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MANUFACTURING AND DEVELOPMENT OF LOW COST ASBESTOS-FREE BRAKE PAD COMPOSITE MATERIAL

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ABSTRACT
Brake materials have special features such as corrosion resistance, light weight, long life, low noise, stable friction, low wear rate, and acceptable cost versus performance. The aim of this research is formulation and manufacture of frictional composite material with low cost and high properties for brake pad applications. Frictional material used in brake pads is made of four subcomponents that play different roles. These are; abrasive materials to modify friction, lubricants to stabilize developed friction, binders to hold different constituents together and prevent disintegration and fillers to improve manufacturability as well as to lower the cost. The fabricated friction material with different chemical composition has been tested tribologically and mechanically to measure the performance under different conditions. Tests have been carried out are; hardness, tensile, cross brake, wear rate. All results of these tests presented in this paper showed that the coefficient of friction increased with increasing abrasive content. From the results, it is indicated that the proper reinforcement percentage as well lubricant one's in addition to enough content of binder resin in the material composition result in high values of hardness, internal shear strength, tensile strength and result in good wear properties. More details are discussed in this paper.

KEYWORDS
Asbestos-free, brake pad, composite material.

INTRODUCTION
A brake is a device which inhibits motion. Most brakes use friction to convert kinetic energy into heat, though other methods of energy conversion may be employed. A friction brake is a type of an automotive brake that slows or stops a vehicle by converting kinetic energy into heat energy, via friction. The braking heat is stored in the brake drum or disc while braking, then conducted to the air gradually. The modern automotive brake system has been refined and high development of brake pad material is achieved in recent years, [1]. The compositional design of friction materials is a well-known problem of multi-criteria optimization that involves handling prime classes of constituents, [2]. Formulations of such materials comprised four different categories of materials, where compositional design of such materials is complicated further by the requirement that the materials should exhibit some functional requirement in order to perform their function properly such as; high friction-coefficient stability, low wear of

the brake pad disc and good wear resistance and long life span, [1]. According to Nicholson (1995), the elements of the friction material constituents are categorized into friction additives that determine the frictional properties of brake pad. They contain a mixture of both abrasives like; cast iron, copper powder, silica, and aluminum oxide and lubricant such as graphite and metal sulphides. Besides, fibers and reinforcements which provide mechanical strength, examples of them are; Rockwool fibers, glass fibers, aramid and brass [1]. Fillers which are mainly used to improve fabrication process with a cost reduction wise, they are; barites, kaolin, wollastonite, and cashew dust [2]. The binder is an essential constituent that holds and consolidates the whole components of a brake pad together such as polyester, epoxy, kaolin and phenolic resin, [1].

In the present paper, the investigation will discuss the manufacturing and characterizations of composite frictional material used for brake pad lining formulations. The study includes; producing a frictional material with different compositions in an industrial factory of brake pads and then applying experimental tests to study its characterizations; physical, mechanical and tribology properties.

EXPERIMENTAL

Material Fabrication

Frictional material samples have been fabricated in a form of brake pads. The process includes; Constituents preparation, molding and curing processes

Constituents Preparation:

Material constituents and their percentage for three specimens have been determined then mixing process was performed separately for each sample. The weight and weight percent of constituents for each sample are shown in Table 1:

Table 1: Constituents of test specimens.

		Sample 1		Sample 2		Sample 3	
		Weight (g)	%	Weight (g)	%	Weight (g)	%
Reinforcing material 1	Fiber glass	540	10.5	425	8.5	150	3
Resin	Polyester	1020	19.8	1290	25.8	800	16
Filler	Calcium carbonate	2181	42.3	1840	36.8	1000	20
Abrasive	Nano alumina	1134	22	965	19.3	900	18
Lubricant 1	Barium sulfate	285	5.5	480	9.6	1000	20
Reinforcing material 2	Rock wool	-	-	-	-	850	17
Lubricant 2	Graphite	-	-	-	-	300	6
Total (g)		5160	100	5000	100	5000	100

Moulding and Curing Process:

Samples are compressed in a mould at 145 °C and 60 bars for a time of 30 min, and then samples were put in the oven for time up to five hours. The mould used for fabrication process consists of three parts; block, punch and base as shown in Figure (1-a) and the curing cycle is as graphed in Figure (1-b).

