Performance Evaluation of Unglazed Tiles Produced from Locally Developed Tile Making Machine

Abraham David MORAKINYO[1*] Umar Adeiza Adeika SULLAYMAN[2] Danjuma Sallah YAWAS[3]
1.Department of Industrial Design, Federal University of Technology PMB 2076 Yola, Adamawa State
2.Department of Industrial Design, Ahmadu Bello University (ABU) Zaria, Kaduna State
3.Department of Mechanical Engineering, Ahmadu Bello University (ABU) Zaria, Kaduna State
*Corresponding author: abrahamolushola@yahoo.com

Abstract
A tile making machine (TMM) was designed and fabricated (see Plate IV), varieties of tiles in different sizes and thickness were extruded and certain properties of the tiles were also tested. This is in order to determine and certify the functional reliability of the machine and it's products when compared with similar machines earlier in operation. A body of ball (Bomo) clay and kaolin (kankara) clay in equal percentage of 50% was used for the tile extruded. Empirical method was employed to prepare the tile materials beginning with locating, identifying and charting of local deposits, exploration, procurement, transportation, beneficiation, compounding/mixing of ceramic materials, aging, production with the prepared recipes, drying and firing which mark the final stage. Tensile, hardness and impact resistance tests were carried out on the tiles produced with the TMM and two ready-made glazed China tiles in the market. The produced tiles results on the tensile test were (20mm = 1311.06 N/ mm^2, 15mm = 951.78 N/ mm^2 and 10mm = 741.47 N/ mm^2); hardness test: (20mm = 40.2 HRF, 15mm = 29.7 HRF and 10mm = 18.7 HRF); and impact test: (20mm = 5.5J, 15mm = 2.13J and 10mm = 0.63J). The two results compared showed significant relationship in the parameters measured. Even though tiles produced from the TMM machine were not glazed but they met the standard parameters for unglazed tiles as obtained in literatures. From the parameters measured and the results obtained these tiles suitably match with the klinker tiles used as floor tiles and for other hard lining surfaces.
Keywords: Test, Performance, Efficiency, Standard, Unglazed, Mechanical

1. Introduction

Tiles, as a product type of structural ceramics are manufactured using the industrial ceramic process. This is a controlled process of ceramic manufacturing in which mass production of identical wares can be achieved. Industrial ceramics is also the science and technology of designing, formulating and manufacturing ceramic products that have industrial and technical utilities, (Sullayman, 2008). Tiles can be pressed, extruded or cast. Tiles range from wall tiles (such as decorated wall tiles, faience tiles, stove tiles, cottoforte tile, porous single-fired tiles, and exterior wall tiles), to floor tiles (such as quarry tiles, stone tiles, klinker tiles and mosaic tiles) as well as porcelain tiles. Tiles are most often made from ceramic, with a hard glaze finish. But other materials are also commonly used, such as glass, marble, granite, slate, and, kaolin, and are usually formed into a ceramic slurry, which is cast in a mould and fired.

The hardness of ceramic tile is rated from zero to five according to the Porcelain Enamel Institute (PEI) scale. According to www.crossville-ceramics.com 2009) and (Matteucci, et al 2002 in Luz and Ribeiro (2006) the PEI rating determines the suitability of ceramic tile for various surfaces. A rating of zero indicates that a tile is not suitable for use on walls. Such tiles protect walls of buildings and floors and retain their shapes, aesthetic quality and enhanced durability in any surface where they are used. Tiles are also used for surfaces, for antiseptic and hygiene purposes, as well as combine sufficient cleanliness with suitable electrical properties. Ceiling tiles are placed on a steel grid and, depending on the tile selected, may provide thermal insulation, sound absorption, enhanced fire protection, and improved indoor air quality. Some are approved for use in food preparation areas, and some are certified for indoor air quality by the Green Guard Institute (GGI). There are also tiles that are resistant to mould and moisture damage that have enhanced acoustical properties (American Society for Metal (ASM) 1992).

