FRICTION MATERIAL (METAL REINFORCEMENT) ANALYSIS OF BRAKE PAD FOR LIGHT RAIL TRAIN SYSTEM

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A thesis submitted in fulfillment of the requirement for the award of the Degree of Master of Science in Railway Engineering

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OCTOBER, 2016
To my beloved parents, siblings and friends for their endless love, support and tolerance
ACKNOWLEDGEMENT

In the name of Allah, Most Gracious and Most Merciful, Praise is to Allah, the guidance that brought this study to a completion.

I would like to take this opportunity to thank Assoc. Professor Dr Hasan Zuhudi bin Abdullah as my supervisor for his support, encouragement, guidance and motivation through the years. My special thanks to my parents, En. Abdul Rahman bin Ibrahim and Pn Roziah Bte Abu Bakar as well as my siblings for the love and their continuous support and willing to share with me all my joy and pain in completing this study.

My heartfelt thanks go to my co supervisor, Dr Zakiah bt Kamdi in providing necessary guidance and help. So does the entire technician involved in this study for their help and advice throughout the project.

I also highly appreciate the cooperation, guidance and unconditional support from KKTSN committee members as well as my fellows, Sakinah, Aisyah, Nik and Natasya.

Last but not least, I would like to thanks those who have directly or indirectly contributed towards the accomplishment of this study.
ABSTRACT

Brake friction material is very important in braking system where they convert kinetic energy of moving vehicles to thermal energy by friction during braking process. The purpose of this research is to determine the optimal friction materials composition of brake pad for light rail train system. Currently all the component of the train system including brake pad is imported from overseas such as Germany. Hence, this research is use to find the new formulation of the mixture ratio that may replace or compete with the commercial available brake pad. Three different testing which are density and porosity test, shore hardness test and wear test were done in order to select which metal is the most suitable for railway application. Different composition were used, (Cu30% BaSO430%), (Cu25% BaSO435%), (Cu20% BaSO440%), (Steel30% BaSO430%), (Steel25% BaSO435%), (Steel20% BaSO440%), (Al30% BaSO430%), (Al25% BaSO435%), and (Al20% BaSO440%) this study to determine the optimal properties with lower wear rate. The selected material were mixed and compacted into desired mould with 5 tons of pressure. The compacted samples were sintered using two different temperatures which is 600°C and 800°C. Steel30% BaSO430% results in the optimal composition since the result shows the lowest porosity, highest SD reading of shore hardness and the lowest wear rate. The samples were analysed by using Scanning Electron Microscopy (SEM) with an Energy Dispersive Spectrometry (EDS) system to determine the morphology surface and overall composition of the samples. Comparing different sintering temperature, the sintered sample of 800°C shows lower wear rate than the sample sintered at 600°C. This is due to dense sample without crack showing by the samples sintered at 800°C than at 600°C.
ABSTRAK

Bahan geseran untuk brek adalah sangat penting dalam sistem brek di mana ianya menukar tenaga kinetik kenderan bergerak untuk tenaga haba melalui geseran semasa proses brek. Tujuan kajian ini adalah untuk menentukan optimum komposisi bagi bahan geseran pada pad brek untuk sistem kereta api aliran ringan. Pada masa ini semua komponen sistem kereta api termasuk pad brek diimport dari luar negara seperti Jerman. Oleh itu, kajian ini adalah untuk mencari formula baru dengan nisbah campuran yang boleh menggantikan atau menjadi pesaing pad brek yang sedia ada. Tiga ujian yang berbeza dilakukan iaitu ujian kepadatan dan ujian keliangan, ujian kekerasan dan ujian kehausan untuk memilih logam yang paling sesuai untuk digunakan pada kereta api.

