

Fig. 3 Apparent porosity values

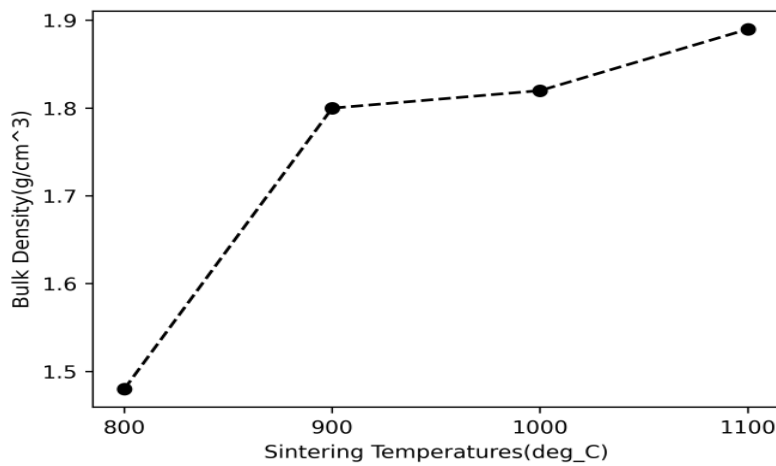


Fig. 4 Bulk density values

### 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°C, sintered bricks dramatically shrunk and darkened in color with clear evidence of spalling. At 1400°C, 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 1600°C. Unfortunately, due to the high amount of fluxing agents (Table I), melting began at a lower temperature of approximately 1400°C.

The highest recorded cold crushing strength was 23.53MPa at the highest temperature of 1100°C – 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°C to 32.50% at 1100°C. 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°C to 900°C followed by a gradual increase to the final sintering temperature of 1100°C as seen in Fig. 4. According to Andrews *et al.*, [7], the temperature range from 800°C to 900°C is where the formation of high viscosity siliceous phase occurs. This in turn enables the formation of mullite. Although an increase up to 1100°C is evident from the figure, the rate of change is significantly lower than the former (800°C to 900°C). Starting at 900°C, 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°C was 1.89 g/cm<sup>3</sup>. Despite the high Fe<sub>2</sub>O<sub>3</sub> 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<sub>2</sub>O<sub>3</sub> to FeO and oxygen. As seen in Fig 5, the first stage of densification is evident from

800°C to 1000°C. 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°C to 1100°C could well be attributed to the conversion of quartz to cristobalite [7]. The maximum shrinkage achieved at 1100°C was 8.12%.

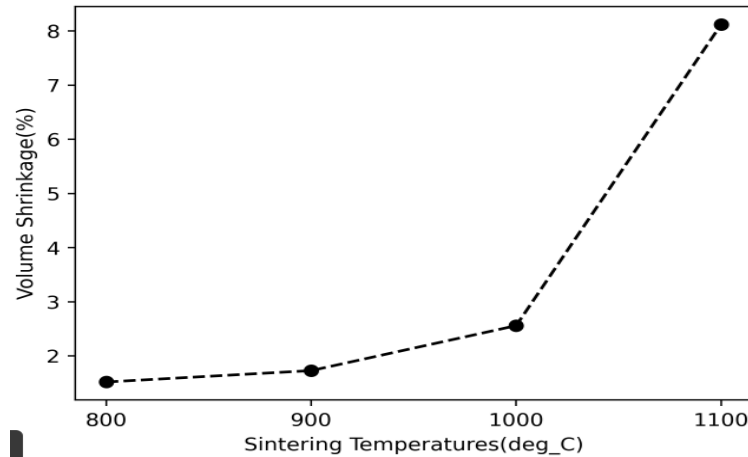


Fig 5. Volume shrinkage values

#### 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% Al<sub>2</sub>O<sub>3</sub>) based on ASTM C27-98[4]. The property values recorded at the optimum sintering temperature of 1100°C were 25.53MPa for cold crushing strength, 32.50% for apparent porosity, 1.89g/cm<sup>3</sup> 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/cm<sup>3</sup> is required; for a high-duty slag resistant fireclay brick, a minimum bulk density of 2.19g/cm<sup>3</sup> 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.

#### ACKNOWLEDGMENT

This project would not be possible without the funding and support of the Department of Science and Technology - Engineering Research and Development for Technology (DOST-ERDT).

#### 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.