THE EFFECT OF GRAIN SIZE ON THE FRACTURE BEHAVIOUR OF GRANITE BASED COMPOSITE

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ABSTRACT

A number of technologies today place much emphasis on mechanical properties of materials that are used to enhance functionality, durability and aesthetic values in products. These properties include hardness, fracture, toughness, density, stress and wear resistance. These requirements when found in any material other than mild steel they are usually exploited as a technical requirement for the production of goods. Ceramic materials have been found to possess load-bearing qualities and as such have been adopted for various manufacturing purposes and applications. In this vein, granite sawing waste, kaolin and ball clay were purposefully sampled and combined for the experiment in this research. Each of these materials was independently analyzed as required by research standards. These materials having been reduced to fine powder form, were independently sieved into three grain sizes using mesh 80, 100 and 120 (177, 149 and 125 microns respectively). They were compounded into three different bodies A, B and C according to the grain sizes above. Tests bars were prepared to test the compressive, harness and impact properties of these ceramic composites. The findings from the research makes bare the usefulness of different grain sizes when it comes to body composition for load bearing purposes. This was proven by the results of the mechanical tests carried out. The hardness test result proves to be higher in value than the two other properties, though they were also useful for toughness and strength requirement. It was also discovered that the inclusion of ball clay into granite body served as the main binder or plasticizer. The use of ceramic materials in the place of steel and other metals to develop functional and structural products remains a viable option in the production process.

INTRODUCTION

The use of ceramic materials in place of steel and other metals in developing functional and structural products remains a viable option that is attracting series of researches. A number of technologies today place much emphasis on mechanical properties of materials that are used to enhance functionality, durability and aesthetic values in products. These properties include hardness, fracture, toughness, density, stress and wear resistance. These requirements when found in any material other than mild steel they are usually exploited as a technical requirement for the production of goods. Ceramic materials have been found to possess load-bearing qualities and as such have been adopted for various manufacturing purposes and applications. Example of this has been the production of balusters, furniture footholds as seen in (Alkali 2015).

One of the most serious drawbacks of ceramic materials is their brittleness due to low fracture toughness. Thus fracture toughness constitutes a major limitation to the optimal performance of ceramic materials. According to Szutkowska (2012), fracture toughness is a measure of a materials ability to resist fracture in the presence of cracks. This deficiency is currently being addressed by several researchers in order to produce tough

and strong ceramics that can perform reliably so as to make ceramics competitive along with other materials used in the manufacture of products.

Vast quantities of goods are needed on a daily basis to meet basic human needs. Necessity therefore lies on researchers to use various technological and innovative processes to achieve product manufacture be it in the building industry or household appliances. One of the technologies adopted in achieving the above has been the development of workable ceramic bodies from earth resources using primary and secondary materials. These attempts have resulted in combining common clays with other residues or industrial wastes from mining activities to produce useful products which serve both domestic and engineering purposes.

For the materials adopted for use in support and load bearing applications, they are selected by measuring their forming ability and performance when put to the exact use. The first step in determining the choice of materials is to analyze them to know their most important compositional makeup and their eventual characteristics when applied for various forming processes, heat treatment and behavior under impact. It is found that materials that are the same in constitutional makeup many times do vary in behavior based on their microstructure or grain size.

Granite dust has been used for the manufacture of several products including roofing tiles, floor tiles, bricks, decorative ceramics, kitchen tops furniture accessories etc. In the production of these goods, no particular note was made on the issue of grain size since such requirement was not needed. However, in structural and load bearing application which is the focus of this research, grain size is the central determinant of its fracture resilience, and this is what the research is set to establish. Upon its success, it is hoped to be recommended for applications such as the production of foot stand for side stools, rails balusters and bases for standing fans and lamps.

