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# Inertia Dynamometer Evaluation of Automotive Brake Pads produced from Palm Kernel Shell

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**Abstract:- This study investigates the use of inertia dynamometer as an alternative to actual vehicle testing for evaluation of automotive brake pad produced from palm kernel shell. The usage of palm kernel shell in place of asbestos in the production of brake pad was an attempt to enhance agricultural waste management and usage for automotive applications. Palm Kernel Shell (PKS) at varying percentages were added to aluminum oxide, calcium oxide, calcium carbonate and epoxy resin based on 176g weight of commercial brake pads. The produced pad were evaluated using the inertia dynamometer and Microstructural observation of samples were carried out to ascertain the wear pattern and distribution of various additives in friction materials using a digital metallurgical microscope.**

***Keywords:-*** *Inertia dynamometer, brake pad, palm kernel shell, wear rate, friction coefficient, asbestos.*

## I. INTRODUCTION

The evaluation of friction mechanisms of braking systems is a complex task as brake pad manufacturers strive constantly to improve the performance of brake pads complying with the changing laws (Waldemar et al, 2019). Research has shown the use of small sample friction machines such as friction material testing machines which do not correspond to the vehicle brake duty cycle in ascertaining brake pad performances. As a result, the performances of these braking materials when subjected to vehicle testing do not match. However, vehicle testing is not only time consuming but also very expansive. Also, certain conditions such as the climate which are not under the control of the researcher makes this option a very cumbersome one (J. Preston, 1973). Automotive brakes functions by converting the vehicle's kinetic energy into heat energy. During braking, the heat is first borne by the two contact surfaces of the brake, namely the brake disc and the brake pad (or drum and shoe in the case of drum brakes) which is then transferred to the contacting components of the brake such as the callipers as well as the surroundings.

However, to ensure safety during driving, the importance of brake pads testing cannot be over looked. The inertia dynamometer, a device designed to test brake pads and discs from automotive ranging from light to heavy duty vehicles allows for testing of brake pads and disc during braking (Stanisław et al, 2019). The results obtained (Preston et al, 1970) showed the dynamometer produced results similar to those obtained through vehicle tests. This research paper aims at carrying out an inertia dynamometer evaluation of the properties of asbestos free brake pads produced from palm kernel shell in comparison with commercially available brake pads.

## II. MATERIALS AND EXPERIMENTAL PROCEDURE

The palm kernel shell (PKS) used were obtained from cracked palm kernel nuts and dried under the sun for two weeks. This is to remove moisture from the shells. Using a hammer mill, the dried PKS were reduced to powdered form and sieved to 100 μm using BS 410 Standard sieves. Chemical composition of PKS was performed using an XRF machine. The brake pads were developed by varying the percentage of the sieved PKS added to aluminium oxide, calcium carbonate and epoxy resin based on 176g weight of commercial brake pad. To achieve homogeneous state ready for moulding, the combinations (shown in Table 1) were dry-mixed separately using a blender and transferred separately into a designed mould placed on the backing plate and pressed at 100kN for 2 minutes at room temperature and cured at 250ºC for 90mins. It was finished by grinding to standard size of 16mm thickness. One of the samples developed is shown in Fig 1.

Fig. 1: Produced Brake Pad Sample.

## III. TESTING

The produced brake pads were evaluated using inertia dynamometer with specifications as; maximum drive power of 375kW (540HP), max drive torque of 2527Nm, max drive speed of 2500rpm (400km/h), max brake torque of 25000Nm, flywheel inertia of Max/Min 1900/400 kgm$^2$, pressure brake of 6000N*2, acceleration time of 1min 30 sec and test wheel diameter of Ø 700, 1120 mm. Microstructure of samples were examined to describe the wear pattern and distribution of various additives in friction materials using a digital metallurgical microscope.

