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Parametric Effects of Moisture On the Coefficient 0f Friction of a Novel Composite Material for Automobile Brake Lining

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ABSTRACT: *Automobile brake lining, a friction material has over the years been produced mainly from asbestos. The health problems of asbestos necessitated the need to source friction-lining materials from other safer directions. A novel composite from local materials was developed. The production was a dispersion hardening process using the techniques of powder metallurgy of finely divided particles of the raw materials powder mix. The raw materials included sawdust, resin, rubber latex, clay, carbon black, brass chips, zinc oxide, and sulphur. The effect of moisture on the coefficient of friction* μ_s *was analyzed in comparison with known brake lining material- Ferodo. The immersion of both materials in water for a few minutes and testing each with pressures of 100KPa and 200KPa corresponding to normal forces of 400N and 800N respectively was done. The gradual decreasing rate of the coefficients of friction* μ_s *for both Ferodo and Novel Samples (after shoot-up at removing them from water into air) was the reversing back recovery process of their friction coefficients* μ_s *to pre-immersion values of 0.39 for dry Ferodo and 0.42 for the dry Novel Sample respectively. This average recovery process showed an overall positive comparison of the average responses of the Novel Sample against Ferodo. Furthermore, the curves of 100KPa for the vertical normal force W of 400N and the curves of 200KPa for the vertical normal force W of 800N, and their corresponding horizontal forces* F_s *were essentially similar because* F_s *is proportional to W.*

KEYWORDS: coefficient of friction, moisture, brake lining, materials, effects.

INTRODUCTION

Brake linings have been traditionally manufactured from asbestos. However, the cost, scarcity, and health hazards associated with asbestos have driven researchers to seek cheap, locally available, and environmentally friendly materials to replace asbestos. Generally, all modern designs are avoiding asbestos materials because of these health hazards **(Towoju, 2019).** 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 the ground until recently. A lot of foreign exchange had thus been spent on importing such asbestos-based brake lining materials.

Development of alternative brake linings based on locally sourced raw materials will therefore surely conserve the much-needed foreign exchange hitherto wasted on importation, especially in a unilateral revenue earner country such as Nigeria. Hence, the development of 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 μ_s **(Obidiegwu, Mgbemere, Ochulor, & Ajayi, 2020).** 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 **(Ogbeide & Anwule, 2019).** These two challenges are directly related to the coefficient of friction μ_s of brake linings during their performance and operation usually at high temperatures and pressures. They are caused by the drop in the coefficient of friction μ_s. High temperatures bring about a drop in the coefficient of friction μ_s and so have great propensities to brake fade and brake squeal effects. Increasing pressures affect the temperature at a given rubbing velocity as well as the rate of wear and the smearing of the softer component which in turn affects the pressure coefficient **(Naveen, Ajayi, Goyal, & Kunvar, 2021).** Incidentally, high temperatures are induced by friction heat and the principles and performance of the brake linings are based on friction **(Pradnya, Pradeep, & Ranjendra, 2020).** This paper detailed and dispassionately investigates the effects of moisture on the coefficient of friction μ_s of the novel brake lining and its subsequent rate of recovery.

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 the 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 to the brake lining **(Avant, Samir, & Arvind, 2018**). 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 liters 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. A 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 it **(Zhang, et al., 2019).** 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 perfectly thermosetting. This was used along with rubber latex which was added in small quantities. The two acted as binders and bonding agents. Clay was further added 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 to impart more mechanical strength and black colour to the brake lining. Brass chips were added for better wear resistance and to reduce disk scoring or galling **(Liker & Banu, 2021).** However, optimal amount too needed to be added since superfluous amount leads to over-resistance **(Belhocine & Bouchetara, 2013**). 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.

Mould Assembly

This was produced by welding plain carbon steel sheets into a mould according to 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.

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 **(Keyan, et al., 2020). T**he production equipment consists of the mould assembly comprising molds, 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 (**Kumbhar, Patil, & Sawant, 2017**).
(c) Hot Pressing, which 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 **(Agarwal, Bharadi, Bhukan, Dewangan, & Shenkar, 2021).** 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.

