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Towards Local Processing of Ceramic Raw Materials in Nigeria: the Ball Mill

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ABSTRACT

Ceramic materials often occur in rock-like form needing processing to render them to useable forms. This has been challenging locally due to lack of processing equipment chief of which is the ball mill. As the cost of foreign mills is prohibitive, this study focuses on the fabrication of a low-cost ball mill with consideration for appropriate ball mill speed. The effectiveness of the ball mill was determined using material charges of quartz and feldspar prospected locally. Ball milling was done on batches of the materials sequel to which the particle size spread was analysed descriptively on a multiple bar chart. It was observed from analysis that the milled materials became finer with increased spread of materials within the fine range as they were milled for longer periods. This study has assistedin revealing the quality of local content in the fabrication of a ball mill.

Keywords: Local Processing, Ceramic Raw, Materials, Nigeria, Ball Mill.

INTRODUCTION

Ceramics, seen as the heat treatment of non-metallic, inorganic materials in earthy rock-like forms to obtain useful products, essentially involve raw material processing to achieve desired results. The bulk of raw materials obtained from the earth's crust are in need of further processing before deemed useful for body and glaze formulation. Equipment for material processing vary from those that break up large lumps to pebble sizes, to those that pulverize and render materials to the ultra-fine stage. Modern ceramics without a number of these key equipment becomes almost impracticable- a key factor for the slow development of ceramics in Nigeria as adduced to by several authors Alkali (2003); Gukas (2003); Opoku (2003) to mention a few.

Due to the exorbitant cost of importing this equipment, local production becomes inevitable if ceramics' development and sustainability is desired. Though research efforts over the years have been made in this regard notably Datiri (2005)-"Engineering Challenges in Dry Processing of Ceramic Raw Materials-The Home Made Mill", Gonah, Yaro and Ahuwan (2003)-"Design and Fabrication of Ceramics Glaze Materials Processing Machine", Ojie and

Nwaogu (1999)-"Construction of Prototype Blunger" as revealed by literature, it must be said that efforts at developing a ball mill have been sparingly attempted,a possible reason being the difficulty in lining the inside of the mill, using suitable materials which may be hard to come (Akinbogun and Kashim, 2006). This becomes particularly worrisome as Cardew (1969) regarded the ball mill as the most important raw material processing equipment of the ceramist.

The importance of fine processing in glaze formulation cannot be over stated, as the extent of glaze melt to achieve desired outcome, is dependent on particle size and spread of constituent raw materials, as much as it is on composition or formulation using scientific or empirical methods (Fraser, 1984). It is of note that the availability of the ball mill within the reach of the cottage ceramic industry will ease the processing of the abundantly available local raw materials (Kashim, 2004)hence, reducing the current over-dependence on foreign materials. This will positively affect the quality of indigenous ceramic products as an in-depth knowledge of raw materials will enhance their exploitation and beneficiation. Other advantages include the availability of essential raw materials at reduced cost as possible specialization in raw material processing will arise, increase in local demand for ceramic products due to improved quality and savings in foreign exchange amongst others.

Based on the foregoing this research embarked on the production of a ball mill, with a material charge of 15kg using porcelain tiles as liners, inlaid in a metal jar, to possible contamination of milled materials. Design in the context of this research focuses on the use of local resources, with foreign input where necessary. Adaptive design was employed which involves the study of existing designs of ball mills, with minor modifications made to produce one, with better affordability in terms of cost when compared to imported mills. The research is targeted at solving ceramic raw material (fine) processing problem which is deemed as the most difficult and laborious activity of the ceramist in the entire production process. The need to process the abundant ceramic raw materials and the availability of skilled manpower and expertise in ball mill production prompted this research.

The Ball Mill

Nelson (1988) described the ball mill as porcelain or metal jar filled often with porcelain-type grinding media and rotated with either a wet or dry charge of materials. According to Norsker (1989) it is used for fine grinding and blending of ceramic materials. The grinding action in ball mill takes place between porcelain balls through impact and abrasion (termed as rubbing by some authors) as the balls roll, one over another in the rotating metal jar (Fraser, ibid). This is achieved only at a suitable speed, as under and excessive speeds do not aid the balls in their milling function.

