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Mechanical Properties of Fireclay Bricks from Binaliw Clay

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***Abstract* - Binaliw clay, considered to be local waste from crushing and quarrying operations, was utilized to produce fireclay bricks. The chemical and mineralogical composition of the raw material were determined through various tests. Clay samples were prepared by milling, sieving, molding, drying, and sintering from 800^{0}C to 1100^{0}C at 100^{0}C intervals for 2 hours. Mechanical properties such as cold crushing strength, volume firing shrinkage, apparent porosity, and bulk density were identified through the appropriate ASTM standards. It was found out that the aforementioned properties, except apparent porosity, increased with increasing temperature- apparent porosity decreased on the contrary. The polymorphic transformations of kaolin and quartz to mullite and cristobalite supported the trends of the mechanical properties at increasing temperatures. However, the values attained in this study were ineligible for classification according to ASTM C27-98 due to the values being lower than the stipulated requirement. Nevertheless, the researchers believe that through a refinement of the manufacturing processes and an addition of additives, Binaliw clay could be a feasible raw material for the production of fireclay bricks.**
***Keywords:* Refractories, Fire Bricks, Ceramics, Waste Conversion**

I. INTRODUCTION

Majority of refractory bricks are made up of aluminosilicate clays composed mainly of kaolinite and silica. The amount and combinations of these minerals, along with a few impurities, contribute to the properties of these bricks -which are ideal for high temperature applications such as furnaces, kilns, crucibles, and flues [5]. Aluminosilicate bricks can vary in chemical composition from almost 100% alumina and little silica to almost 100% silica and little alumina [4]. Due to the multitude of variants, ASTM have devised a classification of these bricks based on physical and chemical analysis.

The fireclay subgroup is classified based on its physical characteristics due to the overlap of alumina and silica contents that usually occur in these types of bricks. Fireclay bricks are made from fireclay, a clay classification having lesser than 50% Alumina [4]. These types of bricks are different from their high-alumina aluminosilicate refractory counterparts which have greater than 50% alumina content. According to the Silica-Alumina phase diagram [6], high alumina bricks have a higher eutectic point thereby inhabiting higher refractory properties than their silica-rich firebrick counterparts. Nevertheless, fireclay bricks are still widely used for their low cost and ease of fabrication [7]. These bricks are still used mainly in the lining of furnaces, kilns, chimneys, and wood ovens.

Barangay Binaliw is located on the northern part of Cebu City, Philippines. Within the barangay, a soil aggregate company conducts crushing and milling operations to supply aggregates for various constructions demands. The by-products of such operations are soils believed to be feasible for the production of the aforementioned fireclay bricks as shown in their chemical (Table I) and mineralogical composition (Fig 1).

It is therefore the objective of the researchers to investigate the feasibility of these waste products as suitable raw material for the production of firebricks; and to assess the manufactured bricks with regards to the standards [4] set by the Americal Society for Testing and Materials (ASTM) for fireclay bricks.

II. MATERIALS AND METHODS

A. Materials

Silt was taken from a quarry site in Binaliw, Cebu City. These soil samples are byproducts from the crushing operations of a local aggregate company. Prior to crushing and grinding, silt specimens were dried for 24 hours at 110^{0}C in a drying oven. Crushed silt was mechanically sieved to particles sizes lesser than 150 microns which were then dried for 24 hours in a drying oven at 110^{0}C. Binaliw silt was sent to DOST-ITDI (Bucutan, Taguig City) for the determination of its chemical composition through Wavelength Dispersion X-ray fluorescence spectroscopy (Rigaku Supermini-200).

Table I indicates that the soil sample is high in silica yet low in alumina, contrary to the initial findings of high aluminum content through an earlier FESEM-EDS analysis(citation). Fe_2O_3, MgO, CaO, TiO_2 comprises 44.28% of the tested sample. These compounds serve as fluxing agents - lowering the eutectic temperature at higher temperatures which proves to be detrimental to the structural integrity of the refractory bricks at extreme temperatures by promoting the formation of a liquid phase. The minor constituents comprising K_2O, MnO, SO_3, ZnO, NiO, CuO, Cl, Rb_2O contribute to a total of 5.51% of the whole sample.

