Journal of
Engineering for
Development

Journal of Engineering for Development Vol. 9, April (2010) pp.54-64

MANUFACTURE OF ABRASIVE GRINDING WHEEL USING SILICON CARBIDE ABRASIVE MATERIALS

Odior.A.O[a],Oyawale.F.A[b],Charles-Owaba.O.E[c]andAkpobi.J.A[d]

1,4 Department of Production Engineering, University of Benin, Nigeria.
2,3 Department of Industrial and Production Engineering, University of Ibadan,
NigeriaEmail: waddnis@yahoo.com

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. A grinding wheel is made of very small, sharp and hard silicon carbide abrasive particles or grits held together by strong porous bond. The manufacture of silicon carbide abrasives and grinding wheel in Nigeria has been severely impeded by the difficulty of identifying suitable local raw materials and the associated local formulation for abrasives and grinding wheel with global quality standards. This paper presents a study on the formulation and manufacture of abrasive grinding wheel using silicon carbide abrasive grains in Nigeria. 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 coarse and fine grades of abrasive grains. Combining each grade with appropriate proportion of latex binder to form paste in a compressed mould cavity of desired shape and size, coarse and fine grinding wheels of international standard were produced.

Keywords: Abrasive Materials,Grinding wheel, Silicon Carbide, Taguchi Method

1. 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, (Maksoud and Atia, 2004; Odior and Oyawale, 2008).

Abrasive materials for grinding, honing, lapping, and super finishing are classified into two groups, natural and synthetic abrasive materials and except for diamonds, manufactured abrasives have almost totally replaced natural abrasive materials. 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,1999).

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, (Arunachalamand Ramamoorthy, 2007).

A grinding wheel is an expendable wheel that carries an abrasive compound on its periphery. 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, 2008).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 (Eduardo *et al.*, 2003).

The art of grinding dates back 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, (Salmon, 1992). 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, (Salmon, 1992). 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, (Theodore, 2009). 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 (Elston, 2006). Silicon carbide which is formed in the Acheson furnace varies in purity, according to its distance from the graphiteresistorheat 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).

Abrasives and 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.

The various component materials used for the production of ISO certified grinding wheels 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 grinding wheels. A pilot study was therefore conducted on various raw materials to identify suitable local material substitutes which were locally sourced, beneficiated and processed. These materials include quartz, the core material; coal, the reactant material; sodium carbonate, sawdust, sodium chloride, which are catalysts and natural rubber latex, a bond.

2. PILOT STUDY.

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 they were crushed and sieved for our formulation. A pilot study was also conducted on charcoal, snail shell, coal and petroleum coke as reactants. Charcoal and snail shell were found to be unsuitable due to high melting temperature of 3550°C and porosity of charcoal and low carbon content of snail shell which failed to form the 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. A pilot study was equally conducted on natural rubber, epoxy resin and silicate as bonds and they were found to be quite suitable in the formulation. However, rubber latex bond was selected because it is locally available in abundant quantity in Nigeria.

3. EXPERIMENTAL DESIGN AND MATERIAL FORMULATION.

The levels of raw materials for the formulation of silicon carbide abrasives after several trial formulations are given in the Table 1. The codes "a" to "e" are quantities of materials at high-level settings, while the low level settings are shown in last column. A medium level setting may also exist between the high level and low level settings.

Table 1.Components for the formulation of silicon carbide abrasives.

S/No	Material	High Level	Low Level
1	Quartz	A	a – 4
2	Coal	B	b – 3
3	Sodium Carbonate	C	c – 3
4	Sawdust	D	d – 2
5	Sodium Chloride	E	e – 2

3.4.2: Factor Levels for Silicon Carbide Abrasives Manufacturing Parameters

Taguchi method ofexperimental 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. While the Taguchi method of orthogonal arrays was used to develop the factor levels for the silicon carbide abrasive and grinding wheel manufacturing parameters as presented in the Table 3.

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)**	**Baking temp. (T_b)**	**Baking time (t_b)**
Exp.	1	2	3	4				
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: 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
Moulding Pressure	10.25	15.75	20.25MPa
Baking Temperature	150°C	200°C	250°C
Baking Time	1hr	2hrs	3hrs

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 each material constituent.