In the last two decades, the technology of producing porcelain and glass tiles has become more efficient, allowing more mass production. Because of the invention of automated tile lines and state of the art equipment, that use diamonds to cut and finish stone slabs into tiles, it has made stone tiles more available. The invention of automated tile lines and state of the art equipment has allowed tiles to move from being small business into broader markets (www.infotile.com/publications, 2009) and (http://www.encyclopedia.com) in (Morakinyo, 2012). The two contributors above further revealed that the technical properties of tiles are also available for consumption because of technology that is available. This makes tiles production/selection for use on any surface easy without much difficulty.

Nigeria as a nation lags behind in regards to the production of industrial ceramic wares - like tile production. This is because most of the productions are done manually due to lack of requisite machines and equipment. The availability of such needed machines will increase the scope of functions in industrial ceramics and make production easier.

A tile making machine was developed and several varieties of tiles in different sizes and thicknesses were produced. Relevant property tests of the tiles were also conducted. This is in order to determine and certify the functional reliability of the machine and it's product in comparism with similar machine already in existence elsewhere in the world. This study therefore, is geared towards the revelation in the potential of the design and fabricated TMM, evaluate the results of the tiles produced and bring to fore necessary findings base on the potentials in ceramic equipment design and fabrication in Nigeria. The availability of this machine is an answer to the quest for locally produced machines that can manufacture ceramic products which can compete favourably with similar machines made outside the nation.

1.1 Tiles and Their Functional Definition

Tiles can be defined according to their types. Drews, (1983) stated that ceramic floor and wall tiles include all ceramic products used as wall and floor covering, tiles and components for swimming pools, as well as relevant accessories.

Ceramic Wall and Floor Files:- Uni, (1985) says the European standard EN87, approved in Nov. 1981 specifies that "ceramic wall and floor tiles are building materials that are generally designed for use for floor and wall. These are coverings, for both indoors and outdoors. Regardless of their shapes and sizes, these are manufactured by standard ceramic processes and prepared from mixture of ball clays, sand, fluxes, colouring agents and other mineral raw materials. Tiles raw materials are processed by milling, screening, blending and wetting. The shaping of tiles is carried out either by pressing, extrusion, casting or other processes normally at room temperature. After shaping, tiles are subsequently dried and fired at high temperature by single or two stage firing- glazed which are unglazed or engobed.

The definitions below are given by American National Standard Institute Specification for ceramic Tile (ANSIA137.1) as in their types and functions:

a. Ceramic Mosaic Tile; Decorative Wall Tile; Paver Tile; Porcelain Tile;
b. Quarry Tile; Wall Tile; Individual Tile White Ware Grades

1.2 Classification of Ceramic Tiles

It is on record that many classifications have been proposed to define tiles. Some are classifications of usage or based on the characteristics of the starting materials or firing cycle. Drews, (ibid) recorded that it is difficult to give exhaustive classification owing to the extreme heterogeneity of tile products, yet these are still categorized thus:

- ***Red Ware and White Ware —*** Red and white tiles are different based on the amount of iron content. The iron reacts with other body's components which give more or less colouration and modify the behaviour of the body in firing (Nassetti, 1985).
- European (EN) and America Society for Testing and Materials (ASTM) standards, classify ceramic tiles based on the function of water absorption and shaping method.

I. ***Tiles Classify by Shaping process***: They tiles classify by shaping process are also divided into three (a) Extruded floor tile, these includes split tiles and individual extruded tiles. (b) Dry-pressed floor and wall tiles and (c) Cast floor and wall tiles.

II. ***Tiles classify by Water (H_2O) absorption:*** This is directly related to porosity and it is represented with E, expressed as a mass fraction given as a percentage:

a. Group I (low H_2O absorption) where $E \leq 3\%$
b. Group II (medium H2O absorption) where $3\% < E \leq 6\%$, (Group IIa) where $6\% < E \leq 10\%$ (Group IIb)
c. Group III (high H_2O absorption) where $E > 10\%$.

- ***Shaping process and water absorption:-*** These parameters are directly related to the physical, chemical, mechanical and micro-structural properties such as: modulus of rupture of fired tiles, abrasion resistance, chemical resistance and frost resistance.