Phase compositions were determined through X-ray diffraction operating at 40kV and 30 mA using Cu radiation. Samples were scanned from 20 to 700(2θ) at a step size of 0.020. X-ray diffraction pattern of the sample in Fig. 1 detected the presence of quartz, kaolinite, and feldspar based on the intensity peaks at d = 3.34 A0, 14.53 A0, and 3.21 A0, respectively. The aforementioned minerals are labeled “1”, “2”, “3” respectively in Fig. 1.

TABLE I CHEMICAL COMPOSITION OF BINALIW CLAY(%WT)

SiO_2	Fe_2O_3	Al_1O_3	MgO	CaO	K_2O	TiO_2	MnO
43.7	28.8	11	7	6.49	3.43	1.99	0.87
SO_3	P_2O_5	SrO	ZnO	NiO	CuO	Cl	Rb_2O
0.54	0.32	0.33	0.22	0.19	0.15	0.08	0.03

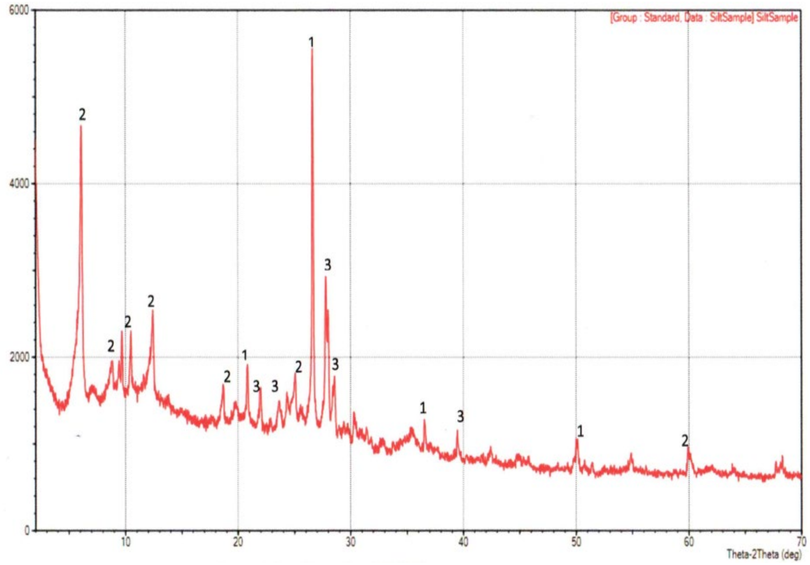

Fig. 1 XRD spectra of Binaliw clay

B. Experimental Procedure

Brick formulations were prepared from the dried and sieved particles (<150 microns). 250 g of clay was mixed with 25g of distilled water until a minimum moldable consistency was achieved. 5.2cm x 5.2cm x 5.2cm bricks were produced by compressing the powdery sample in a metallic mold at a pressure of 30MPa and held for 1 min. The compressed green bricks were then dried in an oven for 24 hours at 1100C. The green bricks were then sintered in a muffle furnace at a heating rate of 50C/min and soaked at temperatures of 800ºC, 900ºC, 1000ºC 1100ºC, for 2 hours. Results presented are the average values from 5 trials at each sintering temperature. Apparent porosity, bulk density, volume firing shrinkage, and cold crushing strength were determined using the appropriate ASTM standards [1]-[3].

