

EFFECT OF PARTICLE SIZE, BAKING TEMPERATURE, MOULDING PRESSURE AND BINDER ON THE RESISTIVITY OF CARBON BRUSH USING COCONUT SHELL

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ABSTRACT : Carbon brush is a minute, but very critical and important component in motor and generator; performs both mechanical and electrical function in the system. Its operation in the generator and motor is affected by several factors like: baking temperature, moulding pressure, binder's quantity, etc. This paper examines the effect of particle size, baking temperature, moulding pressure, and binder's quantity on the resistivity of carbon brush. Carbon from Coconut Shell (CS) through pyrolysis using furnace at 500 °C was used for this research. The carbon content was determined using particle accelerator model 5SDH. The pyrolysed CS was calcined at 1100 °C. The amorphous calcined carbon was graphitized at a pressure of 1.74 KN with a soaking temperature of 1000 °C for 5, 10, 15 and 24 hours, respectively. Copper, zinc and the graphitized material were ground, sieved and mixed together with resin binder. Taguchi experimental design was used to determine the formulation. Samples of carbon brushes were produced. Resistivity, hardness, coefficient of friction, bulk density, and conductivity were used as responses and their values were determined. The carbon contents for Coconut shell was 76.38%. The optimization from the Taguchi L9 orthogonal gave a particle size of 350 microns, temperature of 150 °C, moulding pressure of 250 Bars and 5% binder quantity. The resulting Resistivity, hardness, coefficient of friction, bulk density, resistivity and conductivity were 79.6Kgf, 2.1588Kg/cm³, 1344(Ωcm)⁻¹ and 0.000643Ωcm respectively. The desirability is 0.682. A one factor graph of resistivity to particle size, baking temperature, moulding pressure and binder quantity were plotted. The resistivity value increases as the particle size, baking temperature and moulding pressure increases and decreases as binder quantity increases.

Keyword: Resistivity, Particle size, baking temperature, Moulding pressure, Taguchi Experimental design.

1.0 INTRODUCTION

A carbon brush is an electrical component which makes contact between a stationary and a moving electrical circuit. A carbon brush has both an electrical and mechanical functions within a system; it is a conductor of current in an electrical circuit and is subjected to mechanical forces as it makes physical contact with a surface in motion. (Jeff, 2006) Electrical carbon brushes were invented a century ago in England and the development of them was accompanied with that of motors (XIA Jin- Tong et al. 2007). Brush performance greatly determines the performance of rotary equipment such as motors and generators, therefore brushes must be carefully selected. (Schunk, 2013)

Resistivity of a material is its resistance to the flow of electrical current. Materials with high resistivity increase the overall resistance in the commutation circuit and lead to improve commutation. Resistivity is a key parameter in the choice of the suitable carbon brush grade. *Hu et al. (2008)* researched on the wear property of high- resistivity carbon brushes made with and without Molybdenum disulfide (MoS₂) in variable humidity. Four kinds of high-resistivity carbon brushes with MoS₂ content of 0%, 2%, 4% and 6% (mass fraction) were prepared respectively. They concluded that wear rate of brush made without MoS₂ in 10% relative humidity is two times larger than that of 50% relative humidity, but the wear rates change little for brushes made with MoS₂.

Taguchi's parameter design (PD) methodology has proved to be an effective approach to producing high-quality products at a relatively low cost. The objective of parameter design (also known as robust

design) is to determine the best settings of the process parameters, thereby making the process functional performance insensitive to various sources of variation. In the optimization process of multiple quality characteristics, the objective is to determine the best factor settings which will simultaneously optimize all the quality characteristics of interest to the experimenter. (J. Antony, 2001) The Taguchi's design was chosen based on the fact that it is suitable for improvement of product quality and process performance. It is also good for settings of process parameters. Taguchi's design can also be used for optimization of process of multiple quality characteristics.

2.0 METHODOLOGY

Sample of Coconut Shell (CS), was washed, dried and pyrolysed using a pyrolysis furnace in order to obtain the amorphous carbon from the coconut shell. The percentage of carbon in amorphous particle obtained from the pyrolysed CS was determined using particle accelerator model 5SDH. It was calcined to 1100 degree Centigrade to remove the remaining carbonaceous materials. The calcined amorphous material was subjected to pressure using torque wrench and a temperature of 1000 degree centigrade for 5, 10, 15 and 24 hours at constant pressure of 1.7 KN. This process was used to graphitized the amorphous carbon to become graphitic structure. After which copper, zinc and tin were added and mixed together. The Taguchi L9 experimental design model with the following factors: Particle Size (PS), Baking Temperature (BT), Moulding Pressure (MP) and Binder Quantity (BQ) were used. Resistivity, hardness, bulk density, conductivity and coefficient of friction were adopted as response for this experiment. They were measured and the results analyzed. Table 1 shows the number of factors and levels used in the L9 Taguchi for the production of carbon brush.

