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PERFORMANCE EVALUATION OF ABRASIVE GRINDING WHEEL FORMULATED FROM LOCALLY SOURCED MATERIALS

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Abstract
This paper presents a study on the formulation and manufacture of abrasive grinding wheel using locally formulated silicon carbide abrasive grains. Six local raw material substitutes were identified through pilot study and with the initial mix of the identified materials, a systematic search for an optimal formulation of silicon carbide, the intermediate product, was conducted using the Taguchi method. The mixture was fired in a furnace to 1800°C for 6 hours forming silicon carbide chunks, which were crushed and sieved into abrasive grains that were used to produce the grinding wheels. These locally manufactured grinding wheels were further subjected to some mechanical tests and the test results show that they conform within the range of values specified in the international standard handbook.

Keywords: Formulation, Grinding wheel, Local Raw Materials, Silicon Carbide, Taguchi Method.

1. Introduction

Abrasive materials are materials of extreme hardness that are used to shape other materials by a grinding or abrading action and they are used either as loose grains, as grinding wheels, or as coatings on cloth or paper. A grinding wheel is made of very small, sharp and hard silicon carbide abrasive particles or grits held together by strong porous bond. Abrasive materials are processed in a furnace after which they can further be pulverized and sifted into different grain sizes called grits [1, 2]. The most important physical properties of abrasive materials are; hardness, brittleness, toughness, grain shape and grain size, character of fracture, purity and uniformity of the grains [3]. They are generally used for grinding, honing, lapping, and super finishing. Abrasive materials are classified into two groups, natural and synthetic abrasive materials and except for diamonds, manufactured abrasives have almost totally replaced natural abrasive materials.

Natural abrasive materials are those materials that are found existing naturally and are used for the manufacture of abrasive grains and among the important natural abrasive materials include; aluminosilicate mineral, feldspar, calcined clays, lime, chalk and silica, flint, kaolinite, diatomite and diamond, which is the hardest known natural material [4–6]. While synthetic abrasive materials are those abrasive materials that are usually manufactured, and their qualities and compositions can easily be controlled and they include: silicon carbide, aluminium oxide and Cubic Boron Nitride (CBN) [7- 9].

The art of grinding dates back to many centuries, since man first discovered that he could brighten up and sharpen his tools by rubbing them against certain stones or by plunging them into sand several times. The emery stone appeared when man found that the softer sand stone did not work well on the newly discovered harder materials [10]. By the early nineteenth century, emery (a natural mineral containing iron and corundum) was used to cut and shape metals. Acheson discovered silicon carbide in 1891, while he was attempting to manufacture precious gems in an electric furnace, and a few years later, Jacob developed aluminium oxide from claylike mineral bauxite. Also, in 1897, Pulson made the first grinding wheel by combining emery with potter's clay and firing it in a kiln. He noted that emery was a natural abrasive of non-uniform texture, so its quality as a grinding wheel varied greatly [10]. However, emery's variable quality and problems with importing it from India prior to its discovery in the United States prompted efforts to find a more reliable abrasive mineral. By the 1890s, the search had yielded silicon carbide, a synthetic abrasive mineral harder than corundum [11]. Silicon carbide abrasive is manufactured in an Acheson graphite electric resistance furnace charged with a mixture of approximately 60 percent silica sand and 40 percent finely ground petroleum coke. A small amount of saw dust is added to the mix to increase its porosity so that the carbon monoxide gas formed during the process can escape freely. Common salt is also added to the mix to promote the carbon-siliconreaction and to remove impurities in the sand and coke. The mixture is heated in an Acheson graphite electric resistance furnace to temperature of within the range 1800^{o}C to 2200^{o}C, at which point a large portion of the mix crystallizes to form silicon carbide abrasives [12]. Silicon carbide which is formed in the Acheson furnace varies in purity, according to its distance from the graphite resistor heat source. Colorless, pale yellow and green crystals have the highest purity and are found closest to the resistor. The color changes to blue and black at greater distance from the resistor, and these darker crystals are less pure [13, 14].