Sembilan komposisi, (Cu30% BaSO430%), (Cu25% BaSO435%), (Cu20% BaSO440%), (Steel30% BaSO430%), (Steel25% BaSO435%), (Steel20% BaSO440%), (Al30% BaSO430%), (Al25% BaSO435%), dan (Al20% BaSO440%) digunakan dalam kajian ini untuk menentukan sifat-sifat optimum dengan kadar haus yang lebih rendah. Bahan yang dipilih adalah bercampur dan dipadatkan ke dalam acuan yang dikehendaki dengan 5 tan tekanan. Sampel dipadatkan disinter menggunakan dua suhu yang berbeza yang 600°C dan 800°C. Steel30% BaSO430% menghasilkan komposisi yang optimum kerana hasilnya menunjukkan keliangan yang paling rendah, bacaan SD tertinggi bagi ujian kekerasan dan kadar haus yang paling rendah. Sampel kemudiannya dianalisis dengan menggunakan SEM dengan sistem EDS untuk menentukan permukaan morfologi dan komposisi keseluruhan sampel. Bagi perbandingan suhu pembakaran yang berbeza, sampel yang disinter pada suhu 800°C menunjukkan kadar haus lebih rendah daripada sampel disinter pada 600°C. Ini adalah kerana sampel padat tanpa menunjukkan retak pada sampel yang disinter pada 800°C berbanding pada 600°C.
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LIST OF SYMBOLS AND ABBREVIATIONS

Cu - Copper
Al - Aluminium
°C - Degree Celcius
cm³ - Cubic centimeters
g - Gram
kg - Kilogram
mm - millimeter
rpm - Rotation per minute
µ - micron
% - percent
LRT - Light Rail Transit
SEM - Scanning Electron Microscopy
EDS - Energy Dispersive System
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CHAPTER 1

INTRODUCTION

1.1 Background of study

Braking system is a crucial part in a rolling stock which where it convert mechanical energy into heat energy through a friction to stop a vehicle (Yoong et al., 2010). Brake friction materials play an important role in braking system. They convert the kinetic energy of a moving car to thermal energy by friction during braking process. The ideal brake friction material should have constant coefficient of friction under various operating conditions such as applied loads, temperature, speeds, mode of braking and in dry or wet conditions so as to maintain the braking characteristics of a vehicle (Jang et al., 2004). Besides, it should also possess various desirable properties such as resistance to heat, water and oil, has low wear rate and high thermal stability, exhibits low noise, and does not damage the brake disc (Xin, Xu, & Qing, 2007). However, it is practically impossible to have all these desired properties. Therefore, some requirements have to be compromised in order to achieve some other requirements. In general, each formulation of friction material has its own unique frictional behaviours and wear-resistance characteristics.
Friction materials are generally consist of a number of different materials. Sometimes up to 20 or 25 different components are used. These components including:

1. Binder - which holds the other components together and forms a thermally stable matrix. Thermosetting phenolic resins are commonly used, often with the addition of rubber for improved damping properties (Chan & Stachowiak, 2004).

2. Structural materials - providing mechanical strength. Usually fibres of metal, carbon, glass, and/or Kevlar are used and more rarely different mineral and ceramic fibres. Before its prohibition in the mid 80's, asbestos was the most commonly used structural fibre (Maleque et al., 2012).

3. Fillers - mainly to reduce cost but also to improve manufacturability. Different minerals such as mica and vermiculite are often employed. Barium sulphate is another commonly used filler (Chan & Stachowiak, 2004).

4. Frictional additives - added to ensure stable frictional properties and to control the wear rates of both pad and disc. Solid lubricants such as graphite and various metal sulphides are used to stabilise the coefficient of friction, primarily at elevated temperatures. Abrasive particles, typically alumina and silica, increase both the coefficient of friction and the disc wear. The purpose of the latter is to offer a better defined rubbing surface by removing iron oxides and other undesired surface films from the disc (Selamat, 2006a).
1.2 Problem statement

Previously asbestos has been widely used as the main material in a brake pad; however it has been avoided due to its cancer-causing nature (Idris et al., 2015). The brake pad is a very important component in a railway where a regular replacement needed and it is imported from overseas where it might cause higher maintenance cost (Bouvard et al., 2011). Therefore a new asbestos free brake pads need to be developed and manufactured locally to avoid health problem and reducing the production cost and eventually will upgrade Malaysia railway industry level. Thus, the exact formula for the mixture ratio of the brake pad need to be studied to formulate and create a stronger or at same level of properties of the brake pad that had been use commercially by local rolling stock.

