Faculty of Mechanical Engineering

MATERIAL SELECTION FOR CAR DISC BRAKE PAD USING MCDM METHOD

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Bachelor of Mechanical Engineering
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A thesis submitted
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DECLARATION

I declare that this project report entitled "Material Selection for Car Brake Pad Using MCDM Method" is the result of my own work except as cited in references.

Signature: …………………………….

Name : …………………………….....

Date : ……………………………

DEDICATION

To my beloved mother and father, i am sincerely thank you for supporting me to complete this final year project

APPROVAL

I hereby declare that I have read this project report and in my opinion this project is sufficient in terms of scope and quality for the award of Bachelor of Mechanical Engineering (with Honours)

Signature : ……………………………………………...

Supervisor Name : ……………………………………………...

Date : ……………………………………………...

ABSTRACT

The function of the automotive braking system is to slow down the speed of the vehicle. Normally the braking system consists of brake discs and paired with various composite brake pads. The aim of this research is to use material selection method to select optimum material for replacing asbestos fibre in the application of automotive brake pad. The methods used for selection of materials is VIKOR method and compare against standard brake pad properties. The mechanical properties of brake pad such as tensile strength, wear, thermal conductivity, the coefficient of friction and hardness are the criteria in material selection. The alternative materials were evaluated among natural fibre reinforcement composites such as palm kernel fibre, date palm fibre, sisal fibre and bamboo fibre. The VIKOR method result shows that date palm fibre composite is the most appropriate material for replacing asbestos fibre in brake pad.

ABSTRAK

Fungsi sistem brek automotif adalah untuk memperlahankan kelajuan kenderaan. Biasanya sistem brek terdiri daripada cakera brek dan dipasangkan dengan pelbagai pad brek komposit. Tujuan kertas ini adalah menggunakan kaedah pemilihan bahan untuk memilih bahan yang optimum untuk menggantikan serat asbes dalam aplikasi pad brek automotif. Kaedah yang digunakan untuk pemilihan bahan adalah kaedah VIKOR dan bandingkan dengan ciri pad brek standard. Sifat mekanikal pad brek seperti kekuatan tegangan, pakai, kekonduksian terma, pekali geseran dan kekerasan adalah kriteria pemilihan bahan. Bahan alternatif telah dinilai di antara komposit tetulang gentian semula jadi seperti fiber serat sawit, serat kurma, serat sisal dan serat buluh. Keputusan kaedah VIKOR menunjukkan bahawa komposit serat sawit tarikh adalah bahan yang paling sesuai untuk menggantikan serat asbestos di pad brek.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ASME	American Society of Mechanical Engineers
COF	Coefficient of Friction
CO_2	Carbon Dioxide
DSC	Differential Scanning Calorimetry
ELECTREE	Elimination and Choice Expressing Reality
ENTROPY-PROMETHEE	Entropy Fuzzy Preference Ranking Method for Enrichment Evaluation
FRP	Fibre Reinforced Polymer
FRPC	Fibre Reinforced Polymer Composite
FUZZY AHP	Analytic Hierarchy Process Based On Fuzzy Scales
HRR	Hardness Rockwell R
MADM	Multi-Attribute Decision Making
MCDM	Multi-Criteria Decision Making
MODM	Multi-Objective Decision Making
NIS’	Nigerian Industrial Standard
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
PROMETHEE II	Preference Ranking Organisation Method for Enrichment
PMC	Polymer Matrix Composite
SAE	Society of Automotive Engineers
SI	International System
TGA	Thermal Gravimetric Analysis
TOPSIS	To Ideal Solution
VIKOR	VIsekriterijumsko KOmpromisno Rangiranje
WDM	Weighted Decision Matrix

LIST OF SYMBOL

A_i	-	Alternatives
A'	-	Best ranked
A''	-	Second best ranked
C_j	-	Criterias
DQ	-	Decision of Majority
F_f	-	Force of friction
F_n	-	Normal force
f_{ij}	-	Normalization matrix
f_j^*	-	Positive Ideal Solution
f_j^-	-	Negative Ideal Solution
HV	-	Hardness value
L_{pi}	-	Metric equation
m	-	Number of alternatives
n	-	Number of criterias
v	-	Weight of strategy
Q_i	-	VIKOR values
S_i	-	Distance rate of alternative to positive ideal solution
S^-	-	Maximum distance rate of alternative to positive ideal solution
S^*	-	Minimum distance rate of alternative to positive ideal solution
R_i	-	Distance rate of alternative to negative ideal solution
R^-	-	Maximum distance rate of alternative to negative ideal solution
R^*	-	Minimum distance rate of alternative to negative ideal solution
μ	-	Coefficient of friction
w_j	-	Weight of attributes
x_{ij}	-	Original value of ith alternatives and jth criterias
℃	-	Degree Celsius

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

In this era, most of the people have their own transportations such as automobiles. Most of the car manufacturers spend money and efforts to improve and further research on their products in terms of performance, safety and comfort. When a person wants to purchase an automobile, the first concern is the car's safety. Therefore, the braking system is one of the most crucial systems because it can protect and ensure the safety of passengers. Safety of cars has the leading role in automotive industry than the performance of the cars, (Anderson, 1980).

The brake is a device that stops motion. Energy conversion occurs when reducing the speed of the car. A friction brake is to stop a moving vehicle by converting kinetic energy into heat energy through fiction. Therefore, a braking system must also good in coefficient of friction. However, there are two types of brakes such as drum brake or disc brake. The drum brake is a brake that use brake shoes compress against the inner surface of a rotating drum to cause friction. Meanwhile, disc brake stops the motion of car with the friction produce by using a pair of brake pads against a rotating disc.

The brake pad is a part of the disc brakes. Brake pad converts the kinetic energy of car to heat energy by friction. There are many types of brake pad such as metallic pad, asbestos pad, ceramic pad and semi-metallic pad. Brake pad made up of the binder, filler, reinforced fibre and frictional additives (Eriksson et al., 2001). The criteria of brake pads are high coefficient of friction, high thermal conductivity, low wear rate, optimum hardness and good mechanical properties (Eriksson et al., 2002; Nagesh et al., 2014; Pohane et al., 2016).

Reinforcing fibre in brake pad is to provide mechanical strength to the friction material. When mechanical stress and thermal stress occur, the binder will hold the components of brake pad firmly preventing from falling apart. The filler is used to reduce cost and improve the manufacturability of brake pad. Frictional additives are lubricant which added to brake friction material used to ensure the frictional properties and control wear rate.

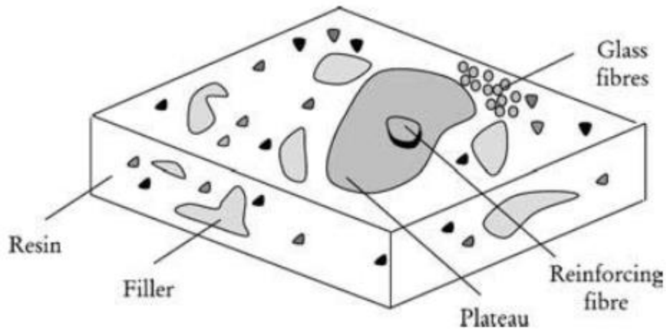

Figure 1.1: Enlarged isometric view of a used brake pad (Gachoki and Kathenya, 2006)

1.2 PROBLEM STATEMENT

Nowadays, many manufacturers focus on using material that requires low cost and produces high-performance products. A disc brake pad usually made up of many materials. The scientist and manufacturers have found out a way to achieve same performance of actual disc brake pad by using natural fibre reinforced composite to replace the reinforcing fibre in disc brake pad since the natural fibres is easily available, has lightweight criteria, low cost, and comparable mechanical properties. The objective of this study is to select the suitable natural fibres for fibre reinforced composites to apply in disc brake pad by using the VIKOR method and comparing the mechanical properties with the standard brake pad material (Nigerian Industrial Standard, 1997; SAE, 2001).

1.3 OBJECTIVES

The objectives of this project as follow:

i. To select the suitable natural fibre reinforced composite for disc brake pad using VIKOR method.

ii. To compare the performance of the new natural fibre reinforced composite brake pad against standard brake pad.

1.4 SCOPES OF PROJECT

The scopes of this project are:

i. The part of the car being focused in this project is automotive disc brake pad.

ii. The material selections is focusing on natural fibre reinforced composite class to replace reinforcing fibre in disc brake pad.

iii. Material selection of natural fibre was carried out by using VIKOR Method.

iv. The performance and properties of standard disc brake pad are studied.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A literature review is a fundamental element in a research which provides a description, summary, and critical evaluation of research problem by surveys books, scholarly articles, and any other sources relevant to the area of research. Furthermore, the literature review can be used to obtain information regarding general properties of natural fibre, multi-criteria decision method procedure, mechanical properties and criteria of the brake pad.

2.2 BRAKE PAD

The brake pad is a part of the brake system that made up by a combination of various materials and the function is to decelerate or stop the vehicle. The materials selected for brake system must consist following criteria: coefficient of friction, thermal conductivity, wear, tensile strength and hardness. Figure 2.1 shows example of brake pad

Figure 2.1: Example of brake pad (Bosch Brake Pad)

2.3 NATURAL FIBRE

Natural fibre is defined as substances produced by using raw material obtained from plants and animals to be spin into filament, thread and others such as woven and knitted. Lately, the researchers found out that the natural fibres provide tremendous environmental advantages such as worldwide availability, biodegradability, low pollutant emissions and low greenhouse gas emissions (Faruk et al., 2012; John et al., 2008; Mohanty et al., 2005). Natural fibres are easily available around the world furthermore the marketing price for natural fibres are cheap. The natural fibre has moderate mechanical properties compared to synthetic fibre but natural fibre has a higher moisture sensitivity (Sanjay et al., 2016). Figure 2.2 shows the classification of fibre into the natural fibre and synthetic fibre. Table 2.1 shows the comparison between natural fibres and synthetic fibres.