Benlloch *et al* (1981) further deduced that most of the tiles available in the market are single fired or twice-fired. Such tiles are made up of the basic components listed below: they are clay minerals; inert materials, such as feldspars, and pegmatite. Others are calcite dolomite & other oxides etc.

However, some specialized bodies for specific applications contain other components, such as alumina in certain porcelains and bone ash in bone china. Cubbon and Till (1983) said most tiles and floor white ware bodies are prepared by single firing technology, which steps were specify by Dardi et al (1990) which are as follows: batching – grinding - spray-drying – pressing - dying - glazing and firing. With the following steps above varieties of tile types can be produced with diverse applications.

Clay (primary and secondary clays) was the major material use to produce the tiles in this study. The steps for the preparation were similar to the steps mentioned by Cubbon and Till (1983) above, this however exclude the spray drying and the tiles were also prepared for two firings.

2. Materials and Method

The major material used for the tile production is clay. The clay for tile has different compositions depending on the type of tile to be made. The body used for this research is composed of two major materials: namely clay; and kaolin in different, compositions to determine a suitable and workable body. Clay and kaolin in ratio 50:50 was used.

Clay- Basically can be classified into two types: primary clay and secondary clay. Kaolin is less plastic and contains larger particle size. It is white in nature and fires at an extremely high temperature. Monteiro *et al.* (2003) in Alkali (2009) said the kaolinitic nature and the presence of high percentage of aluminium hydroxide confers a refractory behaviour on kaolin which impairs sintering during firing in some cases. This, he said results in the greater porosity associated with elevated values of water absorption of primary clay and reduces the mechanical strength of forms at green ware stage.

In preparing the tile material, empirical method was employed as stated by (Morakinyo 2010). This method begins with locating, identifying and charting of local deposits, exploration, procurement, transportation, beneficiation or treatment (ball milling/grinding, drying, sieving and measuring), compounding and mixing of ceramic materials, aging, application “or” production with the prepared recipes, drying and firing which mark the final stage (see Figure1) :

From this tile body, different tile sizes and shapes were extruded from the fabricated tile making machine. These tiles were in sizes of 20x20cm, 15x15cm and 10x10cm; with varied thickness of 20mm, 15mm, 12mm and 10mm.

2.1 Performance Evaluation of the Unglazed Tiles Produced

The extruded tiles were mechanically evaluated after firing.

When in service, ceramic tiles are subjected to forces or loads. It is necessary to know the characteristics of the material and to design the member from which it is made such that any resulting deformation will not be excessive and fracture will not occur. The mechanical behaviour of a material reflects the relationship between its response and deformation to an applied load or force. (William 1996). Important mechanical properties to ascertain in tile production are strength, hardness, ductility, and stiffness.

Mechanical properties of tile are ascertained by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. Mechanical properties are of concern to a variety of parties like the producers, consumers, research organisation, government agencies and many more.

Tiles’ body are frequently chosen for structural applications because they have desirable combinations of mechanical characteristics. This helps to understand the material, its mechanical behaviours, relationship with others and its service requirement (William, ibid).

Three mechanical tests were carried out on the tiles produced from the TMM, these are: tensile strength, impact resistance and hardness tests. The test results were compared to two existing glazed tile samples from China. Chappy Impact Testing Machine was employed to carry out the impact test, while “Indentec Universal Hardness Test Machine” was used to carry out the hardness test on F scale. The Rockwell test was performed on F scale as designated with minimal load of 10kg and total of 60kg, as given by (William, 1996).

The averages of the three tests carried out for each thickness was calculated. While on the tensile strength the result was deduced by using the correlation between hardness and tensile Strength.

3.0. Results and Discussion

Three mechanical property tests were carried out on the tiles extruded and bisque fired (unglazed): tensile strength, impact and hardness tests; these results are shown in Figure 2, 3 and 4.