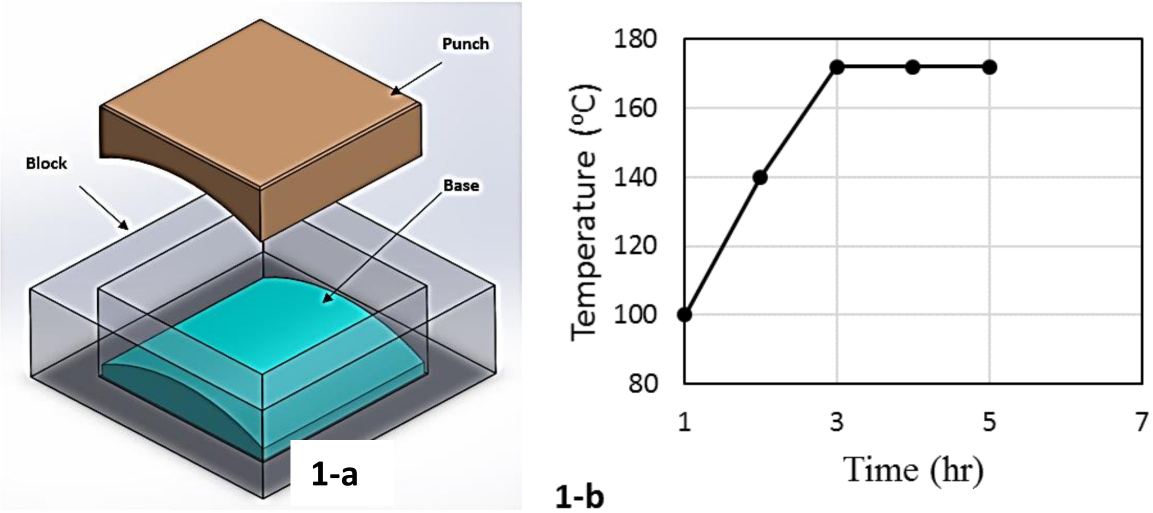


Fig. 1: a) Mould parts, and b) curing cycle.

Experimental tests

Three test categories were performed for the three studied samples by using an Indenter Hardness Tester, Tensometer and a Dynamometer type RWDC 270E. These tests are:

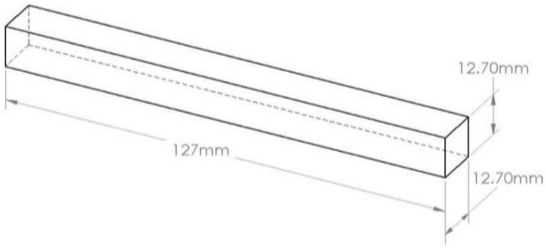
Physical Test (Density Test); it was conducted by using Archimedes' principle to measure density of each specimen.

Mechanical Tests

Hardness Test was performed with the first digital models (AC-D series). The hardness parameters are; automatic load of 50 gm and adjustable dwell timer 1-30 sec. the sample during carrying out the test is as shown in Figure 2. The Cross-breaking Test has been carried out using Tensometer machine, whereas the specimen is placed symmetrically across two parallel "V" shaped supports as shown in Figure 3-a. The sample dimensions as in Figure 3-b. The load was applied uniformly across the width of the specimen by means of a third "V" shaped block parallel to and midway between the supporting block. The load was increased steadily so that the specimen occurred in 5 to 15 seconds. The cross- breaking strength of the specimen was calculated from the load value at facture. The ambient temperature at the machine was 20 °C ± 5 °C.

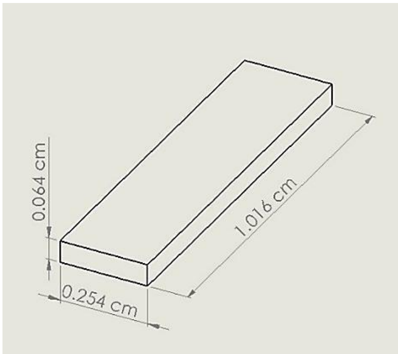
Tensile strength: it has been done using Tensometer machine as shown in Figure 4-a, the specimen dimensions is as in Figure 4-b. The specimen is held in the ''V'' grips mounted on the Hounsfield Tensometer in axial alignment with the direction of specimens pulling. Load is applied by separating the grips at a substantially constant rate. The tensile strength of the specimen was calculated from the value load at its breaking point.

Fig. 2 Indenter Hardness Tester.



3-a 3-b

Fig. 3 a) Cross break testing machine, b) Cross break test specimen.



4-a 4-b

Fig. 4 a) Tensile strength machine b) Tensile test specimen

Tribological test

It is employed to measure the frictional coefficient and the wear rate of each specimen by using the Dynamometer type (RWDC 270E). The tests were carried out according to AK Master Test.

RESULTS AND DISCUSSION

The results of the experimental tests that are performed on specimens labeled; (sample 1, sample 2 and sample 3) are compared with conventional models according to different authors. The following paragraphs include the details of the results. Results of density of the three brake pad specimens are graphed as shown in Fig. 5. This Figure shows that density of the samples may decreases as the filler decreases. In sample 2 which has wt. % of 36.8 % filler has less density (2 gm/cm^3) than this of sample 1 which has density value = 2.22 gm/cm^3 for composition contains filler of 42.3 wt. %. As well sample 3 has least filler of 20 wt. %. The results agree with literature, [3 and 4], which concluded that an increase in specific gravity attributes to increase of filler particles. Filler forms more homogeneity in the entire phase of the brake pad composite body and lower density denotes better quality. However, in this investigation, weights of the composite specimens compared favorably over the conventional model. The density of a conventional brake pad is 2.22 g/cm^3, [5]. According to Olabisi and Nuhuo, the obtained density value was 1.369 g/cm^3, [6].

