Advances In Multidisciplinary & Scientific Research
A Multidisciplinary & Interdisciplinary Journal
Vol. 3 No. 2, June 2017

Effect of Particle Size, Baking Temperature, Moulding Pressure and Binder on the Hardness of Carbon Brush Using Coconut Shell

Oyetunji O. R.[1], Anyaeche C. O. [2], Ajayeoba A. O. [3], Olafimihan E. O.[4] and Oyawale F. A. [5]
[1,3,4] Mechanical Engineering Dept Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
[2] Industrial and Production Engineering Department, University of Ibadan, Oyo State Nigeria
[3] Mechanical Engineering Department, Covenant University, Ota, Ogun State Nigeria.
Corresponding Author's E-mail: oroyetunji@lautech.edu.ng[1]

ABSTRACT

Carbon brush is a minute, but very critical and important component in motor and generator, performs both mechanical and electrical functions in the system. Its operation in the generator and motor is affected by several factors like: temperature, environmental condition (dust, moisture, humidity etc), spring pressure on the brush, grain size of the material used in its manufacture, moulding pressure, binder quantity, etc. This paper examines the effect of particle size, baking temperature, moulding pressure, and binder quantity. The Taguchi experimental design was used to optimize the effect of these factors on the production of carbon brush. Carbon from Coconut Shell (CS) through pyrolysis using furnace at 500 ºC was used for this research. The carbon content was determined using particle accelerator model 5SDH. The pyrolysed CS was calcined at 1100 ºC. The amorphous calcined carbon was graphitized at a pressure of 1.74 KN with a soaking temperature of 1000 ºC 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. Hardness, coefficient of friction, bulk density, resistivity and conductivity were used as responses and their values were determined. The carbon contents for Coconut shell was 76.38% . The mean resistance of graphitized CS at 1000 ºC was 3.60 µΩ. The optimization from the Taguchi L9 orthogonal gave a temperature of 150 ºC, particle size of 350 microns, 5% binder quantity and a pressure of 250 Bars. The results of the hardness, coefficient of friction, bulk density, resistivity and conductivity are 79.6Kgf, 2.1588Kg/cm^3,1344(Ωcm)$^{-1}$ and 0.000643Ωcm respectively. The desirability is 0.682. A one factor graph of hardness to particle size, baking temperature, moulding pressure and binder quantity were plotted. The hardness value increases as the particle size and baking temperature increase and decreases as moulding pressure and binder quantity increase.

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

Aims Research Journal Reference Format:
Oyetunji O. R., Anyaeche C. O., Ajayeoba A. O., Olafimihan E. O. & Oyawale F. A. (2017): Effect of Particle Size, Baking Temperature, Moulding Pressure and Binder on the Hardness of Carbon Brush Using Coconut Shell. Advances in Multidisciplinary Research Journal. Vol. 3. No. 2, Pp 143-150

1. 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). Solberg (1927) defined hardness as the measure of the hardness of the brush material as obtained by the rebound of a diamond pointed weight dropped through a glass tube from a height of about 6 inches in an instrument known as the shore scleroscope.

The rebound is measured in units on a scale from 0 to 100. The hardness factor will only give indication of the rideability of the carbon brush on the contact surface. Resistivity, density, strength and filming rate are far more important factors in determine performance (Jeff, 1993). Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration (Gordon, 2013). It is referred to as the resistance to bending, abrasion or cutting. The hardness of a brush gives the indication of the ridability of the brush on the contact surface.

Taguchi's parameter design (PD) methodology has proved to be an effective approach to producing highquality 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. METHODOLOGY

Sample of Coconut Shell (CS), was washed, dried and pyrolysed using a pyrolysis furnace in order to obtained 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 ºC 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). Resistivity, hardness and bulk density were used as response for this experiment. They were measured and the results were analyzed. Table 2.1 shows the number of factors and levels used in the L9 Taguchi for the production of carbon brush.

Table 2.1: 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 Bulk Density

The bulk density is defined by the equation:

$$\text{Bulk density} = \frac{m}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.1$$

Where m is the mass of test specimen (dry) v is the volume of the material.