Procedure

Granite sawing waste, kaolin and ball clay were purposefully sampled and combined for the experiment in this research. Each of these materials was independently analyzed as required by research standards. Tables 1, 2, 3 show the results of the analysis of each sample. The materials having been reduced to fine powder form, were independently sieved into three grain sizes using mesh 80, 100 and 120 (177, 149 and 125 microns respectively). A micron is another measurement used for measuring particle size, which is one-millionth of a meter or one twenty-fifth thousandth of an inch (Netafim, 2015; Meshmicrons sizes, 2015; Mesh, 2015 and Cameron, 2015). After this, they were combined in different compositions based on their microstructure as indicated in table 4. These materials were further soaked and made into lumps and test bars were produced from them. These were fired to 1260°C which was the recommended temperature for these composites in (Alkali, 2014).

Table 1: Chemical Analysis of Ball Clay

Compound	Al	Si	S	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Ag	Eu
Consc. Unit	17.9 %	56.4 %	0.085 %	4.17 %	1.57 %	1.89 %	0.075 %	0.025 %	0.040 %	14.10 %	0.033 %	3.47 %	0.20 %

Source: Defence Industry Corporation Multi-purpose Science Laboratory, Kaduna State.

Table 2: Chemical Analysis of Granite

Compound	Al	Si	S	K	Ca	Ti	V	Mn	Fe	Cu	Zn	Ba	Eu	Re
Consc. Unit	11.8 %	59.4 %	0.089 %	11.3 %	5.06 %	1.22 %	0.032 %	0.19 %	10.33 %	0.026 %	0.058 %	0.35 %	0.16 %	0.09 %

Source: Defence Industry Corporation Multi-purpose Science Laboratory, Kaduna State

Table 3: Chemical Analysis of Kaolin

Compound	Al	Si	K	Ca	Ti	V	Mn	Fe	Ni	Cu	Ca	Re	Ti	
Consc. Unit	37.1 %	56.7 %	2.00 %	0.69 %	0.69 %	0.15 %	0.00 %	0.06 %	2.23 %	0.04 %	0.069 %	0.17 %	3.47 %	

Source: Defence Industry Corporation Multi-purpose Science Laboratory, Kaduna State

Table 4: Base materials Combination in the Kaolin and Ball Clay

Mesh Size	80	100	120
Granite Waste	70%	60%	50%
Ball Clay	20%	20%	10%
Kaolin	10%	20%	40%

Source: Personal Studio Experiment

Mechanical Property Test

The mechanical property test of these composites which are recommended for the production of load bearing structure was carried out. This is because, in applications of this nature, mechanical properties of materials play a central role in determining its functionality. According to Askland and Phule (2003) engineering materials are selected by specifications indicating service condition expected of the component. So, in order to determine some of the properties required for this body to work: fracture toughness, wear, compressive strength and hardness test bars were made as earlier stated and were used to carry out the test.

Mechanical Property Test Specimen Preparation

In order to test some properties that make these accessories efficient and functional, different samples of test bars in Plates I and II were prepared in accordance with the three mesh sizes of 80, 100 and 120 used in sieving the body for this experiment to different grain sizes. This were formed into bodies with the addition of water to a stiffen consistency that is workable. Some of the bodies were semi-plastic, relatively plastic and non-plastic. Before the formation into tests bars they were left inside a plastic container to age for few days as it existed in ceramic production.

The samples were labeled A, B and C; for the purpose of identification and avoidance of confusing the body, since they look alike. These were used to carry out mechanical properties tests like compressive strength, hardness and impact test, see items in plate 1 and 2.



Plate 1: Spacemen for Impact, Hardness and Compressive Test
Source: Researcher Photograph, 2015



Plate 2: Spacemen for Impact, Hardness and Compressive Test
Source: Researcher Photograph, 2015

Compressive Strength Test

The compressive strength test was carried out using the Norwood Car. Nr 261 Universal Material Testing Machin-100 Kilo Newton (KN) in the department of Mechanical Engineering ABU Zaria. Compressive strength is the capacity of a material or structure to withstand axially directed pushing force (s). When the limit of compressive strength is reached, materials are crushed. Compressive strength is usually measured on a Universal Material Testing Machine (UMTM). Mechanical testing measuring maximum and minimum amount of compressive load a material can receive before fracturing.