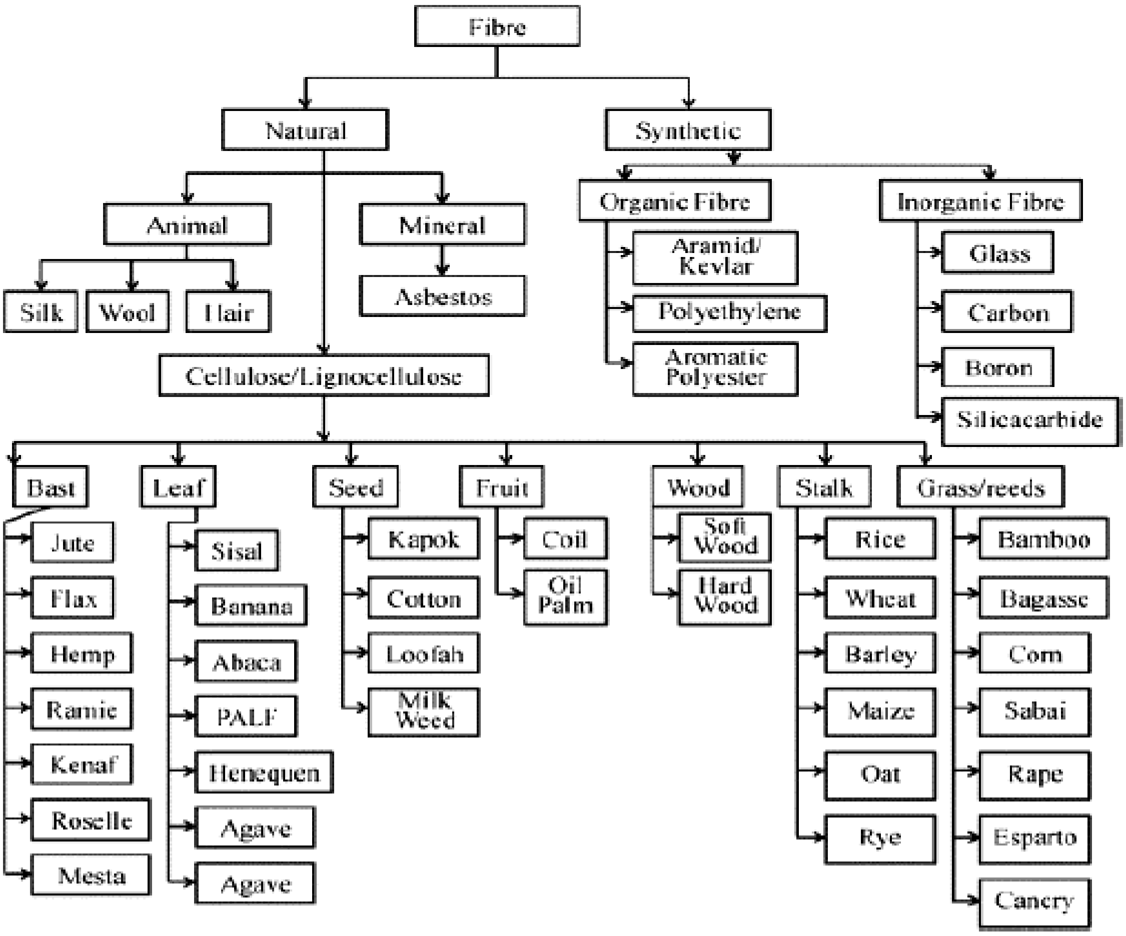

Figure 2.2: Classification of fibre (Alkbir et al., 2016)

Table 2.1 Comparison of natural fibres and synthetic fibres in different properties (Sanjay et al., 2016)

Aspect	Property	Natural fibres	Synthetic fibres
Technical	Mechanical properties	Moderate	High
	Moisture sensitivity	High	Low
	Thermal sensitivity	High	Low
Environmental	Resource	Infinite	Limited
	Production	Low	High
	Recyclability	Good	Moderate

Natural fibre such as kenaf, hemp, flax, jute and sisal are selected as reinforcement in automobile parts due to natural fibres are lightweight and low cost. Holbery and Houston (2006) had studied about natural fibre reinforced polymer composites in an automotive application, the study found out that the natural fibre composites with thermoplastic and thermoset matrices have good physical and mechanical properties to fulfil the requirement as a part of the material in car component. While in 2006, the European Union legislation had been implemented for expedition of natural fibre reinforced plastic automotive insertion and 85% of the car must reused or recycled in 2015 (Official Journal of the European Communities, 2000). Thus, the implementation of natural fibre reinforced composite in automotive component should be enhanced in worldwide. Table 2.2 shows the advantages and disadvantages of natural fibre.

Table 2.2: Advantages and disadvantages of natural fibre (Alkbir et al. 2016)

Advantages	Disadvantages
Low specific weight results in a higher specific strength and stiffness than glass	Lower strength especially impact strength
Renewable resources, production process need only little energy and CO_2 emissions	Variable quality, affected by weather condition
Production with minimum investment	Poor moisture resistance, which causes swelling of fibres
Thermal recycling is possible	Price fluctuations depend on agriculture policy
High electrical resistance	Low durability
Good thermal and acoustic insulation properties	Poor fire resistance
Biodegradable	Poor fibre or matrix adhesion

The mechanical performance and properties of several natural fibres and synthetic fibre in the automotive application was being reviewed (Koronis et al., 2013). Table 2.3 shows the mechanical and physical properties of natural fibres. Based on Table 2.3, the pineapple fibre was the highest tensile strength range of 413 - 1627 MPa while the tensile strength of sisal fibre only around 350 - 640MPa.

Table 2.3: Mechanical and Physical properties of natural fibres (Alkbir et al., 2016)

Fibres	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Density (g/m^3)
Sisal	350-640	12.8-22	3-7	1.41-1.45
Oil palm	70.9-248	14-6.7	14-25	0.7-1.55
Bamboo	215-218	28-30	1.3	0.6-0.91
Banana	529-914	427-32	5-9	1.35
Coir	120-304	4-6	15-40	1.15-1.25
Cotton	287-800	5.5-12.6	3-10	1.51-1.6
Flax	345-1500	23.9-27.6	1.6-3.2	1.5
Hemp	690	60-70	1.6-4	1.4-1.5
Jute	393-780	13-30	1.9	1.3-1.45
Kenaf	284-1191	21-60	1.6-3.5	0.13-0.17
Pineapple	413-1627	60-82		1.07-2.4
Ramie	400-938	44-128	1.2-8	1-1.55

2.4 NATURAL FIBRE REINFORCEMENT COMPOSITE

The term "reinforcement" in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. Meanwhile, the term "composite" means a combination structural component produced by a physical combination of two or more materials. In addition, the term "composite" in material science provide meaning that a material is made up of a matrix containing reinforcing agents. Fibre reinforced material is divided into the continuous phase and discontinuous phase. The continuous phase is known as matrix while discontinuous phase is known as fibre. The composite material consists of one or more discontinuous phase that is embedded in continuous phase to become reinforcing material that has stronger and hard material characterisation (Chandramohan and Marimuthu, 2011). Figure 2.3 shows the categorization of the composite into three main divisions.

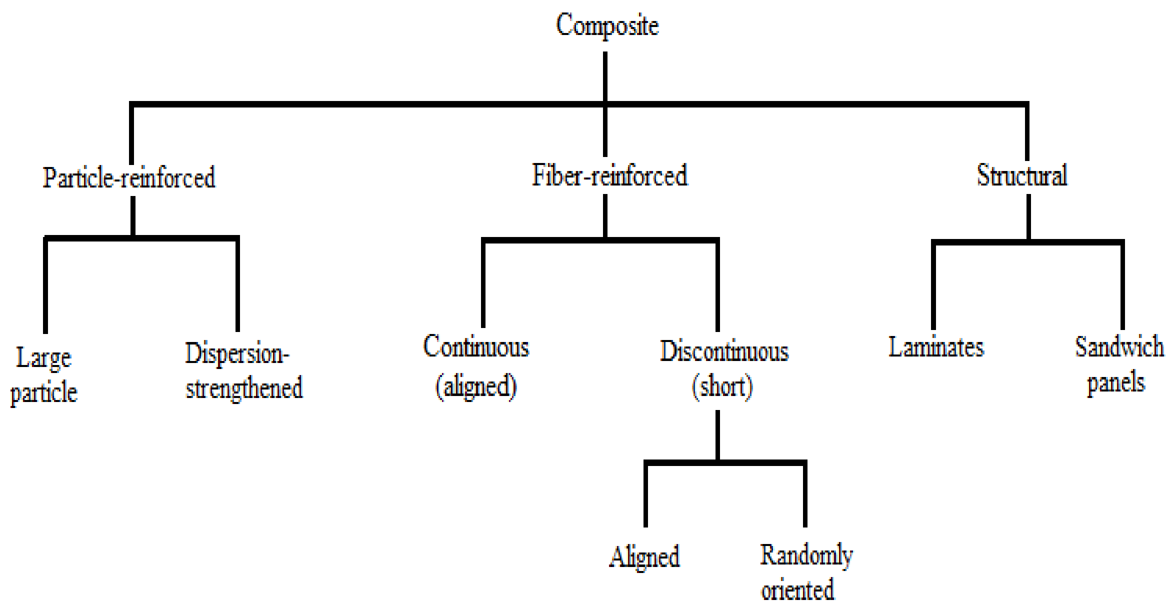

Figure 2.3: Composite categorization (Callister, 2006)

In automotive industries, natural fibre reinforced composites, deriving from renewable resources, have therefore attracted extensive attention as promising alternatives to replace traditional fibre (Joshi et al., 2004; Koronis et al., 2012; Puglia et al., 2005). Natural fibre reinforced polymer composite such as jute, flax, hemp, sisal and others have already been embraced by European automobile manufacturers for manufacturing automotive interior and exterior parts like door panels, package trays, dashboards, headliners, seat backs and trunk liners (Ahmad et al., 2015). According to Monteiro et al. (2010) on his previous studies about natural lignocellulosic fibres. Figure 2.4 shows the Mercedes Benz Sedan automotive parts had done some changes such as natural lignocellulosic reinforcement polymer composite are replacing the synthetic fibre in automotive parts. The results show the smallest diameter of lignocellulose fibre obtained high tensile strength (Monteiro et al., 2010).

