Study into the Effect of Elevated Temperature on the Friction, Wear Behavior and Wear Mechanism of Typical KTMB Rail Track using Pin-on-Disc Testing Technique

by

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Dissertation submitted in partial fulfillment of

the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

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CERTIFICATION OF APPROVAL

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Approved by,

………………………………
(Mustafar bin Sudin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JUNE 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD SHAZWAN BIN CHE ISMAIL

ABSTRACT

For many applications, including power generation, aerospace, rail track and the automobile industry, high temperature wear provides serious difficulties when two or more surfaces are able to move relative to one another. During, rail track applications that operate at higher temperatures without any lubrication contact between the rail track and train’s wheel will consequently accelerated wear. This project studies the effect of elevated temperature on the typical rail track. The main activity for this project is to investigate the wear behavior and identify the wear mechanisms during the elevated temperature. This activity has been done by conducting experiments using pin on disc testing technique. The equipment which perform pin on disc testing was Multi-specimen Wear Tester. The test has been done according to ASTM G99. The procedure for this experiment was started with the specimen preparation. After that it followed by the taking the temperature at the real rail track situation. Then, the author takes the initial data before the experiment. The author continues with the experiment and lastly completed with the analysis.

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CHAPTER 1

INTRODUCTION

1. BACKGROUND

Wear is an unavoidable and a potentially serious problem in all areas of engineering. Under the normal conditions, a good design practice along with appropriate materials selection and the use of an appropriate coating or lubricant system may be sufficient to minimize wear of interacting surfaces or components to an acceptable level.

In general, there are four different types of wear in engineering components: adhesive, abrasive, erosive, and fretting. In adhesive wear, the wear appears from the adhesion between two sliding surfaces. When the two surfaces rub each other, a certain area of one surface comes in contact with a similar area on the other surface. These two surfaces start to wear and particles are released from the two surfaces as wear debris. Secondly is abrasive. Abrasive wear occurs, when a sharp object is pressed onto another surface. The softer material gets grooves that are cut into the surface; and this removal of material is also called wear debris. Next is Erosive. Erosive wear is mostly dependent on nature and mostly caused by impact of erosion. Fretting wear takes place when slipping occurs between two materials. The slipping that takes place is mostly caused by vibrations [1].

From the work of Archard and Hirst, study was done on the basis of the wear by volume removal versus sliding distance. The volume removal is the amount of material that used during the test runs of the pin and disc. They estimated the volume removal by using the Archard's equation. The calculations form the literature uses the wear coefficient, load, sliding distance, and hardness [1].

2. PROBLEM STATEMENT

In the middle of the day, the environment temperature rise until exceed its maximum about 34˚C. But for the steel rail track, the temperature may rise in range of 50˚C to 90˚C. The rising temperature for rail track will give the major effect on friction, wear behavior and wear mechanism. At the elevated temperature, the different wear regime and friction behavior will occur. Further investigation will provide the detail of the effects for rail track in elevated temperature. With the knowledge of the wear behavior and wear mechanism obtained this study, hope that it will prevent the rail track from damages and failures.

3. OBJECTIVES

i. To investigate the wear behavior during the elevated temperature of sliding action.
ii. To identify the wear mechanism during the sliding action at elevated temperature.
iii. Analyze the results obtained from this study.

4. SCOPE OF STUDY

This study scope is about the effect of elevated temperature on friction, wear behavior and wear mechanisms of Typical Rail Track Using Pin on Disc Testing Technique. The rail track that exposed to the high temperature will affects based on friction, wear behavior and wear mechanisms. By using a pin on disc technique, the rail track sample material will be tested to investigate the wear behavior the wear mechanism during elevated temperature due to sliding condition. After that, both results must be analysis and summarize.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1 LITERATURE REVIEW

2.1.1 - Friction

2.1.1.1 Definition of Friction

The frictional force is defined as the resistance to movement produced when one body moves against another. Friction may be defined as sliding or rolling friction (see Figure 2.1). Sliding friction can be said to occur where the interfaces of two rigid objects move relative to one another, whereas in rolling friction, one or both of the objects has freedom of movement other than that in the direction of the sliding action, allowing it to 'rotate' or 'roll'. It is to be pointed out that due to other factors such as misalignment or relative movement of asperities past each other on interface surfaces, that an element of sliding friction will always be involved where rolling wear occurs [2].

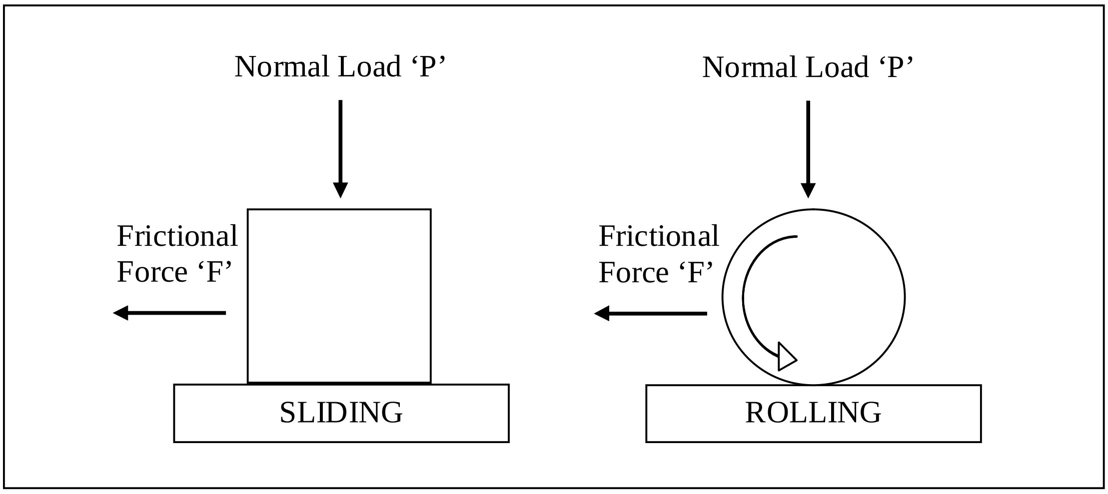


Figure 2.1: Modes of relative motion – sliding and rolling [2]

2.1.1.2 The Sources of Unsteady Data [3]

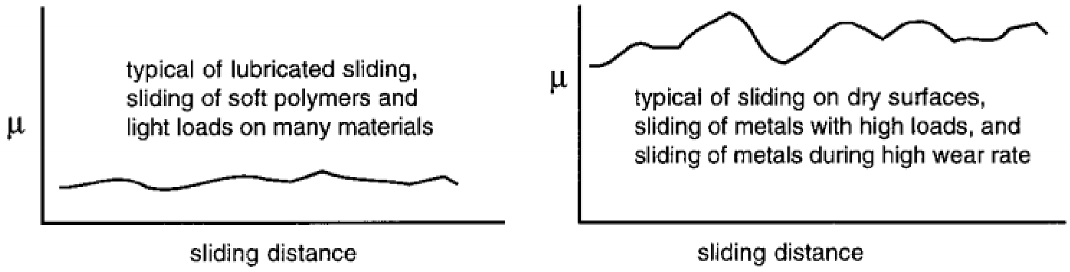
Unsteady data may be classified as two major types, those that are independent of machine dynamics and those that result from interaction between inherent frictional behavior and machine dynamics. There are at least four sources of unsteady data that are independent of machine dynamics. These are:

1. Surface roughness, with wavelength of the order of, or larger than, the size of contact regions, which usually produces high frequency variations in friction [3].

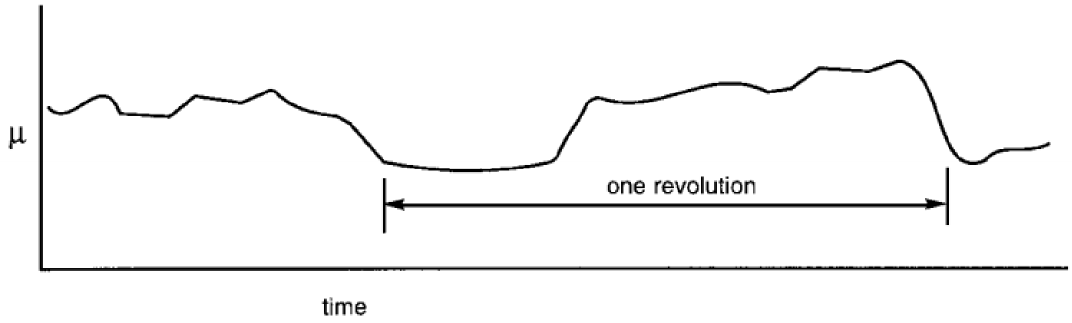
2. Inherent and repeatable variation of friction along a sliding path, under all steady-state conditions with ideal specimens and machines, usually producing high frequency variations in friction. These variations are greatest in the case of dry metals, ceramics and hard polymers: they are the least in the case of well-lubricated surfaces or when a metal sphere slides on a soft plastic. A sketch of such data is shown in Figure2.2a [3].

3. Inherent and repeatable variations of low frequency that are cyclical in nature due to misaligned test machine parts, bad bearings, poorly made specimens, or vibrations transmitted from outside the machine, etc. Figure 2.2b shows such cyclical variations superposed upon noncyclical data [3].

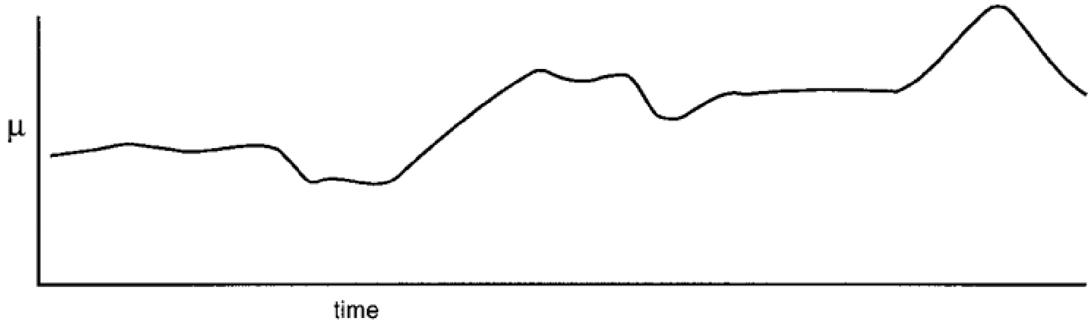
4. A long-term change due to changing conditions in the contact region of specimens. This is shown in Figure2.2c [3].



a. Friction behavior under two sets of conditions



b. Irregularity of friction due to machine inaccuracies



c. Long term changes in friction due to changes in friction mechanisms

Figure 2.2: Three forms of surface traces and read-out.

2.1.2 - Wear Theory

2.1.2.1 Archard and Hirst – Distiction between Mild and Severe Wear

In 1956, Archard and Hirst categorized wear into groups, mild and wear and severe wear.

'Mild wear' occurs when the debris produced (generally oxide) prevents direct metal-to-metal contact. Although Quinn does not specifically mention the oxidation reaction in his review of oxidational wear when discussing the definition of mild wear, the vast majority of studies into sliding wear to date have concentrated on the oxidation reaction. Debris produced is a very small size (less than 1μm) and complete coverage is not necessarily archived, with oxide in many cases only forming and load-bearing areas such as asperities. Electrical contact resistance is high, due to the presence of the oxide on the wear surface [2].

The model that Archard and Hirst proposed from their work assumes a true area of contact, occurring between a limited number as asperities on the contacting surfaces. The true area of contact can be calculated by equation [2]:

$$A = P/H \qquad \{2.1\}$$

if W is the worn volume and L is the sliding distance producing the wear, then W/L is dependent on and is therefore proportional to the area of the friction junctions or true area of contact [2].

$$W/L \propto A \text{ or } W/L = K_aA \qquad \{2.2\}$$

This gives:

$$W/L = K_aP/H \text{ or } W = K_aPL/H \qquad \{2.3\}$$

the dimentionless parameter K_a being the constant of proportionality and also the probability of a wear particle being generated. It also referred to as the "wear coefficient". An alternative form ($K_1 = K_a/H$) is:

$$W = K_1PL \qquad \{2.4\}$$

K_1 being referred to as the "*K* factor". Taking equation 2.3 and rearranging allows K_a to be expressed in terms of wear depth, sliding velocity and pressure. Dividing by the apparent area of contact gives:

$$d/L = p(K_a/H) \tag{2.5}$$

where d is the depth of wear (volume divided by area) and p is the mean pressure (load over area). If v is sliding speed and t is the time of sliding, $L = vt$. Thus:

$$d/vt = p(K_a/H) \text{ or } t = dH/K_a pv \tag{2.6}$$

$$K_a = dH/pvt \tag{2.7}$$

The above applies that the level of wear will be proportional to the sliding distance and applied load and work by Archard and Hirst showed this to be true over a limited range [2].

The absence of such layers allows contact between the metallic interface, with adhesion, plastic deformation and to varying degrees, material transfer between the surfaces. This is typical of the 'severe wear' situation, examples of which have already been observed in the higher temperature in sliding wear (see Figure 2.3) [2].

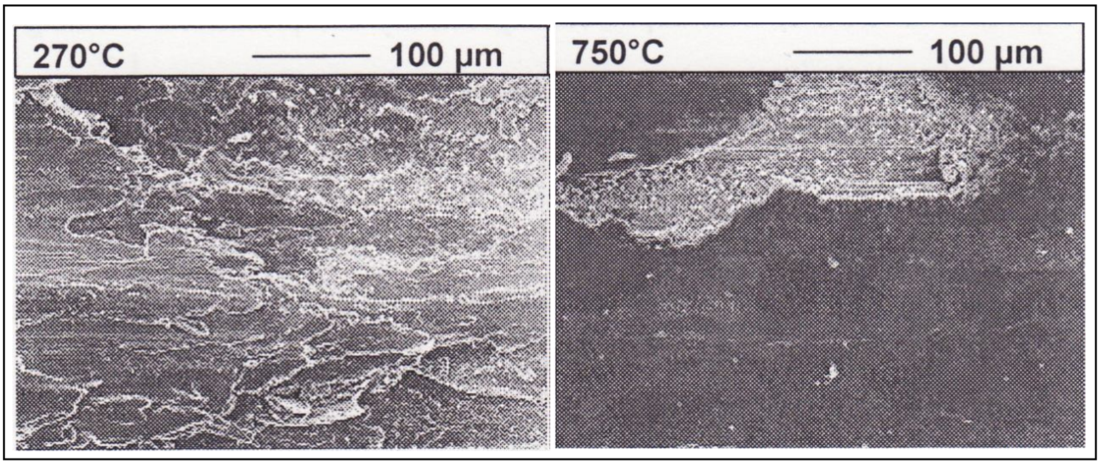


Figure 2.3: Wear surfaces produced during the sliding at 270^{o}C and 750^{o}C [2]

2.1.2.2 Adhesive Wear

In the contact of wear, adhesive wear occurs when contact is made between two surfaces moving or sliding past each other. Provided that the surfaces are clear of contaminants, oxides or other reaction products, the formation of a strong ionic or covalent bond can occur at these points of contacts, which most often are the raised asperities on the sliding surfaces. For sliding to continue, the applied force must be sufficient to lead to failure of the resulting junctions by shear. Where two dissimilar materials are in contact, the strength of the junction is usually the strength of the softer or weaker material, as the strength of the bond between the two is normally stronger than the cohesive strength of the softer material [2].

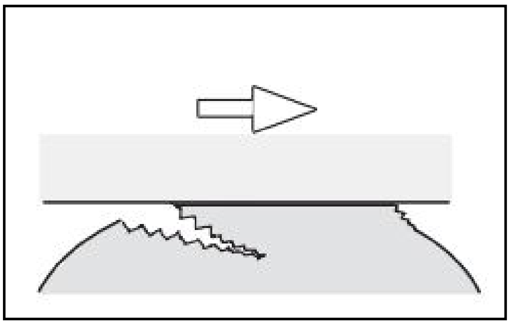


Figure 2.4: Adhesive wear

2.1.2.3 Abrasive Wear

Abrasive wear is the removal of surface material from an object by the action of a second agent or medium. This may be the surface of another object or by hard particles trapped between the two interacting surfaces – referred to as ‘two body’ and ‘three body’ abrasion respectively. The hard particles or surface must be 1.3 times harder than the softer material undergoing abrasion, which Hutchings and Ludema note is the difference of one unit on Moh’s scale of mineral hardness [2].

Hutchings quotes three common models for abrasive wear via plastic deformation, these being *cutting, ploughing* and *wedge-forming*. Adhesion can play a greater or lesser role in the model of abrasive wear observed [2].

i. Cutting – the movement of the asperity or third body ever the softer material results in the creation of a deep groove upon the example surfaces, with long strips of debris forming at the point of contact. This procedure the deepest groove of all three models with the strongest adhesion.

ii. Wedge-forming – material is pushed up ahead of asperities on the counterface, resulting in a grooved wear scar with transverse cracks. Wear rate are lower that for the 'cutting' mode, this model tending to occur where adhesion between surface and counterface is strong.

iii. Plouging – adhesion between the harder and softer material is relatively weak and the grooves thus created are shallower, with lower penetration of the harder asperity or third body into the softer material. Formation of wear debris particles cannot be clearly seen at the point of contact

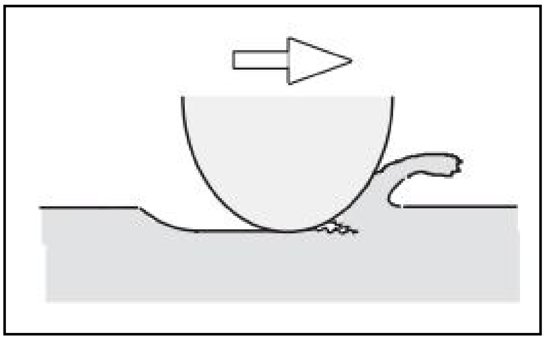


Figure 2.5: Abrasive wear

2.1.2.4 Delamination (Fatigue) Wear

The delamination of fatigue theory of wear was proposed by Suh as an attempt to explain weakness in the Archard theory of adhesive wear. Suh argued that [2]:

i. Archard's theory completely ignored the physics and physical metallurgy of metal deformation.

ii. Many of the assumptions employed in the mathematical model were arbitrary and unreasonable.

iii. The theory did not provide any insight to the wear of metals under different sliding conditions.

Suh’s approach was to base the observed wear mechanisms on dislocation theory and plastic deformation and fracture of metals near a surface. Suh’s reasoning behind the resulting delamination theory of wear was thus (see Figure 2.6) [2]:

i. During wear, the material at and very near the surface does not have a high dislocation density, due to the elimination of dislocations by the image force acting on those dislocations, which are parallel to the surface. Therefore, the material very near the surface work hardens less than that of the sub-surface layer.

ii. With continued sliding, there will be pile-ups of dislocations a finite distance from the surface. In time, this will lead to the formation of voids. Void formation will be enhanced if the material contains a hard second phase for dislocations to pile against. Voids form primarily by plastic flow of matrix around hard particles, when there are large secondary phase particles in the metal.

iii. With time, the voids will coalesce, either by growth or shearing of the metal. The end result is a crack parallel to the wear surface.

iv. When this crack reaches a critical length (material dependent), the material between the crack and the surface will shear, yielding a sheet-like particle.

v. The final observed shape of the particle will be dependent upon its length and internal strains.