Major Experi-ment.	**Varied Components**	**Formulationat Each Experimental Stage (Proportion by Weight (gm))**										**Hardness Value**
		1	2	3	4	5	6	7	8	9	10	(kgf/m
1	Quartz	40	45	50	55	60	65	70	75	80	85	0.35
2	Coal	15	20	25	30	35	40	45	50	55	60	0.38
3	Na_2CO_3	30	27	25	23	20	15	12	10	5	2	0.45
4	Sawdust	0.3	0.5	0.7	0.8	1.0	1.2	1.4	2.2	2.6	23.0	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

MANUFACTURE OF SILICON CARBIDE ABRASIVE CHUCKS

In the manufacture of silicon carbide abrasives, a pit furnace 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 the pit furnace for the melting is presented in Figure 1. 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.

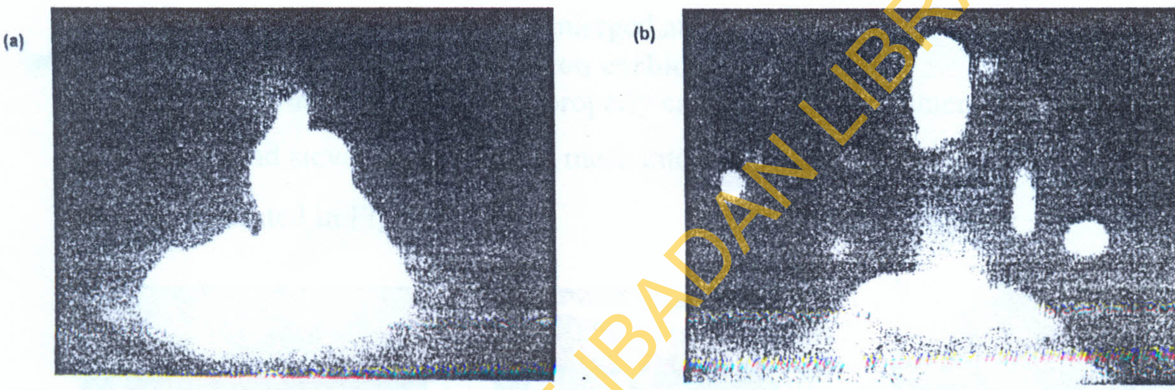


Figure 1: Pit Furnace[(a) Opened pit furnace (b) Closed pitfurnace]

