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Fabrication and Characterization of Anorthite-Based Porcelain using Malaysian Mineral Resources

Hamdan YAHYA[1,a*], Abdul Rois ABDUL MOIS[1,b] and Aspaniza AHMAD[1,c]

[1]Mineral Research Center, Jalan Sultan Azlan Shah, 31400 Ipoh, Perak, Malaysia.

[a]hamdanppm05@gmail.com, [b]rois@jmg.gov.my, [c]aspaniza@jmg.gov.my

ABSTRACT. The purpose of this study is to design a porcelain based on anorthite whose properties will fulfill the tableware market requirements such as high appearance quality and strength. To obtain the anorthite based porcelain, minerals such as ball clay, quartz, feldspar and dolomite were used as raw materials. The anorthite porcelain test pieces were fabricated by uniaxial pressing with 65 MPa and followed by sintering at 1100 °C, 1120 °C, 1150 °C, 1180 °C and 1200 °C for 1 hour soaking. The maximum flexural strength achieved was ~73 MPa when the dolomite used was less than 10 wt.% (TP2) and is comparable with that of the conventional porcelain.

Keywords: *Anorthite-based ceramics, Porcelain, Ceramic table wares;*

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1. INTRODUCTION

Bone china is a highly specialized product in terms of its appearance such as excellent whiteness and good translucency which make it the most premium type of tablewares in the world. Typical composition of bone china bodies are 50 wt.% bone ash, 25 wt.% china clay or kaolin and 25 wt.% feldspar. After sintering, the phases in the fired body usually consisted of 40 wt.% β-tricalcium phosphate (β-$Ca_3(PO_4)_2$), 30 wt.% anorthite ($CaO.Al_2O_3.2SiO_2$) and 30 wt.% calcium aluminosilicate glass [1]. Hence, bone china bodies are extremely crystalline which possessed good resistance to chipping and having high flexural strength of value about 100 MPa.

Unfortunately, bone china bodies require higher firing temperature to develop maturity in the sintered body. Typically, bone china was sintered at temperature about 1230 °C and then the glaze applied and fired on at the range of 1050 – 1100 °C. Usually, the bone ash used was produced from de-gelatinizing of cattle bones with steam to remove most of the organic matter and then calcined at about 1000 °C [2]. Undoubtedly, non-halal bones were used in production of the bone ash, especially in the major regions of the world. Thus, it had become a sensitive issue and as such it is not preferred by global Muslim consumers. Therefore, another source CaO was studied in the production of anorthite-based porcelain such as dolomite ($CaCO_3$. $MgCO_3$), limestone ($CaCO_3$), wollastonite ($CaO.SiO_2$) and calcite ($CaCO_3$).

Nowadays, dolomite was mainly used in the production of anorthite-based porcelain as a CaO source. In Malaysia, dolomite are abundant and cheaper than the other calcium containing minerals. In previous study, anorthite-based porcelain using dolomite as a source of CaO was sintered at low temperature which was less than 1200 °C [1]. This will reduce the cost of production of ceramic tableware products having good physical properties comparable to bone china and unequivocally guaranteed to be halal. In this work, anorthite-based porcelain were prepared using the Malaysian mineral resources namely clay, silica sand and dolomite.

Technological properties such as chemical composition, phase formed, sintering behaviour and flexural strength were investigated and reported in detail.

2. MATERIALS AND METHODS

The studied porcelain bodies were formulated using different combination of four starting raw materials viz. ball clay, feldspar, silica sand and dolomite. Composition of the raw materials are given in Table 1. Two new porcelain bodies (TP2 and TP3) have been designed and a commercial porcelain body (TP1) was used as a comparison. The TP1 was formulated with 30 wt.% ball clay, 40 wt.% feldspar and 30 wt.% quartz. Meanwhile, the TP2 and TP3 bodies were added with 9 wt.% and 23 wt.% dolomite (Table 2), respectively. The mixtures were uniaxial pressed at 65 MPa to produce cylindrical disks with 25 mm in diameter and 8 mm in height. The compacted powders were placed in alumina crucible and sintered at 1100 °C, 1120 °C, 1150 °C, 1180 °C and 1200 °C for 1 h soaking with similar heating rate of 3 °C/min.