3.1 The Comparative Impact Test Results of The Two Glazed (China Tiles) and Unglazed Tiles

From Figure 2, it shows that the hardness of a glazed tile is twice or much stronger than when it is bisque. In other words glaze on tile turns glassy; it’s body rocky, metallic and somewhat seemingly unbreakable. This is because the particles become denser, vitrified and less or non-porous. Encyclopædia Britannica (2013) said the role of the glassy liquid phase in the consolidation of fired clay objects is to facilitate liquid-phase or reactive-liquid sintering. In these processes the liquid first brings about a denser rearrangement of particles by viscous flow. Secondly, through solution-precipitation of the solid phases, small particles and surfaces of larger particles dissolve and re-precipitate at the growing “necks” that connect large particles. Rearrangement and solution-precipitation lead to bond formation and to progressive densification with reduction of porosity. A range of glass contents and residual porosities can be obtained, depending on the ingredients and the time the object is held at maximum temperature.

This suggest that if the TMM tiles were glazed fired they would be much denser, bonded and less porous. This will also mean that in Table 1 the impact value of ‘a’ and ‘b’ will increase while that of ‘c’ could be the same as the impact value of the glazed China sampled tiles.

3.2 The Comparative Hardness Test Results of The Two Unglazed and Glazed Tiles

From Plate I - III these shows that the tiles produced from the TMM are thicker and unglazed but, ‘a’ in Table 2 of the unglazed tiles can in terms of hardness stand side by side with the China tile samples A and B. These results suggest that if the 10mm of TMM tile was glazed it could have the same value in terms of hardness test with the China tiles that are glazed. This also suggests to some certain extend that these tiles can be used hand in hand on the floor where the two China samples will function.

3.3 The Comparative Tensile Test Results of The Two Unglazed and Glazed Tiles

The results of the TMM tiles and the sample China tiles will almost be the same if the TMM tiles were fired for the second time to a glazed temperature.

The two tests carried out on the tiles produced with the TMM and the glazed China tiles shows significant relationship in the parameters measure. Even though tiles produced from the TMM machine were not glazed but these met the stipulated standards for unglazed tiles on the three tests carried out. More to that with the parameters measured and the results obtained the tiles will suitably match with the klinker and quarry tiles used as floor tiles and likewise for other hard lining surfaces. Tiziano and Gian (1991) advanced that klinker and quary tiles are larger and thicker this brings about high mechanical strength, abrasion resistance, impact resistance and frost resistance. Subsequently if the TMM tiles go for the second (glaze) fired the 10mm size can function and fit where the two samples A and B China tiles will fit and function.

Glazing of the TMM tiles will to a greater extent make them have the same value like that of the Sampled Glazed China Tiles. This suggest that the functions and technical properties will not be different thereby making such tiles compete favourably with any other tile industrially produced with the results obtained above.

4.0 Conclusion

The result of this research work is actually instructive and stimulating for further study. But it is evidence that the TMM tiles produced in equal percentage of 50% each of Kaolin and Secondary (Bomo) clay is a good body for tiles production. That is to say tiles can be produced in Nigeria with a taste of international standards.

The available materials within our localities are actually good for tiles production with the results of the parameters measured. This suggests that exploration and exploitation is very necessary to maximise the potentials available in these materials. The material use can actually be further harness and with a little refinement serve in conserving and bringing foreign exchange.

If more materials are introduce to this body like silica, feldspar or Talc or other relevant tile making materials a better body can also emerge. If this is use to produce tiles and fired to a glazed temperature, these tiles will function as any other industrial tiles available.

Further from the overall result obtained the production of tile within the Nigeria-African context has actually emerged. Because, Nigeria has not been listed in tile production within Africa and world over but she is seen as a consumer nation or importer of goods of all sorts.

Another paramount thing of note is that, this can enhance better educational practices within our institutions, with the tiles produced from the locally fabricated machine. It is now possible for students and staff in ceramic sections of Industrial Design Departments in our high institutions to compound bodies that can be extruded with the machine. They can extrude tiles of their own taste and have better properties-parameters-in a nutshell designs of varied ceramic tiles would emerge.

This suggest that a technology has actually evolve that will list the local ceramist and engineers among their colleagues world over. This is actually a research in a research.