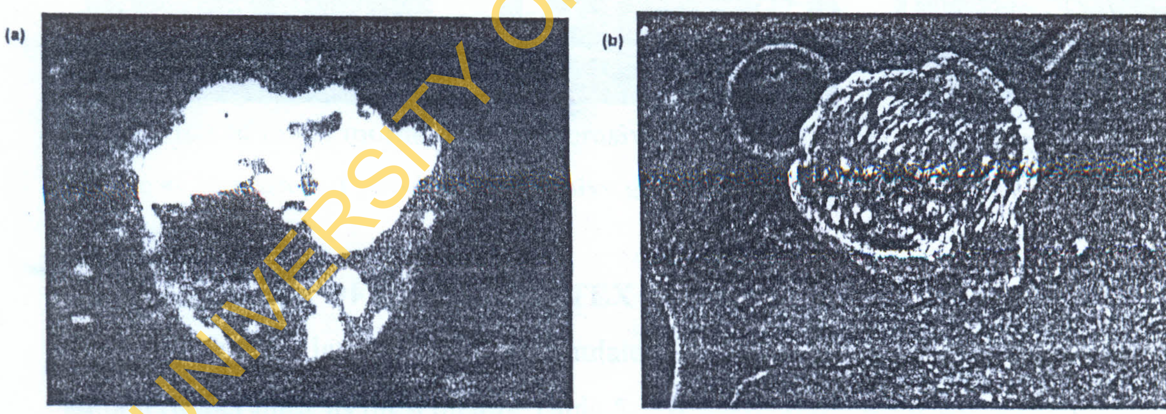
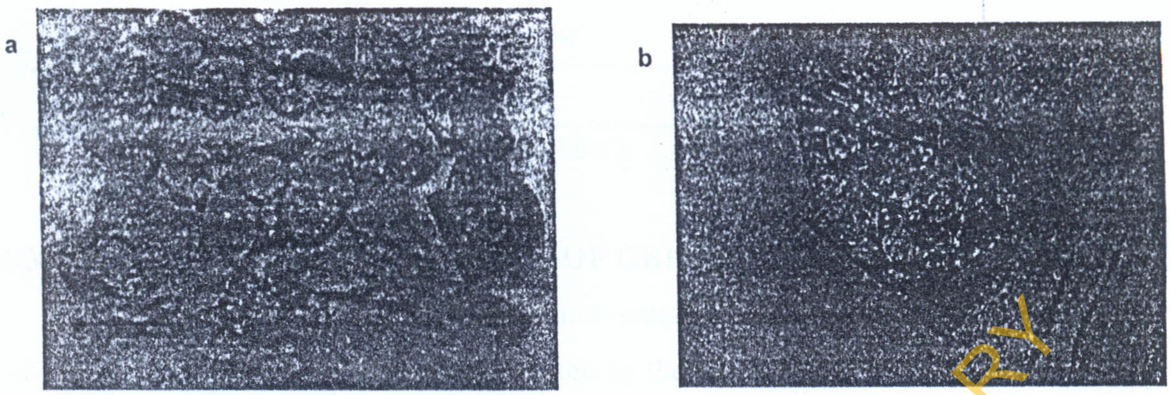
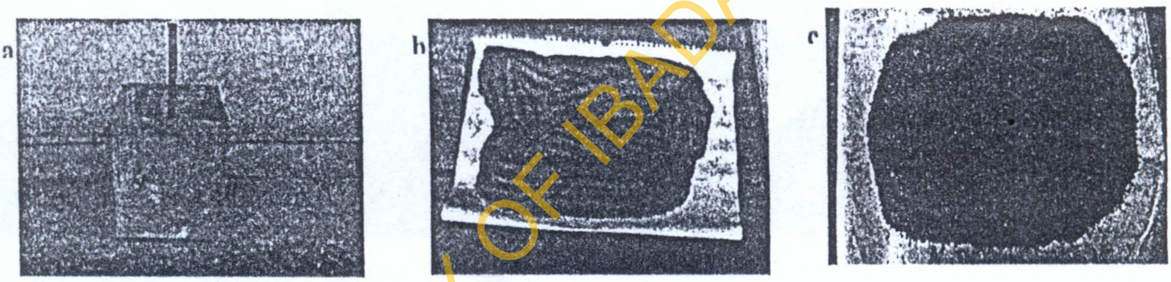


Figure 2.The melted abrasives in crucible pot[(a) Very hot melt,(b) warm melt]



[(a) Silicon carbide abrasives,(b) An enlarged abrasive chuck].
Figure 3.A Sample of produced silicon carbide abrasives.

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



[(a) Fabricated metal mortar (b) Fine abrasive grains (c) Coarse abrasive grains].
Figure 4: Samples of produced abrasive grains with fabricated metal mortar.

FORMULATION OF RUBBER LATEX BOND

The rubber latex bond was formulated by mixing some additives with a sample of natural rubber latex as presented in Table 5.

Table 5. Formulation of rubber latex bond with additives.