Table 1 Chemical composition of raw materials

Raw materials	Constituents (wt.%)								
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	LOI
Ball clay	46.81	37.48	0.58	0.04	0.07	0.16	1.67	0.12	13.02
Silica sand	98.38	1.02	0.03	0.01	0.08	0.02	0.07	0.04	0.35
Feldspar	65.56	18.85	0.08	0.02	0.23	0.03	12.39	2.28	0.56
Dolomite	0.18	0.09	0.05	0.01	31.57	20.92	0.01	0.00	47.17

Table 2 Composition of the investigated samples

Sample	Raw materials			
	Ball clay (gm)	Silica sand (gm)	Feldspar (gm)	Dolomite (gm)
TP1	30	30	40	0
TP2	30	30	40	10 (9 wt.%)
TP3	30	30	40	30 (23 wt.%)

The chemical composition of starting raw materials were determined using X-ray fluorescence (XRF, Shimadzu 1700, Japan). X-ray diffraction (XRD) was carried out to identify the phases present in the sintered bodies using Bruker equipment (Bruker AXS D8 Advance, Germany). The sintered bodies were further examined by measuring some of their physical properties such as linear shrinkage, water absorption, bulk density and flexural strength according to the standard methods as described in ASTM C373.

3. RESULTS AND DISCUSSION

The XRD pattern of samples subjected to the optimal sintering temperature are shown in Fig. 1. Noticeably, anorthite ($CaO.Al_2O_3.2SiO_2$) (ICDD:00-018-1202) and quartz (ICDD: 00-046-1045) are the primary crystalline phases with smaller amount of diopside ($CaMgSi_2O_6$) (ICDD: 04-015-8345) were formed in TP2 and TP3 as shown in Fig.1, possibly due to the addition of dolomite. The mullite ($3Al_2O_3.2SiO_2$) (ICDD: 04-016-1586) having a higher density (2.80 g/cm^3) than anorthite (2.73 g/cm^3) was observed only in TP1 due to the absence of dolomite in the body mixture [3]. Therefore, TP1 exhibited highest bulk density (2.40

g/cm^3) mainly due to formation of the mullite phase, and as such was denser than other porcelain bodies (Fig.4).

Fig. 2 and 3 shows the behaviour of the linear firing shrinkage and water absorption as a function of temperature. The linear firing shrinkage increases depending on the degree of sintering up to firing temperature reaching the optimum sintering temperature. It is noticeable that the linear shrinkage behaves differently below and above 1150 °C. The maximum linear shrinkage are 9.3%and 8.3% for TP2 and TP3, respectively, which corresponds fittingly to their volumetric densification [4]. The water absorption decreases with increase in sintering temperature due to reduction of the apparent porosity through the liquid phase sintering [1]. The TP1, TP2 and TP3 were observed to reach a value of water absorption 0.5% at sintering temperatures of 1200 °C, 1150 °C and 1180 °C, respectively.

