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Parametric Effects on the Coefficient of Friction of a Novel Composite Material for Automobile Brake Linning

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Abstract: Brake lining, a friction lining material has over the years been produced mainly from asbestos. Asbestos health hazards have necessitated the need to source friction lining materials from other safer directions. A novel composite from local materials was developed. The brake lining production was a dispersion hardening process by the techniques of powder metallurgy of finely divided particles of the raw material powder mix. The raw materials included sawdust, resin, rubber latex, clay, carbon black, brass chips, zinc oxide and sulphur. The friction lining material thus produced, with its friction coefficient was analysed relative to its responses to increasing temperatures and pressures. The environment of increasing temperatures and pressures is its operating condition, in situ. Temperature range studied was from 300C-3000C, while pressure range was from 50KPa-250KPa. Results of the analysis showed the fiction coefficient not adversely affected, with minimum value at 0.31 and maximum value at 0.56.

Keywords: Brake Lining, Temperature, Pressure, Coefficient of Friction, Composite Material

1. Introduction

Brake linings have been traditionally manufactured from asbestos. However, the cost, scarcity, and health hazards associated with asbestos have driven researchers to seek for cheap, locally available, and environmentally friendly materials to replace asbestos.

Generally, all modern designs are avoiding asbestos materials because of these health hazards [1]. In addition, asbestos is now banned in all developed countries on account of its cancer related health hazards.

Asbestos-based brake linings have long been imported into the country, Nigeria. This is partly because of the dearth of basic and local raw materials, plus the production technology that had not been developed on ground until recently. A lot of foreign exchange had thus been spent on importing such asbestos-based brake lining materials.

Indeed materials selection in the area of composite is creating new grounds for engineering materials, in their work [2] used Agro waste composite to produce material for brake lining, Also the use of eco-friendly materials in the production of brake lining cannot be over-emphasized [3] used domestic waste with Taguchi analytical tool for the production of brake lining.

Development of alternative brake linings based on locally sourced raw materials will therefore surely conserve the much-needed foreign exchange hitherto wasted on the importation, especially in a unilateral revenue earner country such as Nigeria. Hence, the development of the brake linings based on locally sourced raw materials and in commercial quantities too, will surely help to boost the country's already ailing economy. In this work, we considered a combination of materials for the production of brake lining that is comparable with the existing brake linings in the market. The performance of the produced brake lining was critically analyzed in the areas of the effects of temperature and pressure on the coefficient of friction [4]. This was to bring into focus their mutual and individual effects on the two major challenges to the brake lining performance, namely, brake fade and brake squeal [5]. These two challenges are directly related to the coefficient of friction of brake linings during their performance and operation usually at high temperatures and pressures. In fact, they are actually caused by the drop in the coefficient of friction. High temperatures bring about drop in the coefficient of friction and so have great propensities to brake fade and brake squeal effects. Increasing pressures affect temperature at a given rubbing velocity as well as rate of wear and the smearing of the softer component, which in turn affects pressure coefficient [6]. Incidentally, high temperatures are induced by friction heat and basically, the principles and performance of the brake linings are based on friction [7].

Thus, this paper analyses the performance of the novel brake lining in terms of coefficients of friction versus varying temperatures and pressures.

2. Materials and Method

The selected raw materials used for the production of the brake lining included sawdust (main material), resin, rubber latex, clay, carbon black, brass chips, zinc oxide, and sulphur. Sawdust, a product of wood formed about 45% by weight of the materials for friction lining. It is there for bulk and mechanical strength of the brake lining. Cellulose an ingredient in the sawdust also accounts for the strength of the brake lining because of its linkage with the bonding agents, also added in the brake lining [8]. The brownish iroko sawdust was preferred to the white wood species because of the inherent and natural strength qualities of iroko wood. The iroko sawdust was sourced from a wood factory in Enugu, Nigeria. Sawdust of about 10 litres by volume was initially collected, dried and sieved because of its coarse composition. The sieving process was done with a common domestic sieve, which falls between 80-325 mesh. Flame test was conducted on the sawdust to estimate the degree of flammability. This was necessary because brake lining operation is based on the conversion of mechanical energy into heat through friction. The flame test involved putting some sawdust into a pan placed over an operating gas cooker. It was observed that the sawdust in the pan charred under three minutes suggesting relatively high flammability and then the need to lower it. Hence, fire retardant was added to lower the flammability. This procedure conforms to [9]. However, fire retardant had to be added sparingly and optimally too because of its adverse effects of reducing friction, which is very crucial and critical to the performance of the brake lining.

