

Study the Effect of Zirconia to Increase the Abrasion Resistance and Density in Alumina-Zirconia System

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ABSTRACT

The applications of Al_2O_3 , ZrO_2 ceramics are amazingly large, diverse and include cutting tools, forming dies, wear parts, bearings, seals, valves, nuclear fuels, nose cones and tiles for space shuttles and missiles, and etc. The most common form of crystalline alumina is known as corundum α - Al_2O_3 , in which the oxygen ions nearly form a hexagonal close-packed structure with aluminum ions filling two-thirds of the octahedral interstices. Zirconia (ZrO_2) is also a ceramic, in which the particular crystal structure of zirconium oxide is made stable at room temperature. ZrO_2 adopts a monoclinic crystal structure at room temperature, and it would transit to tetragonal and cubic at higher temperatures. The volume expansion caused by the cubic to tetragonal to monoclinic transformation induces large stresses, and these stresses cause ZrO_2 to crack upon cooling from high temperatures. When the zirconia is blended with some other oxides, the tetragonal phase is stabilized. The dopants such as yttrium oxide (Y_2O_3 , yttria) with 3 mol% could make the Zirconia stabilized. We have to notice that as yttrium is not recommended to use in industry, so it would be better to use titanium instead of yttrium. The present research is a laboratory and case study, in which the effect of Zirconia to increase the abrasion resistance and density in Alumina-Zirconia system, has been observed. The obtained results show that stabilized Zirconia with each of yttria and titanium are nearly similar with each other. Also it has been shown that the stabilized Zirconia with titanium get better results.

KEY WORDS: Zirconia, resistance, abrasion, density, Alumina

INTRODUCTION

Monoclinic crystal structure is stable at room temperature, and it would be transited to tetragonal and cubic phases at higher temperatures, and also 3% volume phase would be occurred in this case. ZrO_2 is not recommended to be used in structural segments. Due to occurring some problems while transmitting the phase in zirconia, so the stabilized Zirconia could be stabilized with Effective dopants include magnesium oxide (MgO), yttrium oxide (Y_2O_3 , yttria), calcium oxide (CaO), and cerium oxide (Ce_2O_3), in which zirconia would be stabilized, and hardness and chemical inertness would be the most common property of it at this time. [1]

From 1900 to 1980, making abrasion particles of fused Alumina and fused Alumina-Zirconia was done via melting bauxite or aluminum. These particles were suitable for wear covers, bands and brushes.

In 1994, composites of Alumina- Zirconia were achieved via flocculation suspension method.

In 1995, abrasion behavior of ceramic composites ZDA was studied. From the second half of 1980 up to now, the first abrasion particles of Alumina- α are gained for abrasion applications via Cell-Gel method, these particles are very tiny; however, this method is very expensive.

In 1998, phase stabilization and mechanisms of increasing toughness in zirconia ceramics were done on zirconium oxide and its properties.

In 2001, Alumina thermal shock ability behavior as a result of increase of m- ZrO_2 was studied.

From 2002 to 2004, some researches were done to make eutectic fuse including oxy carbide aluminum, nitride aluminum, yttria and alumina. These matters were suitable for fibers and wear particles; moreover, increase of ZrO_2 had been studied for increasing toughness of Alumina friction.

From 2004 up to know, ceramic compositions and its constructing method has been studied, the main phase includes ceramic oxides and additives including ceramic oxides. Alumina, zirconia, titania, yttria and silica are samples of ceramic oxides used widely to improve surface properties of matters. Their application is for abrasion resistance cases.

In 2007, some researches were done on cutting tool including ceramic oxide. This cutting tool works based on cooling method, this cooling increases abrasion resistance and tools resistance against breaking. One sample of this tool includes aluminum oxide with 10 percent zirconia. In fact, this cutting tool is made in the form of composite matters, the first phase includes 90 to 99 percent oxides and the second phase includes 1 to 10 percent of oxides. This cutting tool is used on glasses, which are applied in optical waves and include oxides such as alumina, zirconia, and dopants. Moreover, some research has been done on bio ceramics, showing that density of alumina- zirconia with %3 mol of stabilized yttria is more than %8 mol of yttria. Moreover, mechanical properties with 3 percent mol

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of stabilized yttria is better than 8 percent mol yttria and it indicates that the second yttria has cubic phase, while the first one has tetragonal phase, therefore, tetragonal phase is a suitable phase.

