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Optimization of process parameters during the manufacturing of brake friction lining from coconut/palm kernel/periwinkle shells composite using SN ratio and entropy-TOPSIS techniques

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Abstract

This study established the optimum process parameters for manufacturing brake friction lining (BFL) from coconut shells (CNS), palm kernel shell (PKS) and periwinkle shells (PWS) composites. Optimization was achieved in respect of the performance metrics (coefficient of friction, wear rate and hardness) using Signal-to-Noise (SN) ratio and Entropy and Technique for the Ordered Preference by Similarity to the Ideal Solution (Entropy-TOPSIS). The optimum parameters obtained using SN ratio and Entropy-TOPSIS method were compared and are respectively 29 MPa and 29 MPa (molding-pressure), 120°C and 140°C (molding-temperature), 6 and 6 minutes (curing-time) and 2 hr. and 3 hr. (heat-treatment-time). ANOVA using Minitab 21.1.0.0 reveals the effect of the molding pressure and the curing time on the synergized performance metric as statistically significant at α = 0.05 with total contribution of 94.44%. Comparatively, the significant parameters values were unaltered in both methods of optimization. Therefore, it is concluded that any of the optimum parameter values obtained using either the SN ratio approach or the Entropy-TOPSIS method can safely be used for producing BFL of different composition of CNS, PKS and PWS.

Keywords: Parameter Optimization; Brake friction lining; Signal-to-Noise ratio; Entropy-TOPSIS Method.

1. Introduction

The automotive braking system is one of the most important safety systems in a vehicle. Brakes are energy conversion devices, which convert the kinetic energy of a vehicle into thermal energy resulting in vehicle deceleration [1]. Brake friction lining (BFL) form the key component of the braking system because they provide the friction surface for contact with a rotating disc. [2] reported that asbestos was introduced as brake friction lining material in 1908 due to its possession of stable physical and chemical properties over a wide range of temperature. However, the use of asbestos has been linked to established health risk such as asbestosis, mesothelioma, lungs, ovarian and laryngeal cancer, and atelectasis [3].

To meet the increasing demand of the automobile braking system, researches are ongoing to optimize BFL performance. [4] developed BFL by hot molding method from juniperus drupacea cones powder, barite, phenolic resin, coke and fiber types (glass, carbon and basalt). Parameter combinations based on Taguchi $L_{18}(2^1 \text{ x } 3^5)$ orthogonal index was set up for investigating the most ideal content ratio and production conditions for coefficient of friction, density, hardness and wear rate. Analysis was done using signal to noise ratio and ANOVA. The ideal production conditions were established to be molding temperature of 160°C, molding pressure of 100 Mpa, mixing time and molding time of 15mins each. The result also shows that juniperus drupacea cones powder can be used up to 25%, preferably up to 10% by weight in brake friction lining production. [5] obtained the optimal production process parameters for manufacturing coconut shell BFL using Gray Relational Analysis (GRA). Other materials used in the formulation include epoxy resin, graphite and aluminum oxide. The result from the GRA shows that optimized BFL performance can be obtained using molding pressure, molding temperature, curing time and heat treatment time of 14 MPa, 140 °C, 8 min and 5 h, respectively. Heat treatment time was reported to have the most significant effect on the wear rate and coefficient of friction while the hardness and ultimate tensile strength were most significantly affected by the curing time as seen from the ANOVA analysis. The effect of all the factors were insignificant as their p values were greater than (0.010)1%.

[6] investigated the suitability of coal ash and palm kernel shells for brake pad production. The optimum manufacturing parameters with respect to wear rate and hardness responses were investigated using Taguchi method of design of experiment. The result shows that optimum wear rate can be obtained using molding temperature, curing time and heat treatment time of 175°C, 8 mins and

3hrs respectively. The optimum settings for hardness were established to be molding temperature of 175°C, curing time of 6mins and heat treatment time of 3hrs. ANOVA analysis using minitab 2017 was used to affirm that molding temperature and heat treatment time were the most significant factor for hardness and wear respectively. It was also reported that hardness, thermal resistance and specific gravity increases with increase in coal ash content while wear rate reduces with increase of coal ash. The manufacturing process parameters and design mix for the production of eco-friendly brake pads from periwinkle shell and fan palm shells were optimized by Amaren [3]. Optimization was achieved with respect to the coefficient of friction using Taguchi technique. An optimal formulation of 35% resin and 65% periwinkle or fan palm shell was established with the corresponding control factors as molding pressure of 41Kpa, molding temperature of 150°C, curing time 10 mins and heat treatment time of 1 hr. Compared with the commercial control pad, the brake pads developed from 125μm periwinkle particle size exhibited improved mechanical properties with respect to the coefficient of friction, hardness and compressive strength.