The resin used was phenol formaldehyde and it was thermosetting. This was used along with rubber latex, which was added in small quantities. The two acted as binders and also bonding agents. Clay was further added also to act as fire retardant and friction particles. This was very important because of the high flammability of the sawdust. Carbon black was also added in small quantities in order to impart more mechanical strength and black colour to the brake lining. Brass chips were added for better wear resistance and in order to reduce disk scoring or galling [10]. However, optimal amount too, needed to be added since superfluous amount leads to over resistance [11]. Finally, small pebbles of zinc oxide and sulphur were added to act as vulcanizing agents. The equipment used for the study included a pan, a gas cooker, sieves (the common domestic cassava sieves which fall between 80-325 mesh), a cylindrical metal container (of dimensions 100mm diameter and 43mm in depth), a hydraulic jack and a mould assembly.

Characterization of the final mix, sieve analysis and particle size distribution were done using several sieves to determine the size distribution which would provide the basis for checking the specific grading requirements.

2.1. Mould Assembly

This was produced by welding plain carbon steel sheets into a mould according the dimensions of the Peugeot 505 saloon brake linings. Six such moulds were constructed with three in each row and each mould was fitted with a plunger made of hard steel pipe with a flat head conforming to the top internal dimensions of the mould cavity.

2.2. The Brake Lining Production Process

The brake lining production was a dispersion hardening process using the techniques of powder metallurgy of finely divided particles of raw materials powder mix [12]. The production equipment consists of the mould assembly comprising moulds, plungers, sleeves, thermometers and pressure gauges, all enclosed in a fibre glass casing set up on the hydraulic jack. Each mould contained a recycled backing steel plate at the base of the cavity. The recycled backing steel plate was also from the Peugeot 505 saloon car brake lining.

The production involved subjecting the raw materials powder mix in the mould cavities to the following process operations in series:

(a) Cold Pressing, that is pressing (at 6.75-7.00MPa) without heating at room temperature for 10-15 minutes.

(b) Sintering, that is heating (at 205-210^{0}C) without pressure at atmospheric pressure for 15-20 minutes [13].

(c) Hot Pressing, that is heating with pressure (at 205-210^{0}C and 6.75-7.00MPa respectively) for 15-30 minutes.

Additional baking and curing processes of the product followed. This was for the enhancement of hardness, wear resistance and other mechanical properties [14]. The produced samples were subsequently cooled, weighed and dimensions measured before subjecting them to laboratory tests and finally to road performance tests for final confirmation of their operation and reliability.

2.3. Measurement of the Effects of Pressure and Temperature on the Coefficient of Friction.

The reason for these tests is the fact that brake linings, in situ, operate under varying pressures and temperatures. The increasing pressures on the brake linings subsequently result in the generation of heat due to friction [11].

The apparatus used for tests included, steel plate (with smooth surface), flat board (with frictionless pulley attached at the end), insulated support, hydraulic press, wide board (in direct contact with the hydraulic press), 0-400^{0}C range thermometer and electric stoves.

