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Manufacture of Abrasive Grains from Locally Sourced Raw Materials in Nigeria

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Abstract

The manufacture of abrasive grains 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 abrasive grains was conducted. The mixture was fired in a furnace to 1600^{o}C for 6 hours forming silicon carbide chunks, which were crushed and sieved into coarse and fine grades of abrasive grains of international standard.

Keywords: abrasive grains, local raw material, abrasive grains, pilot study, optimal formulation

INTRODUCTION

Abrasive grains are used for the formulation and manufacture of abrasive grinding wheels. Grinding wheels are used for metal removal, dimensioning and finishing and they are made of small, sharp and very hard natural or synthetic abrasive minerals, bonded together in a matrix to form a wheel. Each abrasive grain is a cutting edge and as the grain passes over the workpiece, it cuts a small chip, leaving a smooth, accurate surface. As the abrasive grain becomes dull, it breaks away from the bonding material exposing new sharp grains (Odior and Oyawale, 2008a). The abrasive particles or grits are held together by strong porous bond and during grinding, a small tiny chip is cut by each of these active grains that comes in contact with the work piece as the grinding wheel whirls past it. The size of the chip being cut by each microscopic active grain is so small that it is less than 1 micrometer which is on a nano scale, (Odior and Oyawale, 2008b).

Abrasive grains are manufactured from various abrasive materials and they 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, (Maksoud and Atia, 2004; Odior, 2002). There are two types of abrasive materials; natural and synthetic abrasive materials and 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 (Onibonoje and Oyawale, 1998).

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 (Clark et al, 2003; Brecker, 2006; Eckart, et al. 2007). 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. Like sand stone, these materials lack a uniform bond and are not suitable for high- speed grinding work. Diamond wheels, made with resinoid bond, are especially useful in sharpening cemented-carbide tools. In spite of high initial cost, they have proved to be economical because of their rapid cutting ability, slow wear, and free cutting action, (Arunachalam and Ramamoorthy, 2007). The impurity in natural abrasive materials make them less effective and as such, men began to search for alternative which led to the discovery of synthetic abrasive materials, (Scott, 2010).

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 (Arunachalam and Ramamoorthy, 2007; Suryarghya and Paul, 2007). 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, (Zhong and Venkatesh, 2008). The Cubic Boron Nitride (CBN) shows a great promise in the grinding of high speed steels and its hardness approaches that of diamond. The various grades of each type of synthetic abrasives are distinguishable by properties such as colour, toughness, hardness and friability and the differences in properties are caused by variation in purity of materials and method of processing.

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^{o}C to 2200^{o}C, at which point a large portion of the load crystallizes to form silicon carbide abrasives (Elston, 2006). 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 (Bakken, *et. al*., 1998).

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

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, (Elston, 2006). 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.

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.

The abrasive grains were formulated and manufactured using varying proportions of locally sourced raw materials. Quartz (Q_a), coal (C_o), sodium carbonate (S_oC_a), sawdust (S_a) and sodium chloride (S_oC_h). These components were properly mixed for the production. We now develop neuro – fuzzy model for the production of silicon carbide abrasive grains as follows:

$A_bG_r = Q_a + C_o + S_oC_a + S_a + S_oC_h$

These parameters are now denoted as follows.

$Y = A_bG_r =$ Abrasive Grains,
$X_1 = Q_a =$ Quatz,
$X_2 = C_o =$ Coal,
$X_3 = S_oC_a =$ Sodium Carbonate
$X_4 = S_a =$ Sawdust,
$X_5 = S_oC_h =$ Sodium Chloride.

So we have; $Y = X_1 + X_2 + X_3 + X_4 + X_5$.

The neuro – fuzzy model is given as

$$Y_d = \sum X_iW_i .$$

Where, $Y_d =$ desired output,
X_i =variable proportion of constituents,
$W_i =$ attach weights.