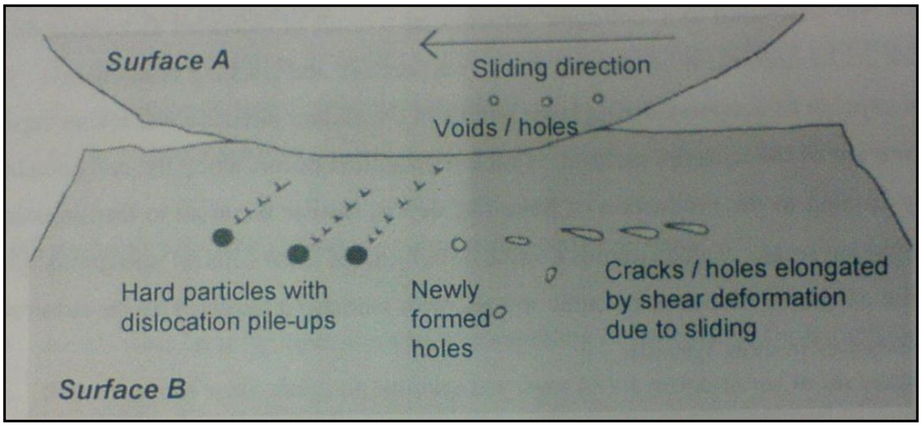


Figure 2.6: Wear particle formation by shear deformation of voids [2]

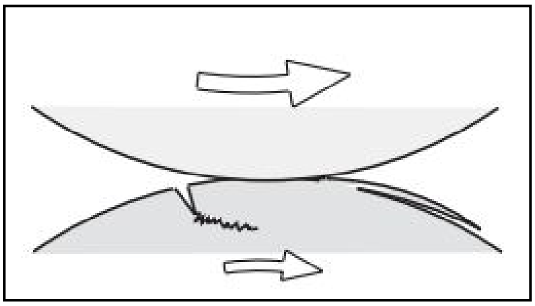


Figure 2.7: Fatigue Wear

2.1.2.5 Corrosive Wear

Rabinowicz defines corrosive wear as the removal of corrosion products by sliding, exposing a fresh surface on which new corrosion products may form. The corrosion products are formed due to reaction between the sliding surfaces and the environment, whether the environment is liquid or gaseous [2].

The corrosion products may act to separate the sliding surfaces (especially if removal is not complete) and thus prevent other mechanisms of wear, such as metallic adhesion, from operating – this more often than not leads to large-scale reductions in wear. This led Quinn to equate the corrosive wear categories of Burwell and Strang with the mild wear category of Archard and Hirst, and processes and reactions involved can be said to be analogous – a relative agent interacts with the sliding interface to produce a corrosion product, which more often than not leads to reduced wear [2].

In most engineering applications, it is oxygen that is the main reactive agent in corrosive wear. Thus the term ‘oxidational wear’ is a very often used term when talking about sliding wear, particularly dry sliding wear, where the lack of a lubricant allows ready environment attack (although the lubrication itself may be the attacking agent or contain oxygen which can attack the wear surfaces) and high temperature sliding wear, where the rate of oxidation is greatly accelerated. In both cases, the formation of oxide (the corrosive product) leading to mild wear may more readily occur [2].

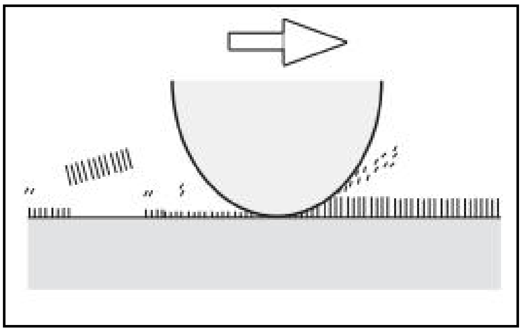


Figure 2.8: Corrosive Wear

2.1.3 - Wear of Rails[10]

Wear of rails is divided into two categories:

(a) *On top or table of the rail head*

Top table of the rail gets worn out due to the abrasive action of rolling wheels over the rails. In dry areas where there is a constant blowing of sand or dust, extra wear occurs due to the grinding action of the sand or dust particles between the wheel and the rail table. In wet weather, the rails are lubricated by rain water and wearing is diminished. Rail-wear also occurs when brakes are applied. On curves, wear on rail-table occurs due to skidding and slipping of wheel rigidly connected by the axle, as it has to cover unequal distances at outer and inner rail. [4]

(b) *On the sides of the rail head*.

Side wear of rail occurs on curved tracks. The centrifugal thrust of the wheel flanges against the side of the outer rail results in the grinding action that causes the side wear of rail. Guiding force on curves depends upon the degree of the curve, the rigid wheel base of the rolling stock, the angle of attack of the wheel flange on rail.[4]

Rolling stock with a low centre of gravity exerts greater wheel flanges pressure on the sides of the rail head, especially if heavy traction motors are laterally unsprung. This explains the heavy sides wear of rails on curved tracks of electrified suburban lines worked by multiple unit stock. [4]

2.1.3.1Permissible Limit of Rail Wear

1. The following three factors are considered in determining the maximum limit of the vertical rail wear.[4]
    - (a) The limit based on the strength of worn out rails to carry maximum axle loads at safe speeds.
    - (b) Reduction in the depth of head of rail to a point beyond which there would be risk of the wheel flange striking the collar of fishplates.
    - (c) The head being worn down to a cross-section so as to risk the sharing for the under edge.
2. Limits of lateral wear and angle of wear are fixed considering the strength of worn out rail and the risk of wheel mounting the rail causing derailment. [4]

2.1.3.2 Measuring Wear of Rails

Rail wear is determined by actual weightment, taking rail-profiles at ends after opening the joints and taking rail-profiles with special profile-measuring gadgets, which can measure rail-profile while the rails are still in track. [4]

The reduction found in the area of worn-out rail-profile indicates the loss of rail section caused by wear. [4]

Computerized rail-wear measuring devices are now available in the international market. They are fitted with sensors, which on contact with rail, plot its profile and indicate the wear in the rail section. [4]

2.1.3.3 Methods of Reducing Rail Wear

Rail wear is less on a well-maintained track with fittings and fastenings in perfect order, as the vehicles on such a track have a smoother roll. Other methods employed to reduce rail wear are:[4]

1. Maintaining Track to 3mm Tighter Gauge. This reduces the hunting of rolling stock thereby reducing rail wear.
2. Provision of Check Rail on Curves: Check rails are provided along the inner rails of curve. The inner face of the wheel rubs against the check rails and the flange of outer wheel is prevented from coming in contact with the outer rail head.
3. Rail lubricators: an important method of reducing wear on curves is by the use of lubricators. The function of the lubricators is to grease the gauge face of the rail head where excessive wear occurs. This reduces the friction and consequently wears. Rail life is increased and even doubled in some cases. Lubrication can be carried out manually or by mechanical devices attached either to locomotives or to rails, the latter being more common. In rail-lubricators, grease is ejected along the gauge side of the rail-head and is carried forward by the flange of passing wheels. On long curves, more than one lubricator is installed on suitable locations to get the optimum results.

In the last few years, interest in the lubrication of rails has considerably increased, as it can make a significant contribution in the saving of energy in heavy haul operations. Box ‘N wagons in use in Indian Railways have been found quite aggressive on track, leading to wear of rails and the wheel flanges. Lubrication on rail gouge-faces in continuous lengths on Box ‘N routes, which include straight tracks as well, has helped in: [4]

- (i) Energy saving in the form of less locomotive fuel/power bill due to the reduced rail/wheel friction
- (ii) Obtaining longer life from rails and wheels
- (iii) Reducing derailments as wheels have less chances of mounting on lubricated rails

Some of the railways systems abroad claim an energy saving of 10-15%, with the rail/wheel flange lubrication, a proper assessment of energy saving on Indian Railways is yet to be made. [4]

Whereas the frequency of rail lubrication adopted on tangent tracks of Box ‘N routs differs from one zonal railway to the other, a weekly cycle of rail lubrication is generally adopted on curves. [4]

2.1.5 - ASTM G 99 – Standard Test Method for Wear Testing with a Pin-on-Disc Apparatus[2]

2.1.5.1 Scope

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disc apparatus. Materials are tested in pairs under nominally non-abrasive conditions. [5]

2.1.5.2 Summary of Test Method[5]

For the pin-on-disc wear test, two specimens are required. One, a pin with a radiuses tip, is positioned perpendicular to the other, usually a flat circular disc. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disc specimen or the pin specimen to revolve about the disc center. In either case, the sliding path is a circle on the disc surface. The plane of the disc may be oriented either horizontally or vertically.

The pin specimen is pressed against the disc at a specified load usually by means of an arm or level and attached weights. Other loading methods have been used, such as, hydraulic or pneumatic.

Wear results are reported as volume loss in cubic millimeters for the pin and the disc separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disc positions.

The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change the disc wear track (in millimeters) are determined by any suitable metrological technique, such as electronic distance gaging or stylus profiling. Linear measures of wear are converted to wear volume (in cubic millimeters) by using appropriate geometric relations. Linear measures of wear are used frequently in practice since mass loss is often too small to measure precisely. If loss of mass in measured, the mass loss value is converted to volume loss (in cubic millimeters) using an appropriate value for the specimen density.

Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. One set of test conditions that was used in an interlaboratory measurement series in given in Table 4 and Table 5 as a guide. Other test conditions may be selected depending on the purpose of the test.

Table 2.1: Characteristics of the Interlaboratory Wear Test Specimen

	Composition (weight %)	Microstructure	Hardness (HV 10)	Roughness	
				R_z(mean)(µm)	R_a(Mean)(µm)
Steel ball (100Cr6) (AISI 52 100) Diameter 10mm	(1.35 to 1.65 Cr 0.95 to 1.10C 0.15 to 0.35Si 0.25 to 0.45Mn <0.030P <0.030S)	Martensitic with minor carbides and austenite	838 ± 21	0.100	0.010
Steel Disc (100Cr6) (AISI 52 100) (Diameter 40mm		Martensitic with minor carbides and austenite	852 ± 14	0.952	0.113
Alumina ball, diameter = 10mm	95% Al_2O_3 (with additive of TiO_2, MgO and ZnO)	Equi-granular alpha alumina with very minor secondary phases	1610 ± 101 (HV 0.2)	1.369	0.123
Alumina disc, Diameter = 40.6mm			1599 ± 144 (HV 0.2)	0.968	0.041

Table 2.2: Results of the Interlaboratory Test

Results	Specimen Pairs			
(ball) (disc)	Steel-steel	Alumina-steel	Steel-alumina	Alumina-alumina
Ball wear scar	2.11 ± 0.27	NM	2.08 ± 0.35	0.3 ± 0.06
diameter (mm)	(2.11 ± 0.27)		(2.03 ± 0.41)	(0.3 ± 0.06)
Ball wear volume	198	…	186	0.08
(10^{-3}mm^3)	(198)		(169)	(0.08)
Number of values	102	…	60	56
	(102)		(64)	(59)
Disc wear scar width (mm)	NM	0.64 ± 0.12	NM	NM
Disc wear volume		(0.64 ± 0.12)		
(10^{-3}mm^3)	…	480	…	…
Number of values		(480)		
	…	60	…	…
Friction coefficient		(60)		
Number of values	0.60 ± 0.11	0.76 ± 0.14	0.60 ± 0.12	0.41 ± 0.08
	109	75	64	76

Wear results may in some cases be reported as plots of wear volume versus sliding distance using different specimens for different distances. Such plots may display non-linear relationships between wear volume and distance over certain portions of the total sliding distance, and linear relationships over other portions. Causes for such differing relationships include initial “break-in” processes, transitions between regions of different dominant wear mechanism, etc. the extent of such non-linear periods depends on the details of the test system, materials and test conditions.

It is not recommended that continuous wear depth data obtained from position-sensing gages be used because of the complicated effects of wear debris and transfer films present in the contact gap, and interferences from thermal expansion or contraction.

2.1.5.3 Significance of Use[5]

The amount of wear in any system will, in general, depend upon the number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment and the material properties. The value of any wear test method lies in predicting the relative ranking of material combinations. Since the pin-on-disc test method does not attempt to duplicate all the conditions that may be experienced in service (for example; lubrication, load, pressure, contact geometry, removal of wear debris, and presence of corrosive environment), there is no ensurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

2.1.6 - MULTI SPECIMEN TESTER

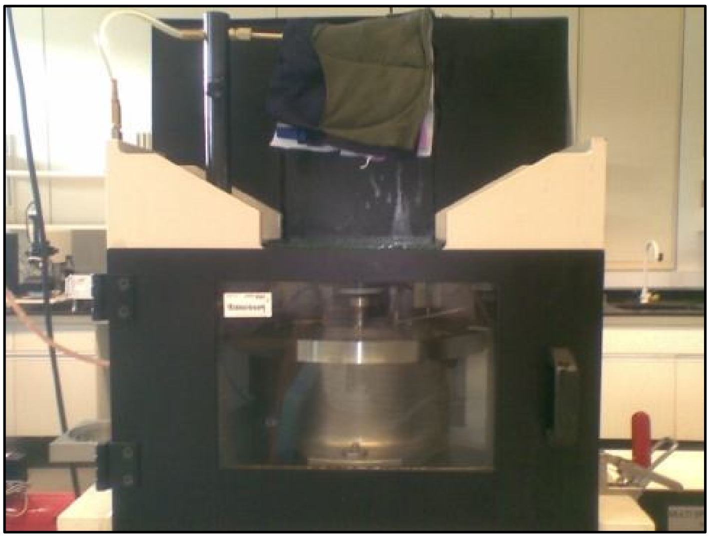


Figure 2.9: Multi Specimen Wear Tester

The Multi Specimen Tester is a machine used for the Pin-on-Disc Test. The machine is compatible of imitating the function and purpose of the Pin-on-Disc machine. These are the procedures for running the Multi Specimen Tester:

1. Run “WINDUCOM 2006” software.
2. Click ‘run continuously’ icon under the toolbar at the left corner of the screen.
3. Click the ‘Power’ icon switch on the machine.
4. Set desired testing time.
5. Set desired speed and speed type.
6. Set desired temperature.
7. Set desired trip value for safety.
8. Enter file name, sample id, etc.
9. Click ‘Acquire’ icon.
10. Set all parameter to zero.
11. Apply balancing load the levers by past 5kg weighting mass to balancing mechanical load.
12. Check whether the wear sensor has touched the disc holder or not.

13. Apply the load by putting the dead weight.
14. Adjust the load icons into desired value by sliding the weighting mass slowly.
15. Click ‘Run’ icon to start the test.
16. It is advisable to perform the running in test for 10 minutes.
17. Rerun the test to the required setting.
18. Click the ‘Power’ icon to switch off the machine.
19. Remove the sample from the holder.

CHAPTER 3

METHODOLOGY

3.1 PROCEDURE IDENTIFICATION

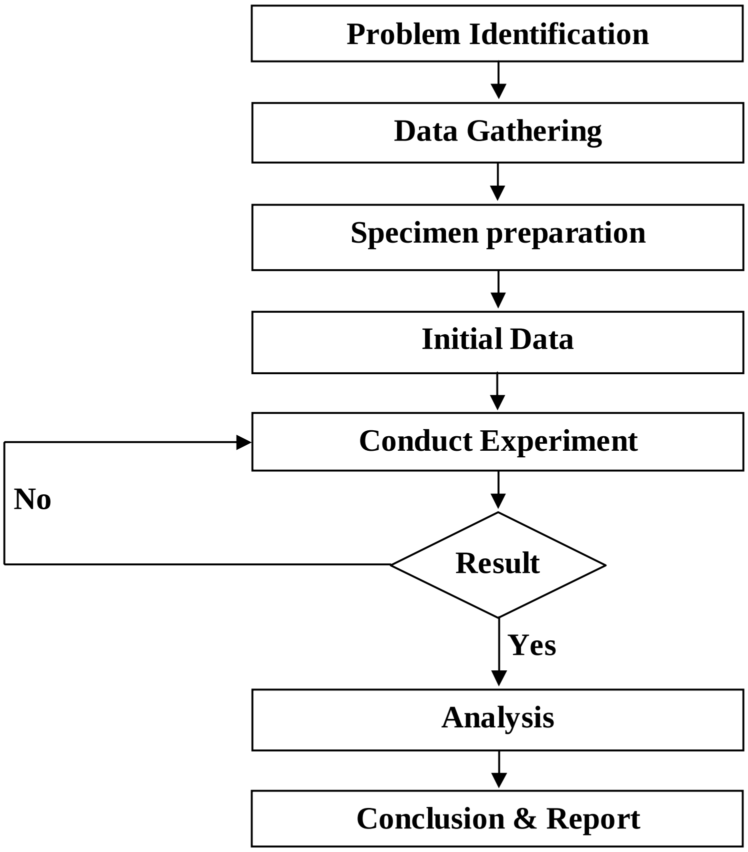


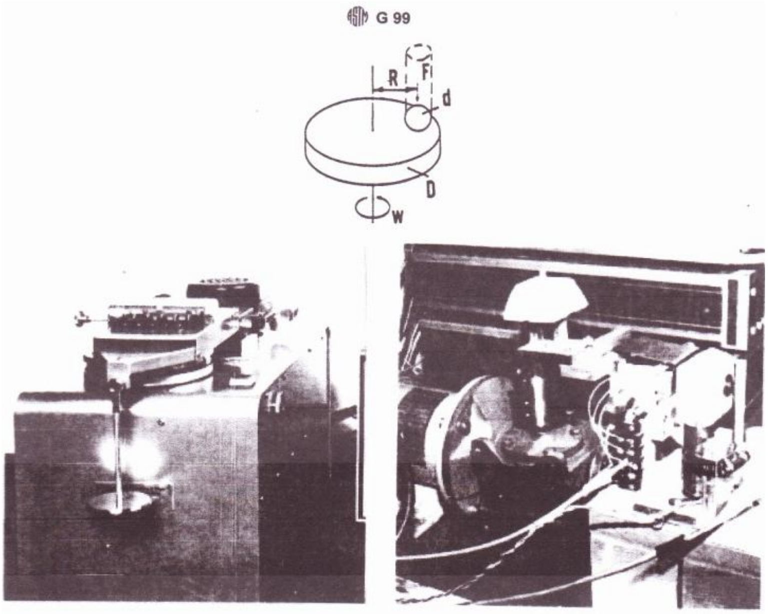
Figure 3.1: Procedure Identification

3.2 TESTING PROCEDURE [2]

3.2.1 - Standard Test Method for Wear Testing with a Pin-on-Disc Apparatus ASTM G99-95a

3.2.1.1 Apparatus

General Description – Figure 18 shows a schematic drawing a typical pin-on-disc wear test system and photographs of two differently designed apparatuses. One type of typical system consists of a driven spindle and chuck for holding the revolving disc, a lever-arm device to hold the pin, and attachments to allow the pin specimen to be forced against the revolving disc specimen with a controlled load. Another type of system loads a pin revolving about the disc center against a stationary disc. In any case the wear track on the disc is a circle, involving multiple wear passes on the same track. The system may have a friction force measuring system, for example, a load cell, that allows the coefficient of friction to be determined.



Note: *F* is the normal force on the pin, *d* is the pin or ball diameter, *D* is the disc diameter, *R* is the wear track radius, and *w* is the rotation velocity of the disc

Figure 3.2: Schematic of pin-on-disc wear test system and photographs of two different designs.

Motor Drive – A variable speed motor, capable of maintaining constant speed (±1 % of rated full load motor speed) under load is required. The motor should be mounted in such a manner that its vibration does not affect the test. Rotating speeds are typically in the range 0.3 to 3 rad/s.

Revolution Counter – The machine shall be equipped with a revolution counter or its equivalent that will record the number of disc revolutions and preferably have the ability to shut off the machine after a pre-selected number of revolutions.

Pin Specimen Holder and Lever arm - In one typical system, the stationary specimen holder is attached to a lever arm that has a pivot. Adding weights, as one option of loading, procedures a test force proportional to the mass of the weights applied. Ideally, the pivot of the arm should be located in the plane of the wearing contact to avoid extraneous loading forces due to the sliding friction. The pin holder and arm must be of substantial construction to reduce vibrational motion during the test.

Wear Measuring Systems – Instruments to obtain linear measures of wear should have a sensitivity of 2.5µm or better. Any balance used to measure the mass loss of the test specimen shall have a sensitivity of 0.1 mg or better; in low wear situations greater sensitivity may be needed.

3.2.1.2 Procedure

1. Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimen. Take care to remove all dirt and foreign matter from the specimen.

2. Measure appropriate specimen dimensions to the nearest 2.5µm or weigh the specimen to the nearest 0.0001g.

3. Insert the disc securely in the holding device so that the disc is fixed perpendicular to the axis of the resolution.

4. Insert the pin specimen securely in its holder.

5. Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disc.

6. Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disc.

7. Set the revolution counter to the desired number of revolutions.

8. Begin the test with the specimen in contact under load. The test is stopped when the desired number of revolutions is achieved.