Investigations into the use of agricultural waste as fibre materials for the development of brake friction lining (BFL) has gained more attention in the automotive industry in recent years. These wastes utilization is not only economical, but can also result in environmental pollution control. Coconut Shells (CNS), Palm Kernel Shells (PKS) and Periwinkle Shells (PWS) are often disposed in large quantities as agricultural wastes. These agricultural wastes possess favorable characteristics which makes them viable for use in BFL production. The suitability properties of CNS for use in automotive industrial applications were reported by [7 - 8] to include good hardness, wear resistance, flame resistance, good acoustic qualities and thermal resistance up to 1500°C. [9 - 10] have also reported low water retention, high heating value and low ash and sulfur contents for PKS. Similarly, [11] reported PWS to be characteristically resistant to wear with an excellent abrasion resistance of 87.5%. Its mechanical properties are very comparable to asbestos [12]. Hence, this research focuses on investigating the optimum manufacturing process parameters for the production of ecofriendly brake pad from composites of Coconut Shells (CNS), Palm Kernel Shells (PKS) and Periwinkle Shells (PWS).

2. Materials and Method

The materials used for the production of the BFL test samples are CNS, PKS, PWS, epoxy resin, powdered graphite, alumina and bamboo fiber.

2.1 Sample Preparation

Powder metallurgy was used in the production of the test samples. The CNS, PKS and PWS consisting of 30kg each were sundried for 7 days after which they were transferred into an electric oven (Model: Memmert, Western Germany) for further drying at 105ºC for five hours. This was necessary to remove all moisture content from the materials. The dried materials were then transferred into a hammer crusher (Type: 000T, PUISSANE: 1.5kv, No: 13634) to reduce the size to 2 mm – 4 mm. Crushed material were transferred into a ball milling machine (Model: 87002 Limoges-France) and left for 2 hours to reduce the particle size into powders. Thereafter, the materials were sieved into 100 μm size using a BS 410 standard sieve. Finally, the materials were properly blended and mix together in a mixer (Model: 89.2 Ridsdale & Co ltd, Middlesbrough Eng) in the proportion shown in Table 1 which is based on a typical composition proposed by Blau [13]. Mixing was done for twenty minutes so as to obtain a homogenous mixture before transferring into a mould for cold pressing.

Table 1: Percentage composition of the BFL

Pad Materials	Composition (wt.%)
Fillers • CNS • PWS • PKS	 15 15 15
Matrix (Epoxy Resin)	35
Friction Additives • Lubricant (Graphite powder) • Abrasives (Alumina)	 7 5
Reinforcing fibre (Bamboo fibre)	8

The homogenous mixture was divided into nine sets for the purpose of producing nine test samples. A cylindrical die cavity (mould) closed at one end with a diameter of 30 mm was made for the production of the test samples. Each set of the powdered mixture was placed in the mould and compressed at room temperature and a pressure of 15MPa using a uniaxial hydraulic hand press (cold compaction). The purpose of cold compaction is to eliminate deformations such as creep and diffusion which are associated with high temperature compacting. After compaction, the product known as green body was ejected out of the die cavity (mould).

Hot pressing (compacting) was done to ensure rigidity of the BFL samples. The manufacturing parameters adopted (moulding pressure, moulding temperature, curing time and heat treatment time) were set up using Taguchi

$L_9(3^4)$ orthogonal array as represented in Table 2. After the hot press, the samples were allowed to cool at room temperature. To ensure that the samples were fully cured, post curing was performed on the test samples in the oven. The process flow for the production of the test samples is summarized in Figure 1.

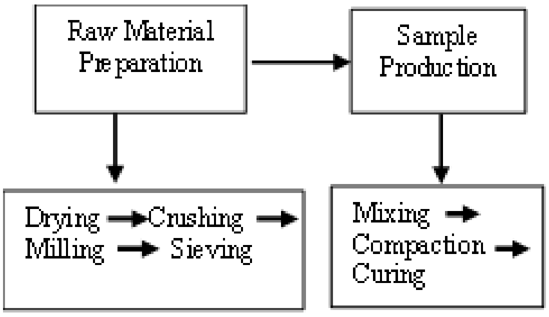

Figure 1. Process flow for the production of the BFL samples.

