# TO DEVELOP PORCELAIN CERAMIC BODIES DOPED WITH $ZrO_2$ AND $TiO_2$ FOR IMPROVEMENT OF ITS PHYSICAL AND MECHANICAL STRENGTH

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**Abstract -** The present study is aimed to enhance the physical and mechanical properties of the alumina porcelain material by using $TiO_2$ (in weight percentage) as a substitute replacing $ZrO_2$. The pallets were prepared in different shapes and dimensions with the help of hydraulic press machine by pressing at 160 MPa for a period of 10min. Different characterizations techniques such as; X-ray diffraction (XRD), and scanning electron microscopy (SEM) were used to evaluate the structural and microstructural changes. The influences of the doping of $TiO_2$ and $ZrO_2$ in base porcelain ceramic body were observed while increasing concentration of one doping material with simultaneous decrease of second one. The measurement of mechanical strength and physical behavior were analyzed for all the samples prepared with different compositions of $TiO_2$ and $ZrO_2$ with varying sintering temperature from 1250 to $1350^0$C.

## I. INTRODUCTION

Porcelain is a ceramic material made by heating materials, generally including kaolin, in a kiln to temperatures between 1,200 and 1,400°C (2,200 and 2,600°F). The toughness, strength, and translucence of porcelain, relative to other types of pottery, arises mainly from vitrification and the formation of the mineral mullite within the body at these high temperatures. Porcelain has been described as being "completely vitrified, hard, impermeable (even before glazing), white or artificially coloured, translucent (except when of considerable thickness), and resonant". Kaolin is the primary material from which porcelain is made, even though clay minerals might account for only a small proportion of the whole[1], [2] and [3]. The composition of porcelain is highly variable, but the clay mineral kaolinite is often a raw material. Other raw materials can include feldspar, ball clay, glass, bone ash, steatite, quartz and alabaster[4] and [5].

Porcelain and other ceramic materials have many applications in engineering, especially ceramic engineering. Porcelain is an excellent insulator for use at high voltage, especially in outdoor applications[6], [7] and [8]. Examples include: terminals for high-voltage cables, bushings of power transformers, insulation of high frequency antennas and many other components. Porcelain can also be used as a building material, usually in the form of tiles or large rectangular panels. Modern porcelain tiles are generally produced by a number of recognized international standards and definitions. Because of its durability, inability to rust and impermeability, glazed porcelain has been in use for personal hygiene since at least the third quarter of the 17th century. In this thesis work, the aim was to build an alumina porcelain material with doping of $ZrO_2$ and $TiO_2$ to improve and enhance its mechanical strength.

## II. MATERIALS AND EXPERIMENTAL METHODS

The primary raw materials used for the sample preparation are: Kaolin, Ball clay, Feldspar, Quartz, Titanium dioxide and Zirconium dioxide. The individual raw materials were crushed and ground to pass 45µm sieve individually before mixing to form the base composition. The base composition of porcelain were selected having mass composition of 40% Kaolin, 25% ball clay, 15% feldspar and 10% quartz. The remaining 10% weight was varied by the $TiO_2$ and $ZrO_2$ as shown in Table1. Binder solution was prepared by mixing 5g PVA powder in 100ml of distilled water with magnetic stirring for one hour. The material is poured in the top sieve which has the largest pore size. The mixes of all composition were mixed by adding PVA solution evenly by constant hand mixing for 1 hour and then ball milled. Planetary ball mill was used with grinding media of $ZrO_2$ balls for further mixing and grinding for 6 hours.