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| Brake Additives | | Epoxy- resin | Palm kernel shell (PKS) | Aluminium oxide | Graphite | Calcium carbonate |
|---|---|---|---|---|---|---|
| Samples in percentage by weight (% wt) | $S_1$ | 19 | 6 | 0 | 5 | 70 |
| | $S_2$ | 40 | 10 | 6 | 29 | 15 |
| | $S_3$ | 23 | 27 | 10 | 10 | 30 |
| | $S_4$ | 25 | 30 | 5 | 5 | 35 |
| | $S_5$ | 15 | 35 | 5 | 5 | 40 |
| | $S_6$ | 30 | 40 | 5 | 5 | 20 |

Table 1: Material composition of used additives

| Elements | Concentration value | Concentration error | Unit |
|---|---|---|---|
| K | 31.80 | ±0.8702 | Wt.% |
| Ca | 17.1344 | ±0.4991 | Wt.% |
| Ba | 2.6701 | ±0.0200 | Wt.% |
| V | 26784 | ±308 | Ppm |
| Cr | 6051 | ±107 | Ppm |
| Mn | 2.4391 | ±0.0101 | Wt.% |
| Fe | 28.431 | ±0.0101 | Wt.% |
| Ni | 4.3461 | ±0.0101 | Wt.% |
| Cu | 4.6780 | ±0.0101 | Wt.% |
| Zn | 2.4601 | ±0.0101 | Wt.% |
| Se | 5433 | ±101 | Ppm |
| Sr | 3304 | ±101 | Ppm |
| Br | 6023 | ±101 | Ppm |

Table 2: Elemental composition of pks

## IV. RESULTS AND DISCUSSIONS

### *A. Elemental Composition*

The elemental composition of the PKS (Presented in Table II) were found to contain basically semi metals and non-metals and these elements are usually found in asbestos which suggests that PKS can equally replace asbestos in the production of brake pads.

### *B. Porosity*

The variation of porosity with speed for the produced brake pads as shown in Fig. 2 remains constant with varying speeds of 5.56 to 27.78m/s. The obtained values of porosity (16-20%) were similar with those given by Ibhadode and Dagwa (16-22.45%), Chand et al (13-23%) and the commercial brake pads (18%).

### *C. Frictional Coefficient*

Jang et al (2004) explained the importance of change in brake's coefficient of friction as a function of speed. He noted that drivers expect same level of friction force at various conditions which often varies as the speed changes. The coefficient of friction obtained for all samples were constant as speed varied from 8.33m/s to 27.78m/s and the values of friction coefficient ranged from 0.17-0.35 as shown in Fig 3. This constant frictional coefficient could be as a result of the non-inclusion of steel fibre as it plays a major role in the increase of frictional coefficient (El-Tayab and Liew, 2009). It could also be attributed to the non-formation of cold welding and rupture of asperites on the virgin brake pad surface (Liew and Nirmal, 2013). This implies no detached asperites were trapped between the sliding surfaces. Another possibility could be the inability of formation rates of oxides as a result of high and flash temperatures at the interface as explained by Ikpambese et al (2016).

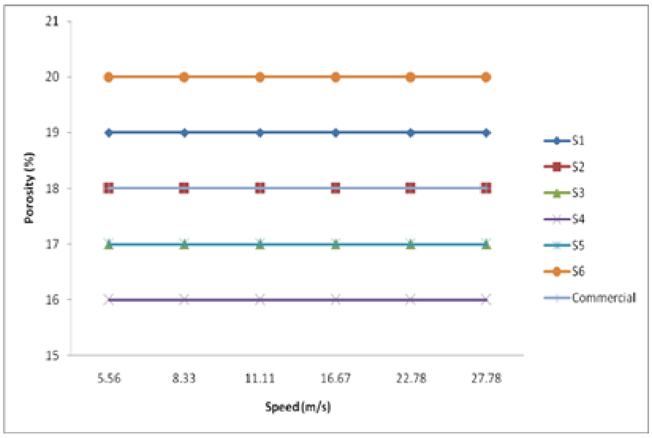


Fig. 2: Variation of porosity with speed for 100 % PKS brake pad samples.