Results of hardness of the brake pad specimens are graphed in Fig. 6. The hardness values of specimens are 108.15, 110.3 and 110.66 HRR for samples 1, 2 and 3 respectively. The variation of abrasive particles wt. % in different compositions is not high enough to affect the hardness properties significantly. Even though that sample 2 of less wt. % of abrasive particles (19.3 wt. %) and sample 3 of least abrasive particles wt. % (18 wt. %) are having a higher values of hardness than that of sample 1 which has more percentage (22 wt. %) of abrasives. The hardness value of conventional break pad is 101 HRR, [4 and 7]. Talib R. obtained average values ranges from 94.7 to 103.8 HRR for different composition samples, [8].

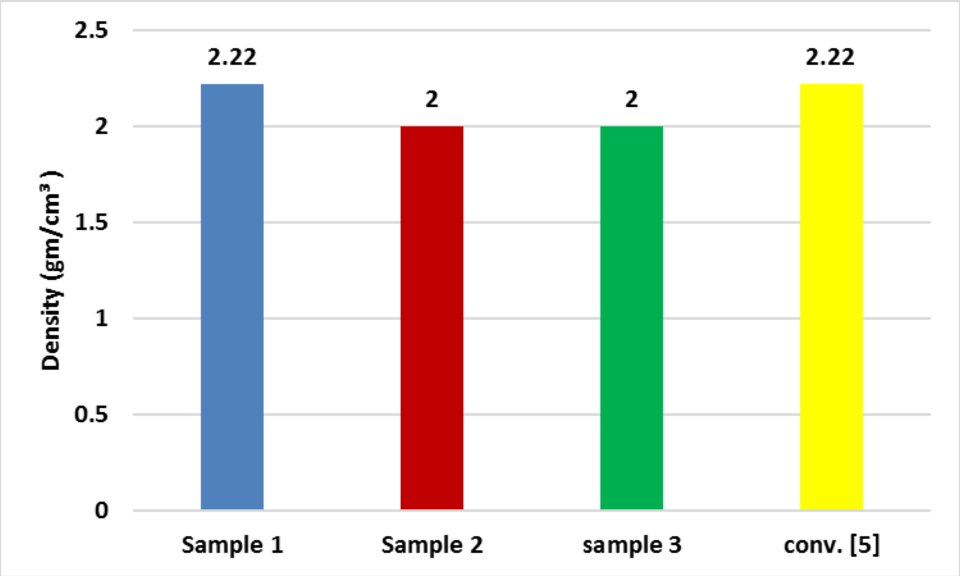


Fig. 5 Density of specimens.

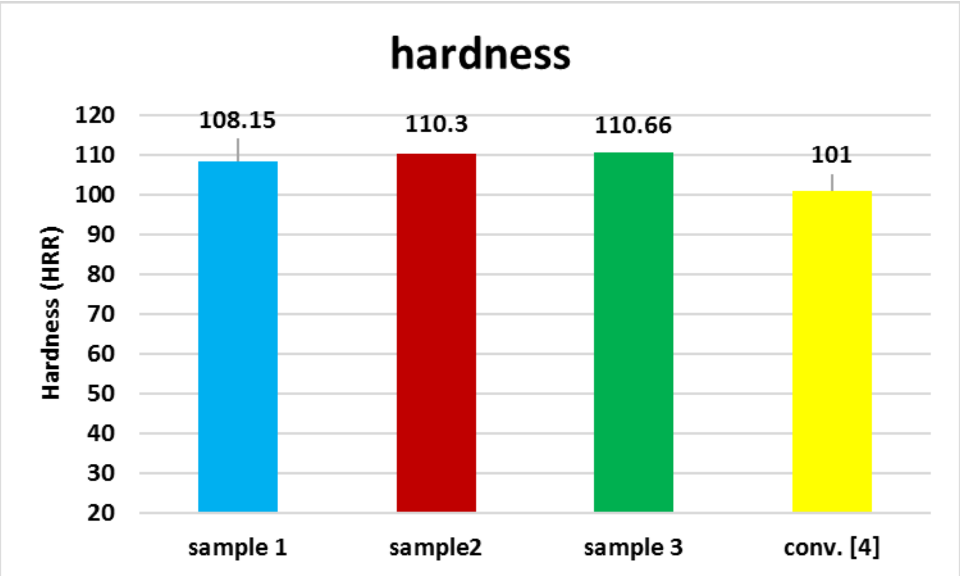


Fig. 6 Hardness of specimens.

Results of the cross breaking of the specimens are displayed in Fig. 7. Despite the less wt. % of reinforcing fiberglass material of sample 1 (10.5 wt. %) it has higher value of cross break strength than that of sample 2 (8.5 wt. %). The values of cross brake strength are; 55.34 and 61.34 MPa for samples 1 and 2 respectively. The results could be interpreted as; containing more reinforcement in the composition without enough wt. % of resin as in sample 1 (19.8 wt. %) leads to disintegration and lack of bonding and as a result low strength is obtained. On the other hand, more wt. % of filler decreases the strength. Concerning sample 3, it has the greatest value of shear strength which probably attributes to the high amount of different reinforcement (Rock wool) which = 17 wt. % in addition to existence of 3 wt. % of fiber glass reinforcement. The conventional model value is 49 MPa for S2 sample according to the designation, [9].

