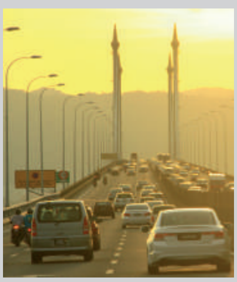
MRR No. 371

Research Report

Comparative Study of Brake Pads in Malaysian Automotive Aftermarket



Afiqah Omar
Fauziana Lamin
Norlen Mohamed

MIROS
MALAYSIAN INSTITUTE OF ROAD SAFETY RESEARCH
ASEAN ROAD SAFETY CENTRE

Comparative Study of Brake Pads in Malaysian Automotive Aftermarket

Afiqah Omar
Fauziana Lamin
Norlen Mohamed

MALAYSIAN INSTITUTE OF ROAD SAFETY RESEARCH
ASEAN ROAD SAFETY CENTRE

Published by:
Malaysian Institute of Road Safety Research (MIROS)
Lot 125-135, Jalan TKS 1, Taman Kajang Sentral,
43000 Kajang, Selangor Darul Ehsan, Malaysia.

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Afiqah Omar
Comparative Study of Brake Pads in Malaysian Automotive Aftermarket / Afiqah Omar, Fauziana Lamin, Norlen Mohamed.
(Research Report; MRR No. 371)
ISBN 978-967-2988-04-5
1. Automobiles--Disc brakes.
2. Automobiles--Brakes.
3. Automobiles--Brakes--Prices--Malaysia.
4. Government publications--Malaysia.
I. Fauziana Lamin. II. Norlen Mohamed.
III. Title. IV. Series.
629.246

Printed by:
VISUAL PRINT SDN BHD (186281-A)
No 47, 47-1, Jalan Damai Raya 1,
Alam Damai, 56000 Cheras,
Kuala Lumpur

Typeface: Calibri
Size: 11 pt.

Contents

List of Tables

List of Figures

List of Abbreviations

FMVSS	Federal Motor Vehicle Safety Standard
OEM	Original Equipment Manufacturer
MIROS	Malaysian Institute of Road Safety Research
FESEM	Field Emission Scanning Electron Microscope
EDX	Energy Dispersive X-ray
Ca	Calcium
Fe	Ferum
Si	Silicon
B	Barium
S	Sulfur
MgO	Magnesia
Al_2O_3	Alumina
MnS	Manganese Sulphide
$CaCO_3$	Calcium Carbonate

Acknowledgements

The authors would like to express our sincerest appreciation to the former Director-General of the Malaysian Institute of Road Safety Research (MIROS), Prof Wong Shaw Voon and the former Director of Vehicle Safety and Biomechanics Research Centre, Dr Norlen Mohamed for providing the grant in conducting this project entitled "Comparative Study of Brake Pads in Malaysian Automotive Aftermarket" and extending their full support in producing this report. Our deepest gratitude goes to Microscopic Unit, Institute of Bioscience Universiti Putra Malaysia for providing their services, time and expertise in material analysis, towards the production of this report. The authors would also like to express special thanks to the CRU team members and research assistants for their help and contribution in completing the project.

Abstract

Friction material requires in depth research to meet the safety standards and requirements during braking, yet must be produced at reasonable cost. Brake pads are one of the most important friction functional materials in the automotive brake system and requires to be changed on time due to wear. As part of composite materials, brake pads are made of different material combinations. Commonly, the main constituents used in commercial brake pads are frictional additives, filler, binder and reinforcing fibre. Each constituent plays important roles in ensuring the brake pads are intact together and function properly. Among the ingredients currently available, the reinforcing fibres play a crucial role in determining the friction characteristics.

The variety of brake pad brands in the market present the customers with many options at various price points. Aftermarket brake pads can vary from as low as MYR25 to MYR300, depending on the model of the vehicle. This report highlights the variation of aftermarket brake pads price in Malaysian market. The study focuses on the selection of front brake pads used in passenger vehicles, specifically brake pads used in Proton Wira, as 25.8% of the car models were involved in fatal accidents, based on MIROS investigated crash cases. For microstructural study, 13 brake pads of low or semi metallic types were collected. The elemental compositions of the brake pads were studied using Energy Dispersive X-ray (EDX).

From the results, there was no standardised or controlled prices that can represent the majority of commercial brake pads exist in the market. In order to substitute asbestos in brake pads, a multitude of different brake pads with their own unique composition can be found in the market. Cost minimisation of brake pads is achieved by blending more expensive substitutes with cheaper but less effective materials. However, significant costs to produce brake lining are still increasing, and affect the selling price of commercial brake pads. Section 4 discusses the constituents used in the brake pads

categorised by price. The composition might be slightly different between the frictional and lateral surface.

From the sample studies, the weight percentage of fibre does not affect the price of brake pads. Expensive brake pads do not necessarily contain the highest fibre content. Metal is widely used due to high density, hardness and good thermal conductivity. The huge price variation from one brand to another may need to be further studied in order to ensure customers are satisfied with the price and quality of the parts.

1. Introduction

An automotive brake system consists of a master cylinder connected hydraulically through lines to disc and drum brake units that stop the wheels (C. Owen, 2010). Brakes are designed to be application-specific (T. Gilles, 2005). It means they are designed to fit a particular vehicle and brake linings material can be different from one vehicle to another.

Brake lining is one of the most important friction functional materials in the automotive brake system. Brake lining is defined as composite materials which brake shoes or brake pads are lined with; it withstands high temperatures and pressures. The friction between brake lining and brake disc together convert the clamping force to braking torque. The physical and chemical properties of brake lining are the main contribution to the efficiency and comfort of the brake. Drum brake linings are called shoes while disc brake linings are called pads. This study will focus on brake pads, as most passenger vehicles are equipped with disc brakes system.

Depending on the type of pad and driving terrain, brake pads must be replaced over time. Car owners have the option to replace the pads with the Original Equipment Manufacturer (OEM) or aftermarket (replacement) pads. OEM pads are labelled with the name of the vehicle's manufacturer (e.g PROTON) while aftermarket pads can have a variety of labels, depending on the manufacturer. By choosing aftermarket pads, the owner can choose various types of brake pads, such as semi-metallic, metallic or organic pads, and the products are sold at varying prices. Organic replacement pads are often less expensive but may also be less durable than semi-metallics. The auto parts store or workshop will usually recommend a size and formulation of brake pad specifically according to the model of vehicle.

The variety of brake pad brands in the market presents customers with choices at a wide price range. In Malaysia, customers can purchase the brake pads either in workshops, service centres, online retailers or auto parts shops. Aftermarket brake pads can vary from as low as MYR25 to MYR300, depending on the model of the vehicle. Usually, foreign vehicles brake pads cost more than local vehicles parts. However, certain brake pads have no specific standards, as the matter is not fully legislated and controlled. Without standards or specifications in place, there are no controls in the market place. Moreover, each manufacturer has their own standard choice of raw materials and processes that suit their final product performance.

1.1 Scope and Objectives of the Study

General Objectives:

- To determine the variability of the brake pads in the Malaysian market.

Specific Objectives:

- To determine the variability of brake pads according to the type, price and size of the components.
- To compare the difference between the type, price and size of the brake pads.
- To review the materials and constituents currently used in automotive brake friction material after the phasing out of asbestos.

The outcomes of this study will provide additional knowledge to road users in selecting the suitable brake pad for their automobiles. In addition, the findings would provide some recommendations for stakeholders in order to control the price variation of brake pads in Malaysian market.

1.2 Limitation of the Study

The preliminary study was conducted only for brake pads sold in the areas of Kajang, Bangi and Semenyih, where the targeted areas are divided into workshops, spare part shops and service centres. Since the brake pads selection was based on the model of the vehicle, this study focuses on the availability of brake pads for the Proton Wira model, which accounts for 25.8% of the total of accidents involving passenger vehicles, from MIROS crash profiling data. The results from this study do not represent the whole industry as the data collected was only from a limited place and focuses on one type of passenger vehicle.

2. Literature Review

Functional brakes are important in ensuring the safety of the vehicle, its occupants and other road users. Braking is accomplished by rubbing two surfaces together, thus producing friction. The components that comprise the braking system are categorised as safety-critical components and are subjected to strict statutory requirements (B. Breuer & K. H. Bill, 2006). The focus of the literature review is the introduction to automotive brake system, the components that are available in the system and its function. Automobiles usually used disc brakes, drum brakes or a combination of the two. The usage of drum brakes was popular around 1930s until 1960s, but due to poor heat dissipation, most of passenger vehicles nowadays are equipped with disc brakes design. In the following sections, topics that are related to drum brakes and disc brakes are discussed.

2.1 Drum Brakes

Drum brakes used to be installed on all four wheels of a vehicle; however, the convention has changed and they are now usually found on the rear wheels in disc-drum applications. Light/heavy trucks, semi-trailers and buses still used drum brakes as their brake system.

Each drum brake has two brake shoes with a friction material called a lining attached. When the brakes are applied, these shoes expand against the inside surface of a brake drum and slow the wheel. The harder the linings are forced against the brake drum, the greater the braking force applied (CDX Automotive, 2012). When the braking operation is complete, springs pull the brake shoes inward again to ensure a clearance between the friction surface of the drum and the brake linings (B. Breuer & K. H. Bill, 2007).