### *D. Wear Rate*

The change of wear rate with speed for produced brake pads alongside the commercial pads were examined as shown in fig 4. An increase in wear rate as speed increases was observed for the produced samples alongside the commercial ones. However, these values tend to differ for different formulations due to the introduction of different additives and weight percentage compositions. This trend is in agreement with Ibhadode and Dagwa (2008) who stated that increase in speeds creates an increase in contact pressure between rotor and brake pads thereby causing an increase in the wear rate. The wear values (3.5-4.0 mg/m) are within the dynamometer standards and observed to be higher when compared to the 4.20 and 4.40mg/m reported by Aigbodion et al (2010). The results obtained also indicated low values of wear rate obtained for some samples could be attributed to the type of binder used for the formulation of the pads.

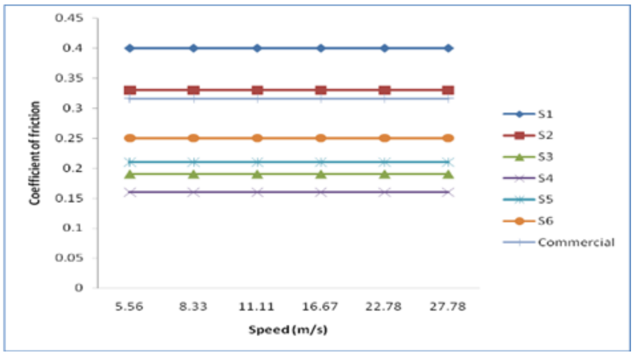


Fig. 3: Variation of Frictional Coefficient with Speed for 100% PKS brake pad samples

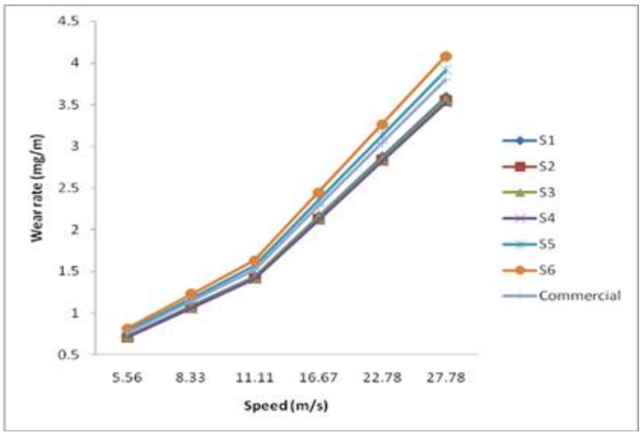


Fig. 4: Variation of Wear Rate with Speed for 100% PKS brake pad samples

## E. Hardness

The time (hours) taken for brake pads to return to their original form after maximum stress is exerted is known as brake pad hardness. As shown in fig 5, this varied from 6.1hrs to 9.6hrs which when compared to values obtained by WanNki et al, 2012 (45.34hrs to 59.83hrs) are better and in line with the values obtained for commercial ones (9.38hrs)

## F. Effect of Moisture

The values 1.04 -2.8% (Fig 6) was obtained from produced brake pad samples and when compared with the standard values of 0-2% given by the inertia dynamometer, and the 1.01% obtained from the commercial brake pads it can be observed that with varied speed, the effect of moisture remained constant.

## G. Noise Level

Noise level generated by produced brake pads (31-47dB) alongside their commercial counterpart (40dB) were examined and presented in Fig 7. It was however observed that excluding S5, the noise levels increased with increasing speed in accordance to formulations, the slope differed.

## H. Temperature

The relationship between temperature and speed was examined and presented in Fig 8. It was observed that temperature rises linearly with an increase in speed and similar findings were reported by Lewis and Nirmal (2013). The temperature rise for brake pads produced varied from 122 – 800 $^{0}$C and compared well with Talib et al (2012) value of 572ºC and 650ºC obtained by the commercial pad.

