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Study the Influence of Sintering on the Properties of Porcelain Stoneware Tiles

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Abstract

Porcelain substantial manufactured through a quick firing method of quartz, kaolin clay, and feldspar blends is a non-equipoise. In this one paper, the porcelain stoneware conformation was structured through mingling (50% kaolin, 40% feldspar and 10% quartz). Sintered models at(1200,1250, and,1300)°C. X-ray diversion displayed that models sintered collected of mullite, quartz, and glassy part. The manners of the fired models was estimated through measurements of porosity, linear shrinkage, microhardness and, bending strength. The linear shrinkage reduced and the porosity, bending strength, and microhardness increased with the increment in the temperature of sintering.

Keywords: Porcelain stoneware, Quartz, Mullite, Glassy phase, Sintering.

INTRODUCTION

The vitrified product porcelain is a muddles of quartz, clay, and feldspar. Structures of porcelain are great particles of stuffing (usually quartz), grain, and bond kind grasped completely by a delicate matrix, which is entirely compact, collected, by the glassy phase and crystals of mullite [Andreola et al., 2002]. Due to the multifaceted between raw materials, routes of processing, and the firing procedure kinetics of the, porcelains signify particular of the most ceramic systems complicate [Claussen et al., 2011].The derivative of porcelain stoneware tile is a building material porcelain categorized by extraordinary technical appearances and actual dense microstructure [Varshneya, 2013]. The chief variance between porcelain stoneware and porcelain on firing platform. Therefore, extended time (some hours) procedure of firing porcelain stimulate the formation of extraordinary mullite while feigned in a quicker firing progression (60-90 min too cooling in porcelain tile associated to 24 h or further in porcelain) porcelain stoneware tile, in the tiles which are into the kiln no extended than 60-90 min[Lee et al., 2011] . The dissimilar process of firing indications to immense variances in the crystal-like phases percentage in the finale output and while glass and mullite comprise chief porcelain parts, which too comprises certain cristobalite, quartz, and tridymite, in porcelain tile quartz is additional rich than mullite. Greatest of the reactions happening throughout ruled kinetically firing procedures [Carty et al.,2009] which do not touch equipoise thermodynamic production of porcelain stoneware, then the series of industrial are littler than 1 hour. Therefore, quick firing procedure, porcelain stoneware is a non-equipoise substantial[Bresciani al.,2002].

The scientific porcelain stoneware properties, exclusively for example chemical confrontation, water absorption, bending strength, and scraping resistance, reason that porcelain stoneware tile other ceramic building substantial was truly the maximum growing in manufacture and sales. Mercantile porcelain have exemplary composition of stoneware tile is 10‑15 wt.% quartz, 35‑45 wt.% feldspars, 40‑50 wt.% kaolin [Sanchez, 2003] . Connection of the technical properties of fired produces and microstructure has been fewer fine calculated, in this scope the research dedicated on glass phase creation and porosity development. It is significant to indicate that the mullite growth influence on scientific characteristics of porcelain stoneware tile has not been before examined, parting important chance for exploration in this scope [Hench,1986].

The intention of the current investigation was to confirm the growing of mullite crystals and effects on porcelain tiles mechanical and physical properties, and to investigate the influence of sintering on the mullite phase growing and advancement of physical and mechanical characteristics.

EMPIRICAL METHODS

Raw Materials

Raw materials used in the current exploration were commercially presented (kaolinite clay, feldspar (Fluka,97%), and quartz sand (Fluka,96%)). The raw materials have chemical composition, determination by "wet methods", and the investigation was achieved via Iraqi Geological and Mining Survey. Table (1) shows the raw materials used in this research chemical composition.

Preparation of the Porcelain Tile Samples

The composition of porcelain tile was intended by blending (50% kaolin clay, 40% feldspar, and 10% quartz) constituents was wet mixed using a planetary ball mill(SFM-1, QM-3SP2) by crushing media the alumina balls, with runs at 300 rpm in ethanol as a dispersive media. 2% of PVA was added as a binder for 8 hours to provide homogeneous fine mixture.

The wet mixture was oven dried at 100 ◦C for 24 hours using electric blast dry box (WG43) to be sure that all moisture was removed.

Table 1: The raw materials chemical composition applied in the research.

