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Wear Performance of Asbestos-Free Brake Pad Materials

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Abstract

Brake lining performance is influenced by configuration of friction material, functional speeds, load, and temperature. Asbestos friction materials are injurious to human health and, therefore, replacement is needed, hence an alternate material with desired tribo-mechanical properties is to be investigated. In this paper, the wear characterestics of two asbestos-free friction materials sliding against grey cast iron disc were investigated. A metallic based (*viz:*AF-22) and fine brass based (*viz:*CL-3003) were prepared by compression moulding process that required pin samples. Wear experiments were performed using a Pin-on-disc tribo-tester. The wear rates were compared under various temperature, sliding speed, and pressure conditions using Taguchi's L_9 orthogonal array. The wear rate of AF-22 was observed between 2.01 to 2.17 mm^3/N.m., and for CL-3003 (1.49 to 1.66 mm^3/N.m). Ranking of the parameters based on the experimental findings and the S/N ratio analysis was done. Temperature is the most influencing parameter, i.e. 82.96% for AF-22 and 87.95% for CL-3003 material. The EDS technique was used to understand material composition. At various magnifications, SEM images of brake pad materials were investigated. Further investigation under in-situ condition is recommended for these materials.

Keywords: Asbestos-free, Wear, Brake Materials, Taguchi Method, Pin-on-Disc, SEM, EDS.

1. Introduction

The brake system must be highly reliable as it safeguards the human life. In modern vehicles, disc brakes are mostly preferred over drum brakes due to its high heat disspation rate and light weight. Brake pads, located in brake calipers facing each other, exert pressure on the disc to stop the wheel by friction, which in turn generates heat at the interface. Friction materials are found to wear linearly at lower disc temperature, however at high temperature and pressure wear tend to be exponential thus reduces useful life of brake pads. Appropriate selection of friction materials for brake pads largely affects performance of a system. The brake padmaterials are among the most multifaceted composite materials due to variety of base materials, i.e., metals, ceramic and polymers. Mettalic based or non-asbestos organic (NAO) materials are most preferred for commercial brake pads. In recent times, many researchers had investigated non-asbestos based organic (NAO) materials as a replacement to the traditional brake pad materials having superiortribo-characterestics, such as being lighter in weight and having improved durability. Most commonly used brake pad materials and thier tribological impact when used with interface disc on the entire braking system were reviewd. The right composition of binders, additives, fillers, and abrasives ensure minimum stopping distance and wear that helps in reducing frictional noise against a metallic disc [1].

The diversity in chemical and physical properties makes it more complex to find the right composition and mixing. Asbestos-based friction compounds have been used so far due to their tribo-mechanical performance, however, they are now banned due to the health risks they impose. Research is being done to formulate envoirnment friendly brake pad materials that are as good as asbestos having similarly good mechanical, thermal, frictional and anti-wear qualities. Developments of agro-waste-based palm kernel fibers [2], periwinkle shell [3-4], maize husks agreo-waste [5-6] brake materials is being done. Wear behaviour of fiber reinforced phenolic composites under different conditions of applied loads and speeds were evaluated and showed improved wear resistance as compared to asbestos [7].

Performance of asbestos and non-asbestos organic materials used in commercial brake pads and their comparision based on crtitical properties need to be evaluated. In particular, the properties required to friction materials which are resistant to wear, thermal fatigue, shear and compression during braking, low sensitivity to environmental conditions, such as water, oil and corrosive salts, thermal stability and oxidation, and a stable friction coefficient under different conditions and time. Binders, reinforcements, friction modifiers, and fillers are commonly used in friction materials; nevertheless, their composition changes with applications, technical advancements, and potential environmental impact. Till now, manufacturers' experience has probably played a larger role than any other attributes in the development of

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friction materials. The Analytic Hierarchy Process (AHP) was used to assess critical attributes for a variety of brake pad materials, the important parameters for braking application was ranked [8]. The analysis, on the other hand, was mostly based on qualitative features.

Friction and wear characteristics of asbestos-free rubber resin bonded metallic brake Pad materials sliding against EN 31 disc were evaluated using Pin-on-disc apparatus and found that temperature is the most dominating parameter in increasing friction and wear [9-10]. A conductive rock-fibers/metallic fibres and thermo-graphite were tried as an alternative to Cu additives and found improvement in their properties other than physical and mechanical properties [11-12]. A role of Cu powder and its amount in a friction material were evaluated. It was found that 10 wt. % of Cu is the optimum amount for better tribological, thermo-physical and mechanical behavoiur of friction materials [13]. Palm slag along with phenolic and metallic binders have shown their potential to use as filler material in brake pad composites [14]. Use of natural fibres, such as coconut fibres reinforced with aluminium showed better physico-mechanical performance at 5-10 % of coconut fibre [15]. An effect of contact area on worn mass were experimented using Taguchi method and validated by finite element simulation [16].

In friction linings, wear occurs principally by adhesion, abrasion, tribo-chemical reactions and ablation. The brake drum or disc, as well as the friction material, wear at a high rate during the early burnishing or wearing of the brakes[17-19].

By the time the primary braking drum or disc asperities have been rounded, the wear rates of the brake linings have stabilized. Brake torque, sliding speed, temperature effects, and brake usage frequency are the influencing parameters on wear [20]. Formation of tribo-chemical film on the counrface disc surface, the analysis of friction bands and wear particals, and an effect of temperature variation through SEM analysis were done to investigate wear mechanism [21-22]. Formation of third body film acts as a wear resistant substance during sliding wear tests. Use of solid lubricant powder, such as graphite, molendinumdisulphide and other iron oxides controls the friction at lower level [23]. Investigations on tribo-performance of brake pad materials were evaluated using pin-on-disc tribometer[23-24], reciprocating sliding test set-up[13, 16-18, 25], brake dynamometers disc brake test etc [26-27] .