## I. Water and Oil Absorption Rates

The relationships between water, oil absorption rates and speed for produced brake pads alongside their commercial counterpart as presented in fig. 9 and 10 respectively were seen to be constant as the speed varied. The water and oil absorption varied from 0.276 x $10^{-7}$ $m^2/s$ to 1.14 x $10^{-7}$ $m^3/s$ and 0.31 x $10^{-7}$ $m^2/s$ to 0.263 x $10^{-7}$ $m^3/s$ respectively. The values obtained when compared with the standard values of 0.288 x $10^{-7}$ $m^3/s$ and 0.0 x $10^{-7}m^3/s$ respectively given by the inertia dynamometer were in agreement, and compared well with the value of 1.18 x $10^{-7}$ $m^3/s$ obtained by the commercial pad.

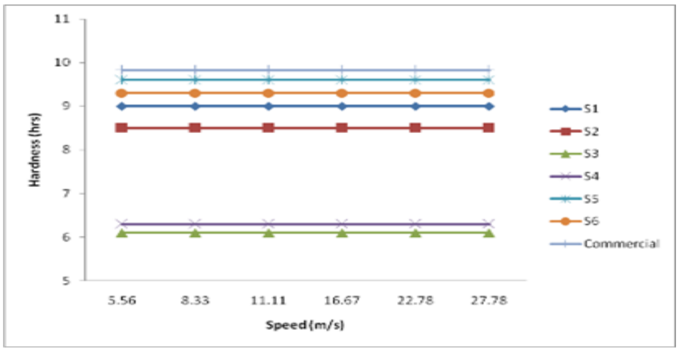


Fig. 5: Comparison of Hardness with Speed

## J. Stopping Time

The time taken by brake pads to bring a moving vehicle to a halt is known as stopping time. This normally increases as the speed of the vehicle increases. As presented in Fig 11, the variation of stopping time with speed indicates an increase from 5.56 to 27.78m/s thus agreeing with the trend reported by Ibhadode and Dagwa (2008). The stopping time for the PKS pads varied from 3.06 to 7.4 s which are better than the values of 4.1 s reported by Ibhadode and Dagwa (2008) and 4.09 for the commercial brake pads at 27.78m/s.

## K. Specific Gravity

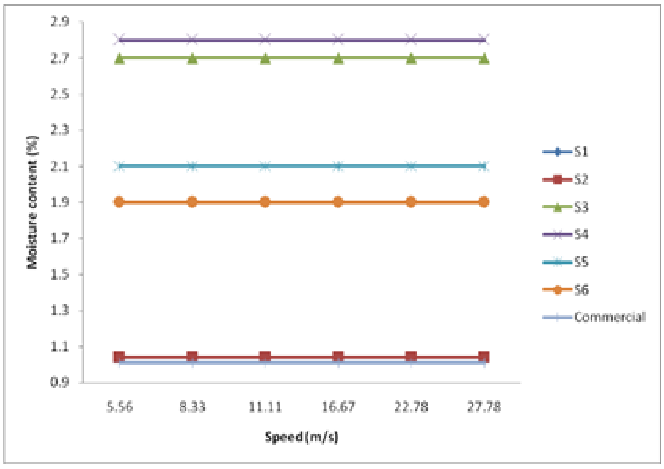


Fig. 6: Relationship between Moisture Content and Speed for 100% PKS Brake Pad sample

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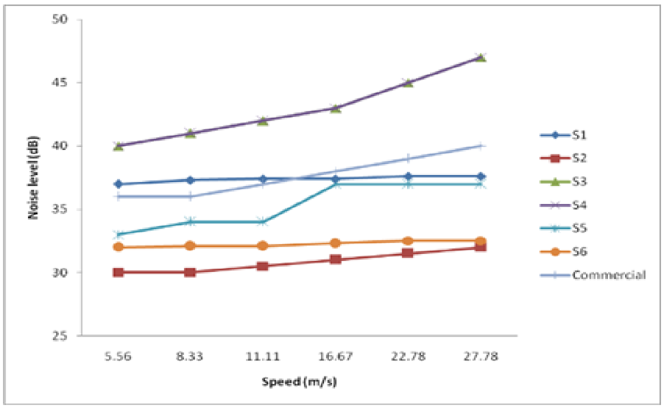