Acknowledgement

The authors would like to recognise the supplementary financial support extended by the Educational Trust Fund (ETF) Nigeria, through the Department of Research and Development FUT-Yola. We also appreciate the Technical Staffs of Industrial Design Programme, Abubakar Tafawabelewa University Bauchi (ATBU) Bauchi, Nigeria and Department of Industrial Design, Ahmadu Bello University (ABU) Zaria, Nigeria for the usage of their equipment in carrying out this research. We will not fail to acknowledge the immerse contribution of the Head of Department and Mr. Yusuf the Chief Technical Officer of the Department of Metallurgy ABU Zaria, Nigeria for granting permission in using their equipment to carry out the three major tests on the extruded tiles.

References

America Society of Metal (ASM) International (2003). *Trends in Welding Research*. Materials Park, Ohio: ASM International.
Alkali, V. (2009) Exploration of The Potentials of Granite Sawing Waste in Developing Ceramic Body and Glazes. A Ph.D. Second Seminar Paper Presented September, 2009 in the department of Industrial Design ABU Zaria.
Benlloch, A. E., Amoros J. L. and Navarro J. E. E. (1981). Studio de Eres Parra Pavimento. Boll Soc. Es. Ceram. Rid., Vol 20, 1981, p17-24
Cubbon, R.C.P. and Till J.R. (1983). Preparation of Ceramic Bodies, Ceramic Monographs-Handbook of Ceramics, Verlag Schmid GmbH, Freigurg, 1983.
Dardi M., Brusa, A. and Bresciani A. (1990). *Single Fired Stoneware Floor Tiles, Int. Ceram.* J., Vol 451990, p 22-31
Drews, S. M. (1983). Wall and Floor Tiles, Ceramics monographs-handbook of Ceramics, Verlleg Schimid Gmbh, Freiburg, 1983.
http://www.encyclopedia.com/doc/ceramictile1G2-2896500032.html.Retrived 17-07-2012.
Luz, A. P. and Ribeiro, S. (2006). Use of Glass Waste as Raw Material in porcelain Stoneware tile Mixtures; Faculty of Chemical Engineering of Lorena (FAENQUIL), Department of Materials Engineering (DEMAR), Polo Urbo Industrial, Gleba A16, CP 116, 12600-970 Lorena, SP, Brazil. (www.elsevier.com/locate/ceramint). Ceramic International 33 (2007) 761-765.
Matteucci, F; Dondi, M; and Guarini, G. Effect of Soda-lime Glass on Sintering
and Technological Properties of Porcelain Stoneware Tiles, Ceram. Int. 28(8) (2002) 873–880.
Monteiro, S.N. Pecanha, L.A. Vieira, C.M.F. (2003): Reformulation of Roofing Tiles Body with Addition of Granite Waste from Sawing Operations. Journal of the European Ceramic Society 24 (2004) 2349–2356.
Morakinyo, A. D; Gadzama R.M; Kawahya P.D, and Umar A. (2010) Exploration of Ceramic Raw Materials in Yola, Adamawa State for the Production of Ceramic Glazes, in *Ashaku Journal of Ceramic*. June, Vol.8, p. 54-63
Morakinyo, A. D. (2012) Design and fabrication of a Tile Making Machine (TMM). (Unpublished Masters thesis) submitted to the Department of Industrial Design ABU Zaria.
Nassetti, G. (1985). Thermal energy Consumptions in the Production of Single Fired Red Ware. Tendedcies and Considerations, Inter Ceram, Vol 34 (No. 4), 1985, p 40-41
Sullayman, U. A. A. (2008). The Processing Technologies and Product Types of Industrial Ceramics: Advantages Over Traditional Manufacturing Routes. A seminar paper presented June, 24th 2008 in the Department of Industrial Design ABU Zaria.
Tiziano, M and Gian C. P.(1991). Tile Whiteware: Department of Chemistry University of Modena, Italy. Engineered Materials Handbook. Glass and Ceramic Vol. 4 America Society of Metal (ASM). International
Traditional Ceramics**.** (2013). Encyclopædia Britannica. *Ultimate Reference Suite.* Chicago: Encyclopædia Britannica.
Uni "Piastrelle di Ceramica per Rivestimanto di Pavimenti e Pareti", Nerme Europe, Uni, Milano, 1985.
William, D. C. (1996). *Material Science and Engineering: Introduction* (4th ed) United States of America, JohnWhiley ans Sons, Inc.
www.Crossville-Ceramics.Com, 2009. Retrived 15th July, 2012
www.infotile.com/publications,2009