Measurement and weight method is adopted in this experiment.

2.2 Hardness

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

2.3 Resistivity

The resistivity was determined using voltmeter – ammeter method using equation 2.2

$$\text{Resistivity} = \frac{U \times b \times w}{I \times l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 2.2$$

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.

3. 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 3.1 shows the experimental layout for the factors and responses used in the production of carbon brush using Taguchi L9 experimental design. Table 3.1.: 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:BBaking 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 Unitles
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

3.1 ANOVA Analysis of Hardness With Respect to Each Factor

The analysis of variance (ANOVA), Table 3.2 shows that the model is significant having a value of Prob>F = 0.0175. (Values of "Prob > F" less than 0.0500 indicates that the terms are significant). Table 3.2 indicates that the model is significant at 95% confidence interval and there is only a 1.75% chance that a model F-value, 56.38, this large could occur due to noise. In the model PS, BQ, interaction of PS/BQ and BT/MP have effect on the production of carbon brush from this research. Effects of these factors is shown in the one factor graph.

Table 3.2: Analysis of Variance (ANOVA) for L9 Taguchi Experimental Design.

Source	Sum square of	Degree of freedom	Mean square	F- Value	Prob>F
Model	188.37	6	31.39	56.38	0.0175
A	32.05	1	32.05	57.55	0.0169
B	0.52	1	0.52	0.93	0.4370
C	1.21	1	1.21	2.17	0.2786
D	47.24	1	47.24	84.83	0.0116
AD	11.65	1	11.65	20.92	0.0446
BC	13.57	1	13.57	24.36	0.0387
Residual	1.11	2	0.56		
Cor Total	189.48	8			

3.2 Development of Model Equation for Hardness with respect to Factors The model equation generated from Taguchi experimental design is given as:

Hardness = +87.13449 + 0.10770 *(PS) – 0.15283 * (BT) – 0.18982 *(MP) + 1.39321 * (BQ) – 8.2783E-003 * (PS* BQ) + 9.85505E-004 * (BT * MP) … 1.0

With this model a certain value of hardness can be produced in a carbon brush taking hardness as the only factor by solving the equation 1.0. The R^2 value of this model is 0.9941.

3.3 Hardness versus Particle size

The graphical relationships between hardness and other factors (baking temperature, particle size, moulding pressure and binder quantity in the carbon brush were then analysed.

3.3.1 Effect of factors used on Hardness property of the produced carbon brush

Figure 1 shows the one plot graph of hardness versus particle size. It shows that hardness of the carbon brush increases as the particle size increase. At particle size of 125µm mesh the hardness value is 74.49 Kg and 80.10 Kg at 350µm mesh. This shows that for higher hardness value, the particle size should be large. It should be recalled that the baking temperature, moulding pressure and binder quantity were held constant at 180 ºC, 175 Bar and 10ml of resin binder. But, hardness is not the predominant factors to predict performance of carbon brush, therefore optimality is required (Jeff, 1993). It is shown in Figure 2 that there is interaction between particle size and the binder quantity and this has effect on the hardness of the brush. At 125µm mesh of particle size and 15ml of binder, hardness is 76.28 Kg. For 125µm mesh of particle size and 5ml of binder, 350µm mesh of particle size and 5ml of binder and 350µm mesh of particle size and 15ml of binder, hardness are 72.70 Kg, 87.62 Kg and 72.58 Kg respectively. It was observed that hardness value decreases from 76.28 Kg to 72.70 Kg as the binder quantity decreases from 15ml to 5ml at constant particle size of 125µm mesh. The baking temperature and moulding pressure remained constant at 180 ºC and 175 Bar respectively.

The result obtained at constant particle size of 350µm mesh when the binder increases from 5ml to 15ml, shows that hardness reduces from 87.62 Kg to 72.58 Kg. This complex relation shows how particle sizes exhibit different hardness value due to variation in binder quantity and verse versa.