It is important to note that the usage of brake drum has its limitation. Under continuous downhill braking (or quick repeated hard braking from high speeds), the internal drum brake could overheat and lose its ability to stop a vehicle with a reasonable brake pedal effort (Disc, 1969). This problem occurred due to the fact that most of the heat generated during braking had to be transferred through the relatively thick wall of the drum before it could be dissipated to the surrounding air. The brake drum is also located within the wheel, which restricts access to airflow that promotes cooling (D. J. Paustenbach, 2010). The effect will cause the brake linings to wear out rapidly and some drivers were unable to apply sufficient brake pressure to the car.

2.2 Disc Brakes

Front wheels of virtually all light and medium vehicles used disc brakes as part of the brake system (G. M, 1986). No law or regulation requires disc brakes on the front wheels, but in the United States, the brake performance requirements of FMVSS 105 make front disc brakes virtually mandatory (C. E. Owen, 2003).

A typical disc braking system consists of a disc (rotor), a caliper housing, a piston, a seal and pads. When the brake pedal is being stepped, pressure from the master cylinder goes to the caliper forcing one or more pistons to squeeze the inner and outer brake pads against the rotor. The clamping action of the brake pads retards the rotational motion of brake disc and the axle that it is mounted on. The motion creates friction, which slow the vehicle and produces heat (M. Mavrigian & L. W. Carley, 1998).

Disc brakes have better stopping power compared to drum brakes. A disc brake consists of two brake pad squeeze against the rotor. The principal operation of disc brake is the application of pressure on a friction pads against a disc which is driven by the road wheel (D. John & R. Hartley, 1981). The friction material used for disc brake pads is generally harder than that used on drum brake linings because the friction surface is smaller and higher pressure are used to push the pads into contact with the disc (K. Pickerill, 2014). This study will focus on the disc brake system, specifically brake pads, because they are more common in newer vehicles.

2.1.1 Brake Disc

Today's brake discs are manufactured primarily from pearlitic gray cast iron with 3-4 wt. % carbon. This material contains free graphite in the shape of small flakes in pearlitic matrix (M. Eriksson et.al, 2001). Grey cast iron is chosen as the main material in brake disc due to having desirable thermal properties, sufficient mechanical strength, satisfactory wear resistance, good damping properties, cheap and easy to cast and machine. Small amounts of chromium and molybdenum additives give the material greater abrasion resistance and improved heat cracking behaviour (B. Breuer & K. H. Bill, 2006).

The brake disc is generally manufactured from grey cast iron, although some high performance vehicles may have ceramic-based or carbon fibre-based discs. The disc is bolted to the wheel hub; therefore the disc rotates at the same speed as the road wheel. The brake disc friction surface is exposed to the atmosphere; so the air flow around the disc as the vehicle moves cools the disc. The brake disc is either of a solid or ventilated type (V. A. W. Hillier & P. Coombes, 2004)

The disc brake rotor has two main parts; the hub and the braking surface (Figure 1). The hub is where the wheel is mounted and contains the wheel bearings. The braking surface is the machined surface on both sides of the rotor. It is carefully machined to provide a friction surface for the brake pads. The entire rotor is usually made of cast iron, which provides an excellent friction surface.

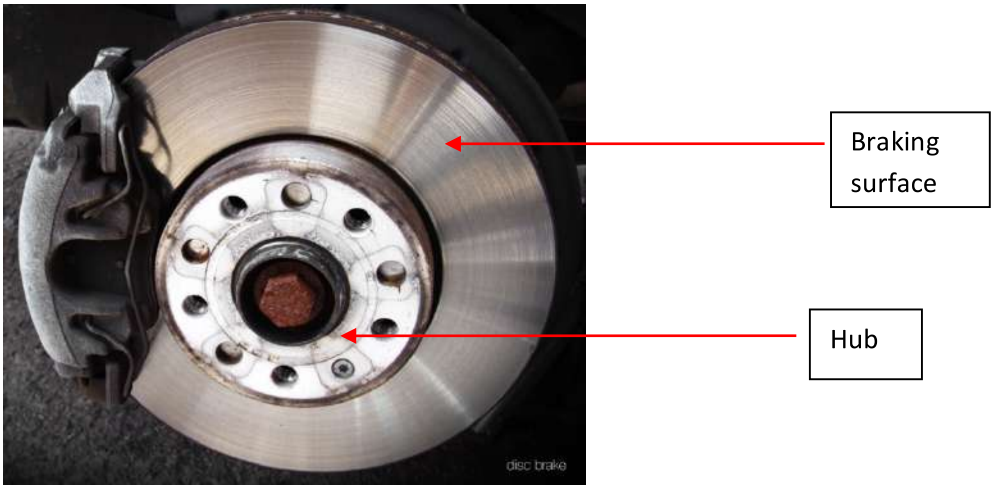


Figure 1 Parts in disc brake rotor (*Source*: cosmone.com)

The size of the rotor braking surface is determined by the diameter of the rotor. Large cars, which require more braking energy, have large rotors while smaller and lighter cars can use smaller rotors. Generally, manufacturers want to keep parts as small and light as possible while maintaining efficient braking ability (J. Erjavec, 2009).

2.1.2 Brake Pad

The brake pad is one of the essential elements in disc brake system. It is part of the brake system which converts the kinetic energy of the vehicle to the thermal energy by friction. The friction lining fitted in the brake pad must be hardwearing and heat resistant. In order to meet the requirement, a brake pad is made of many elements such as resin, fibres, solid lubricants, abrasive particles, metal and fillers.

Automotive engineers use a variety of materials to maximize performance in all areas, often combining five to twenty different material ingredients to form complex composite friction materials (Rhee et al., 1990). Increased customer demands for new technologies in vehicles leads to continuous acceleration of product cycles and growing product complexity.

During braking, the pad material is submitted to severe solicitation which is affected strongly by the microstructure of the material according to the nature of involved ingredient (M. Kumar & J. Bijwe, 2010). The performance of friction material is strongly affected by selection of the ingredients, and more than 100 ingredients available in friction industry (Saffar & Shojaei, 2012). Asbestos is used widely for automotive friction materials such as clutch and brake linings due to its resistance to heat and corrosion. However, asbestos is extremely hazardous to human health; hence its usage has been controlled, reduced and finally prohibited. After the banning of asbestos in brake friction materials, it resulted in the evolution of a multitude of different brake pad in the market; each with their own unique composition.

Industrial pads usually contain a large number of different constituents (A. Keskin, 2011). This is due to the friction materials which have to be designed to keep friction force stable, be of reliable strength and have good wear resistance over a wide range of braking conditions (Anderson A. E, 1992). Moreover, the friction material must be compatible with a composite disc brake by forming reliable friction film (stable third body layer) at the friction surface (Witaker R. & Wirth A. J., 1992). All of these requirements need to be achieved at a sensible cost with minimum environmental load.

The brake pad constituents often contain frictional additives, fillers, binder and reinforcing fibres (D. Chan & G. W. Stachowiak, 2004). L. G. Hayer et al. stated that selection of constituents are usually based on trial and error. Each of constituents plays an important role in the performance of the brake pad:

a. Frictional additives determine the frictional properties of brake pads, which is a mixture of abrasives and lubricants
b. Fillers reduce the overall cost and improve manufacturability of brake pads
c. Binder resin, which holds components of a brake pad together
d. Reinforcing fibres provide mechanical strength. (E.g: metallic, ceramic, glass, acrylic). Usually, commercial friction materials consist of 5 - 25 vol% of fibrous ingredients.

Brake pads can be classified based on the ingredients. Kim et al (2001) stated that the types and the relative amount of fibres affect brake performance and wear life. Metallic brake pad ingredients are predominantly metallic, such as steel fibres, copper fibres, etc. Metals, such as copper, tend to be good friction materials because they are good at dissipating heat generated during braking. Metallic formulations generally have high “hot” friction coefficients making them perform well under extreme braking conditions (Dougherty, 1995). However, metallic brake pads have disadvantages; they work very poorly until they are fully warmed and are extremely noisy.

According to Jang et al. (2004), the first type of asbestos-free friction material was semi-metallic. Semi-metallic is a mixture of metallic and organic ingredients. Semi-metallic generally refers to the presence of iron and steel in the formulation (Delgado, 1994). Semi metallic brake pads are composed of finely powdered iron or copper, graphite and lesser amounts of inorganic fillers and friction modifiers (Toboldt, 1989). It can be differentiated from organic brake pads through appearance of colour and texture. Semi-metallic pads are a darker colour with visible metallic fibres and have a rough texture.

Non-asbestos organic ingredients are predominantly organic, such as mineral fibres, rubber, graphite, etc. Organic pads are a lighter shade of grey and have a smoother texture. Organic brake pads are constructed by mixing non-asbestos fibres, such as glass, rubber, carbon and Kevlar, with filler materials and high-temperature resins (E.Abdo, 2012). Recently, there was a development on friction material containing ceramic fibres and fillers. Several kind of ceramic fibres and fillers, such as potassium titanate whiskers and aluminium-silicon fibres with aramid pulp, were used in this type of material (Han & Huang, 2006).

The purpose of this study is to understand the composition and microstructure of the brake pads, specifically on the usage of raw materials and manufacturing defects, which are highly related to the performance of the brake system. The study discloses relationships between microstructure and properties of materials. The physical properties of a composite material are determined by the properties of its components and the corresponding volume fractions. W. Osterle et al. (2007) stated that material modifications might affect friction and wear properties of automotive disc brakes.

