Formulation of Silicon Carbide Abrasives from Locally Sourced Raw Materials in Nigeria

A. O. Odior and F. A. Oyawale

***Abstract*— 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. The manufacture of abrasives in Nigeria has been severely impeded by the difficulty of identifying suitable local raw materials and the associated local formulation for abrasives with global quality standards. This paper presents a study on the formulation and manufacture of silicon carbide abrasives using locally sourced raw materials in Nigeria. Five 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 abrasives was conducted using Taguchi method. The mixture was fired in a furnace to 1600°C for 6 hours forming silicon carbide chunks, which were crushed and sieved into coarse and fine grades of abrasive grains of international standard.**

Index Terms— **Local formulation, Local raw material, Pilot study, Silicon carbide abrasives, Taguchi Method.**

I. Introduction

Abrasive materials are very hard mineral materials used to shape, finish, or polish other materials. The abrasive materials are processed in a furnace after which they can further be pulverized and sifted into different grain sizes called grits [7], [8]. 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 [9]. There are two common types of abrasive materials include are natural abrasive materials and synthetic 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 [3], [2], [4]. Corundum and emery have long been used for grinding purposes and both are made up of crystalline aluminium oxide in combination with iron oxide and other impurities, [1]. The use of natural abrasive materials goes back to early man who used them to sharpen his tools. Early man shaped weapons and tools by rubbing them against hard and rough stone. Pictographs also show ancient Egyptians using natural abrasive stones to polish pottery and jewelry [10]. Impurities in the natural abrasive materials make them less effective. As a result of this and with advancement in technology, man began to search for better alternative abrasive materials and the search led to the discovery of synthetic abrasive material by Acheson in 1891.

Synthetic abrasive materials are those abrasive materials that are usually manufactured, and their qualities and compositions can easily be controlled. An important characteristic of the synthetic abrasive materials is their purity which has an important bearing in their efficiency [1], [11]. The most commonly used synthetic abrasive materials include silicon carbide, aluminium oxide, Cubic Boron Nitride (CBN), while aluminium oxide and silicon carbide are the most common mineral in use today, [13].

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-silicon reaction and to remove impurities in the sand and coke. The mixture is heated in an Acheson graphite electric resistance furnace to temperature of about 1800°C to 2200°C, at which point a large portion of the load crystallizes to form silicon carbide abrasives [5].

Abrasives for grinding wheels may be acquired in Nigeria either through importation or by manufacturing. Acquiring abrasives in Nigeria through importation may be hindered due to lack of foreign currency and this may not be profitable. Therefore, the feasible alternative for acquiring abrasives for grinding wheels in Nigeria is to manufacture them locally and in this case, foreign firms may have to establish in Nigeria but the literature is sparse on such establishment. Therefore, Nigerians need to manufacture their abrasives directly and to do this; Nigerians need to go abroad for training to acquire the relevant skills. However, from experience, such individuals are handicap because using local raw materials with foreign formulations could not yield abrasives of international standard. Therefore, the need for local manufacture of abrasives for grinding wheels for our

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various industries using locally sourced raw materials with local formulations is the aim of this research work.

II. MATERIALS AND METHOD

The various component materials used for the production of ISO certified silicon carbide abrasives include: silica sand, petroleum coke, sawdust and sodium chloride, [5]. Some of these raw materials are either not available locally in Nigeria or are very unstable. Attention was therefore focused at discovering local substitutes for these raw materials for use in the formulation and manufacturing of silicon carbide abrasives. A pilot study was therefore conducted on various raw materials to identify suitable local material substitutes.

A. Pilot Study of Raw Materials for Silicon Carbide Abrasives

A pilot study was conducted on river white sand and quartz as core materials. The river sand was found to contain some contaminants which made it unsuitable for the work and quartz was found to be suitable for the work due to its purity and availability and it was therefore selected. A pilot study was also conducted on charcoal, snail shell, coal and petroleum coke as reactants. Charcoal was found to be unsuitable due to its porosity and high melting temperature of 3550^{o}C. snail shell was also not suitable due to its low carbon content which failed to form carbide during the test formulation. Petroleum coke and coal were found to be quite suitable for use as reactants but petroleum coke is not readily available in Nigeria, hence coal was chosen as reactant in the formulation. The other materials which are catalysts include: sodium carbonate, sawdust and sodium chloride. These materials are readily available in Nigeria, hence they were selected. Acheson graphite electric resistance furnace was not available and a local pit furnace was used for melting with sodium carbonate added to drop the melting temperature.