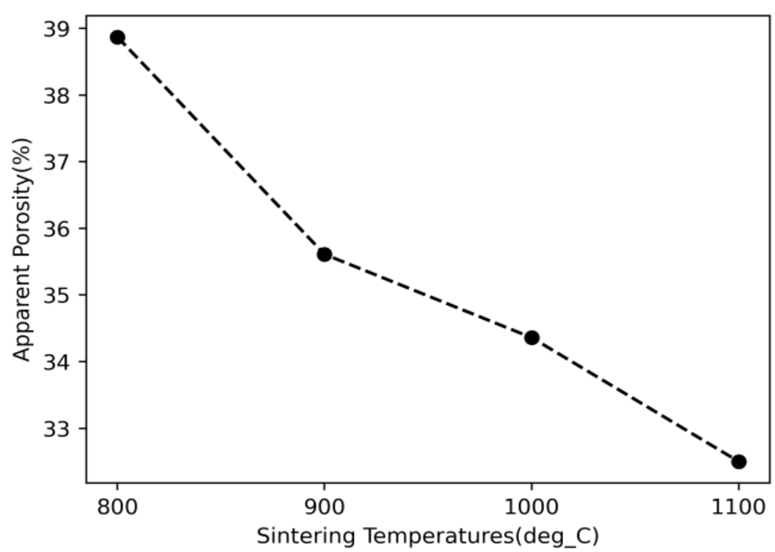

Fig. 2 Cold crushing strength values

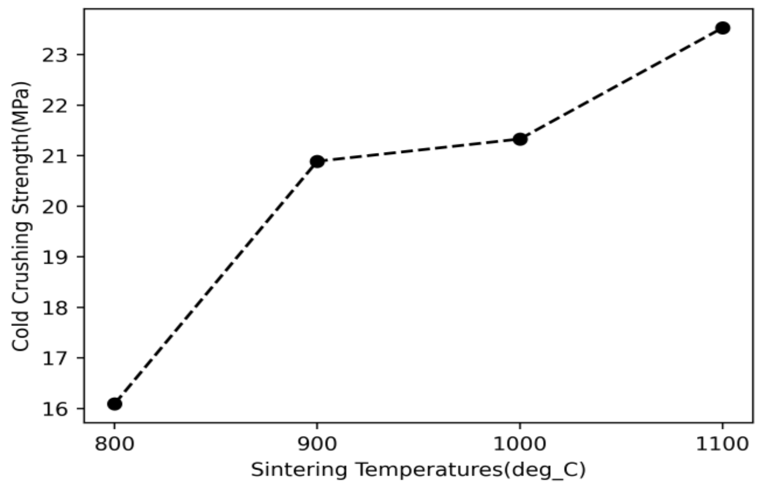

Fig. 3 Apparent porosity values

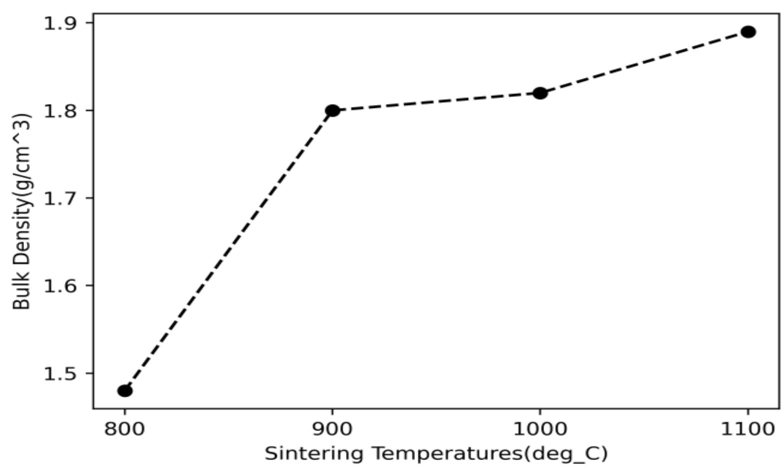

Fig. 4 Bulk density values

III. RESULTS AND DISCUSSION

Cold crushing strength values shown in Fig. 2 displays increasing values as the sintering temperatures increased. This is similar to most cases where the sintering temperatures are increased at arbitrary intervals [7]-[9]. The same can be said for bulk density (Fig. 4) and volume shrinkage (Fig. 5). Apparent porosity, on the other hand, decreased with increasing sintering temperature (Fig. 3).