In recent past, researchers tried to understand wear meachanism in braking system. Gawande et al., compared and investigated tribological behavior of non-asbestos with asbestos brake pad material using dry abrasion test under different loading conditions. It is observed that contact pressure and the covered distance have significant impact on weight loss, and also vary linearly, however, an effect of interface temperature was not under consideration for this study [28].

Till now, there are hardly any research studies that discuss the effect of interface temperature on wear behavior of friction material. An objective of this paper is to study wear performance of metallic based (AF-22) and fine brass based (CL-3003) friction materials under changing working conditions of temperature, sliding velocity, pressure and sliding distance. Friction materials were developed by compression moulding process and prepared to a sample suitable for pin-on-disc apparatus. Furthermore, Scanning electron microscopy (SEM), energy dispersive X-ray microanalysis (EDX) were used to understand wear mechanism in detail. Thermal stability was analysed by Thermogravimetric analysis (TGA). Through extensive quantitative analysis utilising the Taguchi technique, this research presents preliminary examinations of wear performance of brake pad materials as a suitable alternative to asbestos friction material.

2. Materials and Methods

2.1. Materials

Two asbestos-free metallic based friction materials were manufactured from CO-EFF friction bands, Pune, India, viz: AF-22 and CL-3003. Proper mixing fibers, resins, fillers and additives were carried out in a sigma mixer. A preform was prepared in 50 tonne capacity hydraulic press. Heat and pressure was applied during compaction and then curing was done at 150°C. After curing, the composites were ejected from the mould cavity. The test samples were cut from the pad segment and after turning and grinding operations brought into required pin size. The grey cast iron disc was used throughout the experimentations. Disc and bottom surface of pin was ground and polished so as to reproduce interface conditions as precise as possible. A metallic filler-based rubber resin bonded (AF-22) and a fine brass-based organic and inorganic reinforcing fibres with specific synthetic rubber modified resins (CL-3003) and their physicsl properties are mentioned in Table 1.

Table 1. Physical properties **of** brake pad Materials

Materials	Density (g/cm^3)	Compressive Strength (N/mm^2)	Transverse Bending Strength (N/mm^2)
AF-22	2.12	165	78
CL-3003	1.90	190	85

2.2. EDS analysis of Friction Materials

Energy dispersive spectroscopy (EDS) analysis of brake friction materials were carried out. Table 2 shows the main compounds and wt % contribution of commertial NOA (Non-asbestos) brake pad materials.

Table 2. Main compounds and their % contribution, in the brake pad materil

Compounds	AF-22 [wt. %]	CL-3003 [wt. %]
C	31.70	37.77
O	27.72	32.19
Si	12.74	12.67
Ba	7.57	0.00
Sb	6.79	4.16
Ca	6.68	2.92
Mo	3.59	5.00
Al	2.09	3.51
Mg	1.11	1.46
Na	0.00	0.31

The EDS spectra and elemental content of AF-22 material are shown in figure 1. Ingredients include C, Si, Ba, Sb, Ca, Mo, and Al among others. Due to higher concentration of rubber resin, C (Carbon) and Si (Silicon) provides higher strength. It also includes elemental properties of Ba (Barium), Sb (Antimony), Ca (Calcium) and Mo (Molybdenum).

Figure 2 displays the CL-3003 material's EDS spectrum and elemental makeup. It lists elements, such as C, Si, Mo, Sb, Al, Ca, Mg, and so on. Table 2 shows the EDS elemental composition for CL-3003. From Energy Dispersive Spectroscopy plots it can be revealed that, as the additive concentration increases C (Carbon) and Si (Silicon) wt % content increases due to the high cross linkage of organic (hydrocarbon chain of rubber) fiber material. Elemental raw Si and its intermetallic compounds are semiconductors and used as alloy integrals to provide more resistance to the aluminum, magnesium and other metals. Metallurgic silicon with 98-99 % purity with Mo (Molybdenum) enhances harden-ability, toughness of steel and improves strength.

2.3. Thermogravimetric analysis

Thermal stability of both samples were investigated using a thermogravimetric analyzer. Figure 3 shows a thermo-gravimetric examination of the AF-22 material in an oxygen-rich environment. By subjecting each raw material to an identical TGA run and computing the onset temperature of the corresponding change in mass, the thermal stability of the raw materials in the formulation was conformed. Figure 3 demonstrates that the rubber crumb particles exhibited the lowest thermal stability, with a mass loss beginning of 200 °C and a 100 % mass loss by 580 °C.

