SOME GRINDING FACTORS AFFECTING LOCALLY FORMULATED SILICON CARBIDE ABRASIVE WHEELS.

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ABSTRACT

A grinding wheel is an expendable wheel which is made of very small, sharp and hard silicon carbide abrasive particles or grits held together by strong porous bond. This paper presents a study on some factors and parameters of silicon carbide abrasive grinding wheels which were developed and formulated from locally sourced raw materials in Nigeria. Six local raw material substitutes were identified through pilot study and a systematic search for an optimal formulation of silicon carbide was conducted using the Taguchi method. The produced silicon carbide abrasive grains were used to manufacture grinding wheels. Some of the grinding factors of locally manufacture grinding wheel include: wheel wear, wheel grinding ratio, wheel hardness, bond strength, size and grade of the manufactured silicon carbide abrasive grains.
Keywords: Local raw material, Silicon carbide, Wheel Wear, Wheel Grinding Ratio.

1.0 INTRODUCTION

Grinding wheels are used for metal removal, dimensioning and finishing. They consist of an integral shank, pin, shaft or mandrel that drives a mounted wheel or blades. There are many types of grinding wheels some of which are numbered by the American National Standard Institute (ANSI). Among these are the straight wheels which are simple, flat discs without any recesses, flaring or cups. The tapered

grinding wheels have a thicker cross section at the bore and the cylindrical grinding wheels with a feature of a length that is equal or greater than the thickness of the wheel. Others include the cylindrical wheels, the depressed centre wheels and the cone wheels (Aguiar *et al.*, 2002).

Grinding wheels 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).

Grinding wheels use several types of abrasive grains. Among these abrasive grains are aluminium oxide, which is the common mineral in use today and is used either individually or with other materials to form ceramic grains. Silicon carbide which is a synthetic abrasive is also a very common mineral in use and it is typically used with non-ferrous materials such as brass, aluminium and titanium. Aluminium-zirconia grains, fused aluminium oxide and zirconium oxide are used to improve grinding performance on materials such as stainless steel. Synthetic diamond super abrasives are used for grinding non-ferrous metals, ceramics, glass, stone and building materials. Cubic boron nitride (CBN) is second only to diamond in terms of hardness and is another super abrasive, which provides superior grinding performance on carbon and alloy steels. Crushed tungsten carbide grits are used in metal-bonded products to abrade tough materials such as composites, fiberglass, reinforced plastics and rubber, (Mofid and Liangchi, 2006). Silicon carbide is the most commonly used abrasives as it accounts for about 80 to 90% of the total quantity of synthetic abrasive grains, (Elston, 2006). It is sometimes manufactured in an electric arc 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 1800oC to 2200oC, at which point a large portion of the load crystallizes to form silicon carbide abrasives (Elston, 2006).

Grinding wheels are not produced in Nigeria but wholly imported and acquiring grinding wheels through importation may be hindered due to lack of foreign currency. This made this study very necessary to source for local production of grinding wheels in Nigeria. 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.

2.0 THE FORMULATION OF SILICON CARBIDE ABRASIVES

Silicon carbide abrasive chunks were formulated and manufactured from six locally sourced raw material substitutes. These materials include: quartz, coal, sodium carbonate, sawdust and sodium chloride. The Taguchi method of experimental design was used to achieve optimum proportions of these raw materials to be mixed for wheel formulation and the material proportions by weight are: 65gm of quartz, 35gm of coal, 10gm of sodium carbonate, 0.7gm of sawdust and 0.3gm of sodium chloride. 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%. The optimum mix for the silicon carbide abrasives formulation was achieved by varying proportion of one of the raw materials while keeping the other raw materials constant using Taguchi orthogonal design. The formulation involves five major experiments, running ten formulations at each experimental stage as presented in Table 1.

