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The effect of the brake pad components to the some physical properties of the ecological brake pad samples

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Abstract. In this study, brake pad components in powder form such as miscanthus, cashew, alumina, phenolic resin and calcite, were used to manufacture ecological brake pads. In the brake pad applications trial and error method is often used to find the optimum proportion providing the best characteristics of the component in composite. The evaluation process became complicated and time consuming due to the number of components used for the manufacture of brake pad, randomly selected mixing ratios, many samples produced with trial and error method and a vast variety of results obtained from the measurements. Taguchi method was utilized in order to determine how the compositions of the brake pad components in the range of 5-20 wt. % had an effect on the properties of the brake pads. As a result of the experiments such as density, hardness, porosity and wear rate, the characteristics of the brake pad samples were more affected by the proportions of Miscanthus and phenolic resin in the mixture.

1. Introduction

Brake pad lining materials mostly made of five ingredients such as, reinforcement, lubricant, abrasive, binding agent and filler components. Each component has a specific function in composite structure such as, to adjust the balance friction and wear properties, increase strength, improve lifetime, porosity and noise. Different components and/or the proportion of the components in the brake pad formulation are reported in the literature that may affect the physical and mechanical properties of the brake pads to be developed [1-3].

Selection of components' types for the manufacture of brake pad samples is a difficult task because of affect the properties of brake pad samples. There are limited reports in the literature about the investigations of the effects of the manufacturing processes and components of brake pad materials to the mechanical and physical properties of brake pad materials. The physical and mechanical properties of brake pad materials also depend on manufacturing process parameters and the characteristics of the components used in production of brake pad [4].

Aleksendrić and Senatore [5] (2012) were investigated the effects of the manufacturing process such as moulding temperature, time and pressure values, heat-treatment temperature, and heat-treatment time to wear behaviour of the brake friction materials. They used artificial neural networks as an appropriate modelling technique for development of a model representing the effects of the manufacturing process on wear behaviour of the friction materials. In this article, moulding pressure was determined the most influential factor on wear behaviour of the brake friction materials and it is expressed that wear behaviour of friction materials were strongly affected by the manufacturing processes.

Kim, Kim and Jang [6] (2003), in their work, determined the best manufacturing parameters for 16 different manufacturing conditions via applying Taguchi method to manufactured brake pad samples comprising 15 ingredients. Hardness, porosity, friction coefficient and wear properties of brake pad samples were examined via Taguchi method and the best manufacturing parameters were suggested as moulding time 6 minutes, moulding temperature 225°C, moulding pressure 27MPa, heat treatment time 6 hours and heat treatment temperature 200°C for this particular formulation based on the S/N ratio and ANOVA analyses of tests results. It was expressed that there is no apparent relationship between the physical properties and tribological performance of a brake pads.

The effect of brake pad samples produced with different periwinkle shell particle size on the wear behaviour has been investigated by Amaren, Yawas and Aku [7] (2013). Pin on disk machine used to perform the wear tests under different test conditions such as periwinkle shell particle size, sliding speed, applied load and temperature. The results of the study showed that the wear rate increased with increasing the periwinkle particle size, sliding speed, load and temperature.

Pujari, Ramakrishna and Kumar [8] (2014) were discussed in detail about the applications and advantages of jute and banana fibre composites. They expressed that natural fibres are an alternative resource to synthetic fibres, as reinforcement for polymeric materials for the manufacture is cheap, renewable and environment friendly and when compared to glass fibres, natural fibres offer both reduction in density and cost.

Zaharudin, Talib, Berhan, Budin and Aziurah [4] (2012), designed the manufacturing parameters such as moulding pressure, moulding temperature and moulding time to analyse their effects on the physical and tribological properties of the friction materials according to Taguchi's L8 OA. The optimal parameters were determined as 50 tonnes moulding pressure, 150°C moulding temperature and 600 seconds moulding time. It was expressed that there is no relationship between the hardness and specific gravity or wear properties of the friction materials.