About the Authors

Abraham David Morakinyo is a Lecturer at the Department of Industrial Design, Federal University of Technology, Yola, Adamawa Sate, Nigeria. He is a member of Ceramic Association of Nigeria (CeRAN) and member of International Journal of Design (IJD). He holds a Master of Arts (M.A.) in Industrial Design from Ahmadu Bello University (ABU) Zaria. His research interests are in ceramic and creative design, ceramic materials, machine design, modeling, fabrication and production.

Umar A.A. Sullayman is a Professor in the Department of Industrial Design, Ahmadu Bello University (ABU) Zaria, Kaduna State, Nigeria. He holds a Ph.D. degree in advance ceramic science and materials. He was the former Head of Industrial design ABU Zaria.

Danjuma S. Yawas is an Associate Professor in the Department of Mechanical Engineering, Ahmadu Bello University (ABU) Zaria, Kaduna State, Nigeria. He holds a Ph.D. degree in advance ceramic science and materials. He was the former Head of Mechanical Engineering ABU Zaria. His research interests are in production engineering, machine design and fabrication

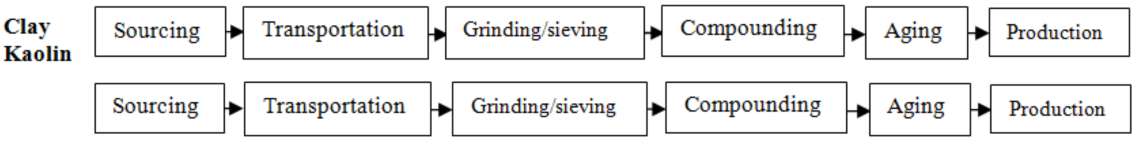


Figure 1: Beneficiation of the Materials: Clay and Kaolin.

