Effect of Wollastonite on the Physico-Mechanical and Optical Properties of Bone-China Ceramics

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***Abstract*— In this present work, investigation has been done to identify the effect on physical, mechanical and optical properties of bone china body on the addition of wollastonite by partial replacement of potash feldspar. Various characterizations like Bulk density, Whiteness and M.O.R were performed. The use of wollastonite in bone china body was found favorable in increasing optical properties in terms of whiteness and translucency, as well as mechanical properties as flexural strength. A reduction was also noted in firing temperature due to the fluxing nature of wollastonite. It was found that bodies prepared by partially replacing the potash feldspar by wollastonite, fired at 1080 °C have better properties than the conventional bone china bodies having potash feldspar sintered at 1160 °C. Thus, lowering of sintering temperature would reduce the cost of production by low fuel consumption and increase life of furnace.**

***Index Terms*— Wollastonite, Bone China, Bone ash, Fluxing agent, Translucent body.**

I. INTRODUCTION

Bone china body is defined as ceramic ware that has a translucent body containing about minimum of 30% of phosphate and also derived from animal bone and calculated calcium phosphate [1]. Bone china body has some advantage over other porcelain body like it has high strength even though it has thinner cross section area and it is fired at low temperature [2]. Whiteness, translucency, decoration quality, bright glaze and high strength, make it differ from other tableware. Raw materials used for production of traditional bone china are bone ash, china clay and Cornish stone [3-6]. The biggest producers of bone china body are China, India, Bangladesh, Sri Lanka and Thailand [7, 8].

Wollastonite is a calcium meta-silicate having chemical formula of CaSiO3 with a theoretical composition of 48 wt. % CaO and 52 wt. % SiO2 [9, 10]. It contains some amount of impurities in the form of manganese, iron, magnesium, titanium, and strontium oxides. It founds in contact of metamorphic rocks. [11, 12]. Wollastonite exists in three polymorphic forms; triclinic at low temperature, monoclinic form, and pseudo- wollastonite occurs in pseudo-hexagonal at high temperature. Pseudo-wollastonite found rarely in nature. The conversion between various polymorphic forms takes place at 1125℃ [13-15]. Generally wollastonite alone is not used for commercial purpose because it has a melting temperature about 1540 ° C. It is well known fact that its reaction with other raw material and potash feldspar, make it appropriate to work as a very good flux. CaO obtained from wollastonite increases the whiteness of body. Use of wollastonite improves the cracking and warping behavior of body on rapid cooling and heating. Beside this other source of CaO causes shrinkage and loss of ignition [16].

In the present work bone china body was formulated by partial replacement of feldspar with wollastonite. Properties like whiteness, flexural strength, apparent porosity and bulk density were measured. Microstructure, surface morphology, and phase identification were done by XRD and SEM.

II. MATERIALS AND METHODS

Cattle bones are usually used for formation of bone ash. Firstly, bone was boiled for removal of cartilage bits and flesh attached to the bone. Elimination of organic waste as well as change in mineralogical structure to suit the use of bone ash for formulation of bone china, were done by burning of bone at temperature around 100°C [3]. After burning the burnt bones were milled until the particles were smaller than 14 µm, for the formation of bone china as recommended in the literature [17, 18]. The chemical composition was determined by using the X-Ray fluorescence (XRF) spectrometer according to ASTM C114-00 shown in Table-1 [19].

Table 1: Chemical composition of bone ash by XRF

Compound	Concentration (%)
CaO	52.2
P_2O_5	44.2

MgO	1.35
SiO_2	1.08
Na_2O	0.51
Al_2O_3	0.34
Fe_2O_3	0.19
K_2O	0.12
TiO_2	0.01

Wollastonite is a calcium inosilicate mineral ($CaSiO_3$) that may contain small amounts of, magnesia substituting for calcium. It is usually white. It forms when impure limestone is subjected to high temperature and pressure sometimes in the presence of silica-bearing fluids as in skarns or contact metamorphic rocks. Some of the properties that make wollastonite so useful are its high brightness and whiteness, low moisture and oil absorption, and low volatile content. The elemental analysis of wollastonite was done by using the energy dispersive X-ray spectroscopy (EDX) shown in Table-2.