The testing piece is made in form of a cube plate II and figure 1, is compressed between the plates (platon and the platform) of a compression testing machine by a gradually applied load by means of a hand pump. Materials such as brick and concrete exhibit a great compressive strength before fracture. The top and bottom areas of the sample are measured by measuring the length and breadth of the sample fig. 1 and hence the compressive strength can be calculated (Asare, 2009).

Before the test, the initial length before fracture is taken and when the load is applied the change in length at the point of fracture and the load (force) applied are taken. This reading is possible from the load cell digital readout connected to the UMTM. Table 5 gives the details and final average results as compressive strength.

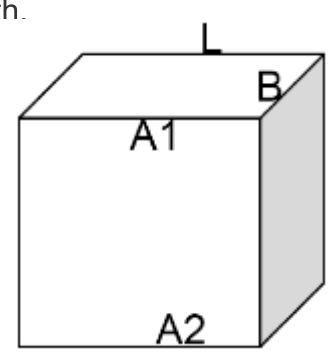


Fig. 1: Cube sample used for the Compressive Test

L = length
B = Breath
A1 = Top Area
A2 = Bottom Area

Area = length x breath

$$\text{Compressive strength} = \frac{\text{Maximum load at failure (KN)}}{\text{Average area of sample face (mm)}}$$

$$Comrpessive\ strength = \frac{Crushing\ load}{Area\ of\ sample}$$

Compressive strength is measured in Kilo Newton per millimeter square ($KNmm^{-2}$) or mega Pascal (Mpa). Below are the compressive test values Table 5 and 6.

Table 5: Compressive Test Result in ($KNmm^{-2}$) for the Samples Fired to Glaze Temperature $1260C^0$

S/N	SAMPLES	LENGTH (mm)	WIDTH (mm)	HEIGHT (mm)	INITIAL LENGTH (mm)	POINT OF FRACTURE REDUCE OR CHANGE IN LENGTH	LOAD K(N)	AREA (mm^2)	COMPRESSIVE STRENGHT (N) ($KNmm^{-2}$)	ACTUAL COMPRESSIVE STRENGHT OF EACH SAMPLE I.E ?X/N ($KNmm^{-2}$)
GLAZE TEMPERATURE SPECIMENS										
1	A	10.6	9.7	10.6	21.90	20.83	4.84	102.82	0.0471	**0.03553**
		10.6	10.2	12.8	21.52	20.07	5.51	108.12	0.05096	
		9.5	10.0	11.7	22.89	22.25	0.81	95.0	0.00853	
								TOTAL	**0,09294**	
2.	B	11.2	11.0	13.6	21.84	20.74	2.81	123.2	0.02281	**0.03098**
		11.0	9.8	12.0	21.26	19.92	4.06	107.8	0.03766	
		11.6	10.7	11.6	21.48	20.60	4.03	124.12	0.03247	
								TOTAL	**0,09294**	
3.	C	10.2	11.0	10.7	21.65	21.18	3.30	112.2	0.02941	**0.06780**
		11.0	9.0	11.3	20.51	17.46	12.30	99.0	0.12424	
		9.5	11.0	11.3	20.78	19.74	5.20	104.5	0.04976	
								TOTAL	**0.20341**	

Table 6: Compressive Test Result for the Samples Fired o Bisque Temperature $800\text{-}900C^0$