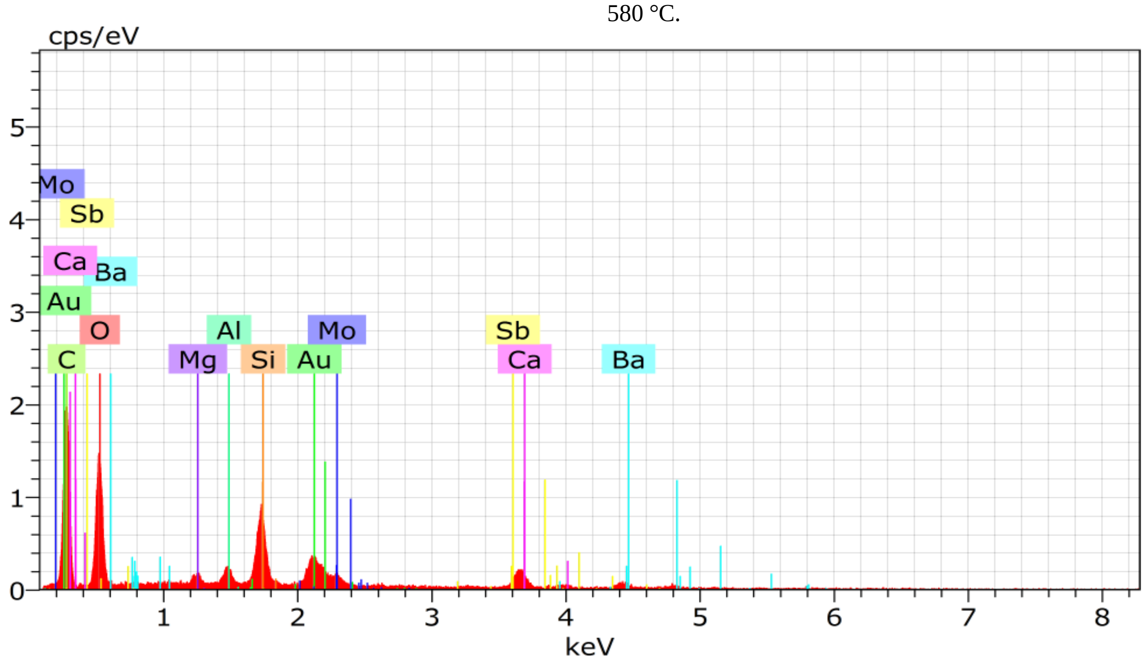

Figure 1. EDS spectrum for AF-22 brake pad material sample as detected

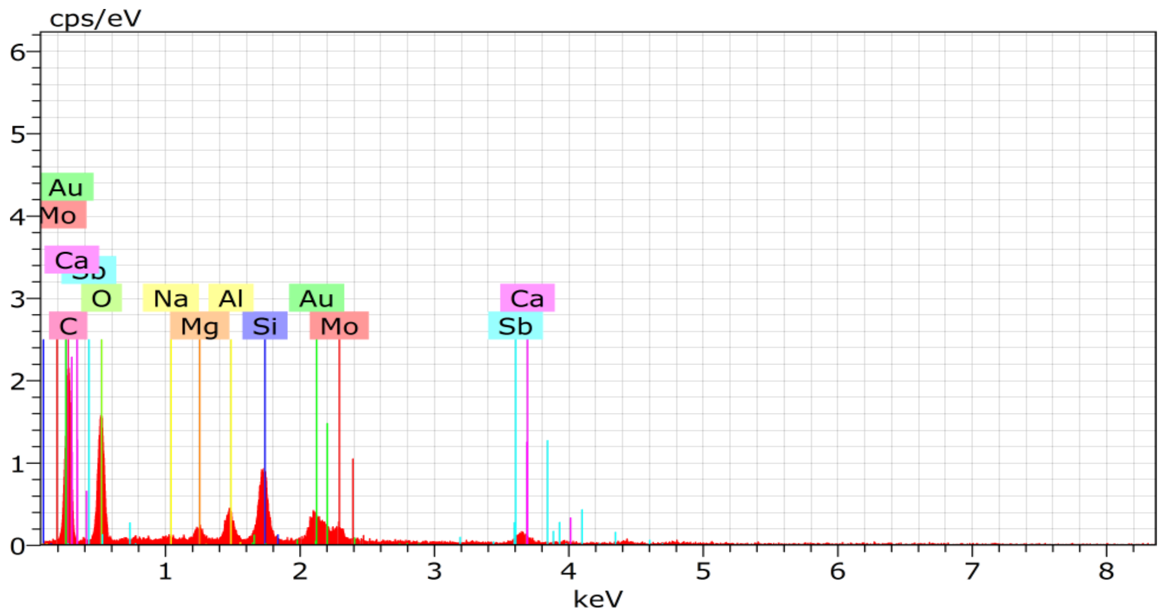

Figure 2. EDS spectrum for CL-3003 brake pad material sample as detected

The direction of mass shift is indicated by the positive and negative notation. The raw materials thermal stability differed greatly in terms of onset temperature, percentage mass change, and rate of mass change. A slow and continuous thermal degradation precedes the primary thermal event, accounting for a 1.55 percent mass loss before 200 °C onset temperature of. Once the major thermal degradation event has passed, the oxidation of metallic compounds within the formulation, such as iron, steel, and antimony, obatined a mass gain between 600 °C and 800 °C.

Figure 4 shows a typical result for a thermo-gravimetric examination of the CL-3003 friction material in an oxygen-rich environment. Brass oxide has a low beginning of mass loss of 285.1 °C for a refractory oxide, but only 1.8 percent of its mass is lost during this early degradation step, as illustrated in figure no. 6. Antimony tri-sulphide had a mixed mass change, with the initial mass loss occurring at 200 °C and the secondary mass gain occurring at 600 °C due to the metal's oxidation.

After a well-defined starting temperature, both ferrous-based iron and steel materials gained mass as a function of temperature. With no start temperature and a total mass loss of 38.4 percent at 600 °C, the minerals perlite and vermiculite had the best thermal stability. The thermal stability of fibrous materials, particularly aramid and natural fibres as illustrated in figure 6, is of particular relevance in this study.

Thermal stability of AF-22 and CL3003 was compared by TGA in order to correlate with hot performance of brake linings. CL-3003 material found shows better thermal stability and less susceptible to thermal fade.