3. Methodology

The material studied are commercial aftermarket brake pads for automotive applications. Based on the wide range of aftermarket brake pads in Malaysia, the study will focus on the selection of brake pads used in passenger vehicles. Since some of the vehicles used different systems for front and rear braking, the study will focus on the brake pads installed in the front brake systems.

The selection of passenger vehicles is based on the vehicle crash profiling data collected by MIROS from 2007 to 2010. Passenger cars are the most common types of vehicles involved in the investigated crash cases (A. N. Syukri et al., 2012). Even though the main cause of the crashes was not due to the brake failure, it is a good start to ensure that the vehicles involved in the accident used the correct automotive parts in its system, especially in braking.

In general, the project consists of six activities i.e market survey, sample retrieval, sample preparation, microscopic analysis, advance analysis, result and database. Figure 2 shows the overall flow of the study.

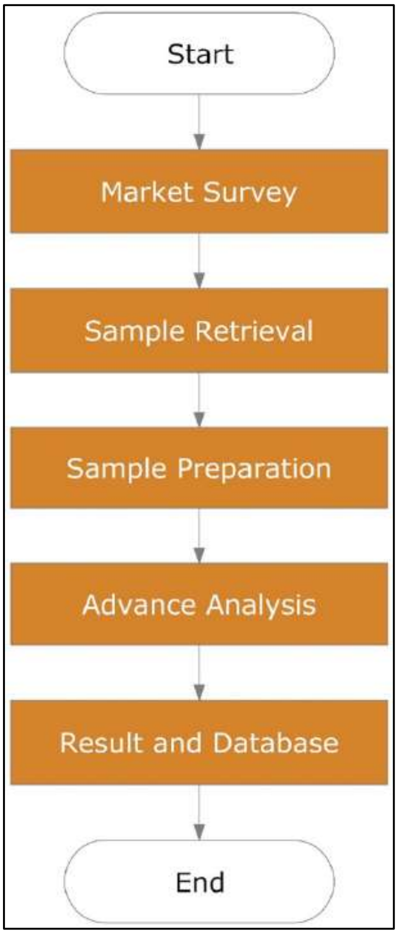


Figure 2 Methodology framework

3.1 Market Survey

Market survey was conducted for approximately four weeks, from 22 July 2013 to 9 August 2013. The survey covers three areas which are Kajang, Bangi and Semenyih, focusing on the place where the brake pads are sold. In Malaysia, automotive spare parts can be purchased in automotive service centres, automotive spare parts dealers, automobile repair workshops and through online purchase.

Service centres are classified as auto parts stores or motor manufacturers who maintain service operations (e.g., Perodua Service Centre). Automobile repair workshops are independently owned and operated businesses, and could be specialty shops specialising in certain parts such as brakes, tyres and exhaust systems. Meanwhile, automotive spare part dealers usually own specialised shops offering choices of spare parts, including local and international parts.

Due to a wide variety of brake pad products, the surveys focussed on the commercial brake pads of passenger vehicles that have been on the road for more than three years. The newer vehicles tend to have fewer choices of brake pads in the market due to smaller demand. The two main vehicles surveyed in this project are local vehicles – Perodua Myvi and Proton Wira. Perodua Myvi was chosen as it is the best-selling model in Malaysia. However in this case, due to different design of brake pads for old Perodua Myvi (2007 - 2011) and new Myvi (2012 above), Myvi brake pads in this study refer to the older Myvi, which were sold between 2007 and 2011. Meanwhile, Proton Wira was chosen as a high percentage of this vehicle were involved in accidents based on MIROS crash profiling data 2007-2010. Out of 275 cases involving passenger vehicles, 25.8% of the vehicles involved Proton Wira.

3.2 Sample Retrieval

Based from the market survey results, selected brake pad brands will be retrieved for study purposes. The commercial brake pads chosen are designed for Proton Wira 1.5. Final selection involved purchasing of total 13 set of brake pads, with different manufacturers and price range.

In the present work, the commercial brake pads are categorised based on its price. CF1 price is the lowest, and as the number increased, the prices also increase (CF13 is the most expensive out of 10 brake pads). From the price range, the brake pads were grouped into low, medium, high and expensive price, in order to study the difference in the microstructure. The grouping is shown in Table 1.

Table 1 Brake pads grouping according to price

Price	Price range	Brake pads
Low	Less or equal to MYR 25	CF1
		CF2
Medium	Less or equal to MYR 50	CF3
		CF4
		CF5
		CF6
High	Less or equal to MYR 100	CF7
		CF8
		CF9
		CF10
Expensive	Above MYR 100	CF11
		CF12

In general, one set of brake pads consist pair of brake pads, one for right braking while the other for left braking system.

3.3 Sample Preparation

In order to prepare the sample for microscopic analysis, the brake pads need to be prepared through sectioning, grinding and polishing. A vertical section of brake pads was obtained by METKON precision cutter MICRACUT 201, with dimension of 1cm x 1cm x 1 cm (Figure 3). For this purpose, the cutter was equipped with abrasive blade and cooling fluid, with feed rate set to 40 µ/sec and the cutting speed 1000 rpm. The parameter is chosen based on the type of material, which is composite in this case.
The lateral and friction sections of this fraction were grinded and polished using FORCIPOL 2V for subsequent morphological and particle resolved composition analysis. The sample was grinded using silicon carbide paper with different mesh (240 grit to 1200 grit). Next, successive polishing steps were performed using 6 and 1 µm diamond paste.

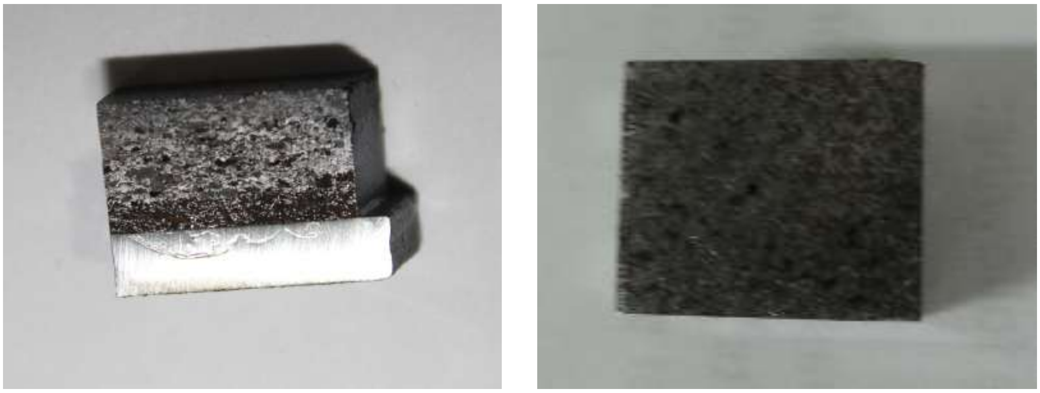


Figure 3 Lateral and friction sections of 1cm x 1cm x 1cm brake pad

3.4 Morphological Characterization

The sections of the brake pads are observed in a light optical microscope (LOM). The purpose is to analyse the surface distribution of the particulates and fillers. Light optical microscope was also useful for checking the coverage of oxide layers in metallic constituents of the pads. Further investigations were performed at higher magnification in JEOL JSM-7600F Field Emission Scanning Electron Microscope (FESEM) equipped with an Energy Dispersive X-ray (EDX). EDX were used to characterise the materials elements in the brake pads. The machines were shown in Figure 4.

Figure 4 JEOL JSM 7600F FESEM attached with EDX

4. Results and Discussions

This chapter discusses the customs data on imported brake pads, the variation of brake pads prices in survey results, the packaging and marking, and microscopic study of the brake pads.

4.1 Customs Data

The need of this study has been inspired by the huge demand of brake pads in the Malaysian market. The quantity of commercial brake pads imported to Malaysia was collected from Royal Malaysian Customs Department. Table 1 shows the amount of brake pads (in kg) imported by Malaysia from January 2012 to July 2013 (as this study was conducted around this time). It can be clearly seen in Figure 5 that a large number of imported brake pads are manufactured in Korea.

In 2012, the total number of brake pads imported by Malaysia was 173,194 kg, with the highest number of those brake pads coming from Korea, followed by Singapore and Japan. From January to July 2013, the number of brake pads imported by Malaysia was 138,183 kg, with the highest supplied by Korea, and followed by China and Singapore. The quantity of brake pads imported from China increased rapidly from 3,040 kg in 2012 to 30,033kg. The figure proves that there is a huge demand of commercial brake pads in the Malaysian market. Similarly, there were several local companies that have taken the initiative to produce local brake pads in order to cope with the demand. These resulted from the rise of rapid motorisation in Malaysia over the years at an alarming rate (Hoque M. & Hossain T., 2006).

The main concern with the data is that all of the imported brake pads come without brand name, and only provided the manufacturer’s details. Hence, there is a possibility of rebranding and the consumers have a slim chance of identifying the origin of the brake pads they install in their vehicles, without packaging information.

