EFFECT OF GRINDING ON SOME MECHANICAL PROPERTIES OF OSUN STATE CERAMIC TILES

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Ceramic is an engineering material that has endeared itself to many sectors especially the building services sector where it is used for floor tiles. Machining is a necessary finishing operation after casting and other forming operations. A very important machining operation performed on ceramic materials such as tiles is grinding to pave way for easy installation, aesthetics and safety. This work investigates the elemental and chemical composition of the raw materials used in the production of the ceramic tiles under investigation and study the effect of different grinding procedures on some mechanical properties of the ceramic tiles. The tiles were ground at two different grinding speeds and two different levels (continuous and intermittent at 2 seconds intervals). Breaking strength, flexural strength, hardness, and surface roughness before and after grinding were analyzed using the Signal-to-Noise (S/N) ratio. The result revealed that the elements and their respective oxides present in the raw materials were able to give strength, rigidity and support to the ceramic article. Also, grinding was found to affect the mechanical properties of the ceramic tile samples as the breaking strength and flexural strength reduces from 339.77 N for the control sample to as low as 273.30 N and 16.40 N/mm^2 respectively.

Keywords: *ceramic tiles, grinding, breaking strength, flexural strength, hardness*

1. Introduction

Ceramic tiles are extremely vitrified clay-based, materials that are usually produced from triaxial blends of kaolin ($Al_2Si_2O_5(OH)_4$), quartz (SiO_2), and feldspar (K, Na, Ca)$_2$O. Al_2O_3. $6H_2O$) [1-3]. It is a hygiene product primarily produced from a porous body and usually with a coating of white or colored glaze [4]. It is one of the most important products usedin the construction sector [5-6]. For hundreds of years, ceramic tile has been used to beautify bathrooms, living rooms, kitchens, laboratories, medical centers, shopping malls, public conveniences, and schools) and the clad exterior walls of buildings [4-7].

Machining is a manufacturing approach that is used to steadily remove excess materials from an article to produce the desired shape, dimension, and surface finish using different cutting methods [8]. Machining operations which usually include grinding, milling, drilling, turning, etc. are mostly carried out on metal and other engineering materials. For instance, Iseri *et al*. [9] machined zirconia ceramic using a custom-made grinding apparatus with different grinding procedures and found out that different grinding procedures had a counteracting effect on the flexural strength of zirconia. Meanwhile, Krajcarza *et al*. [10] evaluated the ability of abrasive water-jet traverse to cut ceramic tiles. The study focused on determining the effectiveness of abrasive water-jet traverse speed on the kerf width of ceramic tiles to be cut and found that the ceramic tiles' kerf width was slightly narrower at the bottom with several micrometers difference.

According to the European Commission [11], it may be necessary to subject ceramic tiles to machining operations while the final geometry or dimensional tolerance of the tiles cannot be achieved technically or with sufficient accuracy during the primary production process. Ceramic bodies are difficult to machine and therefore break abruptly or are damaged during machining operation or functional loading [9, 12-14].

The installation of ceramic tile usually requires cutting and/or grinding [15]. After installation, however, drilling of the tiles on the walls and floors is frequently required for Mechanical and Electrical (M&E) service providers to fix cabinets, sanitary wares, sockets, accessories, etc. While grinding of edges is necessary to ensure quality edge finish after cutting and hazard elimination in other to promote safety. The European Commission [11] also align with machining operation like sawing and grinding as requirements for the installation of wall and floor tiles on buildings; and drilling, to facilitate the installation of sanitary fixtures and accessories.

Meanwhile, several studies have demonstrated that the mechanical properties of ceramic tiles are germane to the performance of tiles after installation [4, 13, 16]. Flexural strength of ceramics is an important property for all applications involving impact loading conditions [4, 9, 13, 16-17], with tiles falling into that category due to various machining operations carried out on it before and after installation. The limits of breaking strength and flexural strength of any specimen are determined by both water absorption and thickness

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Table 1

Ceramic tile samples produced for grinding operation

Runs	Test sample	Dimension (mm)	Designation
1	Flexural strength (Machined)	140 x 45 x 8	R
2	Flexural strength (Control)	140 x 45 x 5	Rc
3	Breaking strength (Machined)	140 x 45 x 8	S
4	Breaking strength (Control)	140 x 45 x 5	Sc
5	Hardness (Machined)	10 x 10 x 10	H
6	Hardness (Control)	10 x 10 x 7	Hc

