Rubber Scrap as Reinforced Material in the Production of Environmentally Friendly Brake Lining

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1 Introduction

Over the years, asbestos has been used as reinforcement material in brake lining production as a result of its good physical and tribological properties. However, recent studies have shown that asbestos poses a great health hazard which can result from its handling and breathing (NIH, 1989). As a result, it has lost its favor, resulting in the need to explore alternative materials. Hence, efforts by researcher have been geared toward finding a possible replacement for asbestos in the production of brake linings. These were exemplified by the work of several researchers who utilized other materials such as palm kernel shell (PKS), coconut shell, metal fibers, etc., for inclusion in brake lining in order to overcome environmental pollution (Ikpambese *et al.*, 2016; Fono-Tamo and Koya, 2013). Also, a non-asbestos friction lining material was developed by Ibhadode and Dagwa (2008) using an agro-waste material – palm kernel shell, as a reinforcement material. Palm kernel shell (PKS) which was used as a reinforcement material was selected due to its favorable properties which superseded other agro-waste. The developed automobile disk brake pads using the derived friction material and the test results obtained indicated that high wear rate was observed on the PKS pad at high vehicular speeds of 80 km h^{-1} and above. Zaharudin *et al.* (2012) adopted Taguchi method to carry out a study on the effect of manufacturing parameters on the properties of friction materials. The parameters studied were molding pressure, molding temperature, and the molding time using semi-metallic friction materials and other additives. Physical properties such as hardness and specific gravity as well as tribological properties (wear and fade) were selected as responses and optimized. Molding pressure was observed to be the most significant factor that affected the physical and tribological properties.

Similarly, Bashar *et al.* (2012) carried out a study on the selection and production of composite brake pad by varying constituent compositions. Coconut shell powder was used in the study including other additives such as cast iron fillings, silica, epoxy resin, a catalyst, and an accelerator. Some of the tests conducted in the study included tensile strength, compressive, hardness, impact, wear, and corrosion. Results obtained were in close agreement with commercial-based friction materials and from the results obtained, it was concluded that the developed composite brake pad had much better mechanical properties than

the commercial brake pad. Higher content of grounded coconut powder showed a lower braking impact, comprehensive strength, and hardness. Agbodion *et al.* (2010) also in an effort to find a replacement for asbestos also developed an asbestos-free brake pad using a bio-waste material, bagasses. The bagasses used in the study were sieved into mesh sizes of 100, 150, 250, 350, and 710 μm. The sieved bagasse powder was used to produce brake pad containing of 70% bagasse–30% resin using compression molding machine. The result showed that samples containing 100 μm (70% bagasse–30% resin) gave favorable properties than other brake pad samples which were tested. It was observed that the lower the sieve sizes of bagasse, the better the properties. The results obtained for the 100 μm sieve size, commercially available asbestos-based brake pad and optimum formulation laboratory palm kernel-based pad by Ibhadode and Dagwa (2008) are all in agreement. Ruzaidi *et al.* (2011) studied the morphology and wear properties of brake pad with the view of replacing asbestos with palm ash and polychlorinated biphenyl (PCB) waste mixed together with metal filler and thermosetting resin binder. Five different ratios were examined and the test results showed that the higher the composition of the palm ash, the better wear, and mechanical properties.

In this study, rubber scrap (tire peels) was used as reinforced material instead of asbestos with other consituents in the production of brake lining. Effect of manufacturing parameters on the tribological and physical properties of the formulated brake lining using Taguchi method will be investigated.

2 Materials and Methods

2.1 Materials

The four materials used for the production of brake lining are reinforced material (rubber scrap – tire peels), friction modifier (graphite), binder (phenolic resin), and abrasive (aluminum oxide).

2.2 Method

2.2.1 Material preparation

(a) The rubber scrap (tire peels) used as reinforced material used in this study was sourced from Altimax RT General Automobile Tire (DOT 650F 3T3). It was cut into pieces and washed thoroughly to get rid of dirt which may have possibly combined with the rubber tire powder. The tire pieces was dried in the sun for 1 week and grounded into fine powder using a bench grinding machine (DT 200A, 550 W). The powder was sieved using a sieve size ≤100 μm to eliminate any fibers that may be present (Ikpambese *et al.*, 2016; Agbodion *et al.*, 2010).

(b) Graphite used in this study as friction modifier used was obtained from used 1.5 V dry cell batteries (TIGER HEAD BRAND). The graphite rod was extracted from the used batteries and crushed to smaller sizes using a hammer. It was then pounded using a mortar and pestle and sieved using sieves size ≤100 μm.

