in order to identify the total distance specimen can make contact with the surface of the disc. As each set of specimen using multiple different parameter such as speed, load and wear track diameter, it is good to have sliding distance as additional parameter that could represent speed and wear track diameter as sliding distance is calculated by using equation :

$$\boxed{\text{Sliding distance (m)} = 3.142 \text{ x speed (rpm) x running time (min)}} \qquad \text{Eq (3.4)}$$

Specific wear rate or also been known as dimensional wear coefficient were also calculated as it takes load and sliding distance variable into account which give more verification on the wear behavior of the rubber compound. The effect of variable that cause wear can be studied in more specific detail. It can be calculated using the following equation:

$$\boxed{\text{Specific wear rate (mm/Nm)} = \frac{\text{volume loss } (\mathrm{mm}^3)}{\text{load (N) X sliding distance (m)}}} \qquad \text{Eq (3.5)}$$

Coefficient of friction could be obtained from the computerized data in Winducom 2010 software.

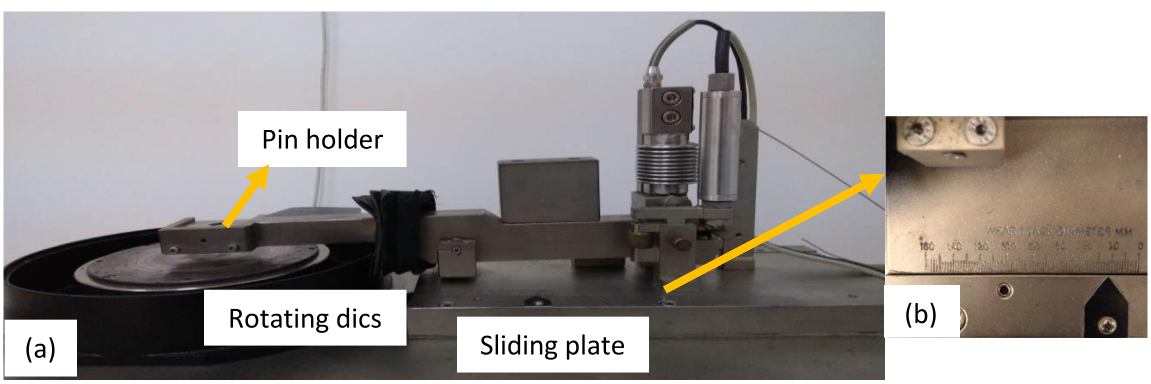

Figure 3.10: (a) Pin on disc tribotester (b) range of sliding plate

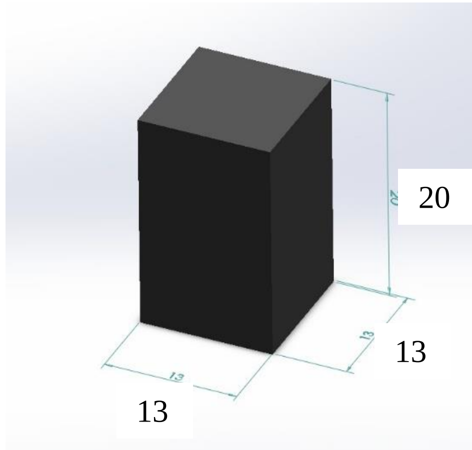

Figure 3.11: size of specimen. All dimension in mm

It was test for different parameter which have 3 level for each parameter as stated below in Table 3.4:

Table 3.4: level of parameter being used

Parameter	**Level**		
	-1	**0**	**1**
Speed (rpm)	100	300	500
Wear track diameter (m)	0.5	0.75	0.1
Load (N)	10	30	50

In order needs to relate all the parameter setting individually to each of other parameter this experiment was conducted by using Taguchi Method which consist 9 set of experiment instead of 27 set if using full factorial design. If using full factorial, the experiment become laborious and complex, if the number of factor increase.[7] For taguchi method, each 9 set of experiment was conducted 3 times which overall consist 27 experiment to count for the variation that may occur as in Table 3.5. Of each set of experiment, the variation for the result was being used to calculate the signal to noise ratio (S/N ratio). For each level of those three parameter the S/N ratio was calculated and the value was used to determine the optimum level of each parameter that were set. Furthermore, the objective function based on this experiment are smaller the better, so the S/N ratio (ɳ) for this function are:

$$\eta = -10 \log_{10}(\frac{1}{n}\sum_{i=1}^{n} y^2 i \qquad \text{(Eq 2.1)}$$

Where, n = sample size and y = volume loss in that run

Table 3.5: Data for experiment using orthogonal array Taguchi method

Set	Parameter		
	Speed (rpm)	**Wear track diameter (mm)**	**Load (N)**
1	100	50	10
2	100	75	30
3	100	100	50
4	300	050	50
5	300	75	10
6	300	100	30
7	500	50	30
8	500	75	50
9	500	100	10