1.3 Objective

The purpose of this research is to study the wear behaviour of a brake pad for light rail train system. Currently all the component of the train system including brake pad is imported from overseas such as Germany. Hence, this research is conduct to find the new formulation of the mixture ratio that can generate a better and stronger brake pad for commercial used. The findings of this study will help in identifying which mixture ratio will produce the finest friction material reinforcement that will generate a good brake pad. In this study, a sample of specimen has been fabricated and gone through several testing such as wear test and porosity test. The outcome of this study is expected to be useful in Malaysia railway industry where it can be a starting point for Malaysia to develop our own train from scratches including all component such brake pad.
The objectives of this study are to:

a) Determine the new ratio of the fibre reinforcement used in fabricating the brake pad for light rail train (LRT) to enhance the friction material reinforcement.

b) Compare the porosity and density, hardness and wear behaviour of the fabricated specimen with the commercial used brake pad.

1.4 Scope of study

This study is focus on light rail train system where it has different load and maximum speed compare to heavy train system and it is focus on the range of study such:

i. Fabrication of brake pad with 9 different content of metal fibre used in the mixture which is (Cu30% BaSO₄30%), (Cu25% BaSO₄35%), (Cu20% BaSO₄40%), (Steel30% BaSO₄30%), (Steel25% BaSO₄35%), (Steel20% BaSO₄40%), (Al30% BaSO₄30%), (Al25% BaSO₄35%), and (Al20% BaSO₄40%) by using mould with diameter size 20mm and compacted with 5 tons pressure for every sample after mixing process.

ii. Sintering temperature for this study is at 800°C and 600°C.

iii. The characterisation of mechanical properties of the samples using shore hardness test.

iv. The characterisation of the physical properties of the sample by using density and porosity test.

v. Study the wear behaviour using weight loss test at 5 N pressures for 5 minutes using 200 RPM speed.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The growth of railway transportation has been increase significantly this day which require urgent attention in transportation industry. Since railway industry in such a massive demand, it should be manufactured locally. In Malaysia, they only manage to manufacture 80% of the train and some of the component was imported such as alarm system component, seat, wheel, heating, ventilation and air conditioning (HVAC) and brake pad. Brake pad is a component that been change regularly, hence, if it is manufacture locally, it can reduce the cost. This study is particularly studied to produce a local brake pad for railway application.

This study based on previous research in order to improve the outcome of previous researcher. The theoretical analysis of the brake pad from the operation up until the details of materials use in a brake pad particularly the one use for railway application will be discussed in this chapter.
2.2 Brake pad

Braking system is the most important parts in a vehicles where it convert the kinetic energy of a vehicles to thermal energy through friction to stop or slower the moving vehicles (Talati & Jalalifar, 2009). There are basically made up by several parts of equipment and brake pads are one of those that play a very important role where it contact and apply pressure and friction to the brake disc. The pressure and the friction that applied to the brake disc will eventually slow and stop the wheels. Thus, the vehicles will stop running when the wheel stop turning.

Though the operation of brake pad looks simple, but the break pad itself play a huge role where it undergo a great stress every time the vehicles is slow down or stop because it is depends on the speed of the wheels rotate and the amount of weight that the vehicles carry. In (Halderman & Mitchell, 2010) book’s explain that there basically two types of brake system which is disc brake and drum brake and both of the system applying the same rule where it slow down or stop the vehicles by engaging hydraulic pistons to press brake pads or brake shoes against the brake disk or brake drums that rotate along the wheels.

Brake pad and brake shoes is actually a different component which have the same function. The main difference between those two is their position in the vehicle. Brake shoes are specially designed to fit in drum brakes, while brake pad are placed on top of brake disk, and act to apply pressure to the discs when applying the brakes (Halderman & Mitchell, 2010). The brake shoes are attached to consumable surfaces in brake systems called lining which use to support the brake shoes. Normally, the shoes are made of two pieces of sheet steel welded together in a T-shaped cross section (Babel, 1933). Brake shoes are more expensive to produce and it is not good for high temperature because it is not durable enough and obviously it is not suitable for railway system because a train running with a huge system and it require equipment that can sustain in high temperature. However, the interesting about brake shoes are it is a solid part that can be relined and reused many time as long as the web (The crescent-shaped
piece which contains holes and slots as shown in Figure 2.1) and lining table are not damage.

