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Effect of Particle Size on the Performance Characteristics of Carbon Brush.

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ABSTRACT

Carbon brush function as life line of motor and generators and functions as both electrical and mechanical components in many machineries in which they are used. In order to enhance their functionality key parameters like resistivity, conductivity, bulk density, hardness and coefficient of friction of the carbon brush were used as performance characteristics and the effect of particle size of materials used in the production was examined. Palm Kernel Shell (PKS) was used as source of carbon in the production after addition of other materials like copper, zinc, silica etc. They were milled to three different particle sizes (125μm, 250μm and 350μm respectively) and the Taguchi experimental design was used to formulate the design process. Factors and responses were also determined using L16. The responses were measured on all the samples of brushes produced and analysed from Taguchi L16 orthogonal array using the experimental design. It was observed that increase in particle size causes an increase in hardness, friction coefficient, bulk density and resistivity, while the conductivity decreases with increase in particle size. Also interaction occurs with other factors like moulding pressure, baking temperature and quantity of binder. It was concluded that the particle size has effect on the performance of a carbon brush such as hardness, resistivity, bulk density, coefficient of friction and conductivity.

Keywords: Quenching, Mechanical Properties, Metals, Mild Steel, Copper & Stainless-Steel

1. INTRODUCTION

The particle size affects the electrical conductivity of carbon brushes and that of the crystalline. High anisometric of the particle shape leads to anisotropic behaviour of the electrical conductivity. Compressibility depends on particle size as well as on the crystalline. Parameters relating to texture of the particle do influence the compressibility and likewise some mechanical properties. The absorption behaviour of binder used in carbon brush is a property of particle size distribution, surface porosity, particle shape and surface tension between graphite and binder. With these properties, a correct selection of graphite helps to reduce the development time. Where there is a good process ability and constant quality of the final product, there will be a high consistency of the absorption properties of the powders used.

The grain sizing has effects on the carbon brush properties. Cure temperature had more influence on the properties of brushes than moulding pressure and grain size (*Xia et al., 2009*). Solberg (1927) said the calcined carbon is sized to about 200 mesh. The smoothness of the materials in the production is an important factor. Taguchi methods have proved to be successful over the last fifteen years or so for the improvement of product quality and process performance (Antony, 2001). 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 (Antony, 2001).

2. METHODOLOGY

2.1 Pyrolysis of the materials

The materials were dried in the Sun for five days to reduce the moisture and were later pyrolysed at a temperature of 500 ºC in a locally made furnace that has a maximum temperature range of 1500 ºC.

2.2 Grinding and sieving of pyrolysed materials

The pyrolysed Palm Kernel shell (PKS) was ground into powder and sieved into different particle size using sieve. The gain sizes used are 125µm, 250µm and 350µm respectively.

2.3 Calcination of the pyrolysed carbonaceous materials

In order to remove the remaining combustible material in the pyrolysed PKS, it was heated in a furnace under air tight crucible to a temperature of 1200 ºC. When the heating was carried out, fumes were coming out through the opening at the top of the furnace. In order to control the effect of the heating the temperature was set at a rate of 5 ºC per minute and heating continues until no more fumes were coming out again. When the fumes stopped it was further heated for five hours. The resulting product after the calcination is amorphous carbon.

2.4 Graphitisation of the pyrolysed carbonaceous materials

After the calcination of the amorphous material (PKS), it was placed in an airtight crucible for graphitisation. It was heated to temperature of 1000 ºC and 1500 ºC, kept constant for 5hours; 10hours, 15hours and 24hours with the application of constant pressure of 1.74kN being the maximum pressure allowed with the mould before it starts buckling. The application of pressure will also enhance the graphitisation of the materials. Pressure was applied due to limitation of getting a furnace with a temperature range up to 3000 ºC.