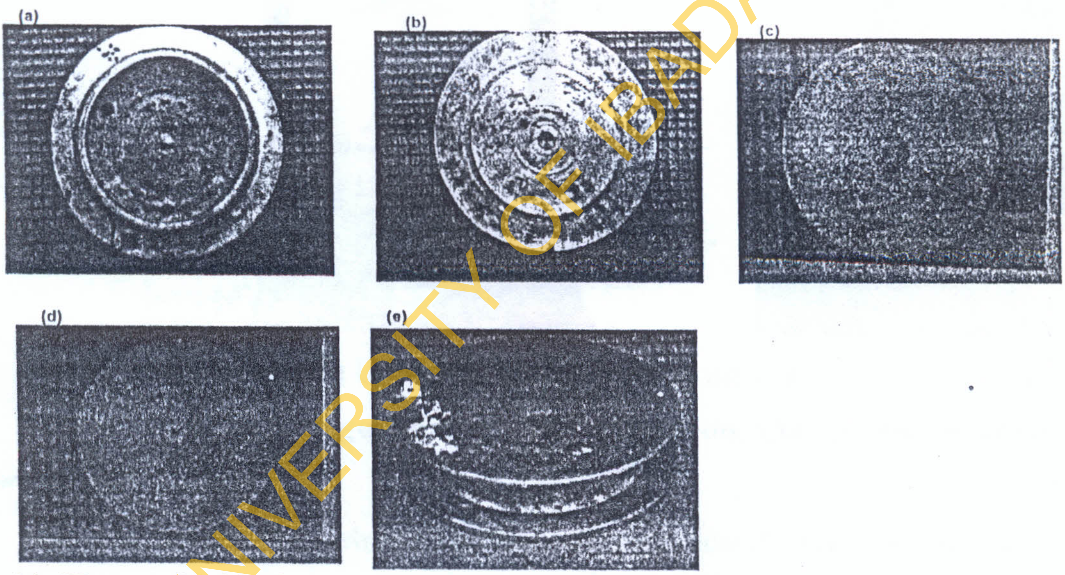
Component material	Weight (gm)	Mixing time (min)
Rubber latex (core material)	100	1 (proper stirring)
Stabilizer	3phgr	4
Vulcanizing agent	5phgr	3
Accelerator	5phgr	2

Activator	2.5phgr	3
Antioxidant	1phgr	2
Total		15

(phgr means per hundred gram of rubber).

FORMULATION AND MANUFACTURE OF GRINDING WHEEL

The grinding wheels were formulated and manufactured using 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; fine and coarse grinding wheels were manufactured. A mould was fabricated using a mild steel material for a wheel size of 200 mm in diameter with a thickness of 25 mm, as shown in Figure 5.

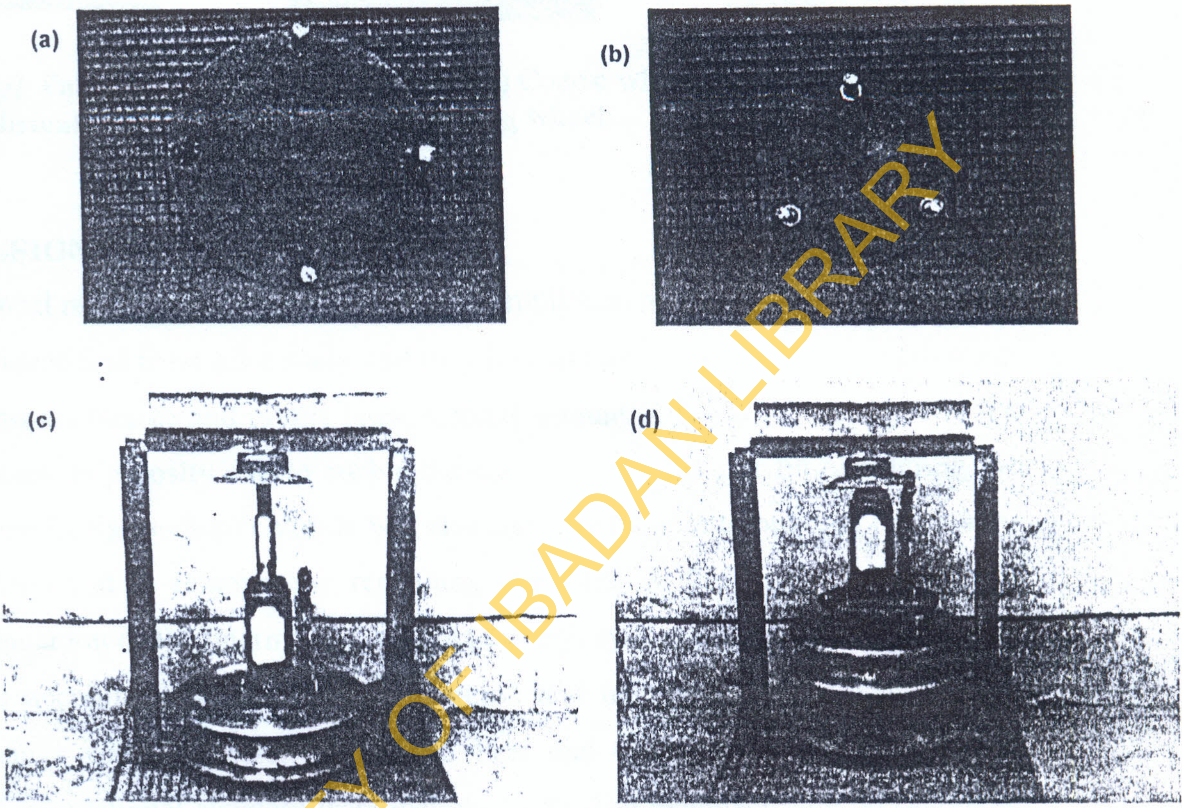


(a) The mould (b) The press (c) Lower inner plate (d) Upper inner plate and (e) The assembled big mould.