Table 2 Lists of imported major suppliers of brake pads in Malaysia in 2012 - 2013 (*Source*: Customs Malaysia)

Year/Export Country	Import quantity in kg						
	Korea	Singapore	Thailand	China	Japan	Denmark	US
2012	93783	34210	13922	3040	16015	9899	2325
Jan - July 2013	56073	26432	5812	30033	9475	10358	None

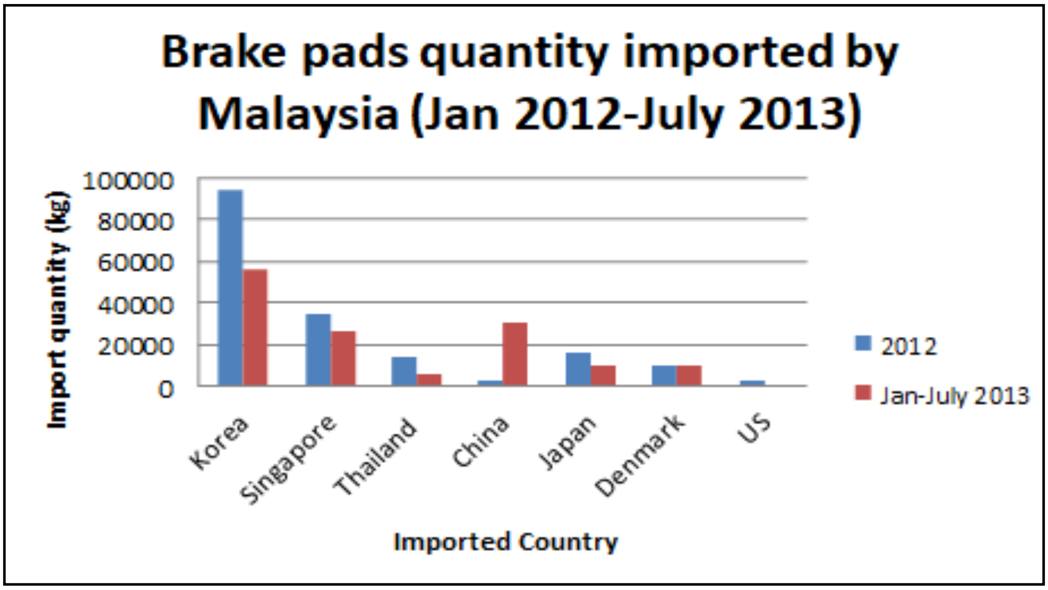


Figure 5 Imported brake pads to Malaysia (*Source*: Customs Malaysia)

4.2 Survey

In the area of Kajang, Bangi and Semenyih, the team visited 103 different locations in order to survey the price of brake pads. From the observation, 28.16% data collected in automotive spare parts shops, 24.27% data collected in service centres while the other 45.57% collected in local workshops.

Figure 6 shows the overall price variation of surveyed brake pads for passenger vehicles. The price varied from as low as MYR25 to as high as MYR300. The average price of passenger vehicles brake pads surveyed is MYR91.88. Since some of the products are from different manufacturers, the development of multiphase composites for the brake lining may result in the price variation.

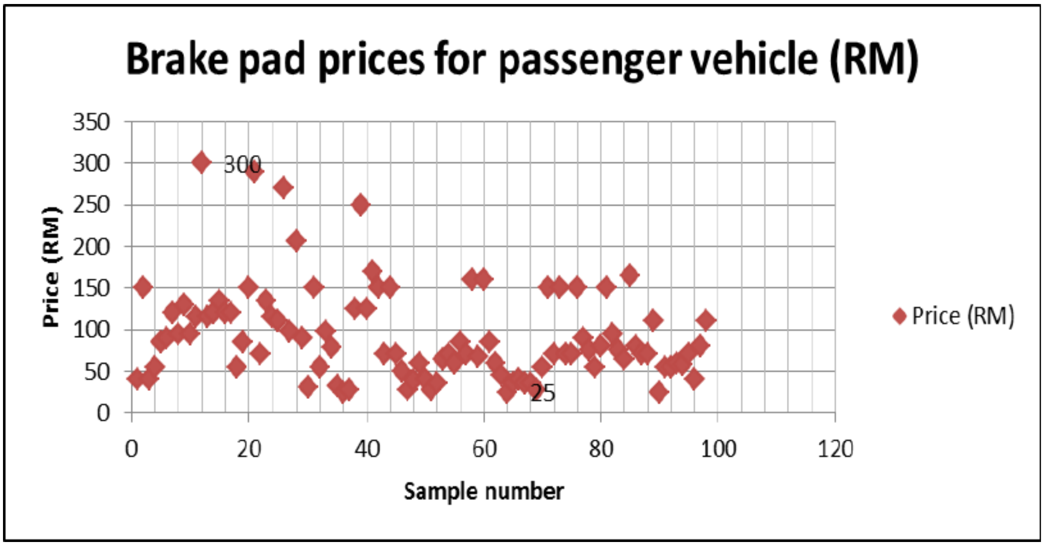


Figure 6 Brake pad prices for passenger vehicle

In Malaysia, brake pads can be purchased in local workshops, service centres and automotive spare parts shops. The brake pad price range was different for each place purchased (Figure 7). The average price in spare parts shops is MYR 67.83, service centres MYR 109. 74 and workshops MYR 97.00. Service centre pricing is the highest, and the prices differ extensively from one brake pad to another, followed by workshops and spare parts shops.

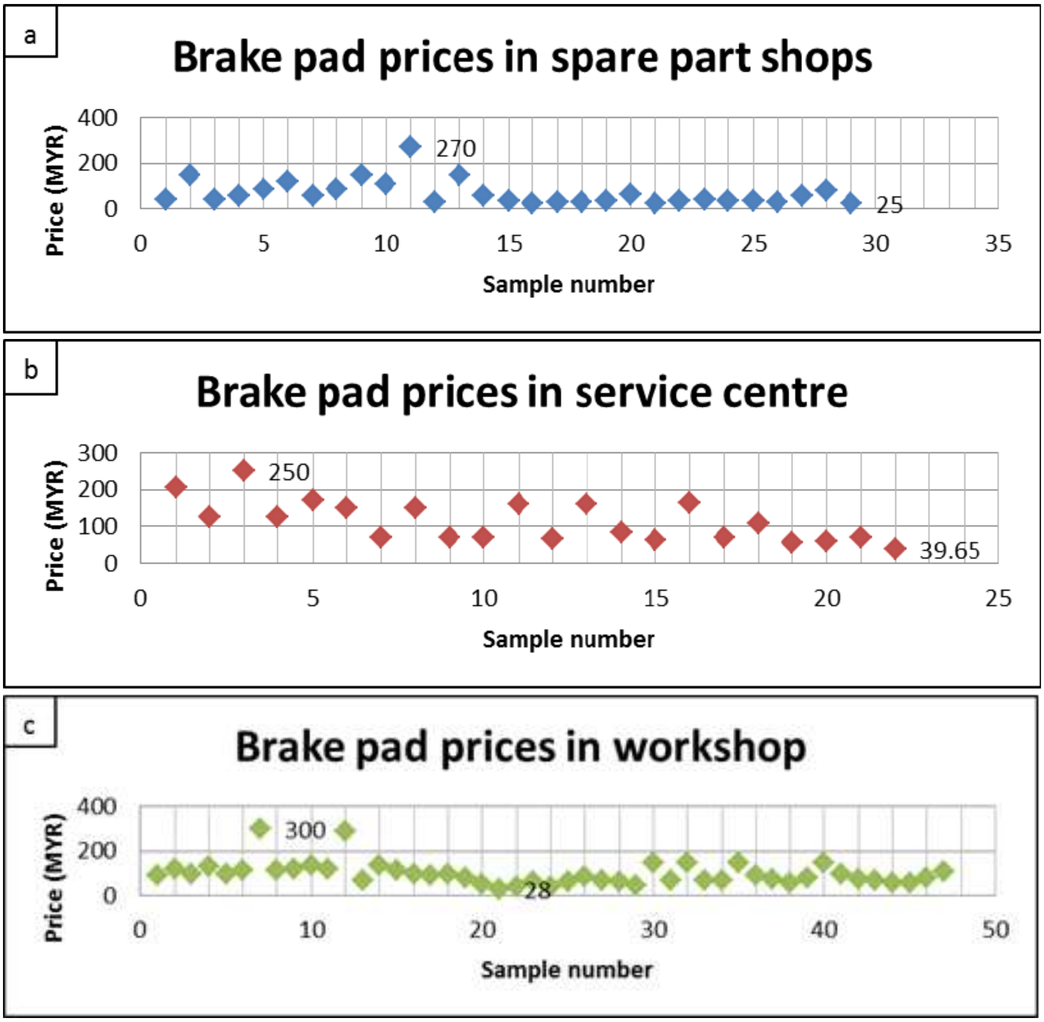


Figure 7 Brake pad prices variation in (a) spare part shops (b) service centres and (c) workshops

4.2.1 Survey Price for Perodua Myvi Brake Pads

There are no specific sizes for brake pads installed in passenger vehicles brake system. Usually, each model of passenger vehicles has their own unique size of brake pads. In this study, brake pads for Perodua Myvi are found to be smaller compared to the size of brake pads used for Proton Wira. The size of brake pads for old Perodua Myvi (2007-2011) also different compared to new Perodua Myvi (2012 onwards).

Figure 8 shows the scattered price of brake pad for Myvi, which range from as low as MYR 35.00 to MYR 170.00. The average price of Myvi brake pad is around MYR 94.50. Usually, the brake pads brands are recommended by the shop owner and the final decision is dependent on the customer's budget.