The use of local substitutes as alternatives to imported raw materials is very important to the rapid growth of economy of our nation and this was also demonstrated by Otunyo and Tyaghera et al. [15, 16]. Abrasives and grinding wheels may be acquired in Nigeria either through importation or manufacturing. Acquiring abrasives in Nigeria through importation may be hindered due to the increase in foreign currency exchange rates and high import duty rates. These limitations make the procurement of abrasives very expensive and as a result, the feasible alternative for acquiring abrasives for grinding wheels in Nigeria is to manufacture them locally. Therefore, local manufacture of abrasives and grinding wheels for our various industries using locally sourced raw materials and the performance evaluation of the produced abrasive grinding wheels is the aim of this research work.

2. Materials and Method

The various component materials used for the production of ISO certified grinding wheels include: silica sand, petroleum coke, sawdust and sodium chloride [12]. Some of these raw materials are either not available locally in Nigeria or are very unstable. A pilot study was therefore conducted on various raw materials to identify suitable local material substitutes for the ISO certified grinding wheels materials. Quartz was found to be suitable as core material due to its purity and availability and they were crushed and sieved for our formulation. Coal was selected as reactant material due to its suitability and availability in Nigeria, while rubber latex bond was also selected because it is locally available in abundant quantity in Nigeria.

2.1. Experimental design for the formulation of silicon carbide abrasives

The levels of raw materials for the formulation of silicon carbide abrasives after several trial formulations are given in Table 1. The codes "a" to "e" are quantities of materials at medium-level settings, while the high-level and low-level settings are shown in first and last columns respectively. Taguchi method of experimental design orthogonal array L9(3^4) was used to develop the factor levels for the silicon carbide abrasive manufacturing parameters as presented in the Table 2.

Table 1: Components for the Formulation of Silicon Carbide Abrasives.

S/No	Material	High Level	Medium Level	Low Level
1	Quartz	a + 4	"a"	a – 4
2	Coal	b + 3	"b"	b – 3
3	Sodium Carbonate	c + 3	"c"	c – 3
4	Sawdust	d + 2	"d"	d – 2
5	Sodium Chloride	e + 2	"e"	e – 2

Table 2.Experimental design layout using Taguchi orthogonal array $L_9(3^4)$.

	$L_9(3^4)$				A	B	C	D
Factors	A	B	C	D	Melting	Melting	Baking	Baking
Exp.	1	2	3	4	temp. (T_m)	time. (Ti)	temp. (T_b)	time (t_b)
1	1	1	1	1	1650°C	4hrs	150°C	1hr
2	1	2	2	2	1650°C	6hrs	200°C	2hrs
3	1	3	3	3	1650°C	8hrs	250°C	3hrs
4	2	1	2	3	1800°C	4hrs	150°C	1hr
5	2	2	3	1	1800°C	6hrs	200°C	2hrs
6	2	3	1	2	1800°C	8hrs	250°C	3hrs
7	3	1	3	2	1950°C	4hrs	150°C	1hr
8	3	2	1	3	1950°C	6hrs	200°C	2hrs
9	3	3	2	1	1950°C	8hrs	250°C	3hrs

Table 3.Formulation of silicon carbides by varying each material constituent.

Major Experi-ment	Varied Compo-nents	Formulation at Each Experimental Stage (Proportion by Weight (gm))										Hardness Value (KN/mm^2)
		1	2	3	4	5	6	7	8	9	10	
1	Quartz	40	45	50	55	60	65	70	75	80	85	0.35
2	Coal	15	20	25	30	35	40	46	50	55	60	0.38
3	Na_2CO_3	2	5	7	10	15	20	23	25	27	30	0.45
4	Sawdust	0.3	0.5	0.7	0.8	1.0	1.2	1.4	2.2	2.6	3.0	0.48
5	NaCl	0.1	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.8	0.52