The ball mill operates on six important factors, which are: Speed of ball mill, Quantity and Size of porcelain balls, Quantity of raw materials, Consistency of raw materials for wet grinding and Grain size of the raw materials to be processed. Norsker (ibid) stated that the appropriate ball mill speed for optimal operation is 70% of the critical speed which is calculated using the formula:$\frac{29.9}{\sqrt{r}}$rpm where "r" is the radius of the ball mill interior in meters and rpm is rotations per minute. He further suggested a volume relationship of ball mill charge to be: Grinding media (45% - 55%), Material charge (20% - 25%) and Water (12% - 20%).

Components used in the fabrication of the ball are as stated in table 1. They were modified through various machining processes using equipment as the Milling machine, Lathe machine, Turning machine, Drilling machine, Power sawing machine, Grinding machine and the Threading machine. Metal finishing processes employed for the study were buffing, lacquering and painting. Buffing involved the polishing of the metal surface, Lacquering the use of a plastic thinner solution to prevent corrosion and rusting and Painting which is the coating of the metal surface.

Table 1: The components list

S/N	Material	Description	Size	Quantity
1	Bolts	for roller bearing for metal drum end flange	12mm × 50mm 10mm × 37.5mm	8 4
2	Roller Bearings		175mm × 62.5mm × 100mm	4
3	Pulleys	input pulley Output pulley	65mm diameter 500mm diameter	1 1
4	Electric Motor	single phase	1400RPM 5hp	1
5	Drive belt	V belt	650mm length	2
6	Flanges	steel plate steel cone	plate: 200mm diameter 12.5mm thickness Cone: 50mm height 40mm diameter	2 2
7	Spur gears	pinion gear Wheel gear	16 teeth 64 teeth	1 1
8	Metal jar	Steel drum	550mm diameter 550mm length	1

Source: Oresegun, A.O. Field work (2012)

Ball mill fabrication poses a number of challenges notably the treatment of liners to render them to suitable forms and sizes, the choice of cutting tool utilized for treatment and its attendant risks, the suitability of available alternative liners in terms of purity and possible contamination of processed materials, the technical-engineering requirement and skill demand in ball mill production, liners' setting and choice of suitable bonding material and the determination of an appropriate ball mill speed to render charged materials to desired fineness. These highlighted problems and many more are best solved through experimentation, maintaining standard procedures where available (and applicable) and creating room for further research to improve on research findings.

MATERIALS AND METHODS

The study is an experimental project. This involved the active modification of components of the ball mill at the different stages of production. Data for the study was obtained from both primary and secondary sources. Data processing involved the calculation of the appropriate ball mill speed using the critical speed formula, fabrication of the ball mill and metal jar using the processes of machining by taking appropriate measurements and electric arc welding to join components permanently. Working drawings (figure 1) and specifications (tables 1 and 2) relevant to the fabrication of the ball mill were adequately prepared as guide.

Table 2: The cutting list

S/N	Description	Size	Material	Quantity	Remark
1	Height Width Length	762.5mm 800mm 968.75mm	62.5mm ×62.5mm angle iron	6 6 4	2 pieces welded at 237.5mm offset for gear train support
2	Length	300mm 200mm	40mm shaft	1 1	300mm carries pinion gear and output pulley 200mm carries wheel gear

Source: Oresegun, A.O. Field work (2012)

The Procedure for the Development of the Ball Mill

This was done in stages as described thus:

Stage 1: Construction of Angle Iron Support Base

A 62.5mm × 62.5mm angle iron of lengths 900mm (12 pieces) and 1200mm (3 pieces) was cut into suitable lengths of 762.5 mm for height (6 pieces), 800mm for width (6 pieces) and 968.75mm for length (4 pieces) using the hacksaw. These cut pieces were welded into a unit using the electric arc welding machine. The unit (Plate 1) acts as support for the metal jar and the transmission system of pulley and gear train.