Figure 2.4: Mercedes Benz automotive parts fabricated by natural fibres

(Monteiro et al., 2010)

2.5 POLYMER MATRIX COMPOSITES

Polymer matrix composites (PMCs) is a class which under of fibre reinforced composite (FRC). Polymer matrix composites are made up of polymer resin as matrix and fibres as the reinforcement medium. Those polymer matrix composites combine with reinforcement type become fibre reinforced polymer composites (FRPC). Fibre reinforced polymer composites (FRPC) are composite materials are made up by combination of polymer matrix with high strength fibres such as aramid, glass and carbon. Recently, the scientist and engineers had researched and utilizing all plant fibres to produce good quality fibre reinforced polymer composites for various field of industry. This research brings a huge opportunity for plant fibres to develop a new composite material. Natural fibre-reinforced polymer composites improve the environmental quality since most of the plant fibres such as kenaf, sisal and jute fibres are biodegradable. Importantly, the plant fibres can become reinforcement for composite material that provides mechanical strength and able to substitute glass, carbon, and aramid in fibre reinforced polymer composite. Cotton-reinforced polymer composites were reported to be the first fibre-reinforced plastics used by the military for radar aircraft (Lubin, 1988; Piggot, 1980). Since natural fibre reinforced polymer composites is low cost, low density, good mechanical properties and simple processing advantages, the research development progress had become faster than before (Satyanarayana et al., 1990).

The advantages of natural fibre reinforced composite are:

- The natural fibres are renewable, low cost, biodegradable and non-abrasive to processing equipment.
- The production of natural fibre reinforced composites give lower environment pollution.
- The natural fibre reinforced composites are lightweight and capable to be used in automotive part components.
- Show good mechanical properties such as good acoustic and thermal insulating properties

The following Figure 2.5 shows the usage of polymer matrix composite in automotive industry.

Figure 2.5: Use of PMC in automotive industries (www.slideshare.net)

2.6 SYNTHETIC FIBRE

Synthetic fibres are defined as man-made fibres from chemicals. Synthetic fibres mostly based on polymers, are stronger than natural and regenerated fibres and can be modified to have different performance characteristics. Table 2.4 shows the advantages and disadvantages of synthetic fibres.

Table 2.4 Advantages and disadvantages of synthetic fibre (Anonymous, n.d.).

Advantages	Disadvantages
Stronger strength	Produced using fossil fuels (petroleum)
Stronger durability	Use chemical which could harm humans and non-environment friendly
Low expensive production	Melting when at hot temperature
Weak water absorption (this is an advantage or disadvantage depending on the application)	Non-biodegradable

2.7 CRITERIA FOR BRAKE PAD

2.7.1 COEFFICIENT OF FRICTION

The coefficient of friction is the value of the force of friction between two objects or more objects are involved. The SI unit for the coefficient of friction is μ. The following Eq 2.1 shows the coefficient of friction is being used in the calculation of frictional force (Burwell and Rabinowicz, 1953):

$$F_f = \mu \, . F_n \tag{2.1}$$

Where F_f is friction force and F_n is the normal force.

One of the most important criteria of brake pad is the coefficient of friction. The friction of coefficients for brake material pairs should be in the range from 0.07 to 0.7. However, most of the vehicles operate within the range from 0.3 to 0.6 in friction coefficient (Anderson, 1980). The coefficient of friction should be maintained at a stable level irrespective of temperature, humidity, the age of the pads, the degree of wear, corrosion, the presence of dirt and water spraying from the road (Eriksson, 2001; Mutlu, 2006).

The society of automotive engineers (SAE) developed a Friction Identification System for Brake Linings and Brake Blocks (SAE Recommended Practice SAE J866a). Edge codes are used to show the coefficient of friction of brake linings and brake blocks. Table 2.5 shows the following list of codes and associated friction coefficients.

Table 2.5: Value of friction of coefficient and codes SAE Recommended Practice J866a (Blau et al., 2001)

CODE	FRICTION COEFFICIENT
C	<0.15
D	> 0.15 BUT ≤ 0.25
E	> 0.25 BUT ≤ 0.35
F	> 0.35 BUT ≤ 0.45
G	> 0.45 BUT ≤ 0.55
H	> 0.55
Z	UNCLASSIFIED

2.7.2 WEAR

Wear in automotive industry meaning as material removal from a surface due to friction with another surface. However, wear rate is known as wear volume per unit distance. Wear rate usually change in the range of 10^{-15} to 10^{-1} mm^3/Nm but it is based on several circumstances such as operating conditions and material selections (Kato and Adachi, 2001).

Meanwhile, the term "wear rate" in brake pad mean thickness loss of brake pad after the braking performance. In SAE J661 test standard, there are 7 tests to test the wear rate and coefficient rate of the brake pad. According to Incesu et al., (2013) previous studies about the design of composite brake pads for the metro with a statistical approach, the brake pad is proved are better to have lower wear rate which is lower than 10%. The Table 2.6 show the commercial brake pads and a testing sample of brake pad undergo SAE J661 Testing Standard. Figure 2.6 shows the simulation software used to measure brake pad wear depth.

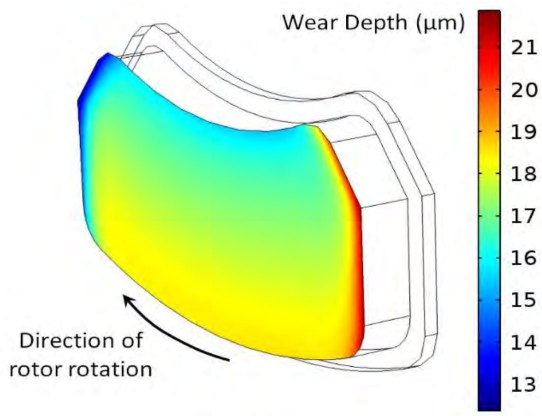

Figure 2.6: Simulation of software measuring brake pad wear depth from (www.comsol.com)

Table 2.6: SAE J661 Testing Standard on brake pad (Incesu et al., 2013)

Part of Test	App No	Temp.(°C)	Friction Coefficient (μ)				
			Commercial Sample	Test Sample 1	Test Sample 2	Test Sample 3	Test Sample 4
BASELINE-1	1	100	0,373	0.328	0.358	0.328	0.358
	5		0,373	0.328	0.269	0.343	0.373
	10		0,388	0.313	0.209	0.373	0.358
	15		0,388	0.299	0.209	0.343	0.343
	20		0,388	0.269	0.209	0.328	0.358
FADE-1		93	0.403	0.269	0.224	0.313	0.313
		121	0.388	0.299	0.239	0.343	0.343
		149	0.388	0.309	0.258	0.373	0.373
		177	0.388	0.343	0.299	0.373	0.388
		205	0.388	0.343	0.299	0.394	0.397
		233	0.388	0.343	0.284	0.394	0.403
		261	0.388	0.343	0.284	0.373	0.403
		289	0.373	0.313	0.269	0.358	0.403
RECOVERY-1		261	0.388	0.328	0.299	0.373	0.433
		205	0.418	0.299	0.284	0.373	0.388
		149	0.418	0.269	0.254	0.313	0.328
		93	0.418	0.239	0.239	0.269	0.299
WEAR	1		0.403	0.313	0.284	0.379	0.343
	10		0.418	0.269	0.328	0.313	0.448
	20		0.448	0.313	0.358	0.328	0.463
	30		0.433	0.324	0.388	0.373	0.448
	40		0.433	0.343	0.418	0.373	0.448
	50		0.433	0.388	0.433	0.388	0.463
	60		0.448	0.403	0.418	0.388	0.448
	70		0.448	0.412	0.433	0.388	0.463
	80		0.448	0.418	0.448	0.403	0.448
	90		0.463	0.418	0.433	0.403	0.448
	100		0.418	0.433	0.433	0.418	0.463
FADE-2		93	0.433	0.338	0.313	0.309	0.333
		121	0.448	0.388	0.328	0.328	0.343
		149	0.433	0.382	0.358	0.338	0.373
		177	0.418	0.418	0.373	0.358	0.373
		205	0.418	0.418	0.388	0.397	0.418
		233	0.433	0.418	0.433	0.418	0.448
		261	0.433	0.403	0.478	0.455	0.478
		289	0.433	0.394	0.478	0.433	0.470
		317	0.358	0.379	0.433	0.397	0.424
		345	0.328	0.348	0.373	0.358	0.373
RECOVERY-2		317	0.373	0.358	0.418	0.343	0.403
		261	0.403	0.388	0.388	0.358	0.388
		205	0.418	0.388	0.373	0.358	0.388
		149	0.439	0.368	0.343	0.324	0.343
		93	0.433	0.328	0.299	0.294	0.328
BASELINE-2	1		0.433	0.328	0.299	0.299	0.313
	5		0.418	0.328	0.328	0.328	0.343
	10		0.433	0.328	0.328	0.328	0.343
	15		0.418	0.338	0.328	0.309	0.328
	20		0.403	0.333	0.328	0.313	0.328

2.7.3 TENSILE STRENGTH

Tensile strength is defined as ability or strength of the material to withstand a pulling force. But in term "tensile strength of material" describes the maximum amount of tensile stress that material can endure before breaking or permanent deformation. However, there are three types of tensile strength such as yield strength, ultimate strength and breaking strength. In the automotive industry, tensile strength is one of the criteria in material selection. By referring to Dow (1985), the standard tensile strength of brake pad friction material should not be less than 20 MPa (Nigerian Industrial Standard, 1997).