Measurement of the Effects of Moisture on the Coefficient of Friction μ_s and the Rate of Recovery.

The reason for these tests is the fact that moisture is a serious and interesting challenge to the performance of brake linings in the automobile industry. Since water is a lubricant, it is expected to reduce the coefficient of friction μ_s, especially when brake linings are saturated in it, which may lead to the reduction of the efficiency of the brake linings in service **(Chinedum, Richard, Chika, & Chike, 2022).** When the brake lining is thoroughly wet, it becomes ineffective because the lining is lubricated by a film of water of low coefficient of friction $\boldsymbol{\mu_s}$**.** With sufficient contact with water, the brake lining saturates heavily because of its high texture porosity. Usually, in operation, it is unavoidably and frequently subjected to moisture, especially during the rainy season when it is inevitably exposed to heavy doses of moisture **(Secrist & Hornbeck, 1976)**. That happens when the wheel installed with the brake lining navigates through water pools. Then the brake lining heavily soaks in water. Driving sessions through ordinary marshy swamps are also enough to impart appreciable moisture onto the brake lining.

The apparatus for the test included a steel plate (with smooth surface), wedge, supporting block, level ground, two flat boards (one with a frictionless pulley attached at the end), insulated support, hydraulic press, wide board (in direct contact with the hydraulic press), bucket and 0-500 gm range weighing balance. The brake linings were weighed dry and later immersed in water in the bucket for a few minutes. This ensured maximum saturation of the brake linings with water since they have high texture porosity. Thereafter, they were weighed again. Respective coefficients of friction μ_s were recorded after weighing dry, before immersion, during immersion, and subsequently after weighing at the end of immersion.

The experiment was performed serially with 400N normal force corresponding to 100KPa for a first set of four samples of the novel brake lining material; then with 800N normal force corresponding to 200KPa for the second set of the novel brake lining material (totaling eight samples), all at 30^0C ambient temperature. Thereafter, the experiment was repeated for eight corresponding samples of the traditional Ferodo brake lining, already in use in the market.

The following tables show the effects of moisture on the coefficient of friction μ_s on brake linings at 100KPa before immersion in water, during immersion in water, and after immersion in water; all at 30^0C ambient temperature**.**

Table 1: Effects of Moisture on the Coefficient of Friction μ_s of Ferodo Brake Lining and Novel Sample 1 at 100KPa and 30^0C Ambient Temperature.

	Ferodo			Novel 1		
Time (m)	**F_s (N)**	**Force W (N)**	$\mu_s = F_S/W$	**F_s (N)**	**Force W (N)**	$\mu_s = F_S/W$
-10	**156**	400	**0.39**	**168**	400	**0.42**
0	112	400	0.28	100	400	0.25
10	200	400	0.5	240	400	0.6
20	196	400	0.49	232	400	0.58
30	188	400	0.47	228	400	0.57
40	184	400	0.46	228	400	0.57
50	184	400	0.46	224	400	0.56
60	180	400	0.45	220	400	0.55
70	180	400	0.45	220	400	0.55
80	180	400	0.45	208	400	0.52
90	180	400	0.45	200	400	0.5

Table 2: Effects of Moisture on the Coefficient of Friction μ_s of Ferodo Brake Lining and Novel Sample 2 at 100KPa and 30^0C Ambient Temperature

	Ferodo			Novel 2		
Time (m)	**F_s (N)**	**Force W (N)**	$\mu_s = F_S/W$	**F_s (N)**	**Force W (N)**	$\mu_s = F_S/W$
-10	160	400	0.4	164	400	0.41
0	112	400	0.28	80	400	0.2
10	200	400	0.5	248	400	0.62
20	196	400	0.49	240	400	0.6
30	188	400	0.47	232	400	0.58
40	184	400	0.46	228	400	0.57
50	184	400	0.46	224	400	0.56
60	180	400	0.45	220	400	0.55
70	180	400	0.45	208	400	0.52
80	180	400	0.45	192	400	0.48
90	180	400	0.45	180	400	0.45

