# THE ROLE OF MAGNESIUM OXIDE ON THE MECHANICAL PROPERTIES OF Y-TZP CERAMIC

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*Abstract- An investigation has been carried out into the effects of magnesium oxide additions in the 0.1 to 1.0 wt% range on the properties and behavior of Y-TZP. All samples have been sintered over the temperature range of 1200°C to 1500°C with a ramp rate of 10°C/ minute and 2 hours of holding time. Upon reaching the peak temperature, the sintering temperature was immediately brought down to a holding temperature of 1250°C and held for 4 hours. Green samples were compacted by uniaxial pressing and cold isostatically pressed at 200 MPa. The results show that the addition of 0.3 wt% MgO was effective in aiding densification (~99% theoretical density). The MgO addition to the Y-TZP matrix also displayed an increment of flexural strength as the content increased. Bulk density and Vickers hardness show the beneficial effect of MgO in aiding the densification of Y-TZP ceramics.*

*Keywords- Magnesium Oxide; sintering behavior; Y-TZP*

## I. Introduction

Zirconia used in many application due to its outstanding mechanical and physical properties. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is a type of zirconia and acts an alternative to other materials traditionally used for ceramic restorations. Y-TZP has esthetic advantages in comparison to metal alloys and is tougher than other ceramic materials. Besides its biocompatibility and high wear resistance, the high strength and toughness of these zirconia materials result from a toughening phenomenon, due to transformation from the tetragonal to the monoclinic structure ($t \rightarrow m$ transformation). The tetragonal structure can be retained by adding oxides such as $TiO_2$, $MgO$, $Al_2O_3$ and $CeO_2$, but may affect the mechanical and physical properties [1- 4].

Long term degradation (LTD), or aging, occurs when there is spontaneous transformation from the metastable tetragonal phase to the monoclinic phase. It raises concerns as the spontaneous tetragonal to monoclinic transformation can drastically decrease the mechanical properties of the Y-TZP by surface roughening, grain pull out, and microcracking. The addition of manganese oxide to Y-TZP resulted in decreased in the density and increased in hardness [5, 7].

Besides that, S. Ramesh [8] also investigated the densification behavior and properties of manganese oxide doped Y-TZP ceramics and found that $MnO_2$-doped Y-TZP achieved a high relative density (>95% of the theoretical value), compared to the pure

samples. Sintering holding time proved to be the key factor in aiding the densification in

this experiment. A. Smirnov and J.F. Bartolome [9] studied the effects on the mechanical properties of $ZrO_2$ by using tantalum. Results showed that the fracture toughness and elastic modulus of 3Y-TZP-Ta sample displayed a higher value compared to the pure 3Y-TZP sample. The grain size plays a pivotal role in altering the mechanical properties. In an investigation the microstructure variables play a major role on the tribological behavior and toughness of Y-TZP. In B. Venkata Manoj Kumar's study, results shows that fracture toughness decreased as the grain size increased. [10- 13].

# II. Experimental Techniques

## a) Sample preparation

The Y-TZP powder was mixed using the wet-milling method with various weight percentages of magnesium oxide, MgO (0.1, 0.3, 0.5 and 1.0 wt %) and produce a mixture. After milling the slurry was oven dried and sieved to obtain soft and ready-to-press powders. Next, circular disc samples (20 mm diameter) and rectangular bars (4mm* 13mm*32mm) were pressed uniaxially at 35 MPa followed by cold isostatic pressing (CIP) at 200 MPa. All samples were sintered at 1200°C, 1350°C and 1500°C. A ramp rate of 10°C/min was used with a holding time of 2 hours.

## b) Characterization

The bulk densities of sintered samples were determined by the water immersion method based on Archimedes' principle. For this measurement, the equipment used was the Mettler-Toledo Balance AG204. This includes placing a beaker of distilled water on the weighing scale, with a holder attached in place. The formula to calculate the bulk density is

$$\rho = ( W_a / W_a - W_w ) \rho w \quad (1)$$

The Vickers hardness [12, 13] and fracture toughness are calculated based on the surface area of the indent using equations (1) and (2) respectively:

$$H_v = 1.854P / (2a)^2 \quad (2)$$
$$K_{IC} = 0.019P (E/H)^{1/2} / C^{3/2} \quad (3)$$

where P is the applied load, a is the indent half diagonal, E is the Young's modulus, H is the Vickers hardness and C is radial crack dimension measured from the center of the indent impression( i.e. c = a + l) and l is the average crack length.