2.5 Selection of orthogonal array

The Taguchi Experimental Design (TED) was used to select the levels and runs for the experiment taking into consideration the cogent factors (variables) for the production of carbon brushes. Nine factors (variables) were considered for the experiment. This is because they were the major factors (variables). The experiment was categorized into two: L16 Orthogonal array (with five variables) and L9 Orthogonal array (with four variables)

2.6 L16 orthogonal array experiment

The major components of carbon brush are: carbon/ graphite, copper, lead, tin and silica. These were used as factors (variables) in L16 orthogonal array in order to optimize the material factors (variables) in the production of carbon brush.

Table 2.1: Factors and levels for L16 orthogonal array for the production of carbon brush

Factors (Parameter)	Symbol	Unit	Level 1	Level 2	Level 3	Level 4
Carbon	C	Ml	30	40	50	60
Copper	Cu	Ml	30	40	50	60
Zinc	Zn	Ml	2	3	5	7
Molybdenum disulphide (lubricant)	MoS_2	Ml	1	2	3	4
Silica powder	SiO_2	ml	1	2	3	4

In L16 orthogonal of Taguchi Experimental Design (TED), the processing factors (variables) - moulding pressure, baking temperature, particle sizes and binder quantity- were held constant and likewise the quantity of tin and silver.

Table 2.2: Factors distribution for each experiment in Taguchi L16 orthogonal array.

Experiment No	Carbon particle	% of Copper content	% of Zinc content	% of Lubricant	%of Silica powder
1	60	30	2	1	1
2	60	40	3	2	2
3	60	50	5	3	3
4	60	60	7	4	4
5	50	30	3	3	4
6	50	40	2	4	3
7	50	50	7	1	2
8	50	60	5	2	1
9	40	30	5	4	2
10	40	40	7	3	1
11	40	50	2	2	4
12	40	60	3	1	3
13	30	30	7	2	3
14	30	40	5	1	4
15	30	50	3	4	1
16	30	60	2	3	2

Digital Innovations
& Contemporary Research in
SCIENCE & ENGINEERING
Vol. 4 No. 3, Sept. 2016

2.7 L9 orthogonal array experiment

The optimum values in L16 were used in designing the L9 orthogonal array experiment. The processing variables- baking temperature, moulding pressure, particle sizes- were used as factors including binder quantity in L9 experiment.

Table 2.3: Factors and levels for L9 experiment.

Factors (Parameter)	Symbol	Unit	Level 1	Level 2	Level 3
Particle size	P	Mm	125	250	350
Moulding Pressure	Pm	Bar	100	200	250
Curing Temperature	Tc	ºC	150	180	210
Quantity of binder	Bq	%	5	10	15

Table 2.4: Experimental run for L9 Taguchi

Experiment No	Factor 1 Particle size	Factor 2 Tempt	Factor 3 Pressure	Factor 4 % of Biinder	Conductivity	Bulk density	Resistivity	Friction Coeff	Hardness
1	125	150	100	5					
2	125	180	200	10					
3	125	210	250	15					
4	250	150	200	15					
5	250	180	250	5					
6	250	210	100	10					
7	350	150	250	10					
8	350	180	100	15					
9	350	210	200	5					

The experiment was carried out in accordance with the table above.

2.8 Measurement of performance characteristics: conductivity, resistivity, bulk density, hardness and coefficient of friction of the carbon brush.

2.8.1 Measurement of performance parameters of the produced carbon brush

After the production of the carbon brush, the brush produced was machined to standard test specimen size of 10mm x 10mm x 64mm, according to IS 13584: 1993.The following test were carried out in accordance with IS 13584: 1993 specification.

2.8.2 Conductivity and resistivity test

The specimens were cut to standard sizes for measurement using multi-meter and the result tabulated. The conductivity (or specific conductance) of an object is a measure of its ability to conduct electricity while the resistivity is a measure of its ability to resist electricity flow in them. The resistivity of the carbon brush was obtained by measuring the resistance of the carbon brush using a multi-meter.