3.4 Scanning Electron Microscopy

Scanning electron microscopy (SEM) is function to record the images of a surface of specimens at a desired position to obtain topographic picture with better resolution and depth of focus. The fracture surface of the test specimens after being tested on Pin on Disc tester can be captured by using SEM (refer Fig. 3.12). In this case, we are using secondary electron signal (SE) as it is more for inspection of the topography of the specimen's surface. To use SEM, data are collected over a selected area of the surface of the sample with different magnification, and a 2-dimensional image is generated that displays information variations in these properties. Besides that, SEM can achieve resolution better than 1 nanometer. Moreover, SEM was performed on the specimen before and after the POD test so that the different in the topographical structure can be compared.

Figure 3.12: Scanning electron microscopy

3.5 Profilometry

In order to measure surface's profile to quantify its roughness and waviness, Surfcom 130 A roughness tester machine was used (refer Fig. 3.13). The machine work by having stylus moved vertically in contact along the surface of the specimen. Waviness is measured through its 50 mm tracing driver while the roughness is measured based on its 1.6 mm deflection range. It will evaluate and displayed roughness values such as Roughness average (Ra) together with the roughness profile.

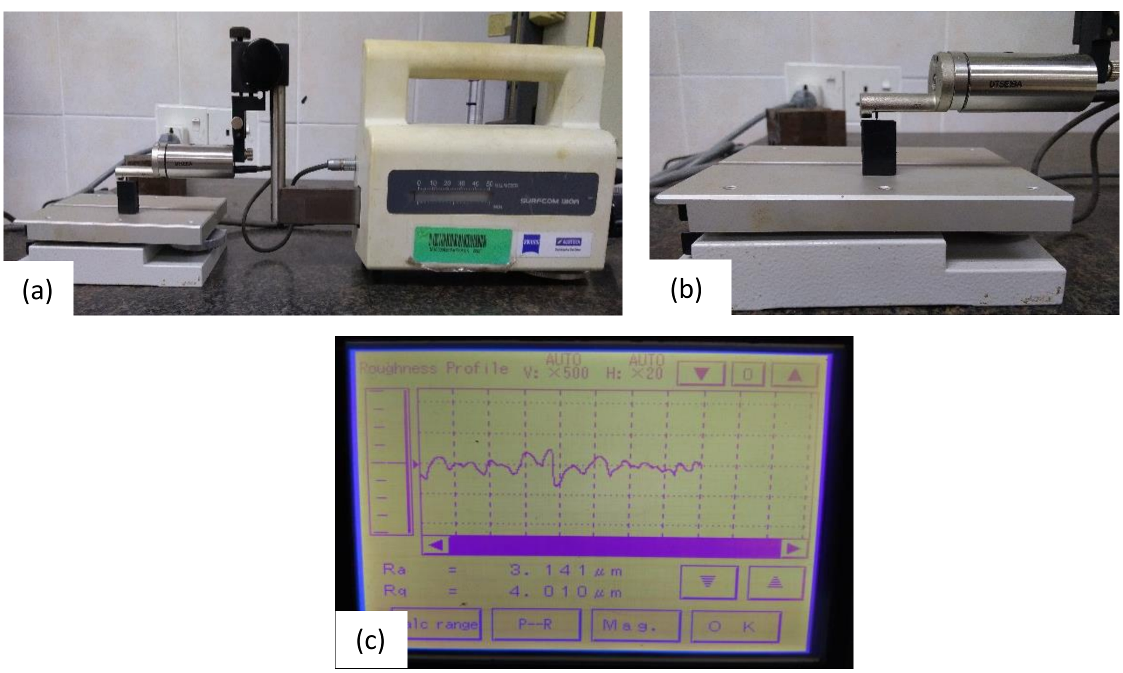

Figure 3.13: (a) Surfcom 130 A roughness tester machine (b) position of specimen during testing (c) Result of roughness profile