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EFFECT OF CASHEW NUT SHELL LIQUID (CNSL) ON TRIBOLOGICAL BEHAVIOR OF BRAKE PAD COMPOSITE

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Abstract: *Effect of CNSL addition as a friction modifier on the wear characteristics and mechanical properties of non-asbestos composites brake pad was investigated. For this purpose, the content of CNSL in the matrix structure was only changed in the range of 0 - 5 wt.% and six different compositions were prepared. Only the amount of resin were changed, other ingredients in the mixture were keept constant. The brake-pad samples were tested for their friction and wear behavior on a pin-on-disk type test configuration according to the NF F 11-292 French standard. It was observed that coefficient of friction of composite decreased with increasing CNSL contents up to 2wt % level, above which coefficient of friction increased. Specific wear rate however, linearly decreased with increasing the amount of CNSL content in the matrix. On the other hand, CNSL addition to the composite matrix decreased the some mechanical properties such as hadness, compressive strength and elastic module of sample, while increased the compressibility values.*

Keywords: *Composite brake pad/shoes, Friction material, CNSL ingredient*

1. INTRODUCTION

Friction materials for trains and automobiles are important parts of the vehicle to slow down and stop the vehicle safely. The characteristics of the brake pad / shoes used as friction material are directly affecting the braking performance of the vehicles. Therefore, they should have effective braking performance under different variable conditions such as speed, temperature, humidity and pedal pressure. In last decades, these commercial products have been produced in the form of composite structure consisting of more than 10 ingredients instead of the single friction materials produced from cast iron in order to achieve the best combination of performance properties of friction materials at a broad variety of braking circumstances [1]. All these ingredients added in the brake pad composite material have an effect on the friction or physical properties of the brake pads. Therefore, type and amount of each ingredient must be selected correctly in the matrix structure of the brake pads. These additives used were collected in four classes of materials named as fiber, binder, friction modifier and space filler according to their effects on the friction and wear performance of brake pad [2].

Increasing demand to produce faster and more powerful vehicles has also dramatically changed the desired performance outputs from the brake friction materials. Many researchers have extensively studied the effects of types and amounts of these ingredients on the friction and wear performance of friction materials in recent years [3-6]. However, in the literature, very limited studies have been undertaken regarding the effect of CNSL additions into the brake pad matrix structure on the mechanical and tribological properties of the brake pad [7]. The purpose of this study is to investigate the effect of CNSL addition on the friction characteristic and mechanical properties of non-asbestos brake pad composite. For this purpose, with five different CNSL content was chosen to be 1, 2, 3, 4 and 5 wt.%. In the present work, periodic braking test according to the NF F 11-292 French standard was conducted on the specimens to analyze their tribological performance. Some mechanical tests were also performed to determine the mechanical properties of composite brake pad samples. Also, scanning electron microscopy (SEM) and 3D surface analysing were used in order to elucudate the wear mechanisms.

2. MATERIAL AND METHODOLOGY

The composition of the composite sample is given in the Table 1. All samples consist of seven constituents; binder (phenolic resin), filler (barite), fiber (rockwool and kevlar), lubricant (graphite) and friction modifier (CNSL) and abrasive (magnetite). Only the concentration of the binder (resin) and friction modifier (CNSL) were changed while the concentration of other ingredient were kept constant to be 80 wt.% in all compositions. The CNSL was added into the composite between 1 - 5wt% by replacing phenolic resin in the pad formulation. All ingredients were mixed for 5 min in a high-speed blender to ensure macroscopic homogenization of the mixture. Subsequently, about 10 g of the mixture was compressed under the pressure of 50 bar into a compression mold pre-heated to 90 °C. Temperature of the mold was then increased to 150 °C, and the samples were cured in the mold under a pressure of 50 bar for 10 min. Finally, post-curing was carried out by using an electrical resistance furnace at 200 °C for 20 min to achieve curing all of the resin into the matrix. All samples produced were then polished with 1000 and 2000 grit SiC papers to attain surface smoothness. Surface hardness of the test samples was measured by a hardness tester (Rockwell Mettest-HT) with a 19.3 mm ball-indenter under the maximum load of 60 kg. The compressive strength and elastic modulus (E) of the samples was determined using a tension / compression test machine (Instron 3382) with cylindrical test samples having the diameter of 20 mm and the thickness of 15 mm. The elastic module (E) of the samples was determined by using the Eq. 1 given below.