The structure of neuro fuzzy model is presented in Figure 1, and it is is made of three distinct parts namely input, layers, and output. The inputs are denoted by 'X'. This could be X_1, X_2 and X_3 for the framework shown in

Figure 1. Each of these 'X' values may represent different inputs such as quartz, coal, sodium carbonate, sawdust, sodium chloride, temperature, etc. As such, the number of 'X' values may be equivalent to the number of input parameters that we are considering. In this case, the structure of the diagram would be more complicated than what is illustrated above. The second division of the neurofuzzy structure consists of layers which are interconnections between the input and output neurons. In this particular defined instance, three layers are specified and they are layers 0, 1, and 2. The next segmentation of the neurofuzzy structure is the output. This is represented by 'y'. Particularly, we have y1, y2, and y3. The output has to be refined in order to obtain the desired output. The refined output is referred to as the desired output, 'yd'. For a clearer view of the neurofuzzy model, the simplified schematic layout diagram in Figure 2 is employed.

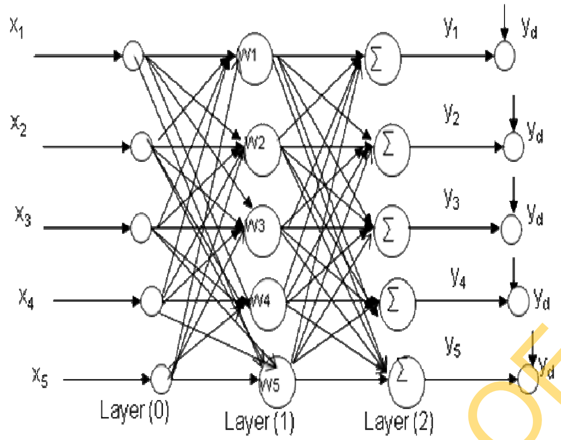


Fig.1: The Structure of Neuro Fuzzy Model.

The above structure is now simplified for a clearer view and better understanding of the neurofuzzy model structure above.

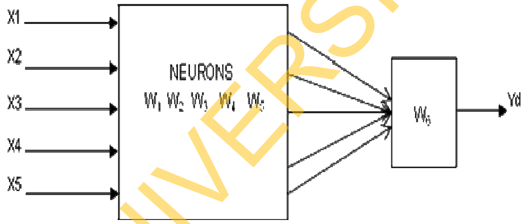


Fig. 2: Simplified Neuro Fuzzy Model.

The input and output parameters for the neuro - fuzzy model with their identified variables are now presented in Table 1 below.

X_1 = Q_a = Quatz,
X_2 = C_o = Coal,
X_3 = S_oC_a = Sodium Carbonate
X_4 = S_a = Sawdust,
X_5 = S_oC_h. = Sodium Chloride.

Table 1: Identified Variables for Neuro - Fuzzy Model Input and Output Parameters.

Variable Name	**Description**	**Fuzzy Variables.**
A_bG_r	Abrasive Grains	Coarse, Medium, Fine, Very Fine.
Q_a	Quartz	Coarse, Medium, Fine, Very Fine.
C_o	Coal	Coarse, Medium, Fine, Very Fine.
S_oC_a	Sodium Carbonate	Coarse, Medium, Fine, Very Fine.
S_a	Sawdust,	Coarse, Medium, Fine, Very Fine.
S_oC_h.	Sodium chloride	Coarse, Medium, Fine, Very Fine.

In the production of the abrasive grains or grits, it was observed that the fuzzy variables fine and very fine gave the same result as that of the fuzzy variable fine. Therefore, the neuro - fuzzy model with their identified variables are now reduced to the form presented in Table 2..

Table 2. Normalized Identified Variables for Neuro-Fuzzy Model Input and Output Parameters.

Variable Name	Description	Fuzzy Variables.
A_bG_r	Abrasive Grains	Coarse, Medium, Fine.
Q_a	Silicon Carbide	Coarse, Medium, Fine.
C_o	Petroleum Coke	Coarse, Medium, Fine..
S_oC_a	Sodium Carbonate	Coarse, Medium, Fine,
S_aD_u	Saw Dust,	Coarse, Medium, Fine.
S_oC_h.	Sodium chloride	Coarse, Medium, Fine.