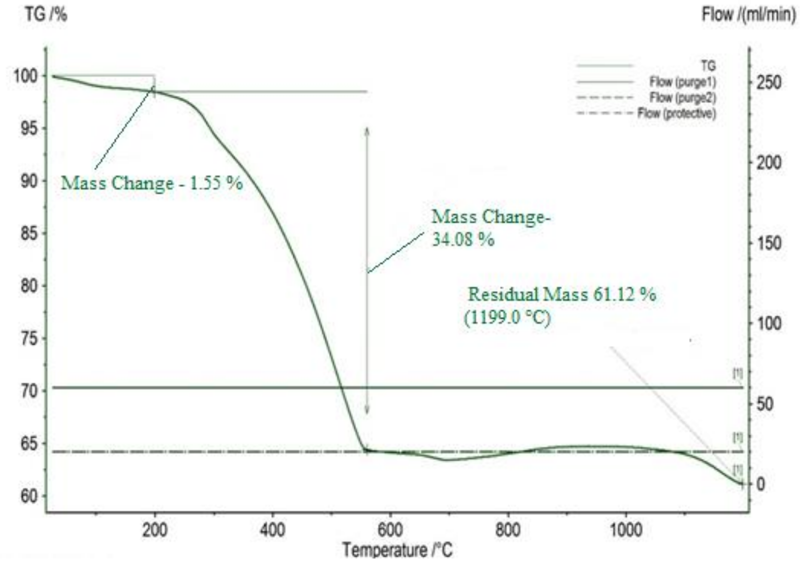

Figure 3. AF-22 brake material thermal analysis

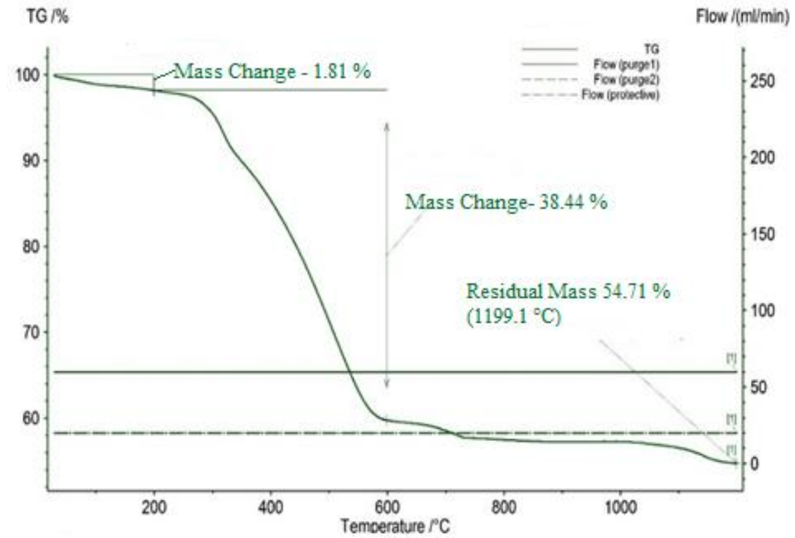

Figure 4. CL-3003 brake material thermal analysis

3. Experimentation

3.1. Sample Preperation:

The pin of 8 mm in diameter was ground and flattened on the bottom surface to ensure full surface contact. The bottom surface of pin is polished with ceramic paper to ensure uniform initial suface roughness through the samples. The combined surface integrity of pin and disc surface is ensured not more than 1.6 µm for all experiments. Roughness of the specimen as well as counterface disc was measured before the test by a Taylor Hobson surface roughness tester, using a cut-off value of 0.8 mm. A Grey Cast Iron (GCI) disc hardened to 60 HRC, of 165 mm in diameter and 10 mm thick, rotates through a powered spindle.

DUCOM (TR-20LE) "Pin-on-disc" test-rig (Figure 5) was used to perform experiments. Experiments were performed using ASTM G99 standard at room temperature under dry conditions. For the experimental study, parameters that correlate to actual braking operations, such as disc sliding speed, brake pad holding pressure, and so on, were deemed to be within their realistic range. In order to achieve sliding velocity between 2.10 to 6.30 m/s, track radius is adjusted between 25 to 75 mm and disk is rotated with a speed range between 200 to 2000 rpm. An interface temperature was varied as 50^0C, 100^0C, and 150^0C. The data acquisition system measures amount of linear wear using WINDUCOM 2010 software which then conveted into wear rate (mm^3/N.m).

3.2. Plan of Experiments

Experimental design based on Taguchi's orthogonal arrays was used in this work. Considering time and economy. Tagichi's orthogonal arrays are preferred over traditional factorial design of experiments. Furthermore, Tagichi's orthogonal array (OA) give more consistency and reproducibility of results.

During experimentation, many external factors which are not designed into standard set of experiments are influencing output response. An effect of these external factors on out-put response is termed as "noise". The signal to noise ratio (S/N ratio) measures sensitivity of the ourput response to the non-controllable factors i.e. noise. S/N ratio is expressed in terms of mean square deviation (MSD). In braking operations, the wear rate is desired to be lower, therefore a lower S/N ratio is considered, since smaller is better is considered as an objective function. MSD and SN ratios can be calculated using equation (1) and (2), for smaller is better [29].

$$MSD = (W_1^2 + W_2^2 + W_3^2 + \text{-----} W_n^2)/Y \quad (1)$$

Where MSD = mean square deviationfrom the true value of the output characteristics.

$$S/N = -10_{\log}(MSD) \quad (2)$$

Where Y is the number of observations and *W* is the wear rate that has been measured.

The L_9 (3^4) array was chosen with two repetations for the experimentation. The column was allocated the factors. The experiment plan consisted of 9 tests (array rows), with the first column representing Temperature (T), the second column representing Sliding Velocity (V), the third column representing Pressure (P), the fourth column representing Sliding Distance (D).

The wear rate (W_R), the reaction of unit load and sliding distance was investigated in terms of specific wear ratein (mm^3/Nm). Specific wear rate is found to be more accurate method to specify wear as compared to weight loss or linear wear method. To enable for study of the variance of the results and S/N ratios, the tests were duplicated twice, yielding a total of 18 observations each for AF-22 and CL3003 material. The weight difference approach was used to determine wear. The parameters and their levels are listed in table 3.