B. Experimental Design and Material Formulation

Taguchi developed a new method of conducting the design of experiment, which uses a set of arrays referred to as orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter [6], [12]. Taguchi method was used in our experimental design for the factor levels for grinding silicon carbide abrasives manufacturing parameters as presented in Table 1, while Taguchi experimental design orthogonal array L9(3^4) was used to develop the factor levels for the manufacturing parameters for silicon carbide abrasives and grinding wheels as presented in Table 2.

The result from the experimental design in Table 2 gives the melting temperature to be 1600^{o}C while the melting time is 6 hours. The levels of raw materials for formulation of silicon carbide abrasives after several trial formulations are given in Table 3. 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.

A. Formulation 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 4.

III. MANUFACTURE OF SILICON CARBIDE ABRASIVE CHUNKS

In the manufacture of silicon carbide abrasives, a pit furnace was charged with formulated mix of Quartz (58.56%), Coal (31.53%), Sodium carbonate (9.01%), Sawdust (0.63%) and Sodium chloride (0.27%) at a temperature of 1600^{0}C for 6 hours. Figure 1 presents the percentage proportions of raw materials in the formulation.

The mixture was regularly poked for proper and homogeneous melting and the melted silicon carbide crystals in crucible pots are presented in Figure 2, while a sample of manufactured silicon carbide abrasives is presented in Figure 3.

The produced abrasive crystals were properly crushed with a hammer and a fabricated metal mortar and sieved with 600 m mesh into fine grains while 1180 m was used to sieve coarse grains as presented in Figure 4.

The summary of abrasive grains manufacturing process is presented in Figure 5.

IV. CONCLUSION

Five local raw material substitutes for the formulation and manufacture of silicon carbide abrasives were identified from pilot study and they include: quartz, coal, sodium carbonate, sawdust and sodium chloride. An optimal formulation of silicon carbide abrasives through systematic search using Taguchi method was accomplished while the formulation and manufacture of silicon carbide abrasive chunks was successfully achieved. Manufacturing process for silicon carbide abrasives was developed, while the formulation and manufacture of silicon carbide abrasives using locally fabricated equipment was successfully accomplished. The produced silicon carbide abrasive chunks were crushed and sieved into fine and coarse graded silicon carbide abrasive grains of international standard.

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Table 1. Factor levels for manufacturing parameters.

Factor:	Low level	Medium level	High level
Melting temperature	1400°C	1600 °C	1800°C
Melting time	4hrs	6hrs	8hrs

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 Temp. (T_m)	Melting Time. (Ti)		
Exp.	1	2	3	4				
1	1	1	1	1	1400°C	4hrs		
2	1	2	2	2	1400°C	6hrs		
3	1	3	3	3	1400°C	8hrs		
4	2	1	2	3	1600°C	4hrs		
5	2	2	3	1	1600°C	6hrs		
6	2	3	1	2	1600°C	8hrs		
7	3	1	3	2	1800°C	4hrs		
8	3	2	1	3	1800°C	6hrs		
9	3	3	2	1	1800°C	8hrs		

Table 3. 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 4. Formulation of silicon carbides by varying proportion each material constituent

Major Experi-ment	Varied Components	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

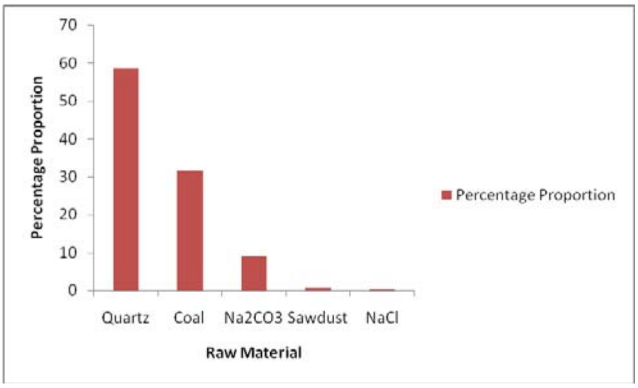
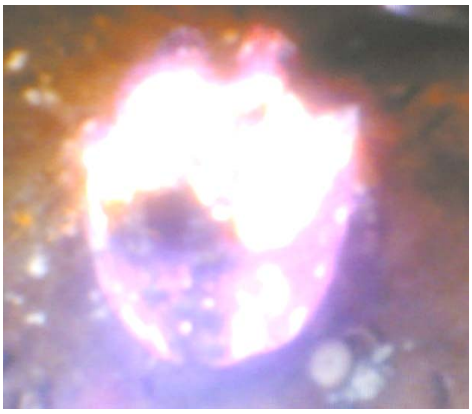


Figure 1: Percentage Proportions of Raw Materials in the Formulation

(a) Very hot melt



(b) warm melt

Figure 2: The melted abrasives in crucible pot

(a) Silicon carbide abrasives

(b) An enlarged abrasive chuck

Fig. 3: The Produced Silicon Carbide Abrasives.