Content (wt.%)	Kaolin	Feldspar	Quartz sand
SiO_2	60.43	72.38	98.87
Al_2O_3	29.11	15.20	0.20
Fe_2O_3	1.22	0.05	0.22
CaO	0.24	0.33	0.08
Na_2O	-----	1.52	0.02
MgO	0.38	0.06	0.04
K_2O	1.66	0.07	0.26
MnO	0.03	8.51	0.03
TiO_2	0.68	-----	------
P_2O_5	0.18	-----	0.05
LOI	6.05	1.98	0.23

The samples were fabricated by cold die pressing using uniaxial pressure device (CT340-CT440) in steel dies at pressure of 50 Mpa, discs of 20 mm diameter and 5 mm height from 3 g of powder were molded. Moreover, (30 g each) of 50x10x5mm square tiles for bending strength measurements were prepared. All compacted samples at 100 ◦C for 24 hours before firing process. The compacts were fired using protherm electric furnace (PLF 160/15, made in Turkey) at different temperatures of 1200,1250 and 1300 ◦C. The models for ~30 min to the prerequisite temperature were heated, drenched for 15 min and then in the furnace cooled to room temperature at 50ºC/min. Figure (1) shows typical processes used to produce and, characterized the porcelain stoneware .

CHARACTERIZATION

X-ray diffraction (XRD)

X-ray diffract meter (Shimadzo, 6000) at room temperature using Cu kα radiation (λ = 1.5405 Å), and a scanning speed of 5◦/min from20 to 60◦ of 2Θ (Bragg angle) and 40 KV/30 mA was used as the main analytical tool**.**

Particle size analyzer

Particle size of prepared porcelain stoneware powder before firing was measured using laser particle size analyzer (Bettersize2000).

Linear Shrinkage

The fired samples linear shrinkage, LS (%),has been calculated by the following equation:

$$LS=\frac{LS-LC}{Ls} \times 100 \text{ ……..(1)}$$

the diameter (mm) of the green and fired samples individually are Ls and Lc [Penalver et al.,2003]. The values of linear shrinkage attained of five samples were be around for each firing temperature.

Porosity, and Water Absorption

According to ASTM C373-88, the measurement of porosity,and water absorption, that includes the specimens experiment drying to mass stationary (D), in distilled water boiling for 5 h and for an 24 h soak additional at room temperature. every sample though in water suspended has mass (S), and their saturated mass (M) next impregnation, is measurement. The experiment was achieved on 4 specimens.

The calculation of porosity, P (%) as shadow:

$$\mathbf{P} = \frac{(M-D)}{V} \mathbf{x\ 100 \ldots\ldots\ldots\ldots\ldots (2)}$$

Where the exterior volume is V(cm^3), calculation as revealed below[Bedoni et al.,2001]:

$$\mathbf{V = M - S \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)}$$

Water absorption, WA (%), states the connection of the mass of absorbed water to the waterless mass of the sample as shadows[Gregg et al.,2012]:

$$\mathbf{WA} = \frac{\mathbf{M-D}}{\mathbf{D}} \times \mathbf{100 \ldots\ldots\ldots\ldots..(4)}$$

Bending strength, and microhardness .

The computerized universal experiment machine with a exam speed of 0.5 mm/min using to determine bending strength trial using rectangular bar samples prepared with dimensions of (Length=50mm,Width=10mm,Height=5mm), the samples prepared according to the ASTM –D790 in steel die. The test was made according to ASTMC1161 procedure. The subsequent equation consuming to intentional strength of bending.

$$(\sigma b)=3\, p_f L/2wt^2 \text{ ……..(5)}$$

Where σb, is the bending strength (Mpa), pf, fracture load (N), w, width sample (mm), t, thickness sample (mm) [Motta et al.,2002].

Microhardness for all samples were tested using Digital microvickers hardness tester (TH-717) at 9.8 N with a dwelling time of 15 second. Disc samples prepared with dimensions of (Diameter=20mm, Height=5mm), samples prepared in steel die. The test was made according to ASTM standard C1327-90. Calculation of Vickers hardness by the equation below.

$$H_v=1.854(p/d^2) \text{ ……..(6)}$$

Where, the Vickers hardness (Mpa) is H_v,, p, load (N), D, diagonal length of the indentation impression (μm) [Marc et al.,2009].