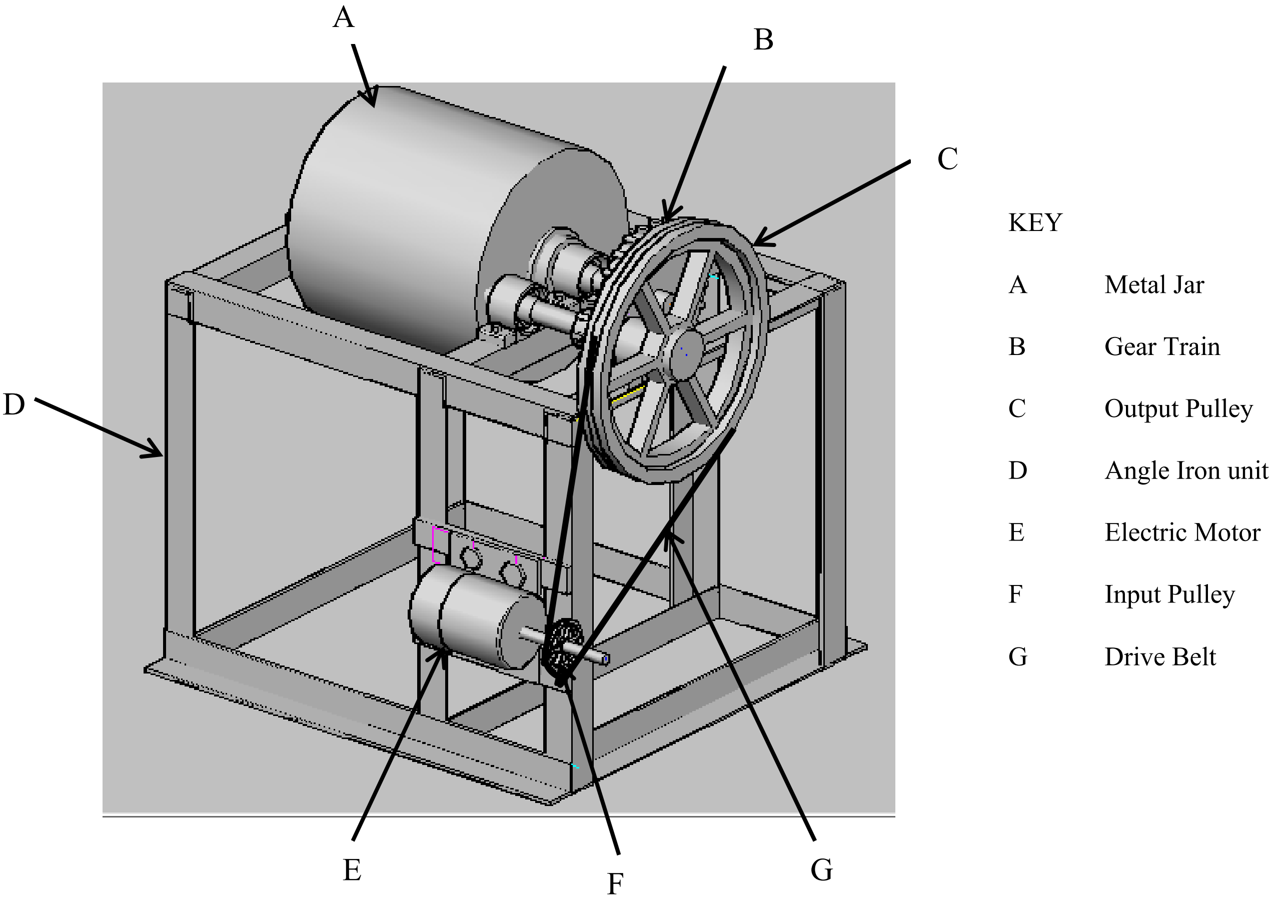


Fig. 1: The Ball Mill Design
Source: Illustration by Oresegun, A.O.

Stage 2: Cutting and Turning of Transmission Shaft

The 40mm diameter, transmission shaft was cut into lengths of 200mm (2 pieces), both to transmit motion to the metal jar. A cut of length 300mm was also made to transmit motion, from the electric motor. These lengths of shaft were machined, using cutting tools on the lathe machine, to fit them into relevant components of the transmission system. Keyways were made on the shafts to hold keys, which prevent their relative rotation against the components they carry.