(c) The phenolic resin used as binder in this study was phenol formaldehyde. It was prepared in the Biochemistry laboratory of Federal University of Technology, Minna, using the procedures outlined by Seong Jin Kim *et al.* (2003).

(d) The aluminum oxide (CAT. NO. 34143; LOT. NO. 44100) used as abrasive for this study was purchased from a chemical store in Kaduna, Nigeria.

2.2.2 Brake lining formulation

The formulation of brake lining sample consists of a series of operations including mixing, cold and hot pressing, cooling, post-curing, and finishing. In the production of the friction lining, the weights of the rubber powder, phenol-formaldehyde resin, friction modifier (graphite), and abrasive (aluminum oxide) was based on 176 g weight of commercial brake pad (Ikpambese *et al.*, 2016). Hence, the following percentage by weight of rubber powder (45), phenolic resin (30), graphite (15), and aluminum oxide (10) were used for the development of brake lining material. Phenolic resin was poured into a container, followed by the addition of small quantity of sulphuric acid (catalyst) and mixed thoroughly. The required quantity of rubber, aluminum oxide and graphite powders were poured into a separate container and mixed thoroughly manually. The mixture was poured into the container holding the resin and further stirred thoroughly to obtain homogeneous mixture. The mixtures were then placed in a mold of size 116 × 116 × 10 mm. The compression and curing of the composite samples was carried at the Polymer Workshop of Nigeria Institute of Leather Research and Science Technology, Samaru, Zaria. A compression molding machine (model; 3851-0, CARVER) was used for the compression of each composite sample. The experimental set up was based on design of experiment (DOE) via Taguchi method and three production parameters namely; molding temperature, pressure, and curing time were considered for experimentation. Hence, there were three input parameters and for each parameters, three levels were assumed as shown on Table 1. For a three-factor-three-level experiment, Taguchi had specified L_9 (3^3) orthogonal array for experimentation as shown on Table 2.

Table 1 Manufacturing parameters and their levels

Factor	*Unit*	*Level 1*	*Level 2*	*Level 3*
Molding pressure (MP)	MPa	0.6	0.7	0.8
Molding temperature (MT)	°C	130	150	170
Curing time (CT)	Minutes	8.0	10.0	12.0

Table 2 Experimental design layout using Taguchi orthogonal array L_9 (3^3)

S. No.	*MP (MPa)*	*MT (°C)*	*CT (min)*
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.3 Evaluation of Formulated Brake Lining Properties

2.3.1 Impact strength

The impact test was carried out using a Charpy impact testing machine (Norwood instrument, model No.: 412-07-0715269C) with each test sample produced to the size 80 × 15 × 5.5 mm dimensions, 450 notch of 1.5 mm depth, and 0.20 mm root radius machined from different composition. The impact energy of the testing machine ranges from 0 to 25 J with a pendulum striking at a speed of 2.887 m s^{-1}. The testing method involved fixing each test samples on the anvil of the testing machine and then setting the pendulum at a certain height. The pendulum is then released to impact the specimen at the opposite end of the notch in order to produce a fractured surface. The absorbed energy which produced the fractured surfaces for all the test samples were recorded. The impact strength can be calculated using the eqn [1]:

$$\text{Impact strength } (S_i) = \frac{\text{Absorbed energy } (E)}{\text{Thickness of specimen } (t)} \quad [1]$$

2.3.2 Hardness

The hardness test was conducted using a Shore A hardness tester (Durometer) with each samples prepared to size 60 × 15 × 5.5 mm. According to ASTM D2240 standard, three prepared specimens from the same sample of different composition were subjected to applied pressure by a calibrated spring to a spherical indenter and an indicating device which measures the depth of indentation.

2.3.3 Tensile strength

The tensile strength test was performed using Tensometer (MONSANTO; Serial No. 05232). The Tensometer consist of two metal fixtures which clamp the test samples prepared to the size 90 × 16 × 5.5 mm. The test specimens were prepared and labeled in compliance with ASTM D638 dumbbell parameters. Specimens dimension was measured using a Vernier caliper of accuracy 0.01 mm. With the machine reading set at 0.00 N, the test was performed by clamping each prepared specimen from different composition between two metal fixtures. A male punch was then forced into a hole in the fixture thereby causing it to shear along the edge of the hole. The Tensometer was used to push the punch until failure occurs. The tensile strength was determined using the relationship in eqn [2]:

$$\text{Tensile strength } (\delta) = \frac{\text{Max force } (P_{max})}{\text{Area of sheared edge } (A)} \quad [2]$$

2.3.4 Corrosion rate

Concentrated sulphuric acid was used and mixed with distilled water in the ratio of 3 ml/0.5 ml acid to water. Before immersion in the corrosion medium, the weight and dimension of each specimen taken from the different composition was measured using a