The conductivity, σ of brush was determined from the equations below;

$$\rho = \frac{RA}{L} \quad 2.1$$

$$\sigma = \frac{1}{\rho} \quad 2.2$$

ρ = resistivity in ohms-meter
R = resistance in ohms
A = contact area (i.e. breadth × thickness of brush)
L = length of brush in meter
σ = conductivity

2.8.3 Measurement of the coefficient of friction (static)

The sliding plane made of copper was used in measuring the coefficient of static friction.

The setup is as shown in figure. 2.1

From the mathematical expression for the coefficient of friction:

$$\text{Tan}\ \theta = \mu \quad 2.4$$

Where μ = coefficient of friction (static)

θ= angle of repose (i.e. angle at which brush just starts to slide).

The brush is placed on a plane surface and gradually tilted until the brush just starts to slide; the angle is noted and taken as θ from which the co-efficient of friction, μ can be calculated using Equ. 2.4 above. The sliding surface is made of copper which is same material as that of a commutator on which the brush is to operate.

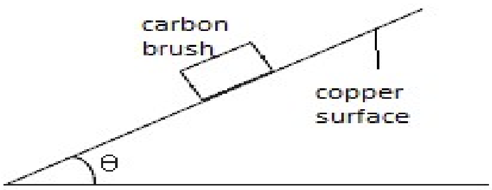

Figure. 2.1: The setup for the determination of the coefficient of friction

2.8.4 Bulk density measurement

The bulk density was measured by measuring the mass of the produced brush and the dimensions: length, breadth and height of the brush produced and the result was tabulated.

2.8.5 Hardness measurement

The samples produced from the L16 and L9 Taguchi experimental designs were taken to the Laboratory at The Polytechnic Ibadan for the measurement of hardness value and that of the commercial carbon brush. All readings were tabulated and analysed.

3. RESULTS AND DISCUSSIONS

3.1 Graph of hardness versus particle size in carbon brush produced

Figure 3.1 shows the one plot graph of hardness versus particle sizes. It shows that hardness of the carbon brush increases as the particle sizes increases. At a particle size of 125µm mesh the hardness value is 74.497 Kg and 80.103 Kg at 350µm mesh. This shows that for higher hardness value, the particle size should be large. Hardness is not the predominant factors to predict performance of carbon brush, therefore optimality is required (Jeff, 1993). There is interaction between particle size and quantity of binder (as shown in figure 3.3). At 125µm mesh of particle size and 5ml of binder, hardness is 72.7049 Kg, and at 350µm mesh of particle size and 15ml of binder, hardness is 72.5815 Kg. This has a resulting effect on the hardness of carbon brush. At 125µm mesh of particle size and 15ml of binder, hardness is 76.289 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 72.7049 Kg, 87.6236 Kg and 72.5815 Kg respectively. It was observed that hardness value decreases from 76.289 Kg to 72.7049 Kg as the binder quantity decreases from 15ml to 5ml at constant particle size of 125µm mesh.