9. Remove the specimen and clean off any loose wear debris.

10. Remeasure the specimen dimension or reweigh the specimen as appropriate.

11. Repeat the test with additional specimen to obtain sufficient data for statically significant results.

3.2.2 – Experiment Data Variable

- One type of disc (50mm x 50mm square) – 5 pieces
- 2 types of pin's material (wheel material and material itself)
- Load: 40N or 2kg
- Test time: 0.2 hours or 12 minutes
- Speed: 100rpm
- Temperature: 50^{o}C and 90^{o}C
- Equipment: Multi-Specimen Wear Tester

Figure 3.3: Multi Specimen Wear Tester

CHAPTER 4

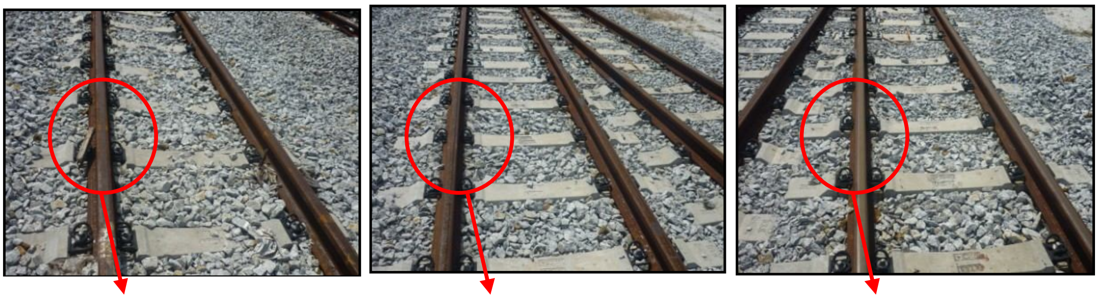
RESULTS AND DISCUSSION

4.1 RAIL TRACK TEMPERATURE

Temperature of the Rail Track has been measured at KTMB Depot Station Batu Gajah in time range of 11am until 3pm.

Table 4.1: Temperature of the Railway track at KTMB Depot Station Batu Gajah

Time	Ambient (^{o}C)	Line 1 (^{o}C)	Line 2 (^{o}C)	Line 3 (^{o}C)	Average (^{o}C)
11.00 am	34.7	47.0	46.4	45.4	46.3
11.30 am	35.2	48.2	48.6	47.9	48.2
12.00 pm	36.6	52.6	50.9	51.2	51.6
12.30 pm	35.8	49.0	47.1	48.3	48.1
1.00 pm	35.1	46.7	47.8	47.9	47.5
1.30 pm	35.4	49.6	49.9	51.4	50.3
2.00 pm	36.7	51.4	52.3	52.3	52.0
2.30 pm	35.5	49.8	50.3	49.7	49.9
3.00 pm	35.9	48.9	50.2	50.3	49.8



Location for Line 1 Location for Line 2 Location for Line 3

Figure 4.1: Location for Measurement Temperature at KTMB Depot Station Batu Gajah

Figure 4.2: Temperature measured at the rail track KTMB Depot Station Batu Gajah

Table 4.1 shows the temperature reding on the surface of the railway track at Keretapi Tanah Melayu Berhad (KTMB) Depot in Batu Gajah Station. This reading was carrying out on Tuesday, 26th October 2010 in time range of 11am until 3pm. Three locations have been selected to take this reading and the reading was taken in every 30 minutes.

In taking the temperature reading, a measuring device used named K-thermocouple model HANNA HI 9043. To obtain the temperature reading of the rail track surface, this device functions by touched the probe indicator to it.

From the table 4.1, the highest average temperature for all lines is 52^{o}c occurred at 2pm and the lowest average temperature is 46^{o}C which at 11am. The value for ambient temperature is around 35^{o}C. During that day, the ambient temperature not increases until the highest temperature because of the unpredictable weather. A KTMB's staff informed that in Cuping Kedah, the temperature can exceed up to 90^{o}c and it may causing the rail track to be buckling.

4.2 SPECIMEN PREPARATION

Before proceed with the experiment, the pin and disc specimen is prepared from the railway track block. Firstly, the railway track is cut using a heavy saw machine in length about 135mm (Figure 4.3). Then, the side of the rail track has been cut about 5mm from the top (Figure 4.4). After that, a rectangular shape with the dimension of 135mm long x 70mm wide x 5mm thick has been produce. Lastly, an Electric Discharge Machine (EDM) has been used to cut the specimen to be 40mm long x 40mm wide x 5mm thick (Figure 4.5).

4.1.1 Cutting the Rail Track (135mm long)

The first process is cut the rail track to length 135mm long. The machine that used to cut this trail track is a heavy saw machine at Building 21. This process takes time about 40 minutes.

Figure 4.3: Cutting the Rail Track

4.1.2 Cutting the Rail Track (7mm Thick)

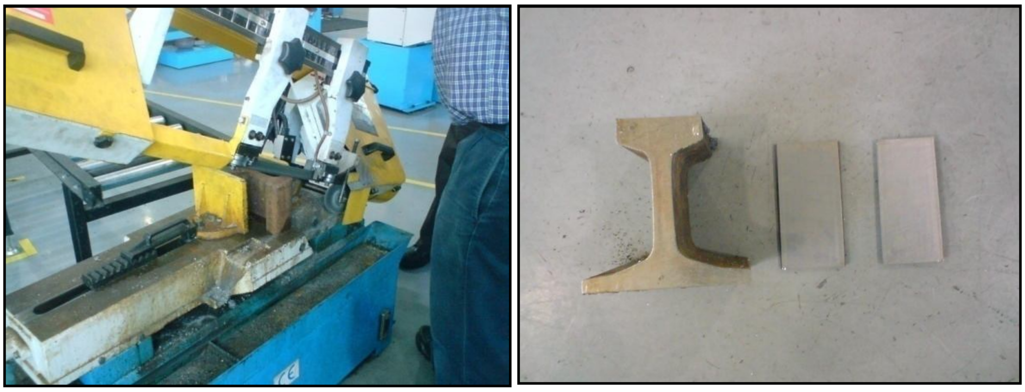


Figure 4.4: Cutting the Head of Rail Track

4.1.3 Cutting with Electrical Discharge Machining (EDM)

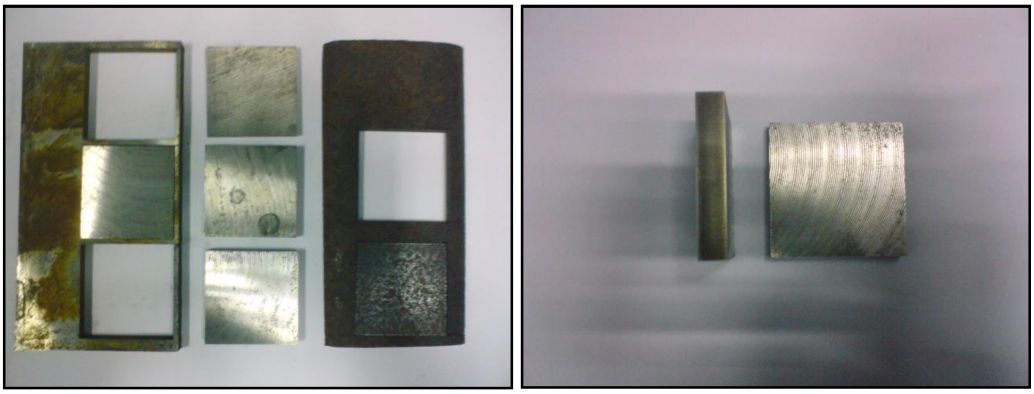
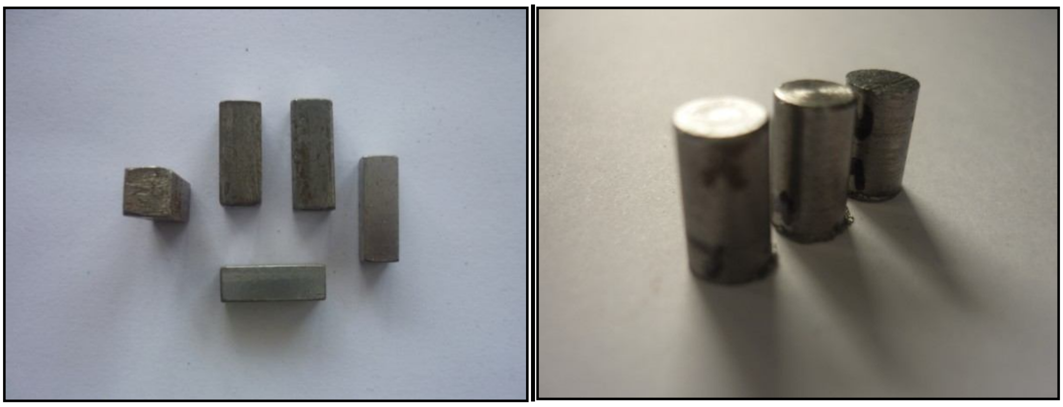


Figure 4.5: Specimen of disc



(a) (b)

Figure 4.6: Specimen of pin (a) pin from material itself (b) pin from wheel.

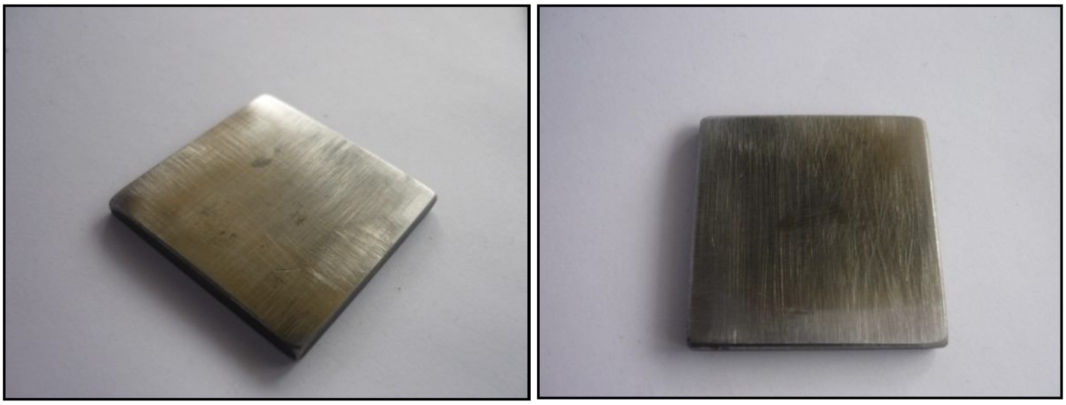


Figure 4.7: Specimen of rail track disc after the polishing with sand paper before conduct an experiment.

In this experiment, there are 2 types of pin specimen needed, a pin specimen from the rail track material and secondly is a pin from the wheel material. For the pin from the rail track material, before cut the rail track block using an Electric Discharge Machine (EDM), a milling machine is used to ensure that the thickness of the plate is about 5mm. Then, a pin specimen with dimensional of 12mm x 5 mm is provided using an EDM machine. For wheel material pin specimen (Figure 26b), it has been supplied from a Post Graduate Student who also doing the pin-on-disc testing technique using the wheel material as the pin specimen.

Before proceed with the next steps, specimen surface's roughness need to be removed to ensure that the experiment run smoothly. To remove the roughness faster and easier, a BOSH Belt Sander Model GBS 75A Professional (Figure 4.8a) is used. the Metallurgical Polishing Machine (Figure 4.8b) is also functioning to clear the surface roughness, but it take a long time to smooth the surface.

(a) (b)

Figure 4.8: Polishing Equipment; (a) Bosch Belt Sander (b) Metallurgical Polishing Machine

4.3 EXPERIMENT RESULT & DISCUSSION

4.3.1 – Weight Loss

Table 4.2: Weight loss during an experiment for Pin: Material Itself.

Weight Loss after an Experiment for Pin: Material Itself				
Experiment Number	**At Temperature 50^oC (Gram)**		**At Temperature 90^oC (Gram)**	
	Disc	**Pin**	**Disc**	**Pin**
1	0.2521	0.1906	0.4515	0.4934
2	0.1813	0.1659	0.4408	0.4475
3	0.3502	0.3311	0.3911	0.3243
Average	0.2612	0.2292	0.4278	0.4217

Table 4.3: Weight loss during an experiment for Pin: Wheel.

Weight Loss after an Experiment for Pin: Wheel				
Experiment Number	**At Temperature 50^oC (Gram)**		**At Temperature 90^oC (Gram)**	
	Disc	**Pin**	**Disc**	**Pin**
1	0.1499	0.2518	0.2043	0.2920
2	0.1504	0.2153	0.1614	0.2337
Average	0.1502	0.2336	0.1829	0.2629

The initial weight of pin and disc specimen is measured before proceed with the experiment. The reading is recorded and the average weight loss is calculated. In table 4.2 shows that the weight loss of the pin specimen material of the rail track (material itself) while in Table 4.3 is shown about the loss weight for the pin specimen material of the wheel.

For the pin specimen material of the track (material itself), the average weight loss is 0.4287g for disc and 0.4217g for the pin at 90°C is larger than the average weight loss of the disc (0.2612g) and the pin (0.2292g) at 50°C. At 50°C, the average weight loss for the disc (0.2612g) is larger than the weight loss for the pin specimen (0.2292g), but at temperature 90°C, it is just a slightly different between the pin (0.4217g) and the disc (0.4278g) specimen's average weight loss value.

In the other hands, for pin wheel material, the average weight loss at 90°C is 0.1829g for disc and 0.2629g for pin. This shows that the average value at 50°C is less lower than the reading at 90°C which are 0.1502g for disc and 0.2336g for pin. Hence, the average weight off weight loss for pin is 0.2335 at 50°C and 0.2629g at 90°C higher than the average weight loss for the disc 0.1502g at 50°C and 0.1829g at 90°C. This shows that the weight loss for the disc material of the track is lesser than the weight loss of the pin made of wheel material.

From Table 4.2 and 4.3, it concluded that the pin in wheel material at 50°C has the lowest weight loss value at 90°C, the pin and the disc material of rail track (material itself) lost the weight the most.

4.3.2 – Specimen for Pin Material Itself at Temperature: $50^{o}C$

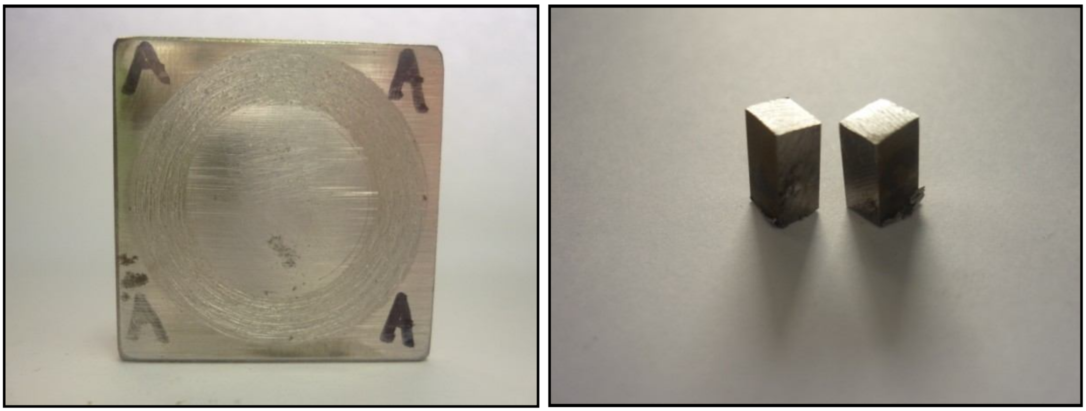


Figure 4.9: Specimen for Pin Material Itself at Temperature $50^{o}C$.

4.3.3 – Specimen for Pin Material Itself at Temperature: $90^{o}C$

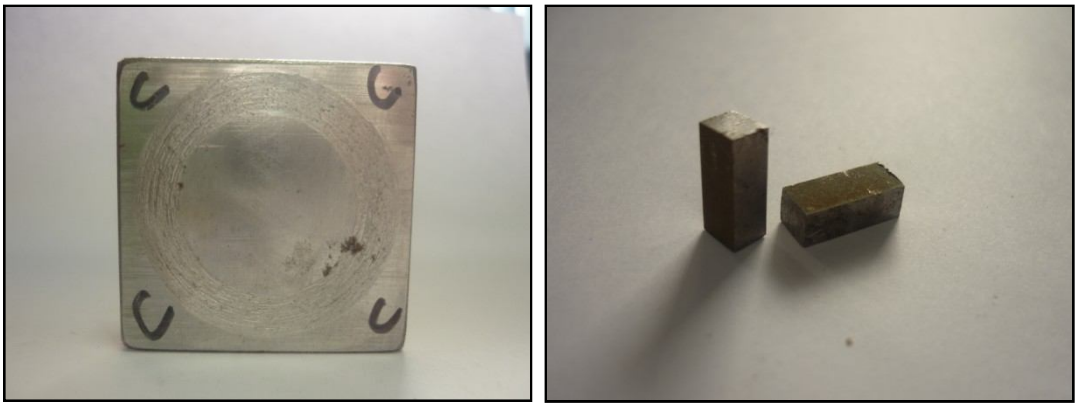


Figure 4.10: Specimen for Pin Material Itself at Temperature $90^{o}C$.

4.3.4 – Microstructure for Pin: Material Itself & Temperature: 50^{o}C

Experiment 1:

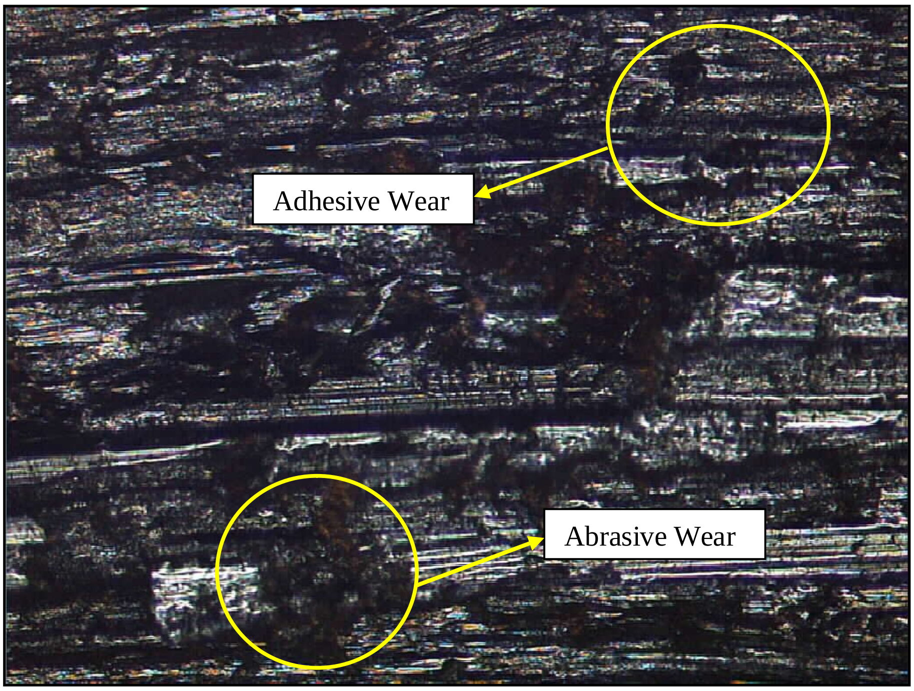


Figure 4.11: Microstructure image of Disc for Material Itself Pin at 50^{o}C Experiment 1.

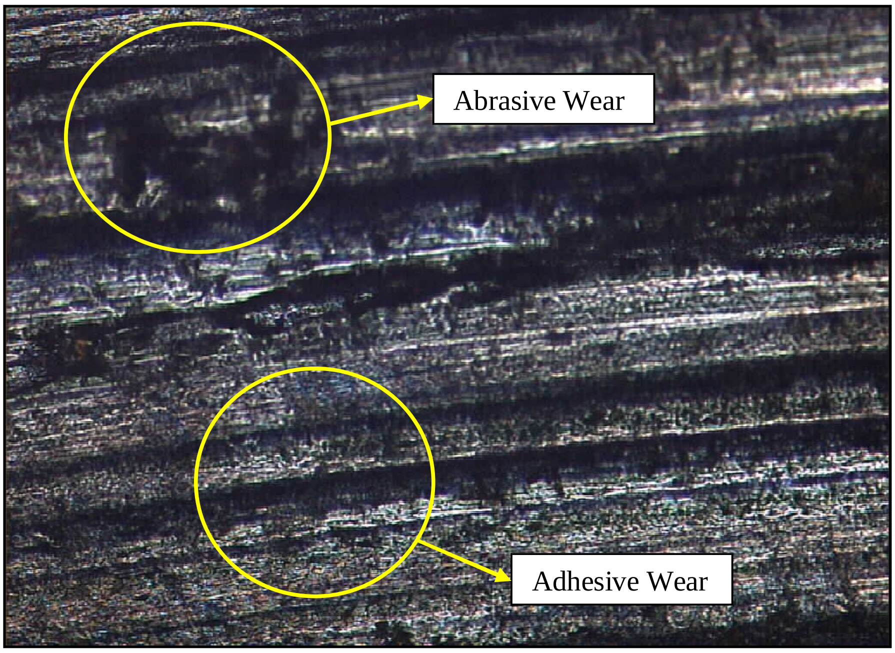


Figure 4.12: Microstructure image of Pin for Material Itself Pin at 50^{o}C Experiment 1.