Table 3: Effects of Moisture on the Coefficient of Friction μs of Ferodo Brake Lining and Novel Sample 3 at 100KPa and 30^{0}C Ambient Temperature

	Ferodo			Novel 3		
Time (m)	F_s (N)	Force W (N)	$\mu_s = {F_S}/{W}$	F_s (N)	Force W (N)	$\mu_s = {F_S}/{W}$
-10	156	400	0.39	164	400	0.41
0	112	400	0.28	80	400	0.2
10	200	400	0.5	256	400	0.64
20	196	400	0.49	256	400	0.64
30	188	400	0.47	252	400	0.63
40	184	400	0.46	248	400	0.62
50	184	400	0.46	240	400	0.6
60	180	400	0.45	236	400	0.59
70	180	400	0.45	236	400	0.59
80	180	400	0.45	228	400	0.57
90	180	400	0.45	220	400	0.55

Table 4: Effects of Moisture on the Coefficient of Friction μs of Ferodo Brake Lining and Novel Sample 4 at 100KPa and 30^{0}C Ambient Temperature

	Feredo			Novel 4		
Time (m)	F_s (N)	Force W(N)	$\mu_s = {F_S}/{W}$	F_s (N)	Force W(N)	$\mu_s = {F_S}/{W}$
-10	156	400	0.39	168	400	0.42
0	112	400	0.28	92	400	0.23
10	200	400	0.5	240	400	0.6
20	196	400	0.49	240	400	0.6
30	188	400	0.47	232	400	0.58
40	184	400	0.46	224	400	0.56
50	184	400	0.46	224	400	0.56
60	180	400	0.45	224	400	0.56
70	180	400	0.45	216	400	0.54
80	180	400	0.45	212	400	0.53
90	180	400	0.45	204	400	0.51

The following tables show the effects of moisture on the coefficient of friction μs on brake linings at 200KPa, before immersion in water, during immersion in water and after immersion in water; all at 30^{0}C ambient temperature.

Table 5: Effects of Moisture on the Coefficient of Friction μs of Ferodo Brake Lining and Novel Sample 1 at 200KPa and 30^{0}C Ambient Temperature

	Ferodo			Novel 1		
Time (m)	F_s (N)	Force w(N)	$\mu_s = F_S/W$	F_s (N)	Force w(N)	$\mu_s = F_S/W$
-10	320	800	0.4	336	800	0.42
0	224	800	0.28	200	800	0.25
10	400	800	0.5	480	800	0.6
20	368	800	0.46	448	800	0.56
30	352	800	0.44	432	800	0.54
40	344	800	0.43	424	800	0.53
50	328	800	0.41	424	800	0.53
60	336	800	0.42	408	800	0.51
70	336	800	0.42	400	800	0.5
80	336	800	0.42	376	800	0.47
90	336	800	0.42	360	800	0.45

Table 6: Effects of Moisture on the Coefficient of Friction μs of Ferodo Brake Lining and Novel Sample 2 at 200KPa and 30^{0}C Ambient Temperature

	Ferodo			Novel 2		
Time (m)	F_s (N)	Force w(N)	$\mu_s = F_S/W$	F_s (N)	Force w(N)	$\mu_s = F_S/W$
-10	320	800	0.4	336	800	0.42
0	224	800	0.28	160	800	0.2
10	400	800	0.5	496	800	0.62
20	368	800	0.46	456	800	0.57
30	352	800	0.44	440	800	0.55
40	344	800	0.43	424	800	0.53
50	328	800	0.41	408	800	0.51
60	336	800	0.42	376	800	0.47
70	336	800	0.42	352	800	0.44
80	336	800	0.42	328	800	0.41
90	336	800	0.42	328	800	0.41

Table 7: Effects of Moisture on the Coefficient of Friction μ_s of Ferodo Brake Lining and Novel Sample 3 at 200KPa and 30^{0}C Ambient Temperature