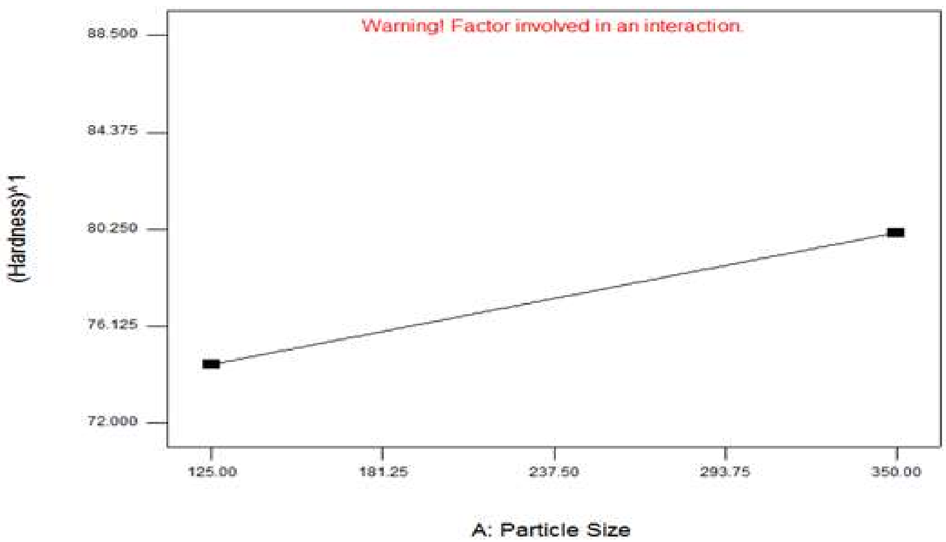

Figure 3.1: Graph of Hardness versus Particle size

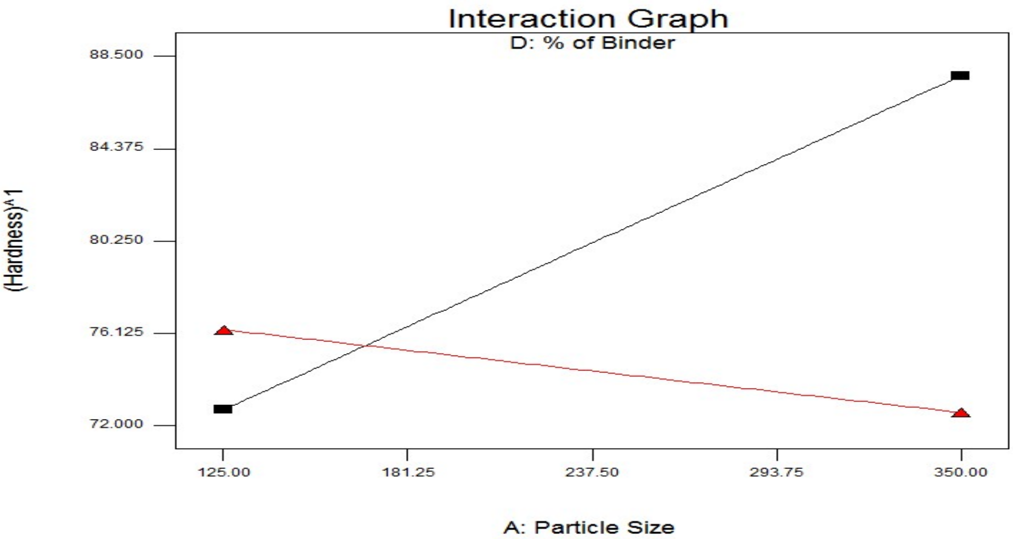

Figure 3.2: Graph of interaction of particle size and binder quantity and its effect on hardness.

3.2 Graph of coefficient of friction versus particle size in carbon brush production

The graph of figure 3.3 depicts the relationship between coefficient of friction and particle size in the production of carbon brush. The graph is not linear, but parabolic, this is an indication that the correlation between them is not linear. At 125µm mesh the coefficient of friction is 0.512456 and 0.571251 at particle size of 350µm mesh. This shows that as the particle sizes increase the friction coefficient increases, meaning the fineness of the particles will definitely cause a reduction in friction coefficient. Moulding pressure sum up to the effect of particle size on friction coefficient as there is interaction between them as shown in figure 3.4.

Also when the processing factors are 125µm mesh particle size and 250 Bar, 350µm mesh and 250 Bar, and 350µm mesh and 100 Bar, coefficient of friction are 0.547894, 0.626658 and 0.515848 respectively. It can be concluded that at constant particle size, with other factors still held constant, an increase in moulding pressure from 100 Bar to 250 Bar causes a reduction in friction coefficient. A contrary result was obtained at constant particle size of 350µm, the friction coefficient reduces when the moulding pressure falls from 250 Bar to 100 Bar. The coefficient of friction is 0.626658 and 0.515848 respectively. This is an indication of how changes in these process factors affect the carbon brush properties.