Table 1: Formulation of Silicon Carbide Abrasives by Varying Each Raw Material

Major Experi Ment	Varied Components	Formulation at Each Experimental Stage (Proportion by Weight (gm))										Hardness Value (KN/mm²)
		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**	45	50	55	60	0.38
3	Na_2CO_3	2	5	7	10	14	**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 results from the various formulations are presented in Figure 1.
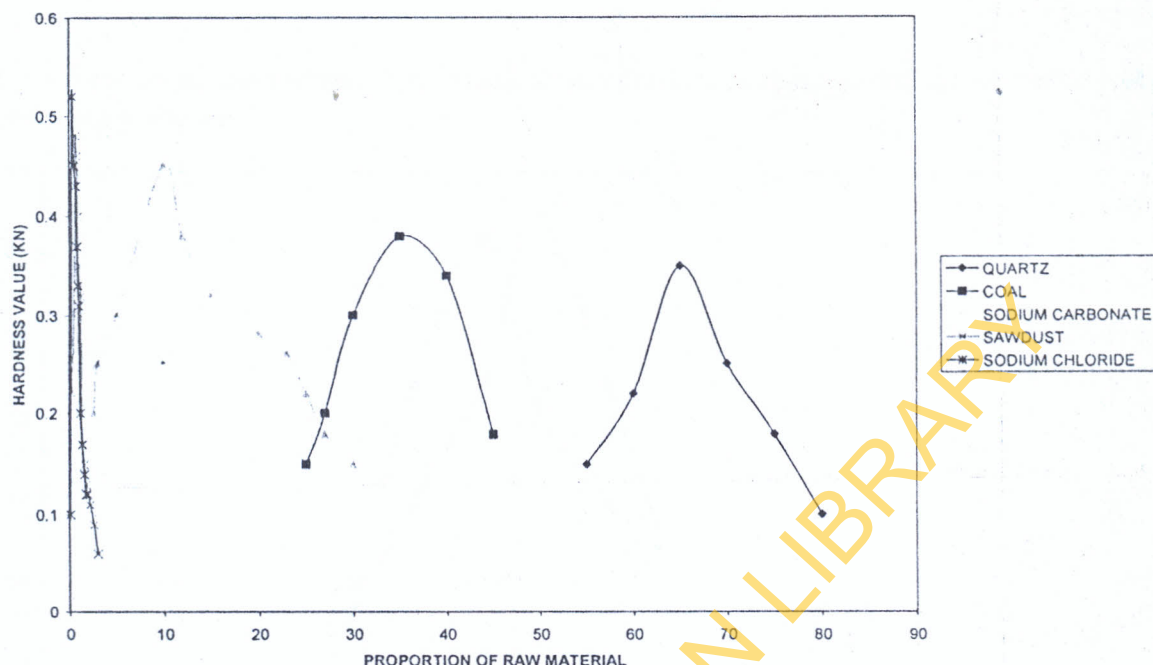
Fig. 1: Formulation by Varying Proportion of Each Raw Material

The percentage proportion of each of the raw materials used in the various formulations of silicon carbide abrasive chucks are presented in Table 2 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 2: 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

3.0 FORMULATION OF ABRASIVE GRINDING WHEELS

In the formulation of grinding wheels, a suitable paste substance for both the fine and coarse grinding wheels was first formulated as a bond material. It was discovered that too much excess of latex bond in the mix resulted in a watery paste which could not be pressed into grinding wheel. Therefore, optimum proportion of 80gm of abrasive grains to 20gm of latex bond was used to form paste for fine grinding wheel while 80gm of abrasive grains to 18gm latex bond was used for paste for coarse grinding wheel formulation. These proportions by weight gave optimum formulated paste used for the manufacture