Smooth steel plate was fixed on a flat board with a frictionless pulley attached to one end. The flat board was insulated underneath. The brake lining sample was placed on the polished smooth steel plate and clamped to it by the hydraulic press [15]. A string was connected to the brake lining sample and passed through the frictionless pulley to a variable weight at its end, and this provided the horizontal force F_s to move the brake lining sample forward. The hydraulic press provided variable pressures from where each vertical force W corresponding to a definite horizontal force F_s was calculated. The electric stoves provided the heating and the thermometers measured the variable temperatures. The brake lining sample was clamped to it by the hydraulic press. For a particular temperature, more and more weights were added to pull the string until the brake lining sample just started to move forward slowly along the smooth steel plate due to the action of the horizontal force F_s. As the brake lining just started moving forward, the horizontal force F_s changed to F_d in motion for each value of normal force W. That was in similarity with [16].

The coefficient of static friction μ_s is given by [17]:

$$\mu_s = \frac{F_s}{W} \qquad (1)$$

Similarly, the coefficient of dynamic friction μ_d is also given by:

$$\mu_d = \frac{F_d}{W} \qquad (2)$$

and

$$W = PA_p$$

Where:

W = Normal Force, P = Pressure as provided the hydraulic, and A_p= Brake lining contact area.

The experiment was performed with different values of vertical force W, ranging from 200- 1000N, that is for separate pressures of 50KPa, 100KPa, 150KPa, 200KPa and 250KPa; then for variable temperatures ranging from room temperature (30^{0}C) to 300^{0}C.

3. Results and Discussion

Table 3.1 below shows the values at constant pressure of 50KPa with static coefficient of friction μ_s and dynamic coefficient of friction μ_d obtained from equations 1 and 2 above for seven experimental runs at temperatures ranging from 30-300^{0}C . Also in the table are the normal static force F_s and normal dynamic force F_d.

3.1 The Effects of Temperature and Pressure on the Coefficients of Friction

Presented below are the effects of temperature and pressure on the coefficient of friction for sample material Figure 1 revealed the effects of temperature and pressure on the novel composite material for brake lining. The static coefficient of friction μ_s and dynamic coefficient of friction μ_d curves at 50KPa mutually displayed similar patterns, but with the value for the static coefficient of friction μ_s at room temperature (30^{0}C) at 0.48, while that for dynamic coefficient of friction μ_d was 0.44. Both increased steadily with temperature till their common peaks at 100^{0}C where static coefficient μ_s was 0.56 and dynamic coefficient μ_d was 0.51.Beyond 100^{0}C, both deceased till at a minimum and common turning point at 200^{0}C with static coefficient μ_s at 0.45 and dynamic coefficient μ_d at 0.41. From here, both again increased till 300^{0}C where static coefficient μ_s read 0.48 and dynamic coefficient μ_d read 0.44 and it is in line with the study of [18].

Table 1. Coefficient of Friction at Constant Pressure of 50KPa and Variable Temperatures from 30-3000C

T(^{0}C)	F_s (N)	$\mu_s = F_s/W$	F_d (N)	$\mu_d = F_d/W$
30	96	0.48	88	0.44
50	104	0.52	96	0.48
100	112	0.56	102	0.51
150	96	0.48	86	0.43
200	90	0.45	82	0.41
250	90	0.45	82	0.41
300	96	0.48	88	0.44