Therefore, the fuzzy model relates the desired output Y_d to the output Y.

Considering the output parameters from the neuro fuzzy model, we have;

(1) $(Y_d - Y)$ = Positive (P) = Optimistic (O_p),
(2) $(Y_d - Y)$ = Zero (Z) = Normal (N),
(3) $(Y_d - Y)$ = Negative (N) = Pessimistic (P_e).

These parameters are to be processed to arrive at the specified desired output by using the following base rules:

(1) IF $(Y_d - Y)$ = P AND $(Y_d - Y)$ = P continues, THEN output = Optimistic (O_p).

(2) IF $(Y_d - Y)$ = Z AND $(Y_d - Y)$ = Z continues, THEN output = Normal (N).

(3) IF $(Y_d - Y)$ = N AND $(Y_d - Y)$ = N continues, THEN output = Pessimistic(P_e)

For the effective production of silicon carbide grains, three major important parameters were considered. These are: the core material (quartz), the reactant (coal) and melting temperature since sodium carbonate, sawdust and sodium chloride are catalysts in the formulation. Denoting quartz by Q_a, coal by C_o and temperature by T_e, we now represent these input parameters by a neuro fuzzy network as follows:

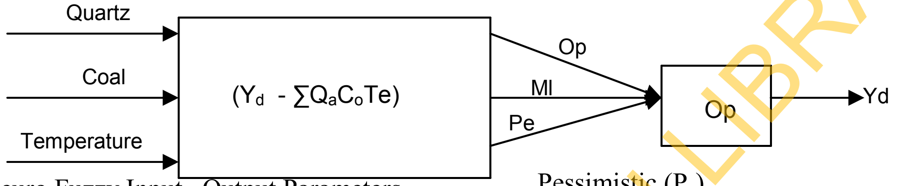


Fig. 3: Neuro Fuzzy Input –Output Parameters.

(2) Normal grade silicon carbide abrasives (Most Likely, M_l),

(3) Poor grade silicon carbide abrasives (Pessimistic, P_e).

The Linguistic Variables;

(1) $(Y_d - \sum S_i P_e T_e)$ = Positive (P) = HGSCA = Optimistic (O_p)

(2) $(Y_d - \sum S_i P_e T_e)$ = Zero (Z) = NGSCA = Most Likely (M_l)

(3) $(Y_d - \sum S_i P_e T_e)$ = Negative (N) = PGSCA = Pessimistic (P_e).

The neuro fuzzy model is now represented with a simplified fuzzy network.

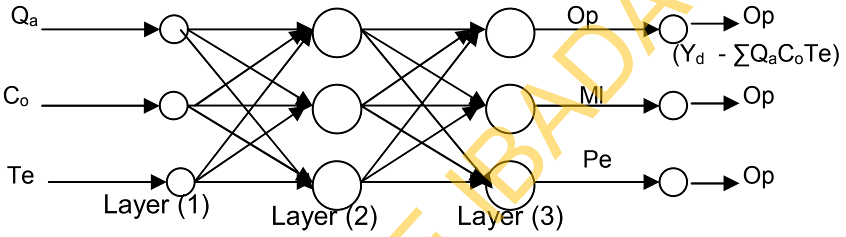


Fig.4: Neuro Fuzzy Network.

Were Q_a, C_o, T_e are input parameters, O_p, M_l, P_e are output parameters, Y_d is the desired output and $(Y_d - \sum Q_a C_o T_e)$ is the linguistic variable.

Output Parameters

The output parameters are;

(1) High grade silicon carbide abrasives (Optimistic, O_p),

The components of fuzzy logic control model for the production of abrasive grains with membership functions are presented in Table 3.

Table 3. Relationship between fuzzy output and membership function.

