# Light Rail Transit (LRT) Brake Materials: Detail Characterization of Hardness and Impact Energy

by

Irwan Bin Mohd Faizal Din Chan

Dissertation Submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
Mechanical Engineering

JUN 2004

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**CERTIFICATION OF APPROVAL**

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Approved by,

(Dr. Mustafar Sudin)

Universiti Teknologi PETRONAS
TRONOH,Perak Darul Ridzuan
JUN 2004

## 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 the original work contain herein have not been taken or done unspecified sources or persons.

________________________________________

(IRWAN BIN MOHD FAIZAL DIN CHAN)

# ABSTRACT

This project is continuation of the preliminary investigation study on Light Rail Transit brake pad material done by the previous student. The main objective of the project is to give specific data on the characterization of materials currently used in Light Rail Transit brake pads. This project will study the properties of different products used by two local Light Rail Transit companies namely Projek Usahasama Transit Aliran Ringan Automatik Sdn. Bhd (PUTRA) and Sistem Transit Aliran Ringan Sdn. Bhd. (STAR) Both companies now under Syarikat Prasarana Negara Berhad. The specific characterization will be focused on brake pads were its hardness, impact, and microstructure characteristics. Experimental testing will be done according to the standards. The resulting data will create a database to compare between the different products in great detail in terms of its properties and characterizations with the verified location.

# ACKNOWLEDGEMENT

In the Name of Allah, Most Gracious, Most Merciful. With His blessings, this project had been completed in time.

The author would like to express many thanks and gratitude to all of the followings:

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## ABBREVIATIONS AND NOMENCLATURE

The following are the abbreviations and nomenclature applied to this report :

| | | |
|---|---|---|
| ASTM | - | American Standards for Testing and Materials |
| EDX | - | Energy Dispersive X-ray Analysis |
| Cr | - | Chromium |
| Cu | - | Copper |
| PUTRA | - | Projek Usahasama Transit Aliran Ringan Automatik Sdn. Bhd |
| Ni | - | Nickel |
| SEM | - | Scanning Electron Microscope |
| PM | - | Powder Metallurgy |
| SI | - | Système International |
| STAR | - | Sistem Transit Aliran Ringan Sdn. Bhd |
| Zn | - | Zinc |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

Brake system consists of part which is known as friction materials or brake pad. Brake pad is a medium where the kinetic energy converted into thermal energy. Heat produced from the contact is absorbed and/or dissipated by the friction material. [Zimmerman,1996] The coefficient of friction, determines the level of performance of the friction material.

There were several basic requirements for the brake pad. For an acceptable friction brake material these may be summarized as follows: Resistance to wear, correct friction level, resistance to heat fade, minimal friction variation, reasonable wet behaviour and quietness of operation. [Jenson, 1989] In order to meet the requirements, the brake pad was not constructed with single material.

Result from the previous research, SIRIM has developed the car braking pad with the powder metallurgy technology. The sizes of LRT brake pad nearly 6 times larger than the car brake pad. Therefore the material formulation, powder metallurgy processing technique, dies design, method of product evaluation and performance will be different from the car brake pad. However, the research methodology used before in producing the car brake pad will be applied in the LRT brake pad research.

## 1.2 PROBLEM STATEMENT

Currently, a local light rail company uses imported brake pads that are not readily available locally. It is understood that the manufacturing and production of such brake pads, including its formulation, materials supply and machineries are strictly governed by foreign companies. Therefore this contributes to the high cost since the products have to be imported. To produce the brake pad locally, extensive study and research must be carried out. Due of the numerous aspect and scope of study of the research, there was collaboration between the client, higher learning institute and the industries in this project.

Previous preliminary study of LRT brake pads has resulted and discussed the mechanical properties and characterization of the brake pads i.e. Hardness, microhardness, impact energy, microstructure and EDX analysis. However, previous study has given only the general information about the brake pad. The resulted data are not specific in terms of its location. Furthermore the frequencies of data measured were also not sufficient. Therefore this project will continue the preliminary investigation of the presently used brake pads and improves these two areas.

Furthermore, in the future this project will contribute to locally manufactured brake pad. It will be benefited not only the local light rail companies, but may also be exported internationally.

## 1.3 OBJECTIVES AND SCOPE OF STUDY

### 1.3.1 Objectives

The main objective of this project is to detail out the characterization of the properties of the material used in the light rail brake pads. From the data resulted in previous project, this project will give more detail information about material properties, especially the mechanical properties that include hardness, impact energy and microstructure. The detail information means the experimental data of the brake pad will be associated with the coordinated location. Furthermore, the amount of the test data will be exaggerated compared to the previous pre-investigation research. The resulted data then will be analysed and discussed.

### 1.3.2 Scope of Works

The scope of study for this project is to prepare the brake pads from STAR and PUTRA to be able being tested its hardness and impact characteristic. Therefore students will study the means of producing the specimens from STAR and PUTRA brake pads for the impact test and hardness test.

Furthermore the scope of study also included study on the factors that contribute to the attained result. The results also will be compared with the previous result.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 BRAKING SYSTEM

The brakes are in essence energy conversion devices, which convert the kinetic energy of your vehicle into thermal energy. In this project, the focused part was the brake's pad. The pad is actually a material design to perform those task; rub against a surface to convert kinetic energy into thermal energy. It's also understood that mechanical stress and thermal stress being applied to the pad during the operation.[Zimmerman, 1996]

Mechanical stress in significant when the brakes are not applied. When the brakes applied, there is compression force towards the pad against the surface of the disk. There are also traction forces resulting from opposing rotary motion. Whereas, the thermal stress generated when all the energy are converted in the form of heat. Distribution of heat flow depends on physical-chemical properties of the two materials. It also known that 80% of cases, the heat generated ends up in the disc.

In order to meet the requirements, the brake pad was not constructed with single material. Nowadays, there are more than 200 different materials involved in brake system components. Very sufficient information is needed in term of material properties and composition before furthering any study towards wear control of the material.

Automotive and truck brake pads usually contain fiber reinforcement, binder, performance modifiers, abrasives, elastomers, lubricants and fillers. [NOOR,2002]

Fiber reinforcement increases the strength and enhances the mechanical properties of the pads. Binder acts to bond together all the composition of the pad. Binder has varies of bonding characteristics and temperature resistance of the final product. Fillers are used to maintain the overall composition of the friction material. Abrasive and modifiers contributes to the main braking properties such as lubricate and raise the friction and help control interfacial films. Furthermore, abrasive like Aluminum and iron oxides can maintain the cleanliness of mating surfaces and control the build-up of friction films.

## 2.2 POWDER METALLURGY

Powder Metallurgy is a continually and rapidly evolving technology embracing most metallic and alloy materials, and a wide variety of shapes. PM is a highly developed method of manufacturing reliable ferrous and non ferrous parts. Some of the benefits the PM process are Tailored Solutions, Consistency, high levels of Porosity and Longevity.

Created by mixing elemental or alloy powders and compacting the mixture in a die, the resultant shapes are then heated or "sintered" in a controlled atmosphere furnace to bond the particles metallurgically. [25] Sintering is the means whereby the powder particles are welded together and a strong finished part produced. The sintering of mechanical parts is usually done in a continuous belt furnace - in special cases a vacuum furnace is used. Simplified model:

- a single metal
- spherical particles in contact

In the pressing operation the powder particles are brought together and deformed at the points of contact. At elevated temperature which is the sintering temperature the atoms can move more easily and quickly migrate along the particle. The process also called diffusion.

Metals consist of crystallites. At the sintering temperature new crystallites form at the points of contact so that the original interparticle boundaries disappear, or become recognizable merely as grain boundaries. This process is called recrystallisation. The total internal surface area of the pressed body is reduced by sintering

Neck-like junctions are formed between adjacent particles as can be seen on the adjoining scanning electron micrograph of sintered filter material made from spherical bronze powder.

## 2.3 HARDNESS THEORY

The Metals Handbook defines hardness as "Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

In mineralogy the property of matter commonly described as the resistance of a substance to being scratched by another substance. In metallurgy hardness is defined as the ability of a material to resist plastic deformation.

The dictionary of Metallurgy defines the indentation hardness as the resistance of a material to indentation. This is the usual type of hardness test, in which a pointed or rounded indenter is pressed into a surface under a substantially static load.

## 2.4 HARDNESS MEASUREMENT THEORY

Hardness measurement can be defined as macro-, micro- or nano- scale according to the forces applied and displacements obtained [15].

Measurement of the macro-hardness of materials is a quick and simple method of obtaining mechanical property data for the bulk material from a small sample. It is also widely used for the quality control of surface treatments processes. However, when concerned with coatings and surface properties of importance to friction and wear processes for instance, the macro-indentation depth would be too large relative to the surface-scale features.

Where materials have a fine microstructure, are multi-phase, non-homogeneous or prone to cracking, macro-hardness measurements will be highly variable and will not identify individual surface features. It is here that micro-hardness measurements are appropriate.

Microhardness is the hardness of a material as determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of the material under 15 to 1000 gf load; usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardness of different microconstituents within a structure, or measuring steep hardness gradients such as those encountered in casehardening. Conversions from microhardness values to tensile strength and other hardness scales are available for many metals and alloys [16].

Micro-indenters works by pressing a tip into a sample and continuously measuring: applied load, penetration depth and cycle time.

Nano-indentation tests measure hardness by indenting using very small, on the order of 1 nano-Newton, indentation forces and measuring the depth of the indention that was made. These tests are based on new technology that allows precise measurement and control of the indenting forces and precise measurement of the indentation depths. By measuring the depth of the indentation, progressive levels of forcing are measurable on the same piece. This allows the tester to determine the maximum indentation load that is possible before the hardness is compromised and the film is no longer within the testing ranges. This also allows a check to be completed to determine if the hardness remain constant after an indentation has been made. [17]

## 2.5 ROCKWELL HARDNESS TEST

The Rockwell Hardness test is a hardness measurement based on the net increase in depth of impression as a load is applied. Hardness numbers have no units and are commonly given in the R, L, M, E and K scales. The higher the number in each of the scales means the harder the material.

In the Rockwell method of hardness testing, the depth of penetration of an indenter under certain arbitrary test conditions is determined. The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius, called Brale. The type of indenter and the test load determine the hardness scale (A, B, C, etc).

The hardness of ceramic substrates can be determined by the Rockwell hardness test, according to the specifications of ASTM E-18. This test measures the difference in depth caused by two different forces, using a dial gauge. Using standard hardness conversion tables, the Rockwell hardness value is determined for the load applied the diameter of the indenter, and the indentation depth. [18]

Rockwell hardness test does not serve well as a predictor of other properties such as strength or resistance to scratches, abrasion, or wear, and should not be used alone for product design specifications.

The Rockwell hardness tester to measure the hardness of metal measures resistance to penetration like the Brinell test, but in the Rockwell case, the depth of the impression is measured rather than the diametric area. With the Rockwell tester, the hardness is indicated directly on the scale attached to the machine. This dial like scale is really a depth gauge, graduated in special units. The Rockwell hardness test is the most used and versatile of the hardness tests. [5]

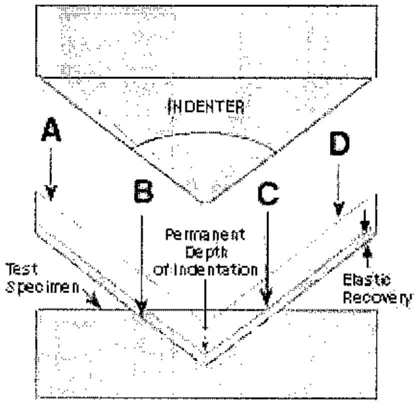
For soft materials such as copper alloys, soft steel, and aluminium alloys a 1/16" diameter steel ball is used with a 100-kilogram load and the hardness is read on the

"B" scale. In testing harder materials, hard cast iron and many steel alloys, a 120 degrees diamond cone is used with up to a 150 kilogram load and the hardness is read on the "C" scale. The Rockwell test uses two loads, one applied directly after the other. The first load, known as the "minor", load of 10 kilograms is applied to the specimen to help seat the indenter and remove the effects, in the test, of any surface irregularities. In essence, the minor load creates a uniformly shaped surface for the major load to be applied to. The difference in the depth of the indentation between the minor and major loads provides the Rockwell hardness number. There are several Rockwell scales other than the "B" & "C" scales, which are called the common scales. The other scales also use a letter for the scale symbol prefix, and many use a different sized steel ball indenter. A properly used Rockwell designation will have the hardness number followed by "HR" (Hardness Rockwell), which will be followed by another letter which indicates the specific Rockwell scale. An example is 60 HRB, which indicates that the specimen has a hardness reading of 60 on the B scale. There is a second Rockwell tester referred to as the "Rockwell Superficial Hardness Tester". This machine works the same as the standard Rockwell tester, but is used to test thin strip, or lightly carburized surfaces, small parts or parts that might collapse under the conditions of the regular test. The Superficial tester uses a reduced minor load, just 3 kilograms, and has the major load reduced to either 15 or 45 kilograms depending on the indenter, which are the same ones used for the common scales. Using the 1/16" diameter, steel ball indenter, a "T" is added to the superficial hardness designation. An example of a superficial Rockwell hardness is 15T-22, which indicates the superficial hardness as 22, with a load of 15 kilograms using the steel ball.

The Rockwell principle measures permanent depth of indentation produced by the preliminary and total test forces. First, a preliminary test force or minor load is applied (figure 2.1). This is the zero or reference position. Then, an additional test force (or major load) is applied to reach the total required test force. This additional force is held for a predetermined amount of time and then released, but with the preliminary test force still applied. The indenter reaches the final position at the preliminary force and the distance travelled from the major load position is measured and converted to a hardness number. [20]

**A.** Depth reached by indenter after applicatic of preliminary test forc (minor load).

**B.** Position of indenter under total test force.




**D.** Position at which measurement is taken.

**C.** Final position reached by indenter after elastic recovery of the material.

Figure 2.1: Rockwell measurement Principles

**2.6 IMPACT TEST**

The impact property of a material is its resistance to fracture when a sudden and dynamic load is applied. A standard notch will be machined in standard specimen to be tested. Charpy V-Notch Test is a single point test that measures a materials resistance to impact from a swinging pendulum with V notch according to
ASTM E-23

The test procedure is as follows; the specimen is clamped into the pendulum impact test and centered to face the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen.

The standard test piece shall be 55 mm long and of square section with 10 mm sides. And also have V notch of 45°, 2 mm deep with a 0,25 mm radius of curve at the base of notch. If standard test piece cannot be obtained from the material, a reduced section with a width of 7,5 mm or 5 mm shall be used, the notch being cut in one of the narrow faces. [21] Refer Appendix 3: Dimension of test specimen for Charpy impact test.

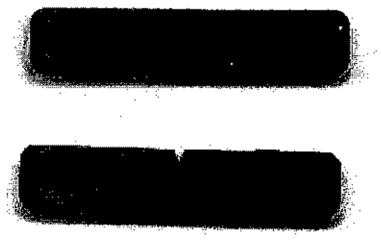


Figure 2.2: Sample of Impact Test

ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J (or ft-lb) by the thickness of the specimen. The test result is typically the average of 5 specimens.

ISO impact strength is expressed in $kJ/m^2$. Impact strength is calculated by dividing impact energy in J by the area under the notch. The test result is typically the average of 10 specimens.