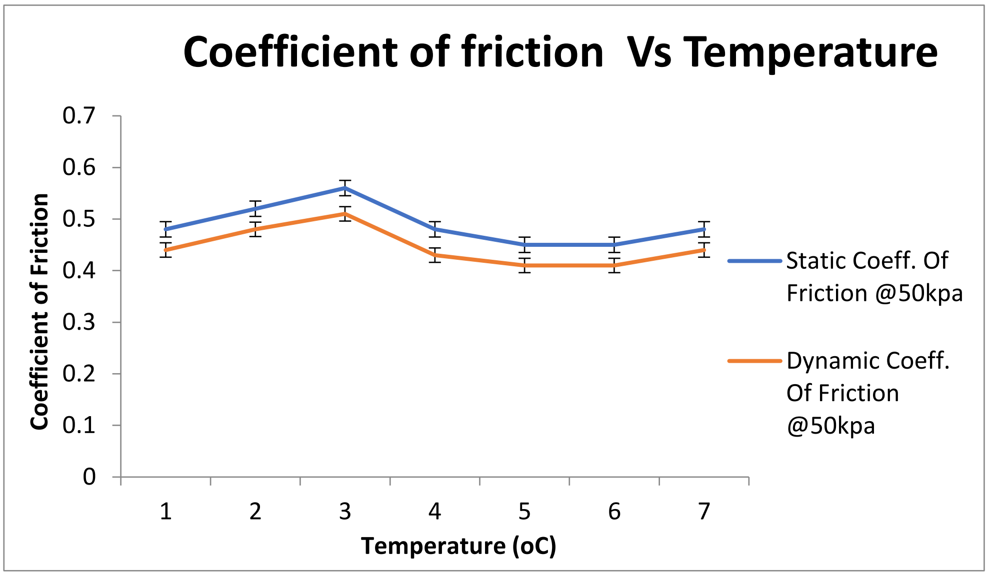

Figure 1. Static and Dynamic Coefficients of Friction at 50KPa

Table 2. Coefficient of Friction at 100KPa Constant Pressure and Variable Temperatures from 30-3000C

T(^{0}C)	F_s (N)	$\mu_s = F_s/W$	F_d (N)	$\mu_d = F_d/W$
30	188	0.47	172	0.43
50	200	0.50	184	0.46
100	212	0.53	192	0.48
150	188	0.47	172	0.43
200	176	0.44	160	0.40
250	172	0.43	156	0.39
300	192	0.48	176	0.44

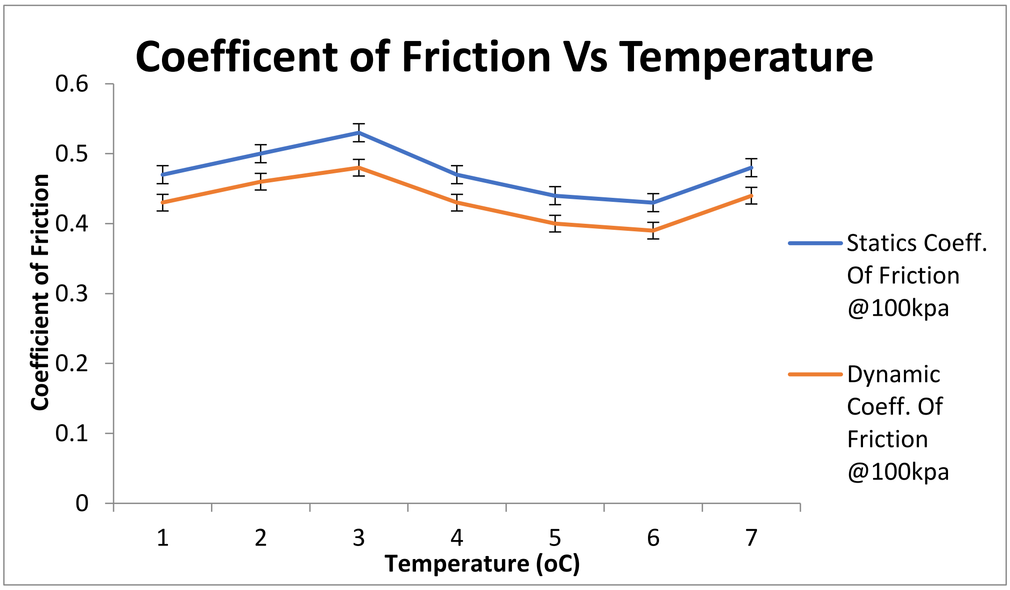

Figure 2. Static and Dynamic Coefficients of Friction at 100KPa

Table 2 above shows the values at constant pressure of 100KPa with static coefficient of friction μ_s and dynamic coefficient of friction μ_d for seven experimental runs at temperatures from 30-300^{0}C. Also in the table are the normal static force F_s and normal dynamic force F_d.