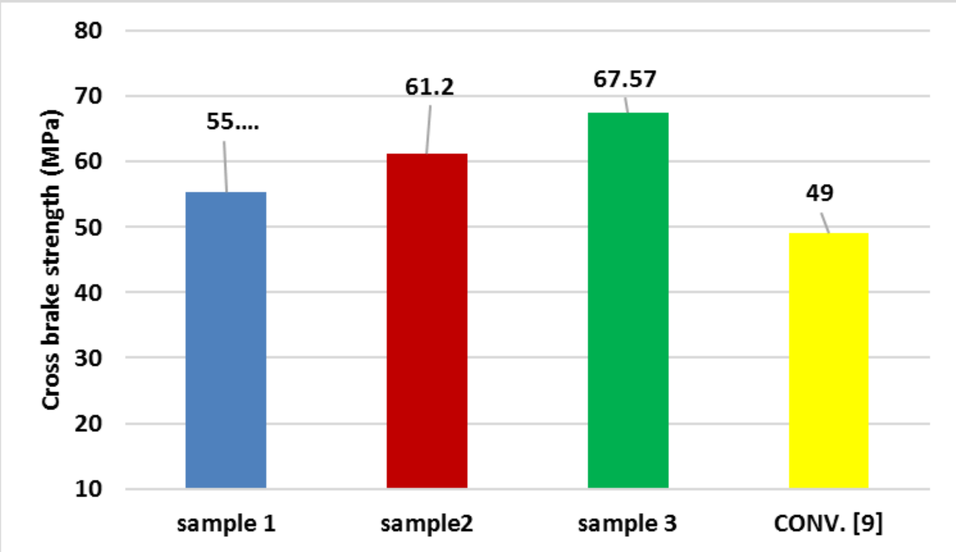


Fig. 7 Cross break strength of specimens.

Tensile strength results of specimens are displayed in Figure 8. There is no significant change in tensile values but still sample 2 has the highest value. This refers to the same reasons discussed in cross brake paragraph (strong consolidation of different constituents due to enough resin content. On the other hand, all studied conditions are having extremely high strength compared with that of the conventional model pad that is 6.8 MPa [4]. The least value of strength in this research is about 357 wt. % of that of conventional one. When Olabisi made a development and assessment of composite brake bad using pulverized coca beans shells filler, they obtained average values of tensile strength; 13.076, 14.339, and 16.882 MPa for three different composition materials, [6].

Friction coefficient output charts of tested specimens are displayed in Fig. 9-a, 9-b and 9-c for samples 1, 2 and 3 respectively. Average values of coefficient of friction results are displayed in Figure 10. The results of all specimens are in the safe range and are compared favorably with the standard value, [10]. In this investigation the maximum value of friction coefficient is 0.51 for sample 1 which has the least value of lubricant content (5.5 wt. %). The coefficient of friction for conventional brake pad ranges from 0.3 to 0.4, [7], When Adeyemi Ibukum Olabisi used coca beans shells as filler to development and assessment of composite brake pad, they obtained minimum value = 0.32 and maximum value = 0.35 for their studied conditions, [6]. Moustafa, A. M. obtained coefficient of friction values are ranges from 0.35 and 0.49 for different composition samples, [11].