Vernier calliper and electronic scale of accuracy 0.01 and recorded. Each specimen were cleansed using distilled water and dry cloth and then immersed into the corrosion medium for 72 h with routine removal of specimens for analysis after every 24 h. During the routine removal, the samples were carefully cleaned and weighed before inserting them back into the corrosion medium and the weight loss was noted (Bashar *et al.*, 2012). The corrosion rate (C_r) was calculated using eqn [3]:

$$\text{Corrosion rate } (C_r) = \frac{k \times \Delta w}{\rho \times A \times t} \quad [3]$$

where k = constant = 87.6 (mm year^{-1}), w = 1 g (1000 mg)$^{-1}$, A = surface area = $2[(l \times b) + (l \times t) + (b \times t)]$ (mm^2), l = length, b = width, t = thickness, and ρ = density.

2.3.5 Oil and water absorption

A specimen of 90 × 16 × 5.5 mm dimension was prepared from each samples of formulated composite brake lining material. Each sample was dried in an oven to constant weight. The initial weight of each specimen was recorded using a digital weighing balance. The specimens were then immersed in distilled water and brake fluid (oil), respectively, at room temperature for a period of 3 days. After every 24 h, specimens were taken out and the surface water and oil wiped off with a cloth and weighed. The new weight of each sample during the routine removal was recorded. The weighing was done within 30 s in order to avoid any error that may occur as a result of evaporation. The weight change in oil and water were calculated by subtracting initial weight from the new weight after 72 h of soak. The percentage water or oil absorption by weight after 24 h was determined using eqns [4] and [5]:

$$\text{Percentage water } (\%\, W_a) = \frac{\Delta w}{w_1} \times 100 \quad [4]$$

$$\text{Percentage oil } (\%\, O_a) = \frac{\Delta w}{w_1} \times 100 \quad [5]$$

where Δw = change in weight and w_1 = initial weight of specimen.

2.3.6 Co-efficient of friction

The coefficients of friction of samples were determined using an inclined plane (NORWOOD Instrument Ltd., model No. 14678) of angular calibration which can read between 0° and 45°. The weights used during the test vary from 0.1 to 60 N; while the weight of the specimen attached to the steel plate was determined using a spring balance. These different weight sizes were attached with the aid of an adhesive (STICKO, super glue, model No. COCNO011421). The samples were cleaned of any surface dirt using a dry cloth and then attached to a mild steel plate with the aid of an adhesive. The weight of each test sample attached to the steel plate was measured using a spring balance. With the addition of known weights to the test sample which was placed on the smooth surface of the incline plane set at 0°. The incline plane was operated by raising the plane surface from the horizontal position toward the vertical position through various angles. The process was immediately stopped when the sample began to slide down the plane surface and the angle at that particular point recorded. The coefficient of friction was obtained by calculating the tangent of the angle at which the test sample started to slide down the smooth surface of the plane (Tono-Tamo and Koya, 2013). Load of various weights were placed on each sample and the experiment repeated. The average angles at various loads for the nine samples were then calculated and the corresponding coefficient of friction obtained. The coefficient of friction was evaluated using eqn [6]:

$$\mu = \tan \theta \quad [6]$$

where, μ is the coefficient of friction and θ is the sliding angle in degree.

2.3.7 Wear rate

The wear rate test was conducted using the method reported by other researchers (Bashar *et al.*, 2012; Aigbodion *et al.*, 2010). The dimension of each specimen was measured using caliper of an accuracy of 0.01 cm. The test was conducted by placing each sample clamped in a rigid position along the disk of the grinding machine (model: MASTER bench grinder, MD-250; 220 V – 50 Hz of diameter 250 mm, and speed of 2950 rpm for a period of 5 s). The weights of the samples before and after the grinding were recorded. The difference in the weight from each sample was calculated as the loss in weight. The same procedure was repeated for a period of 10, 20, 30, 40, and 50 s for each sample. The wear rate was calculated using the following relation in eqn [7]:

$$\text{Wear rate } (W_r) = \frac{\text{Weight loss } (\Delta w)}{\text{Sliding distance } (S)} = \frac{\Delta w}{S} (\text{g m}^{-1}) \quad [7]$$

where weight loss (Δw) = weight difference before and after the grinding (g), sliding distance (S) = $2\pi DNt$ (m), N = speed of grinding engine (rpm), D = disk diameter (m), t = time of exposure of each sample (s).