In this study, Taguchi method was utilized for determining the effect of the brake pad components and production parameters on the some properties of the brake pads. Therefore, reinforcement, lubricant, abrasive and binder components of the brake pad were chosen as the factors with four-levels and then experiments were conducted to $L_{16}(4^4)$ Taguchi orthogonal array design. 16 brake pad samples with different proportions were produced for experiments in accordance with $L_{16}(4^4)$ Taguchi orthogonal array design.

2. Materials and method

All powders were mixed with a 1000 W electrical mixer for 10 minute and then compacted at 170°C under a double acting hydraulic press machine. Brake pad samples were compacted with 175MPa for 10 minutes holding time. The production parameters were determined based on the understanding gained from the previous works and in accordance with literature. Finally, produced specimens were rubbed against an abrasive paper of grade 180, 320, 400 and 800 grit for make them ready to experiments. Specimens were produced in the mould which is designed by authors in Figure 1 and samples produced are dimensioned as diameter 12mm, height 25mm.

Density of produced specimens was calculated by a precision scales that can operate according to the Archimedes' principle (equation (1)) in accordance with the ASTM C-20 [7, 9] (Figure 2). Where ρ_w is density of pure water (22.5°C, ρ w=0.9977 g/cm^3), ρ_s is sample density, (g/cm^3), and m_1 and m_2 are sample weight in air and water (g), respectively.

$$\rho_s = \frac{m_1}{m_1 - m_2} \times \rho_w \tag{1}$$

Hardness values of all specimens were determined at Rockwell Hardness R scale (HRR) with 12.7mm spherical steel ball and 60kg.f the applied load by a hardness test machine (DIGIROCK-

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RBOV). Five positions which were along the radial direction of the specimen were tested for each set of samples.

Porosity affects the properties of composite materials. Generally, for the same material, the lower the porosity is, the less the connected pores are. Thus, composite material has higher strength and thermal conductivity values and lower water absorption values. The porosity values of the brake pad samples were determined by equation (2) [10]:

$$P = (1-\frac{\rho_E}{\rho_T})x100 \qquad (2)$$

where P is porosity (%), ρ is density (g/cm^3), E refers experimental and T refers theoretical.

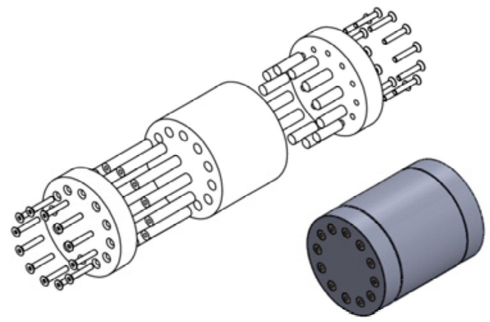

Figure 1. The mould used in the production of brake pad samples

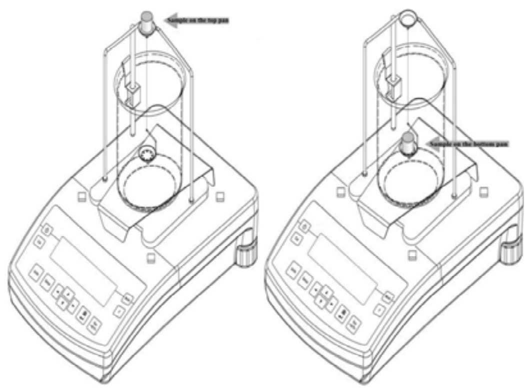

Figure 2. Density calculation kit according to the Archimedes' principle

Wear rate tests were carried out using a pin-on-disc type tribo-test machine. The pin-on-disc test apparatus with disc made of grey cast iron of hardness value 195HB (62.5kg.f, 5mm ball) and 180mm track diameter was used to investigate the dry sliding wear rate of the brake pad specimens in accordance with ASTM:D792 standard. The pin was pressed against the rotating cast iron disc of counter surface at a load of 1MPa, sliding speed of 1m/s and sliding distance of 1000m. All tests were conducted at room temperature. The differences in weight measured before and after tests give the weight loss of the samples. The equation (3) used to convert the weight loss into wear rate (W, mg/m). Where ΔW is the weight difference of the sample before and after the test (mg), S is total sliding distance (m) [11, 12].