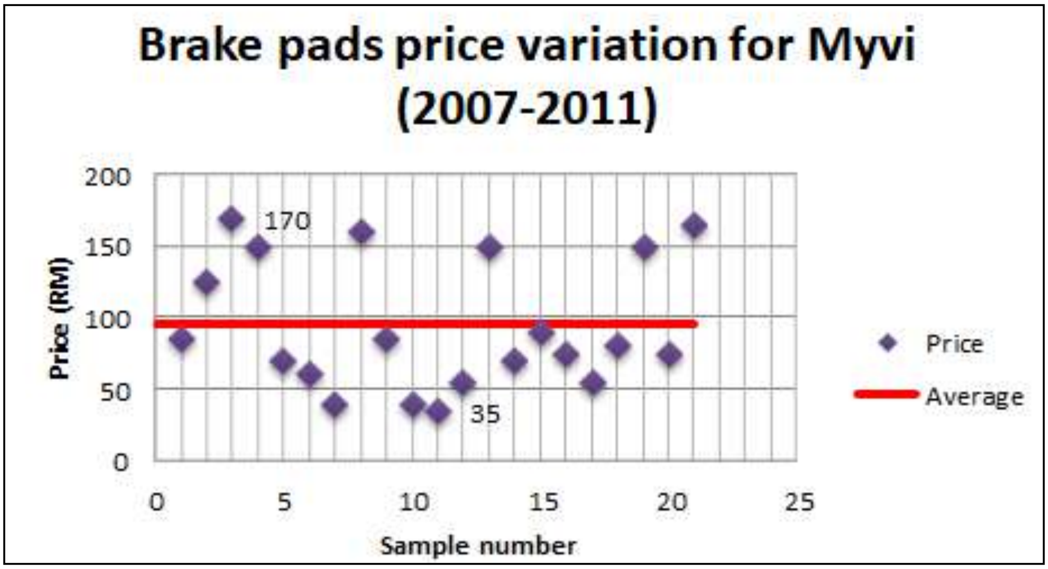


Figure 8 Scattered price of brake pads for Perodua Myvi (2007 - 2011)

4.2.2 Survey Price for Proton Wira Brake Pads

Comparing to Perodua Myvi, the choice of Proton Wira brake pads are much wider since the production of the latter started from 1993 to 2007. Many brands, especially locally produced, can be purchased with variation of prices (Figure 9). The price variation starts from MYR 25 to MYR 160. The average price for brake pads of this model is MYR 65.94, slightly lower than the average price for Myvi model. As the price variations of Proton Wira brake pads are broader, those brake pads were retrieved for further studies.

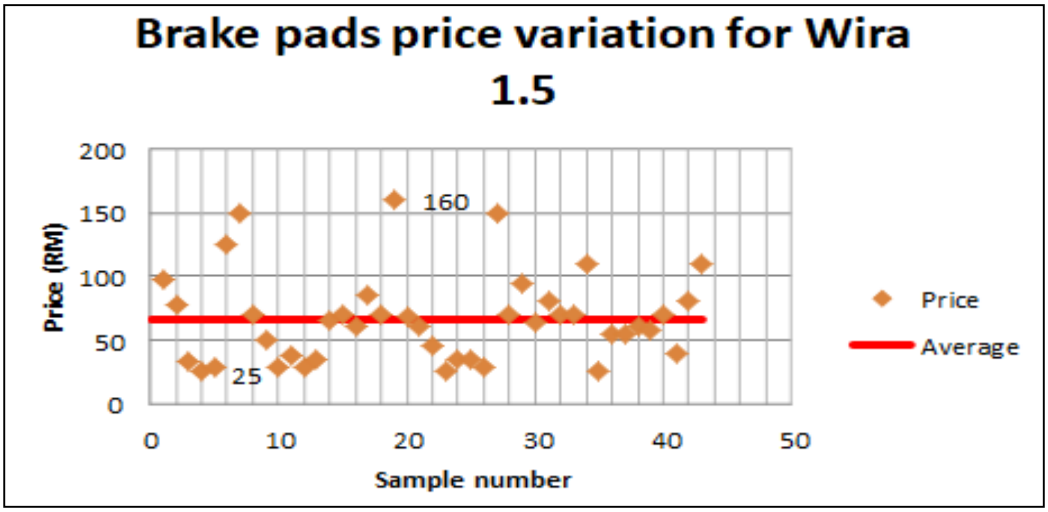


Figure 9 Scattered price of brake pads for Proton Wira 1.5

4.3 Physical Characteristics, Packaging and Marking of Brake Pads

Table 3 shows the physical characteristics of the samples studies. The pad length is the total length of the backing plate and friction material, not including any over-hanging clips. The pad width covers the total width of the backing plate and friction material not including any over-hanging clips while the pad thickness covers total thickness from the flat surface of the backing plate to the flat surface of the friction material. The purpose of identifying the shape, length, width and thickness of the pads are to identify any variation on the friction surface area.

Overall, the length, width and thickness of the brake pads are approximately the same (with variation of ±0.1), since the brake pads are fitted for a specific vehicle, with the same size of brake disc. Brake pad CF3 thickness is the highest (1.546 cm) while brake pad CF5 thickness is the lowest (1.454 cm). According to Lester J.Erlston and Michael D.Miles (2005), pad life is directly proportional to the volume of pad available to be worn away.

Table 3 Physical characteristics of brake pads

Brake pads	Average length(cm)	Average width (cm)	Average thickness(cm)
CF1	11.400	4.966	1.508
CF2	11.410	4.966	1.546
CF3	11.298	5.080	1.519
CF4	11.355	5.080	1.513
CF5	11.411	5.039	1.496
CF6	11.415	5.020	1.454
CF7	11.413	5.100	1.523
CF8	11.390	5.018	1.466
CF9	11.397	5.024	1.493
CF10	11.408	5.080	1.508
CF11	11.390	5.081	1.474
CF12	11.420	5.080	1.538
CF13	11.403	5.100	1.505

According to packaging and marking highlighted in ECE Regulations No 90, replacement brake lining assemblies conforming to a type approved in accordance with the regulation shall be marketed in axle sets. Each axle set shall be contained in a sealed package constructed to show previous opening. The package should contain information such as the quantity of replacement brake lining assemblies, manufacturer's name, make and type of replacement brake lining assemblies, the axles/brakes for which the contents are approved and the approval mark. Table 4 shows the existence of required marking in the brake pads studied.

Out of the 13 pads studied, only four brake pads complied with the packaging marking of ECE Regulation 90 (which is CF3, CF5, CF10 and CF12). Those four brake pads have approval marks from the country they applied for. Most of the pads were not sealed during purchase (8 out 13 pads) and does not contain approval marks (9 pads). The information stated in the packaging is important for customers to know the details of the products they have purchased.

Table 4 Packaging and marking according to ECE Regulation 90

Brake pads	Sealed package	Quantity of replacement brake pads	Manufacturer's name	Make and type of replacement brake pads	Approval mark
CF1	√	√	√	√	x
CF2	x	√	√	√	x
CF3	√	√	√	√	√
CF4	x	√	√	√	x
CF5	√	√	√	√	√
CF6	x	√	√	X	x
CF7	x	√	√	√	x
CF8	x	√	√	√	x
CF9	x	√	√	√	x
CF10	√	√	√	√	√
CF11	x	√	√	√	x
CF12	√	√	√	√	√
CF13	x	√	√	√	x

Figure 10 shows the location of approval mark on the back plate of brake pads. All of the brake pads contain information of manufacturer's on the back plate except for brake pad CF9 (Figure 11). Brake pads CF3, CF5 and CF10 contain E1 approval mark on the back plate of the material.

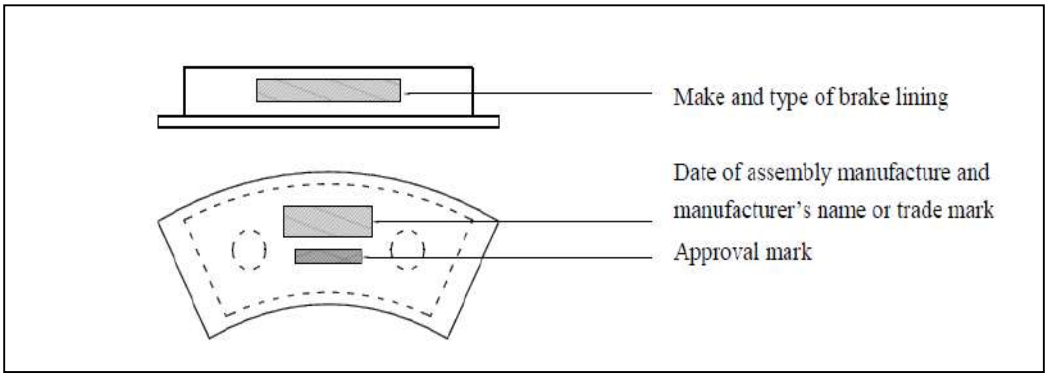


Figure 10 Example of pad assembly marking (*Source*: ECE Reg 90)

Figure 11 Brake pad CF9 without back plate marking

4.4 Optical Microscope

All of the brake pads studied are low or semi metallic brake pads, as indicated in the packaging or as informed by the seller. Since optical microscopic analyses for brake pads have inherent limitations of both resolution and identification, the microstructure study of the brake pads were further analysed in the Scanning Electron Microscopy section.

4.5 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

Details of SEM analysis for low price brake pads are shown in Figure 12. High concentration of filler can be found on both brake pads, CF1 and CF2. CF1 contains high graphite and resin binder, while CF2 dominated by graphite and vermiculite. The presence of ingredients are in different shapes and sizes. This fact is aligned with the function of filler, which reduce the overall cost of brake pads and improve manufacturability (Karla Barabaszova et al, 2008). From the EDX mapping result, it can be seen that the reinforcing fibre are widely scattered as a thin layer. EDX mapping of

CF1 (Figure 13) shows the presence of Cu elements in selected areas, which probably used as friction modifier. Nicholson (1995) stated that Copper is usually used as a powder to control heat. There were small amount of Ca element found in different areas of CF1 and CF2, which probably comes from Calcium Carbonate, Chalk or clay which also type of fillers.