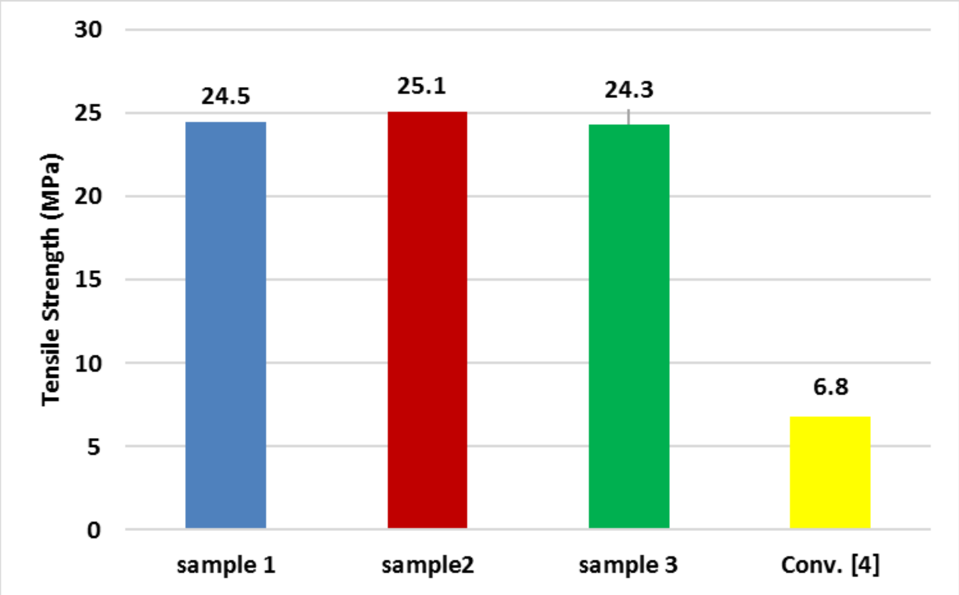
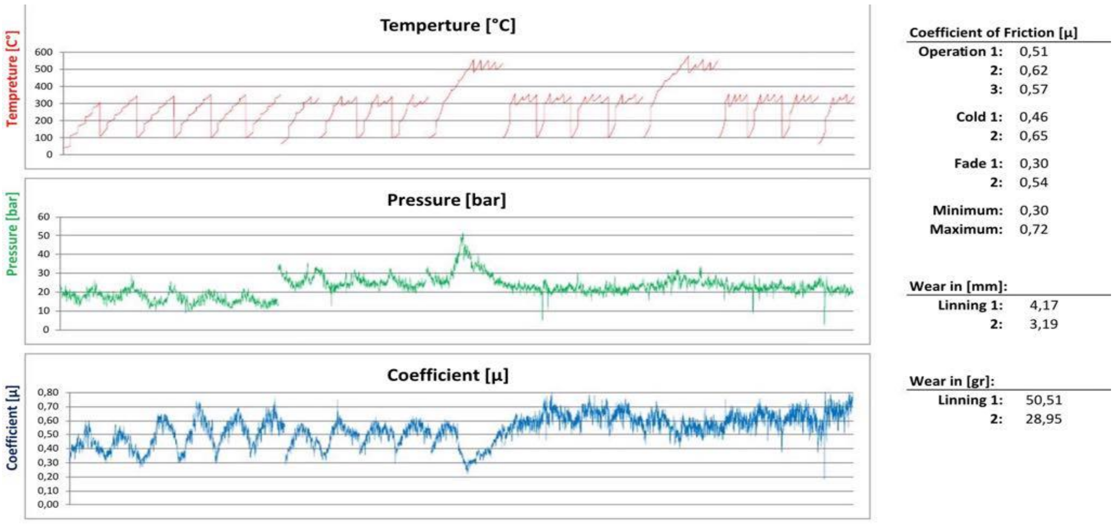
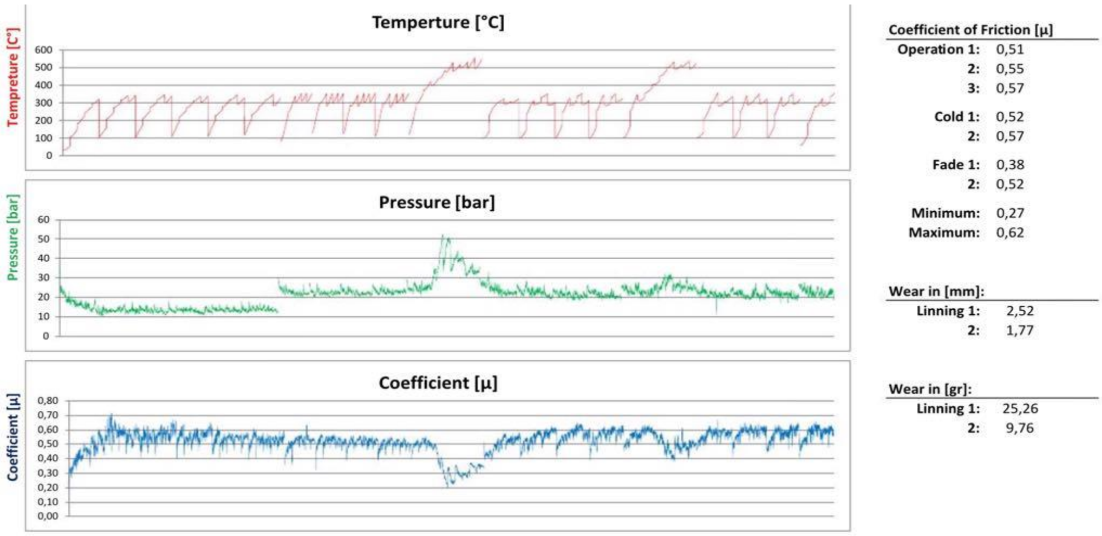


Fig. 8 Tensile strength of brake pad specimens.