Zirconia –Alumina, a combination of zirconium oxide and aluminum oxide, is part of a class of composite ceramics called ATZ composites. In recent years, ATZ composites are commonly used in structural applications, as cutting tools, and in many medical applications, also they have been noted for their mechanical properties. Additionally, ATZ composites feature high strength, fracture toughness, elasticity, hardness, and wear resistance. [4] Al_2O_3 , ZrO_2 ceramics with tetragonal phase and monoclinic phase in zirconia have respectively the least and the most abrasion rate. [5] In ceramics, adding small interstices of alumina could lead to abrasion resistance and hardness in ceramics. [6] zirconia density is nearly 6.15 gr/cm^{-3} , whereas the alumina density is 3.97 gr/cm^{-3} ; thus the effective density in Alumina-Zirconia would be resulted while the zirconia increases. [2] interstices size and oxidized stabilizers are both the important factors in Alumina-Zirconia systems. [3]

Engineering ceramics have the potential for protecting different tools from abrasion, tools which are used in mineral industry. In fact, they work in contact with hardened abrasion fragments, high pressure and high speed. Engineering ceramics have high mechanical properties, chemical neutrality, high abrasion resistance and ability to work in thermal condition.

Used ceramics are for abrasion protections, alumina, zirconia with low porosity, and other ceramics such as carbides, nitrides and so forth. In fact, suitable ceramics are selected based on their physical properties.

Alumina is one of the ceramic matters used successfully in structural applications because of having properties such as high mechanical resistance, good stability, and high abrasion resistance. However, toughness and fracture are the main weaknesses. Thermal leading of it is less than other ceramics; therefore it does not have considerable shock ability, one of the ways to overcome this weakness is increasing zirconia to alumina.

Density of zirconia is about $6/15 \text{ grcm}^{-3}$. Since density of alumina is about $3/97 \text{ grcm}^{-3}$, therefore, effective density of zirconia-alumina increases with increase of zirconia. Particle size and oxide stabilizers are the effective factors in mechanical properties of alumina- zirconia.

In the recent years, a special group of industrial ceramics called ATZ has drawn attentions to itself. These ceramics have toughness and stability more than alumina gained via uniformed distribution of zirconia particles in the field of alumina. Ceramic combinations of Al_2O_3 - ZrO_2 with tetra gel zirconia phase show the minimum abrasion rate, while ceramic combinations with monoclinic zirconia phase show the maximum abrasion rate.

In 2010, researches were done on making circular particles of tetragonal zirconia with special high level. Moreover, in 2011 constructing current stopple in semiconducting tools of D-electric films applicable in the structure of capacitors was studied, the main combination of D-electronic film was O, Al, Zr, moreover, it had crystal structure.

METHODOLOGY

The present research has been accomplished through the materials such as Korea Yttrium Oxide, zirconia, Calcined Aluminium Oxide Powders, Titanium dioxide, Magnesium oxide, and PVA which all these have been used as a stabilizer pre baking. In this research merging method, ASTM: B611-85 standard and X-ray diffraction pattern formed method have been used in order to respectively measure density, abrasion resistance and phase analysis. To stabilize zirconia, moreover the titanium oxide, also Magnesium oxide has been used, in which we would have ($0.1\text{Mgo} + 0.4 \text{TiO}_2$). zirconia was stabilized firstly with 3 mol% yttria, and then with 10 wt% titanium. To add zirconia and observe the effects, the stabilized zirconia with the amount such as (0,2,4,6,8 mol%) was added to Alumina. material batch, except PVA, is added to container, and it has to be blended for one hour, then materials have to be put in dryer in 110°C temperature, in this case they would be calcined and then we have to sift the calcined materials, finally the 5 wt% PVA has to be added and blended in materials. materials were possible to be shaped through isostatic press with 700bar pressure. Calcination was accomplished during 5 hour in 110°C temperature, and patterns baking were accomplished in 1600°C temperature in Gas furnaces, in which putting patterns in maximum temperature was taken along during 4 hours.