2.3.8 Determination of thermal behavior of formulated brake lining

The thermal behavior of formulated brake lining was studied using thermogravimetric analysis. Sample of brake lining for this analysis was prepared with optimal manufacturing parameters for wear rate. The analysis took place under nitrogen environment at a flow rate of 20 ml·min^{-1} and pressure of 2.5 bars using PerkinElmer TGA4000 model.

3 Experimental Results and Data Analysis

The results for all the properties of formulated brake lining are shown on **Table 3** for the nine samples. The significant effect of the manufacturing parameters on each property is shown using analysis of variance (ANOVA) method, while the optimized values of the manufacturing parameters for the properties of the brake lining formulated are shown using the main effect plots in **Table 4**. In determining the optimized values for the manufacturing parameters signal to noise ratio (S/N ratio) become viable means to achieve that. The S/N ratio has three categories of quality characteristics which includes; larger-the-better, nominal-the-better, and smaller-the-better. Therefore, the S/N ratios for each property (output variable or response) were determined using Minitab 16 software. Therefore, the optimum level of the process parameters is the level which has the highest S/N ratio shown on the main effect plot. The confidence level specified for all the analysis is 95%.

3.1 ANOVA

The ANOVA results obtained for all the variables investigated show how each of the manufacturing parameter affect the output variables. For instant, hardness value show that, molding pressure (77.93%) has the most significant effect on the hardness value, while melting temperature (2.99%) has the least significant effect. The influence of manufacturing parameters on impact strength show that curing time (50.43%) has the most influence on the impact strength follow by molding pressure (39.05%) as shown in **Table 5**.

Molding pressure has the most significant effect on the tensile strength of the brake lining material with 75.97% and this is followed by curing time with 10.41% significant effect. The corrosion rate of the brake lining formulated is influenced by curing time (71.56%) and melting temperature (19.21%) as shown in **Table 6**.

Table 3 Experimental results for brake lining properties

Exp. No.	Impact strength ($J\,mm^{-1}$)	Hardness (ShoreA)	Tensile strength (MPa)	Corrosion rate (10^{-5} mm year^{-1})	Oil absorption (%)	Water absorption (%)	Co-efficient of friction	Wear rate (mg m^{-1})
1	0.647	55.0	55.68	7.606	3.701	1.39	0.64	3.60
2	0.900	52.7	58.30	9.201	3.912	1.48	0.63	3.85
3	1.033	50.3	60.23	4.095	4.571	1.38	0.61	2.76
4	0.888	51.3	51.68	9.214	3.938	2.02	0.58	2.84
5	0.782	57.0	56.82	4.292	3.946	2.88	0.56	2.10
6	0.691	63.0	40.92	6.098	5.645	1.64	0.53	2.52
7	1.152	72.0	36.36	5.841	5.696	2.87	0.52	2.77
8	0.961	75.3	38.64	5.395	5.526	1.67	0.53	1.92
9	0.830	79.3	43.18	6.847	5.765	0.93	0.51	2.24

Table 4 Results of the S/N ratio for brake lining properties

	Impact strength, η (dB)	Hardness, η (dB)	Tensile strength, η (dB)	Corrosion rate, η (dB)	Oil absorption, η (dB)	Water absorption, η (dB)	Co-efficient of friction, η (dB)	Wear rate, η (dB)
1	−3.78	34.81	34.91	82.38	−11.37	−2.86	−3.88	−11.13
2	−0.92	34.44	35.31	80.72	−11.85	−3.41	−4.01	−11.71
3	0.28	34.03	35.60	87.76	−13.20	−2.80	−4.29	−8.82
4	−1.03	34.20	34.27	80.71	−11.91	−6.11	−4.73	−9.07
5	−2.14	35.12	35.09	87.35	−11.92	−9.19	−5.04	−6.44
6	−3.21	35.99	32.24	84.30	−15.03	−4.30	−5.52	−8.03
7	1.23	37.15	31.21	84.67	−15.11	−9.16	−5.68	−8.85
8	−0.35	37.54	31.74	85.36	−14.85	−4.45	−5.51	−5.67
9	−1.62	37.99	32.71	83.29	−15.22	0.63	−5.85	−7.01

Table 5 ANOVA for impact strength

Factor	DOF	SS	MS	F-ratio	p-value
MP	2	0.0576	0.0288	4.6392	39.047
MT	2	0.0031	0.0016	0.2497	2.1015
CT	2	0.0744	0.0372	5.9923	50.435
error	2	0.0124	0.0062		8.4167
Total	8	0.1475	0.0184		100.00

