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EFFECTS OFVULCANIZATION IN SEMI-METALLIC FRICTION MATERIALS ON FRICTION PERFORMANCE

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ABSTRACT

The research presented in this paper is focused on the effect of Epoxidised natural rubber (ENR) vulcanization on friction–wear properties of semi-metallic friction composites (SMFC). The friction materials was formulated with the following constituents(vol%): steel wool(32%) as main fiber reinforcement, graphite(7%) as a lubricant, ENR-alumina nanoparticles composites (ENRAN)(47%) as a friction modifier and benzoxazine resin(14%) as a binder. Non-vulcanized samples were produced as acontrol. The vulcanization of ENR affected the properties of the SMFC and a reduction in friction coefficient (μ), hardness as well as porosity and also an increase in volume wear rate (*w*). It could be concluded that in both vulcanized and non-vulcanized samples there isno direct correlation between friction coefficient and wear with hardness and porosity.

Keywords: Friction Materials, Vulcanization, Wear, Friction Coefficient

1. INTRODUCTION

Automotive friction materials are complex composite materials. Earlier researches showed that the friction coefficient and wear characteristics of friction materials depend on a number of different factors such as operating variables, material characteristics, surface geometry, type, design and environment (Filip et al., 1995 and Talib et al., 2001). The four main components of a brake pad,are the reinforcing fibres, binders, fillers and frictional additives (Chan and Stachowiak, 2001).

Fillers, while not as critical as other components such as reinforcing fibres, play an important role in modifying certain characteristics of brake friction material. Actual choice of fillers depends on the particular components in the friction material as well as the type of inorganic fillers (Eriksson et al., 2002). Rubber is an example of commonly used organic fillers. Rubbers were usually incorporated into brake pads for the purpose ofreducing brake noises due to their superior viscoelastic characteristics (Kamioka et al.,1995).

Historically, the term vulcanization referred to the process of heating rubber, sulfur, and white lead. By terminology, the crosslinking process of rubber is often called vulcanization when it involves the utilization of sulfur or sulfur compounds. Crosslinking is a process of forming a three dimensional network structure from a linear polymer by a chemical or physical method (Akiba and Hashim, 1997).

This studY, focused on the effect of ENR vulcanization on friction–wear properties of semi-metallic friction composites (SMFC). The friction materials were formulated with the following constituents(vol%): steel wool(32%) as a mainfibre reinforcement, graphite(7%) as a lubricant, ENRAN(47%) as a friction modifier and benzoxazine resin(14%) as a binder.

2. EXPERIMENTAL METHOD

2.1 Rubber Recipe

The composition used in this study is shown in Table 1.

2.2 Cure Characterizationand Compounding

Compounding was performed in a Haake internal mixer working at 90ºC and a rotor speed of 60 rpm for 6 min. Firstly, ENR was masticated for 1 min before all ingredients except curative agents were added and mixed for another 5 min. Finally,

Table 1 Formulation of the mixes

Ingredient	Loading (phr) [a]
ENR 50	100
Sulfur	1.6
Zinc oxide	2.0
Stearic acid	1.5
CBS[b]	1.9
TMTD[c]	0.9
6PPD [d]	2.0
Alumina	10

[a]Parts per hundred rubber
[b]N-cyclohexylbenthiazylsulphenamide
[c]Tetramethylthiuram disulfide
[d]N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine

curative agents were added into a two-roll mill. From this stock, non-vulcanized samples were cut to allow testing of curing characteristics with a rheometer at 150ºC. Sheets were vulcanized using a semi efficient vulcanization (EV) system in a hot press at 150ºC at the respective cure times (t90), which were derived from rheometer tests.

2.3 Testing

For the porosity tests were cut from the brake pad to a dimension of 25mm×25mm×5mm according to JIS D 4418: 1996 using Tech-Lab Digital Heating Circulator HC 20. The surface was polished smoothly without abrasive powder on its surface. Then the test samples were left in a desiccators at 90 ºC for 8 hours and finally cooled for 12 hours to room temperature in desiccators.

Test samples for friction and wear test were cut from the brake pad backing plate with dimension of 25mm×25mm×6mm according to MS 474 PART10:2003 using LINK CHASE machine. The samples were glued to the braking plate and then attached to brake clipper on brake drum. The friction tests were carried out by pressing test samples against rotating brake drum. Each sample was subjected to friction and wear test according to the test program as shown in Table2.In addition, The test for hardness was carried out using the Shore type D Zwick/RoellDurometer according to ASTM D2240.