A specific pin-on-disc type test system was used to perform friction and wear tests of the brake pad samples. The sample size for friction test was 20 mm in diameter and 15 mm in thickness. The counter disc was made of AISI 52100 steel with the surface roughness (Ra) of about 0.05 mm and hardness of 55-58 HRC. The disc rotated at the speed of 2800 rpm corresponding to the sliding speed of 26 $m.s^{-1}$ (95 km/h). During braking, the 80 kg normal load (corresponding to about 0.8 MPa) was applied to the samples by means of hydraulic cylinder for 20 s and then removed for 150 s. This is called one cycle and this was repeated fifteen times for the testing of each sample. Friction force and coefficient of friction (CoF) was recorded during the tests depending on time. The specific wear rate ($\boldsymbol{Q}$) of the samples was determined by using the Eq. 2 given below. After tribological tests, the worn surfaces of the samples were scanned using a 3D surface profilometer and examined by scanning electron microscopy (SEM) to analyze the wear characteristic of the samples in detail.

$$E = \frac{F\ (N)}{\pi R^2} \text{x} \ \frac{Lo}{\Delta l} \quad (1)$$

Where;

E: Elastic Modulus (MPa)
F: Applied load (N)
R: Radius of the sample (mm)
Lo: Initial thickness of the sample (mm)
Δl: The thickness change (mm)

$$Q = \frac{m\,(g)\,.\,10\text{^}6}{X\,.\,F\,(N)\,.V\left(\frac{m}{s}\right).\,\mu\,.\,t\,(s)\,.\,\rho\,(\frac{g}{cm3})} \quad (2)$$

Where;

Q: Specific wear rate (cm^3/MJ)
m: Weight Loss (g)
X: Number of braking period
F: Applied Normal Load (N)
V: Test speed (m/s)
μ: Average coefficient of friction
t: Braking time in one period (s)
ρ: Density of sample (g/cm^3)

Table 1. Composition of the investigated composite samples.

Element	Composition (wt.%)					
	Base	S1	S2	S3	S4	S5
Phenolic Resin	20	19	18	17	16	15
CNSL	0	1	2	3	4	5
Others	80					

3. RESULTS AND DISCUSSION

3.1 Physical and mechanical properties

Hardness values, compressive strength, compressibility test results and elastic modules of the friction materials are given in Table 2.

Table 2. Physical and mechanical properties of the composite samples.

	Base	S1	S2	S3	S4	S5
Density (g/cm3)	2,05	2,05	2,05	2,05	2,05	2,05
Hardness (HRX)	97	91	88	87	84	82
Compressive Strength (MPa)	128	157	155	150	140	125
Compressibility (μm)	87	92	97	95	113	122
E-Module (MPa)	1520	1290	1180	1150	1070	995

Change in the amount of CNSL affected the physical and mechanical properties of a friction material. Compressive strength and hardness values of the samples decreased generally with increasing CNSL content in the matrix structure, while the compressibility test values increased. This is an expected result. Because the addition of CNSL was balanced only by reducing the same amount of phenolic resin in the matrix. The decrease in the amount of phenolic resin which bonds all ingredients of the brake pad caused to weaken the binding effect. This resulted in a reduction in the mechanical properties of the friction materials.

3.2 Friction and wear behavior

Variation of friction coefficient of the samples with number of braking cycle are presented in Fig. 1. The average friction coefficient values taken from these curves calculated after the 15 cycles friction test are given in the Fig. 2. The results in these figures demonstrated that addition of CNSL as a friction modifier in the main matrix structure resulted in a significant change in the coefficient of friction of the CNSL-free sample. The friction coefficient of the base sample changed over 15 braking cycles. It was about 0.21 in the first braking period and reached to about 0.32 after the 15th braking period. On the other hand, fluctuation was observed at every loading period of friction test for base sample (Fig. 1.) Addition of CNSL in all contents reduced the average coefficient of friction (~0.27) of the base sample. The average friction coefficient was obtained as 0.17 after 1 wt.% CNSL addition and reached to a minimum value of 0.13 with the 2 wt.% CNSL addition. However, when the CNSL content was chosen more than 2 wt.%, friction coefficient start increasing. Average friction coefficient was determined to be 0.18 for the sample having 5 wt% CNSL content. In addition, it was observed that the samples with varying CNSL content have smooth friction coefficient curves during each braking period and 15 braking test cycles.

As can be seen in Fig. 2, addition of CNSL into matrix brought about a reduction in the specific wear rate of composite samples after the 15 cycles braking tests. Unlike the friction coefficient of the samples, their specific wear rate decreased linearly with increasing CNSL content in the matrix structure. The reduction in the amount of specific wear can be explained in terms of increasing in the contact surface area between the sample and the rotating disc. As the contact surface increases, more homogeneous and relatively low wear takes place as also clearly understood from the SEM and 3D images of the worn surfaces of sample (Fig. 3). As seen in Fig.3, primary and secondary plateaus formation controlling the wear of materials were observed on the worn surfaces of all composite samples. However, distribution of these plateaus on the worn surface varied according to the CNSL content of the samples. As seen in Fig. 3, a thick layer of wear debris that generally consists of degraded or melted organic materials was observed on the worn surface of base sample. In general, the debris layer which loosely adhered to the bulk of the composite underneath breaks away from the worn surface and/or transferred to the counter disc surface. The fluctuation observed in the friction coefficient and more wear of the base sample can be associated with this situation. The worn surface is very smooth with increasing CNSL content. As the CNSL ratio increased, the modulus of elasticity of the composite increased and resulted in larger contact surface between the disc and tested sample. This contributed to the dissipation of heat generated at the rubbing surface over the entire surface and resulted in more uniform wear of samples including CNSL.