of fine and coarse grinding wheels. The results of paste formulation for fine and coarse grinding wheels are presented in Figures 2.
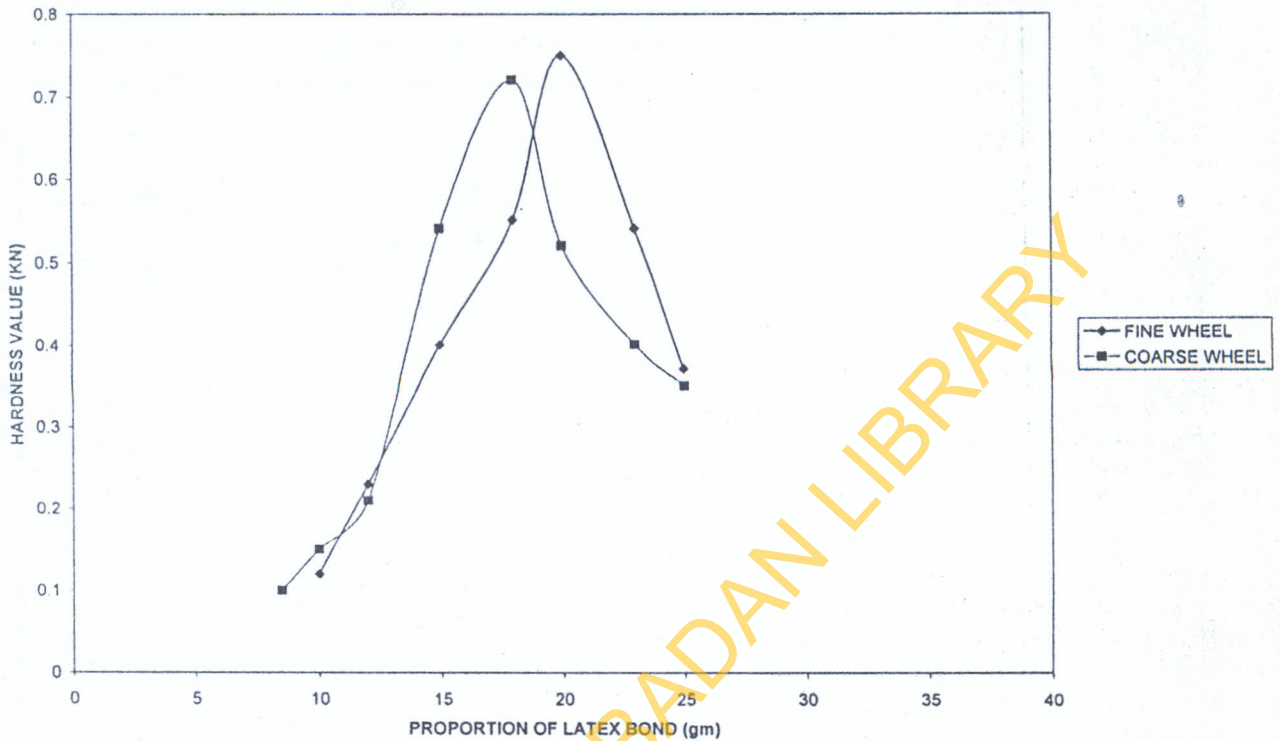

Fig. 2: Formulation of Paste for Fine and Coarse Grinding Wheels.

Formulation of Equations for Fine and Coarse Abrasive Grinding Wheels.

According to Rekha, (2004), equation of a given curve in concave form is given as:

$$y = a + b * (1 - \exp(-k * (x - g))) \tag{1}$$

where a = baseline, b = span, g = start and k = constant.

(a). The equation for the formulation of fine abrasive wheels from Figure 2 is given as:

$$y_{fw} = a_{fw} + b_{fw} * (1 - \exp(-k * (x_{fw} - g_{fw}))) \tag{2}$$

In this case, $a_{fw} = 0.12$, $b_{fw} = 0.63$, $g_{fw} = 10$

$y_{fw} = 0.12 + 0.63 * (1 - \exp(-k(x_{fw} - 10)))$

$y_{fw} = 0.75 - 0.63\exp(10k - kx_{fw})$ when $x_{fw} =$

15, $y_{fw} = 0.40$ (from Figure 4.6)