## 2.7 EDX - ENERGY DISPERSIVE X-RAY ANALYSIS

Scanning Electron Microscope (SEM) is a very widely used technique to study surface topography. [22] A high energy (typically 10keV) electron beam is scanned across the surface. The incident electrons cause low energy secondary electrons to be generated, and some escape from the surface. The secondary electrons emitted from the sample are detected by attracting them onto a phosphor screen. This screen will glow and the intensity of the light is measured with a photomultiplier. The incident electrons will also cause X-rays to be generated which is the basis of the EDX technique. This technique is used in conjunction with SEM and is not a surface science technique. An electron beam strikes the surface of a conducting sample. The energy of the beam is typically in the range 10-20keV. This causes X-rays to be emitted from the point the material. The energy of the X-rays emitted depends on the material under examination. The X-rays are generated in a region about 2 microns in depth, and thus EDX is not a surface science technique. By moving the electron beam across the material an image of each element in the sample can be acquired in a manner similar to SEM. [24] Due to the low X-ray intensity, images usually take a number of hours to acquire. Elements of low atomic number are difficult to detect by EDX. The SiLi detector is often protected by a Beryllium window. The absorption of the soft X-rays by the Be precludes the detection of elements below an atomic number of 11 (Na). In windowless systems, elements with as low atomic number as 4 (Be) have been detected, but the problems involved get progressively worse as the atomic number is reduced. [9]

The detector used in EDX is the Lithium drifted Silicon detector. This detector must be operated at liquid nitrogen temperatures. When an X-ray strikes the detector, it will generate a photoelectron within the body of the Si. As this photoelectron travels through the Si, it generates electron-hole pairs. The electrons and holes are attracted to opposite ends of the detector with the aid of a strong electric field. The size of the current pulse thus generated depends on the number of electron-hole pairs created, which in turn depends on the energy of the incoming X-ray. Thus, an X-ray spectrum can be acquired giving information on the elemental composition of the material under examination.

# CHAPTER 3

# METHODOLOGY

This section will describe the general procedure for preparing the standard sample for the impact test experiment. Initially, the project will focused on strengthen the theory part for the given experiment with literature review. Then site visit will be conducted to further understand the concept of braking system in LRT. Hence the sample also will be asked and obtained. After that, experiments also reviewed for its availability and effectiveness. If the experiment is relevant but the availability is none, the alternative place will be carried out. Beside that, if the experiment required any sample preparation, the sample preparation for the experiment will carried out first. Then the project will be focused on improving the data and perform more frequency of experiments and eliminated experiments that are not usable. And finalize it with discussion and analysis from the results obtained. Figure 3.1 briefly summarized the methodology for the entire project

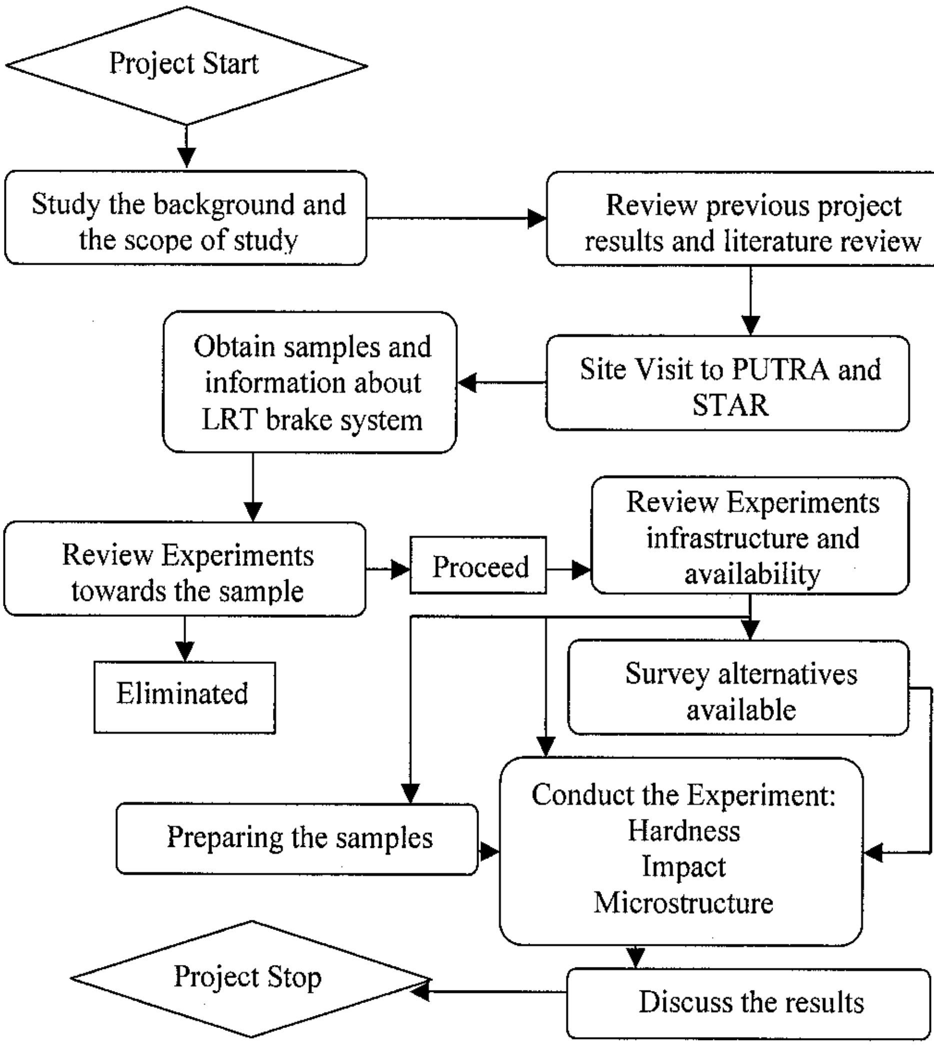



Figure 3.1: Flowchart of Methodology

### 3.1 SITE VISIT

Since this project is continuation project, only one sample obtained from the previous project was left; PUTRA LRT brake pad. Couples of visits already conducted and link between the respective personnel have been established; En Johari B Bujang, Foreman, Boggy Section, STAR and En Ahmad Ridzal Ab. Hamid, Supervisor, Vehicle Maintenance, PUTRA. During the visits 3 of used samples are obtained from the PUTRA LRT and 5 used and 1 new sample from STAR LRT. From the visit student has been exposed to the basic system of the LRT brake mechanism and their system's part. For further review on the visit please refer Appendix 4 and 5.

## 3.2 HARDNESS TEST PROCEDURE

Before proceeding into the hardness test, one of the objectives of the experiment is to know the exact location of the specimen. Therefore the specimens are marked with horizontal and vertical line to construct invisible coordinate system to indicate the exact location on the brake pad. First, couple of the photographs of the samples have been taken and then the samples were matched with the vertical and horizontal line that act as coordinate system to determine the exact location before the hardness test being conducted. Figure 3.2 and 3.3 below showed the location being mark on PUTRA brake pad and STAR brake pad.

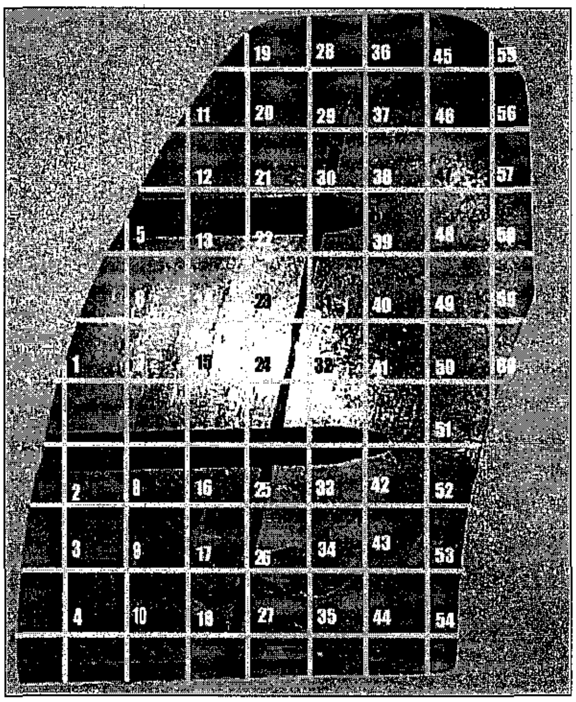



Figure 3.2: Coordinate Location of STAR Brake Pad

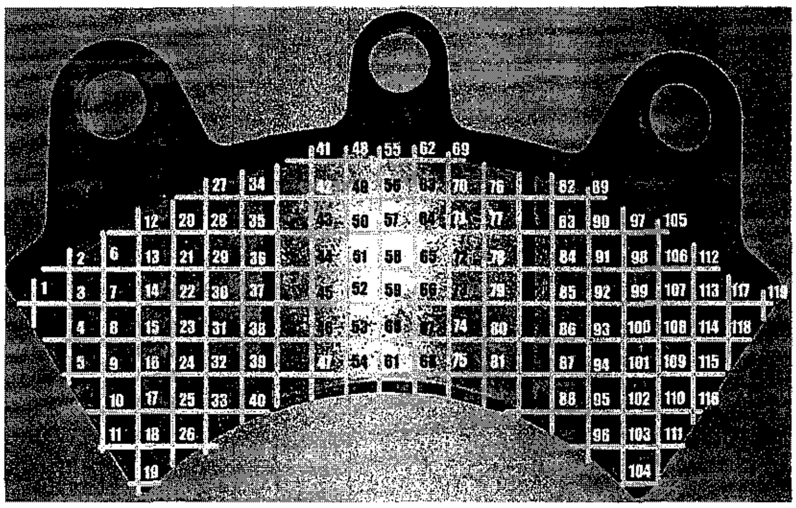


Figure 3.3: Coordinate Location of PUTRA Brake Pad

For hardness test, Rockwell hardness test V scale will be performed on the specimen as similar as the previous project conducted. The experiment has been conducted at UPM since the indenter required for the experiment is not available at UTP. The result obtained will be read as HRV as previous project obtained. To conduct this test, the indenter used is ½" steel ball indenter with minor load 10 kgf and major load is 150 kgf. For STAR brake pad, the hardness test is conducted to compare between new and used samples. Although for STAR samples is conducted two times, but the reference graphic is similar since the test has been conducted at the same location for both samples. But for PUTRA, the hardness test will be conducted once since only used samples obtained. Then the resulting data will be used for the hypothesis.

## 3.3 SAMPLE PREPARATION FOR THE IMPACT TEST

The samples need to be machined to follow the ASTM E-23 standard size specimen. With The sample will be prepared at manufacturing lab with the desired dimension. Before that the hardness of the sample will be read out to ensure proper method will be used for cutting the sample. When the samples of impact test were ready, the experiment will be follow up.

During the preparation of the sample for the impact test, student browsed and studied various cutting tools available in UTP. The machines were Wire Cutter, Milling Machine, Linear Hacksaw and rotating hacksaw. Unfortunately, all of them were not capable of producing exact dimension as required by ASTM E-23 standard specimen. During the preparation process, only linear hacksaw and rotating hacksaw were used. Furthermore, this machines only used for major cutting only. The finished products were done manually by hand hacksaw. Beside time consuming, extra skills required to produce the required dimension that meet ASTM E-23 standard specimen. The flow chart of preparing the sample for impact test as following figure 3.4:

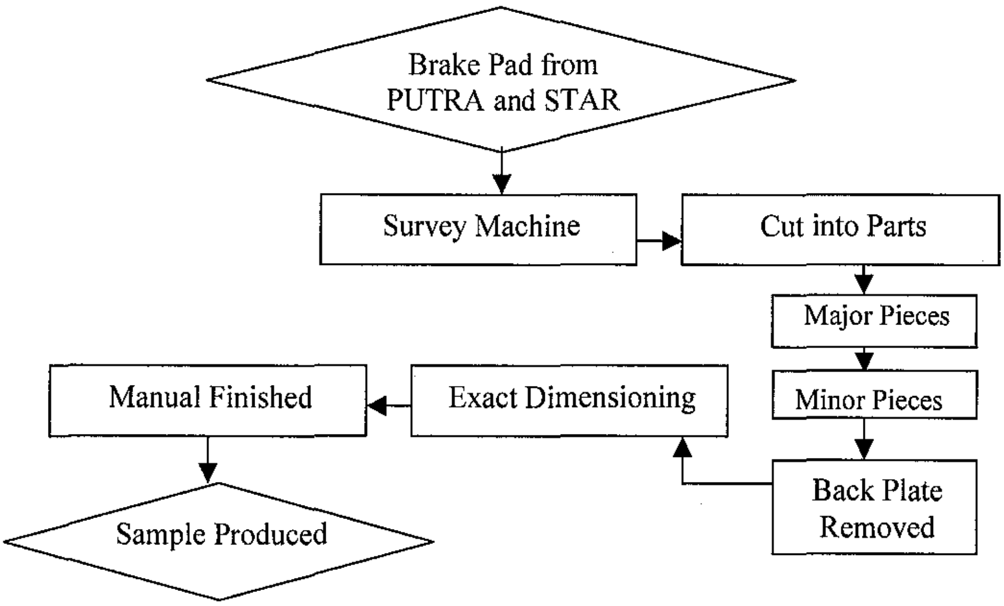



Figure 3.4: Flowchart of preparation for impact test sample.

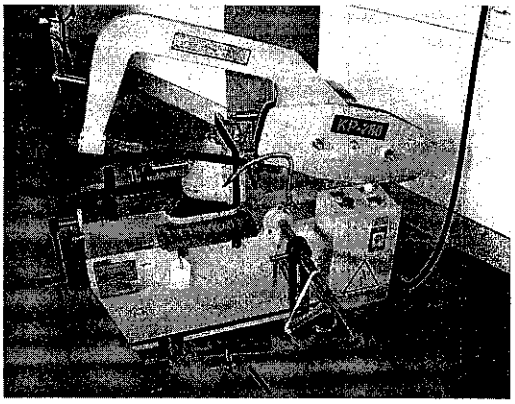
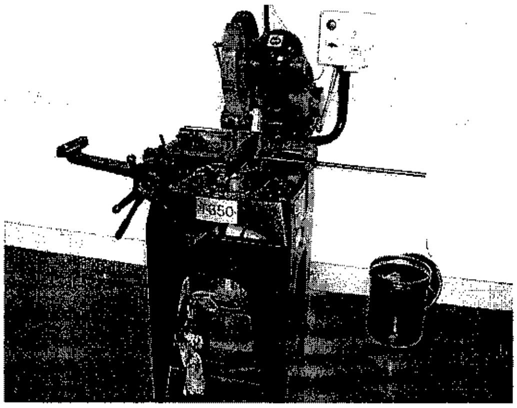
 

Figure 3.5 and 3.6 : Linear Hacksaw machine (on the left) is used to produce 6 major pieces from STAR brake pad. And rotating hacksaw is used to produce 3 major pieces from PUTRA brake pad.

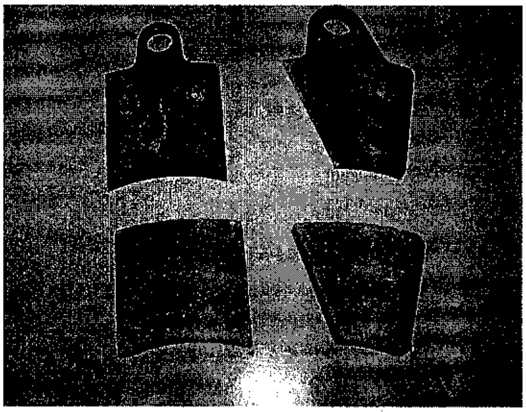


Figure 3.7: major pieces of PUTRA brake pad.

There only two major pieces of PUTRA brake pad shown From figure 3.7. The other one piece is already put under work to produce smaller pieces. As we can see here, the pad already separated from the back plate. The pad being separated by knocking the hole at the back of the pad and thus force the pad separated from the back plate.