Figure 2.1: The crescent-shaped piece that attach with lining tables is called web (Jeffrey & Halderman, 2006)

Basically, the design of a brake pad is somewhat much simpler than brake shoes where it consists of a block of friction material that attached to a stamped steel backing plate. Some of the backing plate is installed with a bent tabs that use to prevent noise. Figure 2.2 show the position of the bent tabs that will hold the pad tightly in place so that it can prevent any brake noise. Usually, the edge of the lining material on a brake pad is straight cut to reduce the vibration and noise. As for brake shoes, the lining material can be fastened to the backing plate in several ways to reduce the vibration and noise (Jeffrey & Halderman, 2006).
Brake pads are widely used in large vehicles including train systems. In the early 1970’s, disk brake is getting on demand and been broadly produce by automobile manufacturers because it had better braking performance than drum brakes (Idris et al., 2013). Brake pads operate by converting the kinetic energy of the vehicles to thermal energy by friction. It happens when the temperature of the brake pad is increase by the contact with break disc to provide stopping power, thus the break pad starting to transfer small amounts of friction materials to the disc. In general, to ensure the safety of the vehicles, the friction materials are required to provide a firm friction coefficient and a best wear rate at numerous operating speeds, pressures, temperatures and environmental condition in order to reduce the extensive wear, vibration and noise during braking. History shown from the past two decades, asbestos had been a common material used in producing the brake pads due to its durability. However, since 1980s, research show that asbestos is found out as harmful content and was banned from being used as the ingredient in producing brake pads as it can cause severe disease (Liew & Nirmal, 2013).
The asbestos exposure was actually can cause scar tissue to form in the lungs and it’s called asbestosis which it gradually will increase the shortness of breath and make a permanent scarring to the lungs (Frank & Joshi, 2014). Besides, asbestos exposure also can lead to lung cancer which normally takes about 15 to 30 years after the exposure. The Occupational Safety and Health Administration (OSHA) have recognised three levels of asbestos exposure in their standard as it is very important to ensure the safety of human being. Any vehicles services company must ensure that the asbestos exposure must less than 0.2 fibres per cubic centimetre (cc) as resolute by air sample and if the level of exposure is exceed the limit, action will be taken by the OSHA organization (Halderman, 2010).

Nowadays, the development of asbestos – free brake pads is increasing through different researcher. There are different kinds of fibres used to replace asbestos such metallic, glass, ceramic and carbon fibres (Solomon, Berhan, & Pad, 2007). Friction materials for brake pad are normally contain metallic ingredient which to improve wear resistance, thermal diffusivity and strength. Most of the vehicles usually using metallic brake pad and made of iron, copper, steel and graphite. Different characteristic of the different type of metallic ingredients can affect the friction and wear of the friction materials (Jang et al., 2004). Metallic brake pads are commonly used because it is cost effective and durable despite that it is also provide great performance and best at shifting heat that generate by friction with the rotor or brake disk.

2.2.1 Application of brake pad for Light Rail Transit (LRT)

Brake pad is the crucial part in vehicles where it faces the greatest wears when every time the pads are pressed against the rotating disc. Thus, it needs a proper maintenance to maintain the effectiveness of the vehicles. The friction material of a break pad plays a very important role where much consideration must be considered such heat resistance and durability. Table 2.1 shows the different types of brake pad materials on various applications where every each of application uses different types of brake pad. Every
each of brake pads has different composition based on their application. Heavy vehicles such as train especially the one with high speed need to choose a proper material for break pad because such vehicles faces with great friction wear. Figure 2.3 (a) and 2.3 (b) show the brake pad that use in ampang line Light Rail Transit (LRT) where it is imported from Becorit GmbH Company that base in Germany.

Figure 2.3: (a) Front view of brake pad that use in ampang line LRT (b) Back view of brake pad that use in ampang line LRT
Table 2.1: Different types of brake pad materials on various applications

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Brake pad material</th>
<th>Advantages</th>
<th>Ref.</th>
</tr>
</thead>
</table>
| Train/Freight   | • Semi-metallic and metallic (iron, copper, steel and graphite all mixed together) | • High stopping power but expensive  
• High operating temperature  
• Sustain high temperature without fade | (Gultekin et al., 2010a) |
| Motorcycle      | • Manufactured using the same materials used in automotive brake pads (ceramic and organic are the one that commonly used) | • Organic brake pads does not wear as fast in light weight vehicles | (Kumar & Bijwe, 2011) |
| Commercial car  | • Organic  
• Kevlar | • Does not pollute the environment as they are easy to dispose  
• Softer compared to other material means quieter | (Kabir & Ferdous, 2012) |
| Racing car      | • Carbon fiber  
• Ceramic | • Great braking performance  
• High operating temperature  
• Lightweight  
• Sustain high temperature without fade | (Renz, Seifert, & Krenkel, 2012) |
| Trucks          | • Ceramic and metallic (iron, copper, steel and graphite all mixed together) | • High stopping power but expensive  
• High operating temperature | (Renz et al., 2012) |