Table 3. Factors and their levels

	Levels			Units
Factors	1	2	3	
Temperature (T)	50	100	150	^{0}C
Sliding Velocity (V)	2.10	4.20	6.30	m/s
Pressure (P)	1	2	3	N/mm^2
Sliding Distance (D)	4000	8000	12000	m

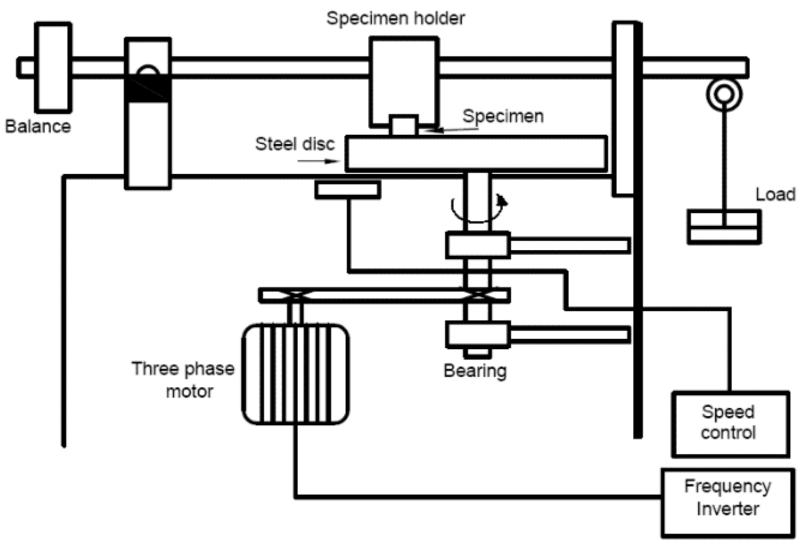

Figure 5. Pin-on-disc set-up

4. Results and Discussion

4.1. Wear Characterestics of AF-22 Material

Linear wear in µm was converted into volumetric loss of material and specific wear rate is calculated in mm^3/N.m.Table 4 illustrates the experimental findings for the AF-22 brake material in terms of wear rate.The spread around a target value is expressed by the signal-to-noise ratio (S/N). The smaller the spread, the higher the S/N ratio.

The parameters for wear were ranked using MINITAB18, Taguchi Design Software, as shown in response table 5.

The main effect for the S/N ratios for wear rate is plotted as shown in Fig. 6. SN ratio plot is exactly reverse to that of mean value plot. Hence, wear rate will be highest at 150^{0}C temperature, 6.3 m/s sliding velocity, 3 MPa pressure and 1.2 km of sliding distance.

Using MINITAB software analysis of variance was calculated as shown in Table 6. Percentage contribution of influencing factors were estimated using the pure sum of squares method.Temperature is most influencing parameter (82.96%) followed by pressure (6.80%), sliding velocity (5.77%), and sliding distance (4.48 %) that are statistically significant to control wear. Tempurature along with pressure cause loosening of matrix material and formulation of granulated wear particles under friction. These granuals further act as a third body particals and lead to more wear of pad material. The binders and fillers plays an important role in controlling wear. Gawande et al., observed linear relationship between wear rate, load and sliding distance; however the effect of temperature was not considered in their study [28]. Using MINITAB software yielded a mathematical equation for specific wear rate (equation 3).

Specific Wear Rate =

$$1.9239 + 0.00106\,T + 0.0071\,V + 0.0167P + 0.000003D \quad (3)$$

Table 5. Response table for S/N ratios

Level	Temperature (T)	Sliding Velocity (V)	Pressure (P)	Sliding Distance (D)
1	-6.241	-6.473	-6.447	-6.460
2	-6.656	-6.504	-6.545	-6.545
3	-6.682	-6.601	-6.587	-6.574
Delta	0.442	0.127	0.141	0.114
Rank	1	3	2	4

Table 6. Analysis of variance for wear rate (AF-22)

Source	DF	Seq SS	Adj MS	Contribution (%)
(T)	2	0.02142	0.01071	82.96%
(V)	2	0.00148	0.00074	5.77%
(P)	2	0.00175	0.00087	6.80%
(D)	2	0.00115	0.00057	4.48%
Error	0	0.00000	0.00000	0.0000
Total	8	0.02582		100.00%

Table 4. Experimental results for AF-22 brake materials

Run	Levels				Specific Wear Rate x 10^{-5} mm^3/N.m		Specific Wear Rate x 10^{-5} mm^3/N.m	S/N Ratio
	T	V	P	D	WR_1	WR_2		
1	50	2.10	1	4000	2.01	2.00	2.005	-6.042
2	50	4.20	2	8000	2.05	2.06	2.055	-6.256
3	50	6.30	3	12000	2.10	2.09	2.095	-6.423
4	100	2.10	2	12000	2.16	2.15	2.155	-6.668
5	100	4.20	3	4000	2.15	2.14	2.145	-6.628
6	100	6.30	1	8000	2.15	2.16	2.155	-6.668
7	150	2.10	3	8000	2.17	2.16	2.165	-6.709
8	150	4.20	1	12000	2.15	2.14	2.145	-6.628
9	150	6.30	2	4000	2.16	2.17	2.165	-6.709