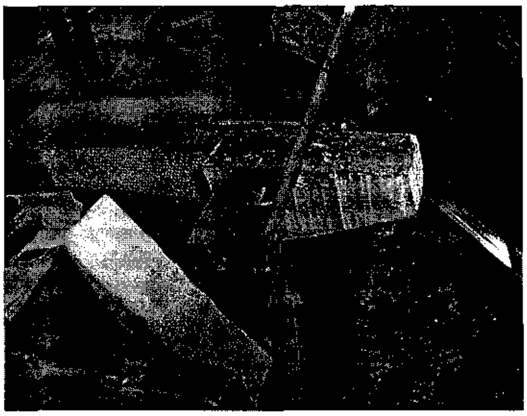
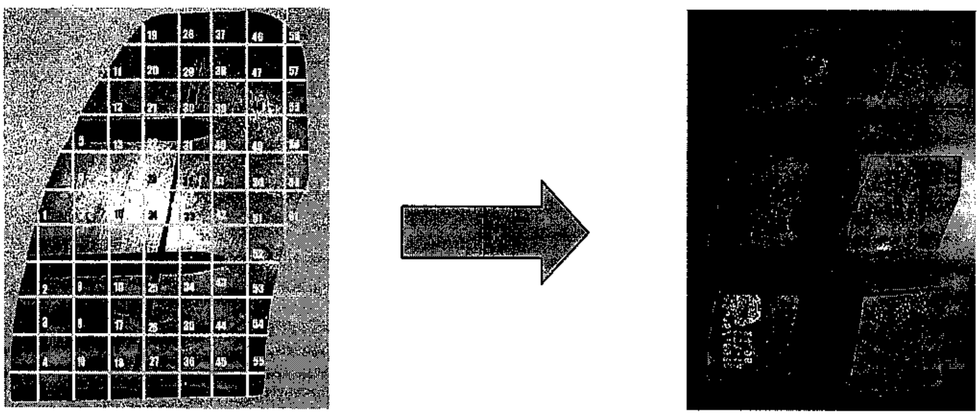


Figure 3.8.1: major pieces removed from back plate of STAR brake pad.

Figure 3.8 showed how STAR brake pad being separated from its back plate using G clamp and chisel. For STAR LRT, the joint and its attachment was much difficult to separate. From observation, seem like the formulation was in fluid form or molten liquid before the material attached to the back plate. Therefore its joint to the back plate is more difficult to removed than PUTRA brake pad. Figure 3.8 below showed major part for new sample STAR brake pad that already separated from its back plate.

Figure 3.8.2: Major pieces for STAR brake pad removed from its back plate

The details locations developed for both new and used STAR brake pad were as following figures



Figures 3.9: Location development for impact test

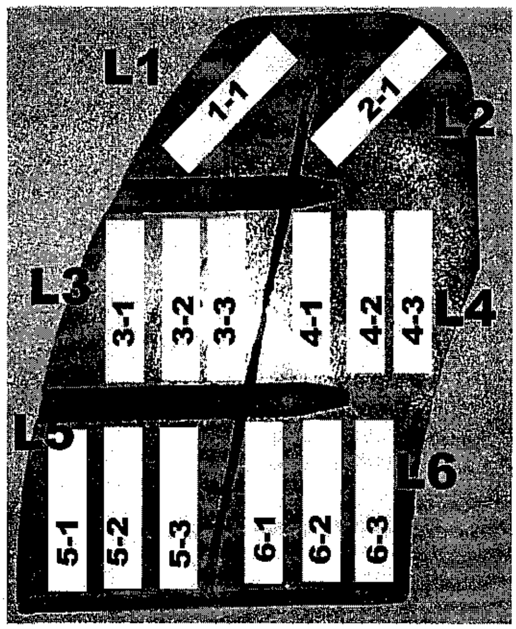



Figure 3.10: Impact test Location at STAR LRT Brake Pad

Figure 3.10 showed how the impact test sample is taken from the STAR brake pad. This area will be the locations where the samples are taken and will be tested. The labels are according to the figure. Basically, the figure 3.10 just showing the area which the materials were taken to produce minor parts. The amount of minor pieces generated is the maximum allowable pieces that can be generated for each major piece. Therefore the total number of impact test specimen will be generated for STAR brake pad is 14.

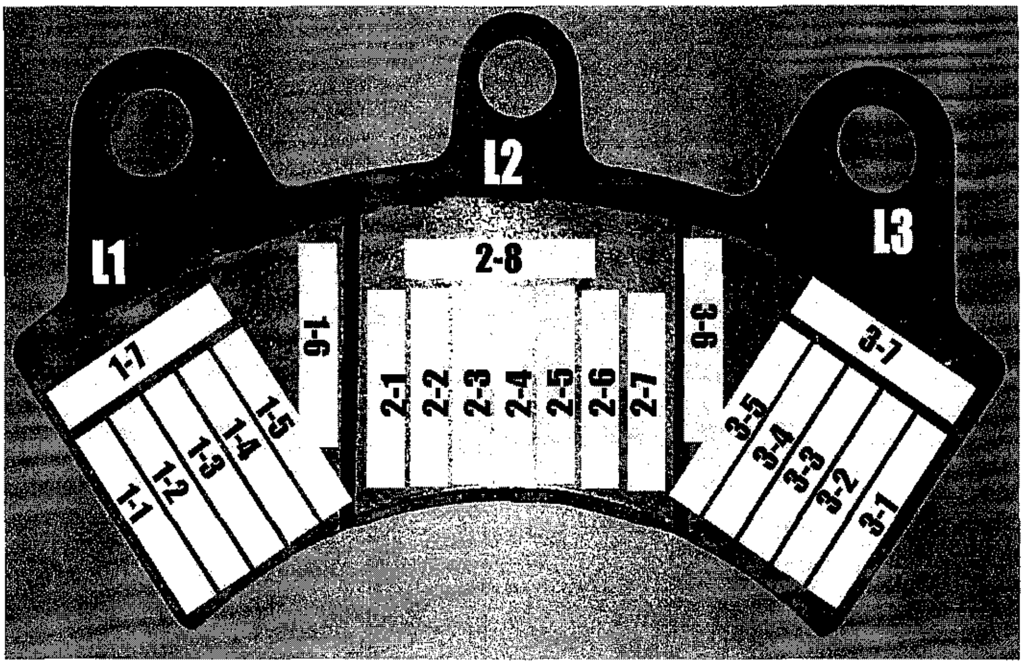



Figure 3.11: Impact test Location at PUTRA LRT Brake Pad

Figure 3.11 indicated the location map for PUTRA brake pad, the amount given is the maximum number of minor pieces that can be taken from the pad. L1, L2 and L3 were the major pieces. For L1 and L3 the number of minor pieces, hence the number of impact test specimen will be generated is 7. Whereas the number of minor pieces that can be generated for the L2 which is the largest major part is 8 minor pieces. So the total number of specimens generated is 22.

Figure 3.12: Hand tools used for dimensioning the minor pieces towards the standard specimen for impact test.

The figure 3.12 showed the hand tools that were used for processing the major pieces of the brake pad into the minor pieces and finally the desired standard specimens. Although, too many cutting tools available at UTP but actually the cutting technology for non-metallic material such as composite, polymer are not currently available. Most cutting tools available at UTP such as wire cutter, CNC milling, were for metal processing. Therefore as figure above shown, these were the apparatus used in processing for preparing the sample for impact test. Hand hacksaw, rubber hammer, chisel, hammer, file and G clamp. Then the major part was cut again into minor pieces as shown in the figure 3.13, the cutting process was done by hand hacksaw. The minor samples were then labelled according to the area or location that the samples being taken then with using the stated hand tools all the minor parts from STAR and PUTRA brake pad will be finalized to meet the ASTM E-23 standard specimen for Impact test. Unfortunately, since the process of finalizing the specimens were done manually the irregularities in the dimension of the samples especially at the notch were unavoidable.

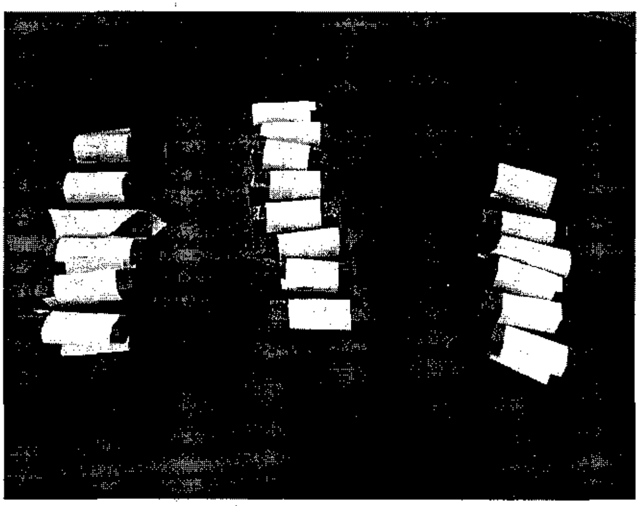


Figure 3.13 Minor Parts produce from Brake Pad

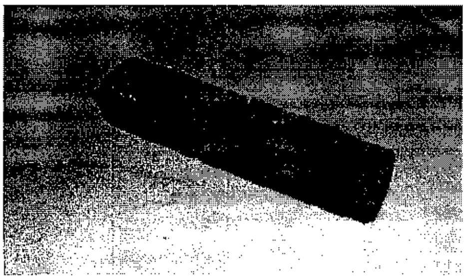


Figure 3.14: The standard specimen produced from STAR and PUTRA brake pad

## 3.4 IMPACT TEST PROCEDURE

Since the specimen was prepared using not standardized machine, it'll undergo dimension checking before performing any test. The machine used for the Charpy V-Notch test is Roel Amslerr RKP 450 from Germany as shown in figure 3.15.

The procedure is quite simple, just put the specimen to the location subjected. The weight already automatically set and the reading will be obtained after the pendulum was released. The indicator then being reset to initial position after the pendulum return to its initial position. Then the data obtained will be recorded at reading meter DIM 200S. The standard setting of the machine was set the initial energy is 300 J.

Compared to the previous machine, this machine will not produced any graph from the results done on the specimens.

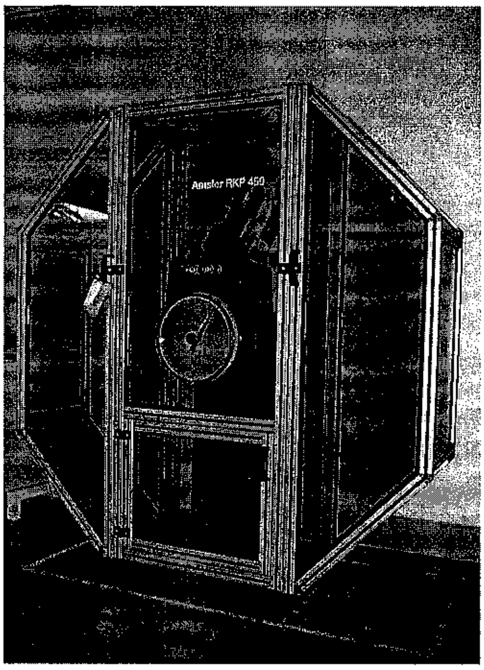


Figure 3.15: Impact Test Machine

### 3.5 MICROSTRUCTURE TEST PROCEDURE

Microscopic examinations are important to understand the associations between the properties and structure. Once the relationships of those parameters have been established, the properties of the material only can be predicted.

To prepare the microstructure test, the 6 location each at PURTA and both new and used brake pad have been chosen. Therefore, there will be 18 micrographs will be generated using the 50X enlargement. The locations selected then being cut and mounted using phenolic resin as their base. The surfaces of the respective sample were the grounded. Since the material of the brake pad is unknown therefore the suitable chemical reagent could not be determine and thus no etching was done towards the samples. Then the samples were brought under microscope where 50X enlargement image will be produced.

# CHAPTER 4

# RESULTS AND DISCUSSION

During preliminary investigation on LRT brake pad material, those experiments and test already carried out. With the data given, it is expected the newer and future data will fall in the range. But its not necessarily will be similar. Previous study has been done in various places and machines. The possibility to attain similar result is quite difficult. Meanwhile, the previous data also will be stated here as means of comparison. Furthermore the result stated here is relatively larger in term of amount of data being taken.

Experiments and testing results will be presented by following manner; Hardness test, Impact test and finally the microstructure test. There will be no discussions in the result. All the description and the discussion will be in the discussion section. The result will be presented in figures, graphs and tables.

Then the discussion section will discuss the result obtained also have similar arrangement like in the result section following manner. The discussion of the results here not just focuses and relates on the result obtained in the test only but also relate with the condition like during sample preparation and services condition.

## 4.1 EXPERIMENTAL RESULT

### 4.1.1 Hardness Test Result

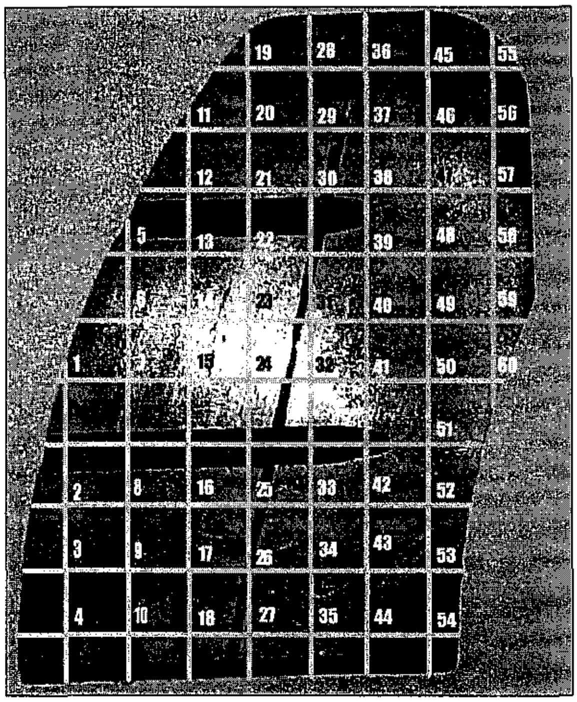


Figure 4.1: Coordinate Location of STAR Brake Pad

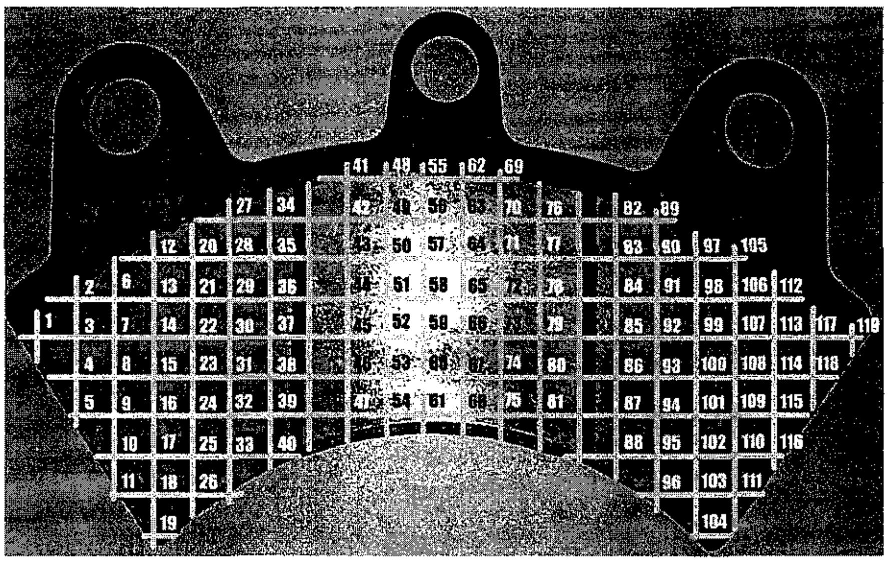


Figure 4.2: Coordinate location of PUTRA Brake Pad

**START LRT Brake Pad Hardness Test Result**

Sample 1 is assign to used brake pad and sample 2 is the unused or new brake pad. Both sample using the same coordinate. The result obtain as below:

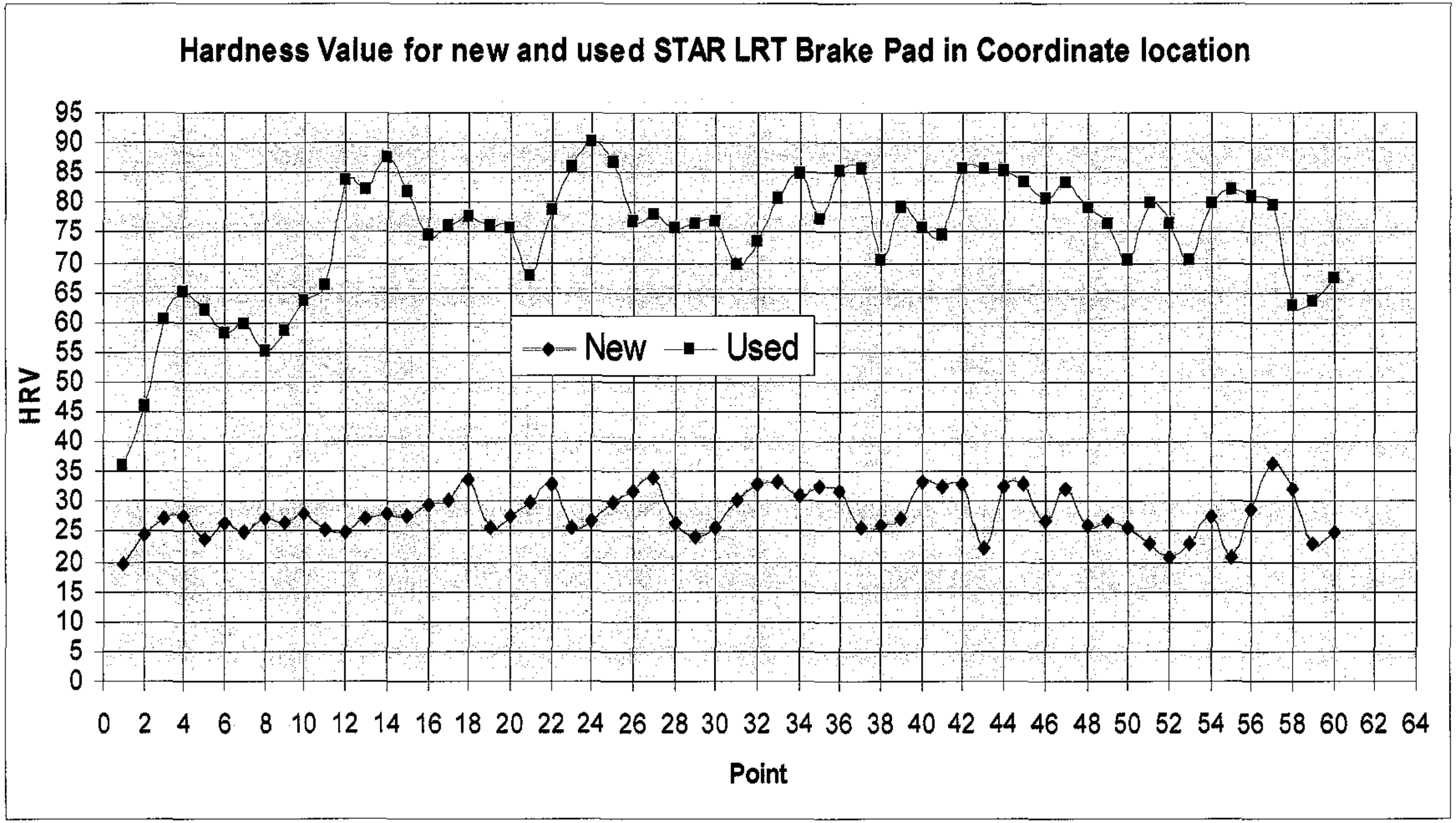
| Sample 1 (Used) | | | | Sample 2 (New) | | | |
|---|---|---|---|---|---|---|---|
| Point | HRV | Point | HRV | Point | HRV | Point | HRV |
| 1 | 36.1 | 31 | 70 | 1 | 20 | 31 | 30.4 |
| 2 | 46.1 | 32 | 73.7 | 2 | 24.9 | 32 | 33.2 |
| 3 | 60.6 | 33 | 80.8 | 3 | 27.6 | 33 | 33.4 |
| 4 | 65.4 | 34 | 85.1 | 4 | 27.7 | 34 | 31.1 |
| 5 | 62.3 | 35 | 77.3 | 5 | 23.9 | 35 | 32.7 |
| 6 | 58.4 | 36 | 85.6 | 6 | 26.8 | 36 | 32.1 |
| 7 | 59.8 | 37 | 85.7 | 7 | 25 | 37 | 25.9 |
| 8 | 55.3 | 38 | 70.5 | 8 | 27.6 | 38 | 26.2 |
| 9 | 58.9 | 39 | 79.4 | 9 | 26.8 | 39 | 27.4 |
| 10 | 63.8 | 40 | 75.8 | 10 | 28.1 | 40 | 33.7 |
| 11 | 66.4 | 41 | 74.7 | 11 | 25.4 | 41 | 32.8 |
| 12 | 83.8 | 42 | 85.9 | 12 | 25.3 | 42 | 33.2 |
| 13 | 82.3 | 43 | 85.8 | 13 | 27.3 | 43 | 22.7 |
| 14 | 87.8 | 44 | 85.4 | 14 | 28.1 | 44 | 32.8 |
| 15 | 82.2 | 45 | 83.7 | 15 | 27.7 | 45 | 33.1 |
| 16 | 74.6 | 46 | 80.8 | 16 | 29.8 | 46 | 27.1 |
| 17 | 76.4 | 47 | 83.6 | 17 | 30.7 | 47 | 32.6 |
| 18 | 77.7 | 48 | 79.5 | 18 | 34.1 | 48 | 26.3 |
| 19 | 76.2 | 49 | 76.8 | 19 | 25.8 | 49 | 27 |
| 20 | 75.8 | 50 | 70.5 | 20 | 27.7 | 50 | 26 |
| 21 | 67.9 | 51 | 80.2 | 21 | 30.1 | 51 | 23.2 |
| 22 | 78.8 | 52 | 76.8 | 22 | 33.3 | 52 | 21 |
| 23 | 86.3 | 53 | 70.5 | 23 | 25.8 | 53 | 23.4 |
| 24 | 90.4 | 54 | 80.2 | 24 | 27.2 | 54 | 27.9 |
| 25 | 87 | 55 | 82.3 | 25 | 30.3 | 55 | 20.8 |
| 26 | 77.1 | 56 | 81.4 | 26 | 32.1 | 56 | 29.1 |
| 27 | 78.2 | 57 | 79.8 | 27 | 34.3 | 57 | 36.6 |
| 28 | 75.9 | 58 | 62.8 | 28 | 26.8 | 58 | 32.4 |
| 29 | 76.5 | 59 | 63.8 | 29 | 24.3 | 59 | 23.4 |
| 30 | 77 | 60 | 67.4 | 30 | 25.9 | 60 | 25.3 |

Table 4.1: Hardness Test Result of STAR LRT Brake Pad According to Coordinates

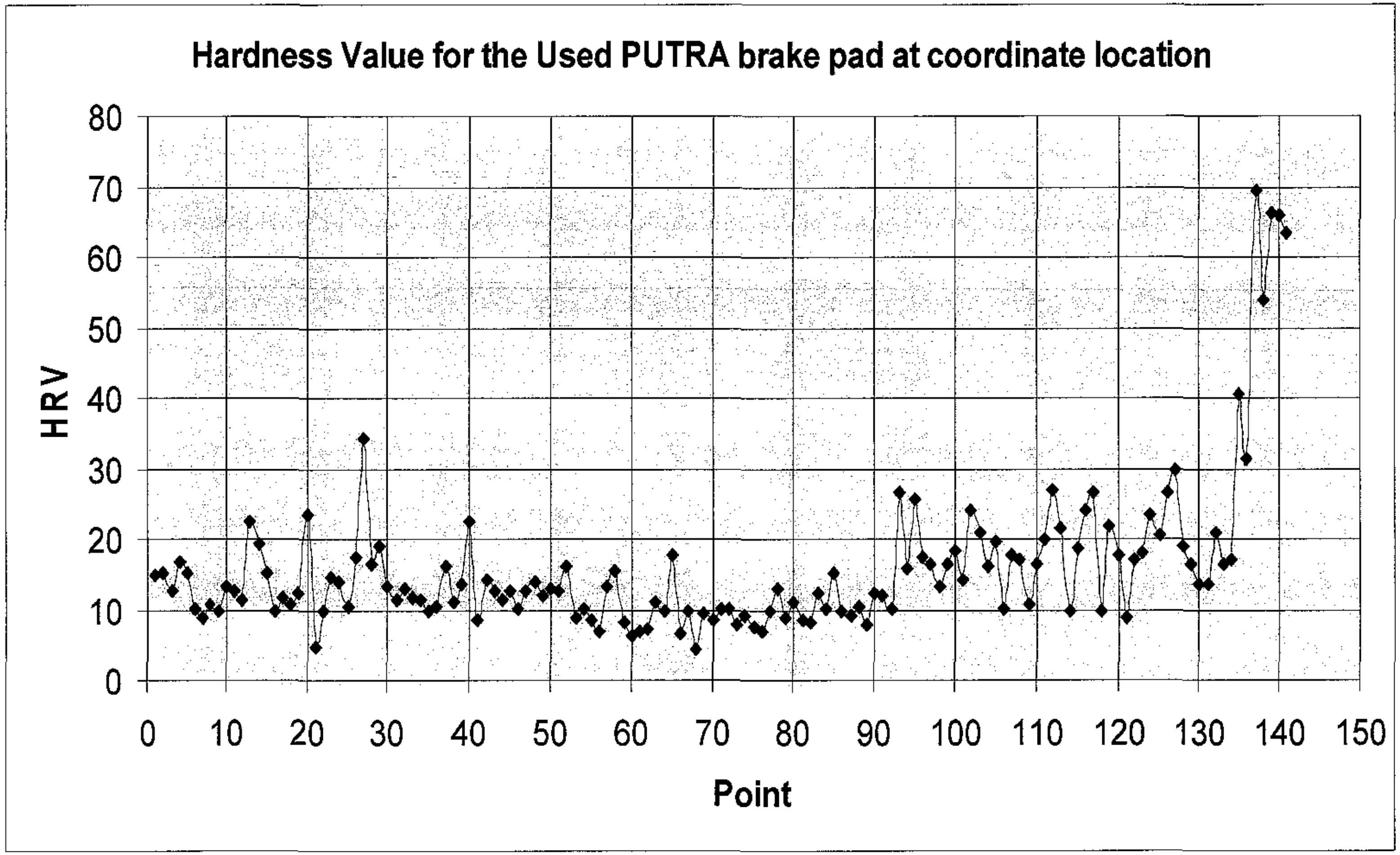
**PUTRA Brake Pad Hardness Test Result**

| Sample 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Point | HRV | Point | HRV | Point | HRV | Point | HRV |
| 1 | 14.9 | 31 | 11.3 | 61 | 7.1 | 91 | 12.2 |
| 2 | 15.3 | 32 | 13 | 62 | 7.4 | 92 | 10.3 |
| 3 | 12.6 | 33 | 11.6 | 63 | 11.1 | 93 | 26.7 |
| 4 | 16.7 | 34 | 11.5 | 64 | 9.7 | 94 | 15.8 |
| 5 | 15.2 | 35 | 9.7 | 65 | 17.9 | 95 | 25.7 |
| 6 | 10.1 | 36 | 10.6 | 66 | 6.7 | 96 | 17.6 |
| 7 | 8.8 | 37 | 16.3 | 67 | 10 | 97 | 16.4 |
| 8 | 10.9 | 38 | 11 | 68 | 4.6 | 98 | 13.3 |
| 9 | 9.9 | 39 | 13.7 | 69 | 9.6 | 99 | 16.5 |
| 10 | 13.3 | 40 | 22.4 | 70 | 8.6 | 100 | 18.3 |
| 11 | 12.7 | 41 | 8.6 | 71 | 10.3 | 101 | 9 |
| 12 | 11.3 | 42 | 14.3 | 72 | 10.1 | 102 | 17.1 |
| 13 | 22.6 | 43 | 12.8 | 73 | 7.8 | 103 | 18.2 |
| 14 | 19.4 | 44 | 11.4 | 74 | 9.1 | 104 | 23.5 |
| 15 | 15.2 | 45 | 12.8 | 75 | 7.7 | 105 | 20.7 |
| 16 | 9.7 | 46 | 10.2 | 76 | 6.9 | 106 | 26.6 |
| 17 | 11.9 | 47 | 12.6 | 77 | 9.9 | 107 | 29.8 |
| 18 | 10.9 | 48 | 14.1 | 78 | 13.1 | 108 | 19 |
| 19 | 12.5 | 49 | 12 | 79 | 8.9 | 109 | 16.5 |
| 20 | 23.6 | 50 | 13.1 | 80 | 11.2 | 110 | 13.8 |
| 21 | 4.9 | 51 | 12.8 | 81 | 8.6 | 111 | 13.8 |
| 22 | 10 | 52 | 16.1 | 82 | 8.2 | 112 | 17.3 |
| 23 | 14.6 | 53 | 9 | 83 | 12.3 | 113 | 40.6 |
| 24 | 14.1 | 54 | 10.1 | 84 | 10.2 | 114 | 31.3 |
| 25 | 10.5 | 55 | 8.6 | 85 | 15.1 | 115 | 69.6 |
| 26 | 17.6 | 56 | 7.1 | 86 | 10 | 116 | 54.1 |
| 27 | 34.2 | 57 | 13.3 | 87 | 9.2 | 117 | 66.2 |
| 28 | 16.6 | 58 | 15.5 | 88 | 10.4 | 118 | 66 |
| 29 | 19.1 | 59 | 8.4 | 89 | 8 | 119 | 63.4 |
| 30 | 13.3 | 60 | 6.5 | 90 | 12.4 | | |