2.7.4 THERMAL CONDUCTIVITY

Thermal conductivity is defined as the property of a material to conduct heat. For example, high thermal conductivity material is commonly used for heat dissipation while low thermal conductivity material used for heat insulation.

Thermal conductivity is one of the main criteria in brake friction material. During braking process, both of the disc brake and brake pad had absorbed a large amount of heat released in a few seconds (Travaglia and Lopes, 2014). The heat absorbed by both disc brake and brake pad must dissipate as fast as possible to prevent malfunction on the operation of braking system (Day and Newcomb. 1984). There are some possible problems will occur such as thermal cracks, premature wear, brake fade and thermally during excited vibration if the temperature of braking process is high (Lee, 1999). The standard thermal conductivity of a brake friction material must be in the range of 0.47 to 0.804 W/mK (Dagwa and Ibhadode, 2015).

2.7.5 HARDNESS

Hardness is defined as the measurement of resistant to solid before changing into any shape when a compressive force is applied. The common materials such as ceramic, metal, and concrete undergo hardness test by using Vickers hardness tester.

Brake pad hardness used to describe friction material durability. According to Unaldi and Kus (2017), the density and hardness properties were affected by alumina component of the brake pad. The hardness of brake friction materials was determined by Brinell Hardness

Test (HB) and using hardness test machine (DIGIROCK-RBOV). An example of brake pad hardness test machine is shown in Figure 2.7.

Figure 2.7: Brake Pad Hardness Test Machine (www.bullbrakes.com)

2.8 COMPONENT OF BRAKE PAD

2.8.1 BINDER

Binder is a type of thermoresin used to hold all other components together in order to form a thermally stable matrix (Feist, 2013; Weintraub, 1998). Phenolic resin is one of the common material which selected as a binder in the brake pad. There are two types of phenolic resin such as alkyl benzene modified phenolic resin and actual phenolic resin. Phenolic is a type of thermoset polymer form by a condensation reaction between phenol and formaldehyde and is able to act as a matrix for binding agent together different substances (Salamone, 1998). Alkyl benzene modified phenolic matrix resin was synthesized from SI chemicals and it was characterized by curing temperature and thermal degradation temperature by standard Differential Scanning Calorimetry (DSC) and Thermos Gravimetric Analysis (TGA) studies.

Balaji and Kalaichelvan, (2013) had studied the thermal and fade aspects of a non-asbestos semi-metallic brake pad formulation with two different resins. Table 2.7 shows the result of both resin conduct SAE J661a test. The result had shown that the alkyl benzene modified phenolic resin (NA-02) has higher coefficient friction and more stable to thermal analysis compare to the phenolic resin (NA-01).

Table 2.7: SAE J661a Frictional Response of Friction Composites (Balaji and Kalaichelvan, 2013)

Properties	NA-01	NA-02
Hot friction or Fade (μ)	0.362	0.465
Normal or recovery (μ)	0.465	0.472
First Fade by Calculation (%)	23.02	12.367
First Recovery by Calculation (%)	90.33	103.83
Second Fade by Calculation (%)	4.396	19.4
Second Recovery by Calculation (%)	87	93.3
Max (μ)	0.474	0.520
Min (μ)	0.310	0.411
Wear loss by wt (%)	5.9	4.7

A research regarding optimization of alkyl benzene modified phenolic resin in a friction composite to the effect on thermal stability, friction stability and wear performance conducted by Balaji, 2014. The research outcome shown the amount of resin in brake pad can affect the integrity of brake pad and other important properties. Furthermore, alkyl benzene modified phenolic resin can be conducted for TGA test. This analysis is to show the thermal stability of materials. Figure 2.8 shows the TGA result of alkyl benzene modified phenolic resin.

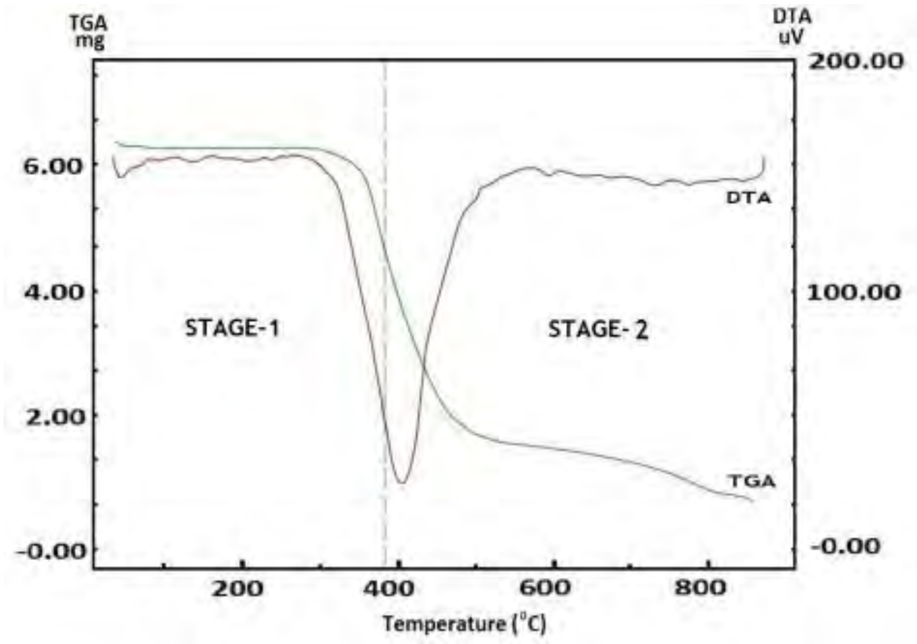

Figure 2.8: TGA of alkyl benzene modified phenolic resin

(http://shodhganga.inflibnet.ac.in/bitstream)

2.8.2 FILLER

The reasons for filler being used in brake pad are to reduce the cost and improve the manufacturability of brake pad. There are two types fillers such as inorganic filler and an organic filler. The materials which consider as inorganic fillers are such as barium sulphate, mica, vermiculite and calcium carbonate. The inorganic fillers have a high melting point. For instance, barium sulphate is commonly used as fillers since it is chemically inert and has a melting point of 1350 ℃ (Lide and Kehiaian, 1994). Barium sulphate imparts heat stability to the brake friction material, at the same time aiding the friction characteristics of the brake friction material (Komori et al., 1990). The behaviours, advantages and disadvantages of some inorganic fillers are shown in Table 2.8.

Table 2.8: Description of inorganic fillers (Chan and Stachowiak, 2004)

Filler	Description
Barium Sulphate	Imparts heat stability to friction material
Calcium Carbonate	Imparts heat stability to friction material characteristic
Mica	Suppresses low frequency brake noise, but cause interlayer split
Vermiculite	Suppresses low frequency brake noise, and low heat resistance
Alkali metal titanates	Lead to stability of friction coefficient
Molybdenum trioxide	Avoid thermal fade and cracking of friction lining
Cashew dust	Suppresses brake noise, but does not handle well to friction material
Rubber dust	Suppresses brake noise, but does not handle well to friction material

Typical organic fillers such as cashew dust and rubber dust. Both have similar properties in that they are usually incorporated into brake pads for the purpose of reducing brake noises due to their superior viscoelastic characteristics (Kamioka et al., 1995). Cashew dust is easily fall off from friction surface during friction and caused crack after leaving behind large pores (Kinouchi et al., 2002). The advantages of cashew or rubber particles are:

- Low thermal conductivity that prevents heat from transmitting back to brake friction material. (Nakagawa, 2001)
- Reduce fluctuations in friction coefficient at elevated temperatures. (Jang and Kim, 2000)

Kim et al. (2004) had studied the effect of potassium titanate and barium sulphate on the physical and mechanical properties of friction composites. The results show that the barium sulphate filled friction composites remain higher density and hardness meanwhile potassium titanate filled friction composite remain maximum void content.

2.8.3 ABRASIVE

Abrasives increase the coefficient of friction during friction and wear rate of counterface material. Typical abrasive include iron oxide, aluminium oxide, quartz, silica and zirconium silicate. Most of the abrasives are hard particles because it must be hard enough to at least abrade the counter friction material which is typically cast iron.