Stage 3: Setting the Transmission System

The pinion gear was set at a length of 125mm on the 300mm long shaft while the output pulley was fixed at an end, supported by a bearing. A second bearing supported the other end of the shaft. The bearings were fixed on parallel positions250mm from the edge of the angle iron base. The wheel gear was fixed at the end of a 200mm long shaft to form a gear train with the pinion gear, the opposite end of the shaft attached to the metal jar. A second 200mm long shaft attached to the opposite end of the metal jar completed the transmission system. The 650mm length of the drive belt, determined the position of the electric motor, providing rotary motion and torque as shown in Plate 3.

In the course of validation it was observed that the mechanism of motion transmission from the electric motor to the output pulley and gear train, proved a simple mechanism, though, the 200mm long shafts showed signs of fatigue during validation. A probable reason was the connection between the shafts and the metal jar which was ineffective. The joint was made more resilient through tougher welding. Also the output pulley had reinforcements of additional fasteners, used to prevent a shift in its position during rotary motion.

Plate 1: The Support Unit
Photo: Oresegun, A.O. fieldwork (2012)

Plate 2: The Metal jar & Hinged Covering
Photo: Oresegun, A.O. fieldwork (2012)

Plate 3: The Motion Transmission System
Photo: Oresegun, A.O. fieldwork (2012)

Plate 4: The reconstructed covering
Photo: Oresegun, A.O. fieldwork (2012)

Stage 4: Construction and Setting of Metal jar

Two steel plates of 550mm diameter each were welded at the ends of the metal jar to serve as coverings. An opening of 225mm × 150mm, with a suitable covering was created in the metal jar to serve as point of material charge/discharge. This was held in place using hinges.

A flange made up of a metal plate and cone was welded at the ends to receive the 200mm long shafts secured with bolts. The constructed metal jar (Plate 2) was set in place on the angle iron base. Torque and speed transmission from the pulley through the gear train to the metal jar, were manually tested by turning the pulley, to which the rotation of the jar was deemed satisfactory.

It was observed during validation that the hinged covering of the metal jar charge/discharge point was ineffective as it was not water tight. The opening was reconstructed to a more functional type utilizing a removable covering on a raised platform with the ends tightened using large bolts as shown in Plate 4.

Plate 5: Lining of the metal jar
Photo: Oresegun, A.O. fieldwork (2012)

Plate 6: Porcelain liners set in bond material
Photo: Oresegun, A.O. fieldwork (2012)

Plate 7: Locally available bond materials
Photo: Oresegun, A.O. fieldwork (2012)

Plate 8: Locally produced balls
Photo: Oresegun, A.O. fieldwork (2012)

Stage 5: Lining of Metal jar

The metal jar was lined with porcelain tiles using the alternate stretcher course tile laying pattern as shown on plate 5 and 6. This is to prevent the contamination of milled materials. Bonding of the tiles with the metal surface was achieved using a bonding material in the form of a brand, 'Cecamix Superb Fix' obtained locally after experimentation on available brands (Plate 7).

Stage 6: Fixing of Electric Motor

Table 6 shows varying diameters of input pulleys with a corresponding operating speed of ball mill in rotations per minute (rpm). In obtaining an appropriate ball mill operating speed of 45.9rpm (70% of critical speed 65.6rpm)the average size of pulleys '2' (62.5mm) and '3' (68.75mm) was calculated. This gave a diameter of 65mm.This was fit on the electric motor and locked on the spindle shaft with a key. It was afterwards mounted on a metal plate affixed to the angle iron base using bolts and nuts. Two V – belts (Plate 3) fit on the pulley provided rotary motion to the other components of the transmission system.

Stage 7: Finishing of the Produced Ball Mill

All welded joints on the ball mill were smoothed using the angle grinder. The surfaces in contact and motion as the shaft, bearings and the gear train were lubricated using thick oil lubricant. The metal surfaces were polished and painted. After fabrication, the ball mill was validated using material charges of feldspar and quartz prospected from Gbegbinlawo, Abeokuta North Local Government Area of Ogun State.

The Procedure for Validating The Ball Mill

Feldspar and Quartz mined in large lumps were manually crushed to smaller (pebble) sizes using sledge hammer. This was done in a bid to reduce the large lumps to manageable sizes that will be suitable for further processing in the form of pulverizing. The pebble sized materials were reduced to sand size about 2000µm (2mm). This procedure was carried out in the mineral processing laboratory of the Metallurgical and Materials Engineering Department of Federal University of Technology, Akure, South-West Nigeria using the pulverizing machine.