2.2 Design of Experiment (DoE)

The manufacturing parameters for the production of disc brake pad are moulding pressure, moulding temperature, curing time, and heat treatment time [2]. Therefore, experimental design based on the Taguchi L9 (3^4) orthogonal array (Table 2) was set up for manufacturing of brake pads so that optimum manufacturing parameters could be investigated. The factor levels for the manufacturing parameters were established from [2]. These values are obtained by creating equal interval between manufacturing parameters as commonly used in brake pad manufacture [3]. Using the percentage composition (wt.%) in Table 1 and the DoE in Table 2, samples of BFL were produced.

Table 2: The L9 (3^4) orthogonal array for the manufacturing parameters.

Samples	Independent Variables/factors/ Manufacturing Process Parameters			
	Moulding Pressure (M_p)	Moulding Temperature (M_t)	Curing time (C_t)	Heat treatment time (H_t)
1	17	120	6	1
2	17	140	8	2
3	17	160	10	3
4	23	120	8	3
5	23	140	10	1
6	23	160	6	2
7	29	120	10	2
8	29	140	6	3
9	29	160	8	1

2.3 Product Characterization

To investigate the optimum manufacturing process parameters of the BFL, the produced samples were characterized to determine the performance metrics namely 1) coefficient of friction, 2) wear rate and 3) hardness. The incline plane method with a wedge placed at 90° was used to determine the coefficient of static friction for the test samples. The angle of inclination was varied gradually until the specimen was just about to slide. The coefficient of friction (μ) was determined using equation (1).

$$\mu = tan\theta \quad (1)$$

$Where, \theta \text{ is the angle of inclination}$

Wear tests was conducted using the Pin-on-disc test apparatus by sliding the test sample over a cast iron surface at a load of 20N and sliding speed and distances of 250rev/min and 2000m respectively. The initial and final weight of the samples were measured using a single pan electronic weighing machine with an accuracy of 0.01g. During the test, the pin was pressed against the counterpart rotating against a cast iron disc (64 HRC) and counter surface roughness of 0.3μm. The pin samples were loaded vertically into the hardened cast iron disc by means of a friction detecting arm connected to a strain gauge. After moving the samples through the sliding distance, they were removed, cleaned and dried. Finally, the samples were weighed to determine the final weight. The difference between the initial and final weight of the samples gives the mass loss. The wear rate was determined using equation (2) [14].

$$Wear\ rate = \frac{\Delta W}{S} = \frac{\Delta W}{2\pi ND \times t} \quad (2)$$

Where: ΔW is the change in weight of the sample before and after test; S is the sliding distance; N is the radial speed (rpm); D is the brake disc diameter and t is the time taken to expose the specimen to wear.

Hardness test was conducted on the samples having 30 mm diameter using the Brinell hardness testing equipment to BS240 on the Tensometer (M500-25KN, Gunt Hamburg Hardness Tester, WP300). Based on the ASME specification, a 10 mm diameter hardened steel ball was pressed into the test sample and the load P, was kept at 500 kgf. The diameter of indentation d was measured using an optical micrometer screw gauge. The test was repeated three times and the mean value was taken and incorporated into equation (3) to obtain the Brinell Hardness Number (BHN).

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2}} \quad (3)$$

Where P is the load applied, D is the diameter of hardened steel ball and d is the diameter of indentation. [12].

2.4 Optimization of the Manufacturing Process Parameters

The values of the performance metrics obtained from product characterization were analyzed using Signal to Noise (SN) ratio. Thereafter, there were synergized and analyzed using SN ratio alongside Entropy and Technique for the Ordered Preference and Similarity to the Ideal Solution (Entropy-TOPSIS), to obtain the optimum parameters for producing BFL from CNS/PKS/PWS mix.