Yiannoulakis, (2015) on his previous studies regarding friction material in brake lining, the magnesium oxide can select as one of brake friction material due to magnesium oxide able to increase the thermal stability of phenolic resin and resistance between friction material furthermore capable to suppress low-frequency noise during braking.

2.8.4 FRICTIONAL ADDITIVES

The main purpose of frictional additives being added to brake friction materials is to modify the friction coefficient and wear rate (Pohane et al., 2016). The frictional additives are solid lubricants like graphite and metal sulphides that is utilized to ensure stable frictional properties and control wear primarily at elevated temperatures (Feist, 2013).

Graphite had played the role of friction modifier since 2003 in brake pad material. The graphite can exist in flake or powder form. However, graphite in flake form improved lubrication properties (Takahasi et al. 1999), meanwhile graphite in powder form capable to dissipate heat generated during braking more effectively (Booher, 1992). Table 2.9 shows properties of some frictional additives.

Table 2.9: Frictional additives of brake pad material (Gachoki and Kathenya. 2006)

Frictional additives	Description
Graphite	Widely used lubricant, usually in natural or synthetic forms.
Metal sulphides	Good lubricating properties, lower conductivity than graphite
Metal oxides or silicates	Abrasives with hardness ranging from 500HV (quartz) to 1750HV (aluminium oxide): example include zirconium silicate and quartz.

Thiyagarajan et al. (2003) had studied the thermomechanical properties of carbon fibres and graphite powder reinforced asbestos-free brake pad composite material. The results show that graphite powder increased the thermal conductivity of the composite brake pad material. The graphite powder also good in controlling the hardness of brake pad to the desired level.

2.8.5 REINFORCING FIBER

The purpose of reinforcing fibre in brake pad is to provide mechanical strength to the friction material. Nowadays, reinforcing fibres are commonly used in automotive industry in order to replace asbestos fibres. In the late 1980s, scientist found out that asbestos is a carcinogen, therefore, manufacturers starting to look for suitable alternatives. Table 2.10 shows the advantages and disadvantages of some reinforcing fibres.

Table 2.10: Advantages and Disadvantages of Reinforcing Fibre (Gachoki and Kathenya, 2006)

Components	Advantages	Disadvantages
Glass	Sufficient thermal resilience (high melting point of 1430 °C, but start soften at around 600°C)	Brittle
Metallic	Thermally resilient steel and copper have melting points higher than 1000°C	Large amounts will cause rotor wear and corrode
Aramid	Good stiffness in weight ratio, excellent thermal resilience, good wear resistance	Soft cannot be used without other fibres
Potassium titanate	Thermally resilient (high melting point of around 1371 °C) and good wear resistance.	Health hazard
Sepiolite	Thermally resilient (high melting point of around 1550 °C); able to absorb traces of fluid	Potential health hazard
Ceramic	Thermally resilient (high melting point of around 1700-2040 °C); good stiff-weight ratio	Brittle

According to Eriksson et al. (2002) in his previous studies regarding on the nature of tribological contact in automotive brakes, the studies had shown that the braking load is carried by tiny plateaus that rise above the lowlands of friction material. The tiny plateaus are formed when the reinforced fibres surrounded by the softer compact components. The friction material should use a mixture of different types of reinforcing fibre with complementary properties.

2.9 RESEARCHES ON BRAKE PAD

There are some researches regarding brake pad had been carried out in these past few years. Most of them share the common idea such as using natural fibre as alternative for asbestos fibre. According to Ghazali et al. (2012) in his previous studies on mechanical properties and wear behaviour of brake pad produced from palm slag, the studies had shown that the hardness, compressive strength and wear behaviour of palm slag had potential to replace as filler in asbestos free brake pad. Besides that, Ghazali et al. (2013) also conducted a studies about mechanical properties and morphology of palm slag, calcium carbonate and dolomite filler in brake pad composites. The research result shown that combination of palm slag and calcium carbonate inside brake pad composite provide better wear properties than dolomite and capable compare to conventional asbestos based brake pad.

Other than that, Idris et al. (2013) had carried out a research about eco-friendly asbestos free brake pad using banana peels. The result shown that the mechanical properties such as compressive strength, hardness and specific gravity of the produced samples such as uncarbonized banana peels and carbonized banana peels have improved with increased in weight fraction of resin addition. Thus, banana peels particles able to replace asbestos effectively in brake pad composite.

Besides that, according to Ikpambese et al. (2014) research about evaluation of palm kernel fibers (PFKs) for production of asbestos-free automotive brake pads, the research used epoxy resin as binder and result show that it is compatible to commercial asbestos. Therefore, palm kernel fibre capable to replace asbestos brake pad.

2.10 MULTI CRITERIA DECISION MAKING (MCDM)

The material selection is one of the important process in engineering design to fulfil the requirement in product design. The material can have many dimensions: technical, economic, aesthetic, personality and ecological dimensions. As an engineer, the physical, mechanical, and thermal properties of material should be checked thoroughly before proceed to selection process. Filter and select the materials that meet product criteria and performance meanwhile try to seek for alternative material can replace the current material used. There are many methods can be used for material selection either using software or non-software. The selection of material and alternative material process should carry out in proper approach.

Multi-criteria decision-making (MCDM) methods had many different approaches. MCDM methods can classify into two categories: discrete MCDM or discrete Multi-attribute Decision Making Method (MADM) and continuous Multi-objective Decision-Making Method (MODM) (Chauhan and Vaish, 2012; Zavadskas et al., 2014). Nowadays, a lot of information, researches and publications have been published regarding MCDM methods and its application in different fields. Material selection using MCDM had been strongly proposed by some authors such as (Liu et al., 2013; Çalışkan et al., 2013; Khorshidi and Hassani, 2013). The Figure 2.9 shows the sequence of MCDM.

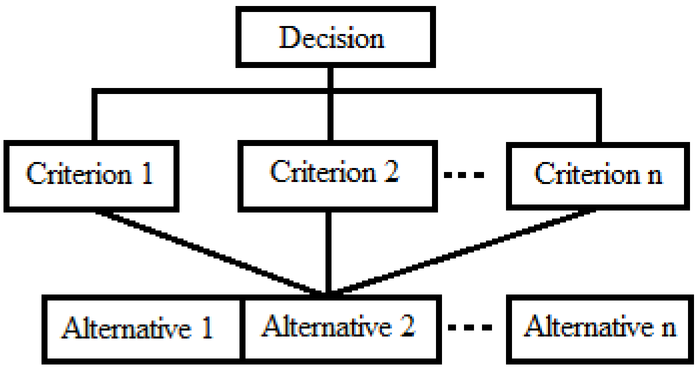

Figure 2.9: Multi-Criteria Decision Making (MCDM) Tree

MCDM method can also be used for material selection in engineering design industry. For example, Kumar and Ray (2014) had used multi-criteria decision making in the selection of material for optimal design. Within MCDM method, there are few methods used to select suitable alternative materials such as weighted sum model (WSM), weighted product model (WPM), analytic hierarchy process (AHP), elimination and choice expressing reality (ELECTRE), technique for order of preference by similarity to ideal solution (TOPSIS), analytic hierarchy process based on fuzzy scales (FUZZY AHP) and VIKOR method.

Recently, MCDM starting become a popular method for material selection in the automotive industry. Maleque et al. (2010) used material selection method to select the most suitable material in the design of automotive disc brake. The disc brake is one of the most important component in car safety because it undergo a few energy transformation process before the car stopped. In this research, digital logic method was used to find weighting factors and the result of each material proposed were ranked and compared.

The researcher Chirag et al. (2016) had used entropy fuzzy preference ranking method for enrichment evaluation (Entropy-PROMETHEE) based decision making methodology to carry out material selection and based on tribological properties of brake friction material. The material selection for brake friction material is being accounted into performance defining criterions. The data of material for performance defining criterions is simplified into a table. In this research, the entropy is used for the estimation of weight for each criterion, while PROMETHEE II is used to rank the alternatives.

Dante et al. (2000) had carried out a lot of experimental technique using Taguchi design concept for friction material formulation. The result showed that the advantages of Taguchi design technique had saved time in the progress of choosing suitable ingredients for ideal material development. Similarly, performance and ranking system can occupied on brake friction material. Satapathy et al. (2004) had studied about the performance of friction materials based on variation in nature of organic fibres part I, fade and recovery behaviour. The research is about to determine the performance ranking of five friction composites by using balancing and ranking method. While the author had been used the combination of AHP-TOPSIS for friction material selection.

Besides, many researches had been done on material selection of natural fibre, hybrid fibre, natural fibre reinforced composite in automotive industry. A few years ago, Mansor et al. (2013) had studied regarding hybrid natural and glass fibres reinforced polymer composites material selection using analytical hierarchy process for automotive brake lever design. The author had utilized the AHP method for material selection of natural fibre that need to be hybridized with glass fibre reinforced polymer composite. The result from research showed the kenaf bast fibre displayed the highest scores and best candidate to formulate the hybrid polymer composites in automotive component construction.