$$W=\Delta W/S \qquad (3)$$

The weight percentage of components such as miscanthus (A), cashew (B), alumina (C) and phenolic resin (D) used for production of ecological brake pad samples were chosen in the range of 5-20wt-% increased by 5wt-%. Calcite used as filler (in the range of 35-80wt-%) was preferred as a complement component for the brake pad mixture, because it had no effect on the characteristics of the brake pad sample as reported in the literature. 256 units brake pad samples can be manufactured considering these mixing ratios. But it is impossible because of the performing production, experimentation and evaluation processes of the brake pad samples. For these reasons, design of experiment is an important tool for designing processes and products. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. Signal-to-Noise ratios (S/N) are used as the quality characteristics of choice on Taguchi Design. In the Taguchi method, the term ‘signal’ represents the desirable target for good products and the term ‘noise’ represents the undesirable value. The experimental observations are transformed into signal-to-noise (SN) ratios and the goal of the experiment is to improve the relationship between the signal factor and the response. The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. SN ratios are available depending on the type of performance characteristics and can be characterized into three categories; Larger is better, Nominal is best and Smaller is better. The SN ratio category selected is important for the goal of the experiments. The parameter level which has the highest S/N value is the best result for the experiments regardless of the selected category of performance characteristics. Therefore, the optimal level of the parameters is the level with the greatest S/N value [13, 14].

According to the ANOVA results, in multiple linear regression analysis, R^2 is the regression coefficient (R^2>0.90) for the models, which indicate that the fit of the experimental data is satisfactory.

In this work, to evaluate the statistical data, the larger-is-better quality characteristic (equation (4)) was chosen for density and hardness and the smaller-is-better quality characteristic (equation (5)) was chosen for porosity and wear rate values of brake pad samples. The quality characteristic was chosen in accordance with the previously conducted studies made by Zaharudin, Talib, Berhan, Budin and Aziurah [4], Kim, Kim and Jang [6], Ibhadode and Dagwa [15]. These formulas were used to calculate SN ratio:

$$\text{Larger is better} \quad S/N = -10.\log[\Sigma(1/Y^2)/n] \tag{4}$$

$$\text{Smaller is better} \quad S/N = -10.\log(\Sigma Y^2/n) \tag{5}$$

Y= measured value,
n= Number of tests.

Table 1. The mean values of physical properties in accordance with Taguchi design.

	A	B	C	D	d	H	Pr	WR
1	1	1	1	1	1.459	105.2	0.15932	1.47E-06
2	1	2	2	2	1.485	104.9	0.1559	1.35E-06
3	1	3	3	3	1.583	109.4	0.15216	1.45E-06
4	1	4	4	4	1.563	112.3	0.17273	1.59E-06
5	2	1	2	3	1.528	105.6	0.16666	1.53E-06
6	2	2	1	4	1.491	104.6	0.16522	1.47E-06
7	2	3	4	1	1.489	111.7	0.21171	1.91E-06
8	2	4	3	2	1.527	106.9	0.23704	1.70E-06
9	3	5	3	4	1.563	108.9	0.16889	1.56E-06
10	3	2	4	3	1.543	111.5	0.16526	2.86E-06
11	3	3	1	2	1.408	100.9	0.22323	2.08E-06
12	3	4	2	1	1.407	104.7	0.25289	2.12E-06
13	4	1	4	2	1.538	108.1	0.17912	3.52E-06
14	4	2	3	1	1.46	105.8	0.21977	3.35E-06
15	4	3	2	4	1.435	102.9	0.21524	3.07E-06
16	4	4	1	3	1.401	95.5	0.24556	2.74E-06

d: Density (g/cm^3); H: Hardness (HRR); Pr: Porosity (%); WR: Wear Rate (cm^3/N.m)