2.2.2 Type of brake pad for railway application

Brake pad is basically the same even for other application except they have different sizes of brake pad based on the suitability of the application. Brake pad that is use in railway industry is almost the same with the one that regularly use in car. Brake pad for railway is slightly larger than car break pad because it needs a better braking system especially with the high speed train that been use widely nowadays, the needs for a better braking system is vital. The selection of brake disc and pad friction pairing has a significant impact on brake safety and life cycle cost. In choosing a brake pad, especially for railway application, the specific thermal simulation and dynamometer test to ensure
proper selection of friction pairing is very important so that it can deliver a reliable and safe braking.

In producing a brake pad there are several important thing that need to consider in the process such as (Schienenfahrzeuge, 2013):

i. Organic brake pads for even wear of friction disc
ii. Silent sinter brake pad for braking without squealing
iii. Flexible sinter brake pad with top braking performance
iv. Temperature resistance with constant friction behaviour
v. Long disc and pad life due to even temperature distribution on brake disc.

2.3 Composition of brake friction materials

Friction materials should keep high and constant friction coefficient, low wear at wide ranges of pressure, speed, temperature and other aspects. In order to encounter those needs, the friction materials typically consist of numerous ingredients such as reinforcing fibres, binders, fillers and friction modifiers (Fei et al., 2015). The composition of the friction material plays a major role in satisfying the target properties of producing brake pads. Brake manufacturers have to meet a number of comprehensive tribological and economic necessities demanded by their customers, predominantly, acceptable friction level, friction stability, wear resistance irrespective of brake conditions and cost reduction (Hentati et al., 2014). Friction and wear characteristic of friction material play an important role in deciding which new formulation developed are suitable for the brake system. The friction and wear is difficult to predict, depends on the various parameters such as microstructure, metallic counter face, rotating speed, pressure and contact surface temperature (Nagesh et al., 2014).
2.3.1 Fibre

Fibres play a critical role in a wet engagement process that absorb stresses and retain the integrity of the composite at elevated temperatures (Fei et al., 2015). Reinforcing fibre plays an essential role in improving the matrix, and avoiding mechanical destruction such as crack and fracture, to the friction material subjected to impact and shearing force. Additionally, it has also an important influence on the friction and wear properties of the friction material. Presently, the commonly reinforcing fibres used for the friction material contain mainly inorganic fibre and organic fibre as shown in Table 2.2, such as ceramic fibre, metal fibre, glass fibre, mineral fibre and carbon fibre. Among these fibres, the most frequent used metal fibre is steel fibre as shown in Figure 2.4. The steel fibre is used widely to the semi-metallic and organic friction material due to its outstanding properties in low cost, high strength and toughness. Alternatively, the steel fibre can provide good friction stability and wear resistance over wide ranges of temperatures. However, steel fibre is easy to be oxidation corrosion, and induce excessive the counter disc wear and the brake squeal and vibration if they are formulated in large proportions (Wang & Liu, 2014).