Table 4.2: Hardness Test Result of PUTRA LRT Brake Pad According to Coordinates




**Graph 4. 1: Hardness Value for new and used STAR LRT Brake Pad in Coordinate location**




**Graph 4.2: Hardness Value for used PUTRA LRT Brake Pad in Coordinate location**

### 4.1.2 Impact Test Result

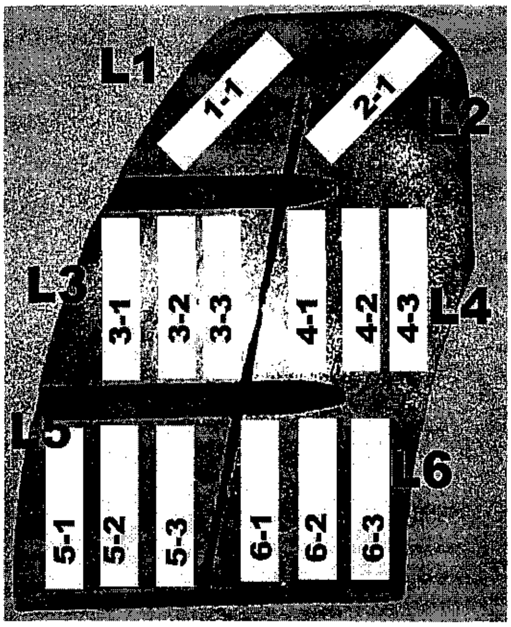



Figure 4.3: Impact test Location at STAR LRT Brake Pad

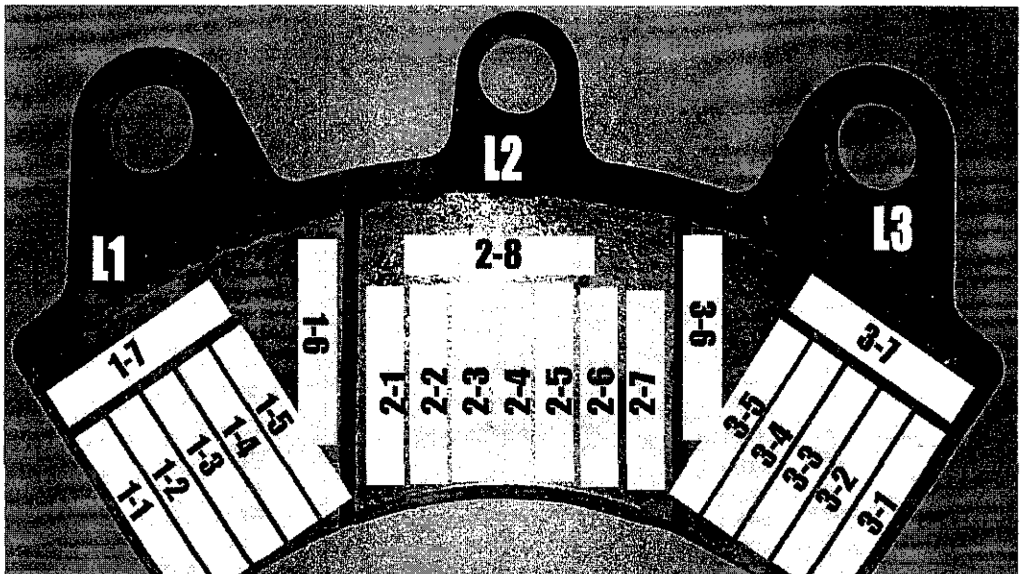



Figure 4.4: Impact test Location at PUTRA LRT Brake Pad

| Location | Point | New (Joule) | Used (Joule) |
|---|---|---|---|
| **L1** | 1-1 | 8.962 | 18.792 |
| **L2** | 2-1 | 9.003 | 17.548 |
| **L3** | 3-1 | 9.107 | 11.543 |
| | 3-2 | 9.151 | 16.546 |
| | 3-3 | 9.007 | 14.396 |
| **L4** | 4-1 | 8.978 | 18.792 |
| | 4-2 | 9.058 | 18.792 |
| | 4-3 | 8.977 | 16.546 |
| **L5** | 5-1 | 9.007 | 11.543 |
| | 5-2 | 9.016 | 11.543 |
| | 5-3 | 8.977 | 17.548 |
| **L6** | 6-1 | 8.977 | 18.792 |
| | 6-2 | 9.007 | 18.792 |
| | 6-3 | 9.007 | 16.546 |

Table 4-3: Impact Test Result for used and new STAR Brake Pad

| Location | Point | Impact energy (Joule) |
|---|---|---|
| **L1** | 1-1 | 4.980 |
| | 1-2 | 4.901 |
| | 1-3 | 5.453 |
| | 1-4 | 5.453 |
| | 1-5 | 5.453 |
| | 1-6 | 5.448 |
| | 1-7 | 5.453 |
| **L2** | 2-1 | 5.015 |
| | 2-2 | 5.448 |
| | 2-3 | 5.453 |
| | 2-4 | 5.347 |
| | 2-5 | 5.453 |
| | 2-6 | 5.347 |
| | 2-7 | 5.474 |
| | 2-8 | 5.453 |
| **L3** | 3-1 | 5.453 |
| | 3-2 | 5.481 |
| | 3-3 | 5.276 |
| | 3-4 | 5.357 |
| | 3-5 | 5.242 |
| | 3-6 | 5.453 |
| | 3-7 | 5.245 |

Table 4-4: Impact Test Result for PUTRA Brake Pad

### 4.1.3 Microstructure Test Result

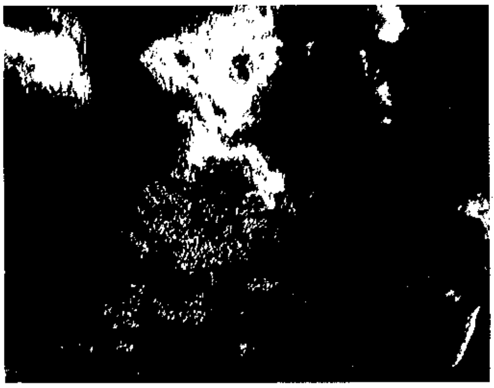
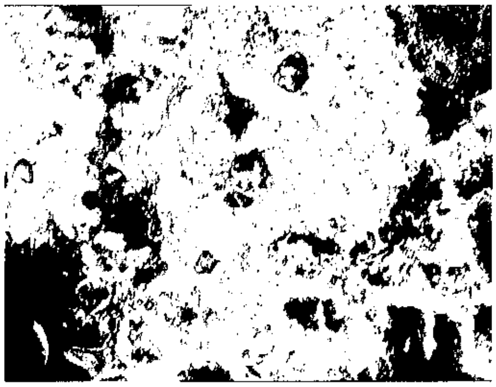



Figure 4.5 and 4.6: Micrograph at Location 1-3 PUTRA Brake Pad and Location 1-6 PUTRA Brake Pad

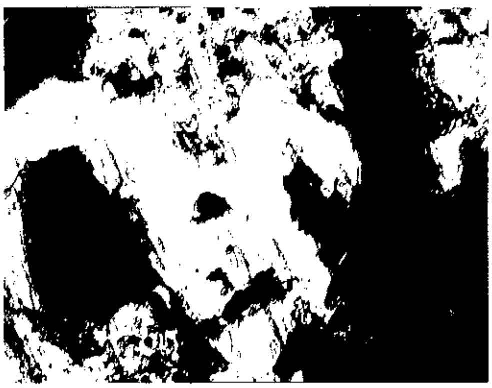



Figure 4.7 and 4.8: Micrograph at Location 2-3 PUTRA Brake Pad and Location 2-8 PUTRA Brake Pad

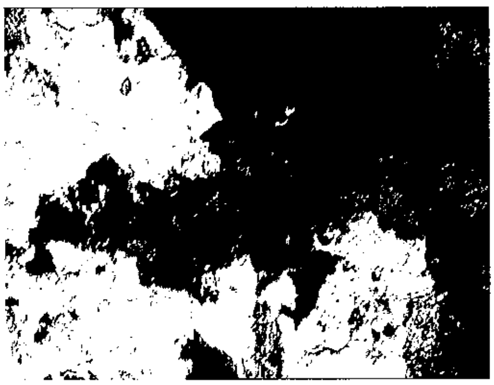



Figure 4.9 and 4.10: Micrograph at Location 3-5 PUTRA Brake Pad and location 3-7 PUTRA Brake Pad

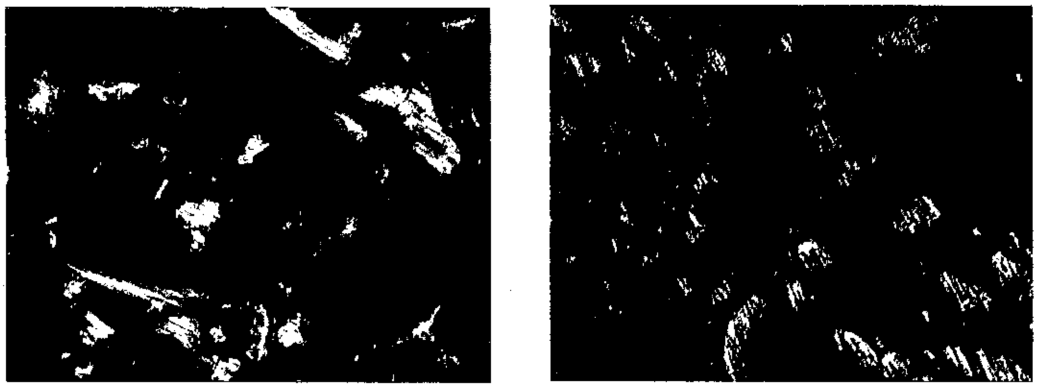


Figure 4.11 and 4.12: Micrograph at Location 1-1 used STAR Brake Pad and Location 2-1 used STAR Brake Pad

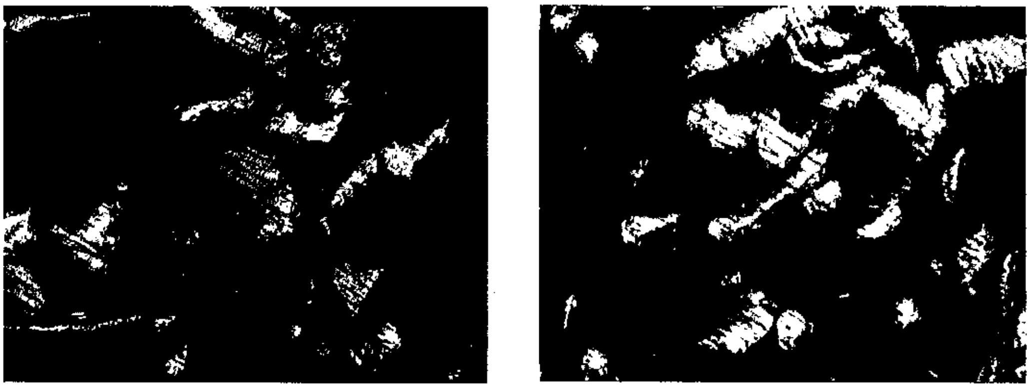


Figure 4.13 and 4.14: Micrograph at Location 3-1 used STAR Brake Pad and Location 4-1 used STAR Brake Pad

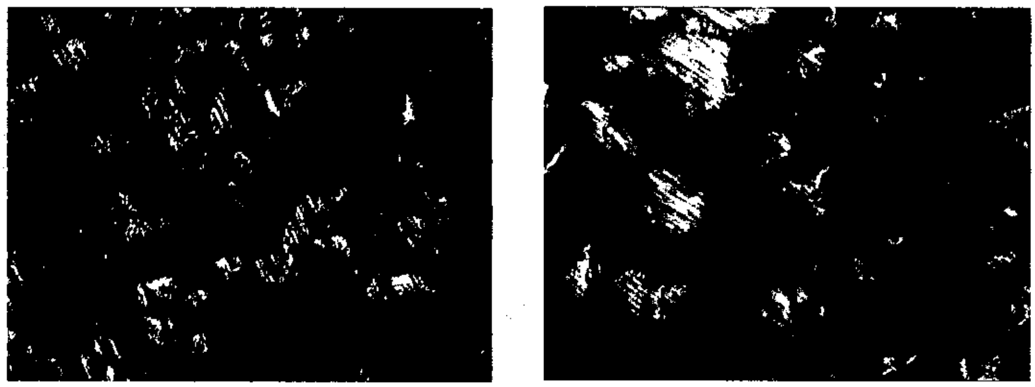


Figure 4.15 and 4.16: Micrograph at Location 5-3 used STAR Brake Pad and Location 6-3 used STAR Brake Pad

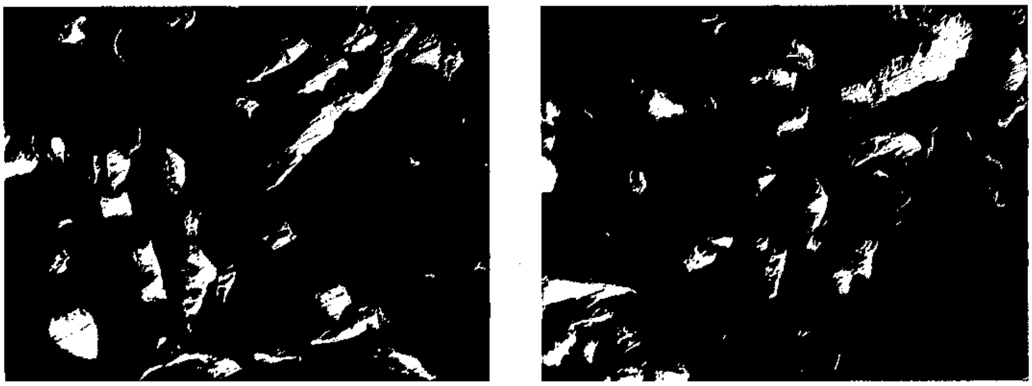


Figure 4.17 and 4.18: Micrograph at Location 1-1 new STAR Brake Pad and Location 2-1 new STAR Brake Pad

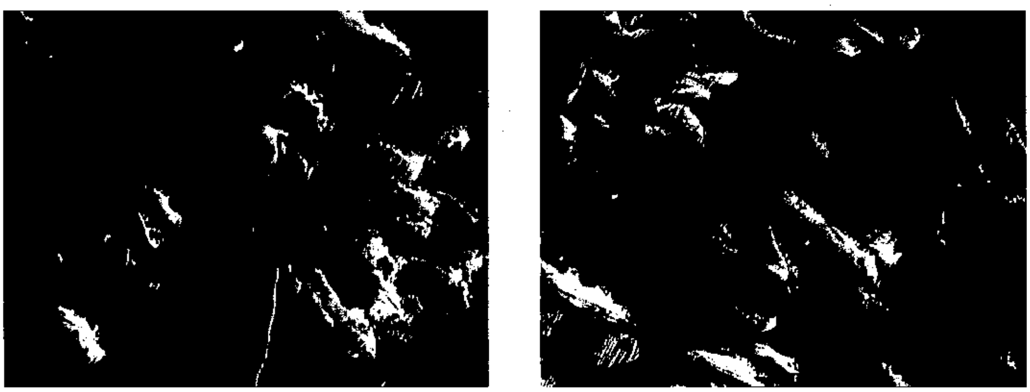


Figure 4.19 and 4.20: Micrograph at Location 3-2 new STAR Brake Pad and Location 4-1 new STAR Brake Pad

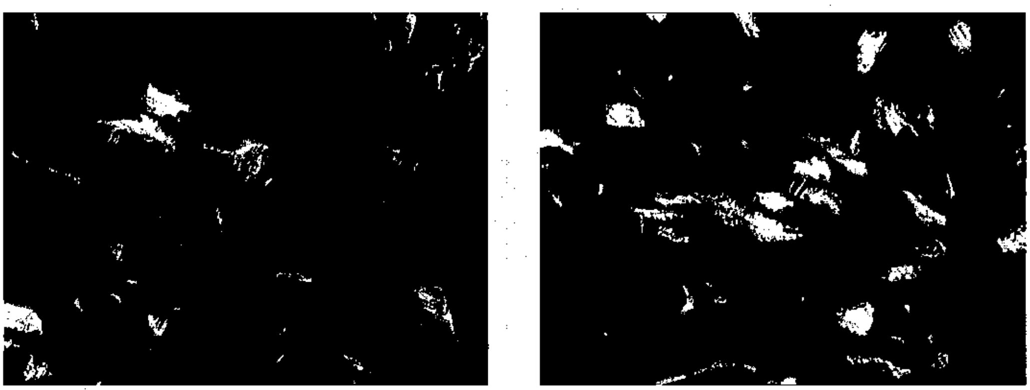


Figure 4.21 and 4.22: Micrograph at Location 5-3 new STAR Brake Pad and Location 6-3 new STAR Brake Pad

## 4.2 DISCUSSION OF THE RESULT

### 4.2.1 Discussion of Hardness Test Result

The result from the experiments showed that the HRV value of used bake pad range from 36.1 HRV (minimum) until 90.4 HRV (maximum). From the result the range of HRV value can be divided into three parts namely range 80-90, 70-79 and 55-69. There is 2 points which is out of range division; point 1 which has the lowest HRV value = 36.1 HRV and point 2 (46.1 HRV). The points that have value from 80-90 HRV were at points 12, 13, 14, 15, 23, 24, 25, 33, 34, 36, 37, 42, 43, 44, 45, 46, 47, 48, 51, 54,55,56, and 57. From the figure 4.23 we can see these point are the area that can be said have most hardened surface. Whereas the points that have the HRV value range from 60-79 that can be referred at Figure 4.24 were at points 16, 17, 18, 19, 20, 21, 22, 26, 27, 28, 29, 30, 31, 32, 38, 39, 40, 41, 49, 50 and 53. Then the lowest range at figure 4.25, fall between HRV value from 55-69 is at points 3, 4, 5, 6, 7, 8, 10, 11, 21, 58, 59 and 60.