Digital Innovations
& Contemporary Research in
SCIENCE & ENGINEERING
Vol. 4 No. 3, Sept. 2016

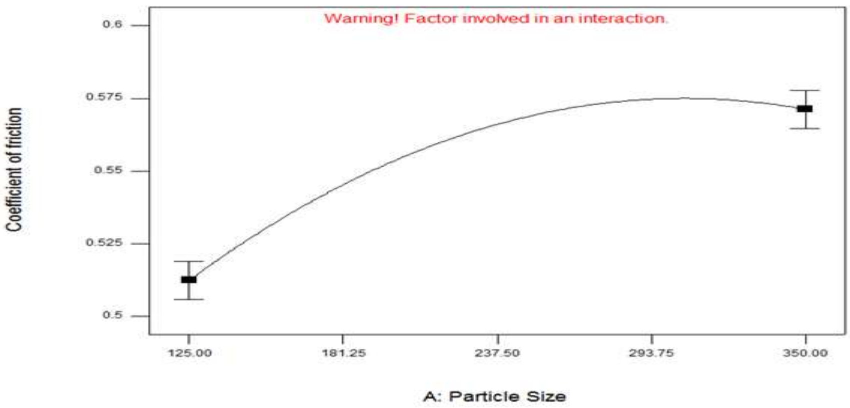

Figure 3.3: Graph of coefficient of friction with particle size

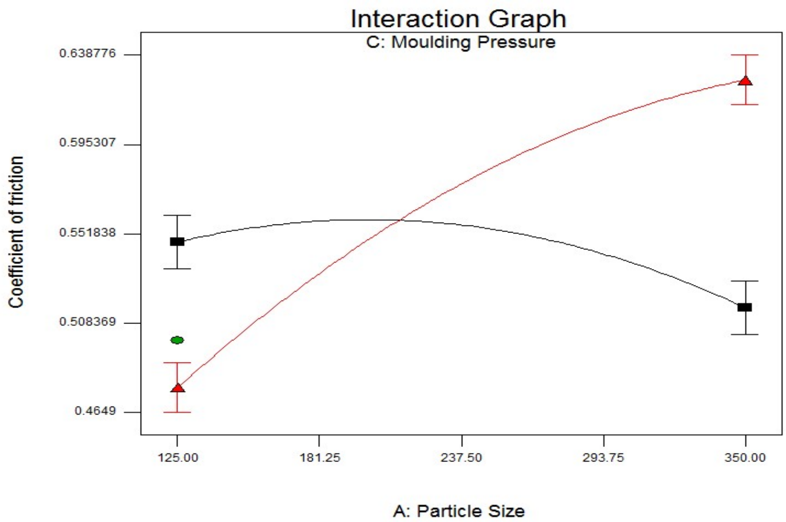

Figure 3.4: Graph of interaction between particle size and moulding pressure and their effect on coefficient of static friction.

3.3 Graph of bulk density versus particle size in the produced carbon brush.

Figure 3.5 shows the relationship between the bulk density and the particle size. The graph shows that bulk density increases with increase in particle sizes of the materials used in the production of carbon brush. At particle size of 125µm mesh, the bulk density is 1.55867 kg/cm^3 and 2.28605kg/cm^3 at 350µm mesh of particle size. It is observed that baking temperature added to the effect of particle size on bulk density, this is displayed in figure 3.6.

At 125 µm mesh of particle size and 210 ºC of baking temperature , 350 µm mesh of particle size and 210 ºC of baking temperature, and 350 µm mesh of particle size and 150 ºC of baking temperature, the bulk density are 0.642468 g/cm^3, 3.02879 g/cm^3 and 1.54331 g/cm^3 respectively. This result shows that at constant 125µm mesh of particle size, increase in baking temperature from 150 ºC to 210 ºC, causes the bulk density to decrease from 2.47488 g/cm^3 to 0.642468 g/cm^3.