Table 6 ANOVA for corrosion rate

Factor	DOF	SS	MS	F-ratio	p-value
MP	2	1.33	0.665	1.0230	4.670
MT	2	5.47	2.735	4.2072	19.21
CT	2	20.38	10.190	15.675	71.55
Error	2	1.3002	0.650		4.565
Total	8	28.480	3.560		100.0

Table 7 ANOVA for water absorption

Factor	DOF	SS	MS	F-ratio	p-value
MP	2	0.875	0.4375	5.284	24.268
MT	2	1.091	0.5455	6.588	30.259
CT	2	1.474	0.7370	8.901	40.881
Error	2	0.166	0.0828		4.5930
Total	8	3.606	0.4507		100.00

Table 8 ANOVA for coefficient of friction

Factor	DOF	SS	MS	F-ratio	p-value
MP	2	0.0176	0.00881	62.0493	90.1105
MT	2	0.0015	0.00075	5.2465	7.61915
CT	2	0.0002	0.00008	0.5634	0.81816
Error	2	0.0003	0.00014		1.45224
Total	8	0.0196	0.00245		100.000

The ANOVA result for oil absorption show that molding pressure (63.28%) has the most significant effect on the oil absorption, followed by molding temperature (23.62%). While curing time (40.88%) has the most significant effect on the water absorption property of the formulated brake lining as shown in Table 7.

It was observed that molding pressure (61.46%) has the greatest effect on the wear rate of the formulated brake lining followed by melting temperature (15.76%). While the result obtained for co-efficient of friction as shown in Table 8, indicate that molding pressure (90.11%) has the most significant effect on the coefficient of friction, follow by melting temperature (7.62%).

3.2 Signal-to-Noise Ratio

In order to obtain the optimal value of the manufacturing parameters for different variables, the three categories of quality characteristics of S/N ratio must be applied correctly. Hence, the larger-the-better will be applied for the hardness value as expressed in eqn [8]:

$$S/N \text{ ratio} = -10 \log \frac{1}{n}\left(\sum_{i=1}^{n} 1/y_i^2\right) \quad [8]$$

where y = responses for the given factor level combination, n = number of responses in the factor level combination. It is observed from the main effect plot using the S/N ratio of hardness values that the optimal manufacturing parameters are molding pressure: 0.8 MPa (level 3), melting temperature: 170 °C (level), and curing time: 8 min (level 1) as shown in Figure 1.

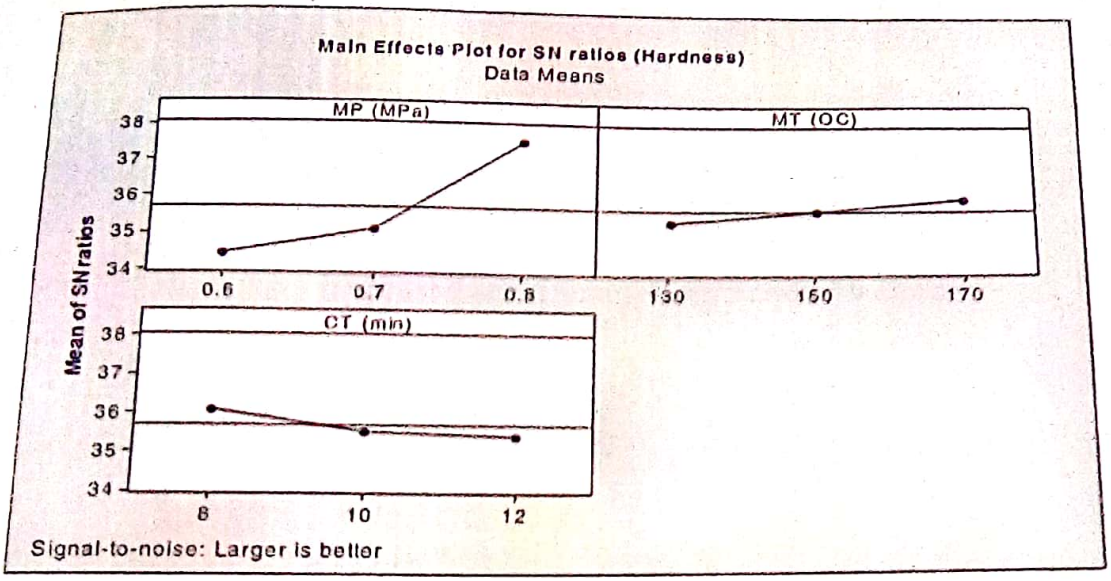

Figure 1 Main effect plots for hardness.