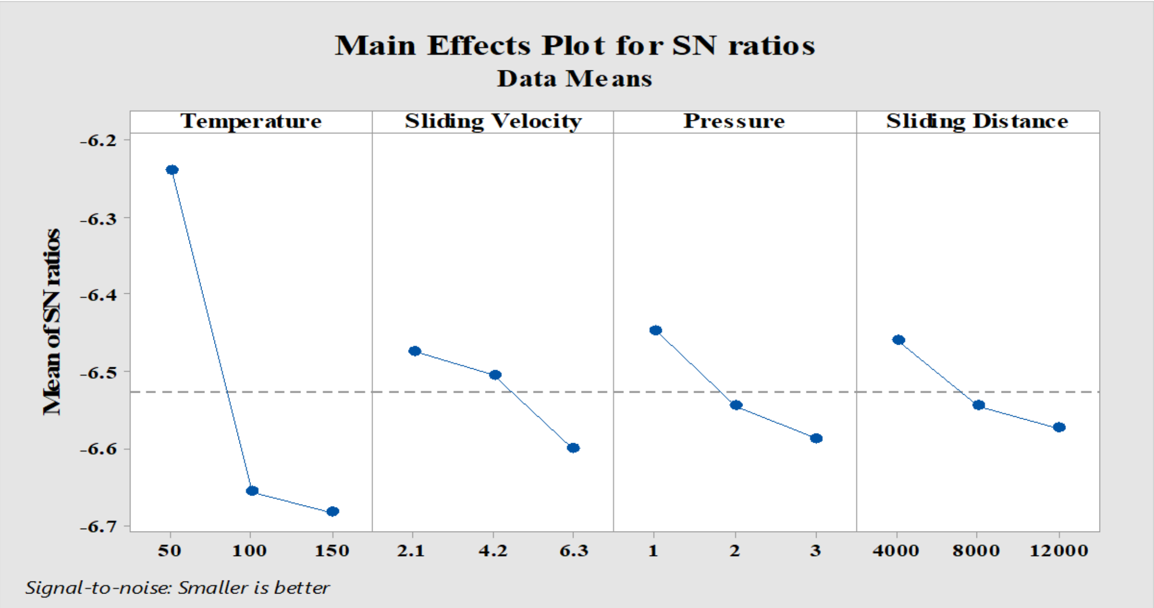

Figure 6. Main effect plot for SN ratios for AF-22 Material

4.2. Wear Characterestics of CL-3003 Material

Table 7 shows the experimental results for CL-3003 friction material.

Fig. 7 shows the main effects plot for the S/N ratios for wear for various parameters such as temperature, sliding velocity, pressure, and sliding distance.

The parameters for wear were ranked using MINITAB, Taguchi Design Software, as shown in response table 8.

The scatter around a target value is expressed by the signal-to-noise ratio (S/N). S/N ratios for wear rate, parameter ranking, and ANOVA are calculated using MINITAB, Taguchi design software. Percentage contribution of influencing factors estimated using the pure sum of squares method.

Table 7. Experimental results for CL-3003 brake materials

Run	Levels				Specific Wear Rate x 10^{-5} (mm^3/N.m)		Mean Specific Wear Rate x 10^{-5} (mm^3/N.m)	S/N Ratio
	T	V	P	D	WR_1	WR_2		
1	50	2.10	1	4000	1.50	1.49	1.495	-3.492
2	50	4.20	2	8000	1.54	1.55	1.545	-3.778
3	50	6.30	3	12000	1.57	1.56	1.565	-3.890
4	100	2.10	2	12000	1.63	1.62	1.625	-4.217
5	100	4.20	3	4000	1.62	1.61	1.615	-4.163
6	100	6.30	1	8000	1.64	1.65	1.645	-4.323
7	150	2.10	3	8000	1.65	1.66	1.655	-4.376
8	150	4.20	1	12000	1.66	1.65	1.655	-4.376
9	150	6.30	2	4000	1.65	1.64	1.645	-4.323

Table 8. Response table for S/N ratios

Level	Temperature (T)	Sliding Velocity (V)	Pressure (P)	Sliding Distance (D)
1	-3.721	-4.029	-4.064	-3.993
2	-4.235	-4.106	-4.106	-4.159
3	-4.358	-4.179	-4.143	-4.161
Delta	0.638	0.150	0.079	0.168
Rank	1	3	4	2

Table 9. Analysis of variance for wear rate (CL-3003)

Source	DF	Seq SS	Adj MS	Con (%)
(T)	2	0.02286	0.01143	87.95%
(V)	2	0.00106	0.00053	4.10%
(P)	2	0.00026	0.00013	1.03%
(D)	2	0.00180	0.00090	6.92%
Error	0	0.00000	0.0000	0.0000
Total	8	0.02582		100.00%

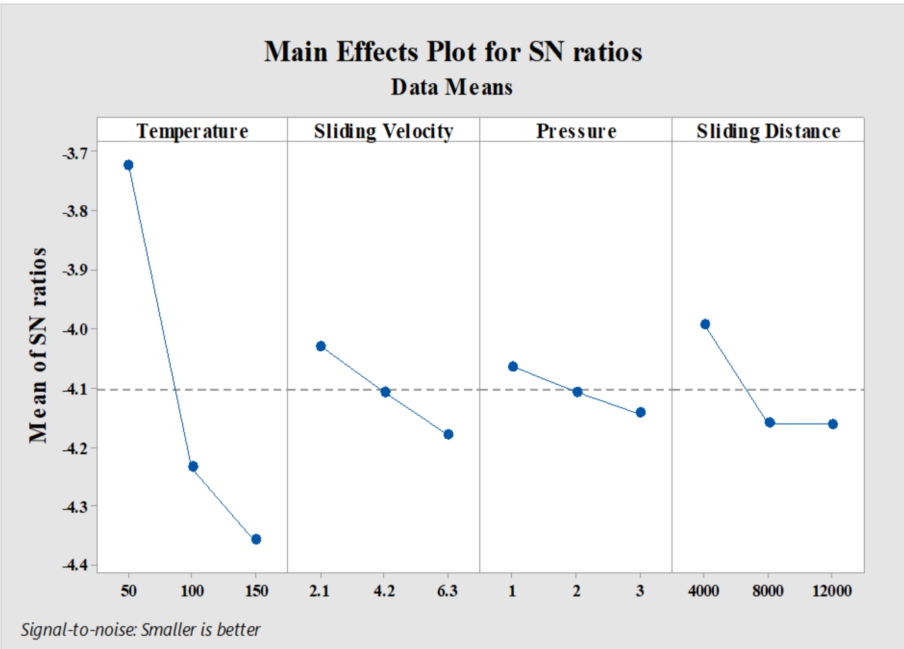

Figure7. Main effect plot for S/N ratioCL-3003 Material

Table 9 shows the results of the ANOVA for wear. Temperature (87.95%) is the highest influencing parameter followed by sliding distance (6.92%), sliding velocity (4.10%) and pressure (1.03%) on wear. Similar effect of parameters are observed on wear characterestics of other non-asbestos materials [9, 24, 28].