But at constant 350 µm mesh of particle size, an increase in baking temperature from 150 ºC to 210 ºC shows an increase in bulk density from 1.54331 g/cm^3 to 3.02879 g/cm^3. Also, at constant temperature of 150 ºC, an increase in particle size from 125µm mesh to 350µm mesh shows a decrease from 2.47488 g/cm^3 to 1.54331g/cm^3.

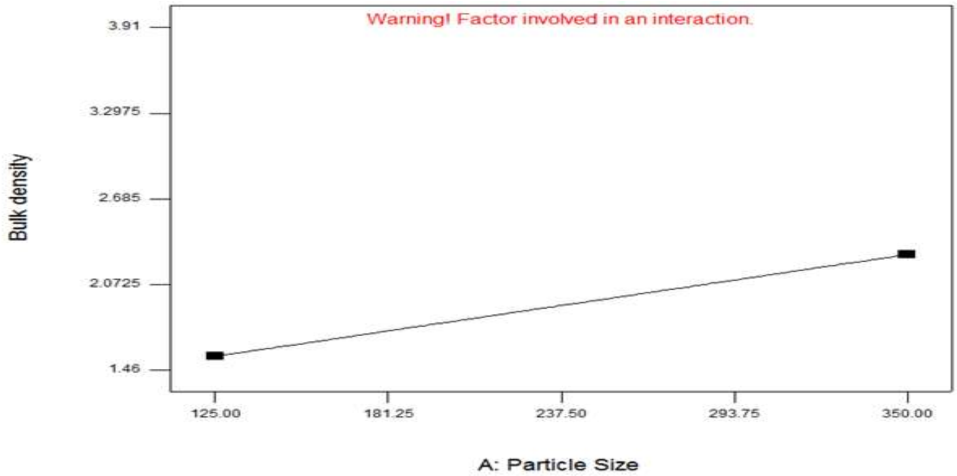

Figure 3.5: Graph of bulk density to particle size in the production of carbon brush.

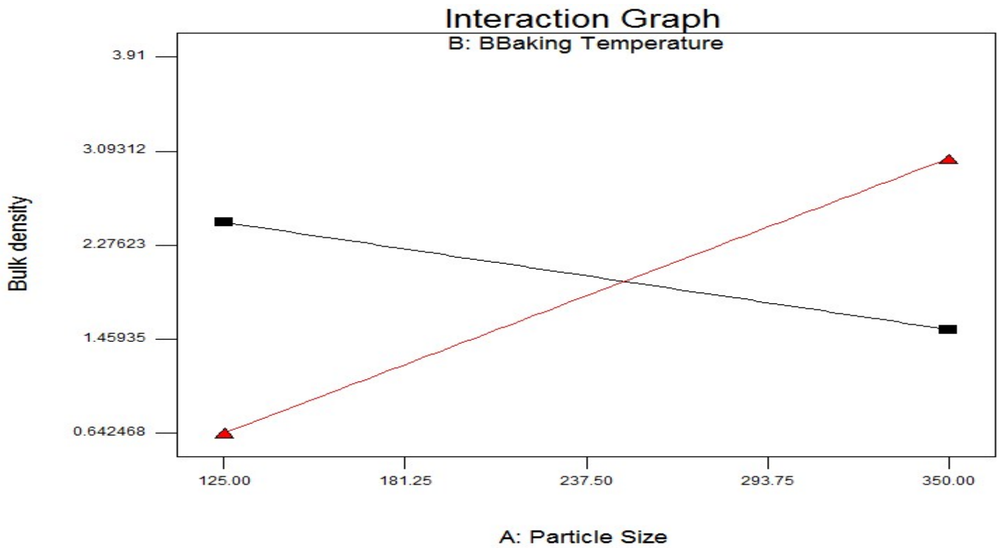

Figure 3.6: Graph of interaction between particle size and binder and their effect on bulk density of the carbon brush.

3.4 Graph of resistivity versus particle size in the production of carbon brush.

The graph of figure 3.7 shows the relationship between resistivity and the 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. Baking temperature also sum up to the effect of particle size on the resistivity of carbon brush, see figure 3.8.