Table 2: Chemical composition of wollastonite by EDX

Compound	Concentration (%)
CaO	25.72
MgO	13.43
SiO_2	60.85

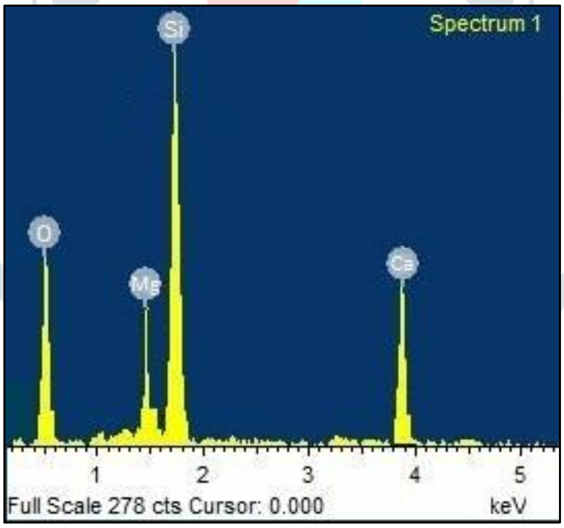

Fig. 1: EDX of wollastonite

The fabrication of bone china body was done with different formulations containing bone ash, kaolin, feldspar and wollastonite. Four different bone china bodies were prepared consist variation of feldspar with wollastonite which is shown in Table-3. All the raw materials are mixed in dry form for 10 minutes then followed by wet milling for preparation of slip. Sodium silicate was added with mixed raw materials as dispersive agent and agitated for 20 minutes in agitator. Drying of slip was done in oven at 110ºC for 1hrs. After drying dried mass was granulated by 325 mesh sieve and then pressing of granulated particles were done in a hydraulic press at pressure 30MPa. The samples were sintered in a “Bysake & Co. Electric Furnace (Model No- 7054)” with a heat schedule of room temperature to 1080˚C in 5hours. The soaking period was kept 2 hours and cooling was done for 7 hours.

Table 3: chemical composition of bodies prepared

Raw Material	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**

	(Wt. %)	(Wt. %)	(Wt. %)	(Wt. %)
Bone Ash	50	50	50	50
Feldspar	25	20	15	10
Kaolin	25	25	25	25
Wollastonite	-	5	10	15

III. RESULT AND DISCUSSION

The boiling water method described in the ASTM C20 [20] was used to determine the apparent porosity (A.P.) and the bulk density (B.D.). At this firing temperature wollastonite structure was breakdown to calcia and silica that silica causes liquid phase formation in the body; due to this liquid all pores are filled-up, that causes decrease in apparent porosity and in increase of bulk density respectively as shown in fig 2 and fig 3.

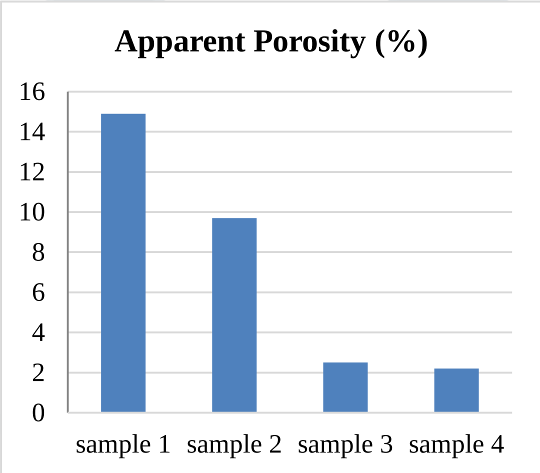

Fig. 2: Effect of addition of wollastonite on Apparent Porosity

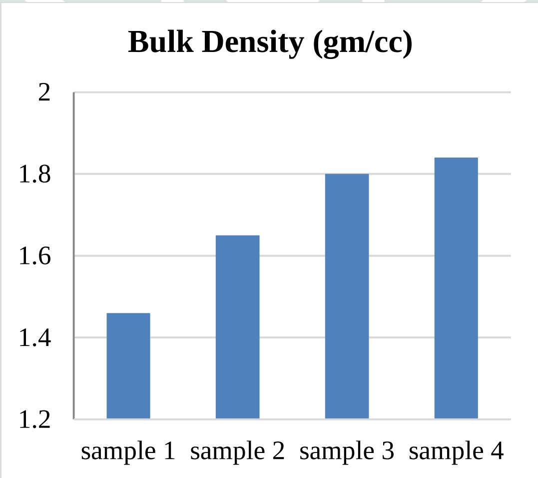

Fig. 3: Effect of addition of wollastonite on Bulk Density

Water absorption was measured by ASTM C20 [20]. Water absorption decreases with addition of wollastonite due to decrease in number of open pores in bone china body as shown in fig 4.