# III. Results and discussion

## a) Bulk Density

The variations of how sintering temperature affects the bulk density of the samples are displayed in Figure 1, the density of Y-TZPs sintered below 1400 °C was significantly improved by the addition of up to 1.0 wt% MgO. In particular, samples containing ≥0.3 wt% MgO exhibited ~96.7% theoretical density (the theoretical density of Y-TZP was taken as 6.1 Mg m$^{-3}$) with a value of 5.9 g/cm$^3$. The increase in density of MgO-Y-TZP is aided by increasing the concentration of dopant.
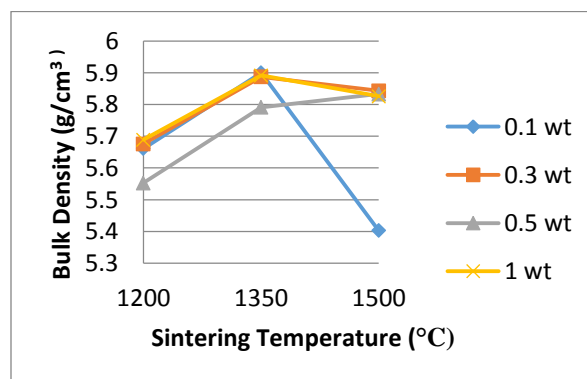


Figure 1. The effect of MgO addition to the bulk density of MgO doped samples

## b) Vickers Hardness

In contrast, the hardness did not change significantly for sintering up to 1350 °C. The hardness of the sample remain steady if not decline when sintered between 1200 and 1500 °C, before increasing rapidly with further sintering. The 0.1 wt% MgO-doped Y-TZP exhibited the highest hardness of 34.71 GPa for sintering above 1350 °C as shown in Figure 2. Also, it is observed that 1350°C is the optimum temperature for density, whereas it proves otherwise for hardness.
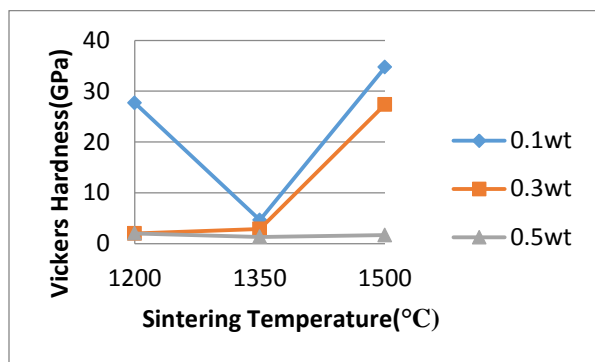


Figure 2. The effects of Mgo content and the sintering at various temperatures (°C) on the Vickers Hardness (GPa)

## c) Flexural Strength & Young's Modulus

In figures 3 and 4, the beneficial effect of MgO in enhancing the stiffness and flexural strength of Y-TZP can be observed particularly when sintered between temperatures 1200 °C to 1350°C. However, as the sintering temperature increased, the values of both flexural strength $E$ value decreased gradually, a contrast to the increasing trend observed for Vickers's Hardness. Samples containing 1.0 wt% MgO showed the highest value for both flexural strength and $E$ value; ~400MPa and 50MPa respectively. The high flexural strength generated is probably due to the reduced grain size of the size.
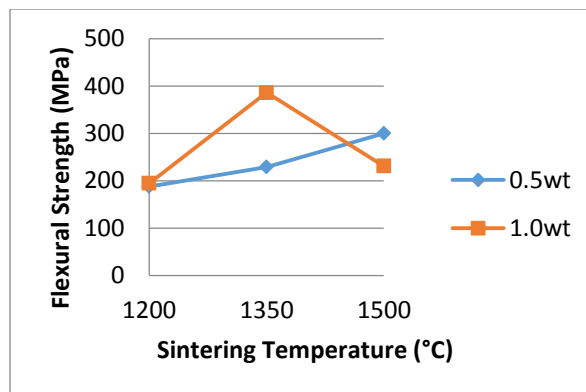


Figure 3. The effects of MgO content and sintering temperature on the flexural strength (MPa)
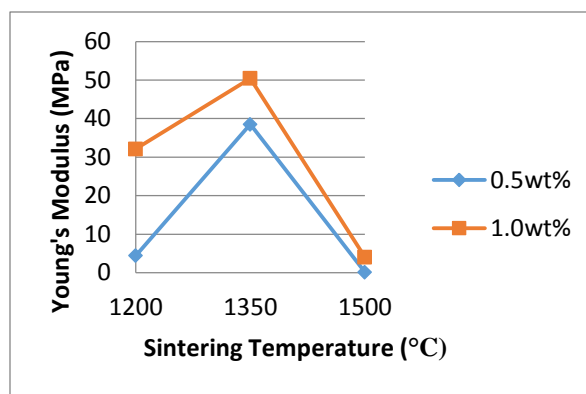