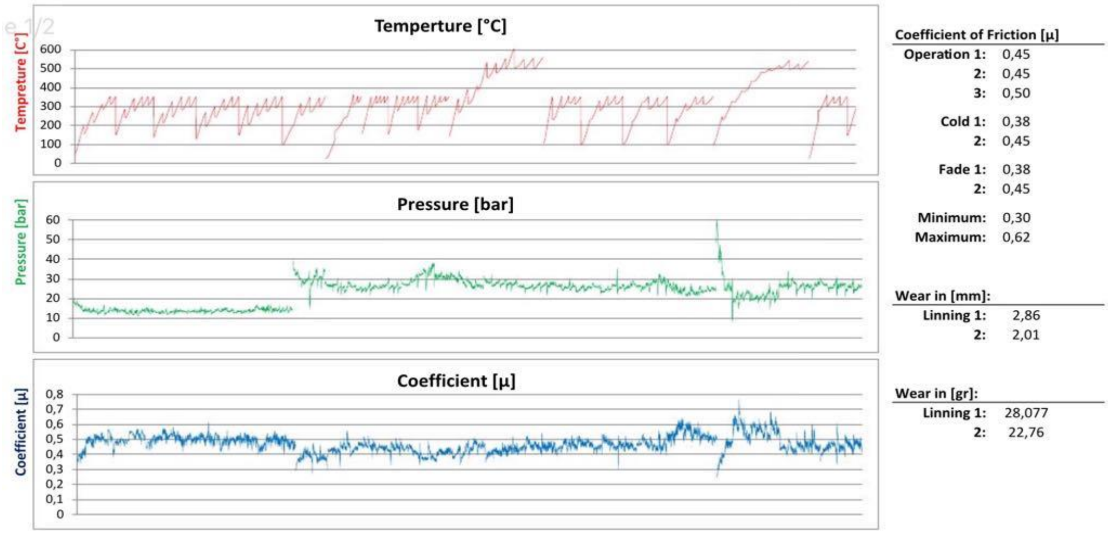
Concerning wear rates, the output data from the wear test of inboard and outboard specimens are shown in Figure (11-a), (11-b) and (11-c) for sample 1, 2 and 3, respectively and the graph of wear rate average values is displayed in Figure 12 and 13 for inboard and outboard, respectively. The average values of wear rate in the graphs of Figure 12 and 13 indicate that the least inboard and the outboard wear rate is achieved in sample 2. This perhaps attributes to the strong bonding and consistency of the composition which are associated with more resin wt.% as well with moderate lubricant wt.%. Lubricant role is to stabilize developed friction, minimize generated heat and improve friction properties and consequently reduce the degradation which could arise due to excess of heat. On contrary, sample 3 which has the highest lubricant wt.% has the maximum outboard ware rate. It may refer to the small resin wt.% (16%) and consequently less bonding force. Also the high amount of abrasives material increases the tendency of particle grabbing from the composition during sliding motion. As a result the voids formation and wear rate increase. On the other hand, the results of wear rate in this research have high values compared to the literatures', this because the wear testes were carried out according to AK Master Test. The test procedures are so far under severe and drastic conditions (high heat and pressure) compared to the realistic service conditions. The temperature and the pressure reach up to 500 ºC and 60 bar, respectively. This is clear on charts of Figure 9-a, 9-b and 9-c. Other hot wear tests are carried out in the automotive industry is explained in ref. [12]. However, wear rate of conventional brake pad is 3.80 x 10^{-6}g/m, [3] [4] but the test was carried out under different conditions.



9-a



9-b



9-c

Fig. 9 Coefficient friction charts of brake pads of; a) sample1, b) sample 2 and c) sample 3.

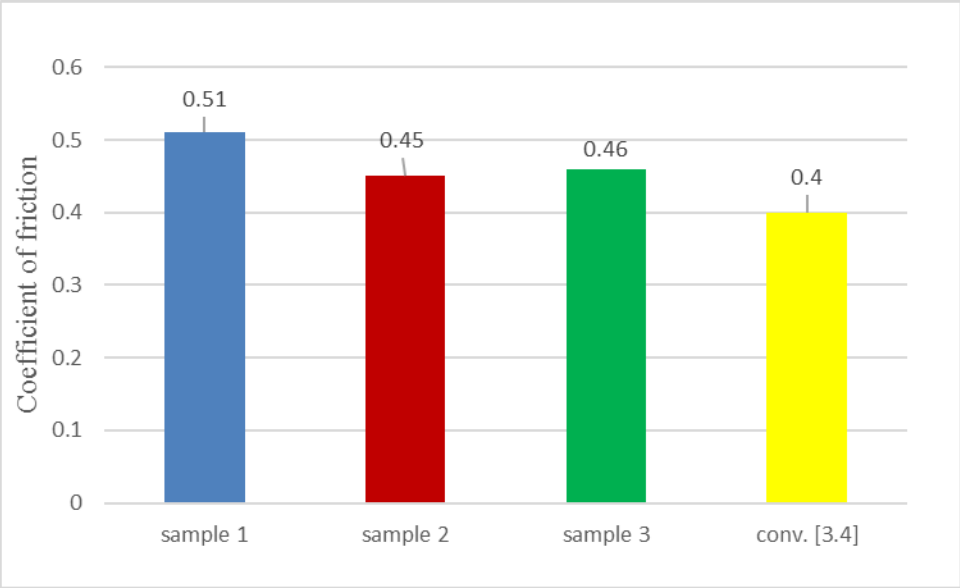
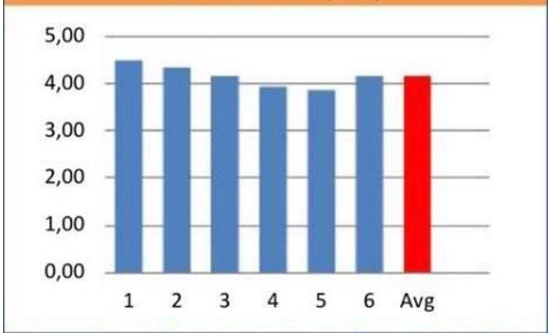


Fig. 10 Coefficient of friction of samples.