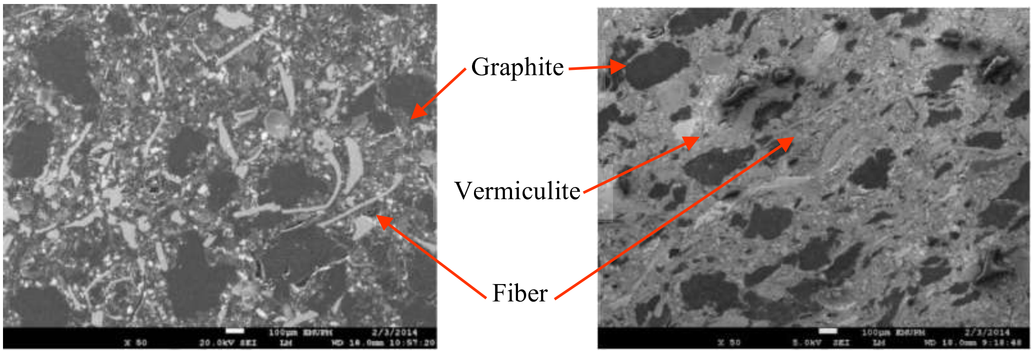


Figure 12 SEM microstructure for low price brake pads (a) CF1 and (b) CF2

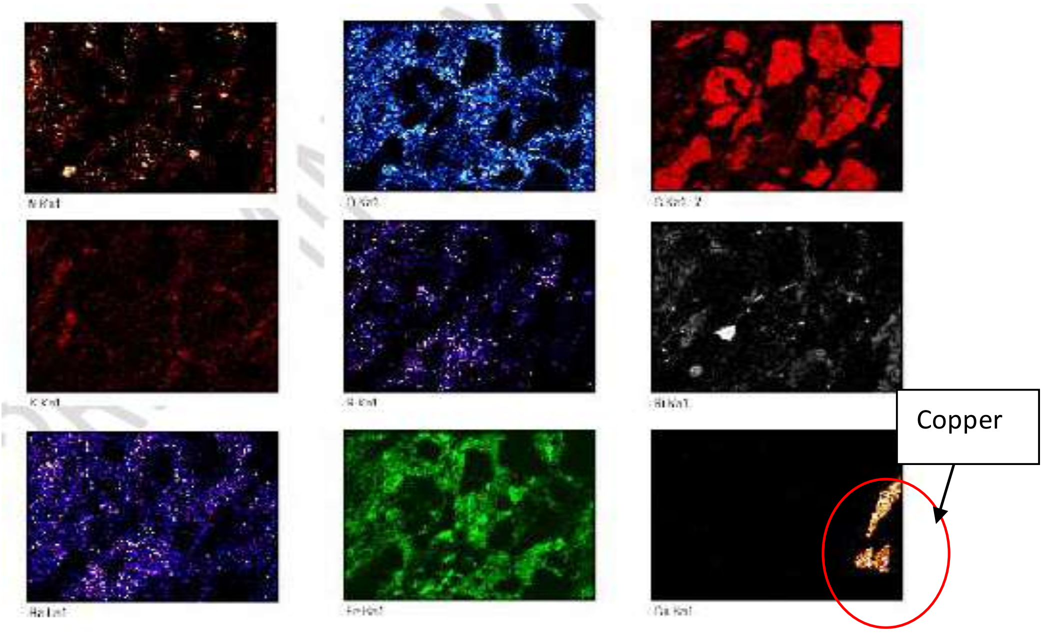


Figure 13 EDX mapping for CF1 brake pads

Figure 14 shows the SEM microstructure for the medium price brake pads. The presence of reinforced fibre is much clearer in this group. In CF3, the metal fibres are in the form of thread-like, and Ba and S elements are widely scattered at the surface; it probably corresponds to Barite ($BaSO_4$) which is a filler. It is the similar case for CF4, there are only several differences in the composition of fillers and frictional additives. The presence of Si and Al elements in CF4 indicates the probable presence of Aluminium Silicates as the lubricants.

Despite the fact that Fe elements in CF5 is lower than CF6, the presence of Fe in CF5 agglomerates in certain areas of brake surface. EDX mapping of CF5 and CF6 (Figure 15) identify particles which are clear and in bulk shapes as metal fibres. From overall brake pads, CF6 contains the highest percentage of reinforcing fibres, which is 31.9 wt%.

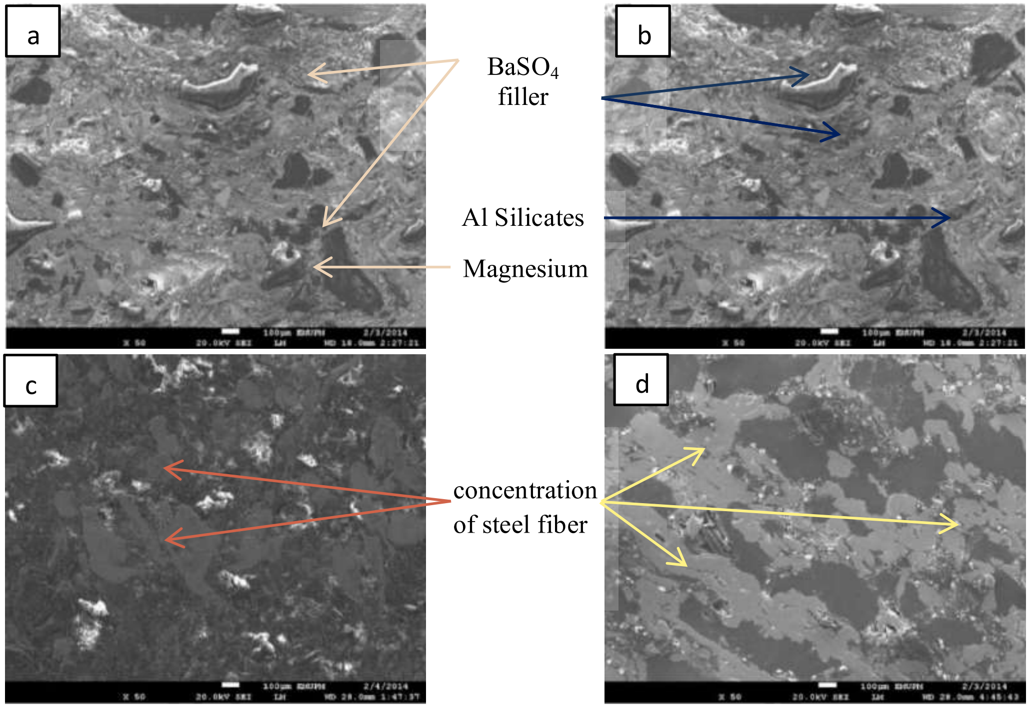


Figure 14 SEM microstructure for medium price brake pads (a) CF3; (b) CF4; (c) CF5 ; (d) CF6

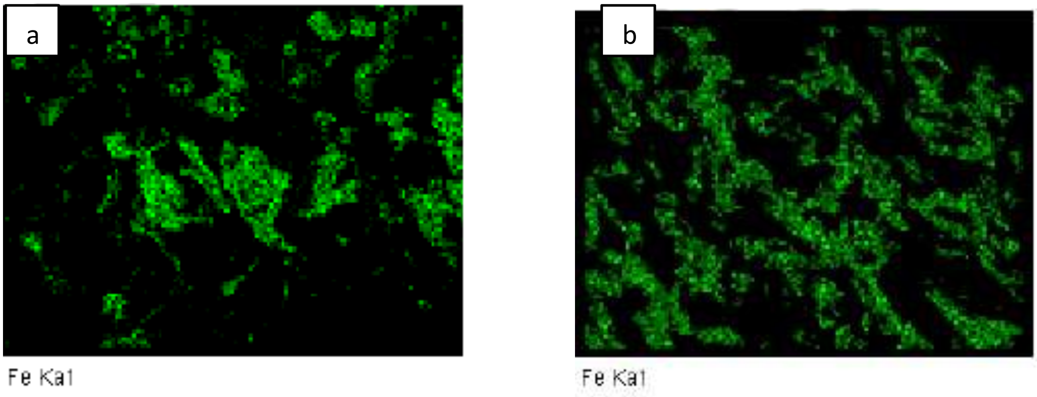


Figure 15 EDX mapping of (a) CF5 and (b) CF6

The SEM microstructures for high price of brake pads are shown in Figure 16. Fine particles of Zirconium were found in CF7, probably used as abrasives. Zirconia is popularly used in the friction materials as an abrasive because it has special function to enhance the coefficient of friction (μ), especially at high temperature values (Yuning Ma et al., 2008). Compared to other commercial brake pads, CF7 has less quantity of Iron elements. CF7 used ceramic abrasives such as Magnesia (MgO) and Alumina (Al_2O_3), in order to keep both dust and noise at a minimum. In CF8, there was reasonable presence of Alumina, which corresponds to the formulation of organic fibres (ceramic). In CF9 and CF10, high metal fibres content were present, and Magnesia with Alumina are found in CF10, which acts as abrasives and friction modifiers in those brake pads.