Mathematical equation for specific wear rate (Equation 4) obtained is as follows:

$$\text{Specific Wear Rate} = 1.4183 + 0.001167T + 0.00635V + 0.0067P + 0.000004D \quad (4)$$

It is observed that the specific wear rate of AF-22 material is around 24 % more than that of CL-3003 material. For both the materials Tempurature is most predominent parameter which affects on wear, however it is more in case of CL 3003. Pressure is least contributing parameter for CL3003, however, it is second largest contributing parameter for AF-22. This may be due to more weight (%) of Mo in CL3003. Similar results for load and sliding distance were obtained by Gawande et al., (2020) for CL 3003 material; however they have not considered interface temperature.

4.3. Wear Mechanism

The base matrix SEM image before test shows chunk, segments and block images of AF-22 compound in figure 8a at 10000 x magnifications. C and Si weight percent are higher due to the presence of rubber resin, as carbon gives hydrocarbon close fit bonding for higher strength. AF-22 also comprises elemental properties of Ba (Barium), Sb (Antimony), Ca (Calcium), and Mo (Molybdenum).

The segmental sections of CL-3003 were measured by SEM, as illustrated in figures 8b. Because of the high cross linking of organic (hydrocarbon chain of rubber) fibred material, it can be concluded from EDS plots that, as concentration increases, content of C and Si weight percent increases. Elemental raw Si and its intermetallic compounds are semiconductors that are used as alloy integrals to give aluminum, magnesium, and other metals better resistivity. Metallurgic silicon with a purity of 98-99 percent and Mo (Molybdenum) improves steel hardenability, toughness, and strength.

After the test, in AF-22 material a brittle and chipped surface shows a typical abrasive wear and tribochemical reactions which is a function of phony surface layer (Fig. 9a). The resultant discontinuity will increase residual stresses leading to develop brittle cracks.

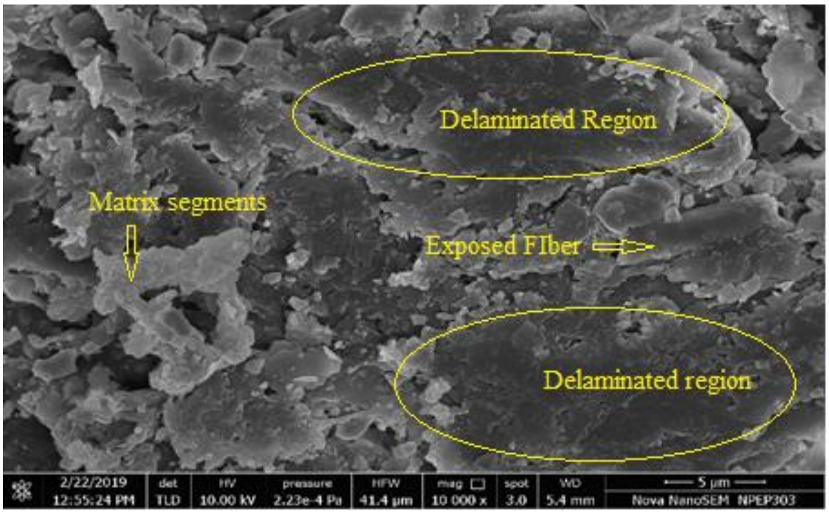

Figure 8. a) AF-22 brake material sample SEM image at 10,000 x magnification

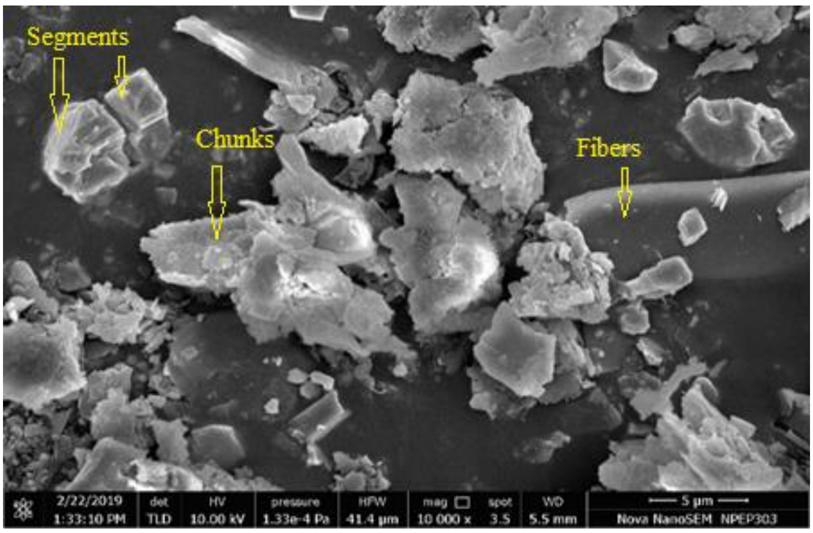

Figure 8. b) CL-3003 brake pad material sample SEM image at 10,000 x magnification