2.4.1 Optimization of Manufacturing Process Parameters Using SN Ratio

The SN ratio of the performance metrics was determined using equations (4) - (5) with regard to the Larger is better Quality Characteristics (QC) and the smaller is better QC respectively [15 -16]. Larger is better QC was used for the coefficient of friction and hardness while the wear rate was optimized using smaller is better QC.

$$\frac{S}{N}(Larger\ is\ better) = -10\log\frac{1}{n}\sum_{l=1}^{n}\frac{1}{y^2} \quad (4)$$

$$\frac{S}{N}(Smaller\ is\ better) = -10\log\frac{1}{n}\sum_{l=1}^{n}y^2 \quad (5)$$

Where n is the number of observations in the array and y is the average of the reading of the

To synergize the performance metrics for analysis using SN ratio, multiple criteria evaluations was employed on the individual performance metric. Then, the Overall Evaluation Criteria (OEC) which represents the relative weight of the individual criterion (equation 6) was employed. [17-18]

$$OEC = \left(\frac{/X_1 - 0.276/}{/0.356 - 0.276/}\right) x\ 38.34 + \left(1 - \frac{/X_2 - 0.049/}{/0.215 - 0.049/}\right) x\ 26.63 + \left(\frac{/X_3 - 16.7/}{/40.5 - 16.7/}\right) x\ 34.98 \quad (6)$$

Where X_1, X_2 and X_3 are the average readings for the coefficient of friction, wear rate and hardness respectively.

2.4.2 Optimization of Manufacturing Process Parameters Using Entropy-TOPSIS

Entropy-TOPSIS method whom details are available in [19] was also applied to determine the optimum manufacturing process parameters. The optimum manufacturing process parameters obtained using the Entropy-TOPSIS method were then compared with those values obtained using SN ratio. Consequently, the optimum manufacturing process parameters for producing BFL from CNS/PKS/PWS mix was established.

2.4.3 Analysis of Variance

Analysis of variance (ANOVA) was conducted using Minitab 21.1.0.0 software to investigate the effect and significance of each factor (Molding pressure, molding temperature, curing time and heat treatment time) on the performance metrics of the BFL. The Analysis was done using the Fisher test (F-test) at 5% significance level (α = 0.05). The process parameter/factor is considered significant if the p value is smaller than the (F0.05) [20].

3. Result and Discussion

The average coefficient of friction, wear rate, and hardness values obtained from the experiments conducted and the SN ratio of the respective performance metrics are presented in Table 3.

Table 3: Experiment results and SN ratio

Experiment/ Sample No	Average Coefficient of Friction	SN Ratio (Larger is better)	Average Wear Rate (g/km)	SN Ratio (Smaller is better)	Average Hardness (BHN)	SN Ratio (Larger is better)

1	0.356	-4.200	0.049	30.967	23.367	32.143
2	0.331	-4.832	0.102	24.600	26.767	33.323
3	0.276	-6.411	0.135	22.165	32.533	35.017
4	0.302	-5.629	0.104	24.431	23.467	32.180
5	0.319	-5.153	0.215	18.122	16.700	29.225
6	0.289	-6.011	0.105	24.347	33.633	35.306
7	0.332	-4.806	0.050	30.792	23.933	32.351
8	0.322	-5.072	0.051	30.620	40.500	36.920
9	0.312	-5.346	0.106	24.265	37.067	36.151

3.1 Optimum Manufacturing Process Parameters (Coefficient of Friction)

Figure 2 shows that the optimum manufacturing process parameters in respect of the coefficient of friction are molding pressure of 29MPa, molding temperature of 120°C, curing time of 6 minutes and Heat treatment time of 1 hr. The ANOVA in respect of the coefficient of friction (Tables 4-5) shows that the molding temperature is the most effective factor on the coefficient of friction with a contribution of 52.69 % while the curing time has the least effect. However, all factors are statistically insignificant as the p-values were greater than 0.05.

It can also be seen from Figure 2 that a lower molding temperature is required for optimum coefficient of friction to be achieved. Also, the coefficient of friction decreases as the molding temperature, curing time and heat treatment time increases. The behavior of the response is quite irregular for the molding pressure.