Figure 2 shows the effect of temperature and pressure on the novel composite material for brake lining. The static coefficient of friction μ_s and the dynamic coefficient of friction μ_d at 100KPa maintained the same mutual relationship as existed at 50KPa, except that static coefficient μ_s value at peak temperature (100⁰C) was 0.53 while the dynamic coefficient μ_d value was 0.8; also the turning point values changed to 0.43 and 0.39 respectively, before rising finally to 0.48 and 0.44 respectively at 300⁰C temperature This discussion is in agreement with [19].

Table 3 shows below the values at constant pressure of 150KPa with static coefficient of friction μ_s and dynamic coefficient of friction μ_d for seven experimental runs at temperatures from 30-300⁰C. Also in the table are the normal static force F_s and normal dynamic force F_d.

Figure 3 shows the effects of temperature and pressure on the novel composite material for brake lining. The dynamic and static coefficients of friction at 150KPa continued the same mutual relationship as we had for 100KPa, with values at peak (100⁰C) as 0.49 and 0.45 for static coefficient μ_s and dynamic coefficient μ_d

Respectively; while values at turning point (250⁰C) were 0.39 and 0.35 for static coefficient μ_s and dynamic coefficient μ_d respectively, and finally rising to 0.40 and0.37 for static coefficient μ_s and dynamic coefficient μ_d respectively at 300⁰C temperature, this also agrees with the analysis carried out by [20].

Table 4 below shows the values at constant pressure of 200KPa with static coefficient of friction μ_s and dynamic coefficient of friction μ_d for seven experimental runs at temperatures from 30-300⁰C. Also in the table are the normal static force F_s and normal dynamic force F_d.

Figure 4 shows the effects of temperature and pressure on the novel composite material for brake lining. The static and dynamic coefficients of friction at 200KPa also maintained similar mutual relationship as obtained for 150KPa, with values at peak (100⁰C) at 0.47 and 0.43 for static coefficient μ_s and dynamic coefficient μ_d respectively. Turning point was at 250⁰C with values at 0.35 and 0.32 for static coefficient μ_s and dynamic coefficient μ_d respectively; while at 300⁰C, values increased to 0.38 and 0.35 for static coefficient μ_s and dynamic coefficient μ_d respectively. This as well agrees with [21].

Table 5 below shows the values at constant pressure of 250KPa with static coefficient of friction μ_s and dynamic coefficient of friction μ_d for seven experimental runs at temperatures from 30-300⁰C. Also in the table are the normal static force F_s and normal dynamic force F_d.

Figure.5 shows the effects of temperature and pressure on the novel composite material for brake lining. The dynamic and static coefficients friction at 250KPa maintained the usual mutual pattern, with values at peak (100⁰C) at 0.42 and 0.39 for static coefficient μ_s and dynamic coefficient μ_d respectively. Turning point was at 200⁰C for static coefficient μ_s with value at 0.32, while at 250⁰C for dynamic coefficient μ_d with value at 0.3, this is in line with [22].

Generally, the static coefficient of friction values were observed to be steadily higher than their dynamic coefficient counterparts.

Both from 50KPa-250KPa generally had a common peak at 100⁰C.

Between 100⁰C and 250⁰C, they were decreasing with increasing temperatures for all pressures, starting from room temperature (30⁰C) and increased with increasing temperatures for all pressures up till 200KPa. However, for 250KPa they decreased with increasing temperatures between 100⁰C and 200⁰C.

Generally, maximum observed value for the two coefficients of friction for all temperatures and pressures under analysis was 0.56, while minimum value was 0.31. This range is not adverse for brake lining performance and operation.