Figure 5.The Fabricated Big Mould.

Pressing Process

The formulated paste was loaded into the fabricated mould and pressed with a hydraulic press as presented in Figure 6c. The pressing process was kept for a period of 6 hours to allow proper solidification and binding. The moulded wheel was then ejected from the mould with the mechanical ejector as presented in Figure 6d and this was carefully done so as not to damage the product.

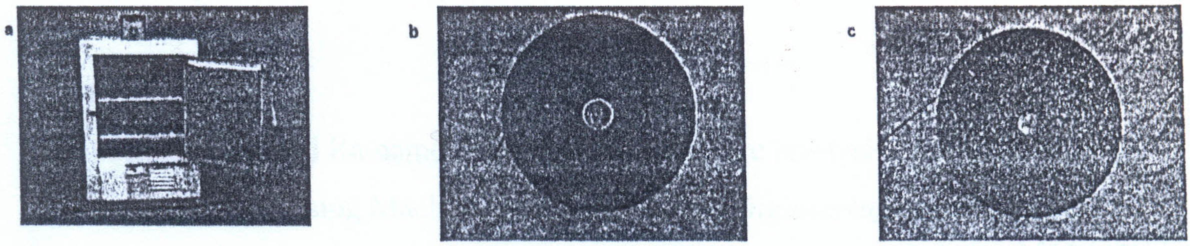


(a) Lower ejector (b) Upper ejector (c) Pressing mechanism (d) Ejection mechanism.

Figure 6: The product pressing and ejection process.

Wheel Baking

The moulded wheels were baked in a fabricated oven at a temperature of 200°C for 2 hours. The purposes of the baking are to properly cure the wheel by melting the binder around the abrasive grains and to convert it to a form that will resist the heat and pressure encountered during any grinding operation.At the end of the baking period, the wheels were allowed to cool to room temperature to obtain hard wheels of international standard as presented in Figure 7.



(a) Fabricated oven (b) Fine wheel (c) Coarse wheel

Figure 7:Fabricated oven and produced grinding wheels.

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 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 the intermediate product through systematic search using Taguchi method was accomplished while the formulation and manufacture of silicon carbide abrasive chunks was successfully achieved. Fine and coarse graded silicon carbide abrasives of international standard were manufactured. The manufacturing processes for fine and coarse grinding wheels were developed, while the formulation and manufacture of fine and coarse grinding wheels which conformed to ISO-certified wheel standard using locally fabricated equipment was successfully accomplished.

Since the manufacture of grinding wheels from locally sourced raw materials is made possible in Nigeria through the proposed formulation and manufacturing process, a further research work to develop an automated process for mass production of grinding wheels is suggested.

REFERENCES

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

Bakken, J.A., Jensen, R., Monsen, B., Raaness, O., and Wærnes, A.N., (1998). Thermal Plasma Process Development in Norway.*Journal of Pure and Applied Chemistry,* IUPAC. 6(3): 23- 30.

Brecker, J.N., (2006). Analysis of Bond Formation in Vitrified Abrasive Wheels.Journal of the American Ceramic Society.57(11): 486 – 489.

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

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

Elston, E. D. (2006).Ceramic Abstracts.*Journal of the American Ceramic Society.* 3(6): 501- 520.

Maksoud, T. M. and Atia, M. R., (2004).Review of Intelligent Grinding and Dressing Operations", *Journal of Machining Science and Technology*. 8: 263-276

Odior, A. O. and Oyawale, F. A., (2008).Application of Neuro Fuzzy to Component Elements of a Grinding Wheel."*Global Journal of Engineering and Technology*, 1: 329-335.

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