The experimental procedure validating the ball mill, involved batch milling of feldspar and quartz in three (3) batches for each material, milled at a time range of 2 – 6 hours. This essentially involved six (6) samples of material batch, milled for 2, 4 and 6 hours respectively using locally produced balls (Plate 8). Weighing of samples was done using a simple weighing balance to a batch weight of 2000g each. Ball milling to the specified time periods was done on each batch using the fabricated ball mill. The level of water in the mill was regularly checked at interval with additions made when needed.

The different batches of milled feldspar and quartz were discharged after milling. On discharge they were allowed to stand and settle in receptacles for a period of 3 hours after which the clear top water was decanted leaving the settled materials in place. These materials were subsequently bagged in cotton pillow cases with weights employed in further draining. The produced soft caked material was dried in the open air to remove moisture content making them suitable for particle size analysis.

RESULTS AND DISCUSSION

The Milling Schedule is as described on table 3. The Milling Log was adequately kept for each batch of material. Water additions to the milling became less frequent with a better understanding of the milling process.

Table 3: The Milling Schedule

Material	Batch code	Duration of milling	Milling Time	Date
Feldspar	FA_2	2 hours	10:34am-12:48pm	6 Nov. 2012
	FB_4	4 hours	01:00pm-05:04pm	6 Nov. 2012
	FC_6	6 hours	09:10pm-03:33am	6 Nov. 2012
Quartz	QA_2	2 hours	11:00am-01:00pm	7 Nov. 2012
	QB_4	4 hours	02:10pm-06:31pm	7 Nov. 2012
	QC_6	6 hours	08:45pm-02:49am	7 Nov. 2012

Source: Oresegun, A.O. Field work (2012)

Particle Size Analysis

This is the grain size distribution of particles within a batch sample of processed raw material (Rado, 1988). The sieving method was adopted using sieves of sizes 20 (841µm), 40 (420µm), 70 (210µm), 140 (105µm) and 270 (53µm) arranged in decreasing order of size (coarse to finest) on a sieve shaker. Sieving for the study was done in a time of four (4) minutes. Material retained by each mesh was weighed. A triple beam balance was employed in weighing small samples.

Table 4: Particle Size Analysis for Feldspar at 4 hours

Mesh Size	Size in Micrometre (µm)	Quantity of Feldspar retained (g)	Percentage retained	Cumulative Percentage retained
20	-840 + 420	7	0.7	0.7
40	-420 + 210	35	3.5	4.2
70	-210 + 105	277	27.7	31.9
140	-105 + 53	503	50.3	82.2
270	-53	178	17.8	100

Source: Oresegun, A.O. Field work (2012)

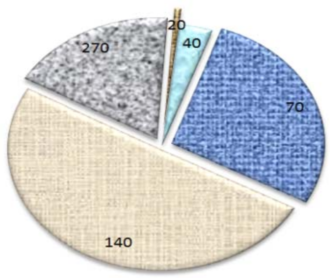
Tables 4 and 5 show particle size analysis with meshes 20 to 270 in levels 1 – 5 for the processed feldspar and quartz samples milled at 4 hours. The quantity of material retained in a mesh is indicative of its spread in the batch. This spread of particle size is described in a pie chart in figures 2 and 3.

Table 5: Particle Size Analysis for Quartz at 4 hours

Mesh Size	Size in Micrometre (µm)	Quantity of Feldspar retained (g)	Percentage retained	Cumulative Percentage retained
20	-840 + 420	7	0.5	0.5
40	-420 + 210	17	1.7	2.2
70	-210 + 105	129	12.9	15.1
140	-105 + 53	586	58.6	73.7
270	-53	263	26.3	100

Source: Oresegun, A.O. Field work (2012)

In establishing the efficiency of the ball mill a descriptive comparison of the particle size analysis of feldspar and quartz at 2, 4 and 6 hours were made in the form of a multiple bar chart. This showed the differences in particle size distribution/ spread of the milled materials at different time periods. This is as described in figures 4 and 5.