Level	Interpretation	Fuzzy Output	Linguistic Variables.
1	Optimistic	Positive	$(Y_d - \sum Q_a C_o Te)$
2	Most Likely	Zero	$(Y_d - \sum Q_a C_o Te)$
3	Pessimistic	Negative	$(Y_d - \sum Q_a C_o Te)$

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.

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

The percentage proportion of each of the raw materials used in the various formulations of silicon carbide abrasive chucks are presented in Table 5 with their respective hardness values. The optimum formulation gave percentage proportions as quartz 59.06%, coal 31.53%, sodium carbonate 8.41%, sawdust 0.73% and sodium chloride as 0.27% with hardness value of 0.52KN.

Table 5. Percentage proportion of components in abrasive chunks produced.

Sample No	**Quartz (%)**	**Coal (%)**	**Sodium Carbonate (%)**	**Sawdust (%)**	**Sodium Chloride (%)**	**Hardness of Abrasives. (KN/mm^2)**
1	51.46	31.67	15.84	0.63	0.40	0.35
2.	53.59	28.85	16.49	0.66	0.41	0.38
3.	58.40	31.45	8.98	0.72	0.45	0.45
4.	58.45	31.47	8.99	0.64	0.45	0.48
5.	59.06	31.53	8.41	0.73	0.27	0.52

The results from the various formulations with the five local raw materials are presented in Figure 5.

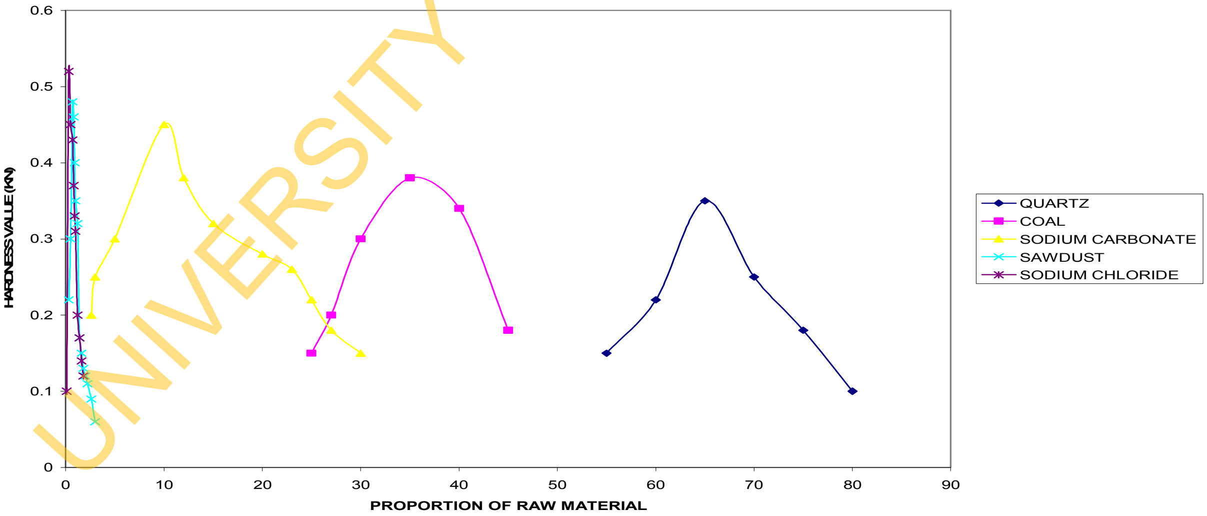


Fig. 5: Formulation by Varying Proportion of Each Raw Material

Manufacture of silicon carbide abrasive chunks

In the manufacture of silicon carbide abrasives, a pit furnace was charged with formulated mix of Quartz (59%), Coal (32%), Sodium carbonate (8%), Sawdust (0.7%) and Sodium chloride (0.3%) at a temperature of 1800^0C for 6 hours. The mixture was regularly poked for proper and homogeneous melting and the pit furnace for the melting is presented in Figure 6. The melted silicon carbide crystals in crucible pots are presented in Figure 7, while a sample of manufactured silicon carbide abrasives is presented in Figure 8.