Experiment 2:

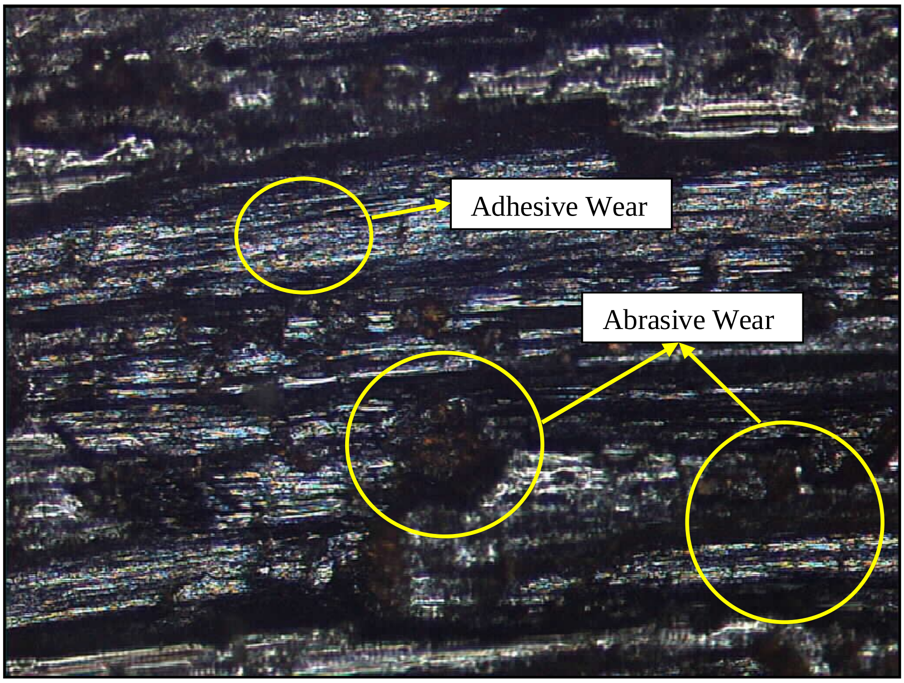


Figure 4.13: Microstructure image of Disc for Material Itself Pin at 50^{o}C Experiment 2.

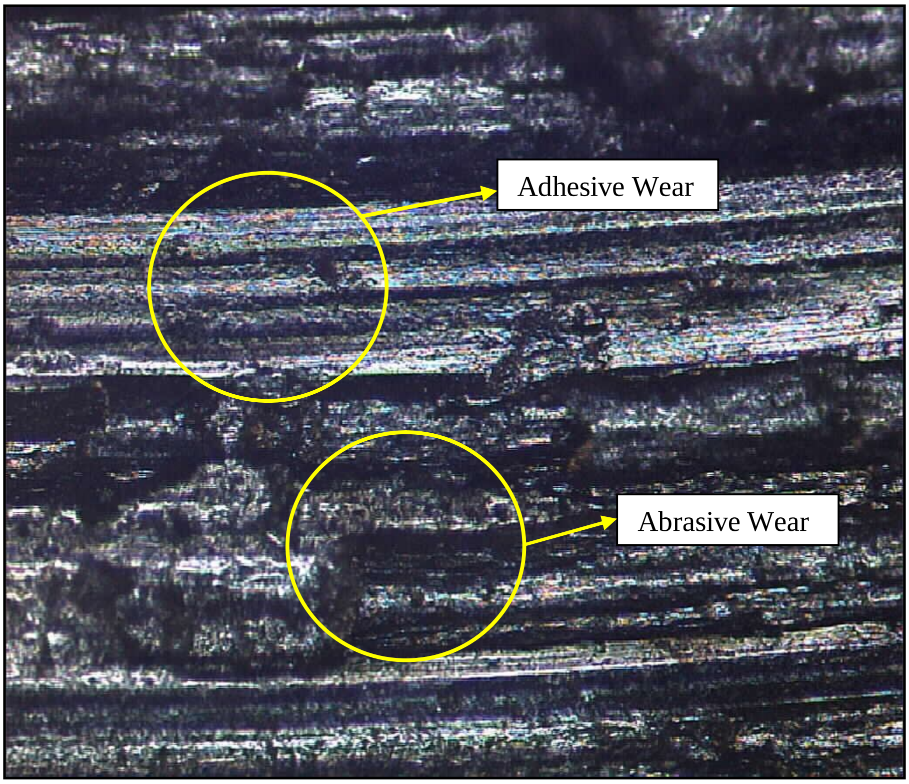


Figure 4.14: Microstructure image of Pin for Material Itself Pin at 50^{o}C Experiment 2.

Experiment 3:

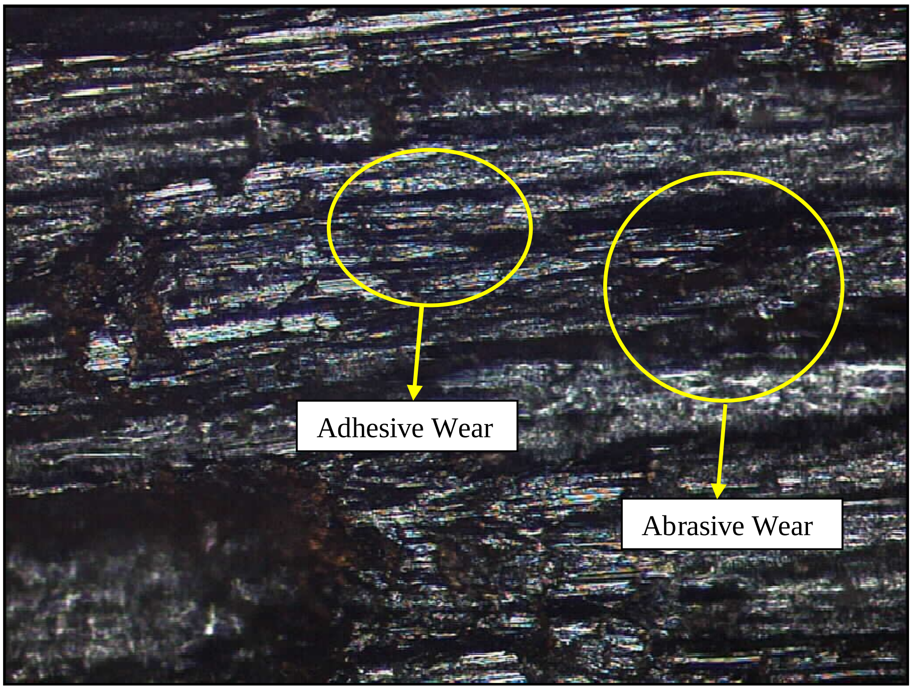


Figure 4.15: Microstructure image of Disc for Material Itself Pin at 50°C Experiment 3.

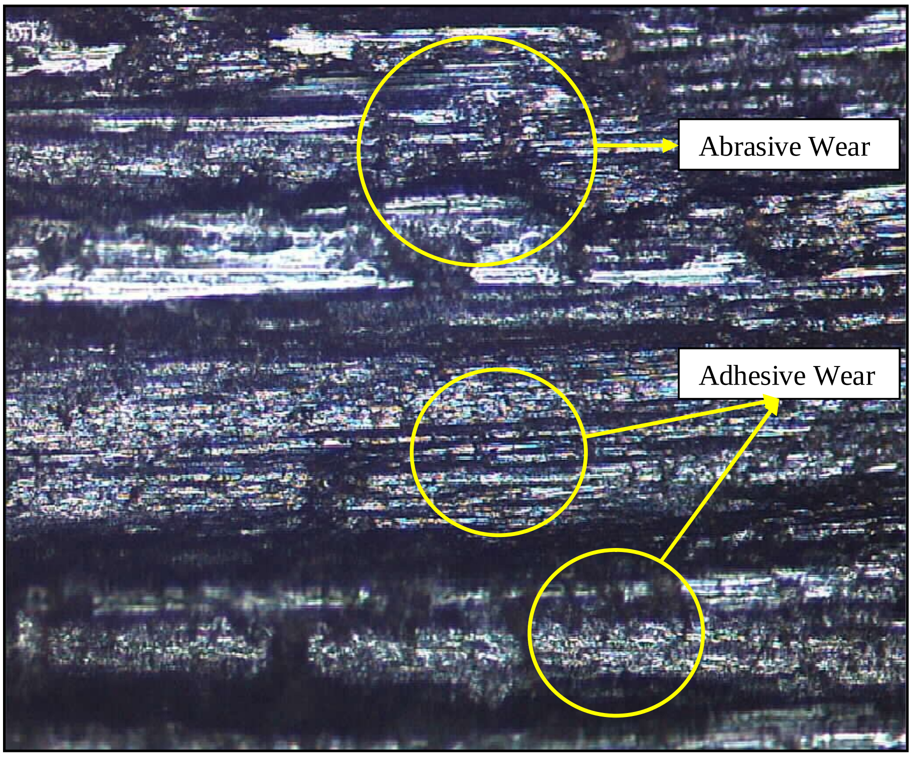


Figure 4.16: Microstructure image of Pin for Material Itself Pin at 50°C Experiment 3.

4.3.5 – Graph Wear vs Time for Pin: Material Itself & Temperature: 50^{o}C

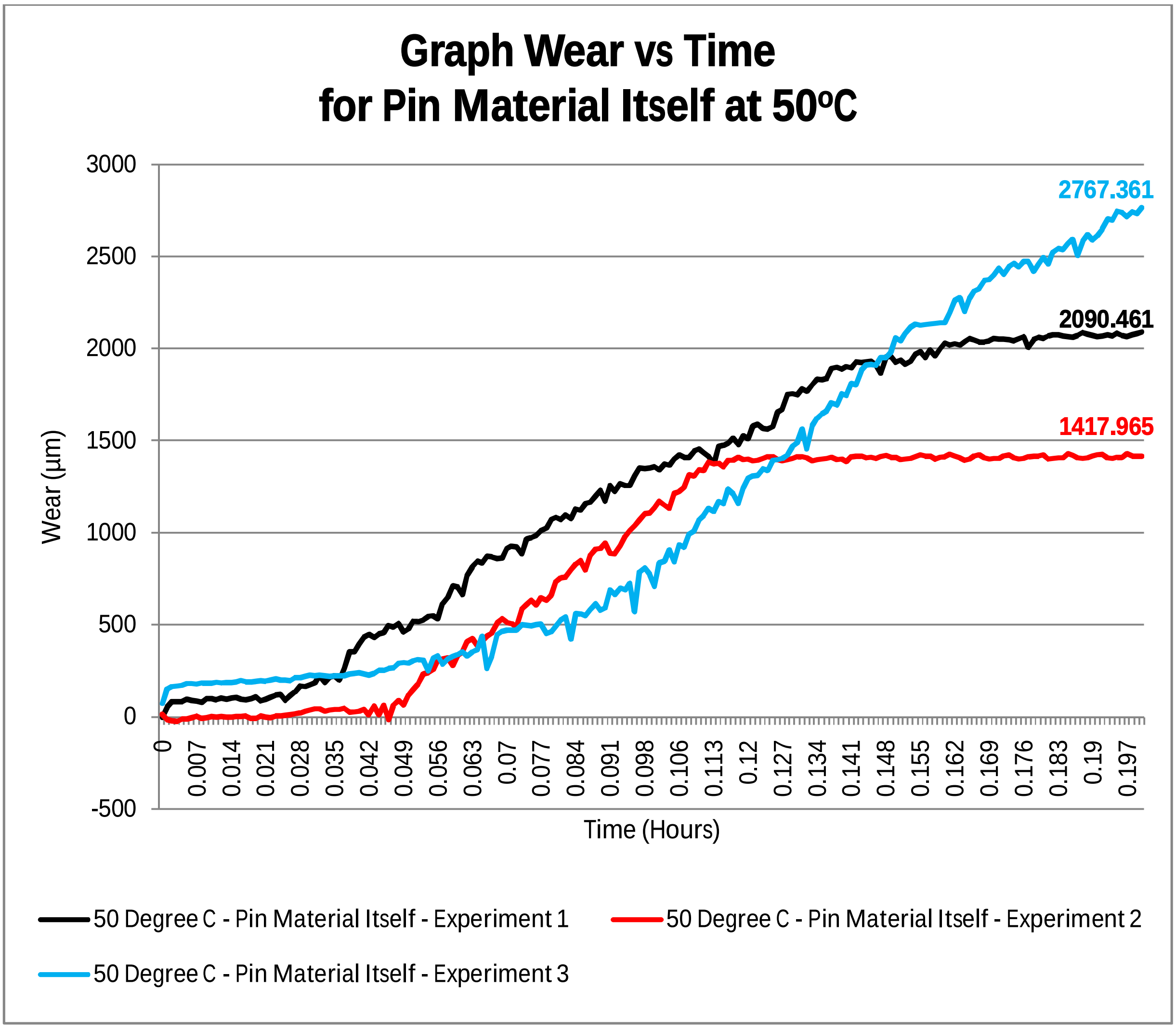


Figure 4.17: Graph Wear vs Time of the Pin Material Itself and Temperature 50^{o}C

4.3.6 – Graph Coefficient of Friction vs Time for Pin: Material Itself & Temp: 50°C

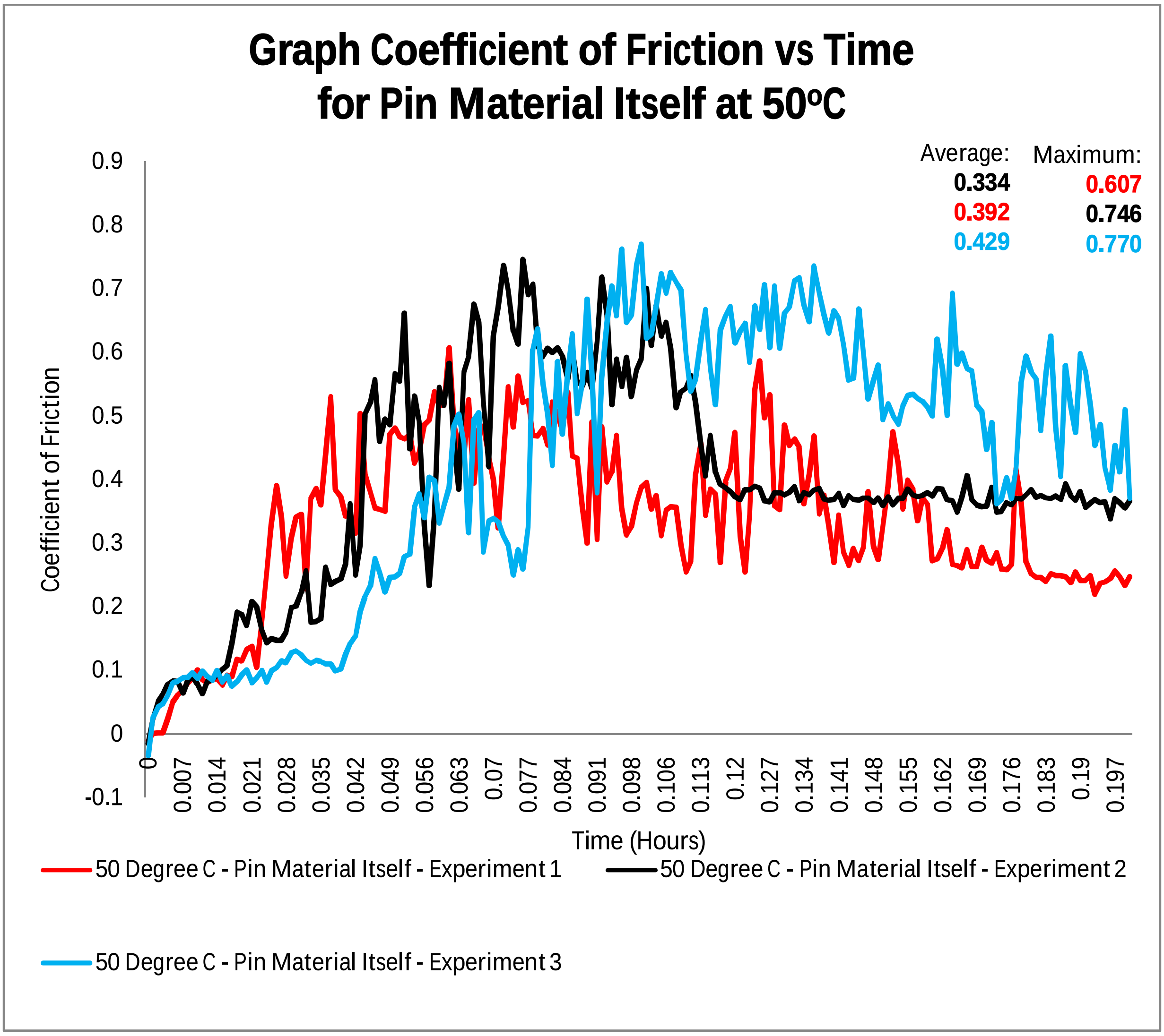


Figure 4.18: Graph Coefficient of Friction vs. Time for the Pin Material Itself and Temperature 50°C

For rail track (material itself) as the pin material at the temperature 50^oC, three repeated experiment has been conducted by using Multi Specimen Wear Tester. Figure 4.11, 4.13 and 4.15 show the microstructure of the disc specimen and Figure 4.12, 4.14 and 4.16 shows the microstructure of the pin specimen. In Figure 4.17 shows that the graph of wear rate versus time while in Figure 4.18 shows that the coefficient of friction versus the time for all of three repeated experiments.

By referring the microstructure view, it shows that the specimen disc and pin both has adhesive wear and abrasive wear effects. The abrasive wear rate is more affected at the disc specimen compared than the adhesive wear rate while then at the pin specimen, it is in vice-versa condition at the disc specimen where the adhesive wear effect affected more than the abrasive wear effects.

Graph in Figure 4.17 shows that the average wear rate value versus time for pin wheel material of 50^oC for experiment 1, 2 and 3. The total amount of wear rate for experiment 1 is 2090 µm, for experiment 2 is 1418 µm and for experiment 3 is 2767 µm. From the result obtained, it seems like the result of the experiment 1 is the best and accurate among these three experiments. This is happened because the temperature of the disc specimen is already increasing when the experiment 1 and 2 is conducted and the disc specimen temperature will become lower than 50^oC. When the temperature measured for experiment is based on “WINDUCOM 2006” software, the software will show the temperature reading of the heater, not the temperature for the disc specimen.

Graph in Figure 4.18 shows that the friction coefficient value versus the time for pin rail track (material itself) material of 50^oC for experiment 1, 2 and 3.Reffering the graph, the result of experiment 1 is the most accurate value with the average friction coefficient value is 0.33 and the maximum value is 0.77. From the shape of this graph, it concluded that this is the typical sliding condition on dry surface and sliding of metal with high load and high wear rate.

4.3.7 – Microstructure for Pin: Material Itself & Temperature: 90°C

Experiment 1:

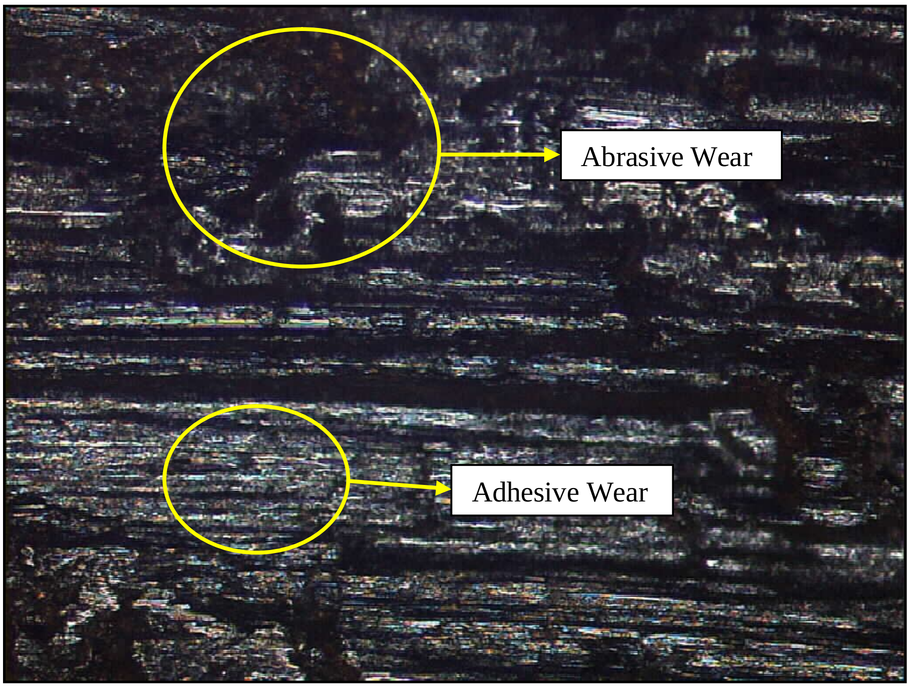


Figure 4.19: Microstructure image of Disc for Material Itself Pin at 90°C Experiment 1.