	Ferodo			Novel 3		
Time (m)	F_s (N)	Force w(N)	$\mu_s = {}^{F_S}/_{W}$	F_s (N)	Force w(N)	$\mu_s = {}^{F_S}/_{W}$
-10	320	800	41	336	800	0.42
0	224	800	0.28	160	800	0.2
10	400	800	0.5	512	800	0.64
20	368	800	0.46	496	800	0.62
30	352	800	0.44	480	800	0.6
40	344	800	0.43	464	800	0.58
50	328	800	0.41	448	800	0.56
60	336	800	0.42	416	800	0.52
70	336	800	0.42	392	800	0.49
80	336	800	0.42	368	800	0.46
90	336	800	0.42	376	800	0.47

Table 8: Effects of Moisture on the Coefficient of Friction μ_s of Ferodo Brake Lining and Novel Sample 4 at 200KPa and 30^{0}C Ambient Temperature

	Ferodo			Novel 3		
Time (m)	F_s (N)	Force w(N)	$\mu_s = {}^{F_S}/_{W}$	F_s (N)	Force w(N)	$\mu_s = {}^{F_S}/_{W}$
-10	320	800	0.41	344	800	0.43
0	224	800	0.28	184	800	0.23
10	400	800	0.5	480	800	0.6
20	368	800	0.46	416	800	0.52
30	352	800	0.44	400	800	0.5
40	344	800	0.43	392	800	0.49
50	328	800	0.41	392	800	0.49
60	336	800	0.42	384	800	0.48
70	336	800	0.42	376	800	0.47
80	336	800	0.42	360	800	0.45
90	336	800	0.42	344	800	0.43

RESULTS AND DISCUSSION

The results below show The Effects of Moisture on the Coefficient of Friction μ_s on Brake Lining, for normal force of 400N for a pressure of 10KPa and 800N for a pressure of 200KPa, respectively.

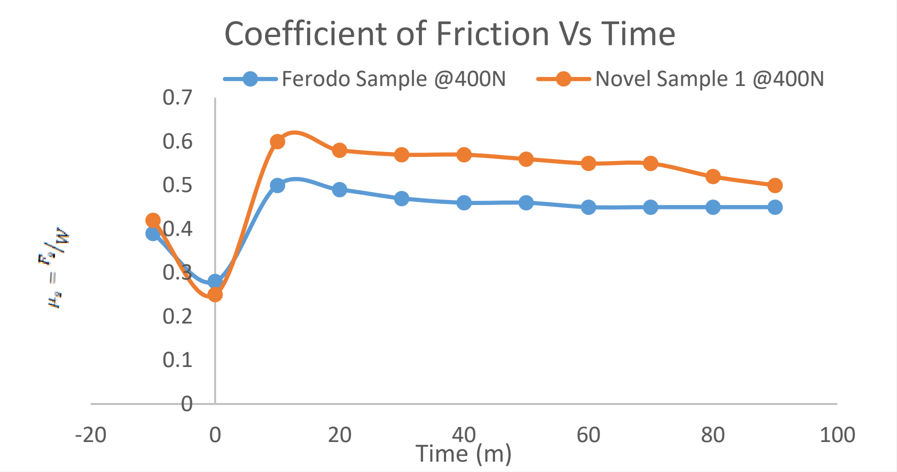

Fig. 1: The Effects of Moisture on the Coefficient of Friction μs at 100KPa (400N) for Ferodo and Novel Sample 1.

Figure 1 revealed that before immersion in water from air at -10 minutes, the coefficient of friction μ_s for Ferodo was 0.39, then it crashed down to 0.28 at 0 minutes on immersion. Similarly, before immersion at -10 minutes, the coefficient of friction μ_s for the Novel Sample was 0.42, which also crashed to 0.25 on immersion at 0 minutes. At removal from water into air, ie at 10 minutes, the coefficients of friction μ_s for both Ferodo and the Novel Sample had shot up because of the difference in viscosities of water and air. The viscosity of water is higher than that of gases **(Yang, Chen, & Yue, 2019)**. However, while the coefficient of friction μ_s of Ferodo shot up from 0.28 to 0.50, which the Novel Sample shot up from 0.25 to 0.60. In air after removal from water, the coefficients of friction μ_s of Ferodo and the Novel Sample, in a recovery process, started decreasing gradually at 10 minutes after removal from water into air when the coefficient of friction μ_s of Feredo decreased from 0.50 to 0.45 at 90 minutes; same for the Novel Sample whose coefficient of friction μ_s decreased from 0.60 at 10 minutes to 0.50 at 90 minutes. This agrees with the work of **(Nam & Chul-Gao, 2015).**