Table 1: L9 Factors and Levels for the production of the carbon brush.

Factors	Level 1	Level 2	Level 3
PS	125	250	350
MP	100	200	250
BT	150	180	210
BQ	5	10	15

2.1 RESISTIVITY

The resistivity was determined with voltmeter – ammeter method using equation 2.1

$$\text{Resistivity} = \frac{U \cdot b \cdot w}{I \cdot L} \quad 2.1$$

Where U = voltage drop between the potential pointers in volts

b = thickness of the test specimen

w = width of test specimen

I = current through the test specimen

L = distance between the potential pointer in the meter.

2.2 BULK DENSITY

The bulk density is defined by the equation:

$$\text{Bulk density} = \frac{m}{v} \quad 2.2$$

Where m is the mass of test specimen (dry)

v is the volume of the material.

Measurement and weight method was adopted in this experiment.

2.3 HARDNESS

There are two methods use for determining the hardness of carbon brush: rebound and indentation methods. The indentation method was used with Rockwell hardness test apparatus.

3.0 RESULTS AND DISCUSSION

The effects of the factors: PS, BT, MP and BQ were observed on the responses: resistivity, bulk density, hardness, conductivity and coefficient of friction of the brush. Table 2 shows the experimental layout for the factors and responses used in the production of carbon brush using Taguchi L9 experimental design.

3.1 ANOVA analysis of Resistivity with respect to each factor

The analysis of variance (ANOVA), Table 3 shows that the model is significant having a value of Prob>F = 0.0469. (Values of “Prob > F” less than 0.0500 indicates that the terms are significant). Table 3 indicates that the model is significant at 95% confidence interval and there is only a 4.69% chance that a model F-value, 268.94, this large could occur due to noise. In the model PS, BT, PS² and interaction of MP/BQ have effect on the production of carbon brush from this research. Effects of these factors were shown and discussed in the one factor graph.

Table 3: Analysis of variance (ANOVA) for L9 Taguchi experimental design.

Source	Sum square	of Degree freedom	of Mean square	F- Value	Prob>F
Model	3.96	7	0.57	268.94	0.0469
PS	1.61	1	1.61	768.15	0.0230
BT	0.27	1	0.27	128.61	0.0560
MP	0.096	1	0.096	45.89	0.0933
BQ	0.11	1	0.11	50.30	0.0892
PS ²	0.62	1	0.62	296.95	0.0369
PS/BT	0.26	1	0.26	121.76	0.0575
MP/BQ	0.55	1	0.55	262.21	0.0393
Residual	2.101E-003	1	2.101E-003		
Cor Total	3.96	8			

Table 2: L9 experimental layout showing factors and responses in the production of carbon brush.

Std	Run	Block	Factor 1 A: Particle Size Microns	Factor 2 B: Baking Temperature Degree Centigrade	Factor 3 C: Moulding Pressure Bar	Factor 4 D: % of Binder %	Response 1 Resistivity Ohms centimeter	Response 2 Bulk density g/cm ³	Response 3 Hardness Kg	Response 4 Conductivity Per Ohms per	Response 5 Coefficient of friction Unitless
9	1	Block 1	350.00	210.00	200.00	5.00	14500	3.91	88.5	6.896E-005	0.6
6	2	Block 1	250.00	210.00	100.00	10.00	2110	1.9	77	0.0004739	0.59
5	3	Block 1	250.00	180.00	250.00	5.00	1740	1.88	79.7	0.0005747	0.57
7	4	Block 1	350.00	150.00	250.00	10.00	3940	1.61	77	0.0002538	0.59
8	5	Block 1	350.00	180.00	100.00	15.00	2690	1.48	73.5	0.0002538	0.53
4	6	Block 1	250.00	150.00	200.00	15.00	1530	1.86	72	0.0006535	0.54
1	7	Block 1	125.00	150.00	100.00	5.00	3580	1.46	75.5	0.0002793	0.51
3	8	Block 1	125.00	210.00	250.00	15.00	2030	1.64	78.5	0.0004926	0.54
2	9	Block 1	125.00	180.00	200.00	10.00	1620	1.69	74	0.0006172	0.5

3.2 Development of Model Equation for Resistivity with respect to Factors

The model equation generated from Taguchi experimental design is given as:

$$\text{Resistivity} = +15.75746 - 0.041014 * (\text{PS}) - 0.026254 * (\text{BT}) - 0.011575 * (\text{MP}) - 0.28659 * (\text{BQ}) + 4.63891\text{E-}005 * (\text{PS})^2 + 1.40980\text{E-}004 * (\text{PS} * \text{BT}) + 1.39955\text{E-}003 * (\text{MP} * \text{BQ}) \quad 1.0$$

With this model a certain value of resistivity can be produced in a carbon brush taking resistivity as the only factor by solving the equation 1.0. The R² value of this model is 0.9995.