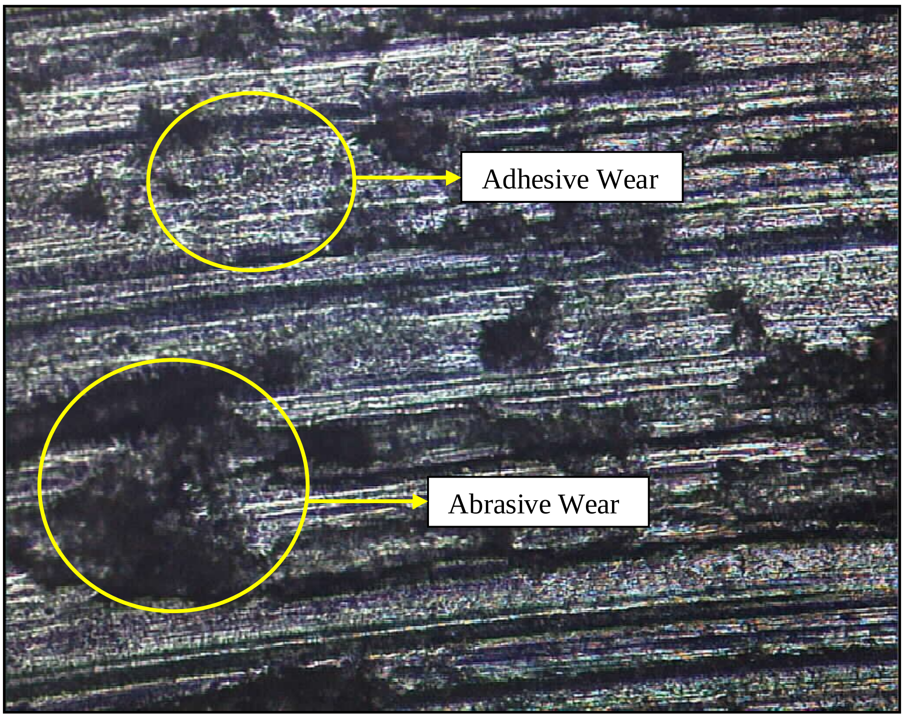


Figure 4.20: Microstructure image of Pin for Material Itself Pin at 90°C Experiment 1.

Experiment 2:

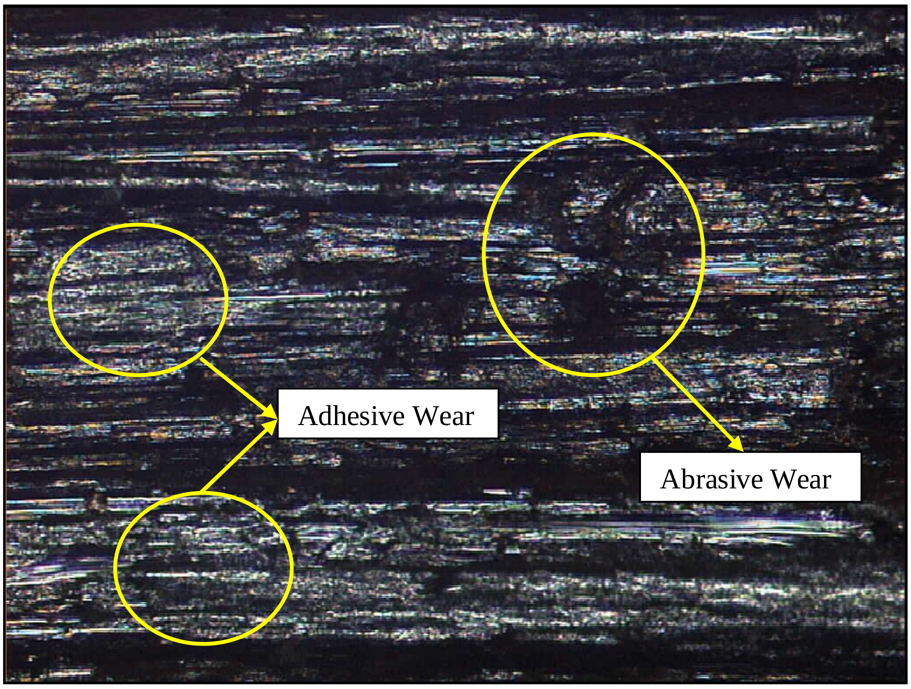


Figure 4.21: Microstructure image of Disc for Material Itself Pin at 90^{o}C Experiment 2.

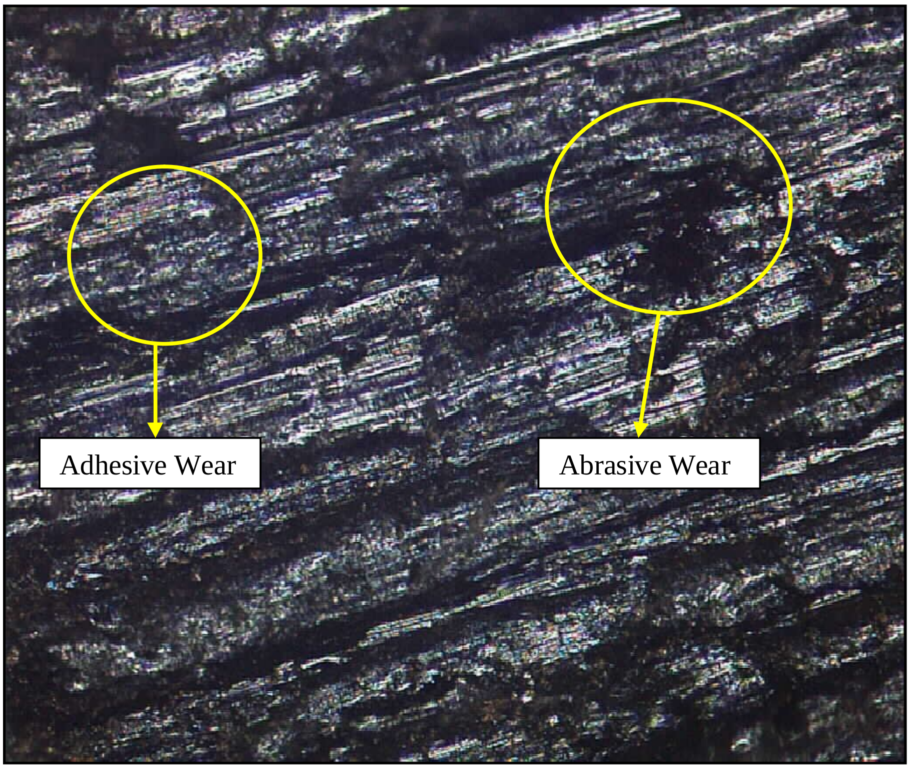


Figure 4.22: Microstructure image of Pin for Material Itself Pin at 90^{o}C Experiment 2.

Experiment 3:

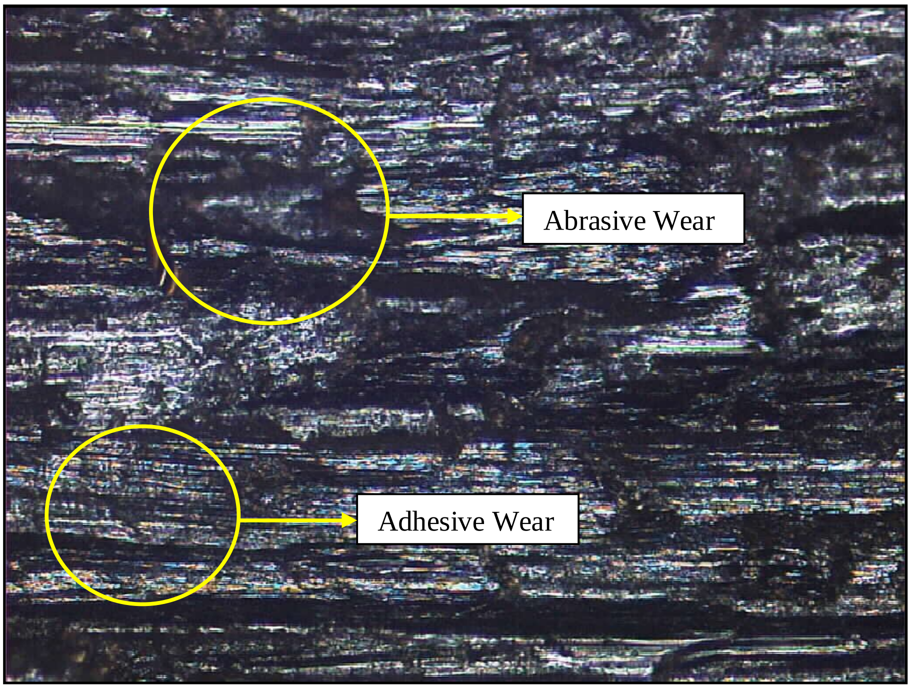


Figure 4.23: Microstructure image of Disc for Material Itself Pin at 90^{o}C Experiment 3.

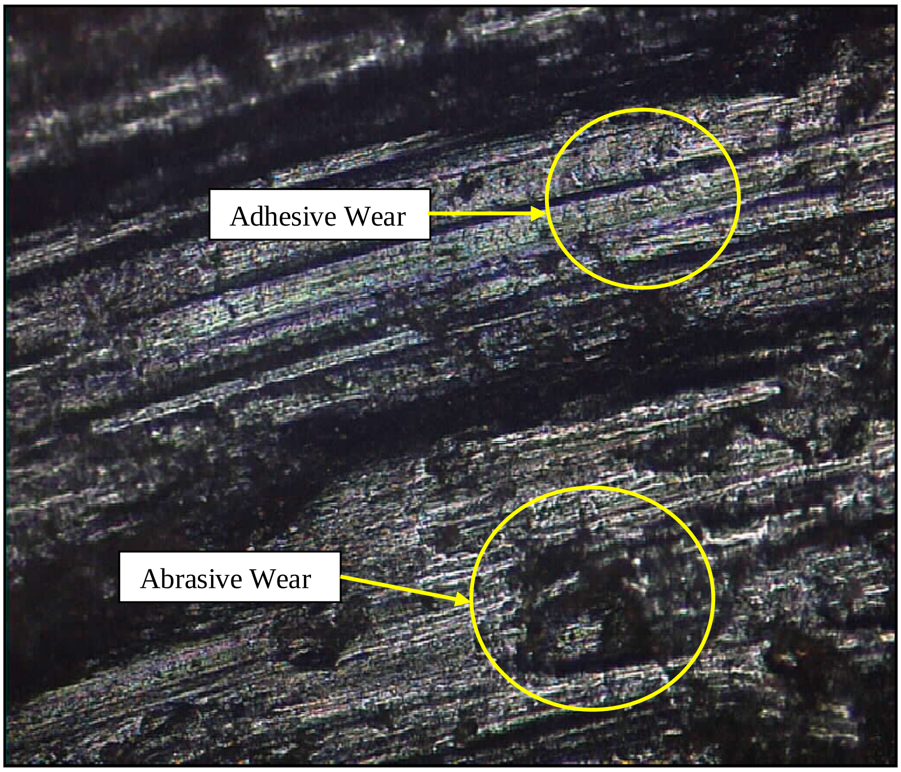


Figure 4.24: Microstructure image of Pin for Material Itself Pin at 90^{o}C Experiment 3.

4.3.8 – Graph Wear vs Time for Pin: Material Itself & Temperature: 90°C

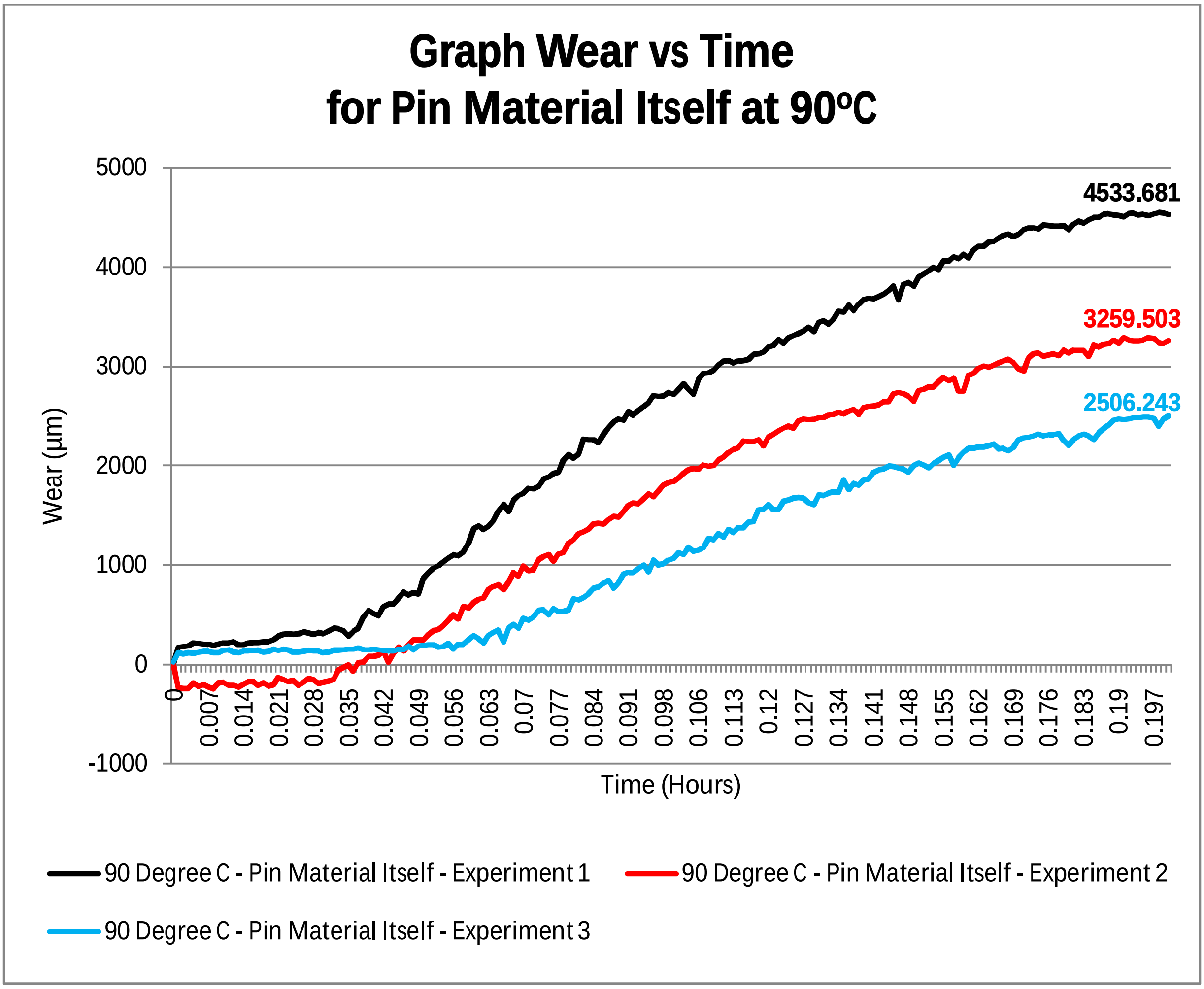


Figure 4.25: Graph Wear vs Time of the Pin Material Itself and Temperature 90°C

4.3.9 - Graph Coefficient of Friction vs Time for Pin: Material Itself & Temp: 90^{o}C

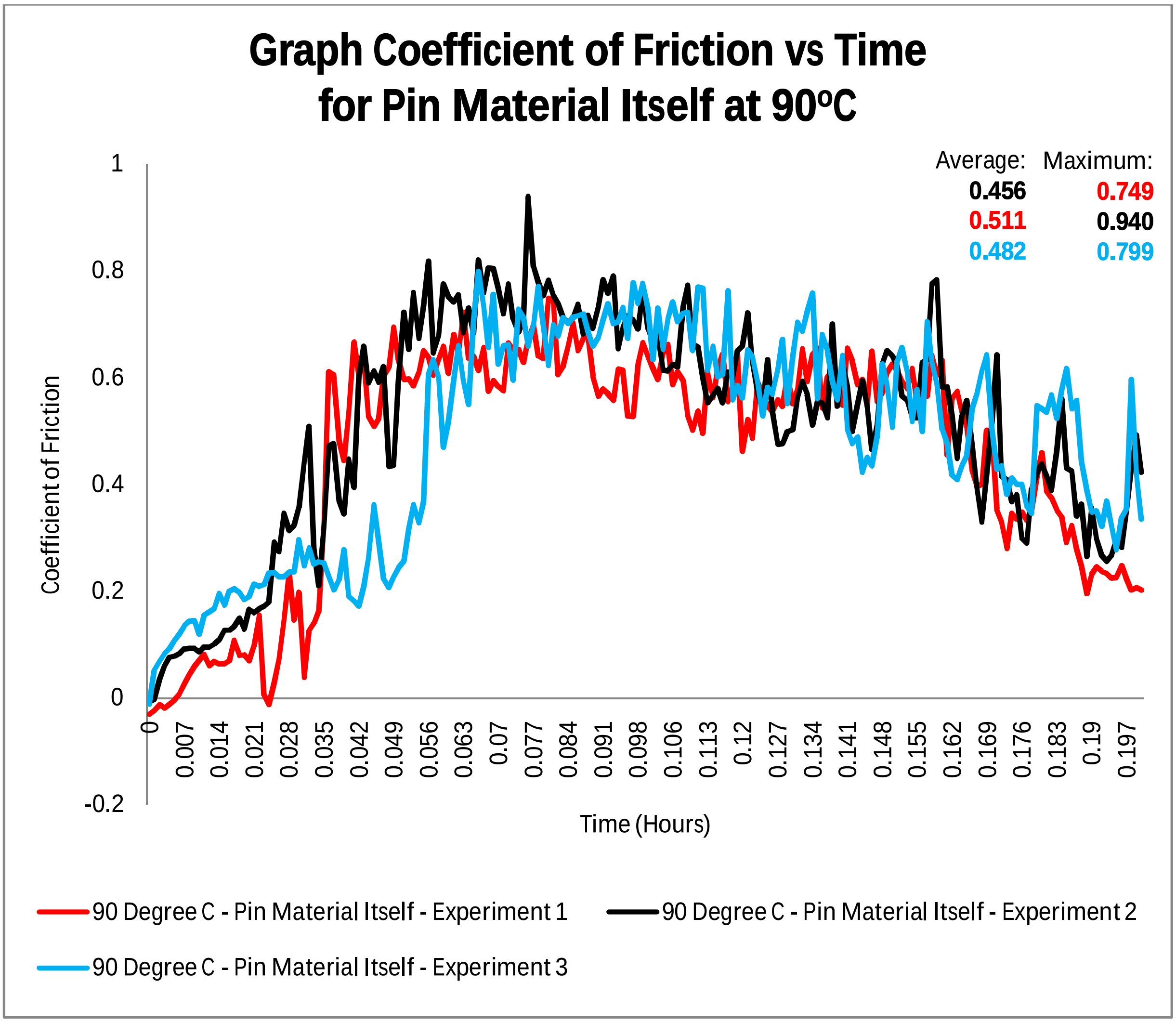


Figure 4.26: Graph Coefficient of Friction vs Time for the Pin Material Itself and Temperature 90^{o}C

For rail track (material itself) as the pin material at the temperature 50^{o}C, three repeated experiment has been conducted by using Multi Specimen Wear Tester. Figure 4.19, 4.21 and 4.23 show the microstructure of the disc specimen and Figure 4.20, 4.22 and 4.24 shows the microstructure of the pin specimen. In Figure 4.25 shows that the graph of wear rate versus time while in Figure 4.26 shows that the coefficient of friction versus the time for all of three repeated experiments.