2.10.1 VIKOR METHOD

The VIKOR algorithm was proposed by (Opricovic, 1998), an MCDM method commonly used for a complex system based on ideal point method. The objective of VIKOR is determining positive ideal solution and negative ideal solution in the first place. The positive ideal solution is the optimum value of alternatives under criteria, and the negative ideal solution is the worst value of alternatives under criteria. Lastly, proceed to the priority arrangement of the schemes based on the proximity of the alternatives assessed value to the ideal schemes. The multi-criteria measure for compromise ranking is developed from the L_p-metric used as an aggregating function in a compromise programming method shown in Eq. (2.1) (Yu, 1973; Zeleny, 1998).

$$L_{pi} = \{ \sum_{j=1}^{n} [w_j \ (f_j^* - f_{ij}) / (f_j^* - f_j^-)]^p \}^{1/p} \quad (2.1)$$

Where $1 \leq p \leq +\infty$; $i = 1,2, \dots I$. I respects the number of alternatives. Each alternative is indicated as a_i , f_{ij} is the evaluation value of the ith criterion for alternative a_i

; the measure L_{pi} means the distance between alternative a_i and positive ideal solution. Ranking by VIKOR may produce different values of criteria weights. Criteria weights greatly affect compromise solution. The VIKOR method determines the weights stability intervals, using the methodology proposed by (Opricovic, 1998). He compromise solution obtained with initial weights w_i , i = 1,2,... n will be replaced if the value of a weight isn't within the stability interval.

2.11 MATERIAL SELECTION

The selection of material for brake pad is not an easy task because the need to undergo a different process by according to the stages. The Figure 2.10 shows the flow chart of material selection for brake pad material. VIKOR method is used for material selection in brake pad friction material. The materials involved in material selection are natural fibre reinforced composite and natural fibre reinforced polymer composite.

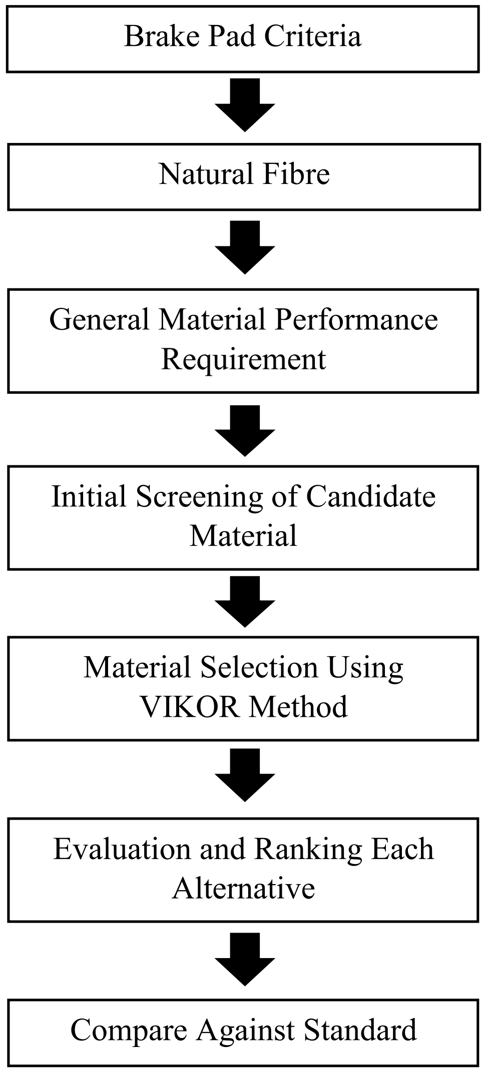

Figure 2.10: Flow chart of material selection for brake pad

2.11.1 POTENTIAL MATERIAL TO REPLACE ASBESTOS FIBRE

The traditional reinforcing fibre for automotive brake pad is asbestos fibre. Due to asbestos fibre is harmful to human and environment, therefore research on potential alternative material to replace asbestos fibre is carried out. The following describes the potential alternative material can be used for brake pad.

i. Palm kernel fibre

Palm kernel fibre is easily available, low cost, and have quite good mechanical properties such as coefficient of friction, hardness and others. Ikpambese et al., (2014) prepared brake pad material using natural fibre called palm kernel fibres (PKFs) for its eco-friendly nature with $CaCO_3$, graphite and Al_2O_3 as other constituents. Epoxy resin is used as a binder. The composition of 40% epoxy-resin, 10% palm wastes, 6% Al_2O_3, 29% graphite, and 15% calcium carbonate gave better properties than other composition.

ii. Date palm fibre

Advantages of date palm fibre was low cost, low density, chemical resistance, high strength to weight ratio and good relative mechanical properties (Alajmi et al., 2015). Moreover, the date palm trees are renewable source of fibres.

iii. Sisal fibre

Sisal fibre is a type of natural fibre made up of cellulose structure. A piece of sisal fibre is not a single filament like carbon or glass fibre but a bundle of cellular aggregate consisting of more than 100 irregular hexagonal hollow ultimate cells (Barkakaty, 1976). A few research had been conducted on sisal fibre reinforced composites because sisal fibre is environmentally friendly, cheap, lightweight and good mechanical performance (Xin et al., 2007).

iv. Bamboo fibre

The bamboo fibre had become one of choice for composite material due to their properties such as low density, good hardness and mechanical properties are comparable to glass fibres (Ma et al., 2012). Bamboo fibre also biodegradable and environmental friendly which does not cause harm to human health.

Based on the properties, potential candidate materials for automotive brake pad were selected as:

- Sisal fibre reinforced resin brake composites (15 wt% resin , 20 wt% fibre)
- Date palm fibre reinforced epoxy composites (100 wt% epoxy, 35 wt% fibre)
- Bamboo fibre reinforced composites (3 wt% fibre)
- Palm kernel fibre reinforced composites (40 wt% epoxy resin, 10 wt% fibre)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methodology of material selection of natural fibre which can be become either natural fibre reinforced composite or natural fibre reinforced polymer composite for the brake pad. The tools and methods used in this project is VIKOR method, table of selection and comparative approach. All material selection are selected after searching from various sources and comparing the material properties against the requirement of the brake pad. The VIKOR method is used to calculate and rank the best material by using the data of materials provided. Table of selection is used to identifying the best material as final material in this studies. While, the comparative approach is to compare to final material against standard criteria value, in order to determine whether final material fulfil the requirement of standard brake pad criteria. Thus, Figure 3.1 shows the workflow for each stage in the whole project.

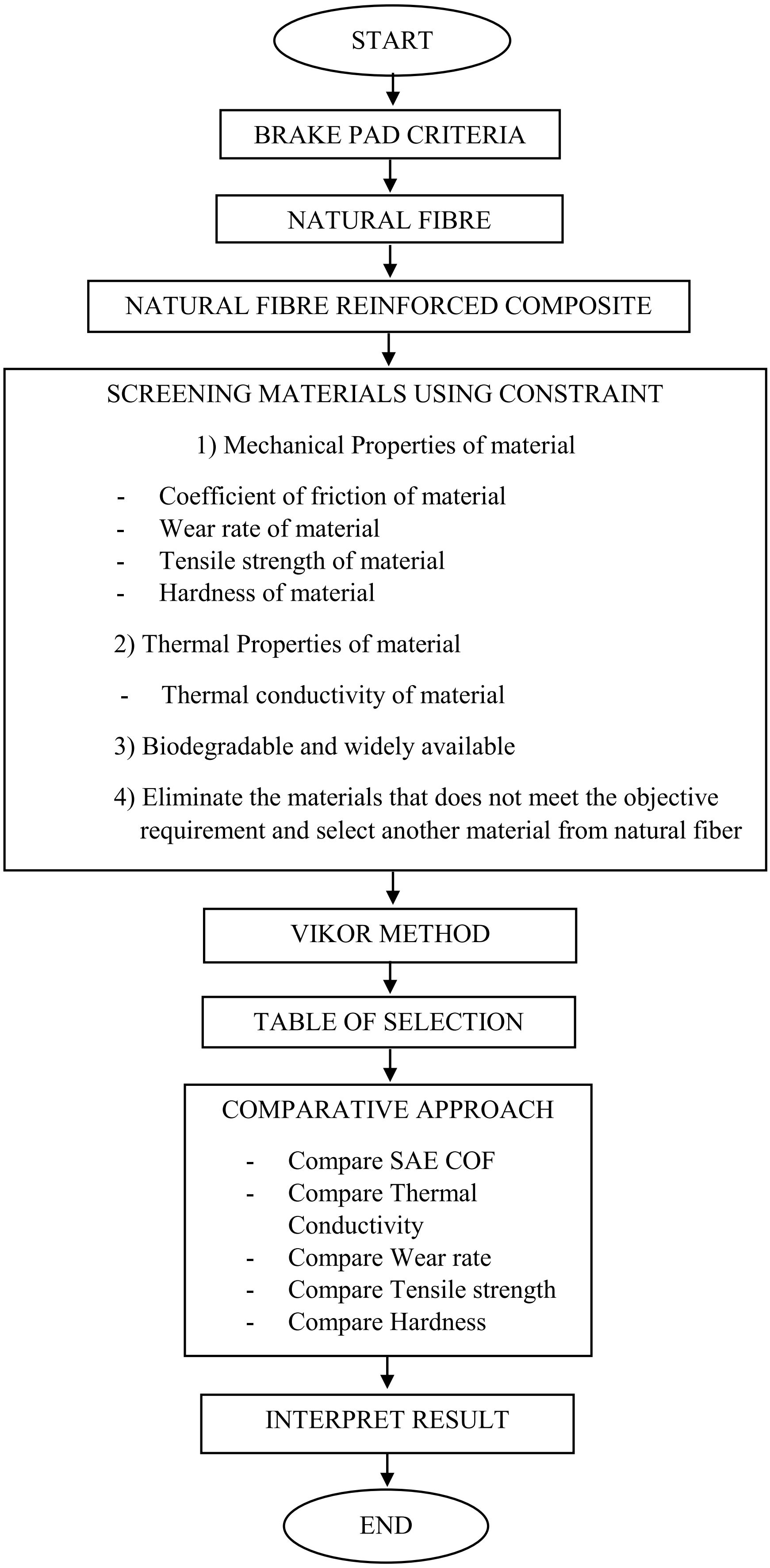

Figure 3.1: Work flow of the project

3.2 WORKING STEPS OF VIKOR METHOD

1) Calculate the normalized value

For example, there are m alternatives and n attributes. The different I alternatives are denoted as x_i. The rating of the jth aspect is denoted as x_{ij} and this is for alternatives x_j. In progress to obtain normalized value, the following Eq. (3.1) can be used by assuming that x_{ij} is the original value of ith option and jth dimension.

$$f_{ij} = x_{ij} \Big/ \sqrt{\sum_{j=1}^{n} x^2{}_{ij}}\,,\ i = 1,2,\dots; m' j = 1,2,\dots,n \tag{3.1}$$

2) Determine the best and worst values

Calculate each criterion's value f_j^* and negative ideal solution's value f_j^- for j = 1,2, …n by using Eq. (3.2) and Eq. (3.3) respectively.

$$f_j^* = \max f_{ij},\ i = 1,2,\dots,m \tag{3.2}$$

$$f_j^- = \min f_{ij},\ i = 1,2,\dots,m$$

3) Determine the weights of attributes

The w_j are the weights of criteria, to express their relative importance.