S/N	SAMPLES	LENGTH (mm)	WIDTH (mm)	HEIGHT (mm)	INITIAL LENGTH (mm)	POINT OF FRACTURE REDUCE OR CHANGE IN LENGTH	LOAD K(N)	AREA (mm^2)	COMPRESSIVE STRENGHT (N) ($KNmm^{-2}$)	ACTUAL COMPRESSIVE STRENGHT OF EACH SAMPLE I.E ?X/N ($KNmm^{-2}$)
BISQUE TEMPERATURE										
1	A	11.0	12.0	12.8	22.04	21.05	0.19	132	0.00144	**0.00502**
		11.0	12.2	12.3	22.20	21.03	0.29	134.2	0.00216	
		10.4	12.2	12.6	21.97	20.70	0.18	126.88	0.00142	
								TOTAL	**0.01506**	
2.	B	8.8	12.3	12.8	20.01	19.06	0.50	108.24	0.00462	**0.00489**
		8.7	12.0	12.0	19.95	17.65	0.47	104.4	0.00450	
		8.3	11.3	12.0	19.61	18.42	0.52	93.79	0.00554	
								TOTAL	**0.01466**	
3.	C	9.5	11.2	11.7	20.77	19.94	0.32	106.4	0.03008	**0.01163**
		9.7	11.5	11.5	21.02	20.05	0.26	111.55	0.00233	
		9.7	11.7	12.3	21.05	19.82	0.28	113.49	0.00247	
								TOTAL	**0.03488**	

3.3 Hardness Test

Hardness test measures resistance to penetration of the surface of a material by a hard object. Hardness represents resistance to scratching or indentation and a qualitative measure of the strength of the material. The "Indentec Universal Hardness Test Machine" in Mechanical Engineering Lab for testing Materials ABU, Zaria; was used to achieve the hardness test in this study. The Rockwell test was performed on F scale which is used for soft materials

and aluminium; with a minimal load of 10kg up to a total of 60kg. Table 7 represents The Rockwell Hardness Scale used when testing hardness of materials. The averages of the three tests carried out for each sample were calculated as the ultimate hardness of each. See Table 8.

Fracture Toughness or Impact Test

Chappy Impact Testing Machine was implored for this test; with capacity of 15 and 25 Joules (J). The 25 J is for hard materials while 15 J is for soft materials like ceramics bodies. The specimens where prepared as long rectangles of length 100mm, width 10mm and height 10mm. Two pieces were prepared for each sample, making a total of six pieces. The averages of the two tests carried out for each sample were calculated as the ultimate impact strength of each.See Table 9:

Table 7: ROCKWELL Hardness Scales

S/N	Scale Symbol	Indenter	Major Load *(kg)*
1.	A	Daimond	60
2.	B	1/16 in. ball	100
3.	C	Diamond	150
4.	D	Diamond	100
5.	E	1/8 in. ball	100
6.	F	1/16 in. ball	60
7.	G	1/16 in. ball	150
8.	H	1/16 in. ball	60
9.	K	1/8 in. ball	150

Source: William (1996)

Table: 8 Hardness Test Result

S/N	SAMPLE	TEST 1 (HRF)	TEST 2 (HRF)	TEST 3 (HRF)	TOTAL (HRF)	AVERAGE (HRF)
1	**A**	123.0	123.7	118.0	364.7	**121.57**
2	**B**	114.1	109.5	93.9	317.5	**105.83**
3	**C**	111.9	115.5	110.5	345.9	**115.30**

Where H = hardness, R = Rockwell, F= Scale used

Table 9: Impact Test Result

S/N	SAMPLE	TEST 1 (J)	TEST 2 (J)	TOTAL (J)	AVERAGE (J)
1	**A**	0.4	0.3	0.7	**0.35**
2	**B**	0.3	0.3	0.6	**0.3**
3	**C**	0.4	0.2	0.5	**0.25**

Results and Discussions

The Test samples that came from the compounded bodies were hard enough to withstand the pressure of handling during green drying, bisque and gloss firing operations. One of the most fascinating discoveries in this research is the fast drying rate and none cracking tendency experienced when these samples were exposed at ambient temperature and while under the fan. It was equally found out that the drying rate of each grain size composition differ to an extent. This explanation can be supported from the fact that, fine grain materials have less or no pores because the particles are very compact. While the coarse grain sizes have sufficient pores, so this absorbed more air than the fine grain body. The material sieved with 177 microns-mesh dry faster, than the 149 micron- mesh size and finally the 125 microns-mesh size was slower than both.