Fig. 7: Relationship between Noise Level and Speed for 100% PKS Brake Pad sample

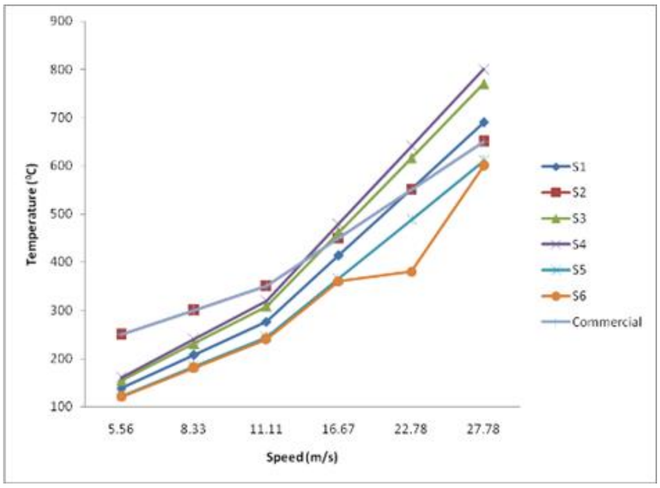


Fig. 8: Relationship between Temperature and Speed

*L. Surface Roughness*

Fig. 15 shows the surface roughness of the produced brake pads along with the commercial pad. It was also observed that surface roughness remained constant with increased speed. The surface roughness of produced samples varied from 2.41 – 3.09 and agreed with the values of 2.04–2.97, reported by WanNik et al. (2012).

*M. Microstructural Observation*

Figs. 12 represents the microstructural observations of worn and unworn surfaces for produced brake pads. Observations were in agreement with those of Idris et al, 2015; by Efendy et al. (2010), and Ibhadode and Dagwa (2008). No cracks or degradation of additives was observed on the examined surfaces signifying the surfaces possess high wear resistance. Also, surfaces were observed to be characterized by abrasion wear (where asperities were ploughed) thereby exposing the white regions on the surface thus increasing the smoothness of the friction materials. Confirming the observations reported by Koya and Fono, 2010 the microstructure revealed wear grooves parallel to disk rotation.

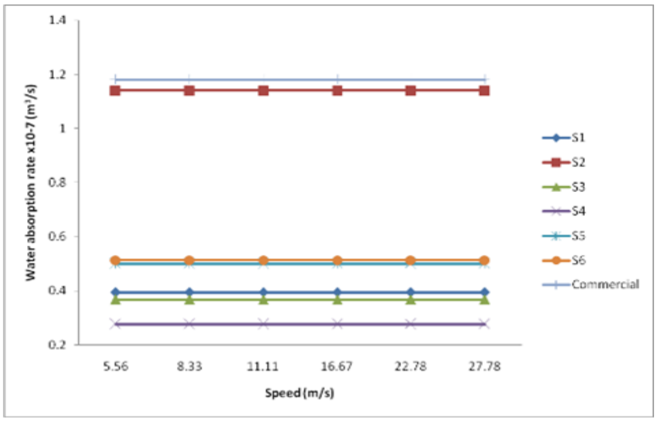


Fig. 9: Relationship between Water Absorption Rate and Speed

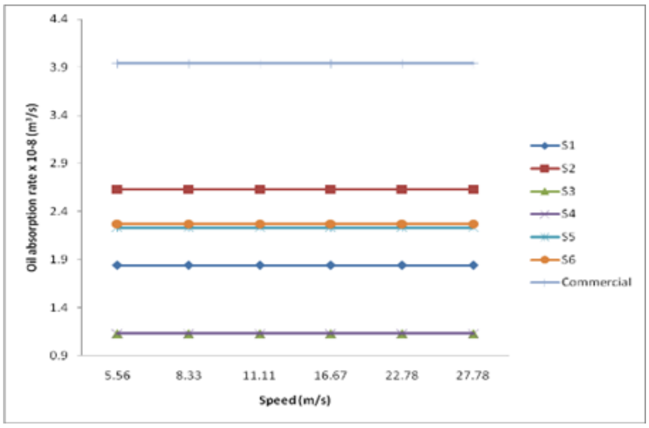


Fig. 10: Relationship between Oil Absorption Rate and Speed

The values of other Engineering properties (see Table IV) when evaluated at constant speed of 100km/hr indicated that most properties agreed with the values obtained when compared with their commercial counterparts since from the evaluation scale, most values were in the range of Average which shows the produced PKS pads are of good and usable quality.