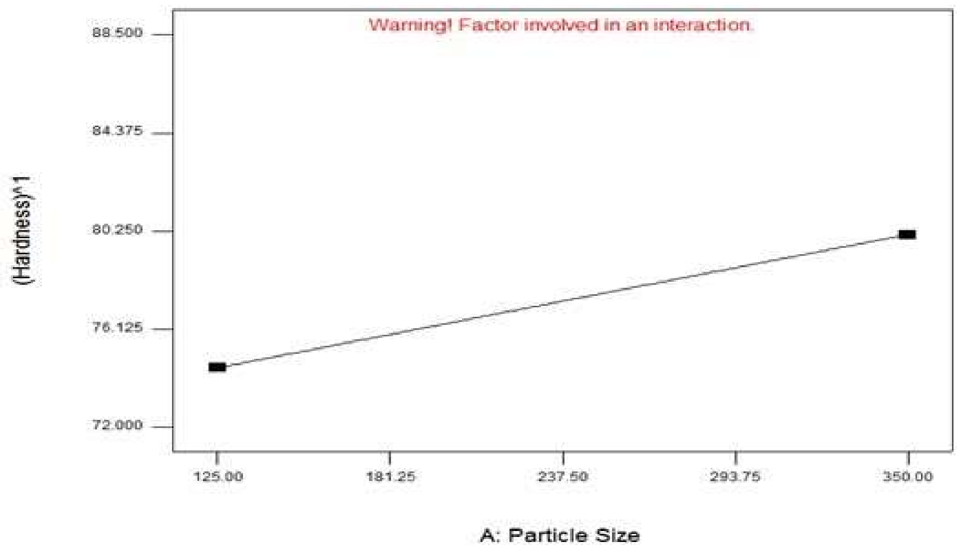


Figure 1: Graph of Hardness versus Particle size

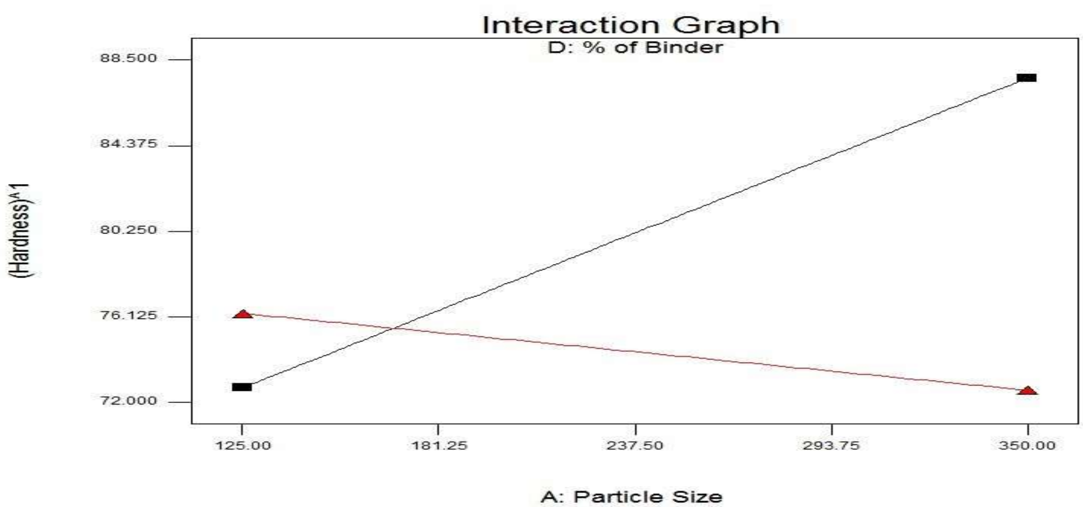


Figure 2: Graph of interaction between baking temperature and binder quantity in carbon brush as it affects the hardness value.

3.5 Hardness Versus Baking Temperature

The graph of figure 3 depicts the relationship between hardness and baking temperature in the production of carbon brush. The design point at 150 ºC gave hardness of 76.71 Kg and 77.88 Kg at 210 ºC. This can be interpreted that as baking temperature increases the hardness value increase. This cannot be taking so directly, since there is interaction effect between the baking temperature and moulding pressure. The interaction graph of figure 4 shows that at 150 ºC baking temperature and 100 Bar moulding pressure , the hardness is 79.86 Kg. At 150 ºC baking temperature and 250 Bar, 210 ºC baking temperature and 250 Bar, and 210 ºC baking temperature and 100 Bar, the hardness of the carbon brush are 73.56 Kg, 79.17 Kg and 76.60 Kg respectively. The particle size and binder quantity are kept constant at 257.50 µm mesh and 10ml of binder quantity respectively.