Whiteness is measured by reflectance meter having magnesia as reference sample with whiteness 99.99%. Whiteness increases with increase of amount of wollastonite due to addition of CaO in body. Whiteness increases up to 30% with addition of 15% wollastonite in bone china body as shown in fig 5.

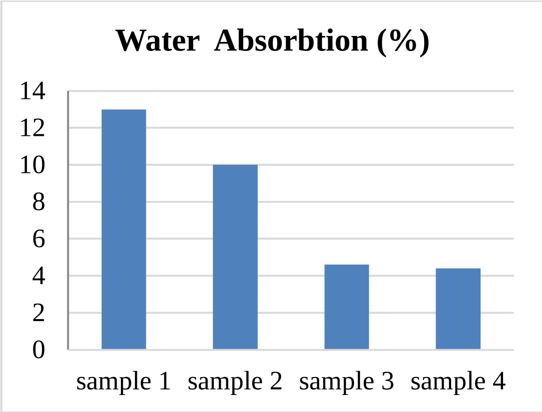

Fig. 4: Effect of addition of wollastonite on Water Absorption

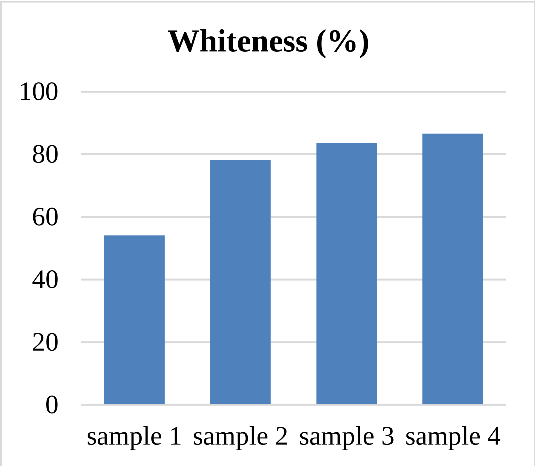

Fig. 5: Effect of addition of wollastonite on whiteness

The Modulus of rupture (M.O.R.) tests were performed with the prescription of ASTM 133 [21]. MOR of bone china sample was increased with addition of wollastonite due to excellent vitrification of body at 1080ºC but after a limit the M.O.R of bone china body was decreased due to formation of excess of glassy phase of silicate between the grains. Body 3 have better MOR results than other bodies as shown in fig 6.

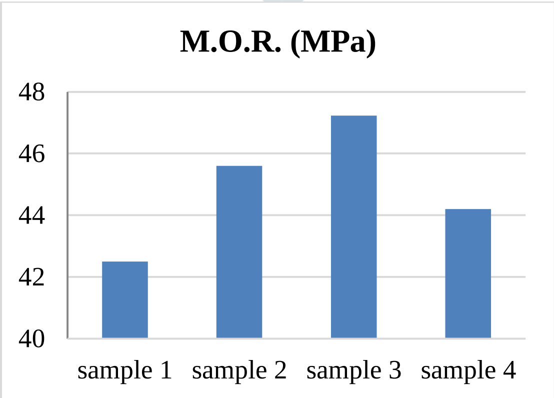

Fig. 6: Effect of addition of wollastonite on Modulus of Rupture

XRD analysis was done for sample 3, because it was optimum sample that gave promising results. XRD was done in "Rigaku mini flex-II desktop X-Ray diffrectometer" at 2Θ, 10º to 60º. The result was studied using JCPDS file to identify the phases developed after sintering. Here Anorthite & Tri-calcium phosphate (TCP) were identified as major phases present corresponding to large peaks. The major ingredient bone ash has contributed to the formation of the low temperature β-TCP. The β-form has two types of columns, each containing calcium and phosphate ions. Some minor peaks corresponding to quartz and β-wollastonite were also identified. The low intensities of these peaks ensure the sintering behavior of the sample driven by liquid phase sintering giving rise to more vitrification and densification. The high amount of liquid formation reduces the porosity to some extent but extensively, it can reduce the mechanical strength after a certain limit.

Figure 8(a) and 8(b) illustrates SEM micrographs of bone china bodies having no content of wollastonite and bone china body having 10% wollastonite content respectively, both fired at 1080ºC. There is a significant difference between surface morphology of both the bodies. Picture (a) shows irregular particle shape where silicon dioxide and alkali oxide are not fused to promote enough grain growth at this temperature, which indicates that the vitrification is not yet achieved. In contrast, picture (b) shows that the specimen is dense and has an obvious grain growth of granular particle shape due to the liquid phase resulted from the addition of wollastonite that above effects shows both completion of reaction and achievement of vitrification in the body at this temperature.