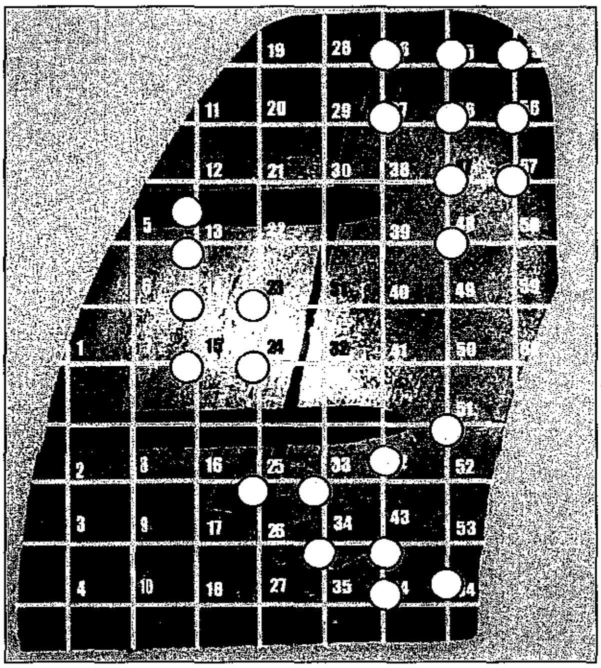


Figure 4.23: HRV Value Range from 80 to 90 HRV for STAR Used Brake PAD

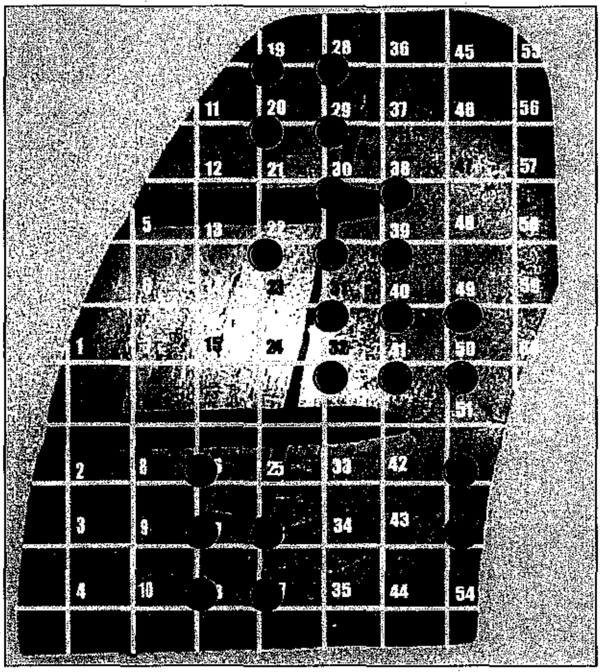



Figure 4.24: HRV Value Range from 70 to 79 HRV for STAR Used Brake PAD

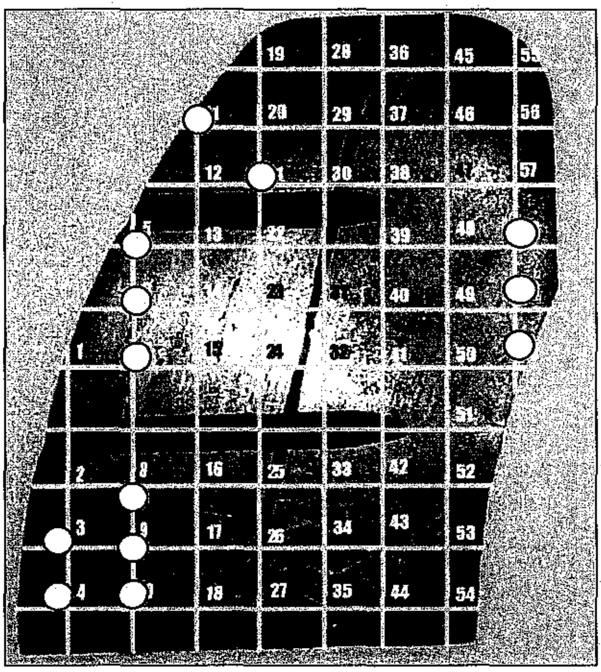



Figure 4.25: HRV Value Range from 55 to 69 HRV for STAR Used Brake PAD

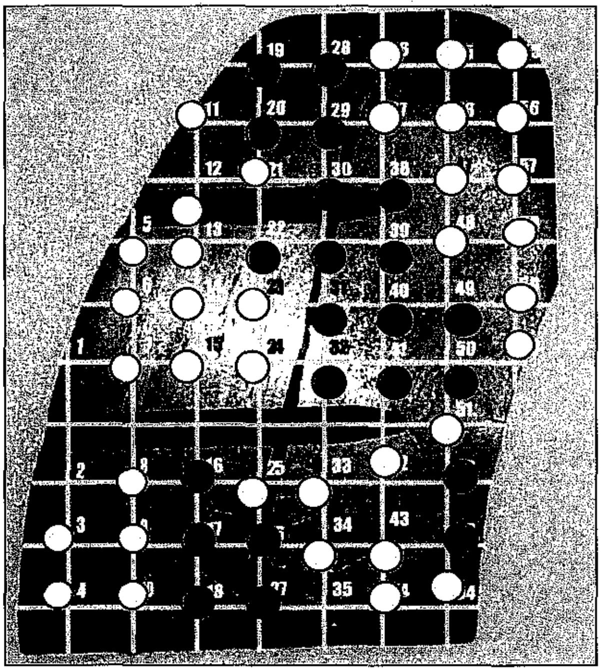


Figure 4.26: Complete HRV Value Range for STAR Used Brake PAD

From figure 4.26, complete view of the HRV value that represents hardness can be viewed. The area that has most HRV value (ranged 80-90 HRV) or hardness mostly at the upper and lower-right of the figure. There is also some portion at the middle-left side of the brake pad. The medium range of classification HRV (range 70-79) also focused at the middle of the STAR brake pad and lower-left side of the brake pad. Lastly the smallest value of HRV can be seen at the left side of the brake pad and little bit on the right-side of brake pad.

As for the new brake pad, the result from the experiments showed that the HRV value of used bake pad have smaller range HRV value. The maximum value is 36.6 HRV and the lowest value is 20.0 HRV.

Generally from the result, the used brake pad has larger HRV value than the new one. This phenomenon clearly showed in Graph 4.1. The graph basically represents the comparison between HRV values at each similar point at used STAR brake pad and new STAR brake pad. From the calculation the used brake pad has average value of 74.68 HRV where as the new STAR brake pad average value of 28.22 HRV. The resultant of the larger HRV value of used STAR brake pad it is assumed by the temperature effect that hardened the material of the brake pad. Due to lifé in service of the used STAR brake pad to be compared with the new STAR brake pad, the used STAR brake pad already exposed to high temperature during friction with the rotor and thus hardened the surfaced. This is proved with the all points in the used STAR brake pad have relatively larger value of HRV than the new STAR brake pad. Since the brake pads are required to transform large amounts of kinetics energy to heat at contact surfaces between the disc and the pad. [Harju,2002] The variation of hardness profile of the used STAR brake pad as can be seen from the graph relatively larger from the new STAR brake pad. This is further proved by the calculation result the standard deviation of the used STAR brake pad is 10.61 where as for the new STAR brake pad is only 3.82. The reason why the heat increase in the disc and the pad is generated by the energy transferred into the pad and disc during the brake sequence. Then the temperature within the pad and disc however turned out to vary in another way. Due to very low heat conductivity of the pad the temperature gradient in the pad was very large while in the disc the temperature was more evenly distributed. [NOOR, 2002]

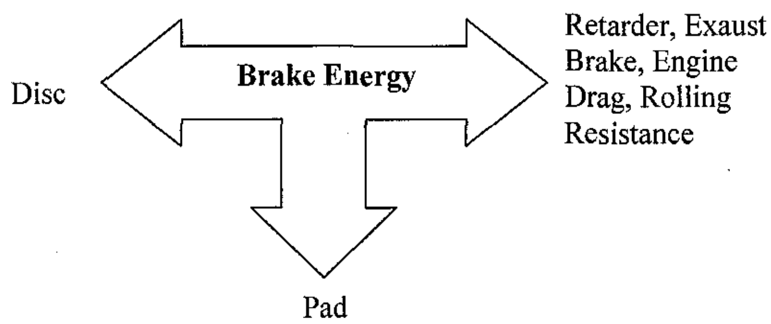



Figure 4.26: Brake energy distribution

This variation of HRV value of used STAR brake pad also occurs with the effect of non-uniform pad loading. Non uniform pad loading can result in taper wear of the linings, which can result in greatly reduced pad life and potential rotor damage in extreme cases.

As the new STAR brake pad has not gone into its service yet, therefore it has never experienced the non-uniform pad loading and thus the variation of HRV values throughout the points on the pad were quite small.

The previous data result was 38.1 HRV in average. From the calculation the used brake pad has average value of 74.68 HRV where as the new STAR brake pad average value of 28.22 HRV. Furthermore the previous results are not fall in any range of the currently hardness test conducted. From the previous result and current result has given quite large variation of harness distribution profile for the STAR brake pad.

The result from the experiments showed that the HRV value of used bake pad range from 4.9 HRV (minimum) at point 21 until 69.6 HRV (maximum) at point 137. The test was conducted towards 141 points on PUTRA used brake pad. From graph 4.2 the variation initially from points 1- 134 are quite small. The resulted standard deviation between that range is 5.49. But after added value from points 135-141 which showed radical value, the standard deviation of the points became 10.99 which showed an increment of nearly 100%. From the result, the radical values only appear in point 135 -141. The HRV values for each responding points is 135: 40.6 HRV, 136 : 31.3 HRV, 137: 69.6 HRV, 138: 54.1 HRV, 139, 66.2 HRV, 140: 66 HRV and 141 63.4 HRV. All the points located at the right side of the brake pad (refer figure 4.2).. Furthermore, to be compared with the STAR brake pad values, the resultant HRV values of PUTRA relatively lower than STAR. Unfortunately there is only used sample from PUTRA brake pad, therefore analysis and comparison with the new sample can't be made. The average value of HRV is 16.15 HRV which is very low to be compared with STAR brake pad and the previous result. The factor of service life should be significant factor that contribute to this phenomena.

### 4.2.2 Discussion of Impact Test Result

From the impact test, the values of impact energy for both used and new STAR brake pads were obtained. From the table 4.3 the value obtained for new STAR brake pad were relatively lover than used STAR brake pad. This is due to the differences in the hardness value where the used STAR brake pad has higher HRV value than new STAR brake pad. The value obtained from the previous student was 17.54 J for STAR brake pad. The result don't indicate where douse this value was achieved. Previous result gave 17.54 J for the impact energy value. The resultant value also was from different machine used.

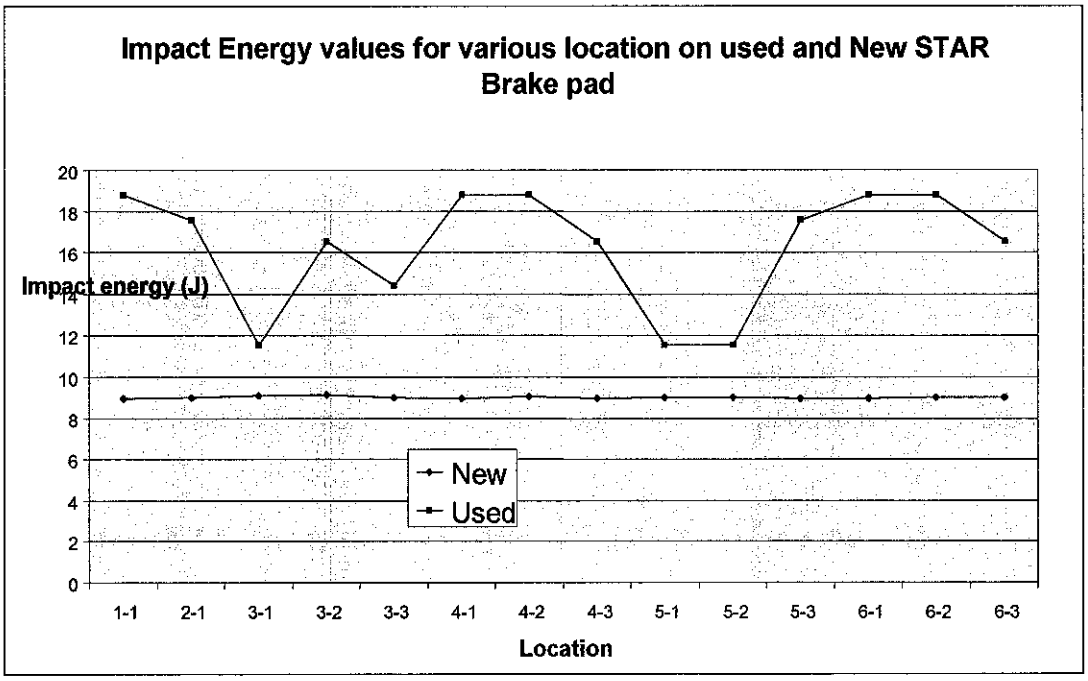
In this project the used brake pad impact energy value fall under range from 11.543 J to as high as 18.792 J. So basically there were locations that have higher impact energy value than the previous attained value, there also locations that were nearly similar and there were locations were less that the previous value attained.

The relatively area that having high impact energy (refer to figure 4.3 for the impact test location on the STAR brake pad and table 4.3) were at point 1-1, 4-1, 4-2, 6-1 and 6-2. The impact energy values at these locations were 18.792 J. Meanwhile, other locations give relatively small different value at locations 2-1 and 5-3 (17.548 J). The further value is 16.546 J were given by locations 3-2, 4-3 and 6-3. There is one location has impact energy of 14.396 J at location 3-3. And the lowest value attained by the STAR brake pad were at point 3-1, 5-1 and 5-2 with the value of impact energy were 11.543 J.

From the graph 4.3, the variation of used STAR brake pad was high. From the calculation the standard deviation thus indicates the variation of the impact test values for the used STAR brake pad was 2.853. However the variation of the impact test value for both used and new STAR brake pad were smaller than the variation in their hardness value.

For the new STAR brake pad, the values were not much difference from each other. As said before, because of not yet exposed to the services and thus the formulation is still stable and no extra force applied. The little variation might be due to the cutting and filing works done by the student during preparation of the impact test standard specimen. The variation can be considered relatively very small as proved by the calculation of the standard deviation for the new STAR brake pad was 0.053 only.

Therefore the result showed the used STAR brake pad not just harder but less brittle than the new STAR brake pad. As indicate in the previous report, the crack propagation will start spontaneously without an increase in magnitude of the stress. Therefore new STAR brake pad required less energy to fracture it. The used brake pad can absorb more energy compared to the new STAR brake pad.




Graph 4.3: Impact Energy values for various location on used and New STAR Brake pad

For PUTRA brake pad, the value of impact energy obtained was relatively lower than the previous project attained. This already expected to occur since the value of hardness of PUTRA brake pad also relatively lower than the previous project. The difference quite large due to n the samples were used and already out of service by PUTRA. The value of mechanical properties will be varies according to the service situation. Unfortunately the history of the brake pad service life could not be obtained since the used brake that already not wanted by PUTRA were not recorded.