Figure 4. The effect of MgO content on the Young's Modulus (GPa) at various sintering temperatures (°C)

## d) Linear Shrinkage and Volume Reduction

The linear shrinkage and volume reduction of samples increased with sintering temperature for all weight percentages of MgO. The addition of 0.1wt % MgO shows the highest value for both linear shrinkage and volume reduction. Also, an increasing trend is observed for all weight percentages between temperatures 1200°C to 1500°C, with the highest percentage attained at 1500°C. It is possible that shrinkage is highest at this temperature due to the spontaneous transformation from tetragonal to monoclinic phase, and the shrinkage rate decreases as additive percentage increases.
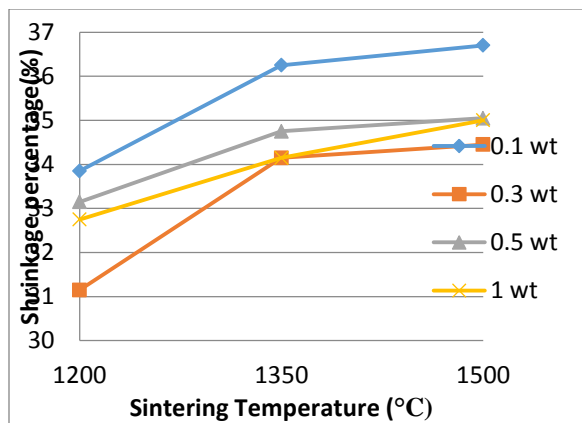
Figure 5. The effects of MgO content and sintering temperature on the linear shrinkage of samples
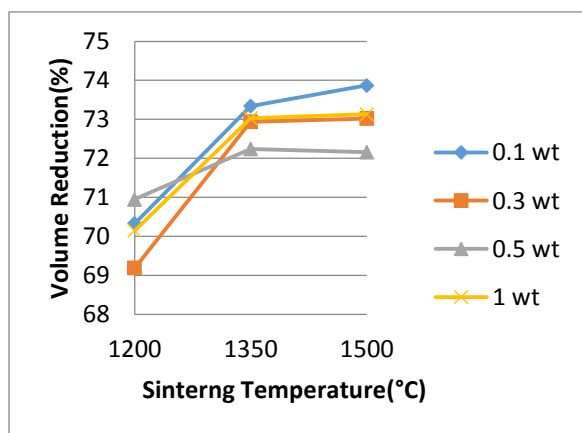
Figure 6. The effects of MgO content and sintering temperature on the volume reduction（%）

## e) Fracture Toughness

The variation in the fracture toughness of MgO doped samples is shown in Figure 7. An increasing trend is observed for the 1.0wt% of MgO between temperatures 1200°C to 1500°C. The transformation toughening phase is known to be related to the transformability of the (t) grains. The fracture toughness can be used to indicate the state of stability of the tetragonal grains in the zirconia matrix, in which a higher value suggests a metastable phase.
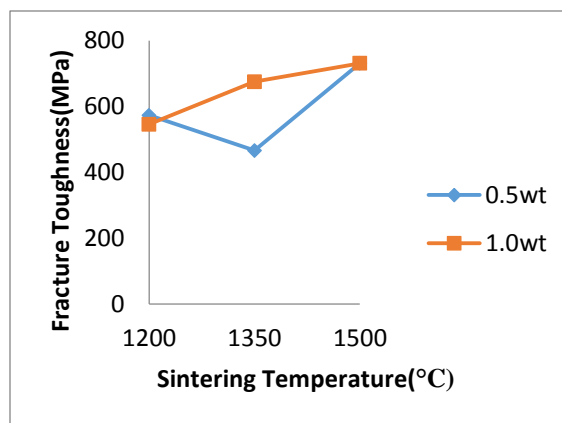
Figure 7. The effect of MgO content on the fracture toughness (MPa) of the samples

## IV.    Conclusion

In the present work, the addition of MgO to Y-TZP proved beneficial as the mechanical properties were enhanced, particularly at 1350°C.The MgO doped samples achieved high density approximately 96.7% of theoretical value when sintered above 1200°C. The highest values of density, flexural strength, Young's Modulus and fracture toughness was achieved with the addition of 1.0wt% of MgO at temperatures 1350°C and 1500°C. On the other hand, shrinkage, volume reduction and hardness occurred for 0.1wt % at 1500°CFigure 7. The effect of MgO content on the fracture toughness

## V.    Reference

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