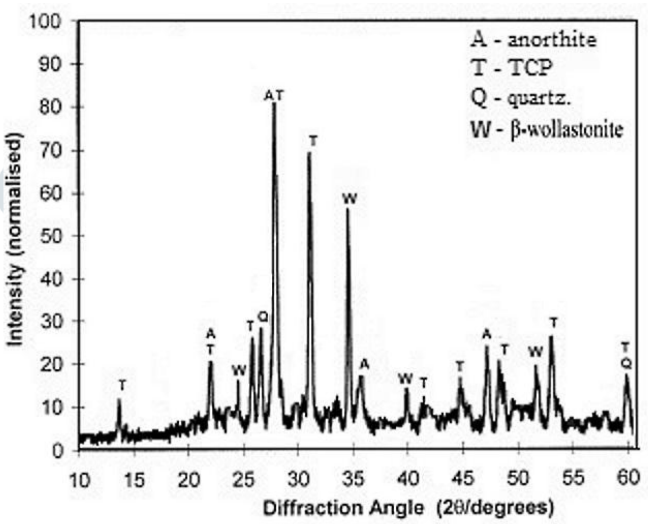

Fig. 7: XRD of bone china body with 10% wollastonite

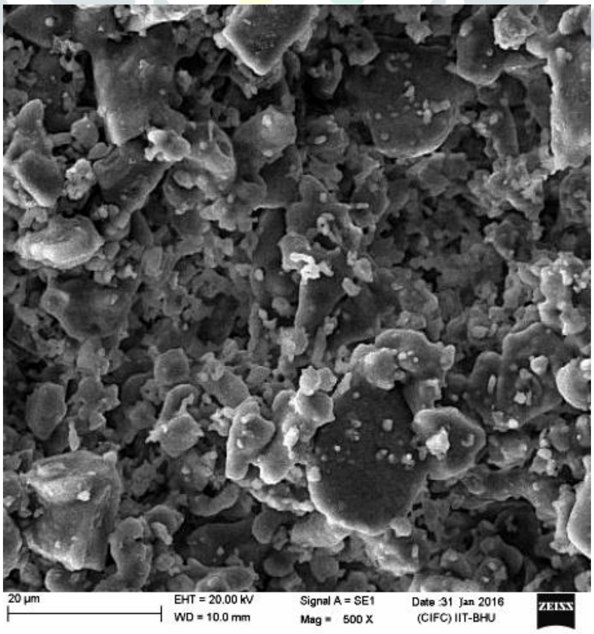

Fig. 8 (a): SEM micrograph of bone china body having 10% wollastonite fired at 1080ºC

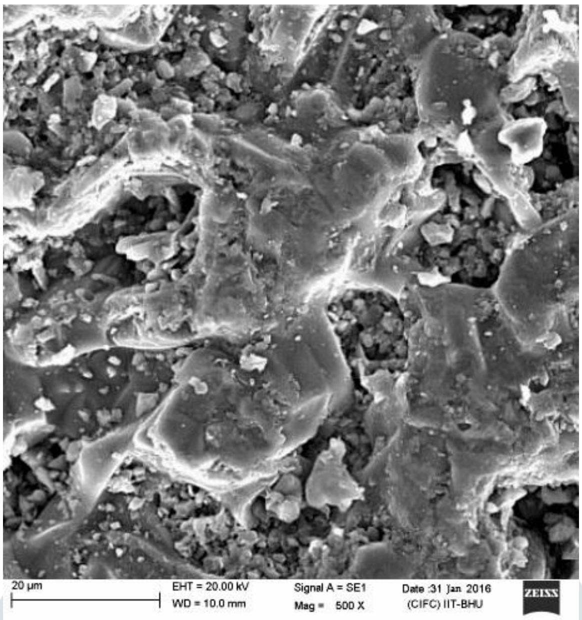

Fig. 8 (b): SEM micrograph of bone china body without wollastonite fired at 1080ºC

IV. CONCLUSION

The use of wollastonite in bone china body causes better physical and optical properties as compared to conventional bone china body in manner of whiteness, flexural strength, and porosity and also in firing temperature. Sample 3 with 10% wollastonite has better properties than remaining samples. Properties like Bulk density, and Whiteness were increased gradually with addition of wollastonite, but flexural strength of the body first increases with addition of wollastonite up to a limit and then decreases due to excess glassy phase formation in the body. Similarly, Apparent Porosity and Water absorption were decreased with addition of wollastonite. Sample 1 having a composition similar to composition of conventional bone china body that is generally fired at 1160°C this shows reduction in firing temperature of bone china body up to 100ºC, that is beneficial for ceramic industries as well as environment, because the greenhouse gases emitted are reduced.