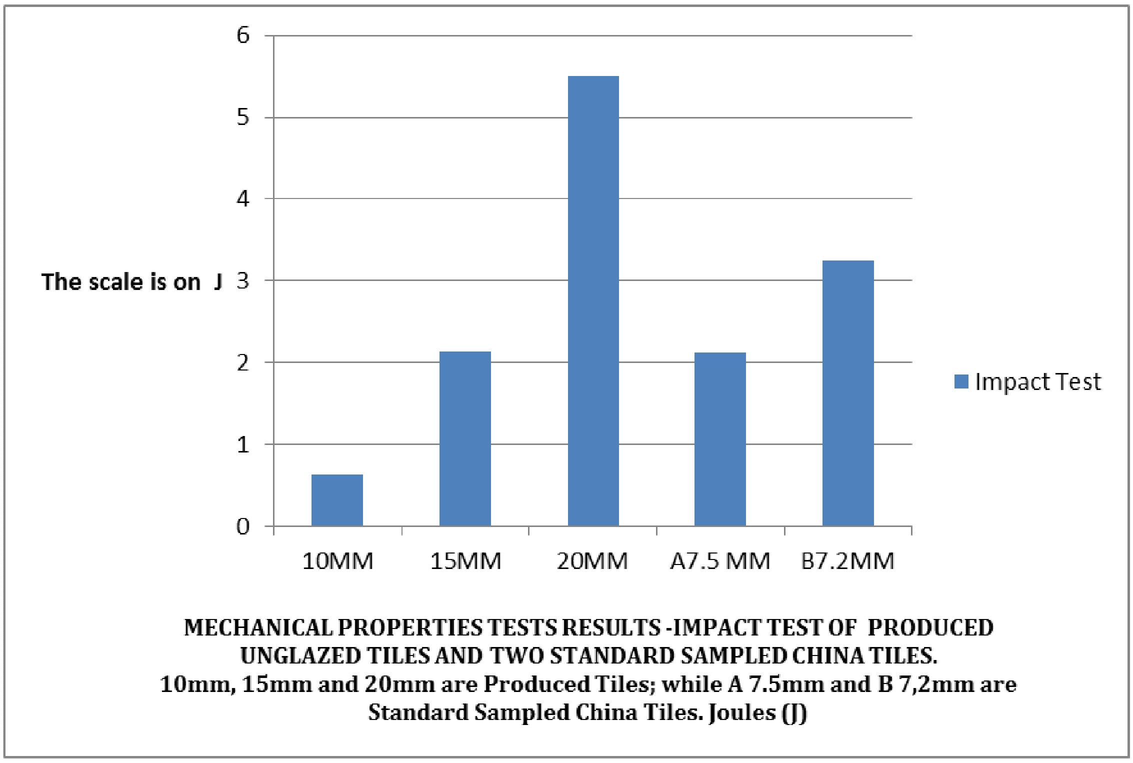
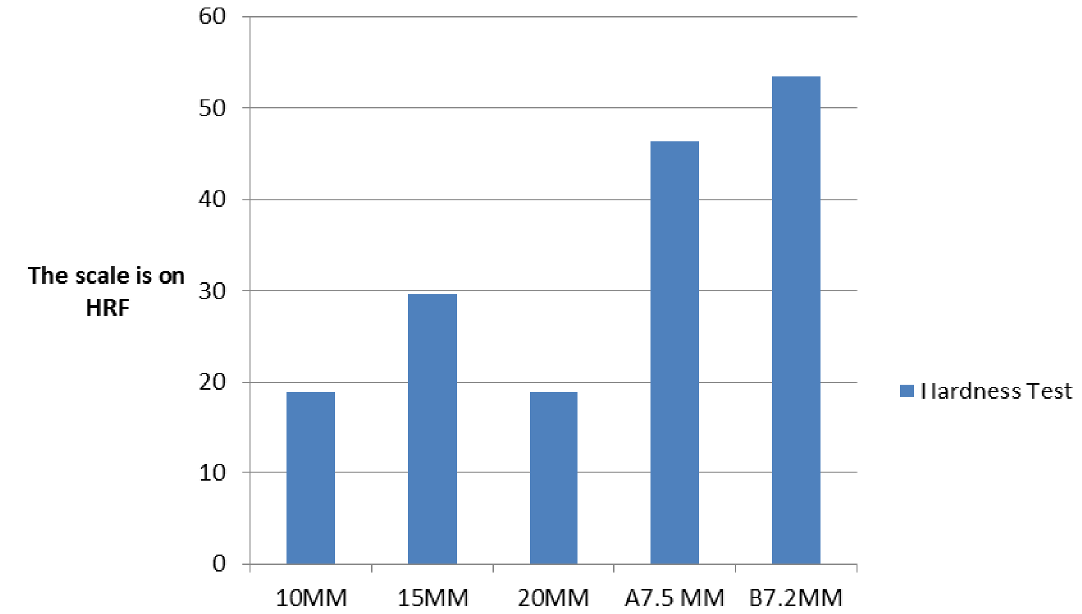


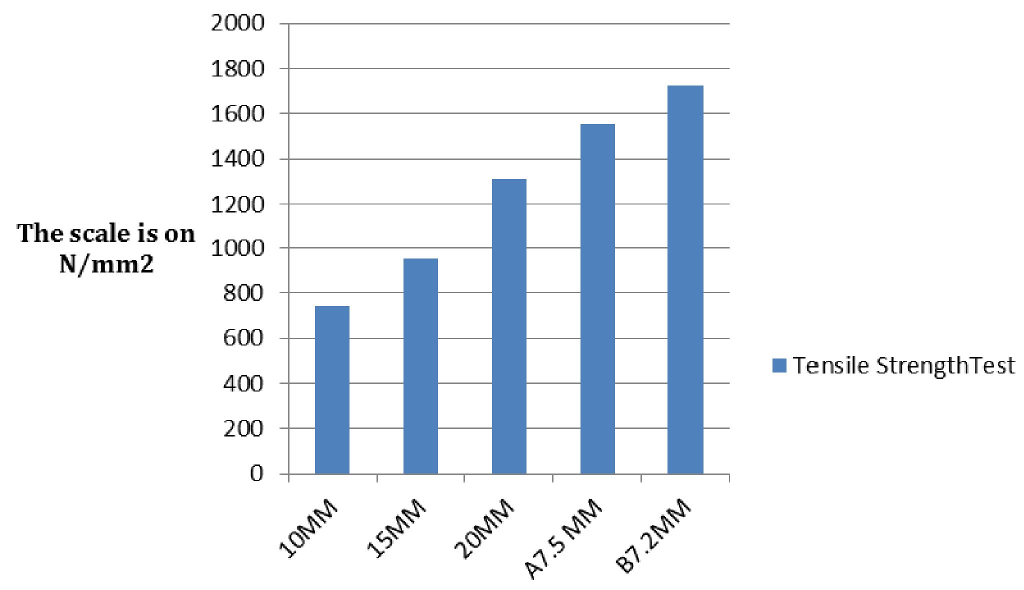
Fig. 2. Impact Tests Results of Unglazed and Two Standard Glazed Tiles