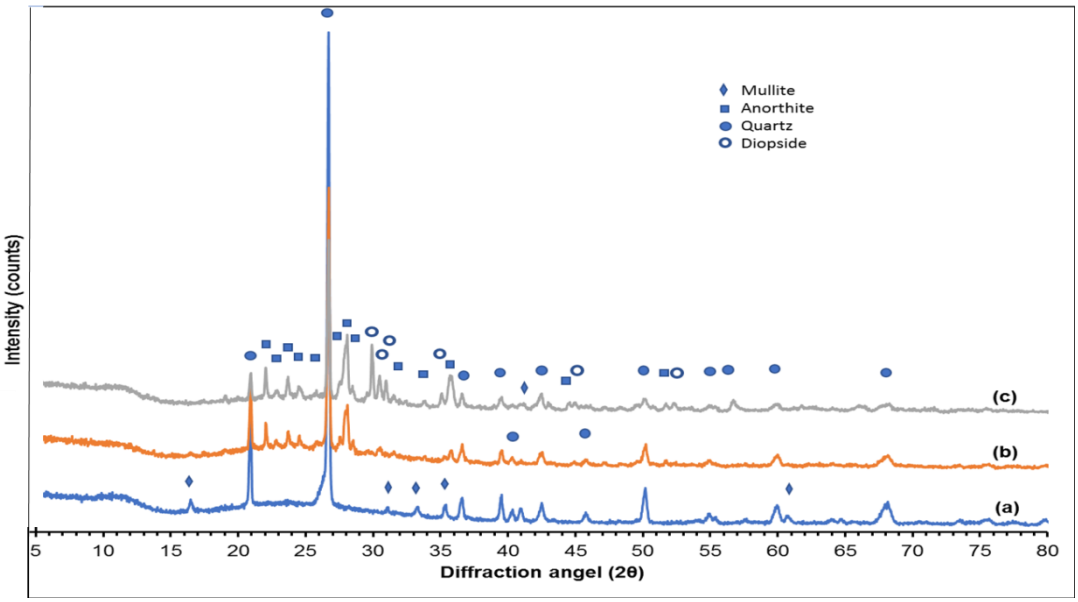

Fig. 1 XRD patterns of the porcelain bodies sintered at 1180°C. (a) TP1, (b)TP2 and (c) TP3