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REFERENCES

[1] Arthur Dodd, David Murfin, British Pottery Manufacturer's Federation, and quoted in Dictionary of Ceramics, 3rd edition. The Institute Of Minerals, 1994.
[2] Ozgundogdu, Feyza Cakir, "Bone China from Turkey", Ceramics Technical, Issue 20, p29-32, May 2005.
[3] Gouvêa D, Alatrista GAV, Brito SLM, Castro RHR and Kahn H, "Surface modification of bovine bone ash prepared by milling and acid washing process", Ceramics International, 35:3043 – 3049, 2009.
[4] Kara A and Stevens R, "Characterization of biscuit fired bone china body microstructure- Part I: XRD and SEM of crystalline phases", J. Euro. Ceram. Soc., 22: 731-736, 2002.
[5] Miyahara RY, Gouvêa D and Toffoli SM, "Preparation and characterization of bovine bone ash for the fabrication of bone china", Cerâmica, 53(327): 234-239, 2007.
[6] Weyl WA, "Phosphates in ceramic ware: II, Role of phosphorus in bone china", Journal of the American Ceramic Society, 24: 245-247, 1941.
[7] Rohan Gunasekera, "Cup and Sources- Asian Tableware Leads the Way", Asian Ceramics, July/August 2013.
[8] "Skeletons in the Cupboard", Asian Ceramics, February 2013.
[9] J. Podporska, M. Błażewicz, B. Trybalska, and Ł. Zych, "A novel ceramic material with medical application", Process. Appl. Ceram., vol. 2, no. 1, pp. 19–22, 2008.
[10] L. Z. Zhu, H. Y. Sohn, and T. M. Bronson, "Flux growth of 2M-wollastonite crystals for the preparation of high aspect ratio particles", Ceram. Int., vol. 40, no. 4, pp. 5973–5982, May 2014.
[11] A. Yazdani, H. R. Rezaie, and H. Ghassai, "Investigation of hydrothermal synthesis of wollastonite using silica and Nano silica at different pressures", J. Ceram. Process. Res., vol. 11, no. 3, pp. 348–353, 2010.

[12] A. T. Volochko, K. B. Podbolotov, and A. A. Zhukova, "Preparation of Porous Ceramic Materials Based on Wollastonite Using Silicon-Containing Components", Refract. Ind. Ceram. vol. 52, no. 3, pp. 186–190, 2011.
[13] W. M. N. Nour, A. A. Mostafa, and D. M. Ibrahim, "Recycled wastes as precursor for synthesizing wollastonite", Ceram. Int., vol. 34, no. 1, pp. 101–105, Jan. 2008.
[14] M. M. Shukur, E. A. Al-majeed, and M. M. Obeid, "Characteristic of Wollastonite Synthesized from Local Raw Materials", Int. J. Eng. Technol., vol. 4, no. 7, pp. 426–429, 2014.
[15] N. Tangboriboon, T. Khongnakhon, S. Kittikul, R. Kunanuruksapong and A. Sirivat, "An innovative CaSiO 3 dielectric material from eggshells by sol – gel process", J Sol-Gel Sci Technol, vol. 58, pp. 33–41, 2011.
[16] C. W. Sinton, "Raw Materials for Glass and Ceramics", John Wiley & Sons, New Jersey, NJ, USA, 2006.
[17] D. Basnett and P. J. Cartwright, "Effect of bone properties on China casting," British Ceramic. Transactions and Journal, vol. 88, no. 5, pp. 191–195, 1989.
[18] J. J. Cooper, "Bone for bone China", British Ceramic Transactions, vol. 94, no. 4, pp. 165–168, 1995.
[19] ASTM C114-00, "Standard test methods for chemical analysis of materials", ASTM International, 2009.
[20] ASTM C20, "Standard test methods for apparent porosity, water absorption, apparent specific gravity and bulk modulus of burned refractory brick and shapes by boiling water", ASTM International, 2010.
[21] ASTM C133, "Standard test methods for cold crushing strength and modulus of rupture of refractories", ASTM International, 2008.