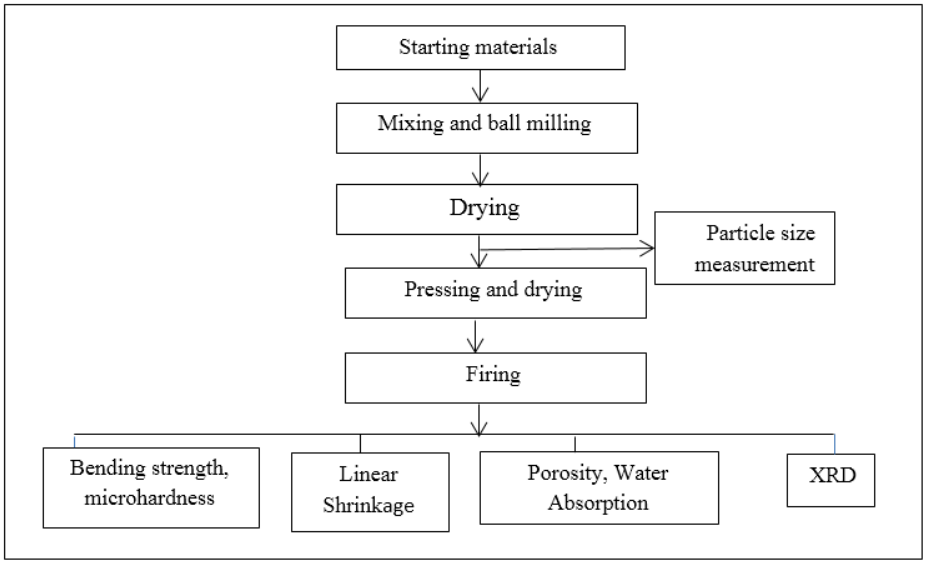


Figure 1. Schematic diagram of typical processes used to produce and, characterized the porcelain tile

RESULTS AND DISCUSSION

X-ray diffraction (XRD)

Figure (2) displays the X-ray diffractograms of the range temperatures firing at 1200,1250 and 1300 ◦C porcelain stoneware body. The mineral phase present in fired products is quartz only associated with XRD standard card no. (46-1045). Each other existing phases mineral in the raw materials(Table 1) have disappear, main substituted via mullite associated with XRD standard card no. (15-0776) and glassy phase.