4) Compute the distance of alternatives to ideal solution

This step is taken for calculating the distance from each alternative to positive ideal solution and sum up all value to obtain final value by referring to Eq. (3.4) and Eq. (3.5).

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right)/(f_j^* - f_j^-) \tag{3.4}$$

$$R_i = \max_j [\, w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-)] \tag{3.5}$$

Where S_i represent the distance rate of ith alternative to the positive ideal solution (best combination), R_i represents the distance rate of the ith alternative to the negative ideal solution (worst combination). The best ranking is based on S_i values and worst ranking is based on R_i values.

5) Calculate the VIKOR values Q_i for $i = 1,2, \ldots, m$. The Eq. (3.6) for Q_i is :

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{3.6}$$

Where v is the weight of strategy of the majority of criteria. If v value is more than 0.5, then index Q_i will shift to majority agreement. If v value is lesser than 0.5, then index Q_i will shift to majority disagreement. Therefore, in general v = 0.5, whereas others represent:

$$S^- = \max_i S_i \, , \qquad S^* = \min_i S_i$$

$$R^- = \max_i R_i \, , \qquad R^* = \min_i R_i$$

6) Rank the alternatives by Q_i values

After insert and calculate all values in each equation, the final value Q_i can obtained to rank the alternatives and make decision.

7) Sorting the rank of alternative by S_i, R_i and Q_i

After calculate and obtain all value of S_i, R_i and Q_i, then proceed for arranging the rank of alternative in ascending order into a table before proceed to checking VIKOR *condition* 1 and 2.

3.3 VIKOR METHOD CONDITIONS

There are two conditions must be done after using VIKOR method.

Condition 1: Acceptable advantage Eq. (3.7):

$$Q(A^{"}) - Q(A') \geq DQ \tag{3.7}$$

Where $A^{"}$ is the alternative with ranked second position in the ranking list by Q;

$DQ = 1, (m-1); m$ is the number of alternatives

Condition 2: Acceptable Stability in decision making:

Alternative A' must also be the best ranked by S or R. This compromise solution is stable within a decision making process, which could be "voting of majority rule" (when The ($v > 0.5$ is needed), or "by consensus" if $v \approx 0.5$, or "with veto" $(v < 0.5)$. The v is the weight of the decision making strategy.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives A' and $A^{"}$ if it is condition 2 are not satisfied
- Alternatives A' , $A^{"}$,..., $A^{(m)}$ if condition 1 are not satisfied; $A^{(m)}$ is determined by the relation $Q(A^{(m)}) - Q(A') < DQ$ for maximum m.

3.4 MATERIAL SELECTION USING VIKOR METHOD

In this study, the best material of natural fibre for brake pad is calculated and ranked from VIKOR method. The objective of this material selection is to select excellent mechanical properties, biodegradable, low cost and widely available material such as natural fibre reinforced polymer composite as one of the reinforced fibre in the brake pad. In order to eliminate the material that unable to fulfil the selection requirement, the general properties, mechanical properties and thermal properties are used in the material screening process. The properties that involve for VIKOR method is the coefficient of friction, thermal conductivity (k), wear, tensile strength (MPa) and hardness.

The Eq. (3.1) is used for a normalized matrix which is the first step in VIKOR method. The properties of brake pad material for VIKOR method are used as C_j represent jth attribute, while the candidates of material is used for A_i represent ith alternative in Eq. (3.1). The result for Eq. (3.1) will be arranged in this form as shown in Figure 3.2. The Eq. (3.2) and Eq. (3.3) are used to determine the maximum and minimum value of jth attributes. The weight of attribute is based on how important of the attribute from journal. Eq. (3.4) and Eq. (3.5) are used to calculate distance of each alternative to positive ideal solution. Good ranking will write on S_i values while worst ranking will write on R_i values. Eq. (3.6) is used for calculate Q_i, VIKOR value of brake pad and finally rank the alternatives based on VIKOR value. After ranking, two conditions are required to be carried out in Eq. (3.7) and Eq. (3.8).

$$f_{ij} = {x_{ij}} \Big/ \sqrt{\sum_{j=1}^{n} {x^2}_{ij}}\,,\ i = 1,2,\dots; m'j = 1,2,\dots,n \tag{3.1}$$

$$f_j^* = \max f_{ij},\ i = 1,2,\dots,m \tag{3.2}$$

$$f_j^- = \min f_{ij},\ i = 1,2,\ldots,m \tag{3.3}$$

$$S_i = \sum_{j=1}^{n} w_j\left(f_j^* - f_{ij}\right)/(f_j^* - f_j^-) \tag{3.4}$$

$$R_i = \max_j[\,w_j\left(f_j^* - f_{ij}\right)/(f_j^* - f_j^-)] \tag{3.5}$$

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{3.6}$$

$$Q\left(A''\right) - Q(A') \geq DQ \tag{3.7}$$

	C_1	C_2	$\cdots$	C_n
A_1	f_{11}	f_{12}	$\cdots$	f_{1n}
A_2	f_{21}	f_{22}	$\cdots$	f_{2n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
A_m	f_{m1}	f_{m2}	$\cdots$	f_{mn}

Figure 3.2: Normalization matrix method

3.5 MATERIAL SELECTION FOR NATURAL FIBRE

The material selection for natural fibre before proceeding to VIKOR method are based on a few conditions. Stage 1 is a limitation stage for natural fibre material candidates to remove the materials from the list that do not fulfil the requirement of brake friction material. The materials are arranged by according to the characteristic of natural fibre such as biodegradable and widely available in the world. The materials contain good mechanical properties that can improve mechanical strength and performance of a brake pad. Stage 2 is searching and screening the materials of natural fibre perform high coefficient of friction. Stage 3 is finding and choosing the materials of natural fibre to contain low thermal conductivity. Stage 4 is the material candidates must have high tensile strength. Stage 5 is the material candidates must have moderate hardness. Stage 6 is about the material candidates should have low wear rate. Combine the result from all stages into a table to proceed for VIKOR method and remove all material candidates which do not fulfil the requirement.

3.6 TABLE OF SELECTION

All the result calculated from VIKOR method is summarised into a table. Based on the result, the ranking of the material candidate is determined. Table 3.1 shows the template table for VIKOR method result.

Table 3.1: Sample template for VIKOR method result (Opricovic, 1998)

Attributes		$C_{j=1}$	$C_{j=2}$	$C_{j=3}$	$C_{j=4}$	$C_{j=n}$
Weights, w_j						
Alternatives	$A_{i=1}$					
	$A_{i=2}$					
	$A_{i=3}$					
	$A_{i=4}$					
	$A_{i=m}$					
f_j^*						
f_j^-						

3.7 COMPARATIVE APPROACH

After the best ranking alternative is obtained, the attribute of the material candidate is used to compare against standard brake pad material attribute. The data for standard brake pad attribute is obtained from Society from Automotive Engineers (SAE international) and Nigerian Industrial Standard (NIS).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Material Selection Table

Initially, the study on the properties of natural fibre and criteria of brake pad was continuously carried out for a few weeks. After gathering and reviewing of important properties of natural fibre in an automotive application, the initial material candidate of natural fibre for brake pad friction material is palm kernel fibre, date palm fibre, sisal fibre and bamboo fibre. However, most of the material candidates are natural fibre reinforced composite and natural fibre reinforced polymer composite. All of the material candidates are biodegradable, environmentally friendly, and easily available. The properties of material candidates are summarised in Table 4.1 before proceeding to VIKOR method. The properties of material candidates used in Table 4.1.

Table 4.1: Properties and Value of Material Candidates

Properties / Natural Fibre	COF (μ)	Thermal Conductivity ($W.m^{-1}.K^{-1}$)	Hardness (HB)	Tensile Strength (MPa)	Wear (%)
Palm Kernel Fibre	0.33	0.696	10	18.62	3.98
Date Palm Fibre	0.52	0.84	84.2	66.2	1.95
Sisal Fibre	0.43	0.25	52	28.6	0.4
Bamboo Fibre	0.31	0.185	22.3	46.7	3.0

4.2 MATERIAL SELECTION RESULTS

The following step is substituting all values into VIKOR method equations. The properties of brake pad material representing the jth attributes while material candidates represent the ith alternatives in normalization matrix for VIKOR method. Coefficient of friction as C_1, thermal conductivity as C_2, hardness as C_3, tensile strength as C_4 and wear as C_5. Meanwhile, date palm fibre as A_1, sisal fibre as A_2, bamboo fibre as A_3, palm kernel fibre as A_4. After all data had gathered and arranged in table, then proceed to normalization matrix tabulation. The results are shown in Table 4.2.