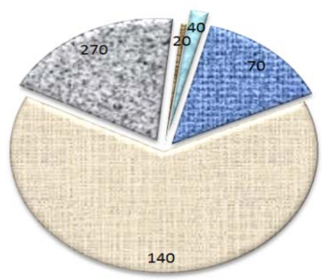


Fig. 2: Chart Showing Particle Size Spread in Feldspar at 4 hours
Source: Oresegun, A.O. Field work (2012)

Fig. 3: Chart Showing Particle Size Spread in Quartz at 4 hours
Source: Oresegun, A.O. Field work (2012)

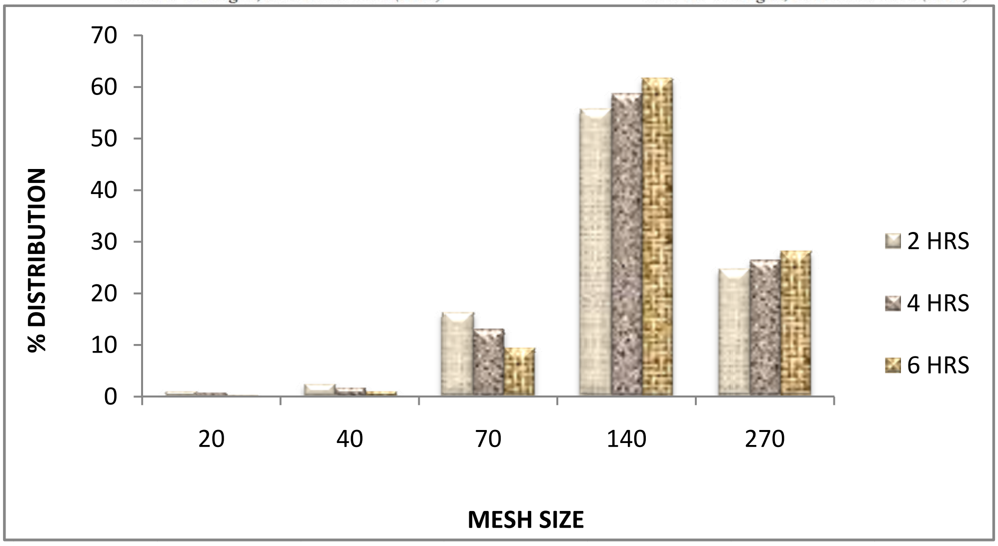


Fig. 4: Chart comparing the Particle Size Distribution of Feldspar at 2, 4 and 6 hours
Source: Oresegun, A.O. Field work (2012)