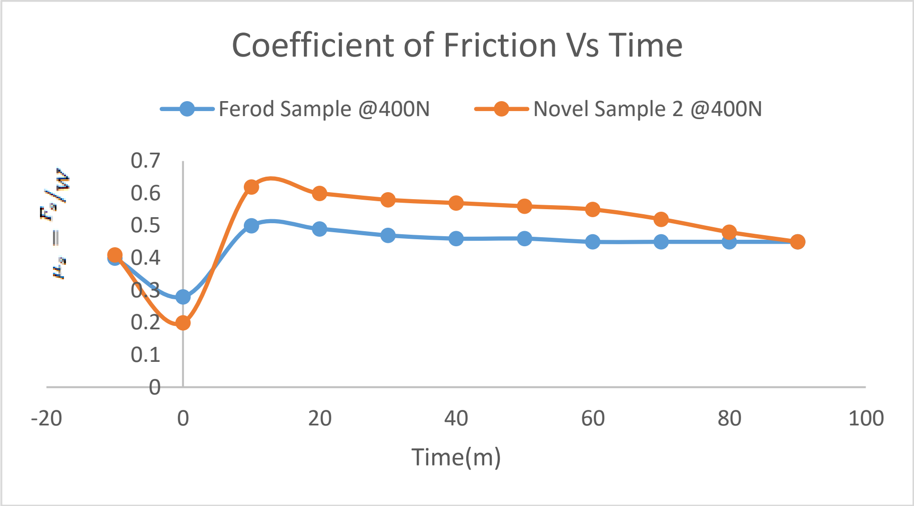

Fig. 2: The Effects of Moisture on the Coefficient of Friction μ_s at 100KPa (400N) for Ferodo and Novel Sample 2

Figure 2 had different values of coefficients of friction μ_s from Figure 1 for both Ferodo and the Novel Sample before removal from air into water at -10 minutes. At -10 minutes the coefficient of friction μ_s of Ferodo was 0.40 and that of the Novel Sample was 0.41. Both, during the recovery process ended up at 0.45 for Ferodo and 0.45 for the Novel Sample at 90 minutes**.**

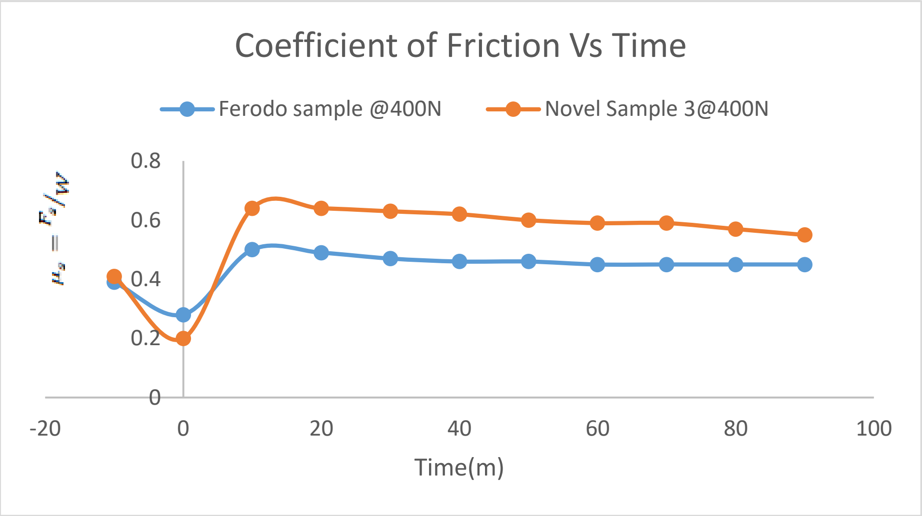

Fig. 3: The Effects of Moisture on the Coefficient of Friction μ_s at 100KPa (400N) for Ferodo and Novel Sample 3

Fig 3 maintained the same value of the coefficient of friction μ_s of 0.39 for Ferodo as Figure 1 but different value of 0.41 for the Novel Sample at immersion at -10 minutes. Both ended up at 0.45 for the coefficient of friction μ_s for Ferodo and 0.55 for the Novel Sample at 90 minutes.