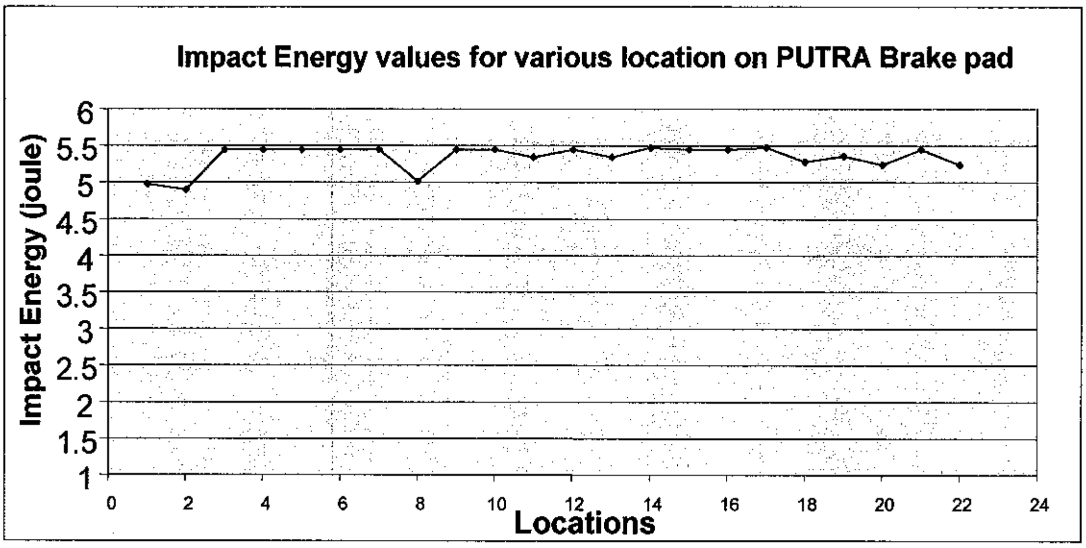
After PUTRA change the brake pad into the new one, the used brake pads just have to be thrown away at certain location with the other brake pads. So the brake pad will mix each other and their respective history such as where does braked pad previously attached was not possible to be traced.

Previously PUTRA brake pad not just has relatively larger value of hardness compared to the STAR brake pad but the value of impact energy also was not much difference. The value of impact energy attained for PUTRA from the previous project was averagely 16.96 J. There was 3 readings taken and one reading exceeds the value for STAR brake pad. Conclusively, the value of impact energy of PUTRA brake pad nearly similar to the STAR brake pad. Meanwhile the expected result was failed to achieve since the failure of hardness value to be same or most likely to be not much difference. The material of PUTRA brake pad that currently being tested not just soft, but also very porous. From the observation and experience, the material of the pad were very easy to crack further prove that the value of HRV relatively true. So the minor pieces of PUTRA brake pad were cautiously being filed and cut due to this condition.

Whereas for PUTRA brake pad impact energy value. The variation of values obtained was small as shown in graph 4.3. The largest impact energy value as indicated in table 4.4 and graph 4.3 is 5.473 J at location 2-7. From the result, the most occur impact energy value is 5.453 J at locations 1-3, 1-4, 1-5, 1-7, 2-3, 2-5, 2-8, 3-1 and 3-6. The minimum value was at location 1-2 with the impact energy value of 4.901 J.

From the graph, the variation of PUTRA brake pad impact energy value was small. As further proved by the standard deviation for the result is only 0.173. As indicated earlier, the contributed factor to this value is the PUTRA brake pad is relatively very soft as proven by the hardness test result. Furthermore, the variation of hardness also relatively small. This means the characteristics of PUTRA brake pads quite uniform throughout the entire surface and composition.

As far as this result is concern, the PUTRA brake pad has given very low value of impact energy. The previous hypothesis and analysis should be reviewed. The indicator said that the iron or Fe as the main constituent as the SEM analysis proved might be true. But is there enough location that have been analyzed and inspected to conclude that the Fe is one of the main constituent. This will further reviewed on the microstructure test result. The result obtained from the impact test, the PUTRA brake pad has given relatively low impact energy value and thus far more brittle than the new STAR brake pad.




Graph 4.4 : Impact Energy values for various location on PUTRA Brake pad

### 4.2.3 Discussion on Microstructure Test Result

From the previous result, the 3 kinds of different phases present. And due to PUTRA brake pad large hardness value. Analysis said that shiny phases was predicted to be hard phase particles. The high volume of shiny phases present contributed to the high mechanical properties such as strength and hardness. The dark phase represent filler or binder that assumed to be much softer with less mechanical properties. The locations stated from figure 4.10 until figure 4.22

Unfortunately although the shiny particles still dominant in the PUTRA brake pad as indicated in figure 4.5 until 4.10 the hardness value as well as the impact energy relatively very low compared to the previous result. The micrographs still present nearly similar what have previously resulted. But from figure 4.5 and figure 4.10, nearly similar what have previously resulted. But from figure 4.5 and figure 4.10, there was a dark area indicate that the surface of PUTRA brake pad relatively hard to be smoothed. Therefore the dark areas present the porosity of the PUTRA brake material. Although there were shiny phases dominant in the PUTRA microstructure but this shiny phase strength also relied on the other material to grip and holds the shiny material as tough as possible. This explained why this sample relatively low hardness value and impact energy is due to this. The other phases, not hard particles as indicated in the previous result were very weak and porous. There were so much area between the particles and don't hold the hard particles and the hard particles were allowed to slip.

This might be due to the coolant injected during the sample being cut by the linear hacksaw machine. But the brake pad is also design to work under wet condition. The issue of coolant injected might be not the main reason contributed to this factor. Furthermore, before the coolant injected, the PUTRA brake pad already resulted very low hardness value as compared from the previous project.

The two phase or multiphase microstructures of powder metallurgy materials make them unique. The tailored microstructures cannot be produced using conventional technique such as forging, casting or heat treatment to achieved desired wear resistance. Some of the microstructure factors that affect wear resistance include volume fraction of hard particles, particle size, particle size distribution and type of hard particles.

During the process of cutting the PUTRA brake pad, student comes across material that assumed to be Fe. The materials were short and look like very short thread. This material, after PUTRA brake pad being cut and further polished will be seem like its dominant and acquired quite large portion. But actually the phase that hold this material were easily rip off and very hard to ensure the smooth surface thus resulted the dark area in the micrograph as showed in figure 4.5 and figure 4.10.

Particle size and distribution of hard phase particles also affect the fundamental mechanical properties of a material. At any given volume fraction, finer particle size results in smaller spacing between hard phase material, resulting in higher hardness and other characteristics.

For STAR brake pad, either new or used as can been seen from figure 4.11 until figure 4.22. The black area is still dominant like the previous project stated. The dominant area is dark phase with spots of shiny particles. But for used STAR brake pad, the dominant of the shiny particles can bee seen more than the new STAR brake pad. From figure 4.12 and figure 4.15, the dominant of shiny material is further seen. As stated before, if the shiny material is dominant, the mechanical properties of the material will be improved provided with the strong firm and grip of the filler.

As a result, used STAR brake pad provides higher value of mechanical properties rather that the new STAR brake pad as well as the PUTRA brake pad. With the test conducted before, and further fundamentally briefed by the microstructure review, with the main composition existed in the material.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

From the test conducted on the samples both new and used STAR brake pad and PUTRA brake pad has managed to obtain mechanical properties of brake pad materials. The hardness test was given detail mapping of hardness value for both new and used STAR brake pad and PUTRA brake pad. From the impact test, the impact energy properties at given location was managed to achieved for each samples. Finally the microstructure test had given a clear picture of the composite structure phase composition. With the combination of all the result obtain from the three experiments conducted; the factors assumed to contribute to the specific value has been described. The hardness value for both used and new STAR brake pad has known at 60 specifics points and 141 points for PUTRA brake pad. For used STAR brake pad the hardness value ranged from 36.1 HRV to 90.4 HRV. While for new STAR brake pad the hardness value ranged from 20.0 HRV to 36.6 HRV. Whereas for PUTRA brake pad the hardness values ranged from 4.9 HRV to 69.6 HRV. Furthermore impact energy for used STAR brake pad relatively highest (ranged from 11.543 j to 18.792 J) from the three samples and the PUTRA brake pad is the lowest among three samples (4.901 J to 5.484 J). The new STAR brake pad has impact energy value ranged from 8.962 J to 9.007 J. The processes of preparing the samples for impact test were quite meticulous. As for recommendation, since the procedure done yet still give the precise dimension, the machine that able to cut and producing accurate samples from the brittle composite or material should be analyzed. Furthermore the microscopic view can be enhanced by using the SEM when the facilities were ready. And the characterization of the obtained from the SEM should be related with the mechanical properties obtained from hardness and impact test.

# REFERENCES

## Books and Journals


1. J.R Zimmerman, ***Clutches and Brakes, Standard Handbook of Machine Desig***n, McGraw Hill, 1996

2. Milton Ohring, 1995, ***Engineering Materials Science,*** Academic Press Inc.

3. Institution of Mechanical Engineers (ImechE), ImechE Conference Transactions 1997, ***Train Maintenance Tomorrow... And Beyond,*** Mechanical Engineering Publications Limited.

4. G.S. Upadhaya, 2001, ***Sintered Metallic and Ceramic Materials; Preparation, Properties and Applications***, John Wiley and Sons Ltd.

5. Pat L. Mangonon, 1999, ***The Principles of Materials Selection for Engineering Design***, Prentice Hall

6. M J Nunney 1997***, Light & Heavy Vehicle Technology***, 2nd Edition, BH Newnes, UK

7. ***Numerical Methods for Engineers*** Bilal M.Ayyub, Richard H. McCuen, Prentice Hall, United States. 1996

8. ***Engineering Statistics*** 2nd Edition, Montgomery,Runger, Hubele, 1996, Wiley, United States

9. ***The Importance of Friction Materials in LRT Applications***, Ir. Zohari Sulaiman, SPNB, Malaysia 2004

10. George E. Dieter, ***Mechanical Metallurgy***. McGraw Hill, New York., 1988

11. W.Jenson, ***Friction Materials, Machine Design***, 1989

12. Donald R. Askeland, 1994, ***The Science and Engineering of Materials***, International Thomson Publishing,

13. ***Simulation of Brake sequences and corresponding brake wear,*** R Harju, Brake and Suspension Systems, Scania CV AB, Sodertalje, Sweden

14. ***Interface Temperatures in Friction Braking,*** H S QI, K NOOR and A J DAY, Dept. of Mech & Medical Eng., University of Bradford UK, 2002

**Websites**

15. ***Hardness scale,*** http://www.calce.umd.edu/general/facilities/hardness.htm

16. ***Microhardness***, http://www.mee-inc.com/microhar.html

17. ***Nano-scale for Hardness***,http://www.kimwin.com.my/inj_89.htm

18. ***Ceramic Hardness,*** http://www.efunda.com/info.htm

19. ***Hardness,*** http://www.engineering.usu.edu/mae/faculty.htm/

20. ***Rockwell Hardness***, http://www.hardnesstesters.com/rockwell.htm

21. ***Impact test,*** http://www.key-to-steel.com/Articles/Art94.htm

22. ***Scanning Electron Microscopy***, http://www.dwi.rwth-aachen.dc

23. ***Energy Dispersive X-ray Detection (EDX),*** http://www.forensicevidence.net/iama/sem-edxtheory.html

24. ***SEM analysis,*** http://www.ukesca.org/tech/sam.html

25. ***Tribological Studies of Brake Pads*** http://www.ornl.gov/~webworks/cppr/y2001/rpt/112956.pdf

26. ***Powder Metallurgy and Sintering,*** http://www.EPMA.com/rvpm/PMprocess/sitering

# APPENDICES

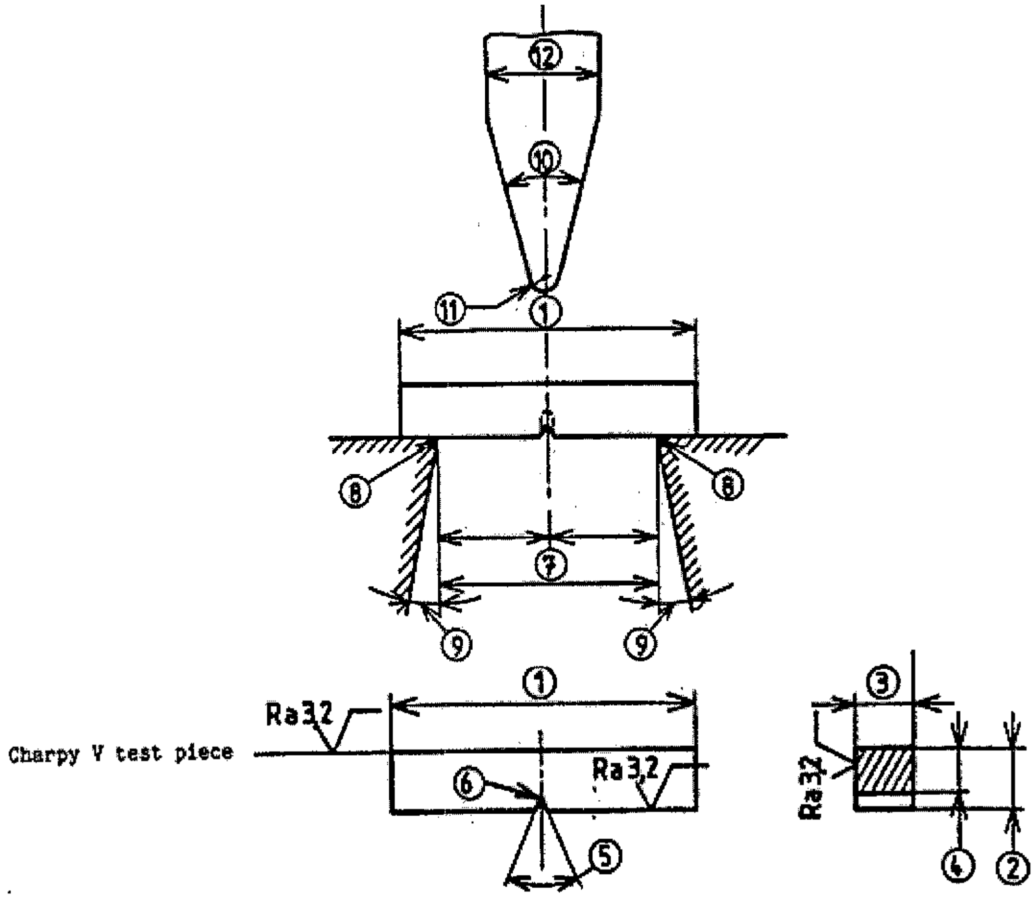
## Appendix 1 : Complete List of Rockwell Hardness Scale

| Scale Name | Indenter | Major Load | Minor Load | Applications* |
|---|---|---|---|---|
| A | Diamond | 60 kg | 10 kg | Cemented carbides, thin steel and shallow case hardened steel |
| B | 1/16" ball | 100 kg | 10 kg | Copper alloys, soft steels, aluminum alloys, mealleable iron |
| C | Diamond | 150 kg | 10 kg | Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardnened steel and the materials harder than HRB100 |
| D | Diamond | 60 kg | 10 kg | Thin steel and medium case-hardnened steel and pearlitic malleable iron |
| E | 1/8" ball | 100 kg | 10 kg | Cast iron, aluminum and magnesium alloys, bearing metals |
| F | 1/16" ball | 60 kg | 10 kg | Annealed copper alooys, thin soft wheet metals. |
| G | 1/16" ball | 150 kg | 10 kg | Phosphor bronze, beryllium copper, malleabel irons. Upper limit is HRG 92 to avoid possible flattening of the ball. |
| H | 1/8" ball | 100 kg | 10 kg | Aluminum, Zinc, Lead |
| K | 1/8" ball | 150 kg | 10 kg | Bearing metals and otehr very soft or thin materials. Use samllest ball and heaviest load that do not give and anvil effect |
| L | 1/4" ball | 60 kg | 10 kg | [Same as K] |
| M | 1/4" ball | 100 kg | 10 kg | [Same as K] |
| P | 1/4" ball | 150 kg | 10 kg | [Same as K] |
| R | 1/2" ball | 60 kg | 10 kg | [Same as K] |
| S | 1/2" ball | 100 kg | 10 kg | [Same as K] |
| V | 1/2" ball | 150 kg | 10 kg | [Same as K] |
| 15N | Diamond | 15 kg | 3 kg | Similar to C scale, but for thin materials |
| 30N | Diamond | 30 kg | 3 kg | [Same as 15N] |
| 45N | Diamond | 45 kg | 3 kg | [Same as 15N] |
| 15T | 1/16" ball | 15 kg | 3 kg | Similar to B scale, but for thin materials |
| 30T | 1/16" ball | 30 kg | 3 kg | [Same as 15T] |
| 45T | 1/16" ball | 45 kg | 3 kg | [Same as 15T] |
| 15W | 1/8" ball | 15 kg | 3 kg | Used for very soft materials |
| 30W | 1/8" ball | 30 kg | 3 kg | Used for very soft materials |
| 45W | 1/8" ball | 45 kg | 3 kg | Used for very soft materials |
| 15X | 1/4" ball | 15 kg | 3 kg | Used for very soft materials |
| 30X | 1/4" ball | 30 kg | 3 kg | Used for very soft materials |
| 45X | 1/4" ball | 45 kg | 3 kg | Used for very soft materials |
| 15Y | 1/2" ball | 15 kg | 3 kg | Used for very soft materials |
| 30Y | 1/2" ball | 30 kg | 3 kg | Used for very soft materials |
| 45Y | 1/2" ball | 45 kg | 3 kg | Used for very soft materials |

