Effects of Process Parameters on the Ultimate Tensile Strength of Coconut Shell Reinforced Friction Lining

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Abstract

In this study, friction linings were producee from non-hazardous materials using response surface methodology (RSM) experimental design. The materials used for production include coconut shell, epoxy resin (binder), graphite (friction modifier) and aluminium oxide (abrasive). Twenty- seven different samples of percentage composition were produced by varying the process parameters. Formulation of the friction lining samples was done using rule of mixture and a weight percent of 52 % reinforcement, 35 % binder, 8 % abrasive and 5 % friction modifier were used for the production. Analysis of variance shows that curing time (31.404 %) has the most significant effect on the ultimate tensile strength of the coconut shell reinforced material. Optimal process parameters obtained from signal to noise analysis shows an optimal value of moulding pressure (10 MPa), moulding temperature (180 ^{o}C), curing time (8 minutes) and heat treatment time (5 hours). Empirical regression model was also developed to predict the value of coefficient of friction of the materials. Optimal value obtained for coconut shell reinforced materials show an ultimate tensile strength of 4.809 MPa.

Keywords: Friction lining, non-hazardous, coconut shells, ultimate tensile strength

1.0 Introduction

Friction lining are heterogeneous materials with varying mechanical properties of developed formulation (Zaharudin *et al.,* 2012). Such materials are classified as reinforcements, binders, abrasive and friction modifiers (Blau, 2001). Varieties of techniques have been employed in order to investigate the development of ingredients for friction materials in order to provide stable friction, durability, adequate wear resistance, thermal conductivity and vibration for all braking, and acceptable environmental conditions (Cho et al., 2005; Jang et al., 2001). Research has shown that asbestos fibers which are used as reinforcement material in commercial friction linings are carcinogenic (cancer causing). Therefore, there is need to find alternative materials that can serve as a substitute for asbestos in friction lining production. Several studies have been carried out using different organic and inorganic material with the aim of replacing asbestos in friction linings. Ikpambese *et al.* (2014), Lawal *et al.* (2016), Dagwa and Ibhadode, (2006), Aigbodion *et al.* (2010) developed a non-asbestos-containing friction lining material using palm kernel fiber

(PKF), rubber scraps, palm kernel shell (PKS) and bagasse respectively as reinforcement material. It was reported in their studies that the materials used exhibited favourable properties. Therefore, in this work, a non-hazardous reinforcement materials (coconut shell powder) combined with other materials were developed using response surface methodology (RSM).

2. Materials and methods

2.1 Materials

The material used for production of the friction lining samples include, coconut shells (reinforcement material), aluminium oxide (Cat. No. 34143; Lot. No. 44100), graphite (obtained from used 1.5 volt TIGER head dry cell batteries), Epoxy resin and hardener (binder (Epoblock, FIP Chemicals; Sikadur 42T, Sika Corporation U.S).

2.2 Method

The development of friction linings involved the preparation of filler materials, formulation, design of experiment and compression moulding process.

2.2.1 Materials Preparation and Formulation of Friction Linings

The method involved in the preparation of the coconut shell and graphite powder involve washing with soap and detergent, cleaning using dried cloth, drying in an hot air oven operating at a temperature of 150 ^{o}C followed by crushing using pestle and mortar as well as grinding with grinding machine and finally sieving using a sieve size of $\leq$ 150 µm. Samples formulation was done using rule of mixture as shown in equ. 1 and 2.

$$\text{Volume fraction of constituent } (V_i) = \frac{w_i}{\rho_i} \div \sum \frac{w_j}{\rho_j} \tag{1}$$

$$\rho_{\text{composite (coconut shell-based)}} = \rho_c V_c + \rho_a V_a + \rho_g V_g + \rho_b V_b \tag{2}$$

Where, ρ_c, ρ_a, ρ_g and ρ_b are the densities of the coconut shell, aluminium oxide, graphite and epoxy resin respectively. V_c, V_a, V_g and V_b are the volume fraction of the coconut shell, aluminium oxide, graphite and epoxy resin respectively. W_i and W_j are the weight percent of the individual and total constituent respectively,

2.2.3 Design of Experiment using Response Surface Methodology

In this study, design of experiment was done using response surface methodology (RSM) via central composite RSM design (CCD). This design method was selected in preference to Box-behnken RSM design (BBD) because it combines two-level full factorial design with additional two points (axial and centre points) and contain combinations where all factors are at their lower and higher levels. This experimental design was built in accordance to standard RSM's $L_{27}(2)^4$ using Minitab 17 statistical software. Table 1 present the factor levels of process parameter where moulding temperature (MT), moulding pressure (MP), curing time (CT) and heat treatment time (HTT) were chosen as the process parameters used in analysing its effects on the ultimate tensile strength (UTS) of the friction materials. While, Table 2 shows the experimental design for RSM -Central Composite Design Layout.