$-0.35 = -0.63\exp(-5k)$

and $k = 0.1176$ $\therefore y_{fw} =$

$$0.75 - 0.63e^{(1.1760 - 0.1176x_{fw})} \tag{3}$$

(b). The equation for the formulation of coarse abrasive wheels from Figure 2 is given as:

$$y_{cw} = a_{cw} + b_{cw} * (1 - \exp(-k * (x_{cw} - g_{cw}))) \tag{4}$$

In this case, $a_{cw} = 0.10$, $b_{cw} = 0.62$, $g_{cw} = 8.5$

$y_{cw} = 0.10 + 0.62 * (1 - \exp(-k(x_{cw} - 8.5)))$

$y_{cw} = 0.72 - 0.62\exp(8.5k - kx_{cw})$

When $x_{cw} = 10$, $y_{cw} = 0.15$ (from Figure 4.7)

$-0.57 = -0.62\exp(-1.5)k$

$\therefore k = 0.0561$

$\therefore y_{cw} = 0.72 - 0.62e^{(0.4769-0.0561x_{cw})}$ $\qquad\qquad$ (5)

Hardness Values for Produced Grinding Wheels.

The hardness results for fine and coarse wheels revealed that the hardness values for fine grinding wheels are higher than those of coarse wheels. Mean hardness values of 0.6961KN for fine grinding wheel and 0.6407KN for coarse wheel which were obtained. The results are presented in Figure 3.
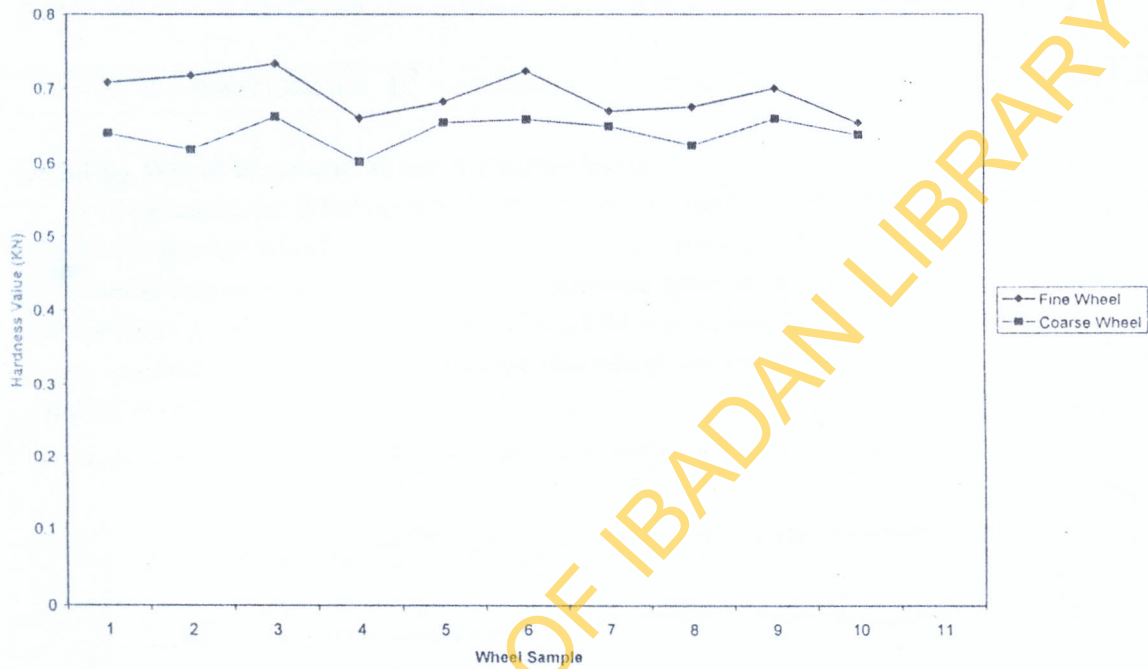

Fig. 3: Hardness Values of Laboratory Wheels.

Correlation Results for Wheel Hardness (Hw) and Latex Binder (X_b).