By referring the microstructure view, it shows that the specimen disc and pin both has adhesive wear and abrasive wear effects. Microstructure for adhesive and abrasive wear for disc and pin specimen is just got a slightly different only. It means that, the amount of wear and friction for disc and pin specimens are almost same. The adhesive wear of disc specimen is more affected at 90^{o}C compared at 50^{o}C

Graph in Figure 4.25 shows that the average wear rate value versus time for pin wheel material of 50^{o}C for experiment 1, 2 and 3. The total amount of wear rate for experiment 1 is 4533 µm, for experiment 2 is 3259 µm and for experiment 3 is 2506 µm. From the result obtained, it seems like the result of the experiment 1 is the best and accurate among these three experiments. This is happened because the temperature of the disc specimen is already increasing when the experiment 1 and 2 is conducted and the disc specimen temperature will become lower than 50^{o}C. When the temperature measured for experiment is based on “WINDUCOM 2006” software, the software will show the temperature reading of the heater, not the temperature for the disc specimen.

Graph in Figure 4.26 shows that the friction coefficient value versus the time for pin rail track (material itself) material of 50^{o}C for experiment 1, 2 and 3.Reffering the graph, the result of experiment 1 is the most accurate value with the average friction coefficient value is 0.456 and the maximum value is 0.94.The coefficient of friction at 90^{o}C for rail track material (material itself) is higher than the coefficient of friction at 50^{o}C. From the shape of this graph, it concluded that this is the typical sliding condition on dry surface and sliding of metal with high load and high wear rate.

4.3.10 – Specimen for Pin Material Itself at Temperature: 50^{o}C

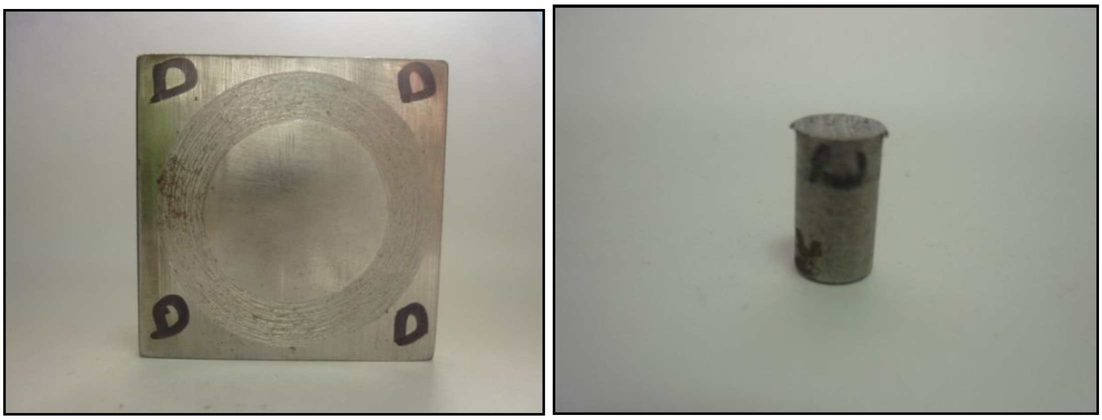


Figure 4.27: Specimen for Pin Wheel at Temperature 50^{o}C.

4.3.11 – Specimen for Pin Material Itself at Temperature: 90^{o}C

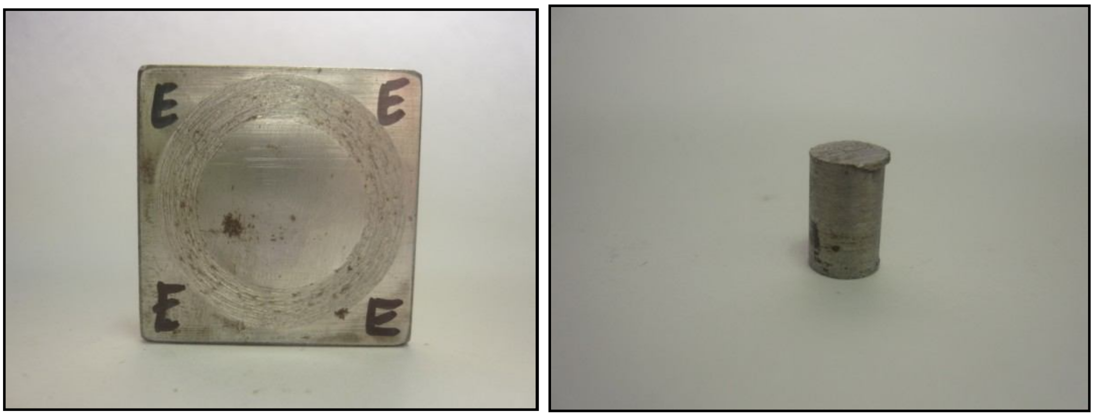


Figure 4.28: Specimen for Pin Wheel at Temperature 90^{o}C.

4.3.12 – Microstructure for Pin: Wheel & Temperature: 50°C

Experiment 1:

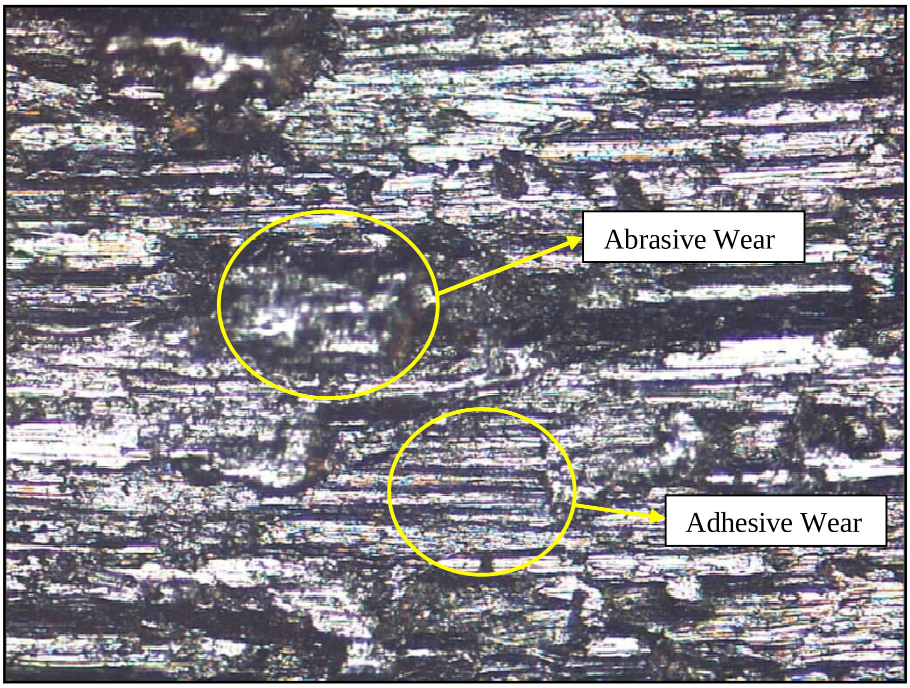


Figure 4.29: Microstructure image of Disc for Wheel Pin at 50°C Experiment 1.

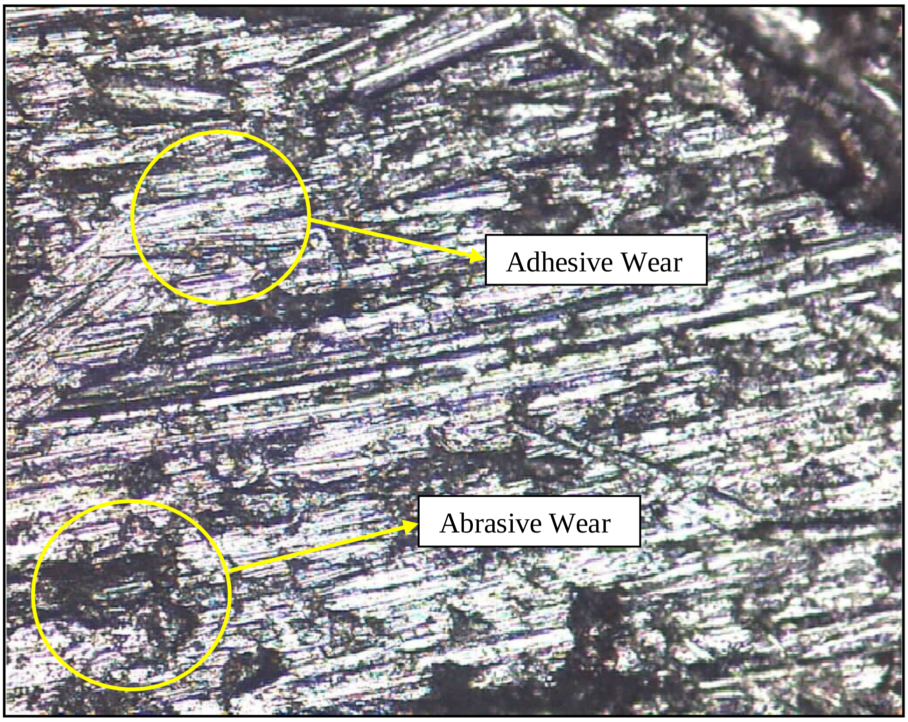


Figure 4.30: Microstructure image of Pin for Wheel Pin at 50°C Experiment 1.

Experiment 2:

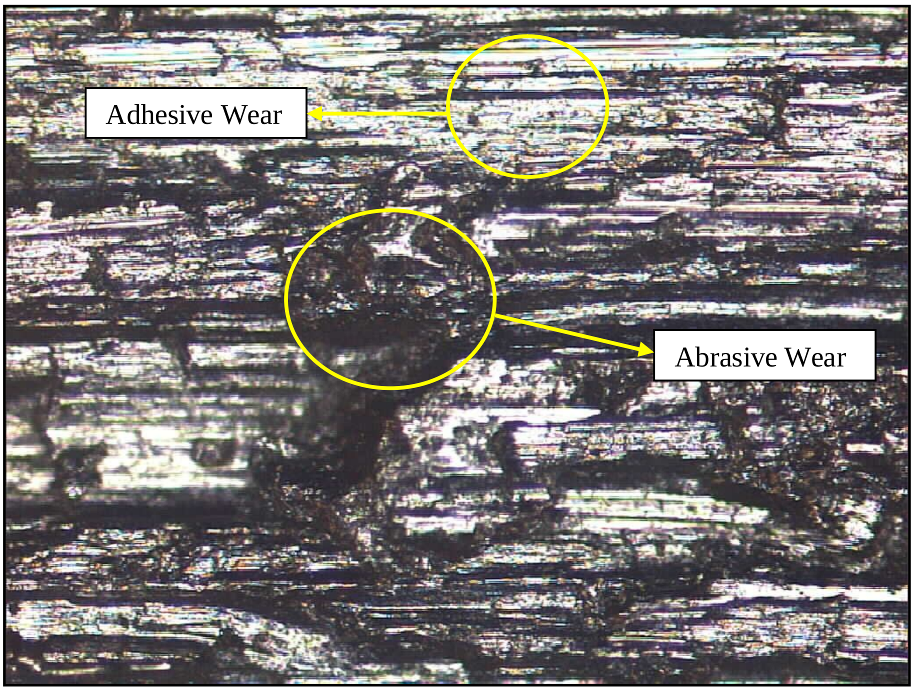


Figure 4.31: Microstructure image of Disc for Wheel Pin at 50°C Experiment 2.

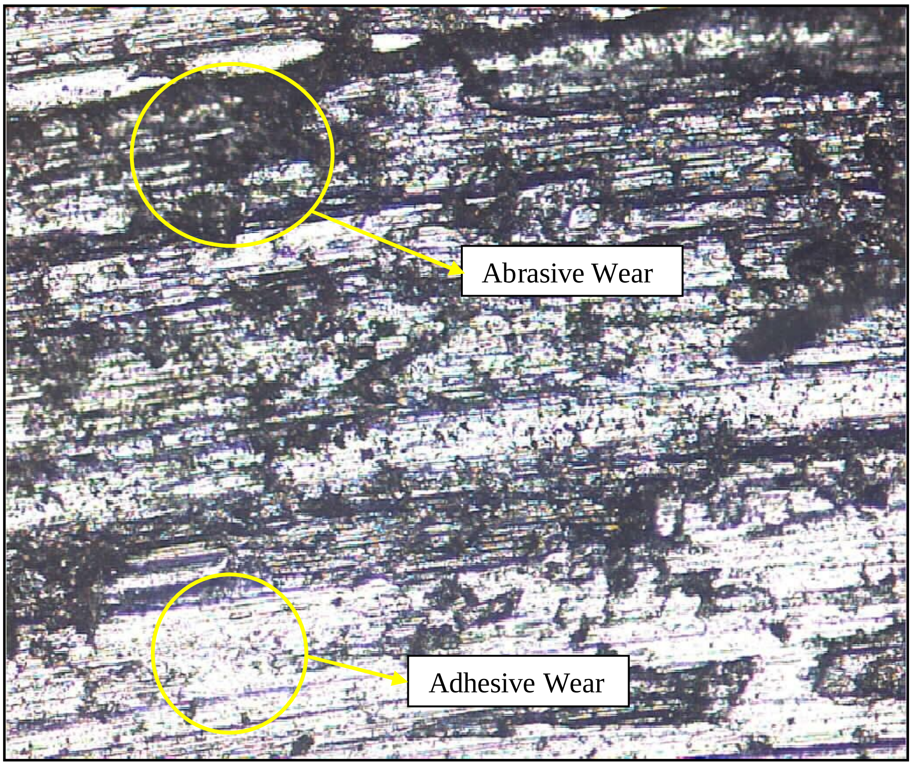


Figure 4.32: Microstructure image of Pin for Wheel Pin at 50°C Experiment 2.

4.3.13 – Graph Wear vs Time for Pin: Wheel & Temperature: 50°C

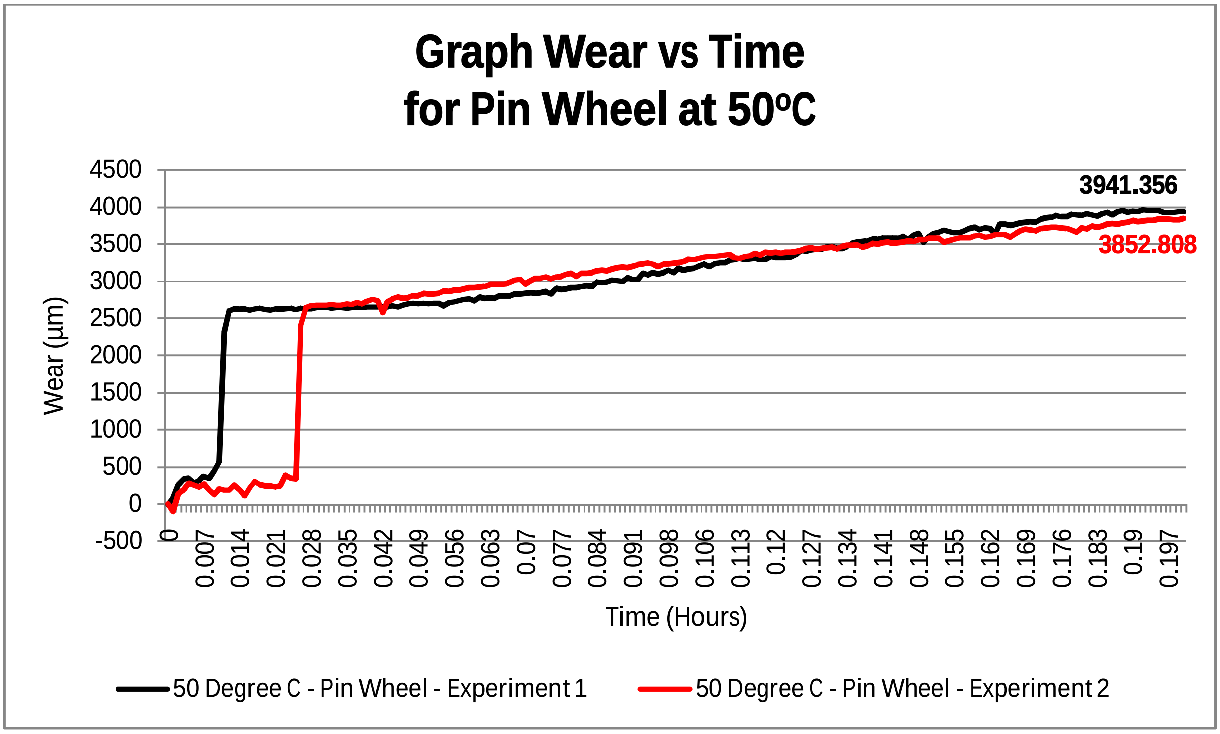


Figure 4.33: Graph Wear vs Time of the Pin Wheel and Temperature 50°C

4.3.14 - Graph Coefficient of Friction vs Time for Pin: Wheel & Temp: 50°C

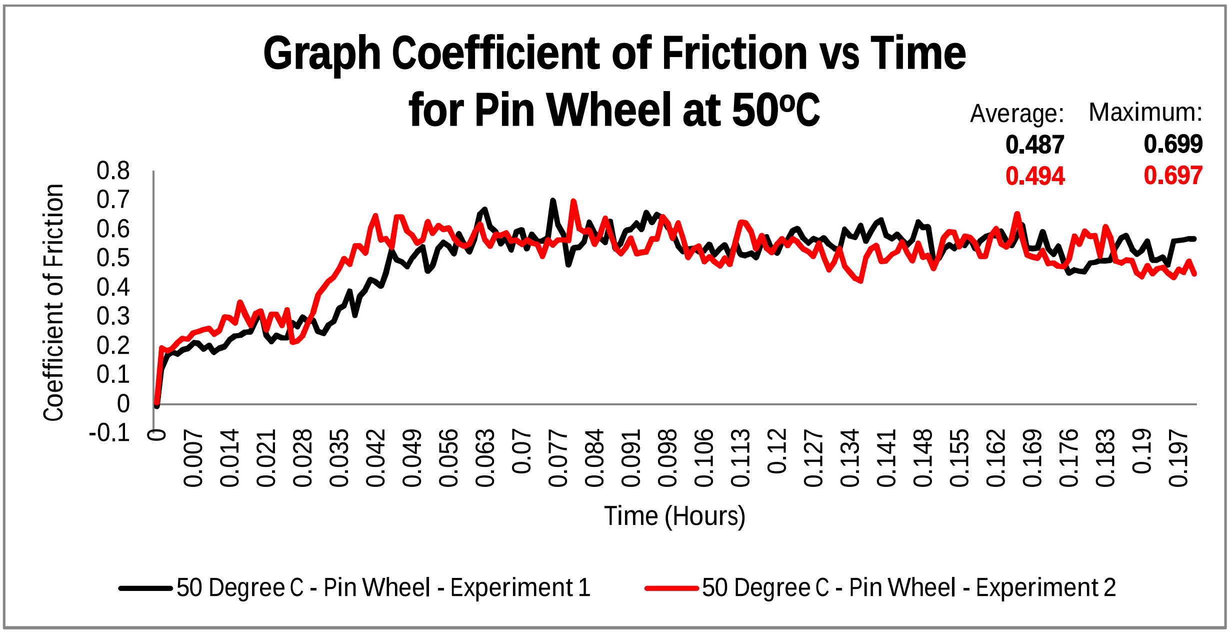


Figure 4.34: Graph Coefficient of Friction vs Time for the Pin Wheel and Temp 50°C

For wheel as the pin material at the temperature 50^{o}C, two repeated experiment has been conducted by using Multi Specimen Wear Tester. Figure 4.29 and 4.31 show the microstructure of the disc specimen and Figure 4.31 and 4.32 shows the microstructure of the pin specimen. In Figure 4.33 shows that the graph of wear rate versus time while in Figure 4.34 shows that the coefficient of friction versus the time for all of three repeated experiments.

By referring the microstructure view, shows that the specimen disc and pin both has adhesive wear and abrasive wear effects. The adhesive wear rate is more affected at the pin specimen compared than at the disc specimen. It is because of the pin is softer than the disc structure. But the abrasive wear rate at the disc specimen is more than the rate of abrasive wear at pin specimen.