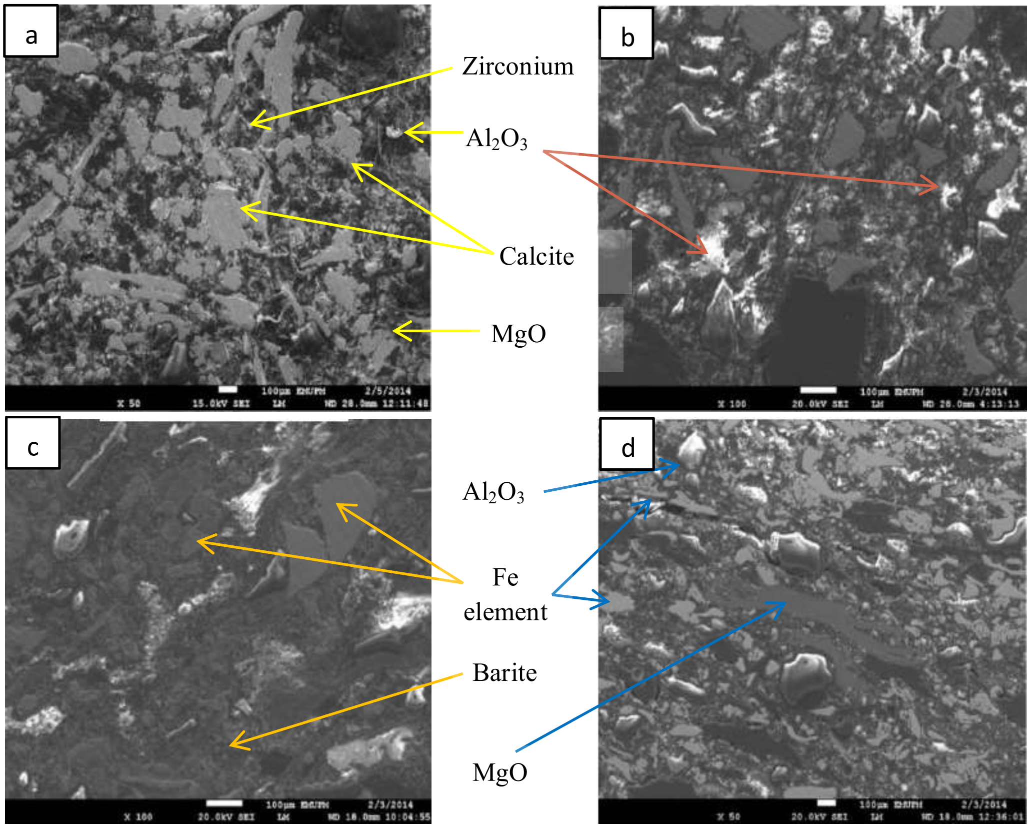


Figure 16 SEM microstructure for high price of brake pads (a) CF7; (b) CF8; (c) CF9; (d) CF10

Figure 17 shows the SEM microstructure for the expensive brake pads. The amount of metal fibres were quite high in these samples, especially in sample CF13 brake pads. Fe elements were found in bulk microstructure in sample CF11. In CF12, Calcite ($CaCO_3$) and Manganese Sulphide (MnS) are randomly distributed in the composite pads. Fine particles of Zinc where found in sample CF13. As stated by Hell M. et al. (2002), certain brake pads include the metals such as zinc distributed over the cross section of the friction lining, in order to form a sacrificial anode for rusting to occur.

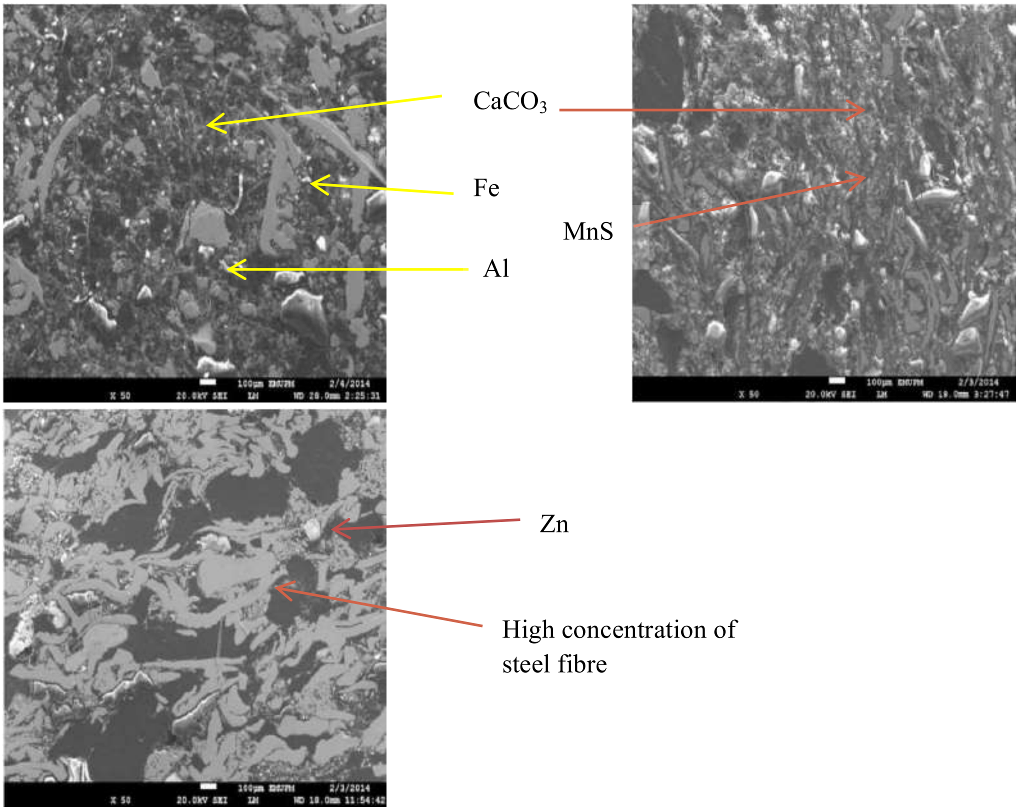


Figure 17 SEM microstructure for expensive brake pads (a) CF11; (b) CF12; (c) CF13

4.6 Fiber Composition in Brake Pads

From the EDX results, the percentages of reinforced fibre are comparable between the studied brake pads. There is an increasing trend on percentages of fibre as the price increased (Figure 18), except for sample CF6. Sample CF6 contains the highest amount of reinforced fibre (31.9 wt%), if compared to the other studied commercial brake pads. Metal fibre has been widely used to replace asbestos because of its resistance to breakdown in mixing, moderate reinforcement, good thermal and frictional stability and ready availability at a flexible cost.

As the purpose of the reinforcing fibers is used to reinforce and strengthen the matrix, the selected fibre's thermal properties clearly affect the overall composition. Sufficient attention need to be given during the fibre selection and how it interacts with other components during braking. Low steel fibres are known to be better in terms of heat dissipation due to their high thermal conductivity (S.B.Park et al, 2009). Through these known compositions of new brake pads, further study on the brake pads can be done in order to clarify whether the high percentage of fibres may improve the braking performance of those brake pads.

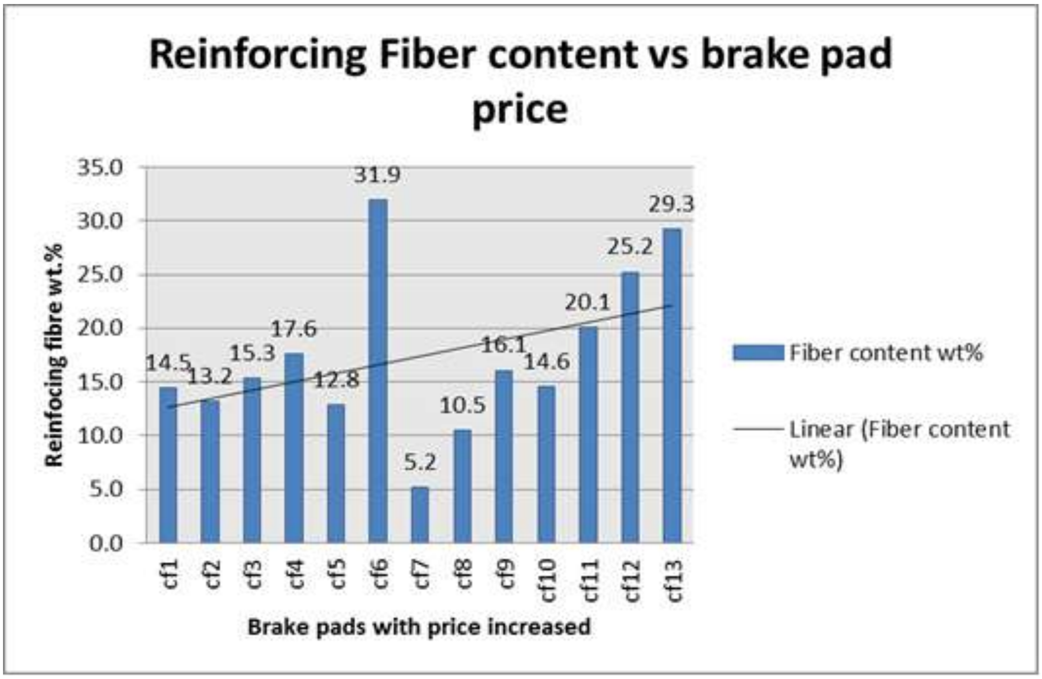


Figure 18 Comparable graph between reinforce fibre percentage and brake pad price

4.7 Difference between Composition of Friction Surface and Lateral Surface

The difference in composition of friction and lateral surface on one of the brake pads are shown in Figure 19. The amount of Iron (Fe) element in friction surface was lower compared to the percentage of Fe at lateral surface. The low amount of Fe on the surface may be due to the reason that metal fibres might cause excessive wear of the brake disc if they are present in large proportions on the friction surface (Jang, H. et al., 2001). Since the brake disc usually used grey cast iron, the low amount of Fe fibre in the friction surface can reduce noise when the two metals come into contact during braking. Those compositions were blended with frictional additives, binders and fillers, in order to provide the best friction pair with brake discs. In contrast, the high amount of Fe on the lateral surface is for the purpose of providing mechanical strength to the whole structure of the friction material.