Table 2

Taguchi's Approach to Design Applied to the Grinding Experiments

Symbol	Factors	Unit	Levels	
			Continues Grinding (CG)	Intermittent Grinding (IG)
X_1	High Speed (HS)	Rev/min	HS	LS
X_2	Low Speed (LS)	Rev/min	LS	LS

HS – High speed, LS – Low speed, CG – Continuous grinding, IG – Intermittent grinding

of the specimen and it depends on the body composition, dimensions, and morphology of the flaws [4]. The flexural strength represents the highest stress experienced within the material at the point of failure. Ceramic systems are materials usually of low modulus of rupture [18].

Iseri *et al*. [9] showed that the flexural strength of zirconia ceramic is greatly affected by grinding, while the machinability of ceramic materials affects its hardness and strength [19] which in turn is affected by the properties of raw materials used in the production of ceramic tiles [3]. Consequently, the work seeks to characterize the raw materials used in the local production of the ceramic tiles and investigate the effect of different grinding procedures on some mechanical properties of ceramic tiles, since grinding is the most common machining process employed during the installation of tiles.

2. Materials and Methodology

Locally produced ceramic tiles manufactured from clay collected from Ipetumodu, an area in Ife North Local Government of Osun State; silica sand collected from the Isasa River, the boundary between the Ayedaade and Ife North Local Government areas of Osun State; and feldspar collected from Osogbo, the capital of Osun State, all in Nigeria was used for the production of ceramic tiles [20]. NEC 5SDH 1.5 MV Pelletron Accelerator (Model: 5SDH with an accuracy of 0.0001%) was used characterized the three localy sourced raw materials as described Abiola et al. [21]. As shown in Table 1, three replicates of ceramic samples run 1, 3, and 5 were produced for flexural strength, breaking strength, and hardness test respectively after grinding. A mini variable speed bench grinding machine (model LYZ3MM manufactured by A1Indusworld) was used to grind the ceramic tiles. The knob of the grinding machine was adjusted until an actual grinding speed of 500 rpm for low-speed and 2600 for high-speed was achieved as verified by a Tachometer. The specimen was marked 3 mm away from one side and ground until a 3 mm reduction of the specimen was achieved with continuous grinding (CG), and 2 seconds of intermittent grinding (IG) respectively. Control specimen was also analyzed but without grinding as described by Iseri *et al*. [9]. The Four runs (L-4) of grinding experiments used in the study are shown in Table 2. Flexural strength, breaking strength, hardness, and surface roughness of the specimens were determined as responses for each run of the experiment and taken as dependent variables.

The averages roughness (Ra) of the surface of machined specimens after the grinding operation was measured using a digital surface roughness gauge with piezoelectric pick up (Model: SRT-6223+) as shown in Fig. 1. The measurement was repeated four times as described by Omidiji *et al*. [22] and the average readings were recorded and presented.

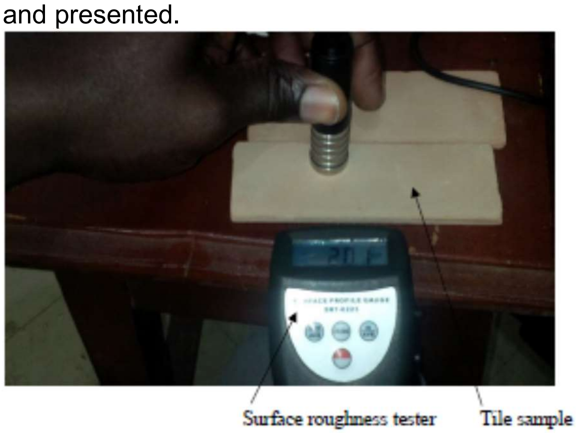

Fig. 1 - Digital surface roughness gauge used for the experiment

2.1. Determination of Signal to Noise Ratio

The term signal represents the desired value and noise represents the possible error [23]. Signal to Noise (*S/N*) ratio cut off unwanted interference that may have happened in the cause of running the experiments. Taguchi's method was used to identify the optimum cutting parameter levels to minimize the surface roughness. A Low surface roughness value will be desirable for maintaining higher tile quality; therefore, the smaller, which is the better, Signal to Noise ratio was used and can be calculated using equation 1.

$$\frac{S}{N} = -10\log\left\{\frac{1}{r}\sum\frac{1}{r}Ra_i^2\right\} i = 1,2,\ldots r, \quad (1)$$

where Rai is the value of surface roughness for the ith run in r replications [22].