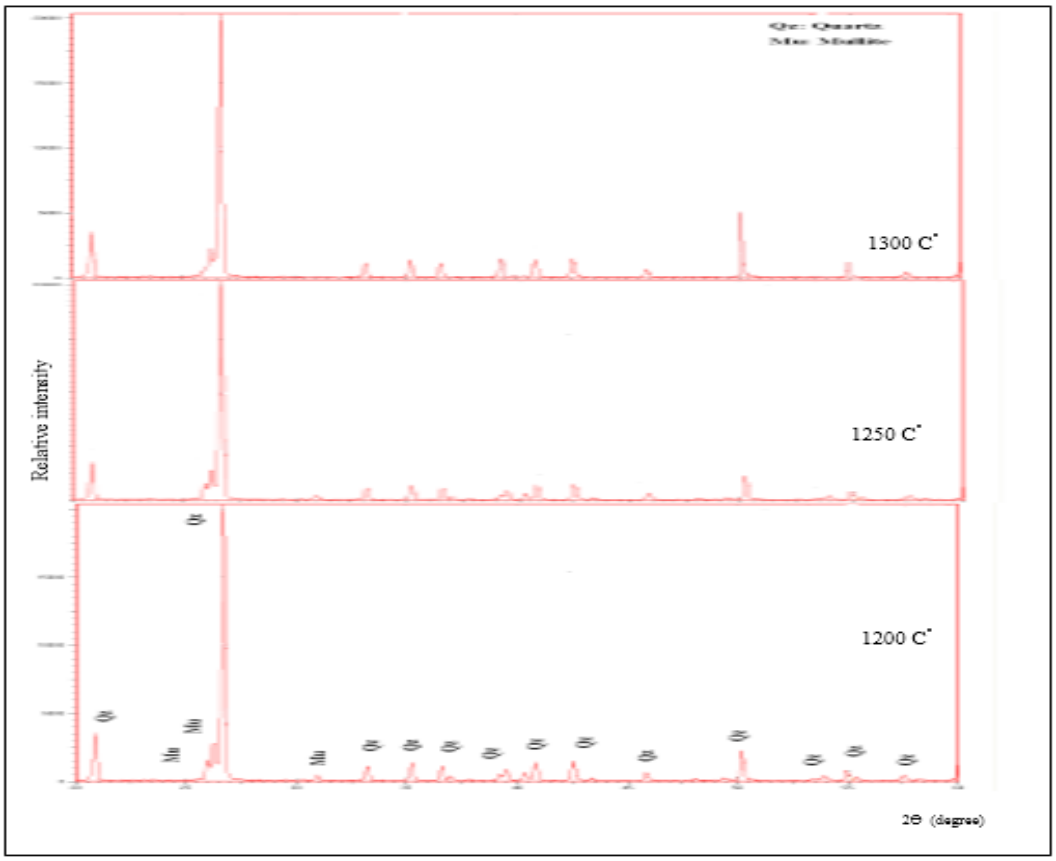
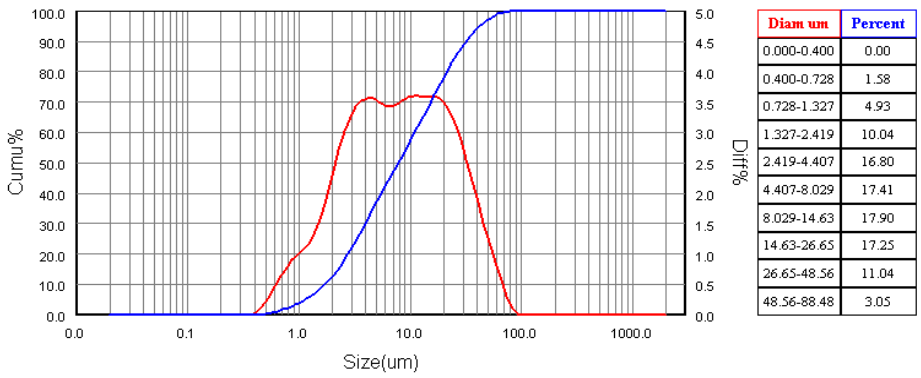


Figure 2. Displays the X-ray diffractograms of the range temperatures firing at 1200,1250 and 1300 ◦C**.**



Diam um	Percent
0.000-0.400	0.00
0.400-0.728	1.58
0.728-1.327	4.93
1.327-2.419	10.04
2.419-4.407	16.80
4.407-8.029	17.41
8.029-14.63	17.90
14.63-26.65	17.25
26.65-48.56	11.04
48.56-88.48	3.05

Figure 3. Particle size analysis of the porcelain stoneware.

Particle Size Analyzer

Figure (3) displays the analysis particle size for porcelain stoneware powder to give an average particle size of 8µm .

Porosity, and Water Absorption

Figure (4) displays at the 1200º-1300ºC range the porosity as assignment of sintering temperature. The mechanism of viscous liquid phase in sintered ceramic substance expression tendency of these properties upon firing [Biffi, 2012]. In reality, it is evident that the increasing in firing temperature cause decreasing in open porosity due to the glassy phase formation is principally created by means of the feldspar. The reason for every an augmentation amount in liquescent phase and a diminution in viscosity liquid phase is augmentation in temperatures. Under the energy forces of the superficies produced thru the contained small pores in the body of ceramic, the tends of liquescent phase to accession the particles and, then, open porosity diminution [Dondi et al.,2011]. Concurrently, in the ambit of firing temperature closed porosity increases, actuality this increasing significant above 1250ºC owing to the gas pressure in the closed pores alleged bloating body, that inclines to enlarge the pores [Orts et al.,2012]. The mixture of individually closed and open porosity offers enlargement to the gross porosity diminution in the sintering first stages, attainment a lowest rate at 1250ºC and then augmentation. This performance is like to that displayed by practically wholly porcelain bodies.