3. Results and discussion

Experiments are conducted in accordance with Taguchi's L16 orthogonal array to determine the degree of influence of components and their ratios constituting brake pad samples to the physical properties of brake pad samples. Experiments were carried out three times and average values of experiments and mixing ratios of produced samples are given in Table 1. The resin was varying from 5 to 30wt% with interval of 5wt%.

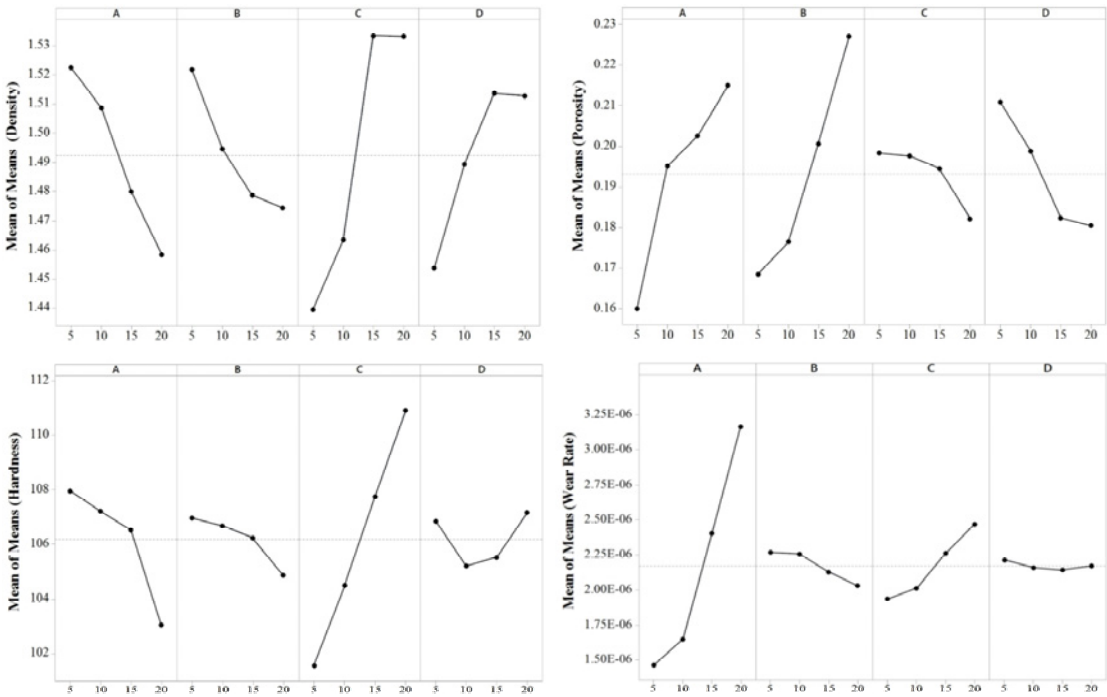

Figure 3. Mean value graphics of physical properties of brake pad samples

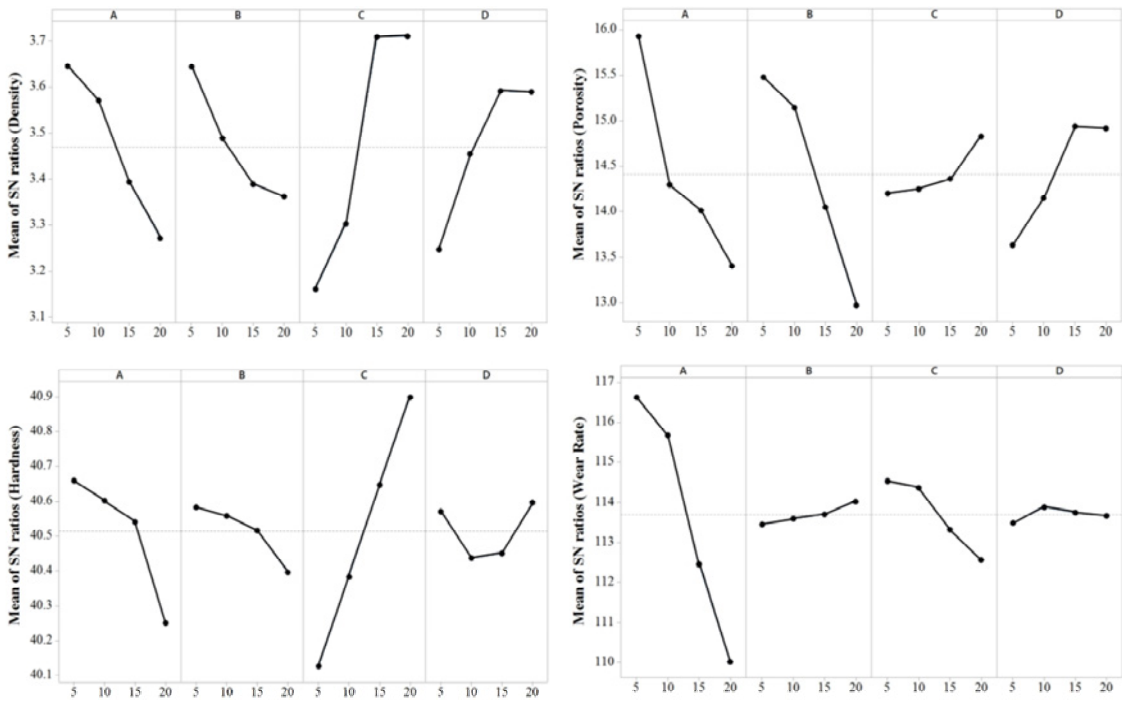

Figure 4. S/N value graphics of physical properties of brake pad samples

Mean value graphs that are obtained from the data in Table 1 are given in Figure 3. When these graphs are examined, miscanthus (A) and cashew (B) components exhibit similar behaviour for the density, hardness and porosity properties of brake pad samples. While miscanthus and cashew components' ratios in the structure of the brake pad samples increase, density and hardness values of the brake pad samples decrease.

While alumina (C) and phenolic resin (D) ratios increase, porosity values increase, and vice versa. The wear rates of the brake pad samples are increasing in proportion to the ratio of miscanthus and alumina. Cashew ratio is inversely proportional to the wear rates and it appears that the phenolic resin ratios have no impact on the wear rate. Referring to the mean value graphics we can make comments it this way. It could not be understood the effect of the brake pad components on the physical properties of the brake pad samples by investigation of the mean value graphics. For this reason, SN ratio graphs and ANOVA tables should be examined.

When the line is horizontal on the mean of SN ratio graphs, then there is no main effect present. When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the characteristic differently. The greater the differences in the vertical position of the plotted points are, the greater the magnitude of the main effect is. By comparing the slopes of the lines, we can compare the relative magnitude of the factor effects. The S/N value graphics plotted to determine the degree of influence of the brake lining components and ratios to the physical properties such as density, hardness, porosity and wear rate of the brake linings are shown in Figure 4 and the ANOVA results are given in Table 2-5. The ANOVA table shows the relative importance of the brake pad components affecting the physical properties of brake pad samples. This can be evaluated from the contribution (Cont.%) in percentage on the total variation indicating their degree of influence on the result. F test is used to observe that the design parameters have a major effect on the quality characteristics. In the analysis, the F-ratio is traditionally used to determine the significance of a factor. P (probability of significance) values give the statistically significant factors affecting the property. The factors whose P values are less than 0.05% (95% confidence levels) are generally regarded as statistically significant. Based on this criterion, it is found that miscanthus ratio is not statistically significant for wear rate and compression strength values [16-18].