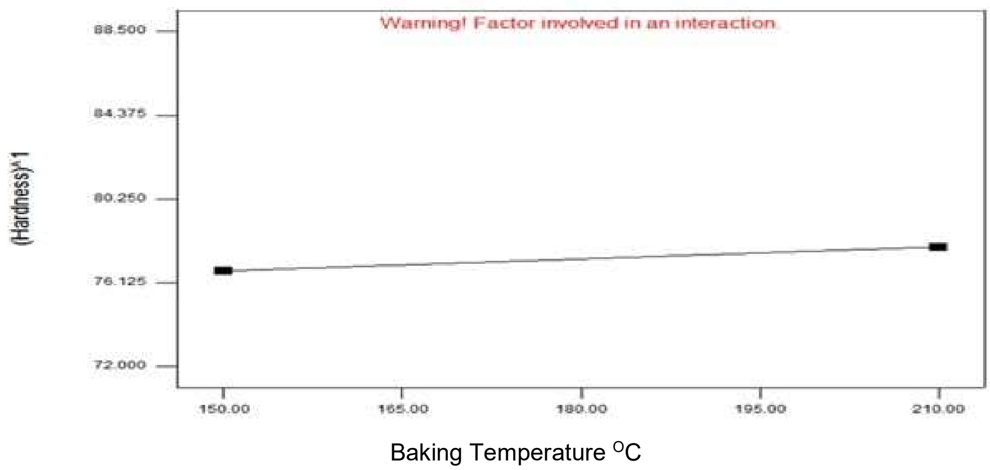


Figure 3: Graph of Hardness versus Baking Temperature

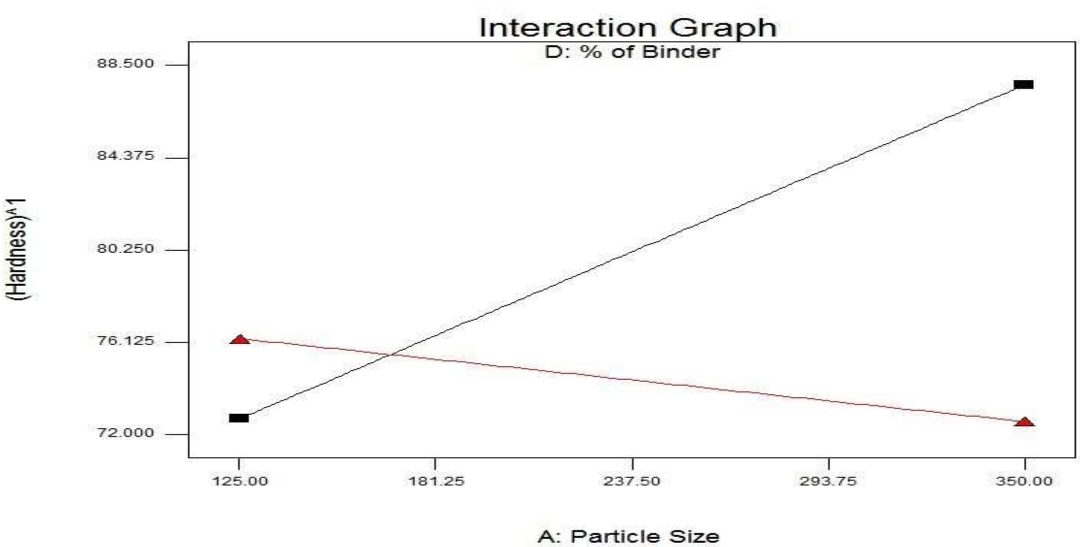
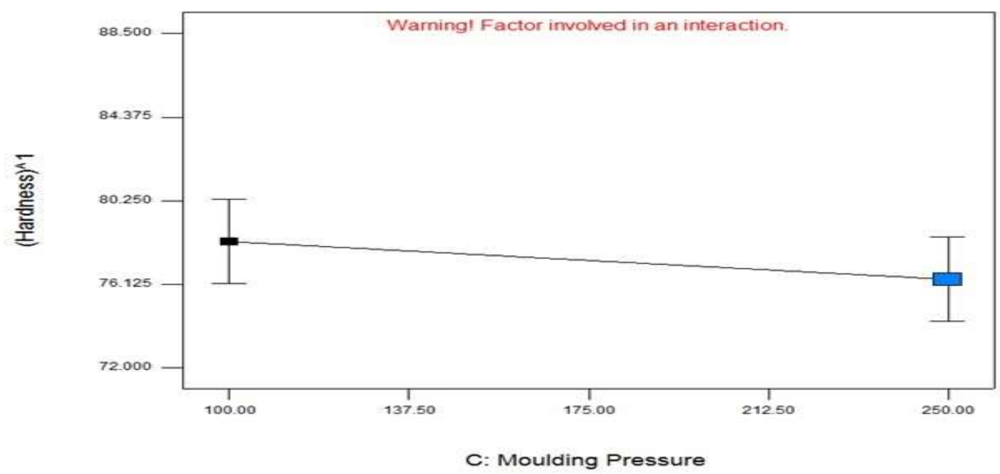