Figure 2.4: Chopped steel wool (steel fibre) that used in medium sized-vehicles brake pad (Tradekorea, 2008)
<table>
<thead>
<tr>
<th>No</th>
<th>Fibre</th>
<th>Advantages</th>
<th>Limitation</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aramid</td>
<td>High strength and toughness, High wear resistance, High temperature stability</td>
<td>Processing characteristics</td>
<td>(Singh, 2012)</td>
</tr>
<tr>
<td></td>
<td>(Kevlar)</td>
<td></td>
<td>- Non-melting and non-softening</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Dimensionally stability</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Life exceeding common binders</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good thermal and electrical insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Steel</td>
<td>High strength, High temperature performance</td>
<td>Processing characteristics, Abrasive, Low coefficient of friction, Poor wear at low temperatures, High density</td>
<td>(Kang, Lee, Kim, &amp; Kim, 2011)</td>
</tr>
<tr>
<td>3</td>
<td>Glass</td>
<td>High strength</td>
<td>Processing characteristics, Abrasive, Softens at high temperature causing fade, Brittle, High wear</td>
<td>(Holand &amp; Beall, 2012)</td>
</tr>
<tr>
<td>4</td>
<td>Cellulosics</td>
<td>Non-melting</td>
<td>Processing characteristics, Poor temperature resistance</td>
<td>(Johnston, 1980)</td>
</tr>
<tr>
<td>5</td>
<td>Carbon</td>
<td>High strength, Thermal stability</td>
<td>Processing characteristics, Brittle</td>
<td>(Dhakal et al, 2013)</td>
</tr>
</tbody>
</table>
Fibre in friction materials used to be made primarily using asbestos because of its heat absorbing properties and quiet operation. Asbestos is a mineral composed of a mixture of silicates, mainly magnesium and iron silicates. The property of asbestos that makes it attractive for use in friction material industry is its tough nature, which combines strength and flexibility with resistance to heat and chemical. However, friction materials (fibre) composition changed intensely when asbestos as the main composition is found to be carcinogenic. Recently, the use of non-asbestos friction materials (fibre) is increasing and many researchers come out with different formulation using organic and inorganic non-asbestos friction material. Table 2.3 show the case study of previous research on friction material (fibre) used in fabricating a brake pad. The brief explanation on material used including the testing method and the results is illustrated in the table. Based on previous study, iron and aluminium based material is the most used material in brake friction material studies because of their strength and thermal conductivity properties.
Table 2.3: Literature review on the friction material (fibre) used

<table>
<thead>
<tr>
<th>Reference (Researcher, year)</th>
<th>Friction material (Fibre)</th>
<th>Purpose of finding /application</th>
<th>Testing and characterisation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Maleque et al., 2012)</td>
<td>Organic fibre</td>
<td>To develop new natural fibre reinforced aluminium composite for automotive brake pad application.</td>
<td>Density, porosity, microstructural analysis, hardness, SEM</td>
<td>Coconut fibre have better properties in terms of higher density, lower porosity and higher compressive strength</td>
</tr>
<tr>
<td>(Liew &amp; Nirmal, 2013)</td>
<td>Asbestos fibre, Steel fibre</td>
<td>To study the tribological properties difference of potentially new designed non-commercial brake pad materials with and without asbestos under various speed and nominal contact pressure.</td>
<td>Pin-on-disc tribotest-rig under dry contact condition</td>
<td>Non-asbestos maintained stable frictional performance and have greater wear resistance</td>
</tr>
<tr>
<td>(Singh, Patnaik, &amp; Satapathy, 2013)</td>
<td>Nanoclay, Multiwalled carbon nanotubes, lapinus, kevlar</td>
<td>To fabricate graphite lubricated phenolic-based friction composites filled with nanoclay and Multiwalled carbon nanotubes (MWCNT) and reinforced with lapinus and Kevlar fibres to evaluate their physical, chemical, mechanical and tribological properties, respectively.</td>
<td>Friction and wear test, SEM</td>
<td>Higher nanoclay:MWCNT ratio showed lowest fading and excellent recovery performance</td>
</tr>
<tr>
<td>(Maleque, Dyuti, &amp; n.d.)</td>
<td>Cast iron, Al-alloy, Ti-alloy</td>
<td>To develop the material selection method and select the optimum material for the application of brake disc system emphasizing on the substitution of this cast iron by any other lightweight material</td>
<td>Compressive strength, friction and wear test, thermal conductivity and specific gravity</td>
<td>The analysis led to aluminium metal matrix composite as the most appropriate material for brake disc system</td>
</tr>
<tr>
<td>(Asif, Chandra, &amp; Misra, 2011)</td>
<td>Iron</td>
<td>To prepare Iron based friction material by using powder metallurgy (PM) processing utilizing hot powder preform forging</td>
<td>Optical metallography, hardness test, density and pin-on disc test</td>
<td>The results indicate that the coefficient of friction is more stable and wear is lower with respect to temperature rise</td>
</tr>
</tbody>
</table>
2.3.2 Filler

Filler are normally a low cost mineral such as clay, calcium carbonate and barites that are function to extend the brake lining other than to occupy space and minimize cost (Selamat, 2006a). ASTM dictionary of engineering science and technology has define filler as an inorganic material that used as an extender and it is added to modify its strength, permanence, working properties and other qualities (ASTM, 2005). In friction materials, fillers can be used either to increase or to decrease the density of a product. This is because the density of filler can reach as high as 10 g/cm³ or as low as 0.03 g/cm³. Fillers may decrease the thermal conductivity of friction materials. The finest insulation properties of composites are obtained with hollow spherical particles as filler.