Table 1-density and Abrasion resistance

	A	B	B	C	C	D	D	F	F
Density	3.92	3.97	3.98	3.97	4.00	4.01	4.02	4.03	4.05
Low volume abrasion resistance	0.0969	0.0453	0.0804	0.0375	0.0733	0.0299	0.0422	0.019	0.0074

A=99.5 wt% Al_2O_3

B=97.5 wt% Al_2O_3 + 2 wt% ZrO_2 (3 mol% Y_2O_3)

B=97.5 wt% Al_2O_3 + 2 wt% ZrO_2 (10 wt% TiO_2)

C=95.5 wt% Al_2O_3 + 4wt% ZrO_2 (3 mol% Y_2O_3)

C=95.5 wt% Al_2O_3 + 4wt% ZrO_2 (10 wt% TiO_2)

D=93.5 wt% Al_2O_3 + 6wt% ZrO_2 (3 mol% Y_2O_3)

D=93.5 wt% Al_2O_3 + 6wt% ZrO_2 (10 wt% TiO_2)

F=91.5 wt% Al_2O_3 + 8wt% ZrO_2 (3 mol% Y_2O_3)

F=91.5 wt% Al_2O_3 + 8wt% ZrO_2 (10 wt% TiO_2)

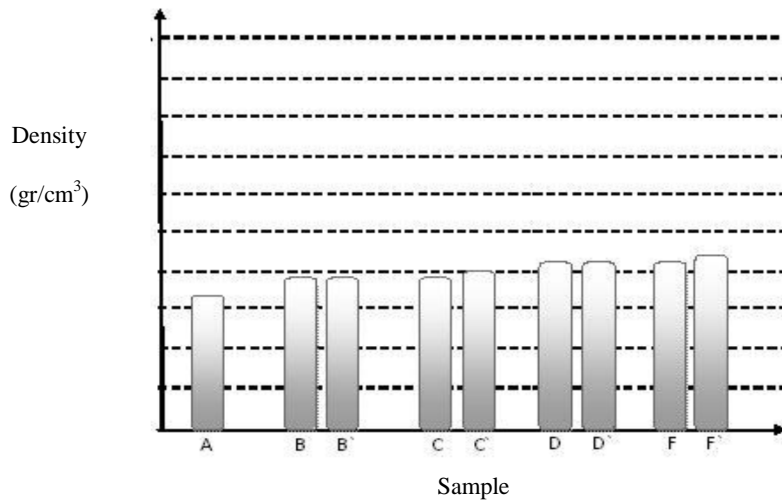


Figure 1-density diagram in samples

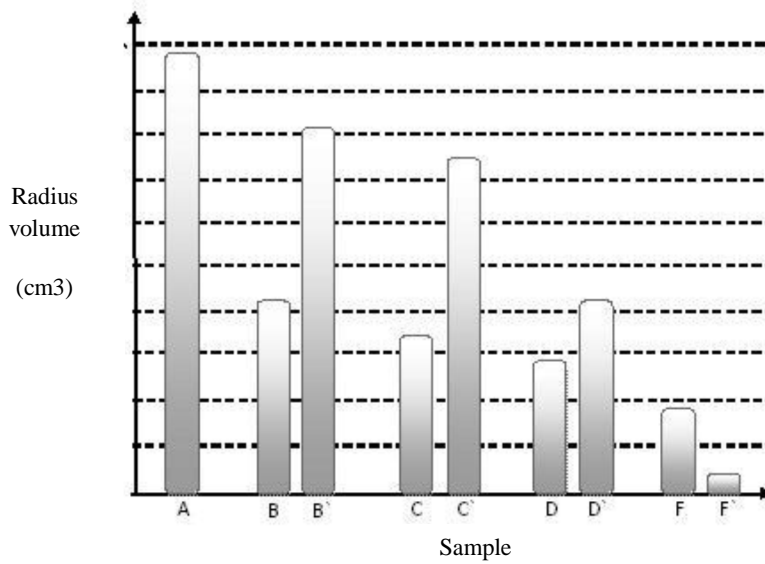


Figure 2- the diagram of volume reduction in abrasion

As observed in table 1 ,through increase of zirconia from 0 wt% to 8 wt% , the density would be increased from 3.9 gr/cm^3 to 4.05 gr/cm^3 . The main reason of density increment is the difference of density between Alumina and Zirconia; Also in this case the volume would be increased from 0.0969 cm^3 to 0.0074 cm^3 , this means that the abrasion resistance has been increased .Figure 3 shows the X-ray diffraction pattern form of Alumina within 8 wt% titanium pre abrasion, and Figure 4 shows this pattern post abrasion. As observed post abrasion, tetragonal phase has been transmitted to monoclinic phase. Mapping image from the pattern $97.5 \text{ wt\% } \text{AL}_2\text{O}_3 + 2 \text{ wt\% } \text{zrO}_2$ (10 wt\%TiO_2) has been shown in figure 5, in which zirconia in a form of single interstices has been spread to $\alpha\text{-AL}_2\text{O}_3$, and little amount of AL_2O_3 in zrO_2 caused to bring about a solid solution.[7]