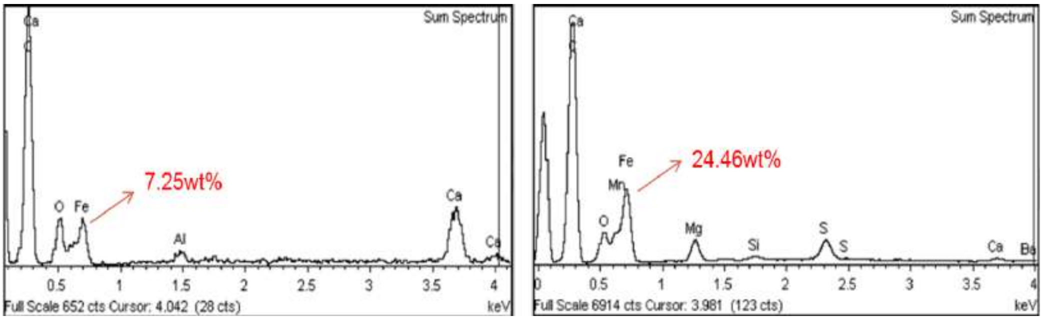


Figure 19 EDX analysis in brake pad sample (a) friction surface; (b) lateral surface

Based on overall EDX analysis of the brake pads, the Fe elements were found higher at the lateral section compare to friction surface of the brake pads.

5. Conclusion and Recommendations

The goal of the study in general is to reveal the relationships between microstructure and properties of materials, by reviewing the materials and constituents currently used in automotive brake friction material. Brake pads are composed of materials that give the right combination of friction, wear, heat distribution, vibrations and noise.

In the commercial brake pads market, complete compositional disclosure of brake friction material is rare because the information is treated as proprietary and manufacturers are not obliged in any way to disclose it to customers. There was no specific composition that can represent the majority of brake pads in existence. Each subcomponent of different brake friction materials will have their own varying ingredients and components; e.g. brake pad sample CF2 may contain graphite as the filler while brake pad sample CF3 and CF4 may use Barite instead. Therefore, brake friction materials have a myriad of possible compositional variations.

During the survey, consumers tend to buy the commercial brake pads based on the seller's recommendation, and they tend to choose the brake pads by price, rather than quality. However, the huge price variation from one brand to another may need to be studied in order to ensure that the customer are satisfied with the price and quality of the parts. Consumers should be adequately informed about the ingredients of the product they used for repair, so that they can choose, with full knowledge of choices offered among the competing products.

From the microscopic study, there is a trend indicating an increasing amount of reinforcing fibre as the price increased. The common elements found in the studied brake pads were Fe element. The main purpose of reinforcing fibres is to provide mechanical strength to the friction material. According to Kumar M., & Bijwe Jayashree (2010), metallic fibres are very important in improving the strength and conduct away the frictional heat generated at the interface of a tribo-couple during friction under severe conditions. The paper stated that the inclusion of metallic ingredients for 0-20% density improved thermal conductivity of the brake pads, where copper powder proved to be the most effective, and steel fibre as the least effective. Steel fibres are extensively adopted due to its resistance to breakdown in mixing, moderate reinforcement, good thermal and frictional stability and ready availability at a considerate cost. It is preferable than stainless steel because they are more readily processed. From the samples studied, metal fibres are still widely used as the candidate fibre for non-asbestos brake pads, and the CF6 contains the highest amount of fibre amongst all.

Based on this report, it is recommended for future study that the samples should be tested mechanically (compressibility, Young's modulus), physically (density, porosity) and tribologically (coefficient of friction, weight loss) in accordance with relevant international standards, in order to study in depth on the effect of quality towards the price of brake pads.

References

Alvarez, A. (2007). *Commercial Motor Vehicle Driver Safety Belt Usage*, Federal Motor Carrier Safety Administration.

Department for Transport. (2007). *Rule 148, Highway Code*, Department for Transport, United Kingdom.

Heishman, S. J. (1998). *Behavioral-cognitive effects of smoking, addicted to nicotine: a national research forum.* US DHHS, PHS, NIH, Bethesda, MD.

http://cosmone.com/auto/discover/all-about-brakes. Accessed on 27 May 2014.

http://www.ceramicindustry.com/articles/print/92468. Accessed on 26 September 2014

Idaho Transportation Department. (2008). *Idaho Commercial Driver's License Manual*. Idaho Transportation Department, Division of Motor Vehicles.

James, L. (1997). *Congressional Testimony on Aggressive Driving*. Honolulu: University of Hawaii.

Jang, H., Lee, J. S., & Fash, J. W. (2001). Compositional effects of the brake friction material on creep groan phenomena. *Wear 2001, 251*, 1477 – 1483.

Joint, M. (1995). *Road rage*. The Automobile Association Group Policy Road Safety Unit, London.

Kentucky Institute of Medicine. (2005). *Saving lives, saving money: the impact of a Kentucky primary seat belt law*. Kentucky Institute of Medicine.

King, Y., & Parker, D. (2008), Driving violations, aggression and perceived consensus. *Revue européenne de psychologie appliquée*, *58*: 43 – 49.

Kumar M., & Bijwe Jayashree. (2010). Role of different metallic fillers in non-asbestos organic (NAO) friction composites for controlling sensitivity of coefficient of friction to load and speed. Tribology International, *43*(2010). 965 - 974.

Leistikow, B. N., Martin, D. C., Jacobs, J., Rocke, D. M., & Noderer, K. (2000). Smoking as a risk factor for accident death: a meta-analysis of cohort studies, *Accident Analysis and Prevention*, *32,* 397–405.

Louis Pilato. (2010). Phenolic Resins: A Century of Progress. Springer.

Mason, J. M., Fitzpatrick, K., Seneca, D.L., & Davinroy, T. B. (1992). Identification of inappropriate driving behaviours, *Journal of Transpn.Engrg.*, ASCE *118*(2), 281 – 82.

Ministry of Transport NSW. (2005). *Safety management system (SMS) guidelines: for bus and coach operators in NSW*. Pursuant to section 9D (2) (c) of the Passenger Transport Act 1990.

MIROS. (2007). *Kod Amalan Keselamatan, Kesihatan dan Alam Sekitar untuk Sektor Pengangkutan*, MCP 1/2007.

Mohd Rasid Osman, Fuad A., Ilhamah O., Zarir H. Z., Noor Faradila P., Mohd Sukri A., & Muhammad Sahidi M. (2008). *Evaluation of the effectiveness of OPS Bersepadu with respect to selected SHE practices,* unpublished report.

National Transportation Safety Board. (1999). *Bus crashworthiness issues*. Highway Special Investigation Report: PB98-917006, NTSB/SIR-99/04, Washington, D.C.

Ontario Medical Association (OMA). (2008). *Cellular phone use and driving: A dangerous combination.* Ministry of Transportation, Toronto.

Parker, D., Lajunen, T., & Summala, H. (2002). Anger and aggression among drivers in three European countries, *Accident Analysis and Prevention*, *34*, 229 – 235.

Queensland Transport. (2003). *Fire extinguishers in buses: Public passenger vehicles inspection*. Vehicle Standards Instruction, Queensland Government.

Shinar, D. (1998). Aggressive driving: The contribution of the drivers and the situation. *Transport. Res.*, Part F 1: 137 – 160.

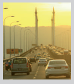
Taylor, M. C., Lynam, D. A., & Baruya, A. (2000). *The effects of drivers' speed on the frequency of road accidents*. TRL Report 421, prepared for the Road Safety Division, DETR.

U.S. Department of Transportation. (2008). *Safety belt usage by commercial motor vehicle drivers (SBUCMVD) 2007 survey*. Final Report, Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

UNCTAD. (2000). *Risk Management*. ASYCUDA, Automated System for Custom Data.

Verona, E., & Sullivan, E. A. (2008). Emotional catharsis and aggression revisited: Heart rate reduction following aggressive responding. *Emotion, 8*(3), 331 – 340.





Research Report

Comparative Study of Brake Pads in Malaysian Automotive Aftermarket

Designed by: MIROS

MIROS
MALAYSIAN INSTITUTE OF ROAD SAFETY RESEARCH
ASEAN ROAD SAFETY CENTRE

Malaysian Institute of Road Safety Research
Lot 125-135, Jalan TKS 1, Taman Kajang Sentral
43000 Kajang, Selangor Darul Ehsan
Tel: +603 8924 9200 **Fax:** +603 8733 2005
Website: www.miros.gov.my **E-mail:** dg@miros.gov.my

ISBN 978-967-2988-04-5
9 789672 988045