2.2. Mechanical Properties Test

After the machining operation, the different ceramic samples were subjected to breaking strength and flexural strength using the Universal Strength Testing Machine (Serial No.: 140535, manufactured by Okhard Machine Tools Ltd); while the hardness test was investigated using Mohr's hardness test method in line with [2].

The breaking strength was calculated from equation (2) as:

$$S = \frac{FL}{b} \quad (2)$$

where, S is the breaking strength, in Newton; F is the breaking load, in Newton; L is the distance between the supporting rods, in millimeters (65 mm); b is the width of the test specimen, in millimeters as shown in Figure 2.

From the same test (Figure 2), the modulus of rupture also known as flexural strength was calculated for each sample of ceramic tiles using equation (3).

$$R = \frac{3S}{2h^2} \quad (3)$$

where R is the modulus of rupture, in N/mm^2; S is the breaking strength or force, in Newton; h is the minimum thickness of the test tile specimen, in millimeters.

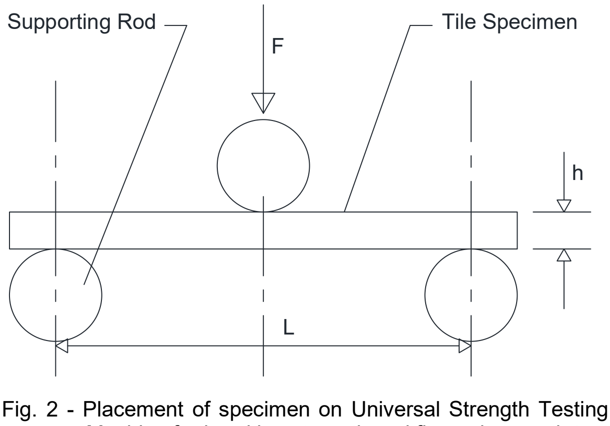

Fig. 2 - Placement of specimen on Universal Strength Testing Machine for breaking strength and flexural strength test

3.Results and Discussion

3.1. Composition of the Raw Materials

The results presented in Table 3 shows the elemental as well as the chemical composition of the clay, silica-sand and feldspar raw materials used in the production of the ceramic tile samples investigated in this study. The result shows that the raw materials (clay, silica-sand and feldspar) has high silicon (Si) content 64.9135%, 93.7597%, and 61.0271%; and its oxide (SiO2), 71.3165%, 95.2810%, and 68.8503% respectively. The clay sample is of the illitic-kaolinitic type and has a sizably high silicon concentration as decribed by Vasic et al. [5]. The clay used to make the ceramic tiles samples gives fluidity or plasticity to the ceramic product during the forming process [23]. Additionally, a high silicon content in the raw materials helps to lessen the tendency of the ceramic body towarp or deform at high temperature, as well as provide support, control shrinkage, improve density, hardness and rigidity in ceramic products [4, 21].

The next predominant element in the raw materials (clay, silica-sand and feldspar) is Aluminum (Al) with 16.5986%, 1.9904% and 16.1590% and its oxide 16.1062%, 1.7865% and 16.1015% respectively. The ceramic tiles made from these raw materials, can safely be reffered to as silicon-aluminate materials [5, 25-26] because of the predominance of silicon and aluminum , as well as their oxides. The increase in aluminum oxide among the other oxides in the clay can help to provide plasticity [4], and the formation of mullite fibers at high temperature can help to improve the flexural strength of ceramic samples [24]. The reduced silicon and increase aluminum and their oxide as well as the large amount of pottacsium oxide (K_2O) and Sodium oxide (Na_2O) in the feldspar compare to the other materials help to guarantee the effectiveness of the feldspar as good fluxing agent by forming a glassy phase at lower sintering temperature during the firing operation [27-28].