The higher the microns the larger the diameter of the sieve which means the larger the particle the bigger the grain size. The lower the microns the lesser the diameter of the sieve which means the smaller and finer the particle/grain size.

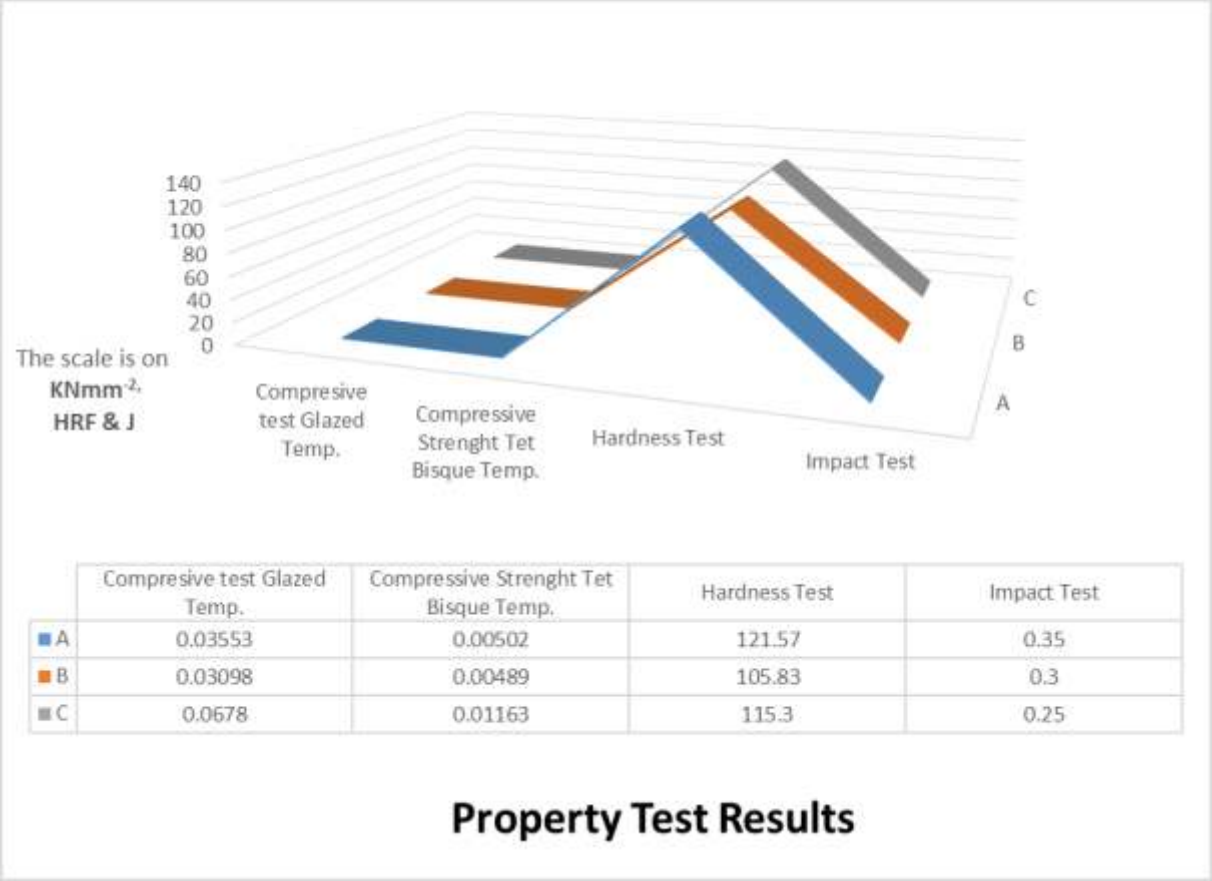
At the point of preparing the bars before green state drying and eventually firing them, the handling was with a great skill and care. This is because the bodies were not that plastic. The percentage of ball clay was not more than 20%.

In terms of the mechanical test, the three samples results were satisfactory. The three materials comfortably gave a result from table 5, 6, 8, 9 and fig 2 that withstood compressive, impact and hardness stresses during application and utilization. The produced bodies proved their ability in load bearing without any fracture.