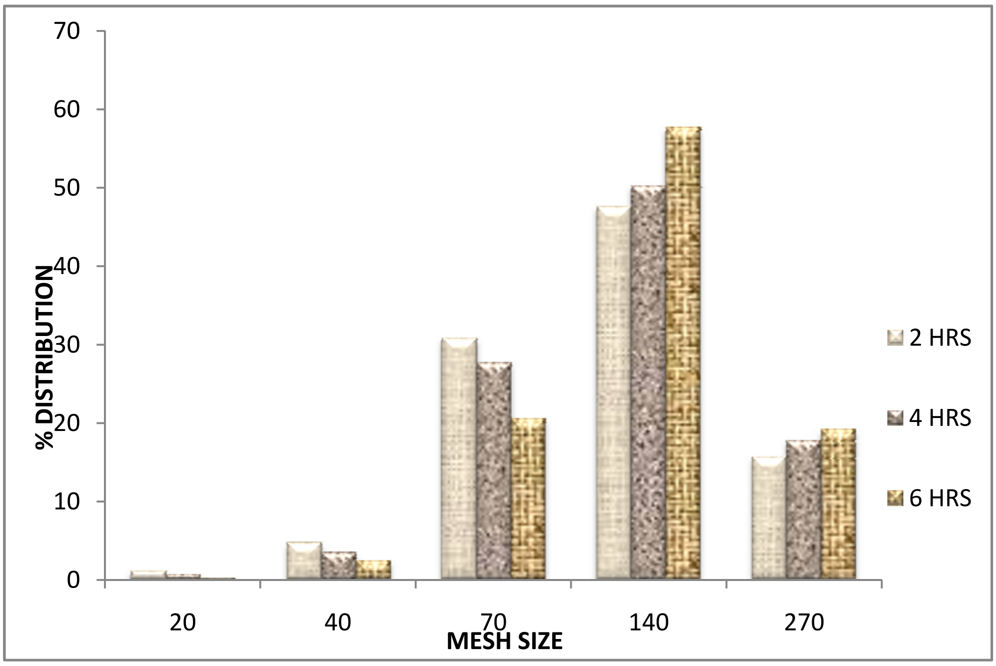


Fig. 5: Chart comparing the Particle Size Distribution of Quartz at 2, 4 and 6 hours
Source: Oresegun, A.O. Field work (2012)

It is observed from the descriptive analysis presented that the milled materials became finer (most evident at 140 mesh) with increased spread/distribution of materials within the super fine range as they were milled for longer time periods. Particle sizes at mesh 20 were negligible for almost all the samples. The larger spread of particle size at 140 and 270 mesh sizes, reflects the efficiency of the fabricated ball mill at reducing particle sizes from the feed size of 2000μm (2mm) to as fine as 53μm (0.053mm) and less.

Though the milling presented a number of challenges specifically water leakage at the charge/discharge outlet, loosening at the ends of the steel drum suspending the shafts and unfastening of the input drive pulley, it was nevertheless successful. The identified problems were rectified – the charging inlet redesigned, the shafts better welded to the steel drum and the input drive pulley provided with a better fitting key.

Table 7: Cost of Ball Mill Fabrication

Material	Cost (₦)
Metal container	17, 000.00
Ball mill components	55, 000.00
Porcelain liners	60, 000.00
Electric motor	20, 000.00
Miscellaneous	40, 000.00
Total	192, 000.00

Source: Oresegun, A.O. Field work (2012)

Cost of Fabrication

Table 7 shows the cost of fabricating the ball mill using components locally procured. Actual prices of components may vary depending on location within the country. A comparison of the production cost with the cost of imported ball mills (Table 8) shows a significant difference in cost and indicates savings in foreign exchange which can be made available to other ends in production.

Table 8: Cost of foreign ball mill

Supplier/Manufacturer	FOB* Price (₦) **
Zhengzhou Huachang Machinery Manufacturing Ltd.	850, 250.00
Jiangxi Province Tongyuan Manufacturing Ltd.	1, 020, 300.00
Gongyi Songling Machinery Co. Ltd.	1, 394, 410.00

* The buyer pays for the cost of shipping. ** Exchange rate of USD to Naira at 170.05
Source: Oresegun, A.O. Field work (2012)

CONCLUSION

The development of ceramics production in Nigeria, strongly hinged on raw material processing will be fast tracked with the ready availability of much needed raw material processing equipment as the ball mill. As the cost of foreign equipment is prohibitive, local development provides a window of opportunities for practitioners to acquire and utilize the equipment for production and subsequently improve over time on their design, fabrication and usage. The fabricated ball mill operates on a simple principle of transmission of motion and torque (power) from a source - an electric motor through a transmission system of pulleys, drive belts and gear train to the steel drum where the grinding media of porcelain balls perform a grinding action through impact and rubbing. Contamination of processed raw materials and possible impact of the grinding media on the steel drum producing excessive noise were eliminated with the use of porcelain liners. The simple mechanism and fabrication process of the ball mill means reproducing the equipment will not pose much difficulty (if any) in the instance of a mass production.

RECOMMENDATION

In the light of the aforementioned, the following recommendations are made: Government at all levels should rise to the challenge of supporting and funding efforts at industrialization through the development of local capacity in man power, machinery and raw materials' usage.

Local ceramic producers should seize the opportunity offered through research activities to consistently utilize developed processing equipment as the ball mill in processing raw materials useful in production. Research efforts should focus on improving the quality and function of developed ceramic processing equipment, so as to perfect their development over time and reduce the present reliance on foreign equipment. Ceramics training at the undergraduate and post graduate levels should include requisite training on relevant engineering and technical principles, as knowledge in these areas are essential in the development and fabrication of the ball mill and other raw material processing equipment.

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