Table 3. Coefficient of Friction at 150KPa Constant Pressure and Variable Temperatures from 30-3000C

T(⁰C)	F_s (N)	$\mu_s = F_s/W$	F_d (N)	$\mu_d = F_d/W$
30	264	0.44	246	0.41
50	288	0.48	264	0.44
100	294	0.49	270	0.45
150	282	0.47	258	0.43
200	234	0.39	216	0.36
250	234	0.39	210	0.35
300	240	0.40	222	0.37

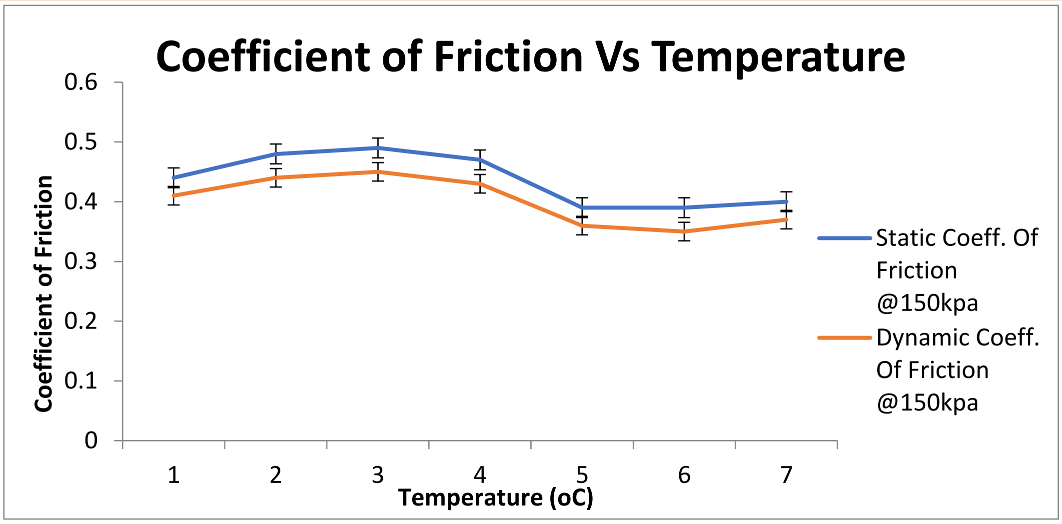

Figure 3. Static and Dynamic Coefficients of Friction at 150KPa

Table 4. Coefficient of Friction at 200KPa Constant Pressure and Variable Temperatures from 30-3000C

T(^{0}C)	F_s (N)	$\mu_s = F_s/W$	F_d (N)	$\mu_d = F_d/W$
30	320	0.40	296	0.37
50	352	0.44	320	0.40
100	376	0.47	344	0.43
150	312	0.39	288	0.36
200	280	0.35	256	0.32
250	280	0.35	256	0.32
300	304	0.38	280	0.35