(a) Silicon carbide abrasives (b) An enlarged abrasive chuck (c) Silicon carbide abrasive grains

Figure 1. A Sample of produced silicon carbide abrasives and abrasive grains

Table 4: Factor Levels for Manufacturing Parameters

Factor:	Low Level	Medium Level	High Level
Melting Temperature	1600 °C	1800°C	1950°C
Melting Time	4hrs	6hrs	8hrs
Moulding Pressure	10.25	15.75	20.25MPa
Baking Temperature	150 °C	200 °C	250°C
Baking Time	1hr	2hrs	3hrs

Figure 2. A sample of manufactured grinding wheels (big and small)

2.2. Formulation and manufacture of silicon carbide abrasives

Formulation of silicon carbide abrasives involves five major experiments, running ten formulations at each experimental stage to determine the optimum mix for silicon carbide formulation. The optimum result for our formulation gives 65gm of quartz, 35 gm of coal, 10 gm of sodium carbonate, 0.7 gm of sawdust and 0.3 gm of sodium chloride as presented in Table 3.

The silicon carbide abrasives were manufactured using a pit furnace which was charged with formulated mix ofQuartz (59%),Coal (32%),Sodium carbonate (8%),Sawdust (0.7%) and Sodium chloride (0.3%) at a temperature of 1800^{0}C for 6 hours. The mixture was regularly poked for proper and homogeneous melting and a sample of manufactured silicon carbide abrasives and the abrasive grains are presented in Figure 1.

2.3. Formulation and manufacture of abrasive grinding wheel

The grinding wheels were formulated and manufactured using the produced silicon carbide abrasive grains and natural rubber latex binding material. The wheels were manufactured by the cold-press method with compression moulding process, in which a mixture of the grains and paste was pressed into shape at room temperature using the moulds which were locally fabricated using a mild steel material. A summary of Taguchi orthogonal arrays which was used to develop the factor levels for the silicon carbide abrasive and grinding wheel manufacturing parameters is presented in Table 4. The moulded wheels were baked in a fabricated oven at a temperature of 200^{o}C for 2 hoursallowed to cool to room temperature to obtain hard wheels of international standard as presented in Figure 2.

3. Results and Discussion

The hardness values for a sample of produced grinding wheels and a sample of commercial grinding wheels were obtained as presented in Table 5. These values were obtained using the hardness testing machines. It was observed that the obtained values for the produced wheels were quite close to those of the commercial wheels. The wheel grinding ratios are usually on the order of 5 or higher for ISO wheels to over 60,000 when internally grinding bearing races using cubic boron nitride abrasive wheels [17, 18].

The grinding ratios were obtained as follows; Each of the manufactured fine and coarse grinding wheels was used to grind a mild steel material for 15 minutes machining time. The weights of wheels and workpiece before and after each machining operation were recorded and the results were used to estimate the wheel grinding ratios and a sample is presented in the Table 6. The wheel grinding ratios and wheel wear for each sample of commercial and manufactured grinding wheels are presented in Table 7.

Table 5. Grinding wheel hardness values

Wheel Sample	Wheel Hardness. (KN)	
	Commercial	Produced
1.	0.7081	0.6595
2.	0.7178	0.7048
3.	0.7481	0.6624
4.	0.7178	0.6599
5.	0.6822	0.6822
6.	0.7237	0.7113
7.	0.7342	0.6695
8.	0.6894	0.6750
9.	0.7120	0.7000
10.	0.6937	0.6694
Mean	0.7127	0.6794

Table 6: Computation of Grinding Ratios for Fine and Coarse Wheels.