The results of regression performed on the proportion of latex bond for the formulation of paste for fine and coarse wheels are presented in Tables 3 and 4. This gives a regression coefficient of R = 0.91 and a regression equation (4.9) for fine grinding wheels.

$\qquad$ $H_w = -0.319562475 + 0.04814407814X_b$ $\qquad\qquad$ (6)

The regression for coarse grinding wheels gives a regression coefficient of R = 0.90 and a regression equation (4.10) :

$\qquad$ $H_w = -0.34019 + 0.05245X_b$ $\qquad\qquad$ (7)

Table 3: Summary of Results from Regression Model (Fine Wheel).

Model Factors	Coefficients	Mean	Standard Deviation	Standard Error	1-tail p-value	2-tail p-value
Constant	-0.319562475	0.47481	0.20938	0.073173	9.6E-5	0.000192
Bond (x_b)	0.0481440781	16.5	3.96863	0.004316	0	0
N = 27,	R = 0.912517896,	R² = 0.8326889,	s = 0.087342,	Durbin Watson = 0.139715		

Table 4: Summary of Results from the Model (Coarse).

Model Factors	Coefficients	Mean	Standard Deviation	Standard Error	1-tail p-value	2-tail p-value
Constant	-0.34019487	0.43346	0.22359	0.080238	0.000143	0.000287
Bond (x_b)	0.05245128	14.75	3.82426	0.005272	0	0

N = 26, R = 0.8971308564, R^2 = 0.804843773, s = 0.10081 ,   DurbinWatson = 0.121115

Grinding Wheel Wear and Wheel Grinding Ratio.