Graph in Figure 4.33 shows that the average wear rate value versus time for pin wheel material of 50^{o}C for experiment 1 and 2. The total amount of wear for experiment 1 is 3941 µm and for experiment 2 is 3852 µm. Referring to the results obtained, it is just a slightly different between these two results. This is happened because of the temperature is measured using the thermometer thermocouple directly to the disc specimen while the heater heating the disc and not using the "WINDUCOM 2006" software who just only read the value of the heater temperature value.

Graph in Figure 4.34 shows that the friction coefficient versus time for pin wheel material of 50^{o}C for experiment 1 and 2. The average value of friction coefficient for experiment 1 and 2 is 0.49 and the maximum value is 0.7. From the shape of this graph, it can concluded that this is the typical sliding condition on dry surface and sliding of metal with high load and high wear rate. The trend for coefficient of friction versus time for wheel material is not as high as the material of the track (the material itself).

4.3.15 – Microstructure for Pin: Wheel & Temperature: 90°C

Experiment 1:

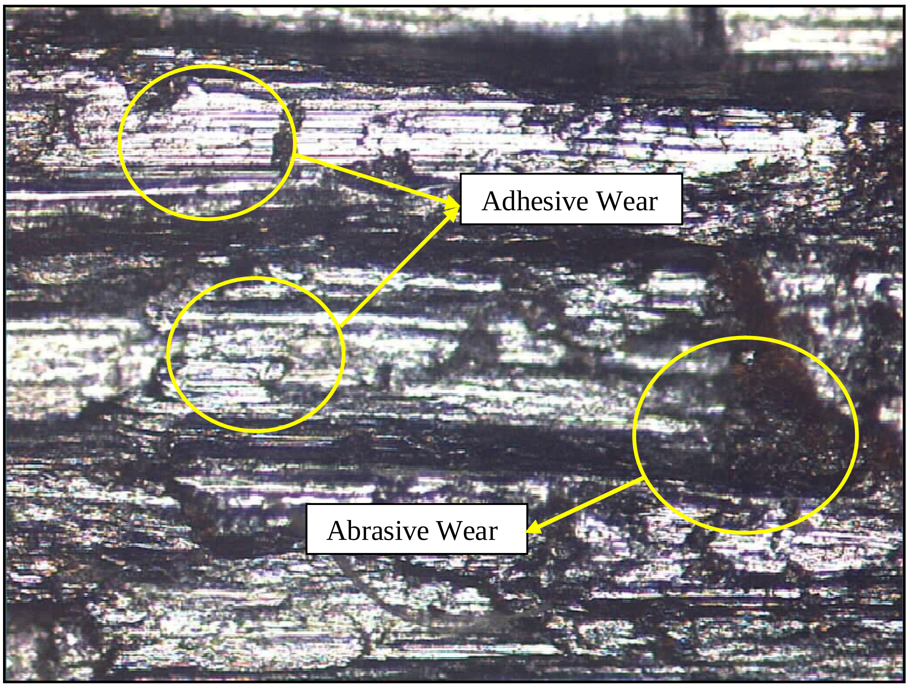


Figure 4.35: Microstructure image of Disc for Wheel Pin at 90°C Experiment 1.

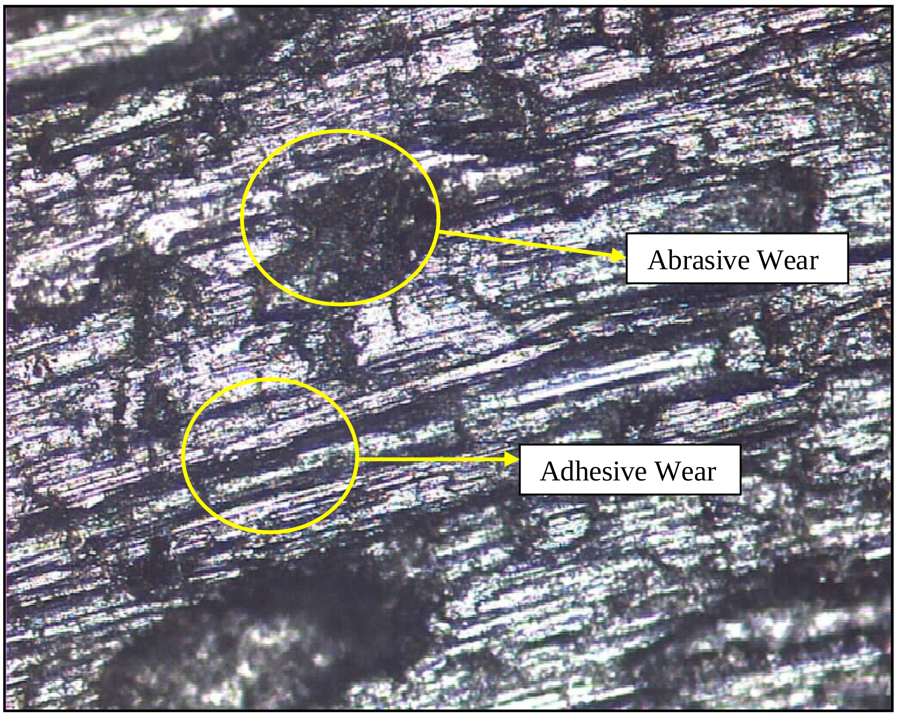


Figure 4.36: Microstructure image of Pin for Wheel Pin at 90°C Experiment 1.

Experiment 2:

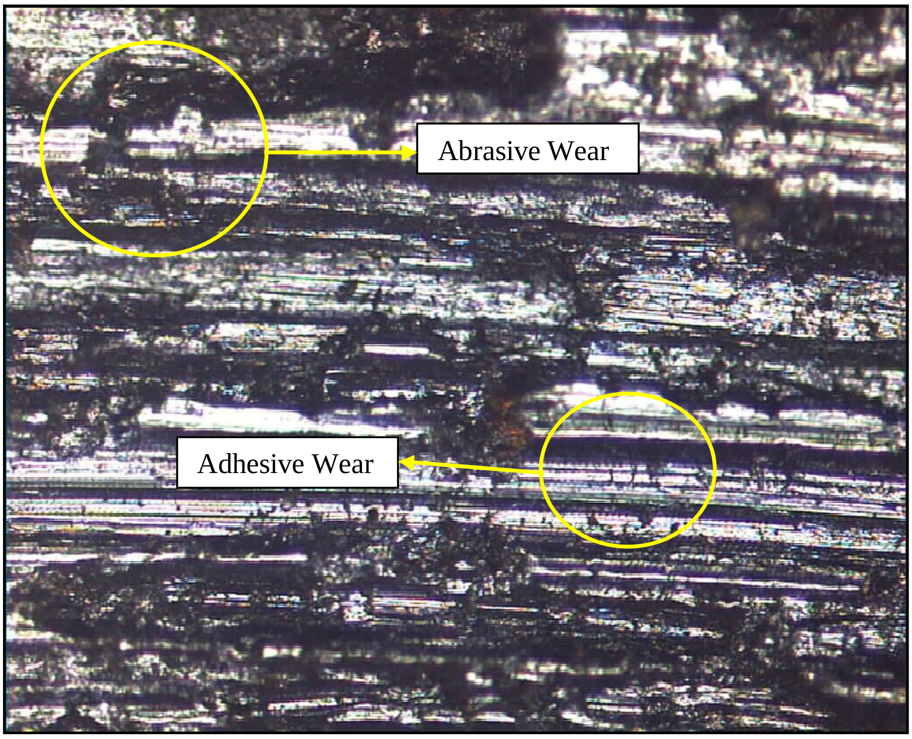


Figure 4.37: Microstructure image of Disc for Wheel Pin at 90°C Experiment 2.

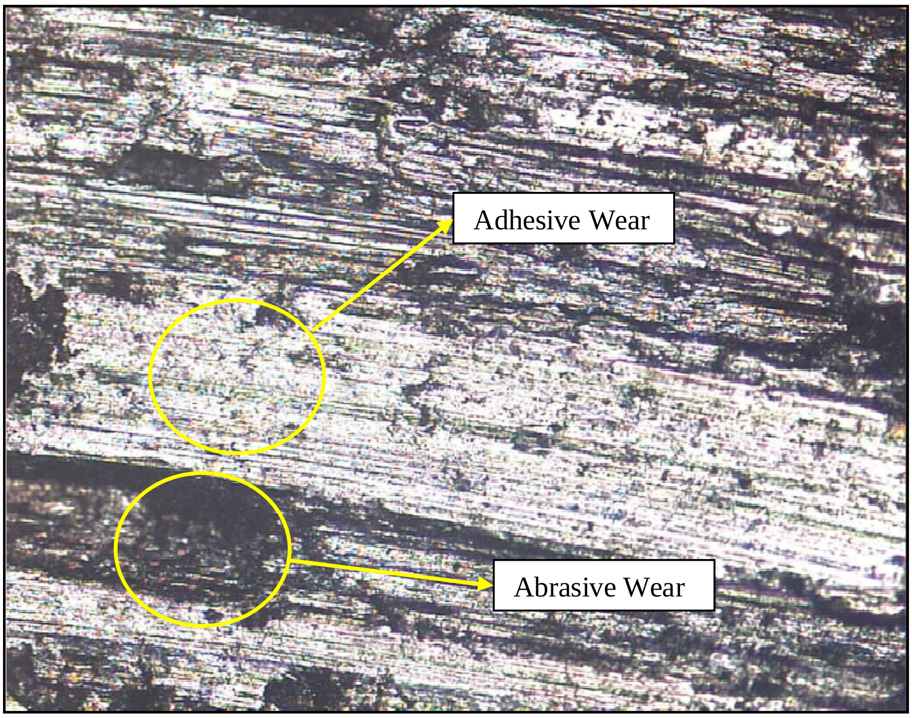


Figure 4.38: Microstructure image of Pin for Wheel Pin at 90°C Experiment 2.

4.3.16 – Graph Wear vs Time for Pin: Wheel & Temperature: 90^{o}C

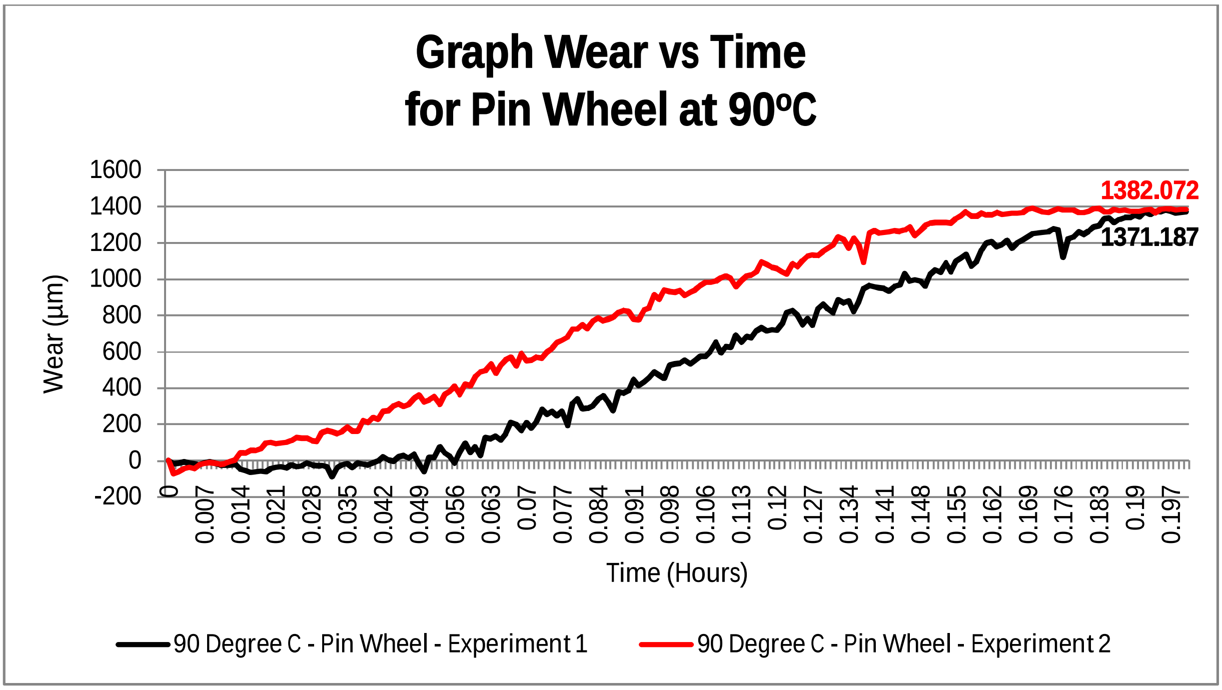


Figure 4.39: Graph Wear vs Time of the Pin Wheel and Temperature 90^{o}C

4.3.17 - Graph Coefficient of Friction vs Time for Pin: Wheel & Temp: 90^{o}C

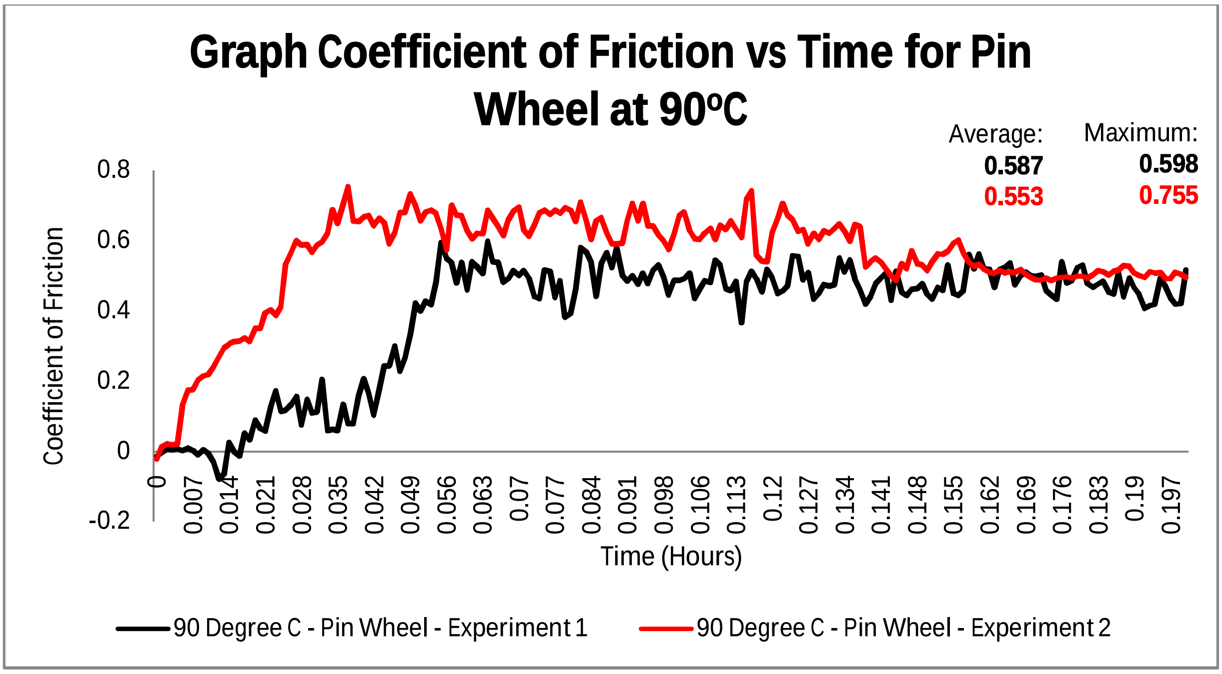


Figure 4.40: Graph Coefficient of Friction vs Time for the Pin Wheel and Temp 90^{o}C

For wheel as the pin material at the temperature 90°C, two repeated experiment has been conducted by using Multi Specimen Wear Tester. Figure 4.35 and 4.37 show the microstructure of the disc specimen and Figure 4.36 and 4.38 shows the microstructure of the pin specimen. In Figure 4.39 shows that the graph of wear rate versus time while in Figure 4.40 shows that the coefficient of friction versus the time for three repeated experiments.

By referring the microstructure view, shows that the specimen disc and pin both has adhesive wear and abrasive wear effects. The adhesive wear rate is more affected at the pin specimen compared than at the disc specimen. It is because the pin is softer than the disc structure. But the abrasive wear rate at the disc specimen is more than the rate of abrasive wear at pin specimen.

Graph in Figure 4.39 shows that the average wear rate value versus time for pin wheel material of 90°C for experiment 1 and 2. The total amount of wear for experiment 1 is 1371 µm and for experiment 2 is 1382 µm. Referring to the results obtained, it is just a slightly different between these two results. This is happened because of the temperature is measured using the thermometer thermocouple directly to the disc specimen while the heater heating the disc and not using the “WINDUCOM 2006” software who just only read the value of the heater temperature value.

Graph in Figure 4.40 shows that the friction coefficient versus time for pin wheel material of 90°C for experiment 1 and 2. The average value of friction coefficient for experiment 1 and 2 is 0.5 and the maximum value is 0.7. From the shape of this graph, it concluded that this is the typical sliding condition on dry surface and sliding of metal with high load and high wear rate. The trend for coefficient of friction versus time for wheel material is not as high as the material of the track (the material itself).