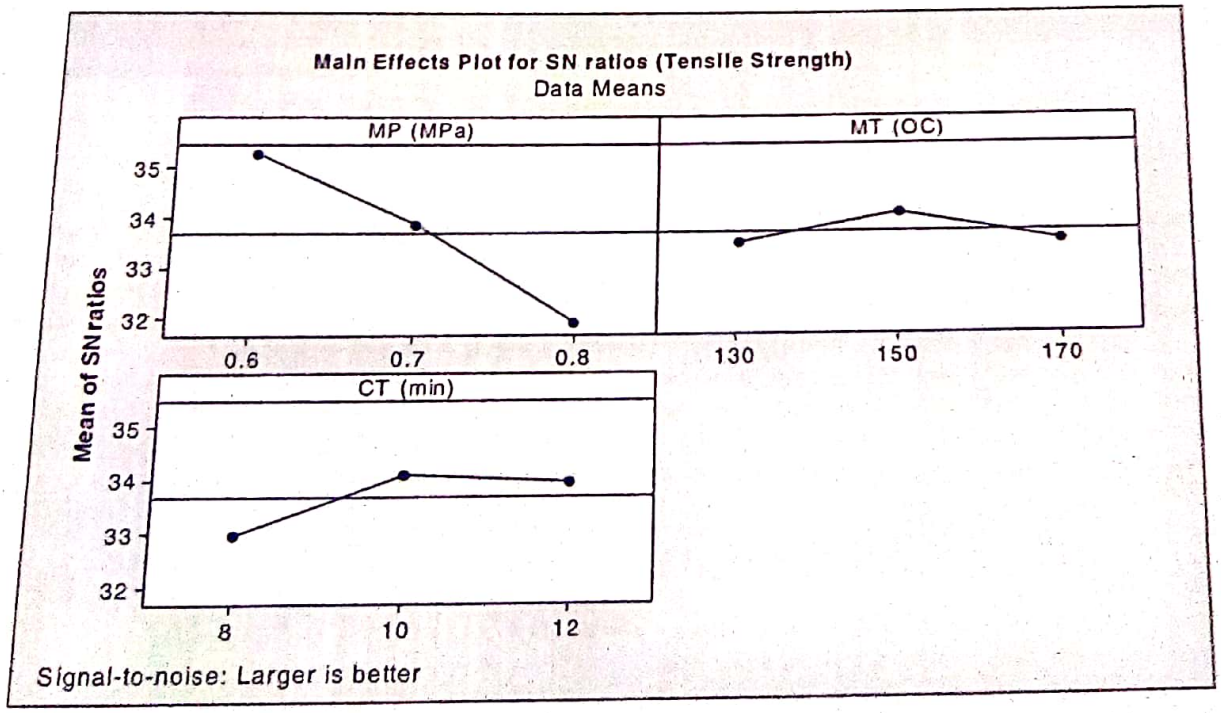

Figure 2 Main effect plots for tensile strength.

And for the impact strength, the optimal manufacturing parameters are molding pressure: 0.8 MPa (level 3), melting temperature: 150 °C (level 2), and curing time: 12 min (level 3) using S/N ratio, the larger-the-better quality characteristics. Similarly, the S/N ratio, the larger-the-better quality characteristics was used to obtain the optimized values of the manufacturing parameters for the tensile strength. Figure 2 shows the optimized values of the manufacturing parameters at molding pressure: 0.6 MPa (level 1), melting temperature: 150 °C (level 2), and curing time: 10 min (level 2).