The interaction between particle size and baking temperature, shows that the resistivity of carbon brush is affected by these factors. At 125µm particle size and 150 ºC baking temperature the resistivity is 7.61858Ωcm. At other design point of 125µm mesh particle size and 150 ºC , 350 µm mesh particle size and 210 ºC, and 350 µm mesh of particle size and 150 ºC, the resistivity are 7.1007 Ωcm, 9.49181 Ωcm and 8.10645 Ωcm respectively. It is observed that at constant 125 µm mesh particle size, when the temperature increase from 150 ºC to 210 ºC the resistivity decreases from 7.61858Ωcm to 7.1007Ωcm. Also at constant particle size of 350 µm mesh, when temperature decreases from 210 ºC to 150 ºC, the resistivity reduces from 9.49181 Ωcm to 8.10645 Ωcm, which is contrary to the result at constant 125 µm mesh particle size. This shows how a small change in these factors affects the resistivity of carbon brush. At this point the moulding pressure and binder quantity remain constant.

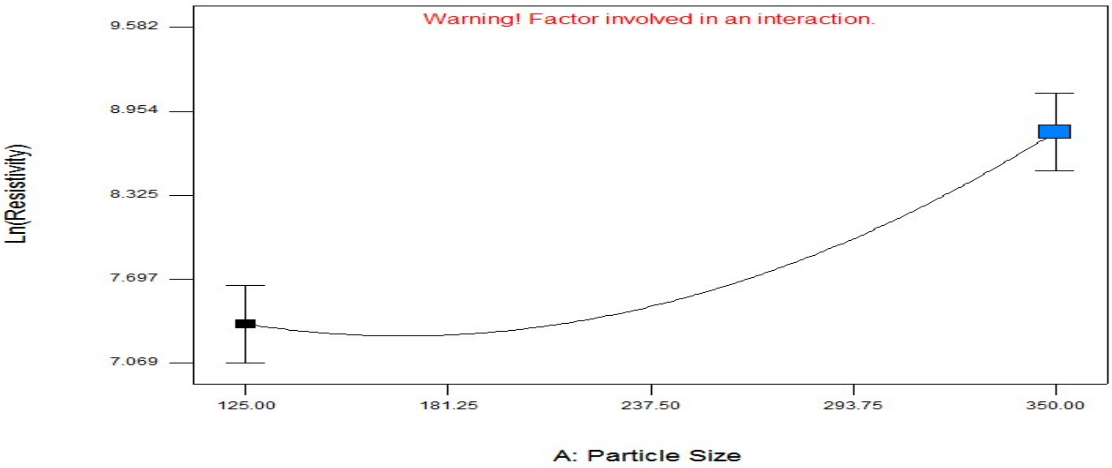

Figure 3.7: Graph of resistivity versus particle size in the carbon brush

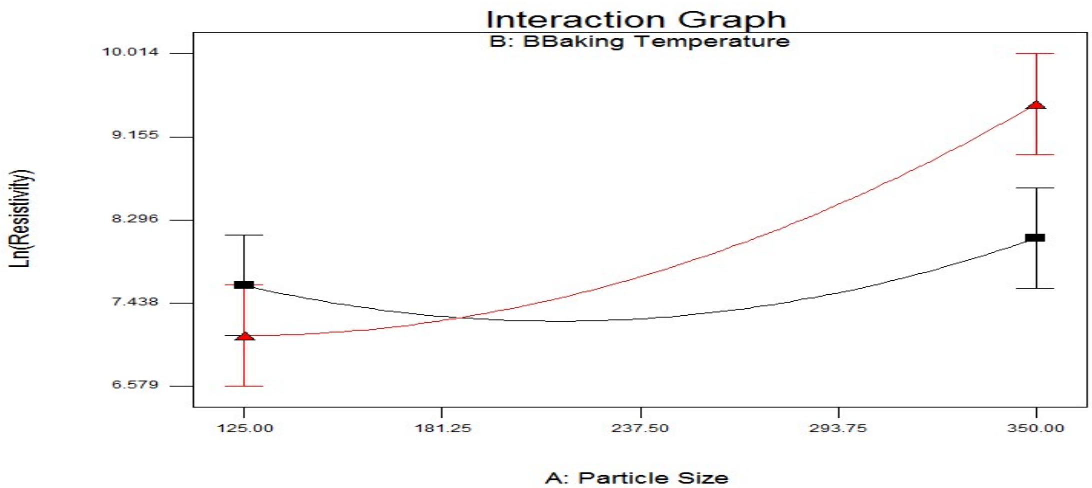