Source: Morakinyo, (2012)



MECHANICAL PROPERTIES TESTS RESULTS -HARDNESS TEST OF PRODUCED UNGLAZED TILES AND TWO STANDARD SAMPLED CHINA TILES.
10mm, 15mm and 20mm are Produced Tiles; while A 7.5mm and B 7,2mm are Standard Sampled China Tiles.Hardness Rockwell Scale (HRF)

Figure 3. Hardness Test Results of Unglazed and Two Standard Glazed Tiles
Source: Morakinyo, (2012)



MECHANICAL PROPERTIES TESTS RESULTS -TENSILE STRENGTH OF PRODUCED UNGLAZED TILES AND TWO STANDARD SAMPLED CHINA TILES.
10mm, 15mm and 20mm are Produced Tiles; while A 7.5mm and B 7,2mm are Standard Sampled China Tiles. Newton per millimeter square (N/mm^2)

Figure 4. Tensile Strength Test Results of Unglazed and Two Standard Glazed Tiles
Source: Morakinyo, (2012)

Table 1. TMM Unglazed Tiles and Sampled Glazed China Tiles Impact Test Results

S/N	TMM UNGLAZED TILES IMPACT TEST RESULT	CHINA GLAZED TILES IMPACT RESULT
1.	**a.** 20mm thickness = 5.5J	**a.** Sample A 7.5mm thickness = 2.12 J
	b. 15mm thickness = 2.13J	**b.** Sample B 7.2mm thickness = 3.25 J
	c. 10mm thickness = 0.63J	

Table 2. TMM Unglazed Tiles and Sampled Glazed China Tiles Hardness Test Results

S/N	TMM UNGLAZED TILES HARDNESS TEST RESULT	CHINA GLAZED TILES HARDNESS RESULT
1.	**a.** 20mm thickness = 40.2 HRF	**a.** Sample A 7.5mm thickness = 46.3 HRF
	b. 15mm thickness = 29.7 HRF	**b.** Sample B 7.2mm thickness = 53.4 HRF
	c. 10mm thickness = 18.7 HRF	

Table4. TMM Tiles and Sampled China Tiles Tensile Test Results

S/N	**TMM UNGLAZED TILES TENSILE TEST RESULT**	**CHINA GLAZED TILES TENSILE RESULT**
1.	a. 20mm = **1311.06 N/ mm^2**	a. Sample A 7.5mm thickness =**1552.83 N/mm^2**
	b. 15mm = **951.78 N/ mm^2**	b. Sample B 7.2mm thickness = **1725.36 N/mm^2**
	c. 10mm = **741.47 N/ mm^2**	

Plate I: Unglazed Tiles in variety of sizes
Source: Morakinyo 2012

Plate II: Fired Tiles up to a Temperature of 1100°C Arranged on a Table after Firing 20 x20 cm.
Source: Morakinyo, (2012)

Plate III: Fired Tiles (Unglazed) up to a Temperature of 1100°C arranged on a Table after Firing 15 x15cm.
Source: Morakinyo, (2012)

Plate IV: The Developed Tile Making Machine
Source: Morakinyo, (2012)