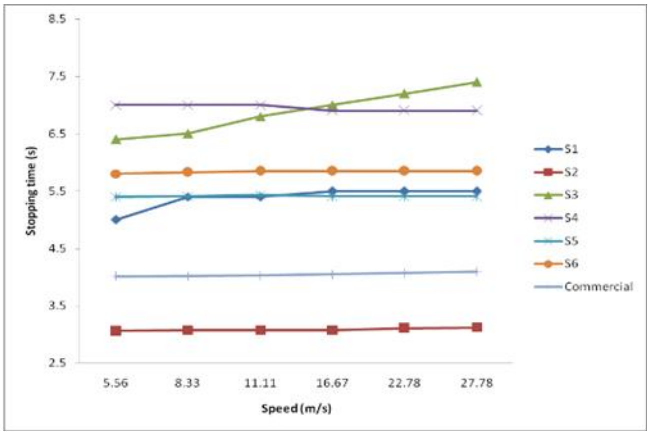
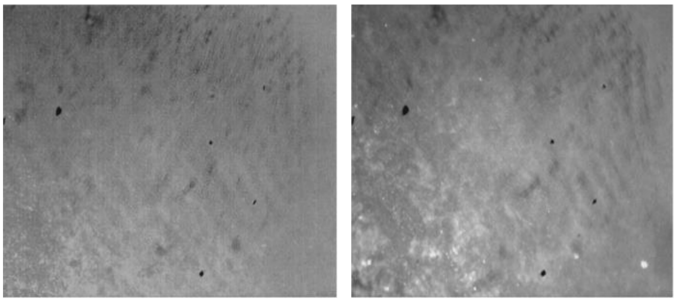
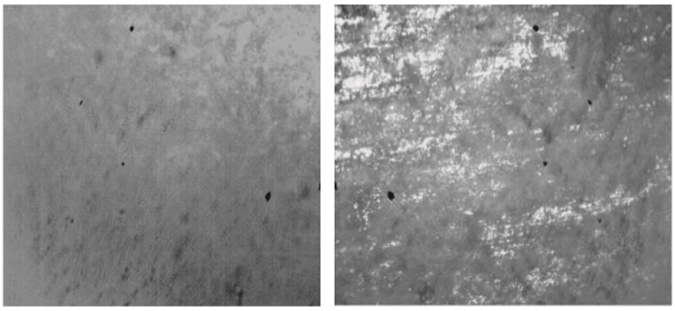


Fig. 11: Variation between Stoppage Time and Velocity



Sample S1 (a & b)

Fig. 12: Surfaces of Samples S1 to S6



Sample S2 (a & b)

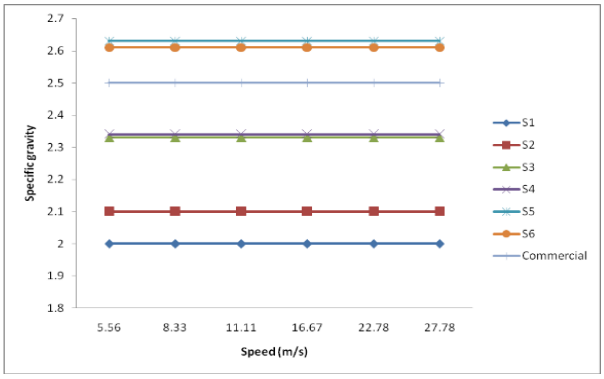
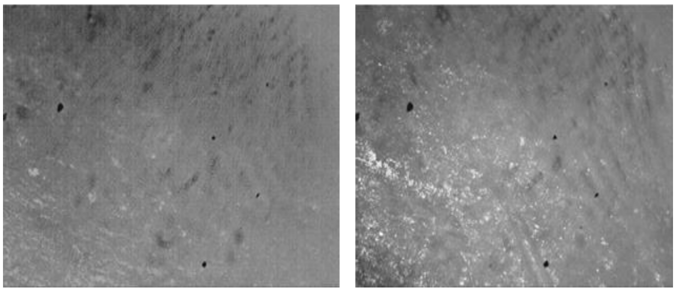
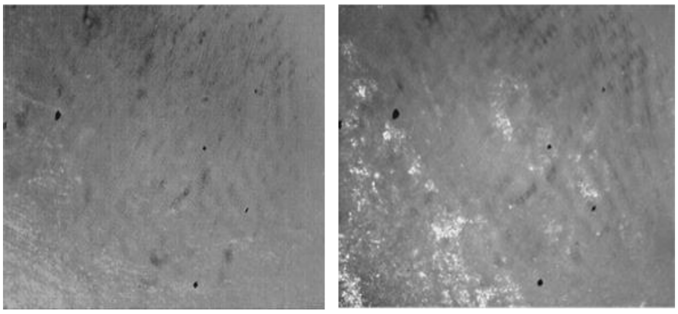