Table2 Friction and Wear Test Program

Test sequence	Load (N)	Rotating speed (rpm)	Temperature (ºC)	Remarks
Conditioning	440	312	< 95	Continuous braking 20 minutes
Initial measurement	667	0	88-99	Take indicator reading at 667 N
Baseline run	667	417		Intermittent braking 10 s ON, 20 s OFF
1st fade run	647	417	82-288	Continuous and heater ON
1st recovery run	647	417	288-82	Continuous and cooling ON
2nd measurement	667	417		Repeat initial measurement
Wear run	667	417	193-204	Intermittent braking 10 s ON, 20 s OFF
3rd wear measurement	667	0		Repeat initial measurement
2nd fade run	667	417	82-343	Continuous and heater ON
2nd recovery run	667	417	343-82	Continuous and cooling ON
Baseline re-run	667	417		Intermittent braking 10 s ON, 20 s OFF
Final measurement	667	0		Repeat initial measurement

The weight of the pads for each sample was taken before and after the each test, and the wear was determined with the mass method following the standard of TSE 555 (1992) and calculated using the following equation:

$$w = (1/2\pi R) \times (1/f_m\, n) \times ((m_1 - m_2)/\rho)) \qquad (1)$$

Where w is the wear rate (cm^3/Nm), R is the distance between the centre of specimen and the centre of the rotating disk, m_1 and m_2 are the average weight of specimen before and after the test (g), ρ is the density of the brake lining (g/cm^3), and f_m is the average friction force (N).

Table3 Test Results

Sample	Porosity (%)	Hardness (Shore D)	Friction Coefficient				Wear Rate (cm^3/Nm)
			Cold	Class	Hot	Class	
Non-vulcanized	7.92	79.6	0.45	G	0.32	E	1.35
Vulcanized	4.19	76.6	0.41	F	0.29	E	1.73

3. RESULTS AND DISCUSSION

In this study, the following tests have been performed; (i) porosity, (ii) hardness, and (iii) friction tests. The test results are as shown in Table 3. It was observed that vulcanized samples for semi-metallic brake pad have less porosity, friction coefficient and lower hardness as compared with non-vulcanized pad.

3.1 Vulcanization Against Porosity, Hardness, Friction And Wear

Coran(1978) illustrated the major effects of vulcanization by the idealization. He noted that the static modulus increases with vulcanization to a greater extent than the dynamic modulus. The dynamic modulus is a composite of viscous and elastic responses, whereas the static modulus is a measure of the elastic component alone. Vulcanization, then, causes a shift from viscous or plastic behaviour to elasticity. So theoretically, vulcanized samples will result in lower friction coefficient and higher hardness due to forming a three dimensional network structure from a linear polymer. But this is not the case with friction materials.

3.2Hardness against Friction and Wear

Hardness is a measure of material resistance to plastic deformation. From hardness results, vulcanized sample was softer than the non-vulcanizedsample with a reading of 76.6 and 79.6 respectively. In general, hard metal has lower frictional resistance and lower wear rate than softer metal, but this is not the case with friction materials. Friction material is not homogenous material;When the indenter hits on the metallic component the hardness is higher; otherwise when it hits on polymeric component the hardness is lower. From Table 3, it could be concluded that there is no direct correlation between friction coefficient and wear with hardness of the vulcanized friction materials.

3.3 Porosity against Friction and Wear

Porosity is the percentage of pore volume with the bulk total volume. Theoretically, lower porosity will result in higher friction coefficient and wear rate due to higher contact areas between the matching surfaces. But in friction materials, this

theory does not apply. From the result shown in Table3, it could be concluded that there is no correlation between friction coefficient and wear with hardness of the vulcanized friction materials.

4. CONCLUSIONS

The conclusions based on the tests result are as follows:

(i) The vulcanization of ENR affected the properties of the SMFE and a reduction in friction coefficient (μ), hardness as well as porosity and also an increase in volume wear rate (w).

(ii) Hardness, porosity and vulcanization of friction materials cannot be simply related to the friction and wear.

(iii) Mechanical properties of friction materials depend on type and weight percentage element in the composition, manufacturing process parameters, design and geometry of friction mechanism.

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