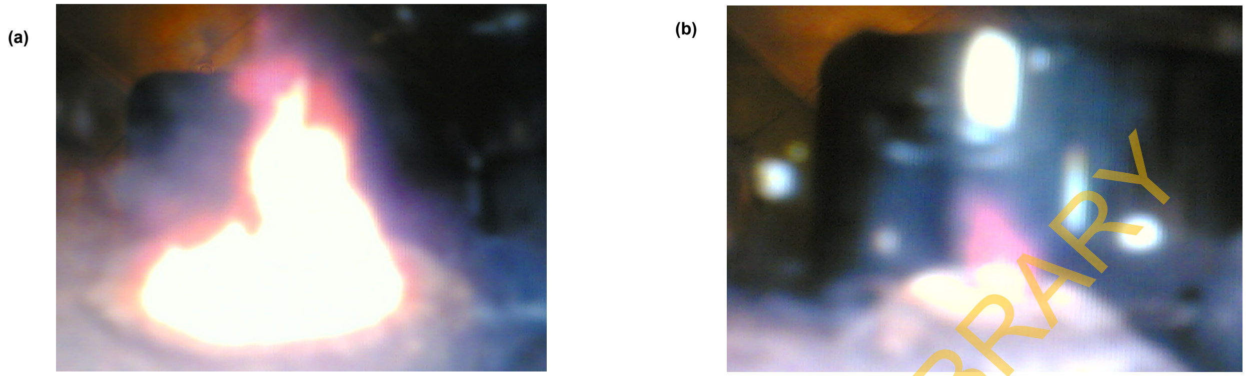


Figure 6. Pit Furnace: [(a) Opened pit furnace (b) Closed pit furnace]

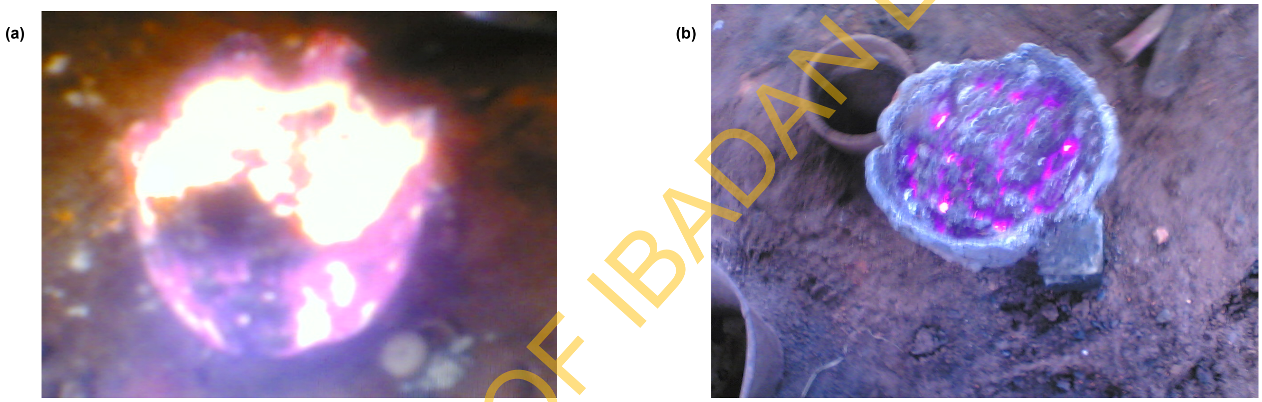
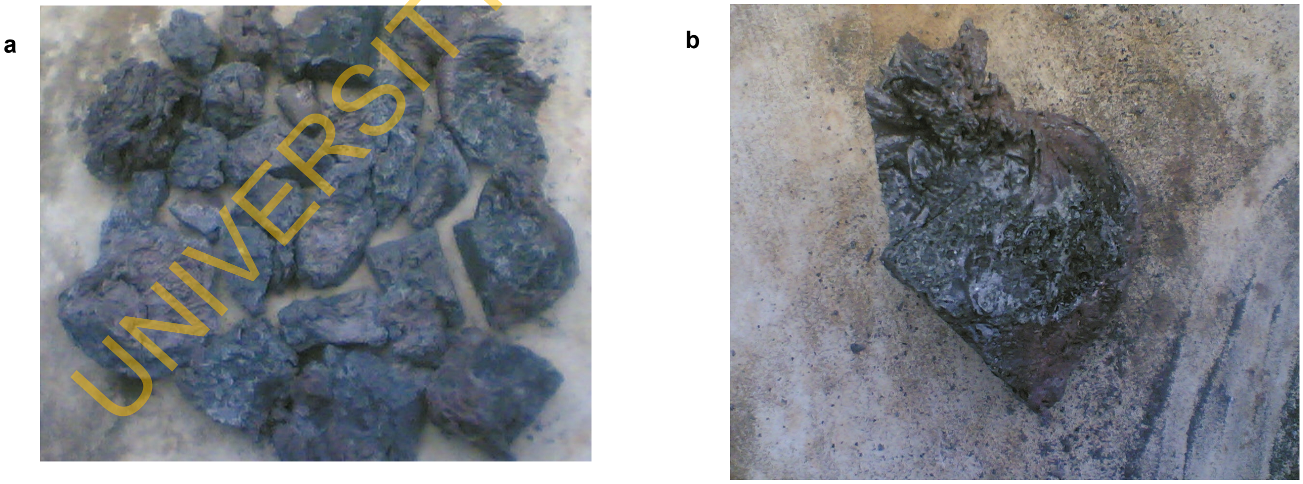