Wear Measurements

Inboard loss (mm)	Outboard loss (mm)



	1	2	3	4	5	6	Avg
Before	15,38	15,14	14,76	14,11	14,30	14,70	14,73
After	10,88	10,79	10,60	10,17	10,43	10,53	10,57
Loss	4,50	4,35	4,16	3,94	3,87	4,17	4,17

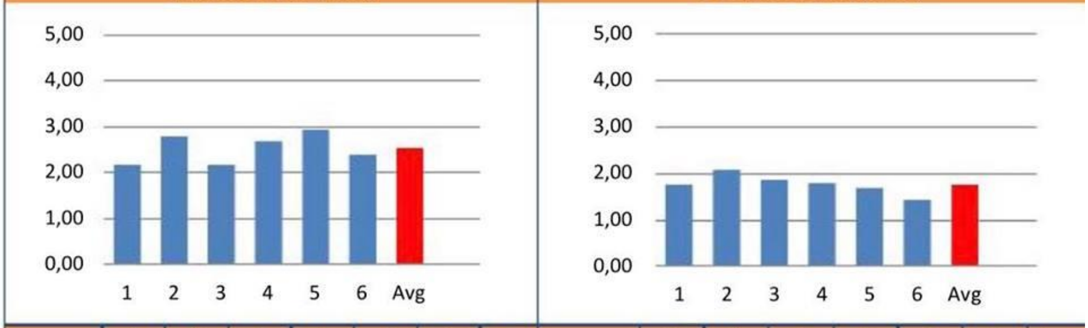
	1	2	3	4	5	6	Avg
Before	16,38	16,14	15,76	15,11	15,30	15,70	15,73
After	13,16	12,73	12,23	11,85	12,45	12,82	12,54
Loss	3,22	3,41	3,53	3,26	2,85	2,88	3,19

Inboard loss (gram)		Outboard loss (gram)	
Before	297,50	Before	291,28
After	246,99	After	262,33
Loss	50,51	Loss	28,95

11-a)

Wear Measurements

Inboard loss (mm)	Outboard loss (mm)



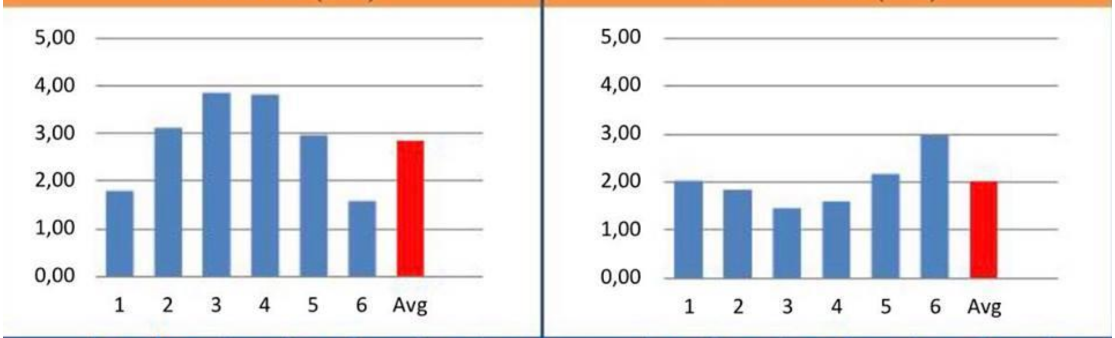
	1	2	3	4	5	6	Avg		1	2	3	4	5	6	Avg
Before	16,46	16,98	16,57	17,03	17,05	16,53	16,77	**Before**	16,30	16,99	16,35	16,41	16,71	16,05	16,47
After	14,29	14,20	14,40	14,34	14,12	14,14	14,25	**After**	14,54	14,92	14,49	14,62	15,02	14,62	14,70
Loss	2,17	2,78	2,17	2,69	2,93	2,39	2,52	**Loss**	1,76	2,07	1,86	1,79	1,69	1,43	1,77

Inboard loss (gram)		Outboard loss (gram)	
Before	303,52	**Before**	292,92
After	278,26	**After**	283,15
Loss	25,26	**Loss**	9,76

11-b)

Wear Measurements

Inboard loss (mm)	Outboard loss (mm)



	1	2	3	4	5	6	Avg		1	2	3	4	5	6	Avg
Before	14,10	14,65	14,52	14,43	14,36	14,11	14,36	**Before**	14,32	14,95	15,22	14,66	14,45	14,30	14,65
After	12,30	11,53	10,66	10,60	11,39	12,52	11,50	**After**	12,29	13,11	13,76	13,06	12,28	11,33	12,64
Loss	1,80	3,12	3,86	3,83	2,97	1,59	2,86	**Loss**	2,03	1,84	1,46	1,60	2,17	2,97	2,01

Inboard loss (gram)		Outboard loss (gram)	
Before	274,14	**Before**	287,32
After	246,06	**After**	264,56
Loss	28,077	**Loss**	22,76

11-c

Fig. 11 Wear rate output data of brake pads of tested samples; a) sample1, b) sample 2 and c) sample 3.