At 1200^0C, sintered bricks dramatically shrunk and darkened in color with clear evidence of spalling. At 14000C, the bricks totally melted. According to the Silica-Alumina phase diagram [6], with a silica content of approximately 40%, melting temperature should be somewhere near 16000C. Unfortunately, due to the high amount of fluxing agents (Table I), melting began at a lower temperature of approximately 1400^0C.

The highest recorded cold crushing strength was 23.53MPa at the highest temperature of 1100^0C – making it the optimum temperature to achieve high strength. Although high alumina content is responsible for the strength of refractory bricks [8], In this case, the maximum cold crushing strength attained can well be attributed to the high amount of fluxing agents present in the raw material due to the significantly low alumina content relative to the related studies [7], [8], [10], [11].

Apparent porosity decreased from a maximum value of 38.87% at 800^0C to 32.50% at 1100^0C. The decreasing trend is similar to the related studies [7]-[10], [12]. The conversion of quartz to cristobalite consequently closes the pores [7]. This phenomenon improves the mechanical properties while reduces the volume of the bricks [6].

There is a sharp increase in bulk density from 800^0C to 900^0C followed by a gradual increase to the final sintering temperature of 1100^0C as seen in Fig. 4. According to Andrews *et al.,* [7], the temperature range from 800^0C to 900^0C is where the formation of high viscosity siliceous phase occurs. This in turn enables the formation of mullite. Although an increase up to 1100^0C is evident from the figure, the rate of change is significantly lower than the former (800^0C to 900^0C). Starting at 900^0C, majority of the aluminosilicate materials have already converted into mullite e.g., quartz and kaolinite from Fig. 1 thereby illustrating a slow rate of increase in densities. The maximum bulk density achieved at 1100^0C was 1.89 g/cm3. Despite the high Fe_2O_3 content in the clay samples, the bulk density never decreased at increasing temperatures similar to the case observed by Raue *et al.,* [13] wherein he attributed that decrease in bulk density to the dissociation of Fe_2O_3 to FeO and oxygen. As seen in Fig 5, the first stage of densification is evident from 800^0C to 1000^0C. At this stage, vitrification occurs which removes pores from the body and the present kaolinite (Fig. 1) undergoes a polymorphic transformation into mullite. The sharp increase in shrinkage from 1000^0C to 1100^0C could well be attributed to the conversion of quartz to cristobalite [7]. The maximum shrinkage achieved at 1100^0C was 8.12%.