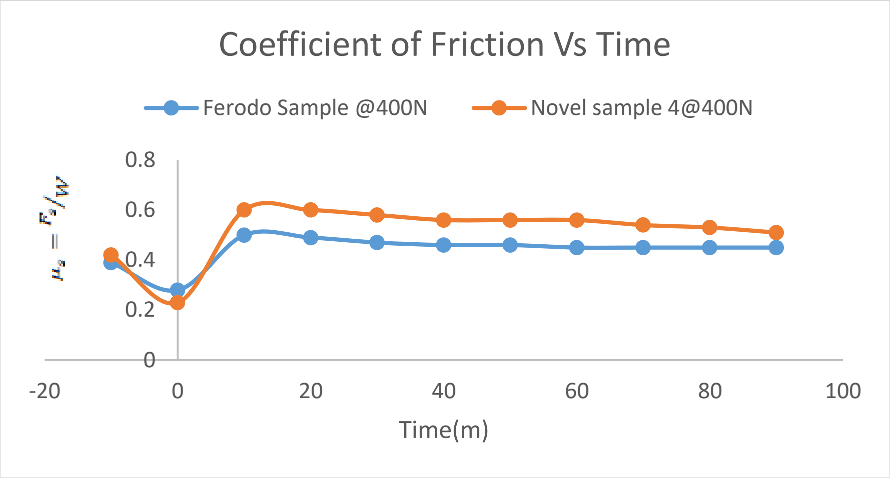

Fig. 4: The Effects of Moisture on the Coefficient of Friction μ_s at 100KPa (400N) for Ferodo and Novel Sample 4

Figure 4 maintained same values of the coefficients of friction μ_s of 0.39 as Figure 1 for Ferodo and 0.42 for the Novel Sample at immersion at -10 minutes. Both ended up at 0.45 for Ferodo and 0.51 for the Novel Sample at 90 minutes. The trend was same for the **(Petinrin, Oyadele, & Ajide, 2016),** though their immersion started at -15minutes.

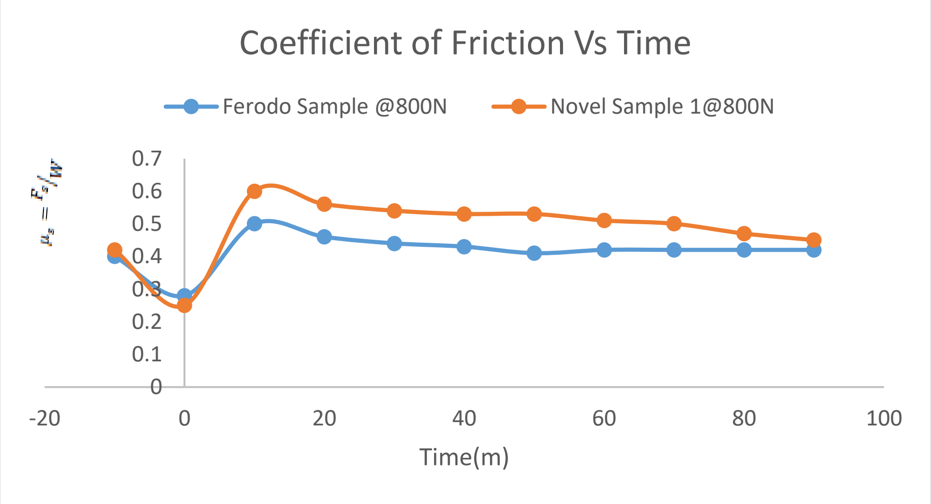

Fig. 5: The Effects of Moisture on the Coefficient of Friction μ_s at 200KPa (800N) for Ferodo and Novel Sample 1

Figure 5 had a different value of the coefficient of friction μ_s of 0.40 for Ferodo from Figure 1, but maintained the same value of 0.42 for the Novel Sample at Figure 1. However, both values of the coefficients of friction μ_s for Ferodo and the Novel Sample were different from their respective values in Figure 1 by taking values of 0.42 and 0.45 respectively at 90 minutes.