Filler is normally classified by particle size since it is affect the performance and in selecting the fillers it require certain levels of conductivity (thermal or electric) and chemical interaction. In one publication, 33 materials were divided into particulates, fibers, and colorants. These distinctions are not helpful for a material designer. For a classification to be useful in filler applications, it must include the most important properties of fillers which affect the resultant material such as (Wypych, 2000):

i. Particle size and distribution
ii. Aspect ratio
iii. Chemical composition of surface
iv. Mechanical properties of filler particles
v. Electric and thermal conductivity
vi. Quantitative description of interactions
vii. Composition of admixtures
viii. Optical properties
2.3.3 Binder

The binder basically a material that hold the brake lining together (Selamat, 2006b). Basically, among all the ingredients used in friction materials, binder plays a major role in determining the performance of friction materials. Although it is not a major component by volume or cost, binder is the main part of friction materials. It is used to bind the rest of ingredients in friction materials and maintain the structural integrity of the composites under mechanical and thermal stresses (Cai et al., 2015). The binder resin strongly affects the important aspects among the various ingredients used in the friction material. Those aspect are includes the fade resistance, pedal feeling, wear resistance, and noise propensity. This is because the physical and chemical properties of the resin affect the wear process and friction characteristics of the friction material. Straight phenolic resin has long been used for commercial brake friction materials and various modified resins are available to improve compressibility, thermal stability, damping capacity, and mechanical strength (Hong et al., 2009).

2.3.4 Friction modifier

Friction modifier is also known as abrasive where it is use to removes the pyrolyzed friction film at the friction interface and controls friction level in the friction materials formulation. Abrasive is a very sensitive ingredient where it may cause brake noise, rotor wear and judder if the composition is not right. There are more than two different abrasives need to be tried in a formulation to terminate negativities of one another in order to balance the variation. Lubes are used to control friction which normally solid lubes form a friction film over the rotor surface and controls noise propensity and rotor wear. Normally Zircon has strong influence on the static friction and hence is optimized with graphite, antimony trisulphide with low ratios say 1–2 % of zircon for a ratio of 10–11 % graphite offset by the usage of $\text{Sb}_2\text{S}_3$ a third of lube used normally for optimization (Sundarkrishnaa, 2013).
2.3.5 Lubricants

Lubricants are added to assist in part removal from the moulds. The example of material used in lubricant is copper sulphide and graphite. In lubricated systems the starting friction is frequently higher than the kinetic friction. When the surfaces slide, lubricant is dragged into the contact region and separates the surfaces. Hence, this will initially lower the coefficient of friction. However, at a higher sliding speed there is a viscous drag which again causes to an increase of coefficient of friction as shown in Figure 2.5 (Sundarkrishnaa, 2013). This McKee-Petroff curve as shown in Figure 2.5 is typical for a shaft rotated in a sleeve bearing. The abscissa is in units of ZN'/P where Z is the viscosity of the lubricant, N' is the shaft rotating speed, and P is the load transferred radially from the shaft to the bearing.

![Graph showing McKee and Petroff curves](image)

Figure 2.5: Coefficient of friction pattern for a typical lubricated contact. Z is lubricant viscosity, N' shaft speed, and P the unit load transferred radially by the shaft to the bearing (Sundarkrishnaa, 2013)
2.4 Fabrication of brake pad

2.4.1 Powder metallurgy

Powder metallurgy is basically a process in manufacturing science to producing solid parts of preferred geometry and material from powders. The ultimate consideration need in powder metallurgy is the powder used for the manufacturing process. The process of powder metallurgy is include the process of mixing, compaction and sintering as shown in the flowchart of the basic powder metallurgy process in Figure 2.6.

1) Powder production
   - In this stage, the raw material will be process into powder form in order to proceed to the blending or mixing process.

2) Mixing of powder
   - In this very stage it often involve the additions alloy in elemental powder form or the combination of a pressing lubricant.