S/No.	Material	Weight of Material in (gm)			Grinding Ratio (G_r).
		Initial weight	Final Weight	Change in Weight	
01	Laboratory Fine Wheel	1030	1027.80	2.20	28.37
02	W/P for Lab. Fine Wheel.	2150	2087.59	62.41	
03	Laboratory Coarse Wheel	1010	1007.49	2.51	23.70
04	W/P for Lab. Coarse Wheel	2150	2090.27	59.73	

Table 7. Grinding wheel wear and wheel grinding ratio

Wheel Sample	Wheel Wear (μm)		Wheel Grinding Ratio	
	Commercial	Produced	Commercial	Produced
1.	2.07	2.51	28.37	23.70
2.	2.09	2.50	28.98	22.50
3.	2.11	2.52	29.05	24.88
4.	2.09	2.59	28.15	23.90
5.	2.12	2.46	29.25	23.50
6.	2.17	2.66	28.32	22.57
7.	2.20	2.59	29.35	23.07
8.	2.18	2.57	29.35	24.10
9.	2.13	2.58	29.44	23.66
10.	2.22	2.61	29.45	24.12
Mean	2.14	2.56	28.97	23.80

Table 8: Signal to noise ratios for wheel hardness and wheel wear

Wheel Sample	Signal to Noise Ratio			
	Wheel Hardness		Wheel Wear	
	Commercial	Produced	Commercial	Produced
1.	57.000	56.137	-6.319	-7.993
2.	57.122	56.110	-6.403	-8.062
3.	57.314	56.151	-6.403	-8.062
4.	56.391	56.151	-6.486	-8.131
5.	56.676	56.191	-6.527	-8.165
6.	57.195	56.110	-6.649	-8.165
7.	56.521	56.124	-6.649	-8.232
8.	56.586	56.178	-6.769	-8.232
9.	56.902	56.124	-6.848	-8.266
10.	56.312	56.096	-6.927	-8.299
Mean	56.802	56.137	-6.598	-8.161

3.1. Signal to noise ratios

Signal to noise ratios are measures employed by Taguchi to minimize deviation from target in a process output that incorporate both the location of the output as well as the variation. The signal to noise ratio provides a measure of the impact of noise factors on performance. The larger the signal to noise ratios (S/N), the more robust the product is against noise. This implies for example, the larger the hardness value of the grinding wheel the better, since it will be able to cut other metals successfully. Similarly the smaller the wear value of the grinding wheel the better for it, since it will also be able to cut other metals successfully without wearing away rapidly..

The Signal to noise ratio values are computed as follows:

(a) Signal to noise ratios for Larger-the-Better

$$\frac{S}{N_{(Larger)}} = -10\log\left(\frac{\sum\left(\frac{1}{y_i^2}\right)}{n}\right) \quad (1)$$

(b) Signal to noise ratios for Smaller-the-Better

$$\frac{S}{N_{(Smaller)}} = -10\log\left(\frac{\sum y_i^2}{n}\right) \quad (2)$$

The signal-to-noise ratios by Taguchi were computed for wheel hardness and wheel wear values using the larger-the-better method for the wheel hardness and the smaller-the-better method for the wheel wear and the results are presented in Table 8. It is clearly seen that the values obtained for the commercial grinding wheels and the produced grinding wheels are quite close.

4. Conclusion

Six local raw material substitutes for the formulation and manufacture of grinding wheel were identified from pilot study and they include: quartz, coal, sodium carbonate, sawdust, sodium chloride and rubber latex.A small amount of sawdust was added to the mix to increase the porosity of the mix and to enable the carbon monoxide gas formed during the process escape freely. Sodium chloride was also added to the mix to promote the carbon-silicon reaction and to remove any remaining impurities in the quartz and coal. An optimal formulation of the intermediate product through systematic search using Taguchi method was accomplished while the formulationof silicon carbide abrasive grains and the manufacture of the grinding wheels were successfully achieved.

The wheel hardness values, the wheel wear values and the values of the wheel grinding ratios obtained for the commercial and produced grinding wheels were found to be quite close. Also, the values of the signal to noise ratios for wheel hardness for both types of wheels were found to be positive which agreed with Taguchi "the larger-the-better" while those for the wheel wear for both types were also found to be negative which agreed with Taguchi's "the smaller-the-better".

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