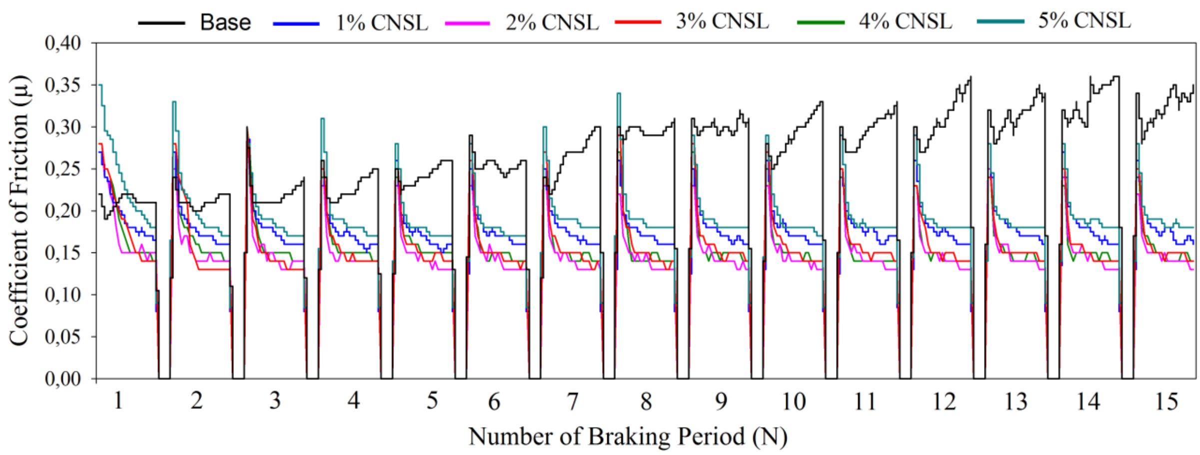

Figure 1. The change of coefficient of friction as a function of number of braking for all friction composites.

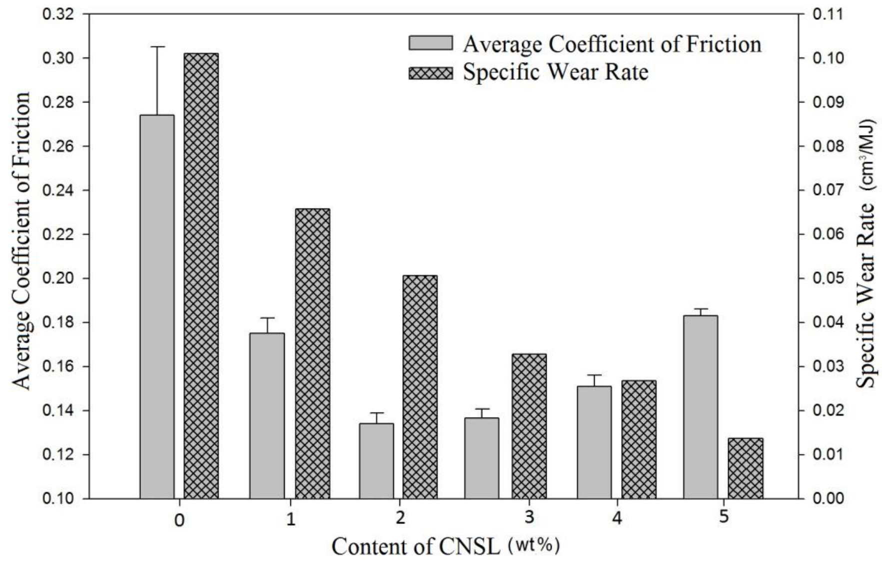

Figure 2. Average coeffient of friction and specific wear rate of composite sample with variying content of CNSL.