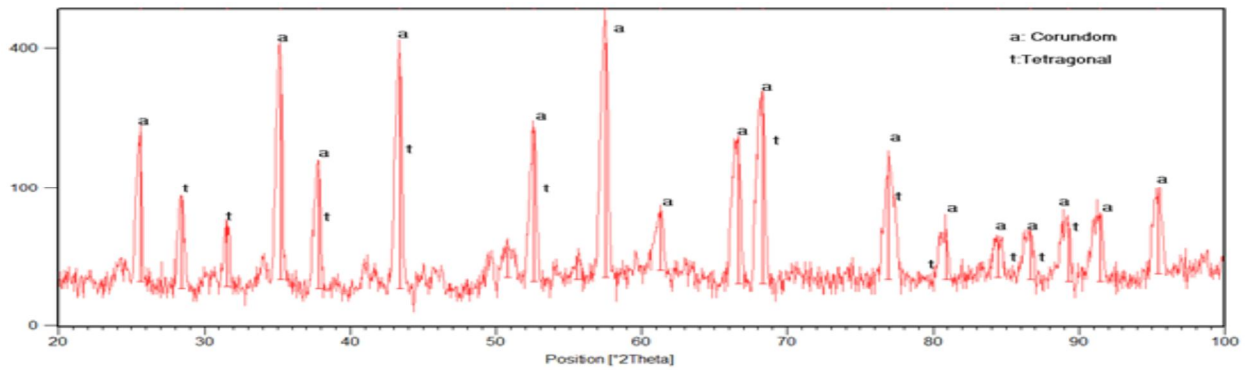


Figure 3- Alumina within 8 wt% stabilized zirconia, stabilized with 10 wt% titanium

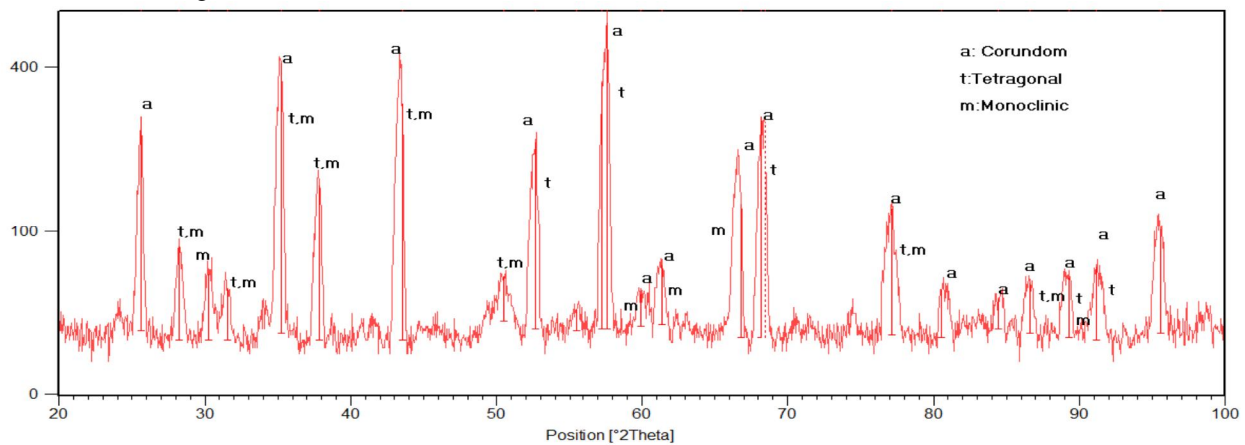
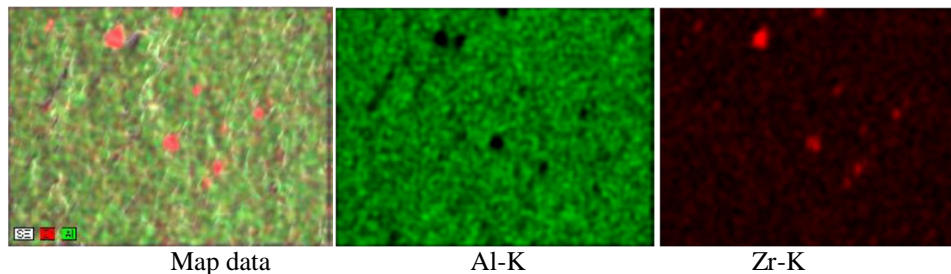