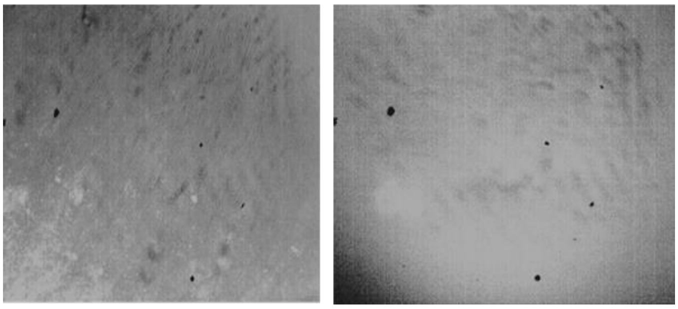

Fig. 13: Variation between Stoppage Time and Velocity



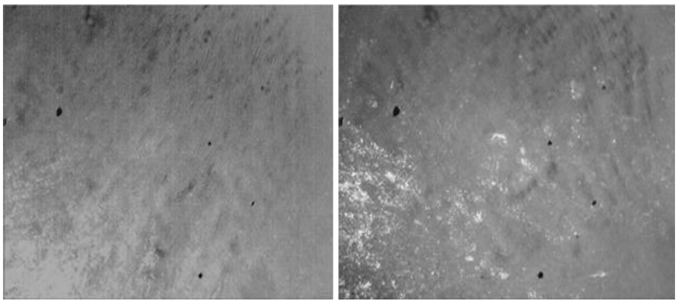
Sample S3 (a & b)



Sample S4 (a & b)



Sample S5 (a & b)



Sample S6 (a & b)

Table 4: Other Basic Engineering Properties.

| PROPERTIES | Mechanical Overload | Thermal Deformation | Fading Behavior | Shear Strength | Cracking Resistance | Over-heat Recovery | Effect on rotor disc | Caliper Pressure | Pad grip Effect | Pad dusting Effect |
|---|---|---|---|---|---|---|---|---|---|---|
| **COMMERCIALS** | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 4 | 3 | 2 |
| **S1** | 2 | 1 | 1 | 2 | 3 | 3 | 2 | 2 | 3 | 3 |
| **S2** | 1 | 2 | 1 | 1 | 1 | - | 1 | 2 | 3 | 1 |
| **S3** | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 1 | 2 | 2 |
| **S4** | 3 | 3 | 3 | 2 | 3 | 1 | 1 | 2 | 2 | 4 |
| **S5** | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 |
| **S6** | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 |

**Evaluation Scale**

| Rating | Value |
|---|---|
| Low | 1 |
| Medium | 2 |
| Average | 3 |
| High | 4 |

## V. CONCLUSION

The inertia dynamometer evaluation of automotive brake pads developed from palm kernel shell (PKS) was investigated and based on the results obtained from the microstructural observations and other properties determined and evaluated, it can be concluded that the inertia dynamometer is a great substitute for evaluating brake pad functions in the absence of real vehicle testing.

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