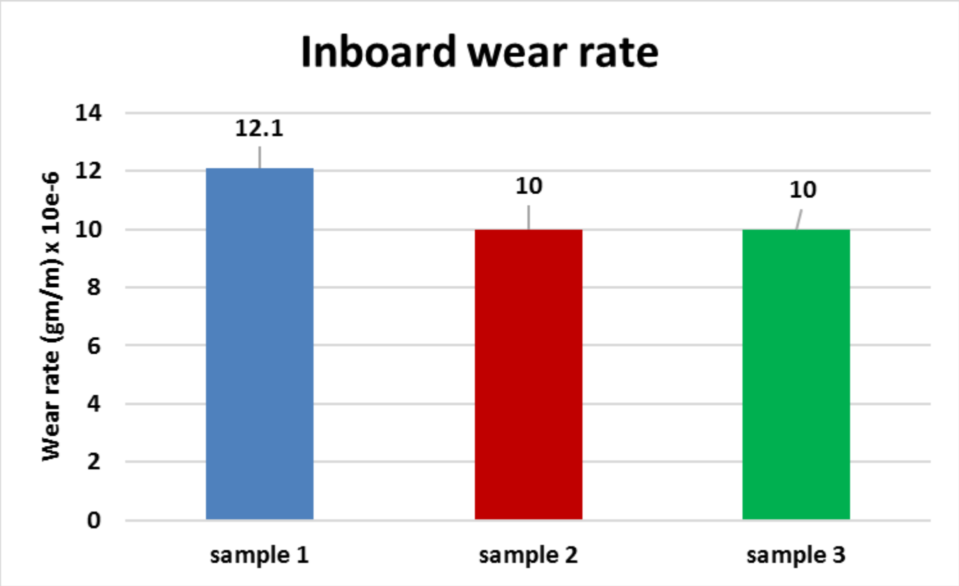


Fig. 12 Average values of wear rate of inboard loss of specimens.

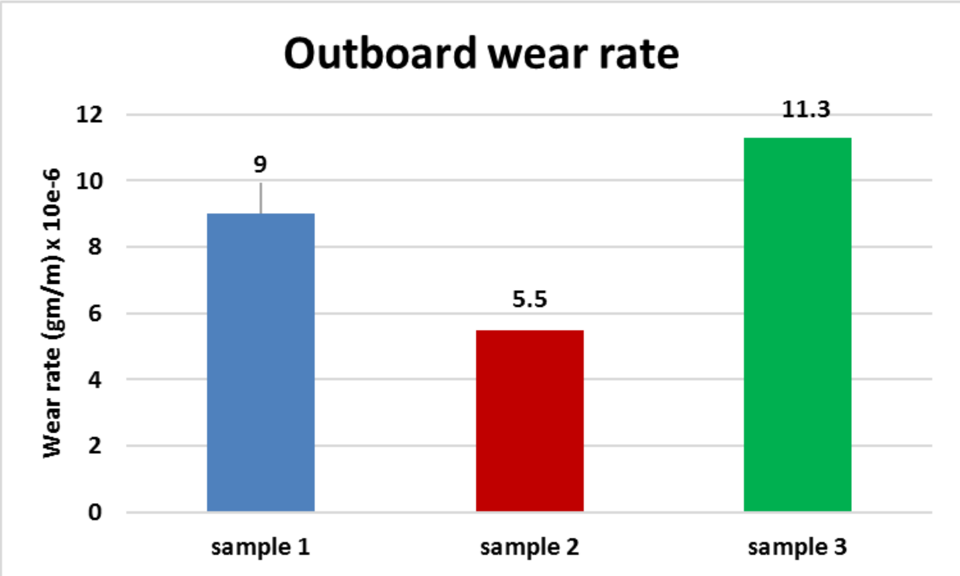


Fig. 13 Average values of wear rate of outboard loss of specimens.

Finally, the proposed composition and formulation of specimen 2 is a good compromise for a friction material with low cost and high performance.

CONCLUSIONS

Throughout the results of experimental tests performed on the brake pad specimens, specimen labeled as sample 2 exhibits better performance. Sample no. 2 has contains barium sulfate lubricant with moderate content (9.6 wt. %), it stabilized developed friction and minimized the negative effect of friction action (heat excess and then the wear properties degradation). Also it has reasonable reinforcement fiber glass content (8.5 wt. %) and it does not have so much high abrasives content (19.3 wt. %), both constituents promoted the mechanical strength without excess in brittleness. In addition, it has less filler content (36.5 wt. %) that minimized the density of the composition. Further, it has high resin polyester percentage (25.8 wt. %) which increased the bonding

force and therefore enhanced the overall properties of this friction material. The properties of the proposed composition are; 2 gm/cc, 110.3 HRR, 61.2 MPa, 25.1MPa, 0.45, and (10 x 10^{-6}) gm/m and (5.5 x 10^{-6}) gm/ m for density, hardness, cross brake, tensile strength, and coefficient of friction and inward and outward wear rates, respectively.

Filler has an effect on the composite material of brake pad properties; it increased slightly density, and decreased strength. The proposed formulation and composition of Sample 3 based on Rock wool reinforcement and graphite lubricant has positive effect on cross brake strength while wear rate properties have not been improved. This because of lack of resin (16%) amount relative to the dry constituents amounts. It is recommended for a future work that at least 25 % of resin should be in such composition to grantee good consolidation and integration of its constituents and hence achieving of better properties. This has been proved by the results of this work, whereas strength and wear rate results have been improved by presence of proper wt. % of resin. As well, properties have been improved with moderate percentage of lubricant and reinforcement.

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