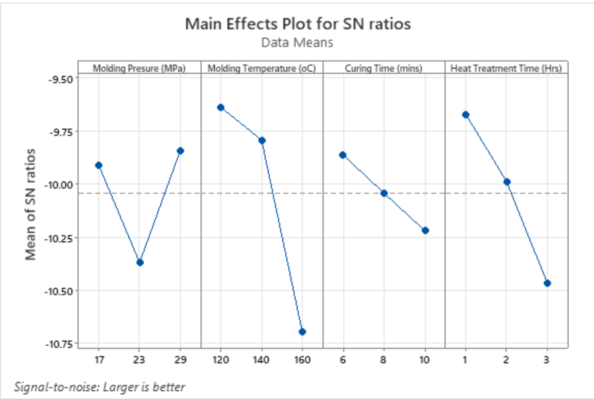

Figure 2. Main effect plot for SN ratios for the coefficient of friction

3.2 Optimum Manufacturing Process Parameters (Wear Rate)

The optimum manufacturing process parameters considering the wear rate are Molding pressure of 29MPa, Molding temperature of 120°C, curing time of 6 minutes and heat treatment time of 2hrs (Figure 3). In addition, Tables 6 and 7 show that the most effective factor affecting the wear rate is the molding pressure with a percentage contribution of 36.55%. This is closely followed by the curing time (28.90%) and molding temperature (24.32%). The influence of any of the factors are statistically insignificant as the p-values are greater than 0.05.

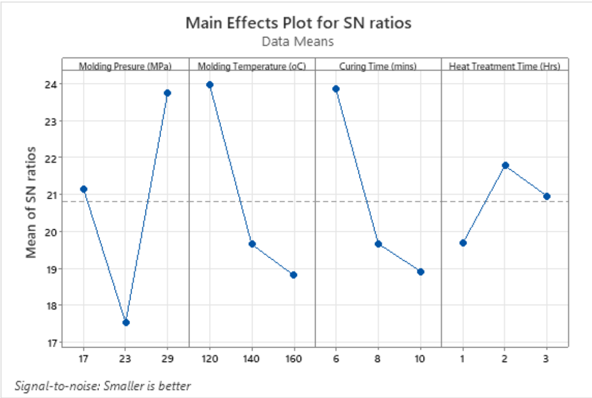

Figure 3. Main effect plot for SN ratios (wear rate)

3.3 Optimum Manufacturing Process Parameters (Hardness).

Figure 4 established the optimum manufacturing process parameter for the hardness of the produced BFL samples as molding pressure of 29MPa, molding temperature of 160°C, curing time of 6 minutes and heat treatment time of 3 hours. The Figure shows that the hardness increases with molding pressure, molding temperature and heat treatment time but decreases with the curing time. According to Tables 8 and 9, the molding temperature is the most effective factor for hardness with a contribution of 37.45%. This is followed by molding pressure (28.11%) and curing time (20.98%). Again, all the factors main effect are statistically insignificant. Figure 4 indicates that the molding temperature should be kept at a high value to achieve good hardness of the BFL, so that the lining strength is increased [4].

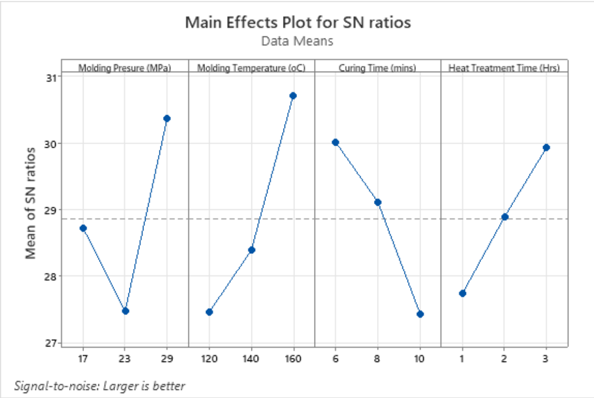

Figure 4. Main effect plot for SN ratios (hardness)

3.4 Optimum Manufacturing Process Parameters (Coefficient of friction, Wear rate and Hardness) using SN ratio and OEC.

Table 10 shows the value of OEC and the respective SN ratio based on the larger-the-better quality characteristics. Figure 5 depicts the optimum manufacturing process parameters for producing BFL of CNS/PKS/PWS mix as a molding pressure of 29MPa, molding temperature of 120°C, curing time of 6 minutes and heat treatment time of 2 hours. Also, Tables 11 and 12 revealed that the most significant factor affecting the synergized quality of the brake pad is the molding pressure. This factor has a percentage contribution of 55.51% closely followed by the curing time (38.94%). Hence, high molding pressure and less curing time will increase the overall quality of the BFL. Finally, The molding pressure and curing time are statistically significant as their p-values are less than 0.05.