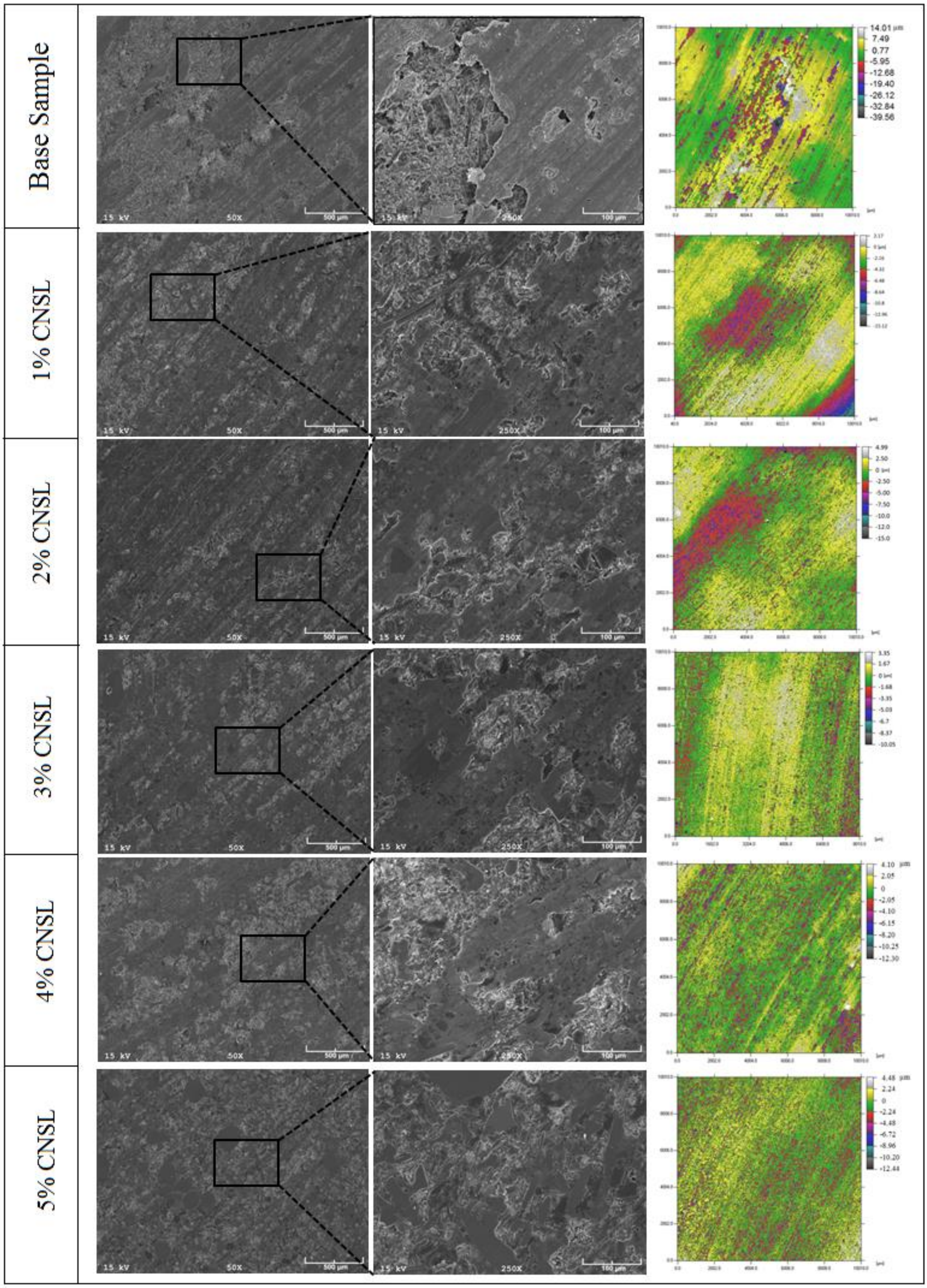

Figure 3. SEM images and 3D topographic view of worn surface of composite sample sample having different amount of CNSL.

4. CONCLUSIONS

- As the CNSL content in the main matrix structure increases, compressibility, hardness and elasticity modulus of the composite sample decrease while confine and unconfine compressibility values increase.
- Average coefficient of friction of base composite sample were determined to be 0.27 duruing the 15 cycles braking test. A parabolic decrease was observed in the average friction coefficient values of composite sample with increasing CNSL content up to 2.0%, above which it start increasing.
- The stability of the friction coefficient changed during the wear tests with increasing the CNSL content. Base composite sample (CNSL-free sample) has a poor friction stability with high amount of fluctuations in friction coefficient values. The best frictional stability was obtained in the composite sample having 5 wt.% CNSL.
- The wear resistance of sample increases with increasing the CNSL content due to better surface contact between the sample and rotating disk.
- The roughness (or waviness) of worn surface of composite samples increased with decreasing the CNSL content in the matrix due to thier high elastic modulus.
- The composite mixture having the highest amount of CNSL (5 wt.%) was proposed to be the most appropriate one considering the mechanical properties and wear behavior of composite sample.

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