The three grain sizes have some degrees of variations in the results collected. This occurred because fine grain sized materials are more compact, stronger and tougher while this attribute reduces with the large particle size. In other words, fine particle size bodies are stronger and tougher than large or coarse size particle bodies.

The three mechanical stress tests carried out; compressive, hardness and impact test have similarities in terms of their results. Tables 5, 6. 8 and 9 shows the results of three different samples labelled A, B and C. The observation generally shows that the three grain sizes displayed a high degree of hardness than the other two tests as depicted in the graph fig. 2 in comparison with the compressive and impact tests.

In terms of the compressive strength, C sample from the graph is the strongest, this is followed by A and then B as the least in terms of strength and resistance to fracture. The reason is because of their variations in grain sizes. The C are the 120 mesh, the A are 100 mesh size and the B are the 80 mesh sized bodies.



	Compresive test Glazed Temp.	Compressive Strenght Tet Bisque Temp.	Hardness Test	Impact Test
A	0.03553	0.00502	121.57	0.35
B	0.03098	0.00489	105.83	0.3
C	0.0678	0.01163	115.3	0.25

Property Test Results

Fig. 2: Graph of Mechanical Property Test Results and the Relationship of the Tests Source : Research Studio Experiement, (2015)

In terms of the impact strength, sample A is the strongest; this is followed by B and then C as the least in terms of strength. The reason is because of their variations in grain sizes also. The A are the 149 microns-mesh size, the B is 177 microns-mesh size and the C are the 125 microns-mesh sized samples.

Further, when materials have reasonable pores there are networks as lattice much more created between the particles. These aids in bonding to each other than the compacted materials that have no or less networks and can easily break.

Considering hardness strength, specimen A is the strongest; this is followed by C and then B as the least in terms of resistance to scratch. At this point the C should have been the strongest, followed by A and them B. This scientific abnormality occurs when there is invisible crack or faults unnoticed while preparing the specimen. The conclusion derived from the test is that, the mechanical performance of these products is based on the grain size of a body.

The findings from the research proves the usefulness of the variation of different grain sizes when it comes to body composition for load bearing purposes. It was also discovered that variation in the inclusion of ball clay into granite body serve as the main binder or plasticizer. This is because without the ball clay as a plastic material included, the composition of granite and kaolin alone no matter how fine the particles may be cannot be moulded except one chooses other production methods other than casting or moulding. Likewise handling generally of such bodies without the ball clay would be difficult.

Though granite dust contains rich

properties that make a body tough, yet it can be best combined with ball clay for the purpose of this research. The kaolin on the other hand is a very refractory material that has some level of plasticity,yet putting the three materials together makes a good composition to obtain a workable ceramics body for use in load bearing applications.

The results obtained from these three bodies were further utilised to produce some simply load bearing accessories plate's III, IV and V for use in furniture production. This proves what George (2002, advanced that the performance of ceramics is evaluated on the basis of full-scale tests.

Conclusion

The tested ceramic compositions exhibited high hardness test and good reliable compressive and impact attributes for load bearing and other similar usage, fig. 2. The three materials combined: ball clay, kaolin and granite dust combined to produce a good stable body. This is seen from the data collected and the samples of accessories produced and further used to prove that ceramics can actually bear load without collapsing or disintegrating.

Ceramics composites are quite promising having high strength characteristic inherent in them. The use of ceramic materials in the place of steel and other metals to develop functional and structural products remains a viable alternative or option. This can comfortably stand or replace steel or other materials for functional purposes. These properties hardness, fracture, toughness, density, stress and wear resistance can be further exploited in other ceramic materials as technical requirements for the production of ceramic related goods.



Plate 3 and 4: Cast and fired Ceramic Armrest and Frontal attachments from the Compounded bodies. Source: **Researcher Photograph, 2016**



Plate 5: Cast and Fired Ceramic Footholds Ceramics Furniture Accessories
Source: Researcher Photograph, 2016

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