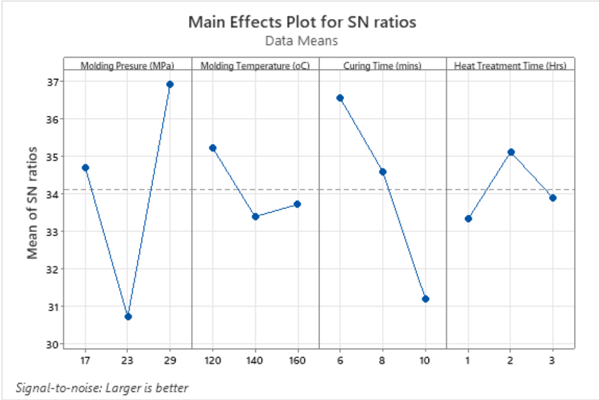

Figure 5. Main effect plot for SN ratios (synergzed quality criteria-OEC)

Table 4: ANOVA for the Coefficient of friction (Vs Molding Pressure and Curing Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Pressure (MPa)	2	0.000662	14.18%	0.000662	0.000331	0.35	0.722
Curing Time (Mins)	2	0.000268	5.74%	0.000268	0.000134	0.14	0.871
Error	4	0.003735	80.08%	0.003735	0.000934		
Total	8	0.004664	100.00%				

Table 5: ANOVA for the Coefficient of friction (Vs Molding Temperature and Heat Treatment Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Temperature (oC)	2	0.002458	52.69%	0.002458	0.001229	5.29	0.075
Heat Treatment Time (Hrs)	2	0.001278	27.39%	0.001278	0.000639	2.75	0.177
Error	4	0.000929	19.92%	0.000929	0.000232		
Total	8	0.004664	100.00%				

Table 6: ANOVA for the Wear rate (Vs Molding Pressure and Curing Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Pressure (MPa)	2	0.008042	36.55%	0.008042	0.004021	2.12	0.236
Curing Time (Mins)	2	0.006358	28.90%	0.006358	0.003179	1.67	0.297
Error	4	0.007602	34.55%	0.007602	0.001900		
Total	8	0.022001	100.00%				

Table 7: ANOVA for the Wear rate (Vs Molding Temperature and Heat Treatment Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Temperature (oC)	2	0.005351	24.32%	0.005351	0.002675	0.74	0.532
Heat Treatment Time (Hrs)	2	0.002251	10.23%	0.002251	0.001125	0.31	0.748
Error	4	0.014399	65.45%	0.014399	0.003600		
Total	8	0.022001	100.00%				

Table 8: ANOVA for the Hardness (Vs Molding Pressure and Curing Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Pressure (MPa)	2	133.40	28.11%	133.40	66.70	1.10	0.415
Curing Time (Mins)	2	99.55	20.98%	99.55	49.78	0.82	0.502
Error	4	241.60	50.91%	241.60	60.40		
Total	8	474.55	100.00%				

Table 9: ANOVA for the Hardness (Vs Molding Temperature and Heat Treatment Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Temperature (oC)	2	177.72	37.45%	177.72	88.86	1.53	0.322
Heat Treatment Time (Hrs)	2	63.88	13.46%	63.88	31.94	0.55	0.616
Error	4	232.95	49.09%	232.95	58.24		
Total	8	474.55	100.00%				

Table 10: OEC values and their SN ratio for the BFL samples (Larger is better).

Experimental Samples	AVERAGE READINGS				
	Coefficient of Friction	Wear Rate	Hardness	OEC	SN Ratio
1	0.356	0.049	23.367	74.749	42.243
2	0.331	0.102	26.767	59.269	40.228
3	0.276	0.135	32.533	36.090	35.919
4	0.302	0.104	23.467	40.196	36.855
5	0.319	0.215	16.700	20.613	31.054
6	0.289	0.105	33.633	48.746	38.530
7	0.332	0.050	23.933	63.915	40.883
8	0.322	0.051	40.500	83.311	43.185
9	0.312	0.106	37.067	64.658	40.984

Table 11: ANOVA for the Synergized Criterion (Vs Molding Pressure and Curing Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Pressure (MPa)	2	1764.8	55.51%	1764.8	882.40	19.98	0.008
Curing Time (Mins)	2	1238.1	38.94%	1238.1	619.05	14.02	0.016
Error	4	176.6	5.56%	176.6	44.16		
Total	8	3179.5	100.00%				