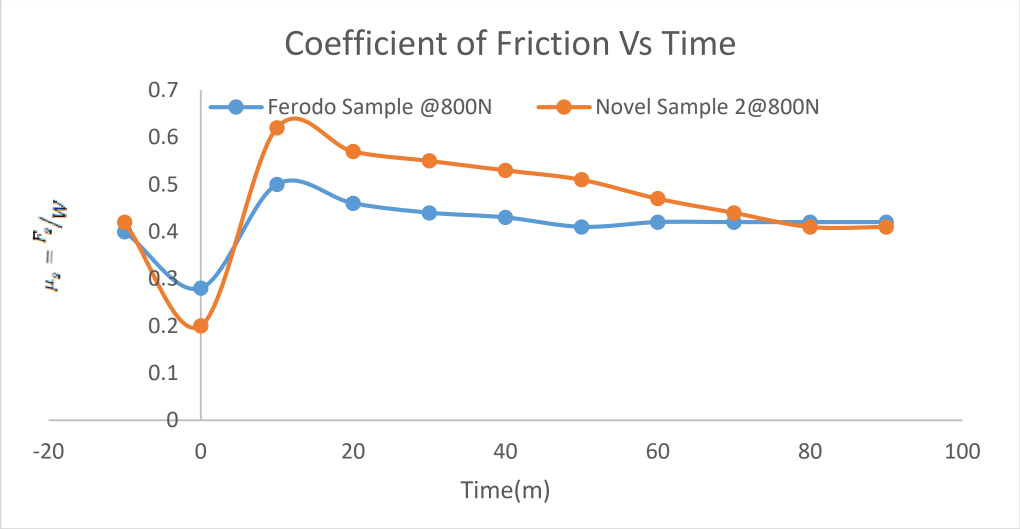

Fig. 6: The Effects of Moisture on the Coefficient of Friction μ_s at 200KPa (800N) for Ferodo and Novel Sample 2.

Figure 6 also differed from Figure 1 for the coefficient of friction μ_s for Ferodo which was 0.40 but the same value of 0.42 for the Novel Sample as in Figure 1. Both values also changed to 0.42 and 0.41 for Ferodo and the Novel Samples respectively at 90 minutes.

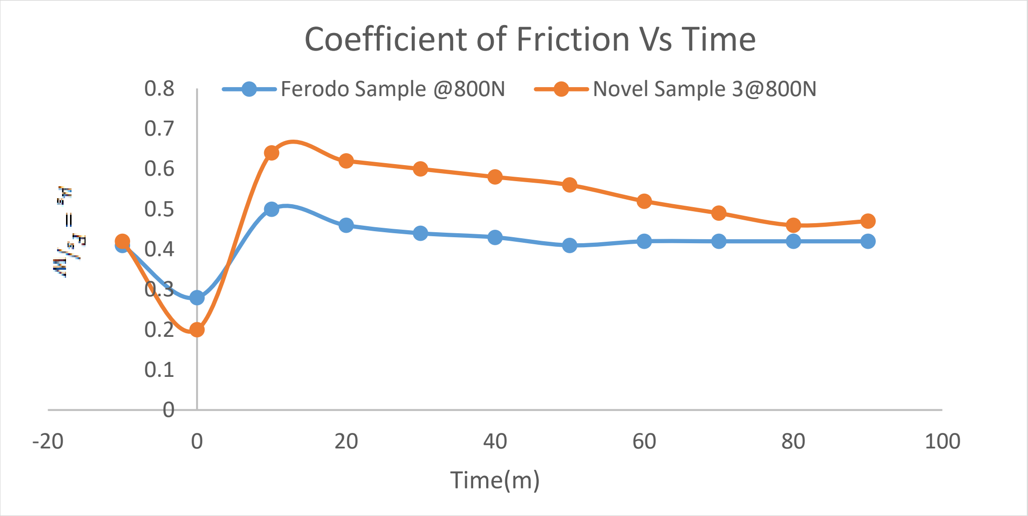

Fig. 7: The Effects of Moisture on the Coefficient of Friction μ_s at 200KPa (800N) for Ferodo and Novel Sample 3