4.4 RESULT ANALYSIS

4.4.1 – Graph Wear vs Time for Pin: Material Itself

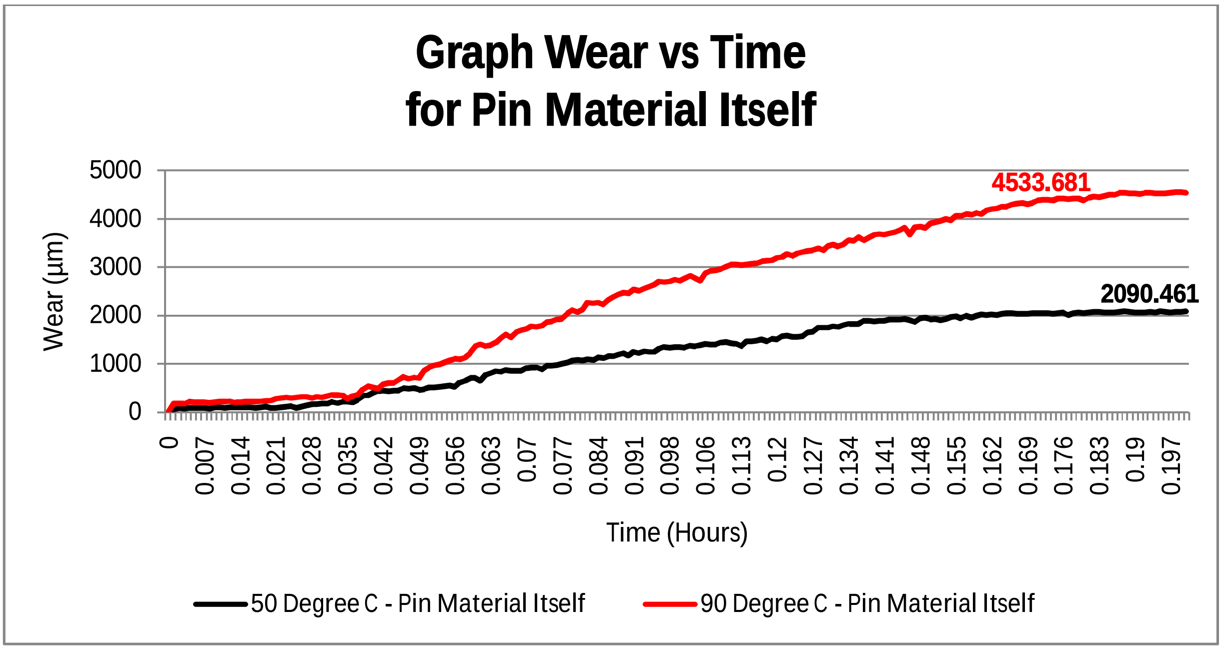


Figure 4.41: Graph Wear vs Time of the Pin Material Itself

4.4.2 – Graph Wear vs Time for Pin: Wheel

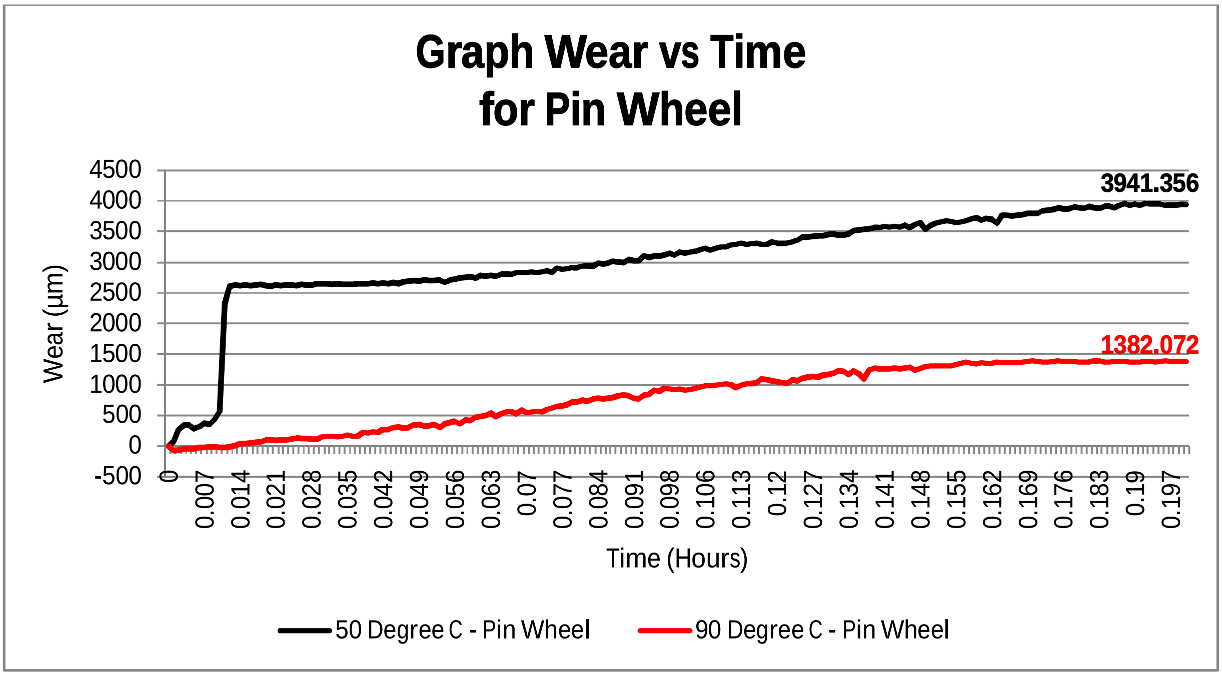


Figure 4.42: Graph Wear vs Time of the Pin Wheel

4.4.3 – Total Graph Wear vs Time

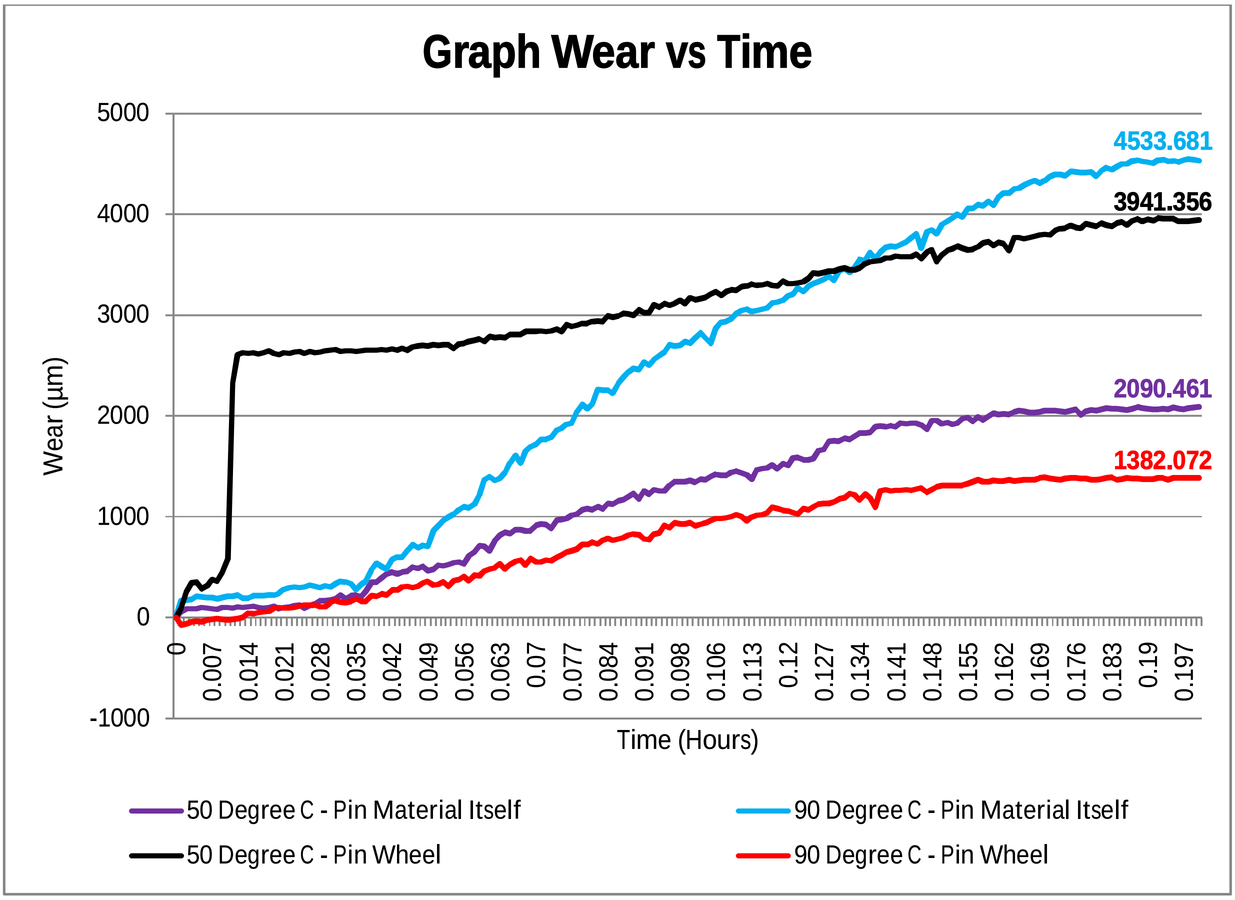


Figure 4.43: Graph Wear vs Time

By referring to Figure 4.43, stated that when the pin specimen using the track material as its material, the wear rate at 90°C (4533µm) is higher than the rate of wear at 50°C (2090 µm).In other hands, if the pin specimen used the wheel material as its material, the wear rate of 90°C (1382 µm) is less than wear rate of 50°C (2090 µm). This is happened caused by the structure of the material. The wear behavior states that the softer the material, the higher rate of wear will be occurred. This proved that the wheel material is softer than the rail track material.

Besides, the temperature also affected the wear rate of the surface. if both used the rail track material as its material, the higher the temperature, the higher wear rate occurred but if the pin used the wheel track material and the disc used the rail track material it will be in vice-versa conditions.

By referring to the graph of the wear rate versus the time for the pin wheel material of 50°C in Figure 4.43, it shows that the wear rate increased rapidly before it reaches the steady state condition as another sample. This is because at lower temperature the dominant wear mechanism which is abrasive in nature tends to wear more. Figure 4.43 proved that the result obtained is similar to Figure 4.33 although this experiment has conducted once again. Although the delay in time between each other is slightly different; the wear rate obtained for both experiments is still the same.

4.4.4 - Graph Coefficient of Friction vs Time for Pin: Material Itself

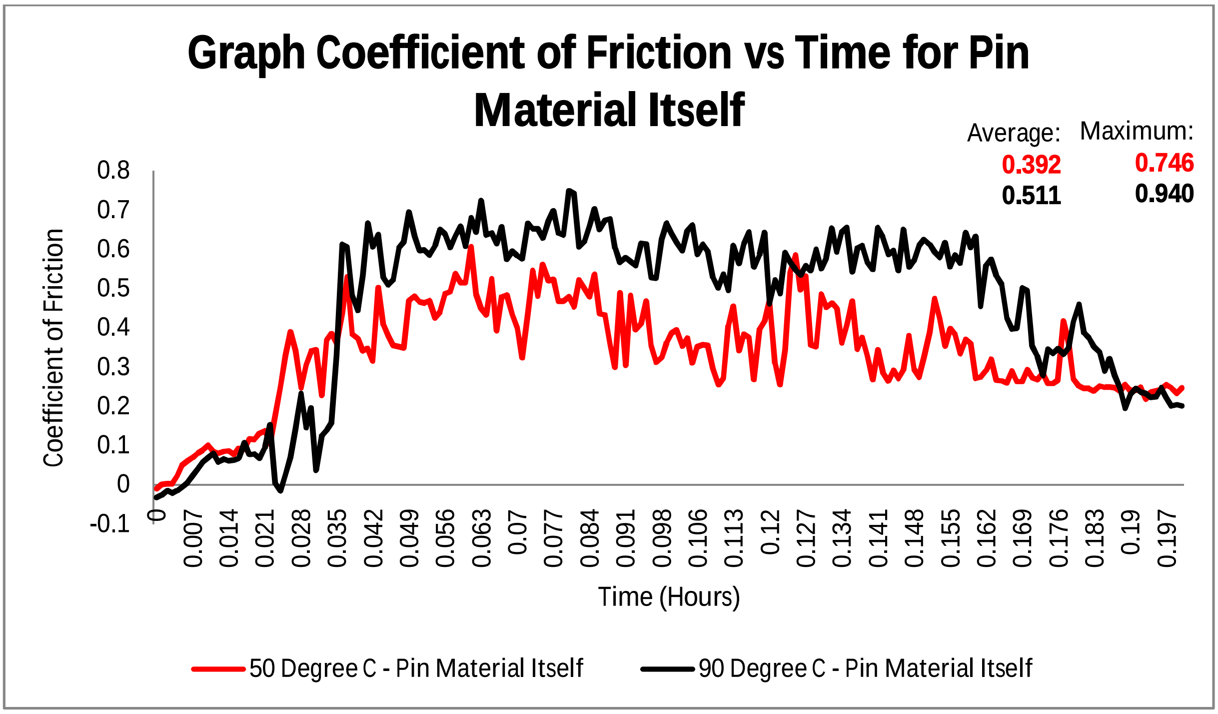


Figure 4.44: Graph Coefficient of Friction for the Pin Material Itself

4.4.5 - Graph Coefficient of Friction vs Time for Pin: Wheel

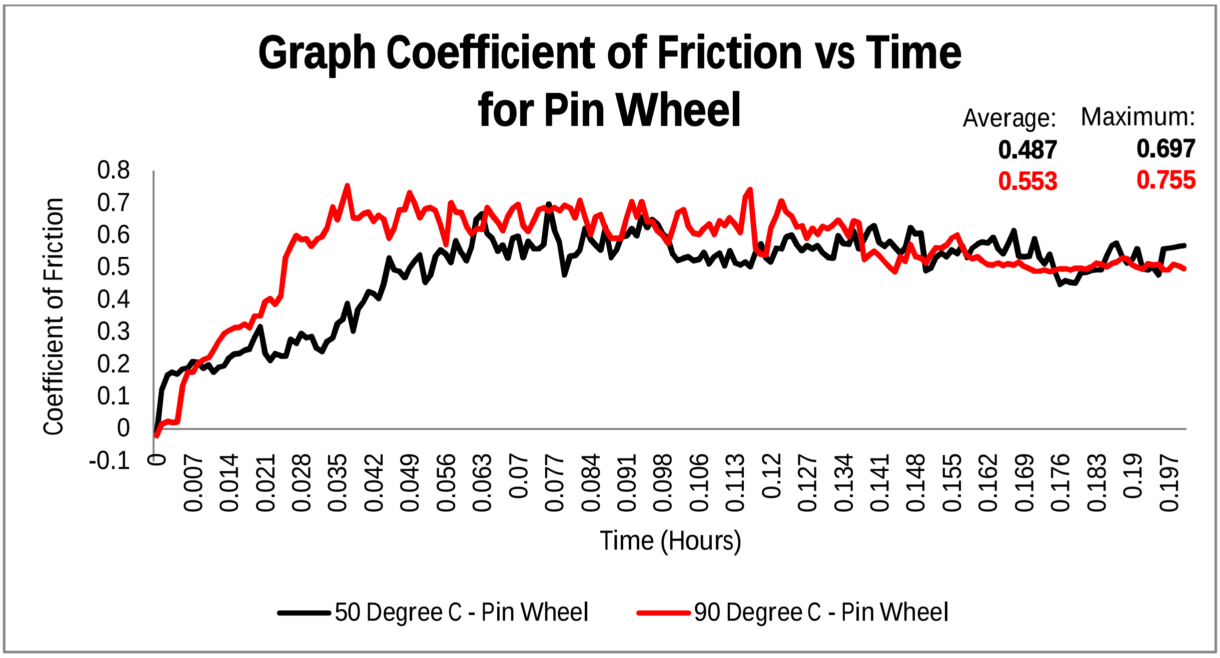


Figure 4.45: Graph Coefficient of Friction for the Pin Wheel

4.4.6 – Total Graph Coefficient of Friction vs Time

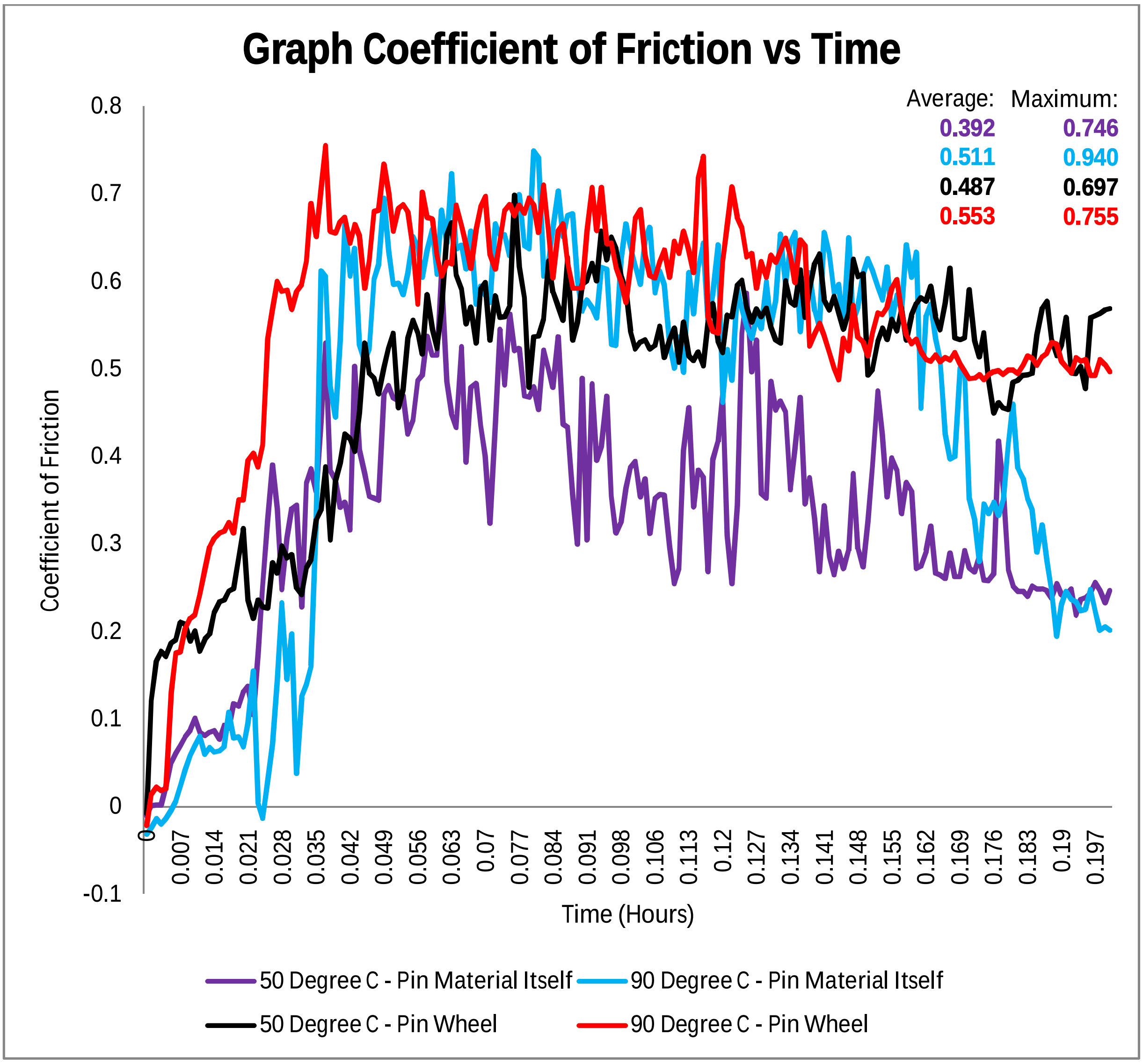


Figure 4.46: Graph Coefficient of Friction vs Time

For the friction coefficient, the amount of friction force at higher temperature is higher than the friction force at lower temperature. The average coefficient of friction results at 90^{o}C is 0.5 while the average coefficient of friction at 50^{o}C is 0.4. Thus, by comparing these two friction coefficient at the different temperature, it will results that the higher the temperature, the higher frictions coefficient obtained.

This happened because at the high temperature, the friction amount will be higher. The higher friction amount will effected to the softer material more. The softer material will be easily to wear at higher temperature.

But the trend for the coefficient of friction at lower temperature is higher than the trend at high temperature. It means that, from the graph, at lower temperature the typical sliding on dry surface or sliding on metal surface with high load or high wear.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

As the conclusion, when both disc specimen and pin were used from same material (material from rail track), higher wear rate (4533 µm) and coefficient of friction (0.7) were found. But if the rail track material (pin specimen) replaced with the wheel material, the wear effect will occurred lower than the result obtained if both disc and pin used the same material (rail track material). This is happened because the hardness of the wheel material is softer than the rail track material.

For the friction coefficient, the trend at lower temperature is higher than at higher temperature. The higher trend means that the sliding condition is on a dry surface or at high load or during high wear.

Practically, the wheel material is softer than rail material. This is because to reduce the wear on the rail. In facts, to replace the rail wheel is easier than to replace the rail track. The softer the material, the higher the wear effects.

5.2 RECOMMENDATION

Instead in getting a precise result, the recommendation is by taking the temperature reading of the rail track and the disc specimen twice or more to avoid errors. Errors may due to the measuring devices or to the person himself. For the disc specimen specifically, software is used to measure the reading of the temperature but it will record the reading of the heater only, not the reading of the disc specimen. To get the exact disc specimen temperature reading, the author measured the temperature by using the thermocouple directly to the disc while the heater is heating the disc specimen.

In order to obtain a better result, the experiment should be done repeatedly and the measuring devices should be calibrated in every use. In every experiment, the calibration of the devices is important to prevent the errors.

The proper specimen preparation for each disc and pin are also important and it must follow the standard procedures occordingly.

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APPENDICES

APPENDIX A:

Gantt chart for FYP 1

Activities / Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**10**	**11**	**12**	**13**	**14**
Topic selection	🟩									Mid semester break					
Preliminary research		🟩													
Submission of Preliminary Report		🟥													
Study on Friction& Wear at Elevated Temperature			🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	
Study on Rail Track Mechanism					🟩	🟩	🟩	🟩	🟩						
Study on ASTM G99							🟩	🟩	🟩						
Preparation for Progress Report						🟩	🟩	🟩	🟩						
Submission of Progress Report											🟥				
Seminar											🟥				
Cutting Process using Chain Saw									🟦		🟦				
Cutting Process using Milling Machine												🟦			
Electrical Discharge Machining (EDM) Cutting Process													🟦	🟦	
Preparation for Interim Report											🟩	🟩	🟩	🟩	🟩
Submission of Interim Report															🟥
Oral presentation															🟥

APPENDIX B:

Gantt chart for FYP 2

	Activities / Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project work continues	🟩	🟩	🟩					Mid semester break							
2	Initial data collection		🟩													
3	Preparing for Progress Report 1			🟩	🟩											
4	Submission of Progress Report 1				🟥											
5	Preparation for Pin of pin-on-disc equipment				🟩	🟩										
6	Pin-on-disc experiment					🟩	🟩	🟩								
7	Submission of Progress Report 2									🟥						
8	Seminar									🟥						
9	Project work continues (data analysis)									🟩	🟩	🟩	🟩	🟩	🟩	🟩
10	Poster Exhibition											🟥				
11	Submission of Dissertation Final Draft															🟥
12	Oral Presentation									During study week						
13	Submission of Dissertation (Hard Bound)									7 days after oral presentation						