Table 1: Factor Levels for Process Parameters

Factors	Unit	Cubic Points		Center Point	Axial Points	
		Lower Level (-1)	Upper Level (+1)	Middle Level (0)	Lower Level (-2)	Upper level (+2)
Moulding Pressure (MP)	MPa	12	16	14	10	18
Moulding temperature (MT)	^oC	120	160	140	100	180
Curing time (CT)	minutes	6.0	10.0	8	4	12
Heat Treatment Time (HTT)	hour	2.0	4.0	3	1	5

Table 2: Experimental Matrix for RSM -Central Composite Design Layout

Run	MP (MPa)	MT (^oC)	CT (minute)	HTT (hour)
1	12	120	6	2
2	16	120	6	2
3	12	160	6	2
4	16	160	6	2
5	12	120	10	2
6	16	120	10	2
7	12	160	10	2
8	16	160	10	2
9	12	120	6	4
10	16	120	6	4
11	12	160	6	4
12	16	160	6	4
13	12	120	10	4
14	16	120	10	4
15	12	160	10	4
16	16	160	10	4
17	10	140	8	3
18	18	140	8	3

19	14	100	8	3
20	14	180	8	3
21	14	140	4	3
22	14	140	12	3
23	14	140	8	1
24	14	140	8	5
25	14	140	8	3
26	14	140	8	3
27	14	140	8	3

2.2.3 Production of Brake Lining Samples

Production of samples was carried out on a compression moulding machine. During the process, the composition of the samples formulated using rule of mixture remains constant throughout the moulding process, while the process parameters were varied as shown in Table 2. As recommended by Chemiplastica (2010), preliminary preparation involved the pouring 41.06 g (23.33 %) of the epoxy resin into a container followed by the addition of 20.54 g (11.67 %) of hardener (catalyst) in the ratio of 2:1. The mixture of epoxy resin and the hardener were manually stirred in a separate stainless steel plate until homogenous mixture was observed, while mixture of the weighed fillers (reinforcement, abrasive and friction modifier) were also stirred manually in another separate stainless steel plate. The overall mixture was then transferred to a fabricated mould of size 124 x 112 x 10 mm for compression moulding after being stirred thoroughly in order to obtain a homogenous mixture. The final products (Fig. 1) were subjected to further heat treatment (150 °C) at varying time as shown in Table 2 using a hot air oven.

Fig. 1: Heat treated Friction Lining Samples

2.2.4 Determination of Ultimate Tensile Strength

The tensile test was carried out according to ASTM D638 standard using a tensometer (MONSANTO; Serial No-05232). As specified by ASTM D638 standard, six specimens from different samples were prepared and labelled in compliance with ASTM D638 in type IV mode. The specimen dimension was measured using a vernier calliper of 0.02 cm accuracy. The test was performed by clamping each prepared specimen from different samples between two metal fixtures. The tensometer was used by pushing the punch until failure of the specimen occurs. The results obtained was utilised in calculating the tensile strength expressed in mega paschal (MPa) as well as the percentage elongation and young modulus.

3. Results and Discussion

3.1 Experimental Results

Table 3 presents the experimental results and the signal – to noise (S/N) ratio for ultimate tensile strength (UTS) of the friction linings. The larger the better quality characteristic (equ. 3) was used to achieve optimisation for the UTS of the developed friction materials.