**Table 1. Composition of samples**

| Sample | $ZrO_2$ (Weight %) | $TiO_2$ (Weight %) |
|---|---|---|
| X1 | 10 | 0 |
| X2 | 7.5 | 2.5 |
| X3 | 5 | 5 |
| X4 | 2.5 | 7.5 |
| X5 | 0 | 10 |

The powder was then collected and stored in containers. Before the pellet formation process, 3-4 drops of 5% PVA binder was added in each powder sample and hand mixed thoroughly for 30 minutes. For pellet formation, the powder is pre-heated in an

oven for 1 hour. The method used for pellet formation was die pressing. In this technique, the powder was compacted in carbon steel die and then isostatically pressed further using hydraulic press at 12ton pressure. The compacted powder i.e. pellet was weighed and its dimensions were measured for calculating green density. Higher green density signifies better compaction. Many pellets of different shapes and sizes were prepared for their use in further tests and characterization. Sintering is a heat treatment applied to a powder compact to impart strength and integrity. The sintering temperature is kept below the melting temperature of the constituents in the mixture. The pellets prepared were sintered at $1250^0$C and $1350^0$C by the pressureless sintering. The sintering furnace was heated at the rate of $5^0$C /min. The holding time was set for 2 hours. For XRD purpose, 1 g powder of each composition was sintered separately. The sintered samples were analyzed for their porosity and bulk density. Samples were also characterized for their phases by X.R.D technique. To study surface morphology, S.E.M of samples of all compositions were taken.

## III. RESULTS AND DISCUSSION

XRD of each sample was carried out and the peaks were analyzed as shown in Fig 1. The major phase present was observed as Mullite;$3Al_2O_3.2SiO_2$ (JCPDS: 79-1453). $TiO_2$ was found as Rutile(JCPDS: 73-2224) phase and $Al_2TiO_5$ (JCPDS: 70-1435). The peaks of these two phases increased from X2 to X5 samples, signifying increase in Ti concentration and reaction of Al with $TiO_2$. In both $1250^0$C and $1350^0$C sintered

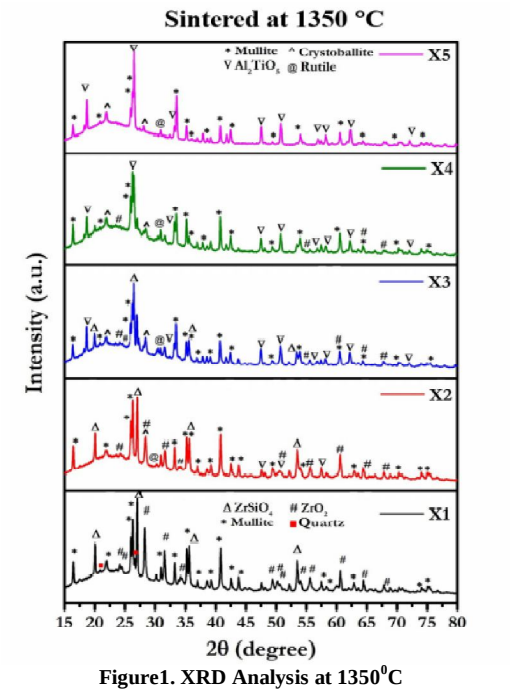



**Figure1. XRD Analysis at $1350^0$C**

samples, $SiO_2$ was found as Quartz(JCPDS: 79-1906) and its peaks decreasing from X1 to X3. Same pattern was observed in $Al_2O_3$(JCPDS: 46-1212) where its peaks decreased from X5 to X3. These two similar patterns suggested the formation of mostly Mullite phase in the sample X3. For the Apparent Porosity, Bulk density and water absorption, the data were collected and plotted as shown in figure2. It can be observed that the