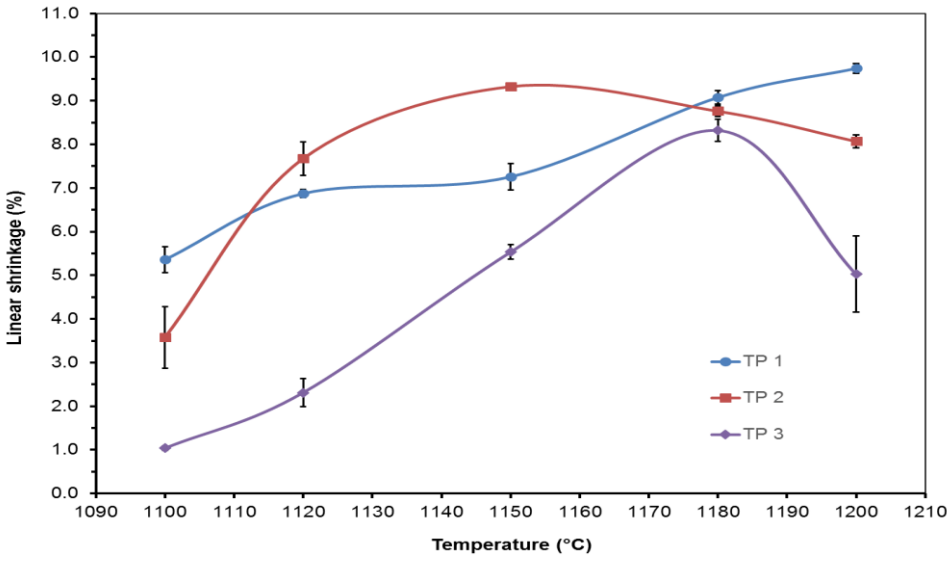

Fig. 2 Linear shrinkage of porcelain

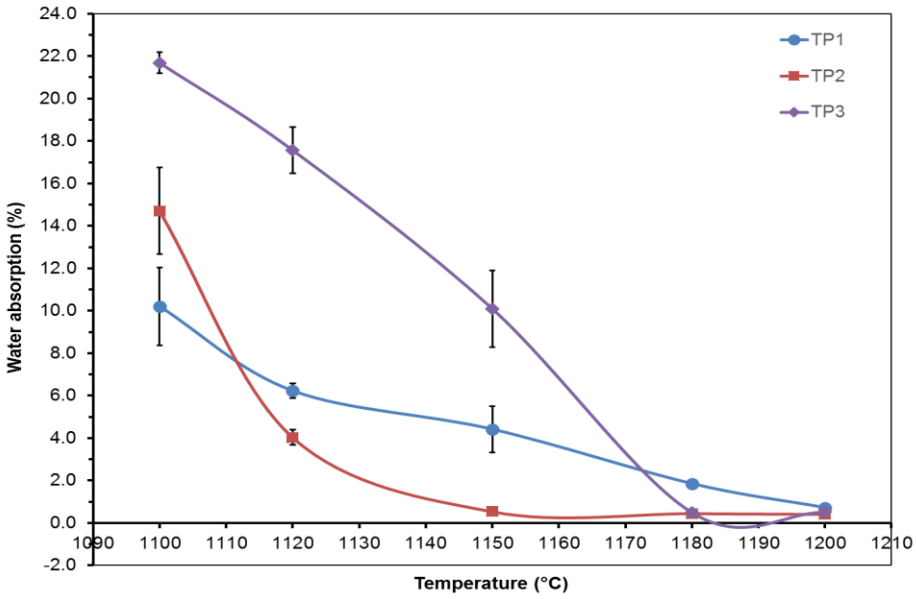

Fig. 3 Water absorption of porcelain

Fig. 4 shows the variation in bulk density with sintering temperature. The bulk density values continue to increase and optimum values are achieved when the apparent porosity reached a minimum value (Fig. 5). Further sintering results to decrease of bulk density mainly due to expansion of the entrapped gases, commonly known as blisters and bloating [3,5]. The apparent porosity decreases with increasing sintering temperature due to the formation of a glassy phase that is mainly derived from the feldspar. Increased temperatures lead to increase in the amount of liquid phase and decreased viscosity of the liquid phase and filled the pores in the body. Therefore, the porosity in the body decreases [5].