Table 2. ANOVA for density SN ratios

Source	Seq SS	Adj. MS	Cont. (%)	F	P
A	0.3431	0.1143	18.69	11.62	0.037
B	0.1968	0.0655	10.72	6.67	0.077
C	0.9525	0.3174	51.88	32.26	0.009
D	0.3141	0.1046	17.11	10.64	0.042
Residual Error	0.0295	0.0098			

Table 3. ANOVA for hardness SN ratios

Source	Seq SS	Adj. MS	Cont. (%)	F	P
A	0.3964	0.1321	20.49	9.21	0.05
B	0.0823	0.0274	4.25	1.91	0.304
C	1.3328	0.4442	68.89	30.98	0.009
D	0.0802	0.0267	4.37	1.86	0.311
Residual Error	0.043	0.0143			

Table 2-5 suggest that alumina, miscanthus, phenolic resin and cashew components are significant parameters for density values of brake pad samples and the contribution values in percentage 51.88, 18.69, 17.11 and 10.72, respectively. Alumina, miscanthus and phenolic resin components' P values are less than 0.05% for density property.

Hardness values of brake pad samples are more affected by alumina and miscanthus components. Because alumina and miscanthus have 68.89, 30.98 and 20.49, 9.21 values of the contribution values (%) and F values, respectively. Alumina and miscanthus components' P values are less than 0.05% for hardness property. Cashew, miscanthus and phenolic resin are more effective components because their contribution values are 43.35, 38.92 and 13.51, respectively, and these components have less than 0.05% P values for porosity property. Miscanthus is a more effective component than others for wear rate property of brake pad samples because of its higher contribution value and F value. According to

ANOVA results, miscanthus and alumina have an effective influence on all the physical properties of brake pad samples whereas others are not so effective. R-Sq values of SN Ratios of density, hardness, porosity and wear rate of brake pad samples are 98.4, 97.8, 98.5 and 99.2 respectively.

Table 4. ANOVA for porosity SN ratios

Source	Seq SS	Adj. MS	Cont. (%)	F	P
A	13.883	4.6275	38.92	26.44	0.012
B	15.465	5.1551	43.35	29.45	0.01
C	0.9818	0.3273	2.75	1.87	0.31
D	4.8199	1.6066	13.51	9.18	0.051
Residual Error	0.5251	0.175			

Table 5. ANOVA for wear rate SN ratios

Source	Seq SS	Adj. MS	Cont. (%)	F	P
A	110.34	36.78	89.94	107	0.001
B	0.721	0.24	0.59	0.7	0.611
C	10.273	3.424	8.37	10	0.045
D	0.325	0.108	0.27	0.32	0.815
Residual Error	1.027	0.342			

4. Conclusion

Ecological brake pad samples were produced the first time using miscanthus as reinforcing component of brake pad. As a result of this study which investigated the degree of influence production parameters and the components constituting the brake pad samples on the physical properties was obtained as follows:

When miscanthus component ratio in brake pad samples increase, density and hardness values of brake pad samples decrease and porosity and wear rate values of brake pad samples increase.

When cashew component ratio in brake pad samples increase, only porosity values of brake pad samples increases and others decrease.

When alumina component ratio in brake pad samples increase, only porosity values of brake pad samples decrease.

When phenolic resin component ratio in brake pad samples increase, density and hardness values of brake pad samples increase and porosity values of brake pad samples decrease. Phenolic resin component has no effect on wear rate values.

The conclusion reveals that density and hardness properties are most affected by alumina component of brake pad samples. Porosity property is most affected by miscanthus and cashew components of brake pad samples. Wear rate property is most affected by miscanthus component of brake pad samples.

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