Larger- the better S/N = $$-10\log\frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{y^2}\right) \quad (3)$$

Where, y = given factor level combination responses, n = number of factor level combination responses

Table 3: Experimental Results and S/N for UTS

Run	% Elongation	Young Modulus (MPa)	UTS (MPa)	S/N (η) Ratio for UTS (dB)
1	1.818	221.80	4.033	12.1119
2	1.212	256.23	3.106	9.8437
3	1.061	633.51	5.702	15.1207
4	1.364	353.60	2.847	9.08714
5	1.818	442.30	7.790	17.8302
6	1.212	238.93	2.757	8.81031
7	0.758	603.69	4.560	13.1795
8	1.364	277.51	3.655	11.2571
9	2.576	33.294	0.875	-1.16282

10	0.606	862.26	5.226	14.3631
11	1.364	430.21	5.816	15.2926
12	0.303	619.51	1.877	5.47067
13	1.970	285.52	5.650	15.0404
14	1.364	369.48	4.998	13.9761
15	1.515	87.11	1.320	2.41082
16	2.424	66.65	1.616	4.16829
17	2.273	257.22	5.781	15.2396
18	1.667	347.71	5.772	15.2270
19	1.212	459.22	4.235	12.5364
20	1.515	454.43	6.718	16.5453
21	0.758	263.08	1.933	5.72284
22	2.121	273.56	5.803	15.2728
23	2.273	302.17	6.861	16.7278
24	1.515	508.72	7.379	17.3602
25	1.515	436.03	6.230	15.8892
26	0.606	1168.1	7.080	17.0001
27	0.909	846.84	6.650	16.4563

3.2 Main Effect and Contour Plots

The main effect and contour plot for the coconut shell reinforced friction linings are shown in Fig 3 and 4;

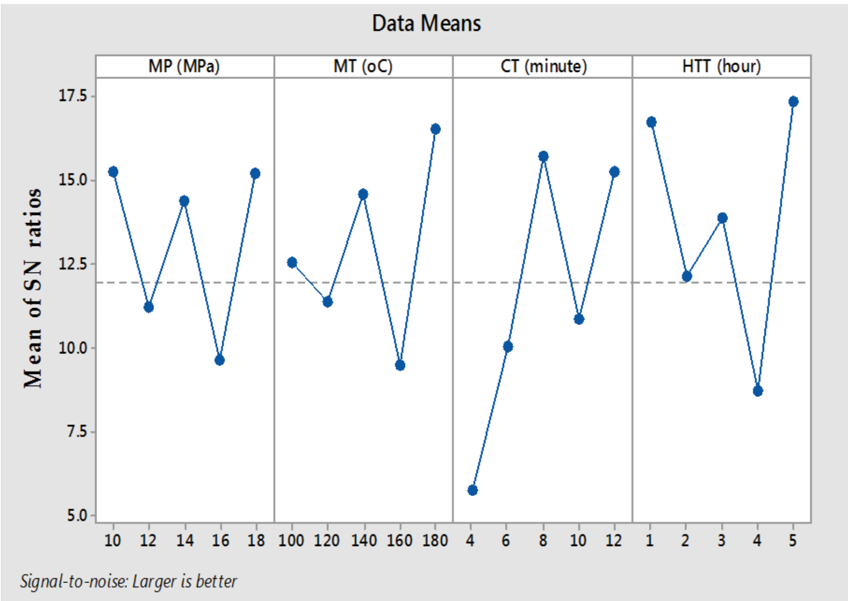

Fig. 3: Main Effect Plot for S/N Ratios for UTS

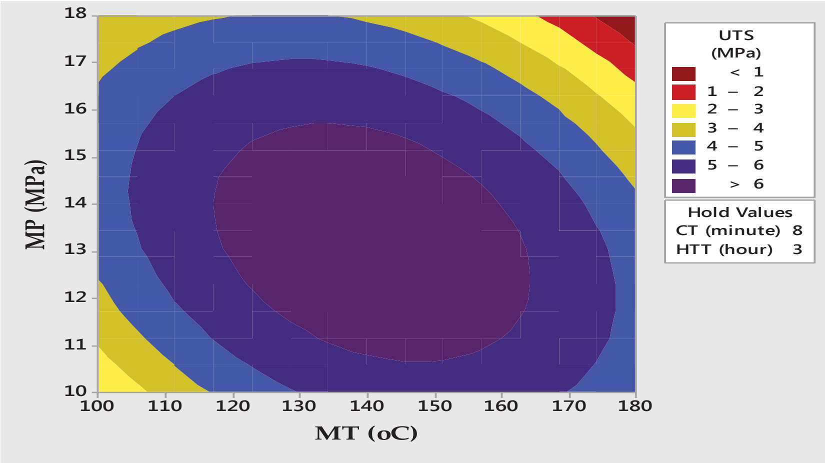

Fig. 4: Contour Plot for S/N Ratios for UTS (MP and MT)