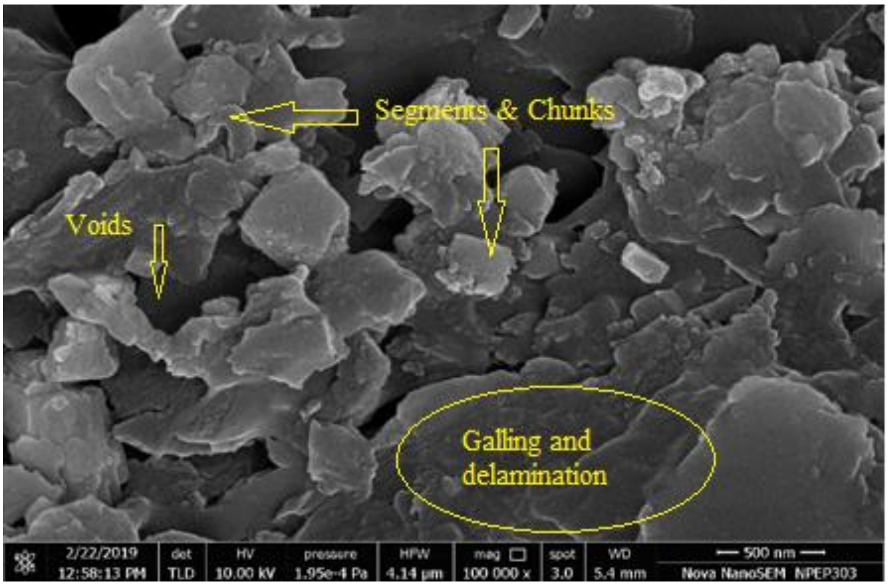

Figure 9. a) AF-22 brake material sample SEM image at 1,00,000 x magnification

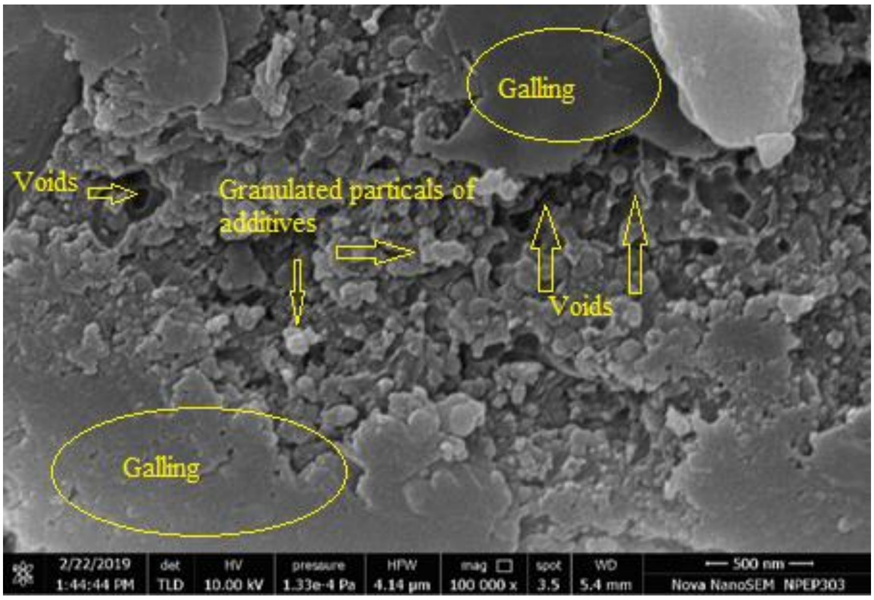

Figure 9. b) CL-3003 brake pad material sample SEM image at 1,00,000 x magnification

At high temperature, softening of matrix phase resulted in ploughing of metallic fibres in CL-3003 material. Frictional heating and pressure tends to melt metallic additives which leads to loose binders and granulated particals causing more wear. Dettachement of these particles will cause three body abrasive wear. This suggests reason for increasing wear with temperature. Interface temperature strongly controls the properties of ingredients of friction material. The mechanical integrity of the compacted wear debris becomes weaker due to increase in temperature and thermal degradation occurs. This is also depends on initial micro-aspirity on pin as well as on disc surface. Whitening of the grain boundry region observed due to stress whitening of matrix material.

In this study, the researcher has compared tribological behavior of two non-asbestos materials viz: AF-22 and CL-3003, and it is observed that CL-3003 material shows less wear rate than AF-22, hence is a better substitute material. Wear rate of friction materials at temperature below 150^0 C is linear; however due to thermanl degradation at high temperate it may be exponential. Wear performance is also affected by composition especially binder materials alongwith temperature, pressure and speed [9,24,28]. Similarly , wear volume is directly proportional to applied load, speed, sliding time and speed in Fibre Reinforced Al And Al-Alloy Metal Matrix Composites also [30-31].

Wear rate of metallic filler-based rubber resin bonded (AF-22) is more than organic and inorganic reinforcing fibres with specific synthetic rubber modified resins based (CL-3003) material. Metling of metal additives and formation of hot spots due to frictional heating is the main cause of increase in wera rate of AF-22. Hence, resin and fillers and their proportion is most important while formulating novel brake pad materials.

Few principal process parameters were taken into consideration for this study, however; for more understanding of wear mechanism due to frictional heating a systematic study under '*in-situ*' condition is suggested.

5. Conclusion

Wear performance of two asbestos- free brake pad materials sliding against a grey cast iron disc were evaluated and compared. The wear performance of compression moulded brake pad materials has been effectively analysed using Taguchi's analysis approach. The wear rate of AF-22 was observed between 2.01 to 2.17 mm^3/N.m., which is higher than CL-3003 (1.49 to 1.66 mm^3/N.m).Ranking of the parameters have been done and it was observed that temperature is most influeincing parameter for both the materials. Linear relationship was observed between specific wear rate and tempurature, pressure, sliding velocity and sliding distance for both materials.When compared to the AF-22 friction material, CL-3003 has a higher heat conductivity. Adhessive deformation of metallic additives in AF-22 contribute considerably in loss of friction due to excessive temperature causing 'fade'.The thermal degradation of the ingredients controls the wear mechanism. Based on Scanning electron microscopy images, thermal degradation causes exponential rise in wear rate. This will lead to engineers that wear rate can be minimised by controlling interface temperature between brake pads and disc either externally and (or) by adding solid lubricants in existing materials. In terms of material, CL-3003 friction material outperforms AF-22. To anticipate the commercial usage of brake pad materials, detailed investigations involving more combinations can be carried out to generate databank for futuristic material.

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