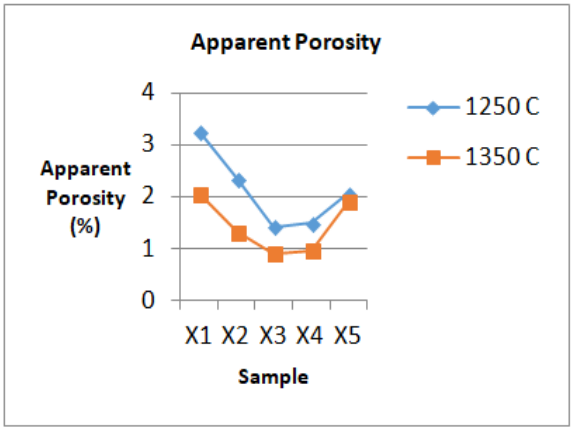



**Figure 2. Variation of Apparent Porosity**

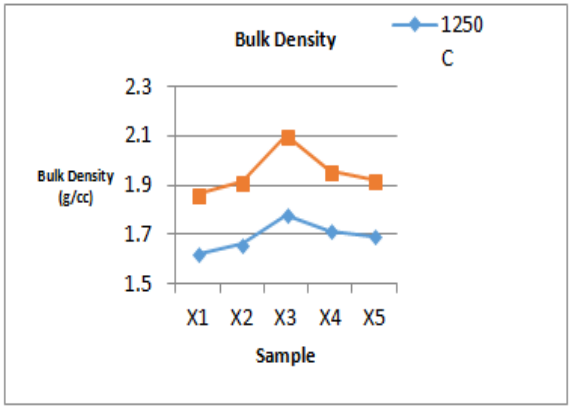



**Figure 3. Variation of Bulk Density**

apparent porosity decreased as the $TiO_2$ content increased with simultaneous decrease in $ZrO_2$ content. Also the porosity decreased in the samples sintered from $1250^0$C to $1350^0$C. From the figure 3, it can be seen that the bulk density increases as the $TiO_2$ content increases with simultaneous decrease in $ZrO_2$. In the figure 4, it can be seen that the water absorption decreases as the $TiO_2$ content increases with simultaneous decrease in $ZrO_2$ content. Also the water absorption decreases with increase in sintering temperature from $1250^0$C to $1350^0$C for each sample. Linear shrinkage as shown in figure 5, decreases with the increase in the $TiO_2$ content with simultaneous decrease in $ZrO_2$ in the samples. Also it can be seen that as temperature increases, the linear shrinkage of each sample increases.

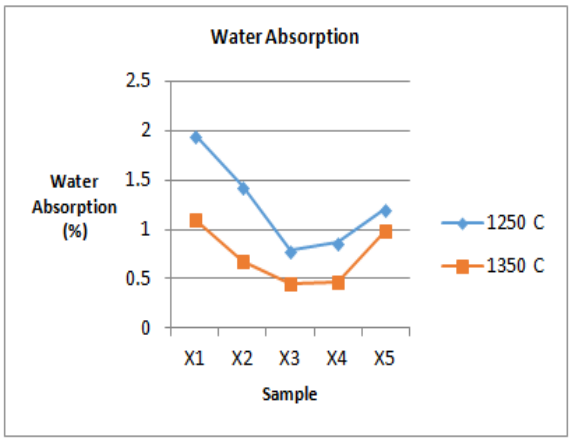



**Figure 4. Variation of Water Absorption**

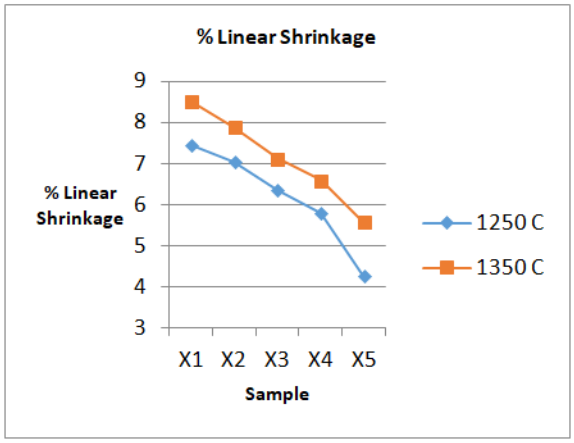



**Figure 5. Variation of Linear Shrinkage**

The mechanical tests were carried out on the universal testing machine. The sample dimensions were measured and fed in the software and the bending and compressive strengths were calculated. The results are plotted in figure 6. It was observed that the bending strength increased initially and then decreased as the $TiO_2$ content in the samples increased with simultaneous decrease in $ZrO_2$ in the samples. Also for higher sintering temperature, the bending strength is higher. This behaviour was in accordance to the XRD analysis, which showed the presence of mullite as a major phase in sample. However, as the $ZrO_2$ content decreased with subsequently decrease in mullite phase development, the bending strength also decreased.