The results for grinding wheel wear show that coarse wheel wears faster than the fine grinding wheel with average wheel wear of 2.14 for fine wheel and 2.56 for coarse grinding wheel. The results are presented in Figure 4. The results for wheel grinding ratios are presented in Figure 5. The results show that the mean grinding ratio for fine wheel is 28.97 which is higher than the grinding ratio of 23.80 for coarse grinding wheel. This shows that the fine wheel has a higher cutting efficiency than the coarse grinding wheel.
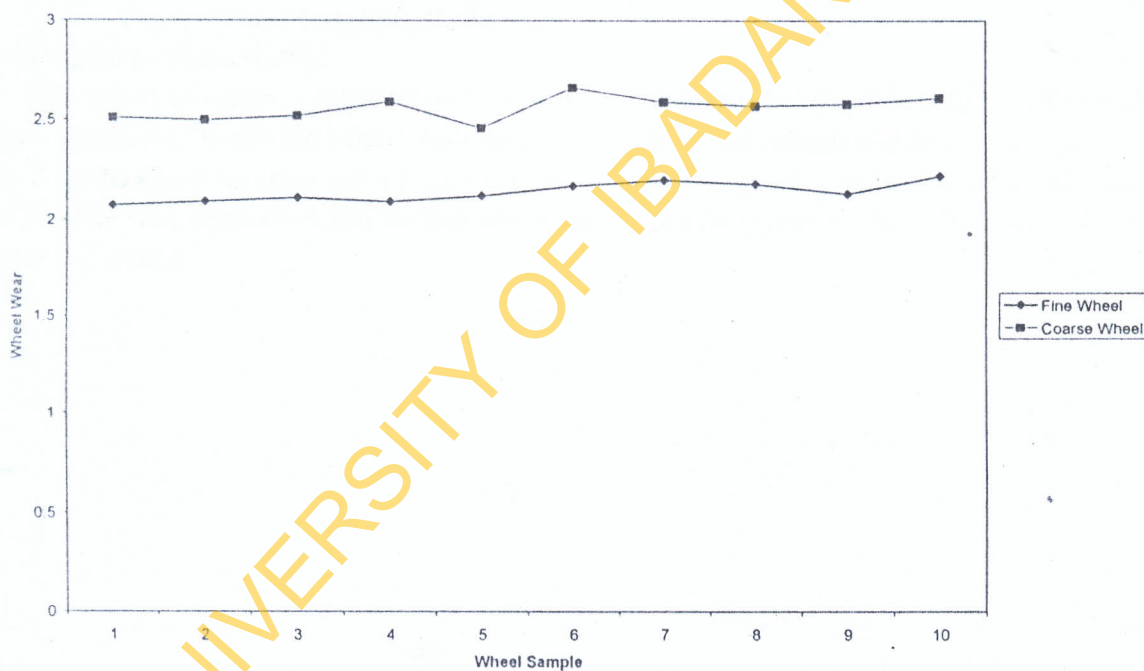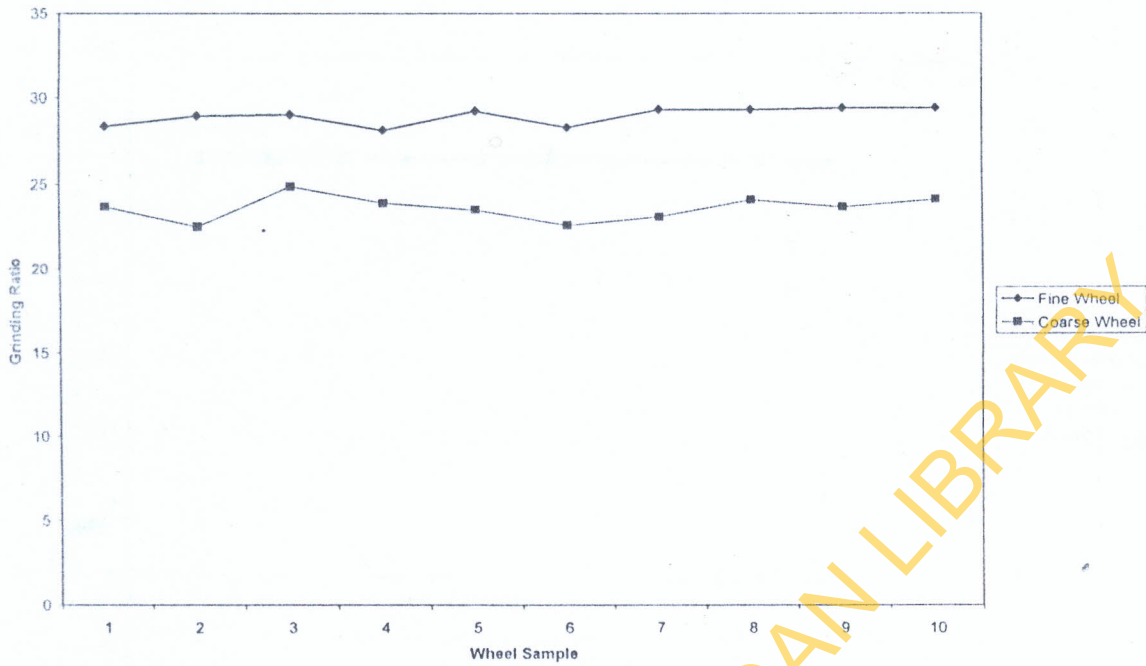

Fig. 4: Grinding Wheel Wear.

Fig. 5: Wheel Grinding Ratio.

Taguchi Signal to Noise Ratios.