3.3 Effect of factors used on Resistivity property of the produced carbon brush

The graphical relationships between resistivity and other factors (baking temperature, particle size, moulding pressure and binder quantity in the carbon brush were analyzed below:

3.3.1 Resistivity versus Particle size

Figure 1 shows the relationship between resistivity and particle size. The relation is not linear but parabolic in nature. At 125 μm and 350 μm mesh particle size, the resistivity is 7.61858Ωcm and 8.799Ωcm respectively. There is an increase in resistivity, as the particle size is increased at constant baking temperature, moulding pressure and binder quantity from 125μm to 350μm mesh. An interaction occurs between particle size and baking temperature as shown in figure 2. The interaction between particle size and baking temperature, shows that the resistivity of carbon brush is also affected by these factors.

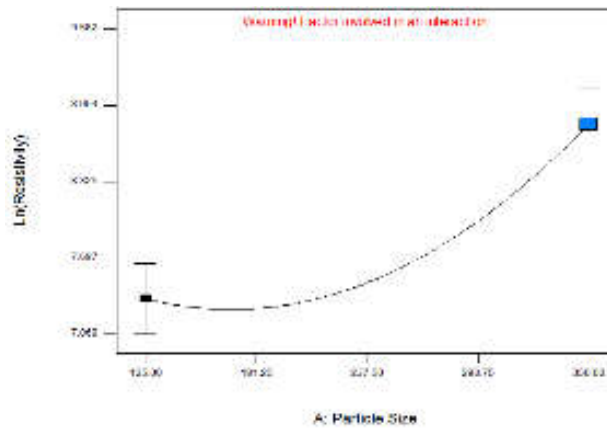


Figure 1: Graph of resistivity versus particle size in carbon brush

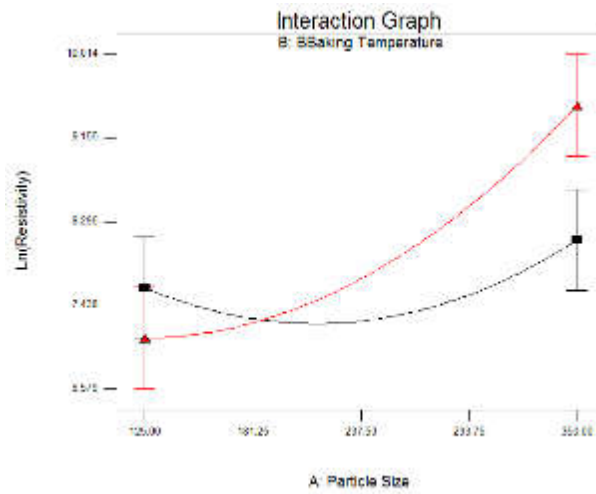


Figure 2: Graph of interaction between particle size and baking temperature.

3.3.2 Resistivity versus Baking Temperature

The graph of figure 3 depicts the relationship between resistivity and baking temperature. It shows that resistivity increases as baking temperature increases. At 150 °C and 210 °C, the resistivity is 7.275Ωcm and 7.709Ωcm respectively. The particle size, moulding pressure and binder quantity are kept constant. It also shows that there is interaction between baking temperature and particle size, as earlier depicted in figure 2 under particle size.

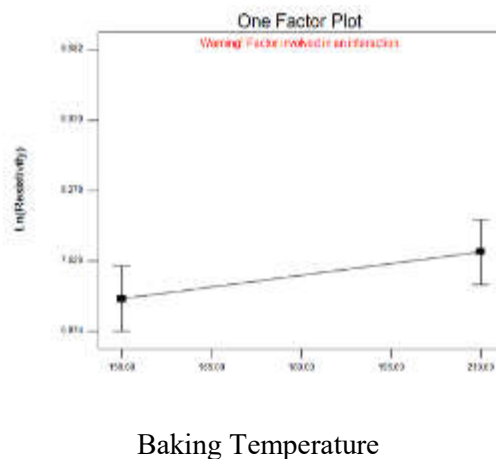


Figure 3: Graph of resistivity versus baking temperature

3.6 Resistivity versus Moulding Pressure

The graph of resistivity versus moulding pressure, depicts an interactive graph shown in figure 4, which shows that resistivity increases as the moulding pressure increases. It is observed that each of these factors is a trade off to the responses depending on which factor is paramount or desired for the carbon brush been produced. At 100 Bar and 250 Bar, the resistivity is 7.311 Ωcm and 7.674 Ωcm respectively. The particle size, baking temperature and binder quantity, remain constant at 237.5 μm mesh, 180 °C and 10ml respectively.