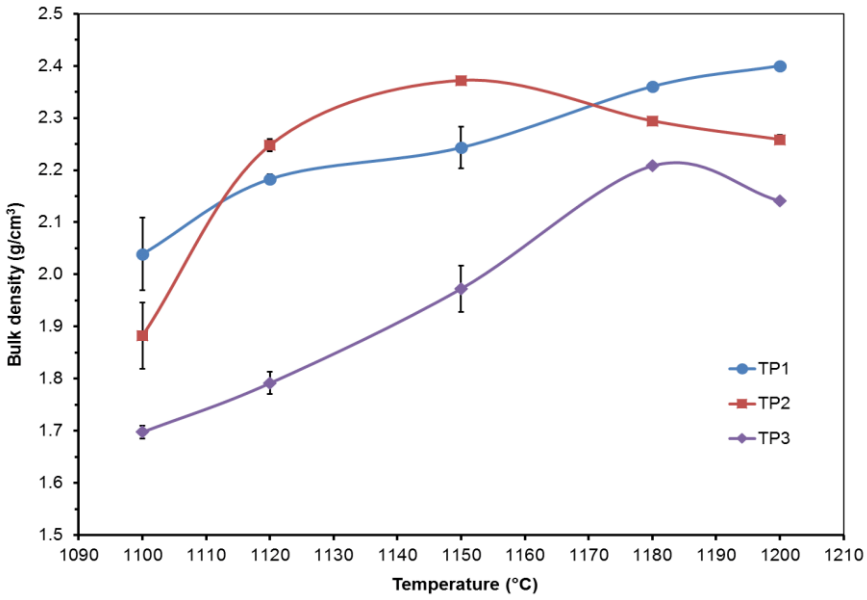

Fig. 4 Bulk density of porcelain

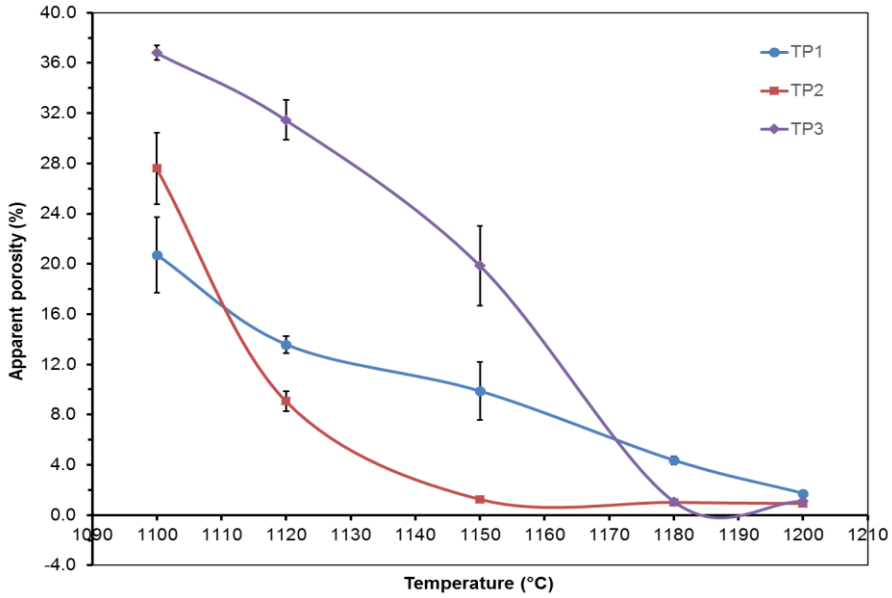

Fig. 5 Apparent porosity of porcelain

Fig. 6 shows the flexural strength behaviour as a function of sintering temperature. The flexural strength of all samples increases with an increase in sintering temperature. On further sintering, the flexural strength values reach maximum values of 62.0 MPa for TP1, 72.4 MPa for TP2 and 71.6 MPa for TP3 and then decrease with a corresponding decrease in density [6]. The maximum flexural strength values for TP1, TP2 and TP3 fulfilled the commercial porcelain strength specification, usually in the range 40 - 80 MPa [3]. Generally, maximum flexural strength develop in a porcelain body when apparent porosity decrease to zero [1]. The similar result was observed in this study.

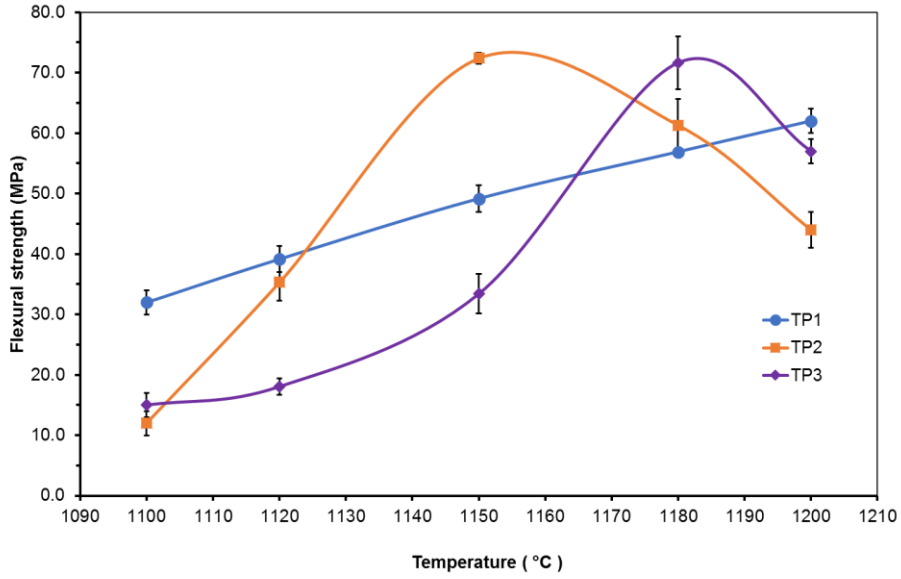

Fig. 6 Flexural strength of porcelain

4. SUMMARY

Anorthite-based porcelains were fabricated by using CaO source from dolomite. The addition of dolomite into the new formulated porcelain bodies has lowered the sintering temperatures. The samples containing dolomite can easily formed substantial glassy phase due to the existence of magnesium element in the material used. The maximum flexural strength achieved was ~73 MPawhen dolomite used was less than 10 wt.% (TP2). This meets the strength and appearance quality specifications of commercial porcelains that are available in the market.

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