**Appendix 2 : Minimum allowable thickness for a corresponding hardness in the respective scales**

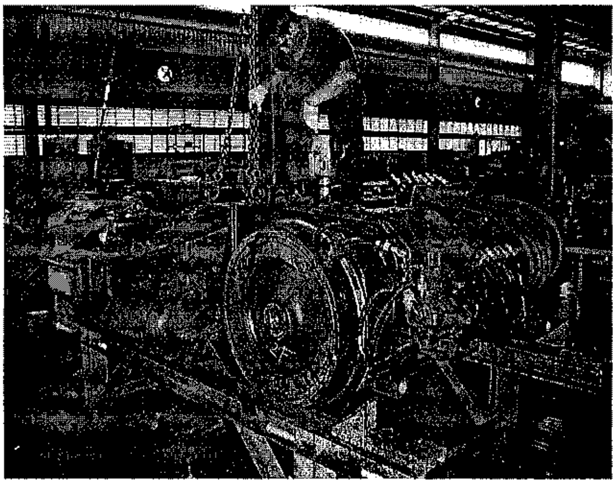
| MINIMUM THICKNESS in. | MINIMUM THICKNESS mm | ROCKWELL | | | SUPERFICIAL ROCKWELL | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C | A | B | 15N | 30N | 45N | 15T | 30T | 45T |
| .006 | 0.15 | ... | ... | ... | 92 | ... | ... | ... | ... | ... |
| .008 | 0.20 | ... | ... | ... | 90 | ... | ... | ... | ... | ... |
| .010 | 0.25 | ... | ... | ... | 88 | ... | ... | 91 | ... | ... |
| .012 | 0.30 | ... | ... | ... | 83 | 82 | 77 | 86 | ... | ... |
| .014 | 0.36 | ... | ... | ... | 76 | 78.5 | 74 | 81 | 80 | ... |
| .016 | 0.41 | ... | 86 | ... | 68 | 74 | 72 | 75 | 72 | 71 |
| .018 | 0.46 | ... | 84 | ... | ... | 66 | 68 | 68 | 64 | 62 |
| .020 | 0.51 | ... | 82 | ... | ... | 57 | 63 | ... | 55 | 53 |
| .022 | 0.56 | 69 | 79 | ... | ... | 47 | 58 | ... | 45 | 43 |
| .024 | 0.61 | 67 | 76 | 94 | ... | ... | 51 | ... | 34 | 31 |
| .026 | 0.66 | 65 | 71 | 87 | ... | ... | 37 | ... | ... | 18 |
| .028 | 0.71 | 62 | 67 | 80 | ... | ... | 20 | ... | ... | 4 |
| .030 | 0.76 | 57 | 60 | 71 | ... | ... | ... | ... | ... | ... |
| .032 | 0.81 | 52 | ... | 62 | ... | ... | ... | ... | ... | ... |
| .034 | 0.86 | 45 | ... | 52 | ... | ... | ... | ... | ... | ... |
| .036 | 0.91 | 37 | ... | 40 | ... | ... | ... | ... | ... | ... |
| .038 | 0.96 | 28 | ... | 28 | ... | ... | ... | ... | ... | ... |
| .040 | 1.02 | 20 | ... | ... | ... | ... | ... | ... | ... | ... |

## Appendix 3: Characteristics of test piece and testing machine and Charpy V Impact test

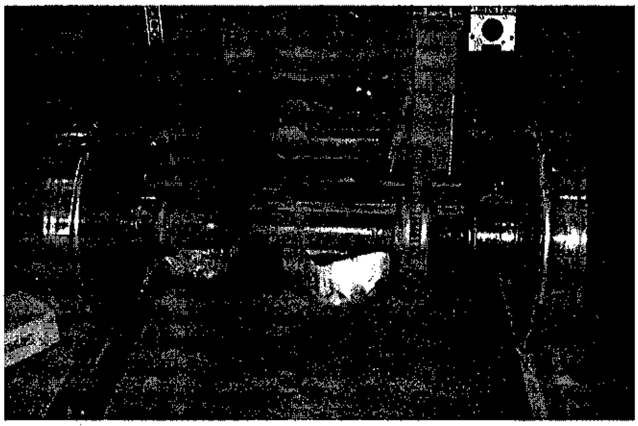



| Reference (Figure ) | Designation | Unit |
|---|---|---|
| 1 | Length of test piece | mm |
| 2 | Height of test piece | mm |
| 3 | Width of test piece | mm |
| 4 | Height below notch | mm |
| 5 | Angle of notch | Degree |
| 6 | Radius of curvature of base of notch | mm |
| 7 | Distance between anvils | mm |
| 8 | Radius of anvils | mm |
| 9 | Angle of taper of each anvil | Degree |
| 10 | Angle of taper of striker | Degree |
| 11 | Radius of curvature of striker | mm |
| 12 | Width of striker | mm |
| - | Energy absorbed by breakage KU or KV | Joule |

**Appendix 4 : Site Visit to STAR LRT at Jalan Ampang, Ampang**

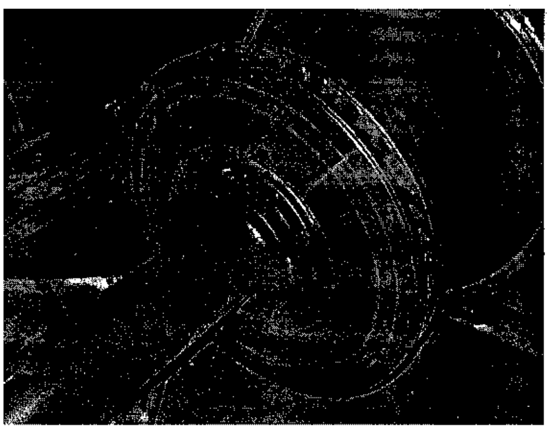


STAR foreman servicing the boggy where the axial, which is 8 brake pad being attached to the Axial. In boggy, there is two axial. One axial located at the right and the other one located at the left side of the boggy. There is 4 brake pad attached at each axial.



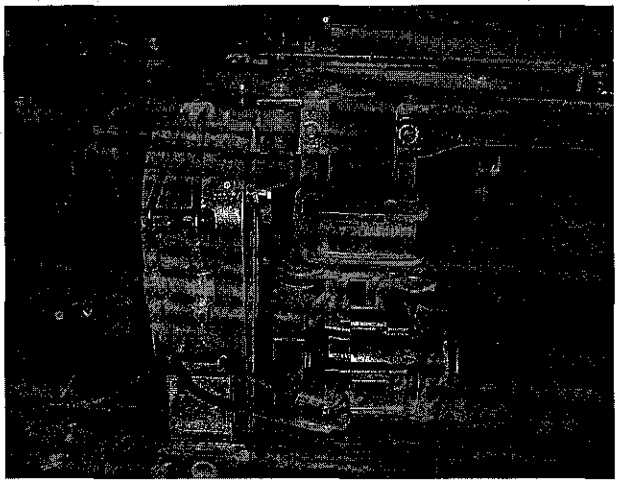
This is part that called axial where the brake disk located(in the circle).

This how the brake pad being arranged. There 4 brake pad that attached to the each disc, 2 at the right and the other 2 at the left side of the brake disc. This arrangement will be slotted in the brake disc at the axial.

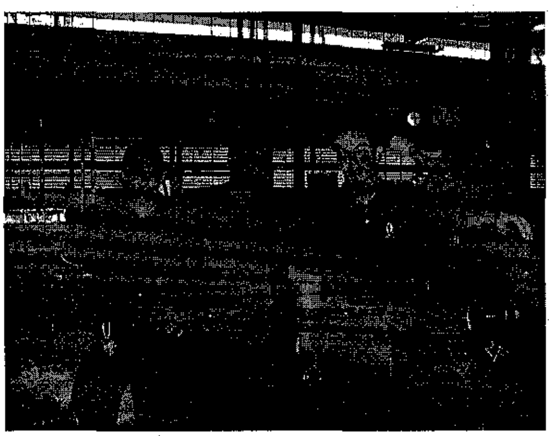


Brake disc at axial were the brake pad being attached

This is the brake hydraulic system, which is forcing the brake pad to function towards the disc. This is where the hydraulic is stored.

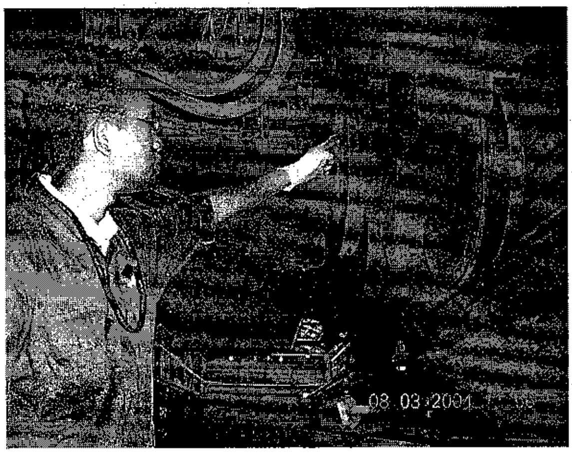


This 2 pictures showed the brake pad which slotted into the brake disc at axial. This is comparison between used brake pad and unused brake pad. At the left side is the used brake pad, and at the right is the unused brake pad. In figure below we can see the amount of thickness that has been wear out during its service life.

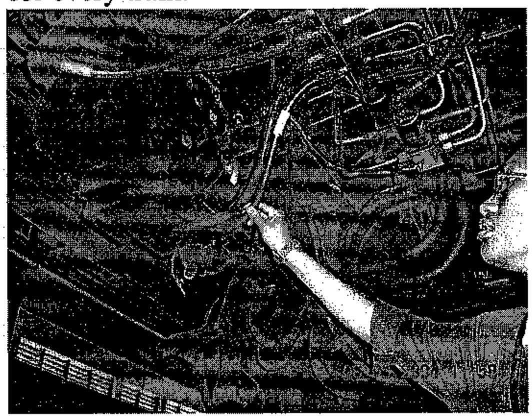


And end of the visit, the student with the En Johari Bujang Foreman at boggy section and other technician.

**Appendix 5: Site Visit to PUTRA LRT, Jalan Lapangan Terbang Subang, PJ**



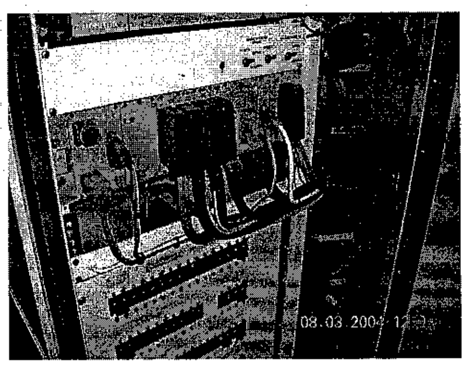
PUTRA Technician pointed to brake disc where the brake pad attached. Each brake disc, there is couple of brake pad being attached. Each boggy consist of to brake disc therefore 4 brake pad attached to every boggy. And every train consist of 4 boggy therefore 16 brake pad attached for every train.

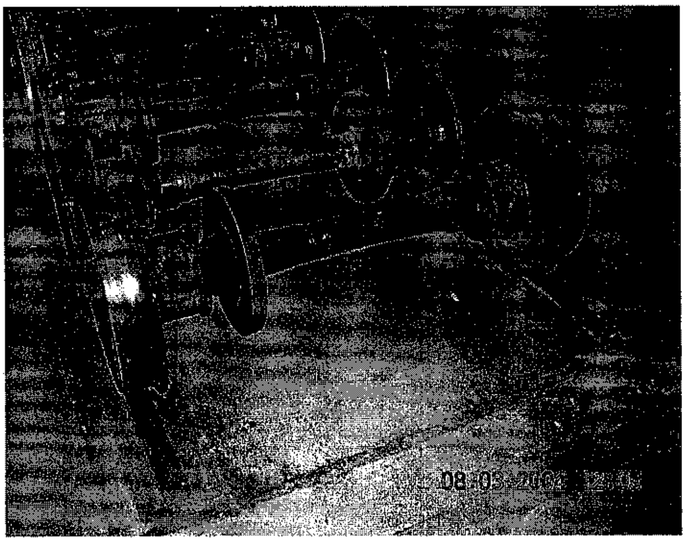


This is the Hydraulic Unit that supply hydraulic power for brake to function. Each line has its own function.

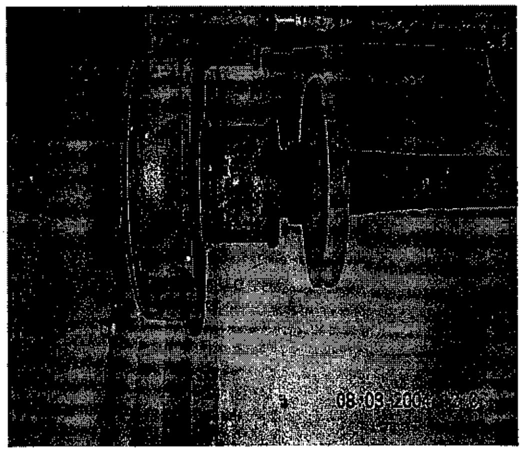
This is emergency brake. For PUTRA LRT, there is 3 type of brake; namely, Reverse current brake which is reverse rotation of the motor and when the train reach 21 km/h the brake pad will functioned that applied to the brake disc and thus stop the train. The other one is here the emergency brake, or brake that applied during at workshop that friction with the rail itself.

This is the control system or ECU(electronic control unit) that control and manipulate when and where to apply type of brake towards the train.

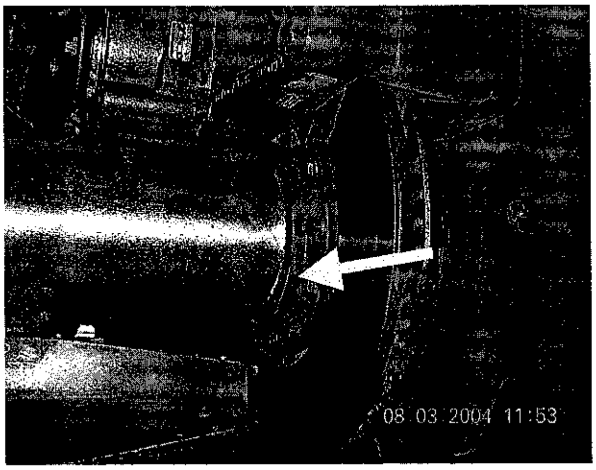




This is axial for PUTRA lrt, as mentioned before each boggy consist of two axial. And each train consist of 4 boggy there fore 8 axial.



This show the brake disc attached at axial where the brake pad applied.




This is how brake pad attached to brake disc (arrow). The brake pad were attached in both side of brake disc (figure below in circle).