Figure 7 also differed from Figure 1 for the coefficient of friction μ_s which was 0.41 for Ferodo but the same value of 0.42 for the Novel Sample as in Figure 1. Ferodo also maintained the same value of 0.42 as in Figure 6 but lower than its value of 0.45 in Figure 1. The Novel Sample had a value of 0.47 which was higher than its value of 0.41 in Figure 6, but lower than its value of 0.50 as in Figure 1 at 90 minutes.

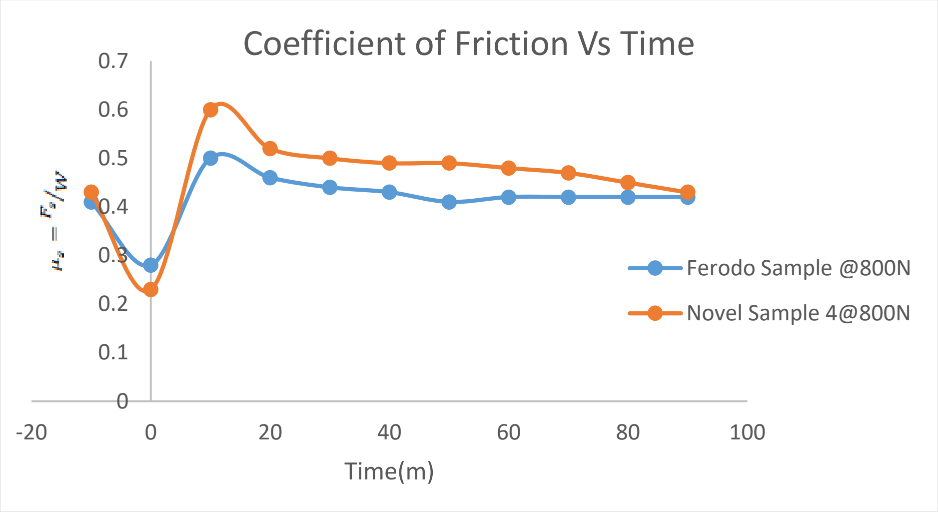

Fig. 8: The Effects of Moisture on the Coefficient of Friction μ_s at 200KPa (800N) for Ferodo and Novel Sample 4

Figure 8 maintained the same values for all coefficients of friction μ_s as in Figure 7 for Ferodo. However, the values for the Novel Sample differed from the values in Figure 7, or its values in Figure 1. Its value was 0.43 at 90 minutes and same for the same pressure of 200KPa at 100 minutes **(Bulsara, Lakhani, Agarwal, & Agiwal, 2017).**

CONCLUSION

Generally, all the entire curves for the Novel Sample and Ferodo, starting from Figure 1 to Figure 8, followed similar patterns. The disparity in the crashing ranges of the coefficient of friction μ_s for the Novel Sample and Ferodo at immersion in water was because of the difference in the porosities of their textures. The average crashing range of the coefficient of friction μ_s of the Novel Sample was higher (from 0.42 to 0.22) than that of Ferodo (0.40 to 0.28), because the porosity of the Novel Sample was more than that of the Ferodo. However, the shoot-up of the coefficients of friction μ_s for both the Novel Sample and Ferodo was because of the difference in the viscosities of water and air, the viscosity of water being higher than that of gases. The average recovery process after shoot-up at 10 minutes landed the average coefficient of friction μ_s of the Novel Sample at 0.47 at 90 minutes as against 0.44 for Ferodo. That showed an overall positive comparison of the average responses of the Novel Sample against Ferodo. Finally the curves from Figure 1 to Figure 4 for the vertical normal force W of 400N, and those from Figure 5 to Figure 8 for the vertical normal force W of 800N, and their corresponding horizontal forces F_s were essentially similar because F_s is proportional to W.

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