Table 4.2: Normalization matrix results

		COF (μ)	Thermal Conductivity ($W.m^{-1}.K^{-1}$)	Hardness (HB)	Tensile Strength (MPa)	Wear (%)
Attributes		$C_{j=1}$	$C_{j=2}$	$C_{j=3}$	$C_{j=4}$	$C_{j=n}$
Weights, w_j		0.25	0.22	0.16	0.18	0.19
Alternatives	$A_{i=1}$	0.64	0.74	0.83	0.75	0.36
	$A_{i=2}$	0.53	0.22	0.51	0.33	0.07
	$A_{i=3}$	0.38	0.16	0.22	0.53	0.56
	$A_{i=4}$	0.41	0.61	0.10	0.21	0.74
f_j^*		0.64	0.74	0.83	0.75	0.74
f_j^-		0.38	0.16	0.10	0.21	0.07

Table 4.3: Distance of alternatives to ideal solution

	C_1	C_2	C_3	C_4	C_5
A_1	0	0	0	0	0.11
A_2	0.11	0.20	0.07	0.14	0.19
A_3	0.25	0.22	0.13	0.07	0.15
A_4	0.22	0.05	0.16	0.18	0

Results of distance of alternatives to ideal solution is tabulated in Table 4.3 by using Eq 3.4 and Eq 3.5. The highest value distance of alternative to ideal solution is 0.25 from first criteria of 3rd alternative material.

Table 4.4: Distance of PIS and NIS

Alternatives	Distance of PIS (S_i)	Ranking (S_i)	Distance of NIS (R_i)	Ranking (R_i)
A_1	0.11	1	0.11	1
A_2	0.71	3	0.20	2
A_3	0.72	4	0.25	4
A_4	0.61	2	0.22	3

Table 4.4 shows the result for distance of PIS of A_1 value which obtained by getting the sum of A_1 in same row. Next, for result distance of NIS of A_1 , the value is obtained by finding the highest value in the same row of A_1 in Table 4.3.

Table 4.5: Value of distance

S^*	0.11	R^*	0.11
S^-	0.72	R^-	0.25

Table 4.5 shows the highest and lowest value of distance of alternatives to positive and negative ideal solution and its data obtained based on Table 4.4. Figure 4.1 show the graph of VIKOR value against all candidate materials.

Table 4.6: VIKOR value and Ranking

Alternatives	V value	(Q_i)	Ranking
A_1	0.5	0	1
A_2	0.5	0.81	3
A_3	0.5	1	4
A_4	0.5	0.80	2

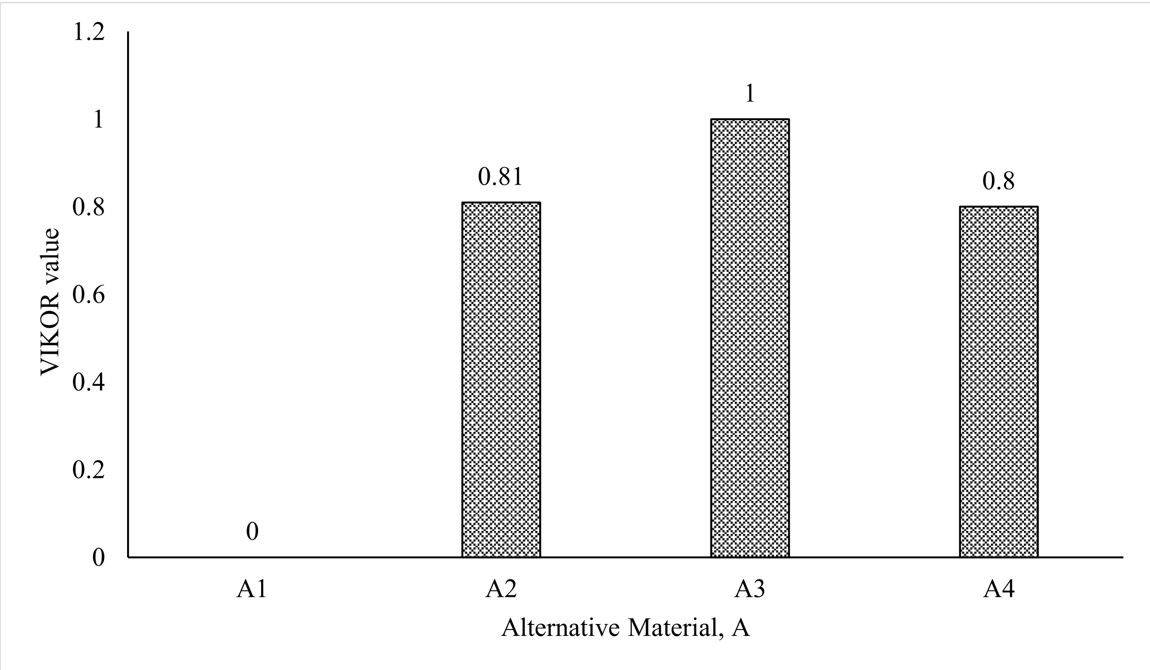

Figure 4.1: VIKOR value against all candidate materials

Sorting the rank of alternative in ascending order by S_i, R_i and Q_i in Table 4.7.

Table 4.7: Ranking of alternative in ascending order

Ranking	(S_i)	(R_i)	(Q_i)
1	A_1	A_1	A_1
2	A_4	A_2	A_4
3	A_2	A_4	A_2
4	A_3	A_3	A_3

4.3 CHECKING ALTERNATIVE FULFIL CONDITION 1 AND 2

Condition 1: (Acceptable advantage)

From Eq 3.7 : $Q(A^{''}) - Q(A') \geq DQ$

DQ = 1 / (4-1) = 0.33

$Q(A_4) - Q(A_1) \geq DQ$ (1st ranking alternative, A_1 satisfy condition 1)

Condition 2: (Acceptable stability in decision making)

Table 4.8: VIKOR value of alternatives with different *v* value

Alternatives	*v* value	(Q_i)	Ranking	*v* value	(Q_i)	Ranking
A_1	0.75	0	1	0.25	0	1
A_2	0.75	0.58	2	0.25	0.73	2
A_3	0.75	1	4	0.25	1	4
A_4	0.75	0.81	3	0.25	0.79	3

The alternative A_1 remain 1st ranking with different *v* value. Furthermore, the alternative, A_1 also best ranked by S_i or R_i. Lastly, the 1st ranking alternative, A_1 do satisfy both condition 1 and condition 2. Alternative A_1, date palm fibre reinforced epoxy composite is chosen as best alternative.

Just as shown in Table 4.2, the normalization method result are conducted by using Eq. 3.1, Eq. 3.2 and Eq. 3.3. Next, regarding the v value in Table 4.6 for all material are the same. The rank for material is $Q_1 > Q_4 > Q_2 > Q_3$, the 1st alternative is the most suitable and best among 4 alternatives for replacing asbestos fibre inside brake pad while 3rd alternative is the worst one.

Therefore, VIKOR method is suitable choice for material selection. By using this method, the best alternative result can be acquired to replace asbestos fibre inside brake pad. The VIKOR method used combination of quantitative method and qualitative analysis, which proved is better than other method.

4.4 COMPARATIVE APPROACH

Table 4.9: Comparison of best ranked alternative against standard brake pad material

Material / Criteria	Date Palm Fibre Reinforced Epoxy Composite	SAE, ASME, NIS and SIRIM Standard (Bahadur, 2003; Blau, 2001; Malaysia Standard, 2003; Nigerian Industrial Standard, 1997)
Coefficient of Friction , (μ)	0.52	≤ 0.55
Thermal Conductivity, ($W.m^{-1}.K^{-1}$)	0.84	0.47-0.804
Hardness, (HB)	84.2	76 -91
Tensile Strength, (MPa)	66.2	$\geq$ 20MPa
Wear, (%)	1.95%	$\leq 10\%$

Since 1st ranked alternative, A_1 criteria values are within international standard brake pad friction material range, therefore alternative A_1, date palm fibre reinforced epoxy composite is accepted as one of components can replace asbestos fibre inside brake pad.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The multi-criteria decision making method is suitable for material selection in the design and application of automotive brake pad. The standard properties and criteria of brake pad were searched from ASME, SAE, NIS and SIRIM. The candidate materials were selected and using VIKOR method to identify the most optimum alternative material. Date palm fibre reinforced composite was identified as best ranked alternative for replacing asbestos fibre inside brake pad. The date palm fibre reinforced composite have good tensile strength, high friction coefficient, good thermal conductivity, low wear and optimum hardness. This project showed that natural fibre reinforced composite capable as a candidate material in manufacturing brake pad and automotive industry able to apply "GO GREEN" concept.

5.2 RECOMMENDATION

For further study this project, some suggestions are using some software such as CES Edupack, Jump and Minitab to filter and select material candidate from natural fibre. The function of software can compare and choose the most suitable material candidate based on criteria requirements of brake pad material. In order to replace asbestos fibre in brake pad, further study is required so that the environment and human safety can be protected.

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