The interaction between moulding pressure and the quantity of binder is shown in figure 5. At 100 Bar and 5ml of binder, 100 Bar and 15ml of binder, 250 Bar and 15ml of binder and 250 Bar and 5ml of binder , the corresponding resistivity are: 8.04392Ωcm, 6.57754Ωcm, 7.99025Ωcm and 7.35734Ωcm respectively. It can be concluded that at constant pressure of 100 Bar, variation of binder quantity from 5ml to 15ml, gave a decrease in resistivity from 8.04392 Ωcm to 6.57754 Ωcm, but at constant 250 Bar, an increase in binder from 5ml to 15ml, causes an increase in resistivity from 7.35734 Ωcm to 7.99029 Ωcm. This is another reflection of how a small change in the factor has effect on the brush properties and functions.

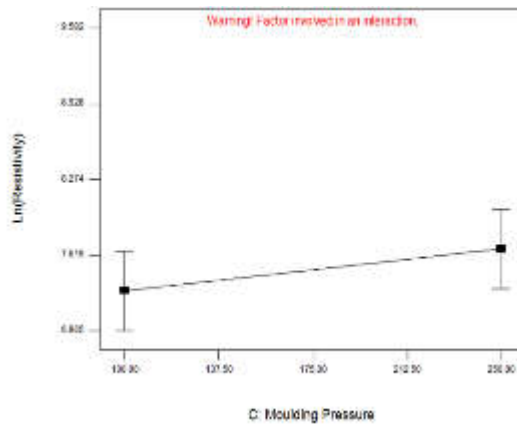


Fig 4: Graph of Resistivity versus moulding pressure in carbon brush

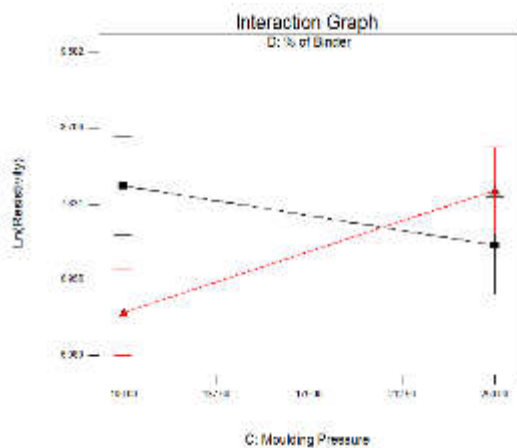


Figure 5: Graph of interaction between moulding pressure, quantity of binder and their effect on resistivity

3.7 Resistivity versus Binder quantity

The graph of figure 6 shows the relationship between resistivity and quantity of binder. It shows that resistivity decreases as the quantity of binder increases. At 5ml and 15ml of binder, the resistivity were : 7.701 Ωcm and 7.284 Ωcm respectively and at constant particle size, baking temperature and moulding pressure. The interaction has been discussed under moulding pressure.

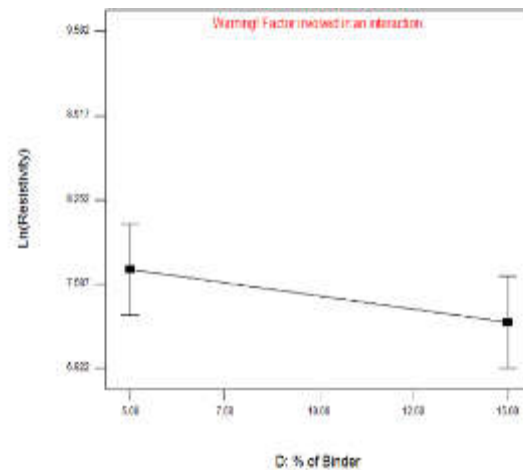


Figure 6: Graph of resistivity and quantity of binder.

4.0 CONCLUSIONS AND RECOMMENDATION

The following conclusions were reached from this study:

1. Resistivity of carbon brush made from Coconut shell increases with increase in particle size, baking temperature and moulding pressure.
2. Resistivity of the carbon brush produced decreases as the binder quantity increases.
3. These factors have interactions, which also contributed to the effect on the interactions

In order to have a direct relationship of these factors on resistivity of carbon brush, the interaction can be further investigated into by varying a particular factor while others remain constant.

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