Figure (5) displays the water absorption and firing temperature at the 1200º-1300ºC range. The water absorption is straight connected to porosity which open, in the gross temperature scope its value decreases. The results displayed in table (2).

Linear Shrinkage

Figure (6) displays the linear shrinkage as cursor of firing temperature at the 1200º-1300ºC range. Total porosity represents like inclination of linear shrinkage, that primarily augmentation, to the extreme value, and up 1250ºC diminution because of increasing in close porosity. The results displayed in table (2).

Table 2. Summary of the average values of apparent porosity, water absorption, and linear shrinkage for the porcelain stoneware sintered at 1200º-1300ºC.

Temperature(ºC)	Apparent Porosity(%)	Water Absorption(%)	Linear Shrinkage(%)
1200	10	5	4
1250	6	4.3	5.3
1300	8.3	1.4	2.4

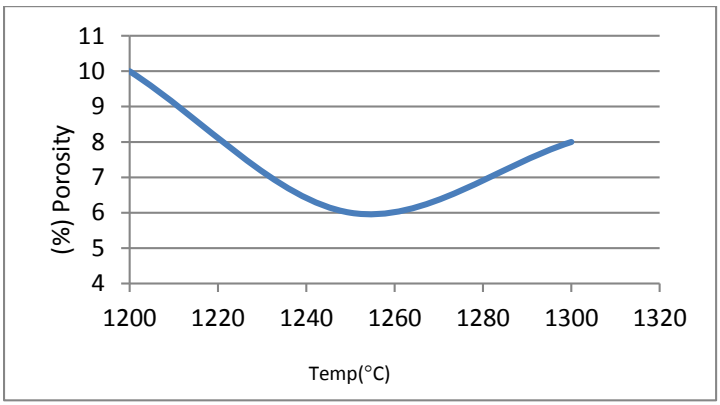


Figure 4. Porcelain stoneware models porosity as cursor of sintering temperature.

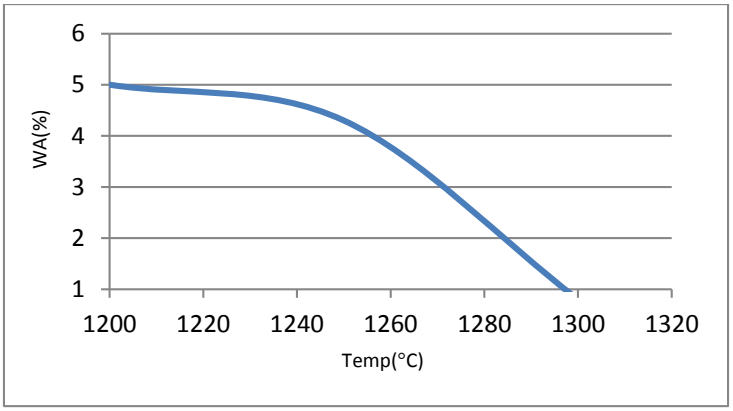


Figure 5. Porcelain stoneware models water absorption (WA) as cursor of sintering temperature**.**

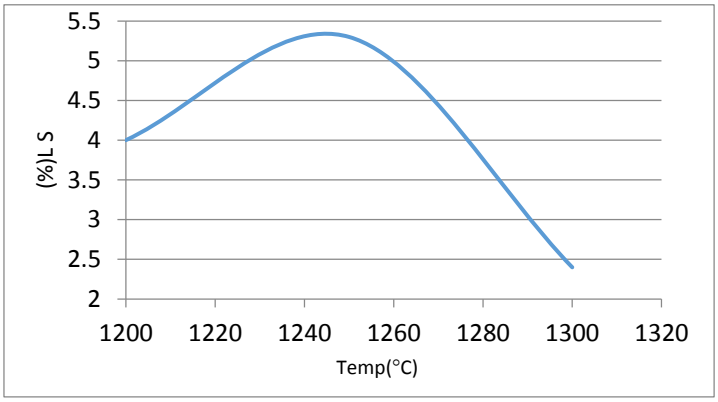


Figure 6. Linear shrinkage (LS) as cursor of sintering temperature.