Figure 4: Graph of interaction between baking temperature and binder quantity in carbon brush as it affects the hardness value.

3.6 Hardness versus Moulding Pressure

The graph of figure 5 depicts the relationship between hardness and moulding pressure. It shows a decrease in hardness as the moulding pressure increase. At the design point of 100 Bar of the moulding pressure, hardness is 78.23 Kg and 76.36 Kg at 250 Bar.



Baking Temperature ^{O}C

Figure 5: Graph of hardness versus baking temperature in carbon brush.

3.7 Hardness versus Binder quantity

Figure 6 shows that hardness decreases as the binder quantity increase. At the design point of 5ml of binder quantity, the hardness is 80.16 Kg and 74.43 Kg at 15ml of binder quantity. This can be explained that high hardness in carbon brush is achieved at less quantity of binder, but the optimum value can be determined from optimization. Also interaction occurred with particle size and binder quantity as earlier explained. The other processing factors are kept constant as before.

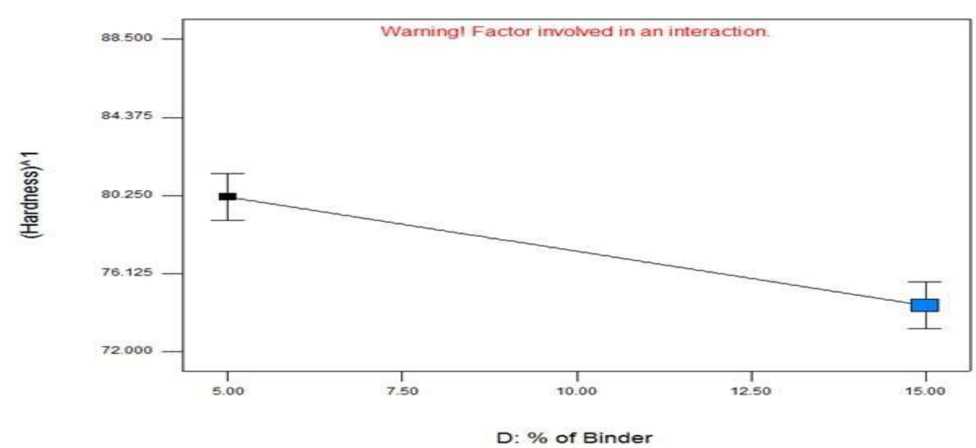


Figure 6: Graph of Hardness versus Binder Quantity

4. CONCLUSION

The following conclusion were reached from this study:

1. Hardness of carbon brush made from Coconut shell increases with increase in particle size and baking temperature.
2. Hardness of the carbon brush produced decreases as the moulding pressure and binder quantity increase.
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 hardness of carbon brush, each of this factors will have to be varied while others remain constant.

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