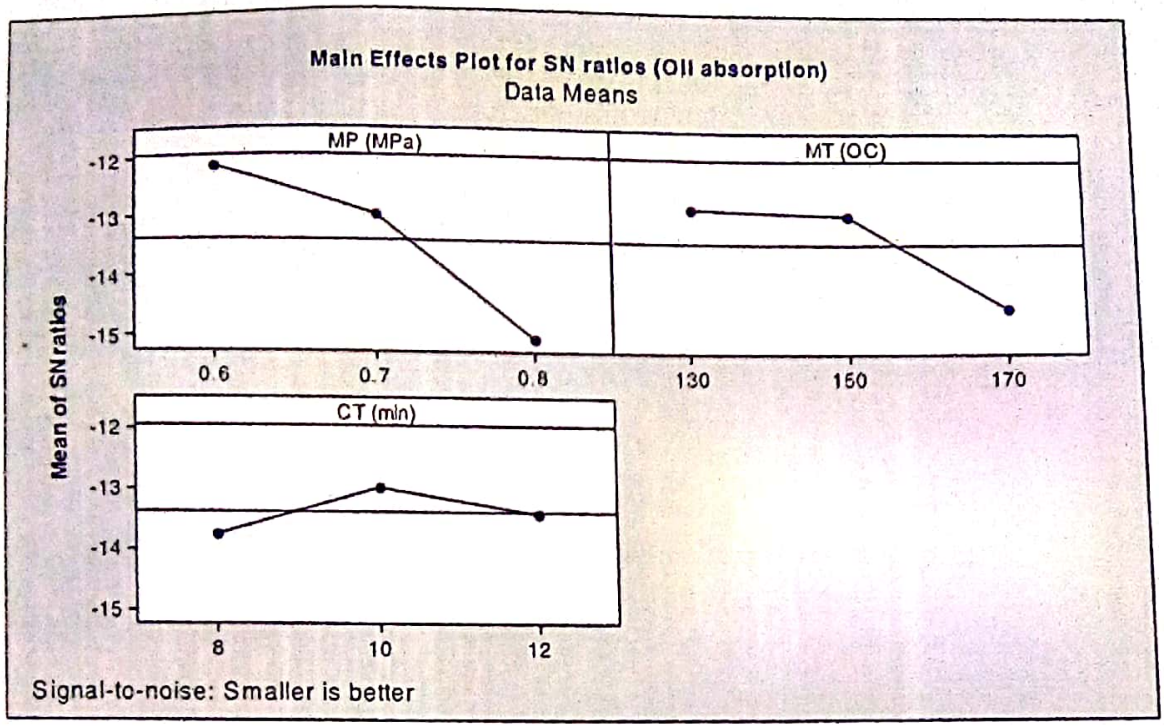

Figure 3 Main effect plots for S/N ratio for oil absorption.

In the same vein, the optimal values of the manufacturing parameters for corrosion rate are at molding pressure: 0.8 MPa (level 3), melting temperature: 170 °C (level 3), and curing time: 12 min (level 3) using the smaller-the-better S/N ratio quality characteristic as depicted in eqn [9]:

$$\eta = -10\log\left(\frac{1}{n}\sum_{i-1}^{n}\gamma_i^2\right) \quad [9]$$

where η is the S/N ratio for the lower-the-better case, γ_i is the measured quality characteristic for the ith repetition, and n is the number of repetitions in a trial.

The optimization values for the oil absorption using the smaller-the-better quality characteristics for the S/N ratio quality characteristics have been determined. The optimal values are: molding pressure: 0.6 MPa (level 1), melting temperature: 130 °C (level 1), and curing time 10 min (level 2) as shown in Figure 3.

The optimized values obtained for co-efficient of friction are molding pressure: 0.6 MPa (level 1), melting temperature: 130 °C (level 1), and curing time: 10 min (level 2) using the larger-the-better quality characteristics for the S/N ratio quality characteristic. While wear rate as depicted in Figure 4 show the optimized values at molding pressure: 0.8 MPa (level 3), melting temperature: 150 °C (level 2), and curing time: 12 min (level 3) using the smaller-the-better quality characteristics for the S/N ratio quality characteristic.

3.3 Thermal Behavior of Formulated Brake Lining

The thermal degradation profile of the formulated brake linning is presented in Figure 5. The sample degraded between 149.89 and 478.36 °C, with a peak degradation at temperature 394.8 °C. This suggest that the formulated brake lining may be used for a system whose braking temperature does not exceed 300 °C.

3.4 Confirmation Test

Regression equations were obtained for all the responses using MINTAB 16 software. The optimized values were used to obtain the experimental values for each of the variable investigated. The same optimized values were used to calculate for each variable. Table 9 show the comparison of the two values. For each of the variable, the appropriate regression equations used are as follows:

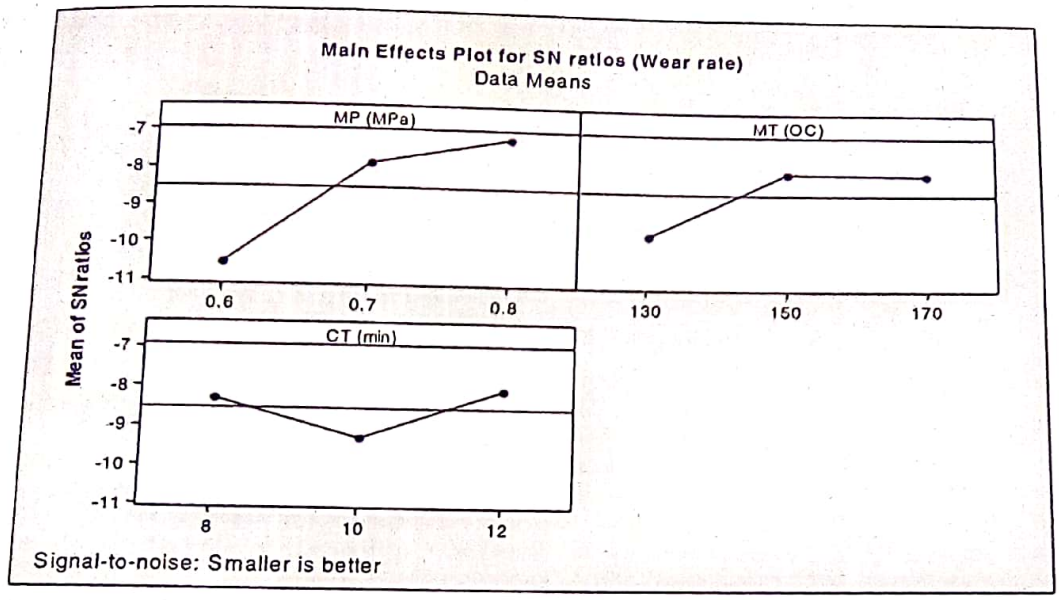

Figure 4 Main effect plots for wear rate.

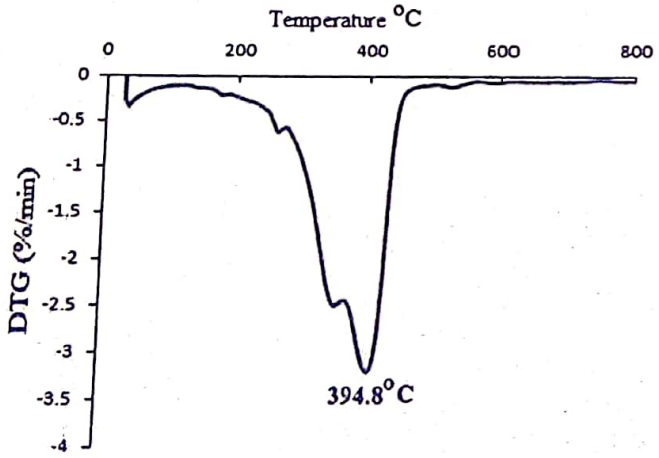

Figure 5 Thermal behavior of formulated brake lining.

Table 9 Validation test percentage error

Variable	*Calculated value*	*Experimental value*	*Percentage error (%)*
Impact strength	0.93	0.95	2.11
Hardness	77.57	76.85	0.9
Tensile strength	0.82	0.81	1.22
Corrosion rate	4.31	4.29	0.46
Oil absorption	3.93	3.701	5.83
Water absorption	1.22	1.28	4.69
Co-efficient of friction	0.63	0.64	1.56
Wear rate	2.11	1.98	6.16

$$\text{Hardness } (H) = -24.5 + 114MP + 0.119MT - 1.17CT \quad [11]$$

$$\text{Tensile strength } (\sigma) = 98.6 - 93.4MP + 0.0051MT + 1.51CT \quad [12]$$

$$\text{Corrosion rate } (C_r) = 20.9 - 4.70MP - 0.0468MT - 0.406CT \quad [13]$$

$$\text{Oil absorption}(O_a) = -3.62 + 8.00MP + 0.0220MT - 0.055CT \quad [14]$$

$$\text{Water absorption } (W_a) = 1.27 + 2.03MP - 0.0194MT + 0.203CT \quad [15]$$

$$\text{Coefficient of friction } (\mu) = 1.06 - 0.533MP - 0.000750MT - 0.00083CT \quad [16]$$

$$\text{Wear rate, } W_r \ (\text{mg m}^{-1}) = 9.01 - 5.47MP - 0.0141MT - 0.0342CT \quad [17]$$

where MP is molding pressure, MT is melting temperature, and CT is curing time

4 Conclusions

The study presented Taguchi method as a reliable method of determining the optimal manufacturing parameters for the improved properties of formulated brake lining using rubber scrap as reinforced material. ANOVA shows that the molding pressure (77.93%) has the most significant effect on the hardness value, while melting temperature (2.99%) has the least significant effect. While the influence of manufacturing parameters on impact strength show that curing time (50.43%) has the most significant influence on the impact strength follow by molding pressure (39.05%). It was observed that the molding pressure: 0.8 MPa (level 3), melting temperature: 150 °C (level 2), curing time: 12 min (level 3) and molding pressure: 0.6 MPa (level 1), melting temperature: 130 °C (level 1), curing time: 10 min (level 2) are the optimal manufacturing parameters respectively for wear rate and co-efficient of friction. The sample formulated from the wear rate optimal manufacuring parameter degraded between 149.9 and 478.4 °C, with a peak degradation at temperature at 394.8 °C. The confirmation tests obtained for all properties investigated shows a close agreement with the calculated results.

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