Figure 4- shows the Alumina within 8 wt% stabilized zirconia, stabilized with 10 wt% titanium post abrasion

Figure 5- MAP image, Pattern (10 wt% TiO₂) 2 wt% ZrO₂ + Al₂O₃ wt% 97/5

Results of xrd stabilized zirconia

With invention of phase toughness in polycrystals of tetragonal stabilized zirconia, this matter has made a large part of structural ceramics. Stabilized zirconia with 3 percent of mol yttria has the ability to make 10 percent of tetragonal phase in room temperature, moreover, low temperature of changing monoclinic phase into tetragonal is considerable. In the following figures, diffraction of X ray and stabilized zirconia with 3 and 8 percent mol have been represented. Zircobia with 8 percent of mol Y₂O₃ has been stabilized in 1600 centigrade temperature and has changed into cubic phase, however, if the considered phase is tetragonal phase, stabilized zirconia with 2 and 3 percent of mol yttria includes tetragonal phase. Regarding XRD, tetragonal phase has twin peaks, but monoclinic and cubic phases are singled peak.

In tests, stabilized zircobia with 3 percent of mol Y₂O₃ has been used, the reason is that with increase of yttria from two percent to three percent, critical size increases from $\cdot/2$ to $\cdot/9$.

As it is suggested in the following figures, stabilized zircobia with 3 percent mol yttria includes % 100 of tetragonal phase. Diffraction pattern of stabilized zircobia with 10 percent of titania in temperature 100 centigrade has been shown in the figures, it has 100 percent of tetragonal phase.

Results of xrd samples

Figure (8) shows diffraction pattern including 0, 2, 8 percent of stabilized zircobia including 3 percent mol yttria in the field of alumia, figure (5-3) shows diffraction pattern of X ray for samples including 2 and 8 percent of stabilized zircobia with 10 percent of titania in the field of alumina in temperature 1600 centigrade.