Fig. 3 shows the optimal values of process parameters obtained from the main effect plots. It can be observed that the control factor of MP, MT, CT and HTT at lower axial point (10 MPa), upper axial point (180 ^oC), centre point (8 minutes) and upper axial points (5 hours) respectively gave the optimal ultimate tensile strength. This implies that, the MP at 10 MPa gave adequate bonding forces and any increase in the moulding pressure may affect the bonding process. Also, the CT at 10 and 12 minutes as well as MT at 100, 120, 140 and 160 ^oC indicate an excessive time and temperature for the bonding process. Therefore, any changes in the process parameters may lead to poor bonding between resin and the fillers.

The contour plot shown in Fig. 4 indicates how a change in MP (MPa) and MT (^oC) affect the UTS of the coconut shell reinforced friction lining while keeping CT and HTT at 8 minutes and 3 hours respectively. The contour levels indicate that UTS value of greater than 6 MPa can be achieved at MP of 13 MPa and MT of 140 ^oC.

3.3 Analysis of Variance (ANOVA)

ANOVA was used to study the significance effect of the process parameters on the UTS. The degree of freedom (DOF), sum of square (SS), mean square (MS), f- value and the significance effects given the order of percentage contribution (p) of the manufacturing parameters as it affect the quality characteristics of the friction materials are shown in Table 4. This analysis was conducted for α = 0.01 significance level, at 99% confidence level.

Table 4: ANOVA for Ultimate Tensile Strength

Factor	DOF	SS	MS	F	P (%)
MP (MPa)	4	21.77	5.443	8.8996	20.340
MT (oC)	4	22.46	5.615	9.1816	20.986
CT (minute)	4	33.61	8.403	13.740	31.404
HTT (hour)	4	23.07	5.768	9.4310	21.556
Error	10	6.115	0.612		5.7140
Total	26	107.03	4.114		100

The ANOVA for UTS of coconut shell reinforced composite shown in Table 4 indicates that CT (curing time) with percentage contribution of 31.404 % provides the greatest impact on the ultimate tensile strength, followed by HTT (heat treatment time) with contribution of 31.56 % and MT (moulding temperature) with 20.99 %, and the least significance, MP (moulding pressure) with percentage contribution of 20.34 %. The effects of all the factors on the UTS are significant since their p-values are greater than 0.010.

3.4 Regression Model

The regression for UTS along with their corresponding regression correlation coefficients (R-sq) are shown in Equ. 4. Optimal value of UTS was obtained using the optimal set of process parameters obtained from the S/N ratio analysis as represented in the main effect plots.

$$UTS\ (MPa) = 7.09 - 0.202\ MP - 0.0043\ MT + 0.221\ CT - 0.251\ HTT \qquad (4)$$

R-sq = 79.61% and R-sq (adj) = 70.01 %

Optimal process parameters; MP = 10 MPa, MT = 180 ^{o}C, CT = 8 Minutes, HTT = 5 hours

Therefore, using Equ. 4, the optimal value of UTS for the coconut shell reinforced lining is 4.809 MPa

4. Conclusion

In this study, coconut shell was used as non-hazardous reinforcement material to produce friction linings. The newly developed material was investigated by determining its ultimate tensile strength. From the optimal value of

UTS obtained (4.809 MPa), it can be concluded that the developed non-hazardous friction materials is in close agreement with the UTS of commercial based friction linings as it falls within acceptable values reported in the work of Dagwa and Ibhadode (2006), Idris et al. (2015) and Adeyemi et al. (2016). Similarly, the experimental results show that variation in the process parameters (MP, MT, CT and HTT) causes difference in the tensile strength of friction materials. Also, the friction lining samples developed using process parameter of 10 MPa moulding pressure, 180 ^{o}C moulding temperature, 8 minutes curing time and 5 hours heat treatment time possesses the optimal ultimate tensile strength. Therefore, developing friction linings for automobile application, it is recommended that these optimal values be used as any alteration in the values may lead to a poor bonding between the resin and its constituent fillers. Finally, the ANOVA analysis shows that curing time (31.404 %) has the most significant effect on UTS while heat treatment time (21.556 %) has the least effect.

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