Figure 7. The melted abrasives in crucible pot [(a) Very hot melt, (b) warm melt]



[(a) Silicon carbide abrasives, (b) An enlarged abrasive chuck].

Figure 8. A Sample of produced silicon carbide abrasives.

Grading of Abrasive Grains.

Grading or sizing of abrasive grains refers to making the particle sizes within the abrasives more uniform so that majority of the particles fall within a given range of sizes.

All abrasives contain particles with a range of sizes. In general, the more uniform in size the abrasive, the more expensive and difficult it is to manufacture. There are three methods which are used for the grading of abrasive grains, these are:

(1) The abrasive particles can be made smaller until they are all the same very small size;
(2) The abrasive particles can be joined together to make larger particles of a desired size;
(3) The particles can be sorted into different sizes using different sieves.

Size Classification

After size reduction, the material is separated into discrete size ranges. This is accomplished by screening process. In screening, the material to be separated is passed over a series of screens with decreasing opening sizes. At the first stage, coarsest screen was used with most of the material passing through, with only the largest particles retained on the screen and eventually collected. At the second screen, the next coarsest fraction is removed, and so on.

The produced abrasive crystals were properly crushed with a hammer and a fabricated metal mortar and sieved with 600 μm mesh into fine grains while 1180 μm was used to sieve coarse grains as presented in Figure 9.

[(a) Fabricated metal mortar (b) Fine abrasive grains (c) Coarse abrasive grains].
Figure 9: Samples of produced abrasive grains with fabricated metal mortar.

CONCLUSION

Silicon carbide abrasive grains were formulated and manufactured using locally sourced raw materials which include: quartz, coal, sodium carbonate, sawdust and sodium chloride. These materials were locally sourced from different parts of the country under different conditions. As a result, they were properly beneficiated and processed before being fed into the furnace for melting. The melting process took 6 hours with regular poking of the mixture for homogeneous melting. A local pit furnace was used for the melting as the only available furnace for the melting. The formulation led to a series of reactions among the various raw materials used. Sodium carbonate was added to the mix to enable the formulation to work with the local equipment by dropping the melting temperature from a high level to a comfortable low level.

A small amount of Saw dust was added to the mix to increase its porosity 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 silicon carbide abrasive grains was accomplished while the formulation and manufacture of silicon carbide abrasive grains was successfully achieved. The formulation and manufacture of silicon carbide abrasive grains 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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