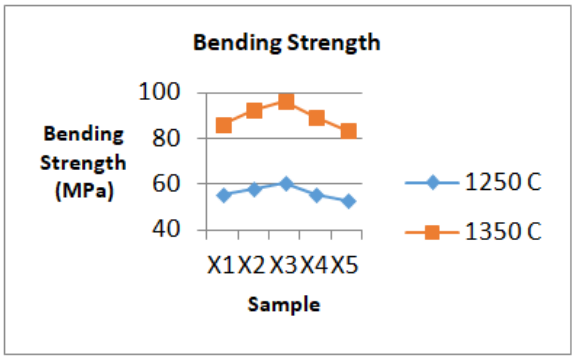



**Figure 6. Variation of Bending Strength**

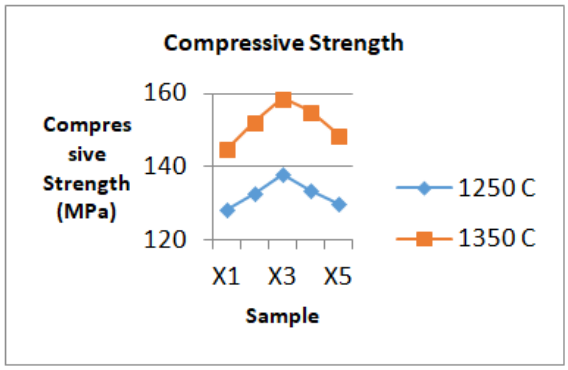



**Figure 7. Variation of Compressive Strength**

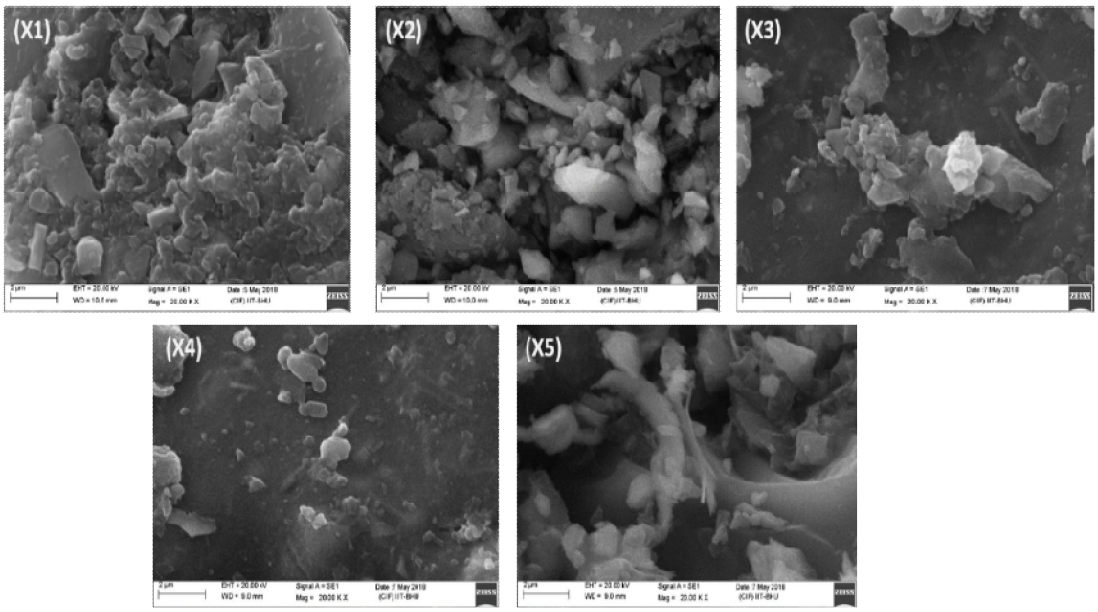



**Figure 8. S.E.M of different samples sintered at 1250$^0$C**

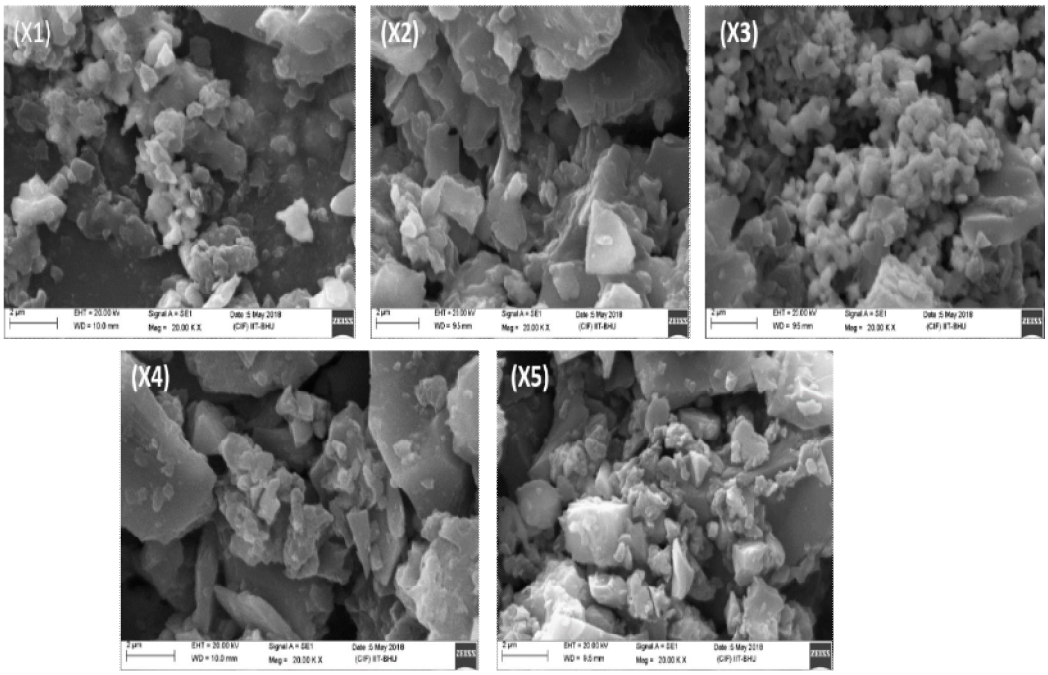



**Figure 9. S.E.M of different samples sintered at $1350^0$C**

The figure7 is representing the variation of compressive strength in the samples. The variation of compressive strength is almost the same as that of bending strength. It can be observed that the compressive strength is maximum in case of X3 which is again in accordance with the XRD analysis of the samples. The SEM photographs of all the samples are shown in figure 8 and 9 at magnifications of 20,000X. In the images it is clear that as the $TiO_2$ concentration of the sample increases, the particle packing density increases upto sample X3, and then the particle packing density starts decreasing. This also signified that as $TiO_2$ content increased in porcelain, the phase development of mullite was better. Also in samples sintered at 13500C, there are types of round types of grains. The samples sintered at $1350^0$C showed better grain density than those of $1250^0$C.The pores also decreased from X1 to X3 and then increase to X5. The pores in $1250^0$C samples were more visible and would be compared to the samples sintered at$1350^0$C.

## CONCLUSION

In this work, mullite rich porcelain was successfully prepared and further mechanical properties were enhanced with doping of $ZrO_2$ and $TiO_2$. The porcelain having 2.5% $ZrO_2$ and 7.5% $TiO_2$ showed highest apparent porosity value. The maximum bending strength was obtained for porcelain doped with 5% $TiO_2$ and 5% ZrO2, suggesting best phase reactions at this composition. The maximum compressive strength was also obtained for the same samples (5% $TiO_2$ and 5% $ZrO_2$), suggesting best phase reactions at this composition. These types of porcelain will be better option for chemical and high tension electrical porcelain.

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