(a). Fabricated metal mortar

(b). Fine abrasive grains

(c). Coarse abrasive grains

Figure 4: Samples of produced abrasive grains with fabricated metal mortar

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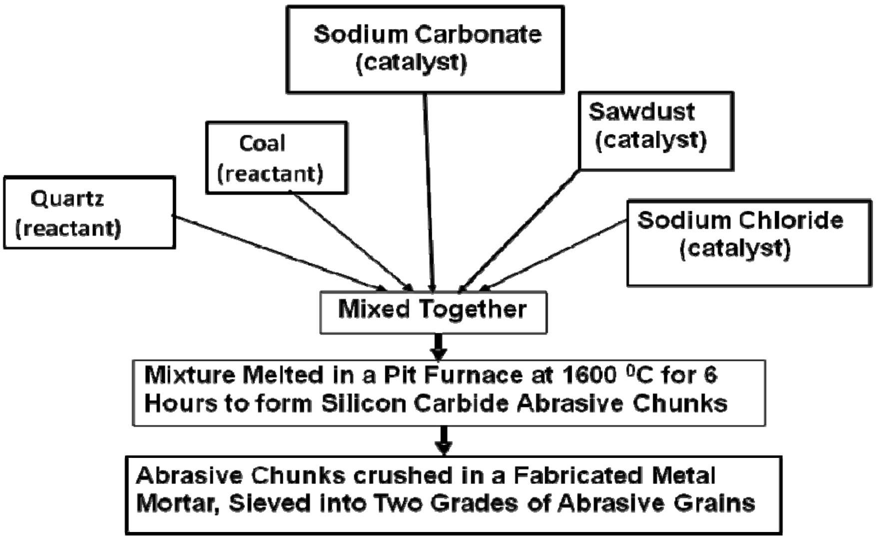

Fig. 5: Schematic Diagram for the Manufacture of Abrasive Grains

References

[1] N. Arunachalam and B. Ramamoorthy, "Texture Analysis for Grinding Wheel Wear Assessment Using Machine Vision", *Journal of Engineering Manufacture,* vol. 221(3), 2007, pp. 419-430.

[2] J. N. Brecker, "Analysis of Bond Formation in Vitrified Abrasive Wheels", *Journal of the American Ceramic Society*, vol. 57(11), 2006, pp. 486-489.

[3] A. C. Clark, A. J. Shih, C.W. Hardin, R.L. Lemaster, and S. B. McSpadden, "Fixed Abrasive Diamond Wire Machining, Part1. Process Monitoring and Wire Geometry and Tension", *International Journal of Machine Tools and Manufacture,* vol. 43(27), 2003, pp. 523-532.

[4] U. Eckart, S. Frank, and H. Christoph, "Economical Aspects of Profiling Diamond-Grinding Wheels", *International Journal of Manufacturing Technology and Management,* vol. 12(1/2/3), 2007, pp.93-107.

[5] E. D. Elston, "Ceramic Abstracts", *Journal of the American Ceramic Society*, vol. 3(6), 2006, pp.501- 520.

[6] A. Jiju, P. Daniel, W. Chengbo, and K. Maneesh, "An Application of Taguchi Method of Experimental Design for New Product Design and Development Process", *Journal of Assembly Automation,* vol. 26, 2006, pp. 18-24.

[7] T. M. Maksoud, and M. R. Atia, "Review of Intelligent Grinding and Dressing Operations", *Journal of Machining Science and Technology,* vol.8, 2004, pp. 263-276.

[8] A. O. Odior, and F. A. Oyawale, "Application of Neuro Fuzzy to Component Elements of a Grinding Wheel", *Global Journal of Engineering and Technology,* vol.1, 2008, pp. 329-335.

[9] O. I. Onibonoje, and F.A. Oyawale, "Manufacture of Abrasive Paper from Local Raw Materials". Proceedings of the Nigerian Institute of Industrial Engineers, Ibadan, 1998.

[10] G. Scott, "Sandpaper: Beautiful Wood", May, 2010 available: http://www.beautifulwood.net/html/sandpaper.html.

[11] C. Suryarghya, and S. Paul, "Numerical Modeling of Surface Topography in Super abrasive Grinding", *The International Journal of Advanced Manufacturing Technology,* vol. 13(6), 2007, pp. 45–57.

[12] G. Taguchi, *System of Experimental Design*, Vol. 1 & 2, Kraus New York, International Publications, 1988.

[13] Z. W. Zhong and V. C. Venkatesh, "Recent Developments in Grinding of Advanced Materials", *The International Journal of Advanced Manufacturing Technology*, vol. 6(3), 2008, pp. 35 – 44.