3.2. Implication of Grinding

Table 4 shows the effect of grinding on the mechanical properties of the ceramic tile samples. The grinding was carried out at low speed (500 rpm) and high speed (2600 rpm) and monitored with a tachometer. Based on the result, the control (unground sample) is the strongest on the bases of its best average breaking strength, 339.77 N; flexural strength, 20.39 N/mm^2; and Mohr's hardness, 4 MH recorded. Apart from the control sample, samples ground continuously at high-speed have higher average breaking strength, flexural strength, and Mohr's hardness (319.09 N, 19.15 N/mm^2, and 3.5 MH) compare to samples ground intermittently at high speed (296.93 N, 17.82N/mm^2, and 3.5 MH) respectively. At the low speed and with continuous grinding, the average breaking strength, flexural strength, and Mohr's hardness were 299.89 N, 17.99 N/mm^2, and 4 MH respectively; corresponding values for samples ground intermittently at low speed were 273.30 N, 16.40N/mm^2, and 4 MH respectively. Comparing the test specimens, sample ground continuously at

Table 3

Chemical composition of the raw materials used in the production of the ceramic tile samples"

Periodic Number	Element	Oxide	Element. Value (%)			Oxide Value (%)		
			Clay	Silica Sand	Feldspar	Clay	Silica Sand	Feldspar
11	Na	Na_2O	1.3722	0.6625	5.7406	0.9499	0.4243	4.0807
12	Mg	MgO	1.1410	0.1516	0.0700	0.9715	0.1195	0.0612
13	Al	Al_2O_3	16.5986	1.9904	16.1590	16.1062	1.7865	16.1015
14	Si	SiO_2	64.9135	93.7597	61.0271	71.3165	95.2810	68.8503
15	P	P_2O_5	-	0.1026	0.1689	-	0.1117	0.2043
17	Cl	Cl	1.1297	0.0137	0.2110	0.5802	0.0065	0.1113
19	K	K_2O	7.3946	0.7230	16.3283	4.5743	0.4138	10.3726
20	Ca	CaO	1.4020	0.3493	-	1.0075	0.2322	-
22	Ti	TiO_2	0.5978	0.9767	0.0495	0.5119	0.7739	0.0436
23	V	V_2O_3	0.0272	-	-	0.0205	-	-
24	Cr	Cr_2O_3	0.0305	-	-	0.0229	-	-
25	Mn	MnO	0.0370	0.0337	0.0032	0.0245	0.0207	0.0022
26	Fe	Fe_2O_3	5.1591	1.1639	0.1837	3.7882	0.7904	0.1385
28	Ni	NiO	-	0.0036	-	-	0.0021	-
29	Cu	Cu_2O	-	0.0414	-	-	0.0221	-
30	Zn	ZnO	0.0018	0.0107	-	0.0011	0.0063	-
35	Br	Br	-	0.0061	0.0013	-	0.0029	0.0007
37	Rb	Rb_2O	0.0016	0.0021	0.0574	0.0009	0.0011	0.0332
38	Sr	SrO	0.0902	0.0090	-	0.0548	0.0051	-
40	Zr	ZrO_2	0.0832	-	-	0.0577	-	-
56	Ba	BaO	0.0202	-	-	0.0116	-	-

Table 4

Mechanical Properties of Grinding Experiments

Runs	Factor level		Responses				
	X_1	X_2	Ra (μm)	S/N ratio	Breaking strength (N)	Flexural strength (N/mm^2)	Mohr's hardness (MH)
Control			62.92	-51.21	339.77	20.39	4
1	HS	CG	71.96	-52.37	319.09	19.15	3.5
2	HS	IG	89.02	-54.22	296.93	17.82	3.5
3	LS	CG	91.27	-54.44	299.89	17.99	4
4	LS	IG	122.26	-56.97	273.30	16.40	4

Ra – Surface roughness; S/N ratio – Signal-to-Noise ration; HS – High speed;
LS – Low speed; CG – Continuous grinding; IG – Intermittent grinding

high speed resulted in the highest strength level while specimen ground intermittently at low speed had the lowest strength values.