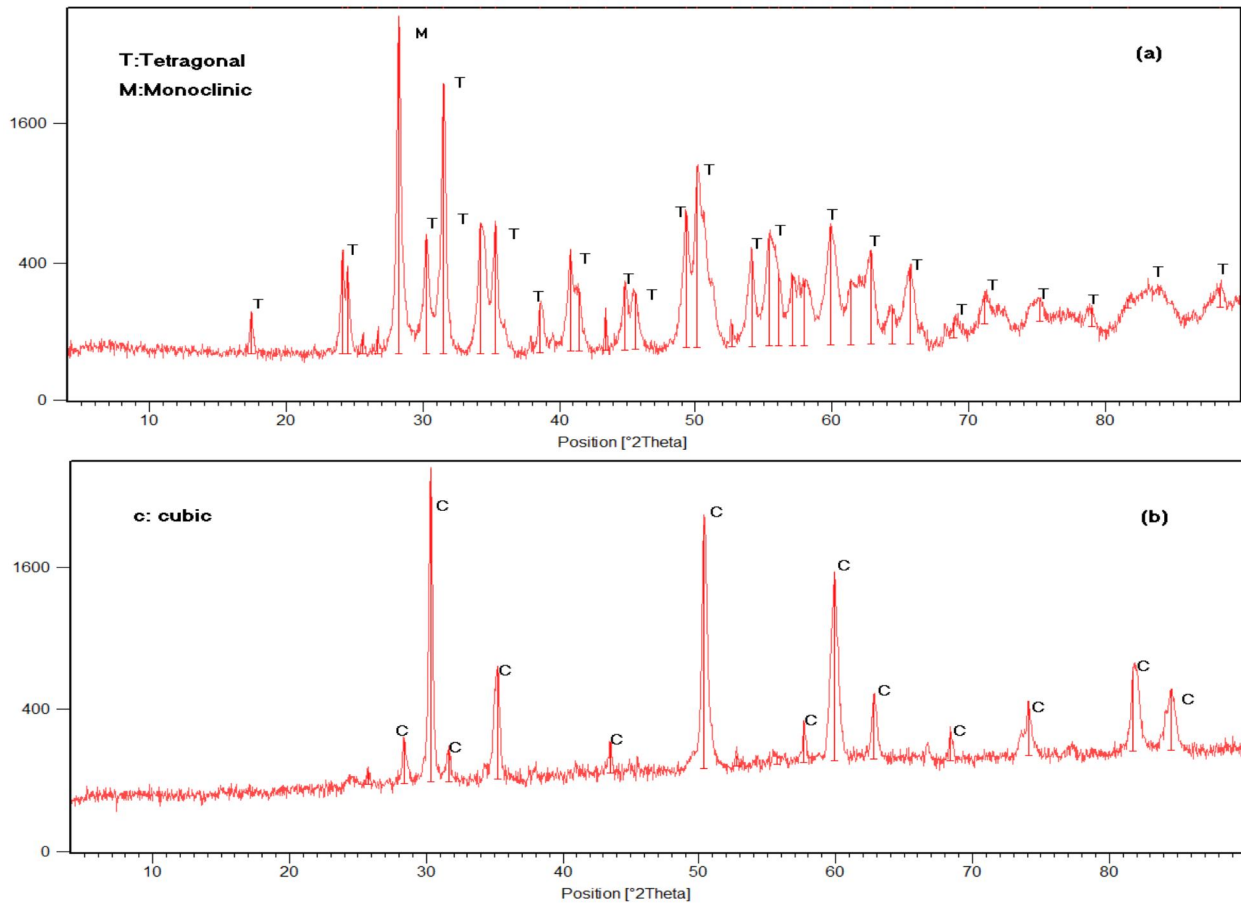


Figure 6: pattern of XRD: a. stabilized zirconia with 3 percent mole of Y_2O_3 b. stabilized zirconia with 8 percent mol of Y_2O_3