The results of signal-to-noise ratios for wheel hardness for both fine and coarse wheels agreed with the Taguchi the "larger-the-better" with mean of 56.802 for fine wheels and 56.137 for coarse wheels. Also the signal-to-noise ratios results for wheel wear also agreed with the "smaller-the-better" idea of Taguchi with mean of -6.598 for fine wheels and -8.161 for coarse wheels. These results are presented in Figure 6.
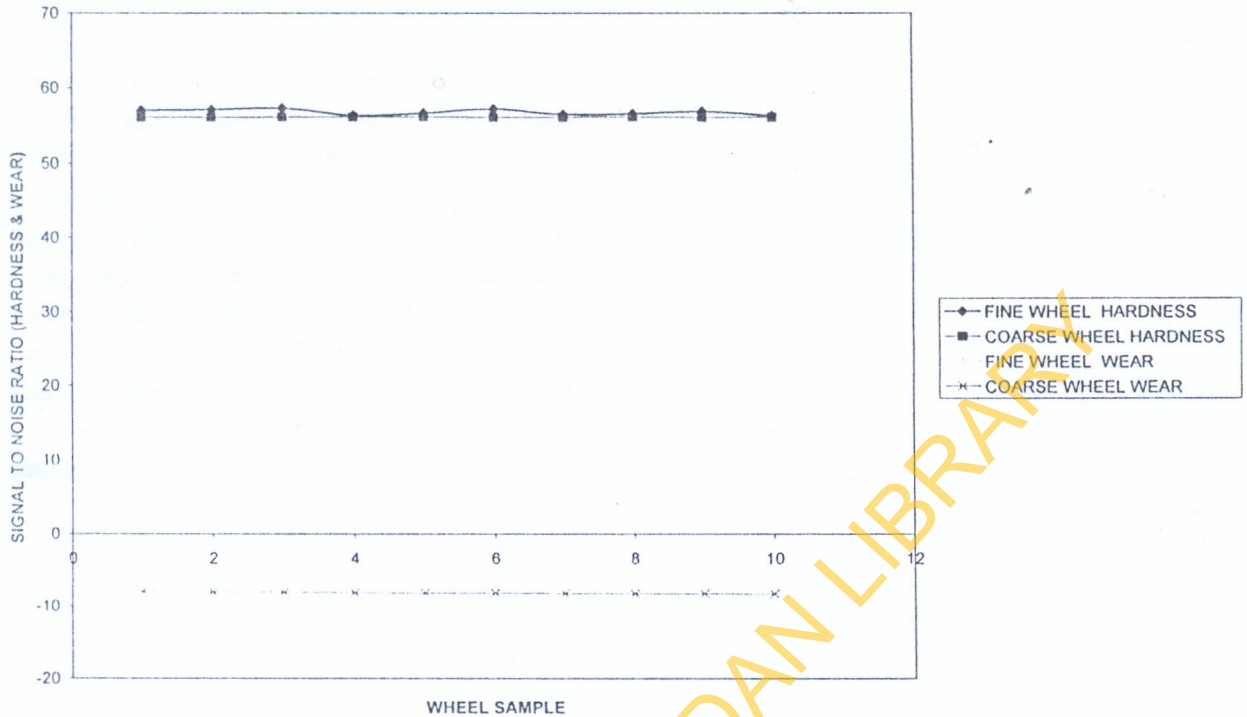
Fig. 6: Signal to Noise Ratio for Wheel Hardness and Wheel Wear.

4.0 DISCUSSION AND CONCLUSION.

The formulation and manufacture of silicon carbides led to a series of reactions among the various raw materials. Sodium carbonate was added to the mix to enable the formulation to work in our environment by dropping the melting temperature from a high level to a comfortable low level. 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. The produced silicon carbide abrasive grains were used to manufacture fine and coarse grinding wheels of international standard.   Some of the prominent factors affecting the produced grinding wheels include: wheel hardness with mean hardness values of 0.6961KN for fine wheel and 0.6407KN for coarse wheel, wheel wear with average wheel wear of 2.14 for fine wheel and 2.56 for coarse grinding wheel and wheel grinding ratios with mean grinding ratio of 28.97 for fine wheel and 23.80 for coarse grinding wheel. Similarly, the results of signal-to-noise ratios for wheel hardness give an average of 56.802 for fine wheels and 56.137 for coarse wheels, while for wheel wear we have a mean of -6.598 for fine wheels and -8.161 for coarse wheels. These values agreed with the Taguchi's the "larger-the-better" for wheel hardness and with the "smaller-the-better" idea of Taguchi. Also, the grinding ratio values for both the fine and coarse wheels conform to that of international standard.

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