Bending strength, and microhardness

Figure (7) and (8) show the bending strength and microhardness as cursor of firing temperature at the 1200º-1300ºC range. It can be noted that the samples fired in the 1260º-1280ºC range have average bending strength between 36 and 41 Mpa, respectively and have average values of microhardness (Hv) between 5.4 and 5.8 Mpa respectively. Table (3) collects the values of microhardness (Hv), and bending strength of porcelain stoneware body sintered at 1200º-1300ºC range.

As the sintering temperature is increased, a significant increase in the regard mechanical properties, it is well known that the porosity dominates the mechanical properties of the ceramics materials that is the lower the porosity the higher mechanical strength[Leonelli et al.,2003]. The results shown in table (3). The values are identical to that exhibited thru mercantile porcelain tiles [Barbieri et al.,1995], that exhibited in Table (4).

Table 3. Summary of the values of microhardness (Hv), and bending strength of the sintered at the 1200º-1300ºC porcelain tile body.

Temperature(ºC)	Microhardness (Hv)(Mpa)	Bending strength (Mpa)
1200	5.4	36
1250	5.6	38
1300	5.8	41

Table 4. Comparable the average values of microhardness (Hv),and bending strength for the sintered porcelain stoneware in the 1200º-1300ºC, and the commercial porcelain stoneware tiles.

Value	Microhardness (Hv)(Mpa)	Bending strength (Mpa)
Measured	5.6	38
Commercial	5.5	35

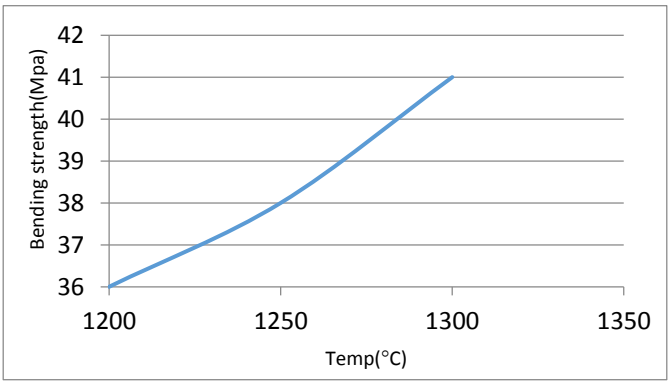


Figure 7. Bending strength as cursor of firing temperature.

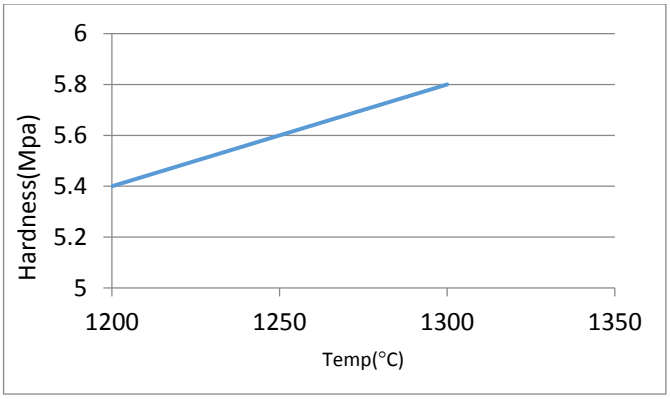


Figure 8. Microhardness as function of firing temperature.

CONCLUSIONS

1) The mercantile porcelain tiles formed by a fast sintering procedure was designated integration of (50% kaolin, 40% feldspar and 10% quartz) . All bodies illustration a good attitude after sintering in the 1200º-1300ºC range.

2) Calculation of the porosity, linear shrinkage, and water absorption for sintering porcelain stoneware models illustration that the procedure carry on by mechanism of viscous liquid phase. Open porosity totally disappears before the increasing in close porosity starts. This performance is due to both quartz dissolution and mullite crystallization in the liquid phase, which initiate an increasing in the viscosity of liquid phase and later, the elimination of open porosity is tardy.

3) The optimal sintering temperature is attained at the 1250º-1330ºC range, after reaching open porosity a minimal value and jointly ultimate value of linear shrinkage.

4) X-ray analysis of models sintered in the optimum sintering temperature pause display that models are consist of mullite, glassy phase, and quartz.

5) The values of the bending strength, and microhardness of samples fired in the 1200º-1330ºC range increased with the increment of firing temperature . These values by commercial porcelain tiles displayed comparable.

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