In this study, the effect of low and high-speed grinding on the mechanical properties of ceramic tiles was compared. The influence of the grinding period (continuous and intermittent grinding) was also evaluated. It was shown that all the different grinding procedures adopted had a contradictory effect on the mechanical properties of ceramic tiles. Table 4 reveals that the flexural strength of the ceramic tile reduces with increased hardness. This was corroborated by Callister [29], who showed that the hardness of any material is inversely proportional to its ductility and that a ductile material withstands higher strain before it ruptures. A brittle material tends to rupture with little strain, the reason for the sample ground at low speed to have higher mohr's hardness and lower breaking and flexural strength.

The specimens ground continuously with low speed had 9.7% higher strength than those ground intermittently while specimens ground continuously with high speed had 7.5% higher strength than those ground intermittently. However, the control sample had 24.3% higher strength than intermittent grinding with low-speed, 12.8% higher strength than continuous grinding with low-speed, 14.4% higher strength than intermittent grinding with high speed, and 6.5% higher strength than continuous grinding with high speed.

Based on the results, it was revealed that grinding procedures had an negative effect on the mechanical properties of the ceramic tiles produced locally which is in agreement with Quinn *et al.* [30]. Intermittent grinding which can be considered as rough grinding, may be responsible for the low strength recorded with intermittent grinding and this is due to residual crack caused by repeated impact with the grinding wheel as described by Wang *et al.* [31]. As the strength of ceramic tiles is known to be affected by a crack [32]; the repeated impact of the grinding machine on the ceramic tiles sample due to intermittent grinding could result in the possible crack(s) which affect the strength of samples ground intermittently. While the higher strength recorded with continuous grinding compared to intermittent grinding may be due to continuous and increased heat generation associated with continuous grinding Iseri *et al.* [9]. It is expected that the higher temperature resulting from continuous grinding could alter the microstructure and crystalline condition of the ceramic sample. Thus, the higher strength with samples ground continuously.

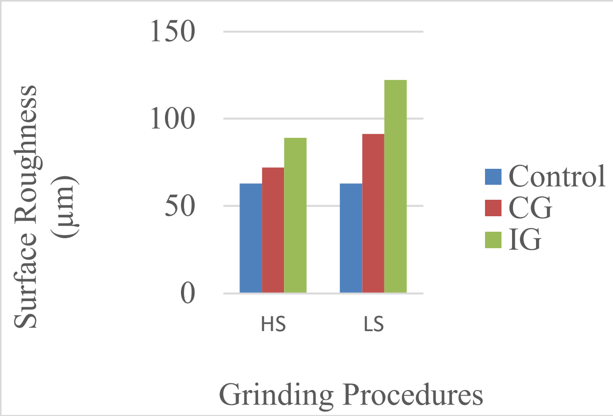

Fig. 3 - Surface roughness of ceramic sample machines using different grinding procedures

Figure 3 shows the comparison between the surface roughness of the different ceramic samples before and after grinding. The surface roughness of the control sample of 62.92 μm and S/N ratio of -51.21 is found to be better when compared to the 71.96 μm and -52.37 for sample grind continuously with high-speed; 89.02 μm and -54.22 for sample grind intermittently with high-speed; 91.27 μm and -54.44 for sample grind continuously with low-speed, and 122.26 μm and 56.97 for sample grind intermittently with low-speed respectively.

Considering the low surface roughness and high Mohr's hardness of the control sample compared to the machined sample, it is convenient to assume that the fluxes developed as a result of the molten feldspar as the ceramic attained its sintering temperature during production have covered the surfaces of the ceramic sample and close all the pores within the ceramic article. Thereby, increasing the hardness in improving the smoothness of the control ceramic sample [20, 26, 33].

It should be noted that scatter obtained in the continuous grinding process is always slightly less compared to the intermittent grinding process. This may be due to mechanical shocks or repeated impact load generated by the intermittent grinding process [34].

4.Conclusion

In conclusion, the raw materials used in this study possesses quality amount of silicon mineral which help to support the rigidity, strength, hardness and control shrinkage in the ceramic tiles. Also, the aluminum, potassium and sodium in the feldspar material help generate enough flux needed to form glassy phase on ceramic articles.

Furthermore, all grinding procedures had a damaging effect on the mechanical properties of the ceramic tile samples. The best ceramic grinding procedure was achieved with continuous grinding at high speed which revealed breaking strength, flexural strength, and surface roughness of 319.09 N, 19.15 N/mm^2, 3.5 MH, and 71.96 μm respectively.

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