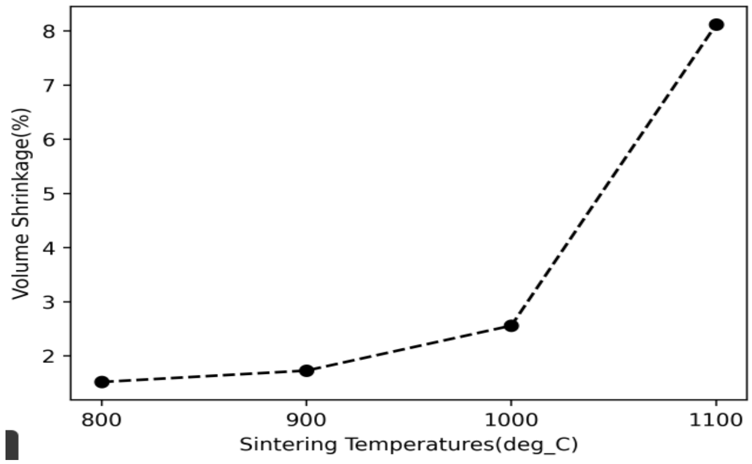

Fig 5. Volume shrinkage values

IV. CONCLUSION

The 11% alumina content (Table I) of Binaliw clay is significantly low which disqualifies itself to be considered as a high-alumina brick(min 50% Al2O3) based on ASTM C27-98[4]. The property values recorded at the optimum sintering temperature of 11000C were 25.53MPa for cold crushing strength, 32.50% for apparent porosity, 1.89g/cm3 for bulk density and 8.12% for volume shrinkage. According to ASTM C27-98[4], the aforementioned values are not qualified to be considered in any of the types of bricks in the standard classification – for a super-duty fireclay brick, a minimum bulk density of 2.24g/cm3 is required; for a high-duty slag resistant fireclay brick, a minimum bulk density of 2.19g/cm3 and a maximum porosity of 15%.; for a semi-silica fireclay brick, a minimum of 72% silica content is required. Despite pure Binaliw clay being ineligible for ASTM standardization, it is believed that its properties could improve through the refinement of manufacturing processes and the usage of additives.

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REFERENCES

[1] C08 Committee, "Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water," *ASTM International,* DOI: 10.1520/C0020-00R22.

[2] C08 Committee, "Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories," *ASTM International,* DOI: 10.1520/C0133-97R21.

[3] C21 Committee, "Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays," *ASTM International,* DOI: 10.1520/C0326-09R18.

[4] Andrews, J. Adam, and S. K. Y. Gawu, "Development of fireclay aluminosilicate refractory from lithomargic clay deposits," *Ceram. Int.,* Vol. 39, No. 1, pp. 779-783, Jan. 2013, DOI: 10.1016/j.ceramint.2012.06.091.

[5] J. A. Amkpa, N. A. Badarulzaman, and A. B. Aramjat, "Influence of Sintering Temperatures on Physico-Mechanical Properties and Microstructure of Refractory Fireclay Bricks," *Int. J. Eng. Technol.,* Vol. 8, No. 6, pp. 2588-2593, Dec. 2016, DOI: 10.21817/ijet/2016/v8i6/160806214.

[6] H. E. Mgbemere, E. O. Obidiegwu, and A. U. Ubong, "The Effects of Sintering Temperature and Agro Wastes on the Properties of Insulation Bricks," *Niger. J. Technol. Dev.,* Vol. 17, No. 2, pp. 113–119, Jul. 2020, DOI: 10.4314/njtd.v17i2.6.

[7] W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to ceramics,* 2d ed. in Wiley series on the science and technology of materials. New York: Wiley, 1976.

[8] J. Osarenmwinda and C. P. Abel, "Performance Evaluation of Refractory Bricks produced from locally sourced Clay Materials," *J. Appl. Sci. Environ. Manag.,* Vol. 18, No. 2, pp. 151, Jul. 2014, DOI: 10.4314/jasem.v18i2.1.

[9] E. K. Arthur and E. Gikunoo, "Property analysis of thermal insulating materials made from Ghanaian anthill clay deposits," *Cogent Eng.,* Vol. 7, No. 1, pp. 1827493, Jan. 2020, DOI: 10.1080/23311916.2020.1827493.

[10] A. Andrews, E. Nsiah-Baafi, S. K. Y. Gawu, and Peter. A. Olubambi, "Synthesis of high alumina refractories from lithomargic clay," *Ceram. Int.,* Vol. 40, No. 4, pp. 6071-6075, May 2014, DOI: 10.1016/j.ceramint.2013.11.057.

[11] N. S. Raut, P. Biswas, T. K. Bhattacharya, and K. Das, "Effect of bauxite addition on densification and mullitization behaviour of West Bengal clay," *Bull. Mater. Sci.,* Vol. 31, No. 7, pp. 995-999, Dec. 2008, DOI: 10.1007/s12034-008-0156-4.

[12] C08 Committee, "Classification of Fireclay and High-Alumina Refractory Brick," *ASTM International,* DOI: 10.1520/C0027-98R22.