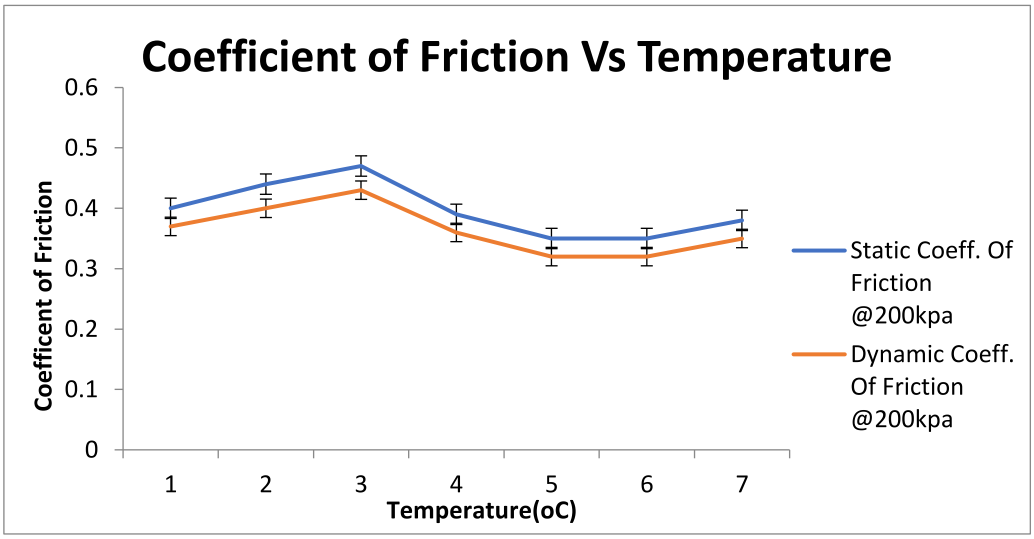

Figure 4. Static and Dynamic Coefficients of Friction at 200KPa

Table 5. Coefficient of Friction at 250KPa Constant Pressure and Variable Temperatures from 30-3000C

T(^{0}C)	F_s (N)	$\mu_s = F_s/W$	F_d (N)	$\mu_d = F_d/W$
30	400	0.40	370	0.37
50	410	0.41	380	0.38
100	420	0.42	390	0.39
150	350	0.35	320	0.32
200	320	0.32	300	0.30
250	330	0.33	310	0.31
300	340	0.34	310	0.31

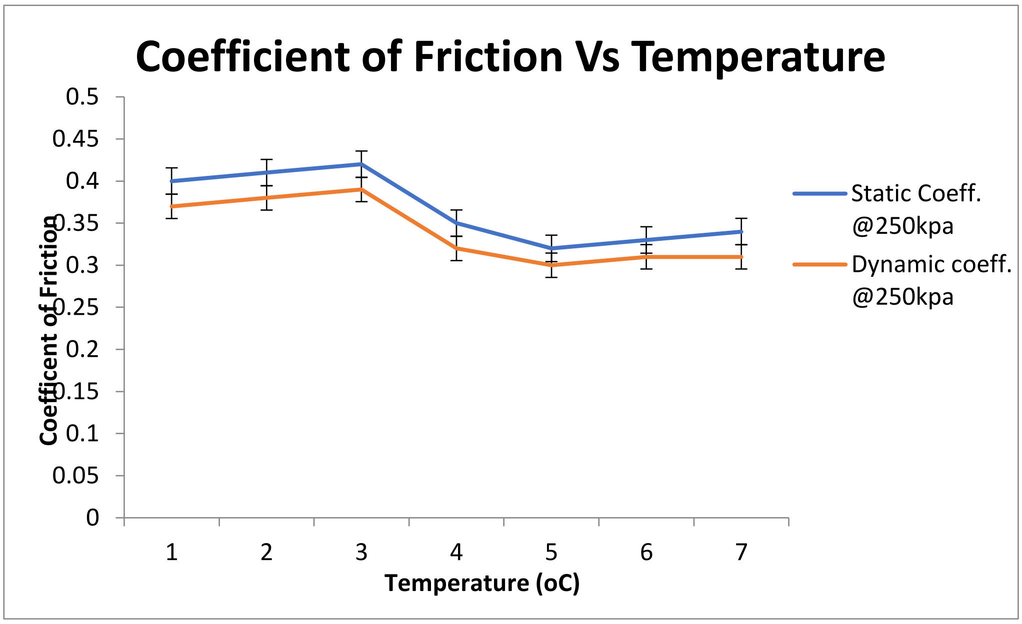

Figure 5. Static and Dynamic Coefficients of Friction at 250KPa

4. Conclusion

The recorded ranges of values for the coefficients of friction are comfortable for brake lining operation in automobiles since they neither have the propensity to brake fade and brake squeal (both are caused by excessive coefficient of friction), nor are they prone to galling and scoring (both are caused by low coefficient of friction).

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Author Contribution Statement

Benedict Iyida conducted the experiments, collected data and contributed in writing the manuscript while Azubuike Nwankwo supervised and contributed in developing the manuscript, Thomas Onah Proofread and edited the work. All authors read and approved the final manuscript.

Has this article screened for similarity?

Yes

Conflict of Interest

The Authors have no conflicts of interest on this article to declare.

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