3) Process of compaction the mixed powder
   - The so called merging process is include the process of pressing in a rigid toolset, comprising a die, punches and mandrels or core rods. Besides, there are other process can be done based on the application.

4) Sintering the compact mixture
   - The sintering process is done to enhance integrity and the strength of the materials. This process is involves by heating the material in a temperature that is below the melting point of the major constituent. At sintering temperature, a minor constituent can form a liquid phase in certain cases.
Figure 2.6: A flowchart of the basic powder metallurgy process for structural press and sintered components
2.5 Characteristic for brake friction materials

All types of brake systems friction materials are having different complex mixtures of filler, fibers and other components in a polymeric matrix in order to create the material designs that meet specific applications. The materials design must meet the specified friction coefficient and wear properties for the given application and also consider a number of other requirements such as any possibilities of undue thermal damage or wear in the opposing surface or induce brake squeal. In producing good friction materials, some of the requirements are contradictory in nature where several compromises may be necessary. Thus, after the design stage, it is supposed to undergo development work and becomes tested and, modified until it is satisfactory in all aspects (Sundarkrishnaa, 2013).

2.5.1 Friction coefficient

Friction coefficient is the amount of friction between two objects or surfaces and it is determined by dividing tensile force by weight force. The tensile force the pulling force required to slide one of the surfaces across the other while the weight force is the force that pushing down on the object being pulled. The friction coefficient can be calculated by following Equation:

\[ \frac{F_t}{G} = \mu \]  

(Eq 2.1)

Where:

- \( F_t \) = tensile force in pounds
- \( G \) = weight force in pounds
- \( \mu \) = friction coefficient
The friction coefficient Equation can also express by:

\[
\frac{\text{Tensile force}}{\text{Weight force}} = \text{Coefficient of friction}
\]  
(Eq 2.2)

The equation above can be used to show the effect different variables have on the coefficient of friction. There are three factors that affect the friction coefficient of vehicle brakes at any given weight force (Jeffrey & Halderman, 2006):

i. Surface finish
ii. Friction material
iii. Heat

### 2.5.2 Wear rate

In rail systems with such a little wear, failure is exhibited by the appearance of closely spaced micro-cracks. Micro-cracks may continue to grow into larger cracks by one of several crack propagation mechanisms. Examples include the shear mode driven by accumulation of plastic flow due to ratcheting, and the crack opening mode due to crack pressurization by fluids (Eadie et al., 2008). The wear rate of a friction material is depends on several element such as temperature, speed and load. Besides, it is directly proportional to applied normal load and speed.

The wear of the friction material will increase exponentially at high brake temperature because of thermally induced degradation of organics resin binders and other substances. When the operating temperature increase the wear rate will also increase. There is a common relationship between friction and wear modification in the formula that decreased wear tends to decrease friction. Wear might reduce by using solid lubricants but it also reduces the friction. Wear is basically a slow process and is based on service life and not on any measurements of varying operating conditions and environment. Service life is not something that easy to determine, because in a brake usage, different routes result in different operating temperatures (Sundarkrishnaa, 2013). In particular, the wear process of brake friction materials at high temperatures has
attracted much attention since the exact understanding of the wear mechanism on a molecular scale can provide significant improvement in wear resistance (Hong et al., 2009).

### 2.5.3 Noise and judder

Normally, braking noise occur due to high friction coefficient and it is related to the design of materials besides the contacting conditions. The braking noise can be eliminate by increasing the material toughness. When the friction materials toughness is increase, higher deformation strength will be achieve thus it will eventually eliminate the noise. The toughness of friction materials is very important where it governs noise, braking performance and wear.

Noise in a friction material brake pad is very complicated where it has different types of noises like Groan, squeal, Gu, Go, as per numerous standards of classification. All Noises in a brake either drum brake or disc brake has a common rule of varying frequency due to temperature, pressure and sensitivity of certain raw materials in the system. Noise in friction material can be easily diminish through matrix alteration by eliminate the air gap between the contacting surfaces during braking. Either way it will eventually achieve higher deformation strength and higher toughness to get better resiliency in braking which eliminates noise (Sundarkrishnaa, 2013).
REFERENCES


Schienenfahrzeuge. (2013). Brake Discs and Pads. Retrieved from w w w . knorr-bremse . c om