Figure 3.8: Graph of interaction between particle size and baking temperature and their effect on resistivity.

3.5 Graph of conductivity versus particle size in the carbon brush

Figure 3.9 below, depicts the variation of conductivity with particle size. The graph is parabolic in nature and shows that as the particle size increases the conductivity decreases. At 124µm mesh and 350 µm mesh of particle size, the conductivity is 0.023$(\Omega cm)^{-1}$ and 0.015 $(\Omega cm)^{-1}$ respectively. This occurred at constant baking temperature, moulding pressure and binder quantity of 180 ºC, 175Bar and 10ml of binder quantity respectively. It can be inferred that the finer the particle size the greater the conductivity in the carbon brush.

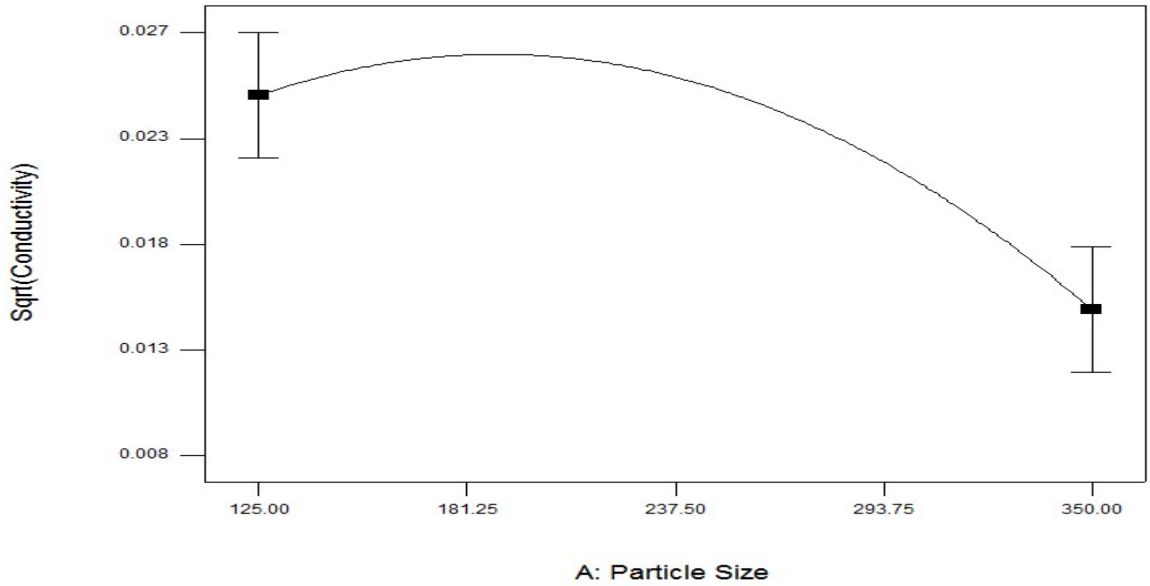

Figure 3.9: Graph of conductivity to particle size.

4. CONCLUSION

An increase in particle size of the carbon brush causes increase in hardness, coefficient of friction, bulk density and resistivity, but leads to decrease in conductivity. It should be noted that effect of interaction among most of the factors cannot be ignored.

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