Table 12: ANOVA for the Synergized Criterion (Vs Molding Temperature and Heat Treatment Time)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Molding Temperature (oC)	2	143.94	4.53%	143.94	71.97	0.10	0.911
Heat Treatment Time (Hrs)	2	32.68	1.03%	32.68	16.34	0.02	0.979
Error	4	3002.89	94.44%	3002.89	750.72		
Total	8	3179.51	100.00%				

3.5 Evaluation of the Optimum Manufacturing Process Parameters using Entropy and Technique for the Order Preference by Similarity to the Ideal Solution (TOPSIS)

Table 13 shows the normalized decision matrix obtained from the values of the performance metrics determined from the characterization of the samples of BFL produced. Following the Entropy-TOPSIS Procedure, the objective weight and relative closeness of the samples to the ideal solution were determined and presented in Table 14 and 15 respectively.

From the ranking of the relative closeness of the samples to the ideal solution, it can be seen that sample 8 has the highest rank with $R_i = 0.920 \leq 1$. Therefore, sample 8 is the best alternative to the ideal solution. The Manufacturing Parameters for Sample 8 are: molding pressure of 29MPa, molding temperature of 140°C, curing time of 6 minutes and heat treatment time of 3 hours (Table 2).

Table 13: The normalized decision matrix

Experiment Samples	**Factors**		
	Coefficient of Friction (μ)	Wear Rate W g/km	Hardness H (BHN)
$\sqrt{\sum_{i=1}^{m}(x_{i,j})^2}$	0.949	0.340	88.705
1	0.375	0.144	0.263
2	0.348	0.301	0.302
3	0.291	0.397	0.367
4	0.319	0.305	0.265
5	0.336	0.633	0.188
6	0.304	0.310	0.379
7	0.350	0.148	0.270
8	0.339	0.151	0.457
9	0.328	0.313	0.418

Table 14: The objective weight (w_j) for the criteria

	Quality Criteria		
	Coefficient of Friction (μ)	Wear Rate W (g/km)	Hardness H (BHN)
e_j	1.496	1.344	1.452
w_j	0.384	0.266	0.350
$w_j(\%)$	38.384	26.632	34.984

Table 15: Relative Closeness to the positive ideal solution

Experimental Sample	d_i^+	d_i^-	R_i	$Rank$
1	0.068	0.137	0.669	4
2	0.069	0.099	0.589	6
3	0.081	0.089	0.522	8
4	0.083	0.092	0.526	7
5	0.161	0.017	0.096	9
6	0.059	0.109	0.650	5
7	0.066	0.134	0.670	3
8	0.014	0.160	0.920	1
9	0.050	0.118	0.701	2

3.6 Comparative Analysis of the Optimum Manufacturing Process Parameters Obtained using SN ratio and Entropy-TOPSIS Method.

Table 16 compares the optimum manufacturing process parameters obtained by SN ratio and Entropy - TOPSIS method. The percentage contribution of the factors and statistical significance is presented as obtained by ANOVA analysis using Minitab 21.1.0.0 (Tables 11-12).

Table 16 shows that the most significant factors (moulding pressure and curing time) were unaltered by both TOPSIS and SN ratio analysis. These factors have a total contribution of 94.44% and are statistically significant. Due to the statistical significance and high percentage contribution of these factors to the quality of the BFL, either of the optimum manufacturing process parameters set obtained using the SN ratio and the Entropy-TOPSIS method can safely be used for BFL of different composition of CNS, PKS and PWS.

Table 16: Optimum manufacturing parameters obtained from SN Ratio and Entropy-TOPSIS Method

	SN Ratio Approach	TOPSIS Approach	(%) Contribution	Statistical Significance	Rank
Molding Pressure (MPa)	29	29	55.51	Significant	1
Molding Temperature (°C)	120	140	4.53	Insignificant	3
Curing Time (mins)	6	6	38.94	Significant	2
Heat Treatment Time (hrs.)	2	3	1.03	Insignificant	4

4. Conclusion

The process parameters for manufacturing autombile disc Brake friction lining of CNS/PKS/PWS mix were sucessfully optimized. Three performance metrics (Coeffient of friction, wear rate and hardness) of BFL were effectively synergized and combined as response to determine the optimum manufacturing parameters setting for producing CNS/PKS/PWS BFL using SN ratio and Entropy-TOPSIS method. Molding pressure and curing time are the statistically significant factors with a total contribution of 94.44%. To achieve optimum settings, the molding pressure should be kept at the maximum and the curing time at the minimum levels within the process window.

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