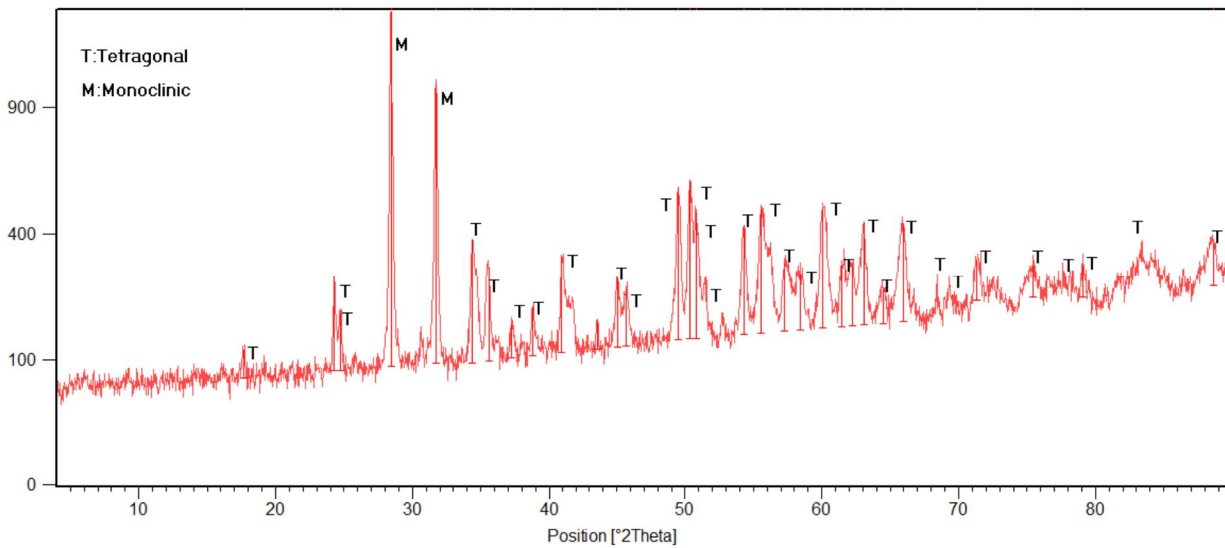


Figure 7: pattern of XRD , stabilized zirconia with 10 percent TiO_2

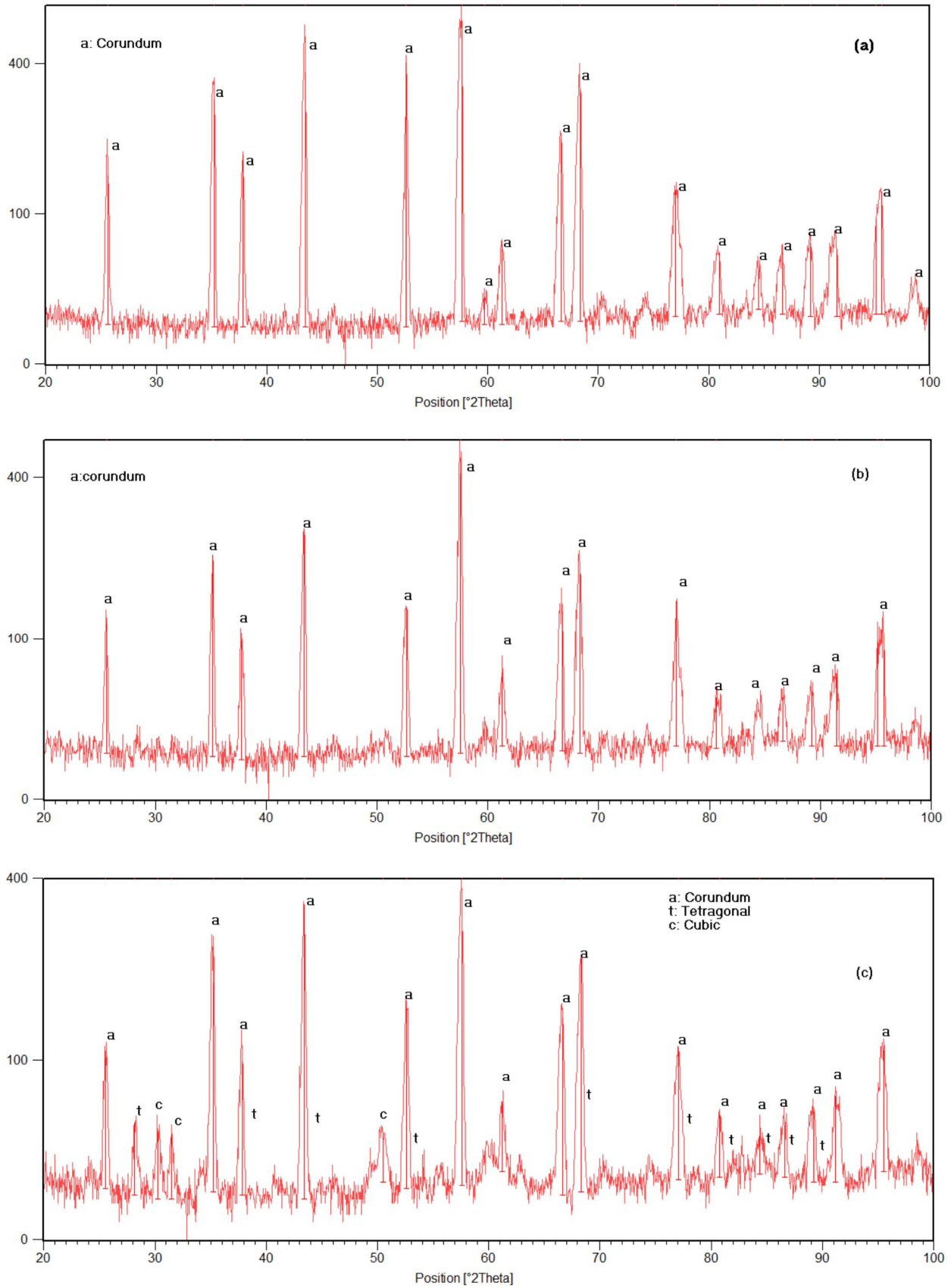


Figure 8: pattern of XRD , a. alumina b. alumina including 2 percent of stabilized zirconia with 3 percent of mol yttria c. alumina including 8 percent of stabilized zirconia with 3 percent of mol yttria

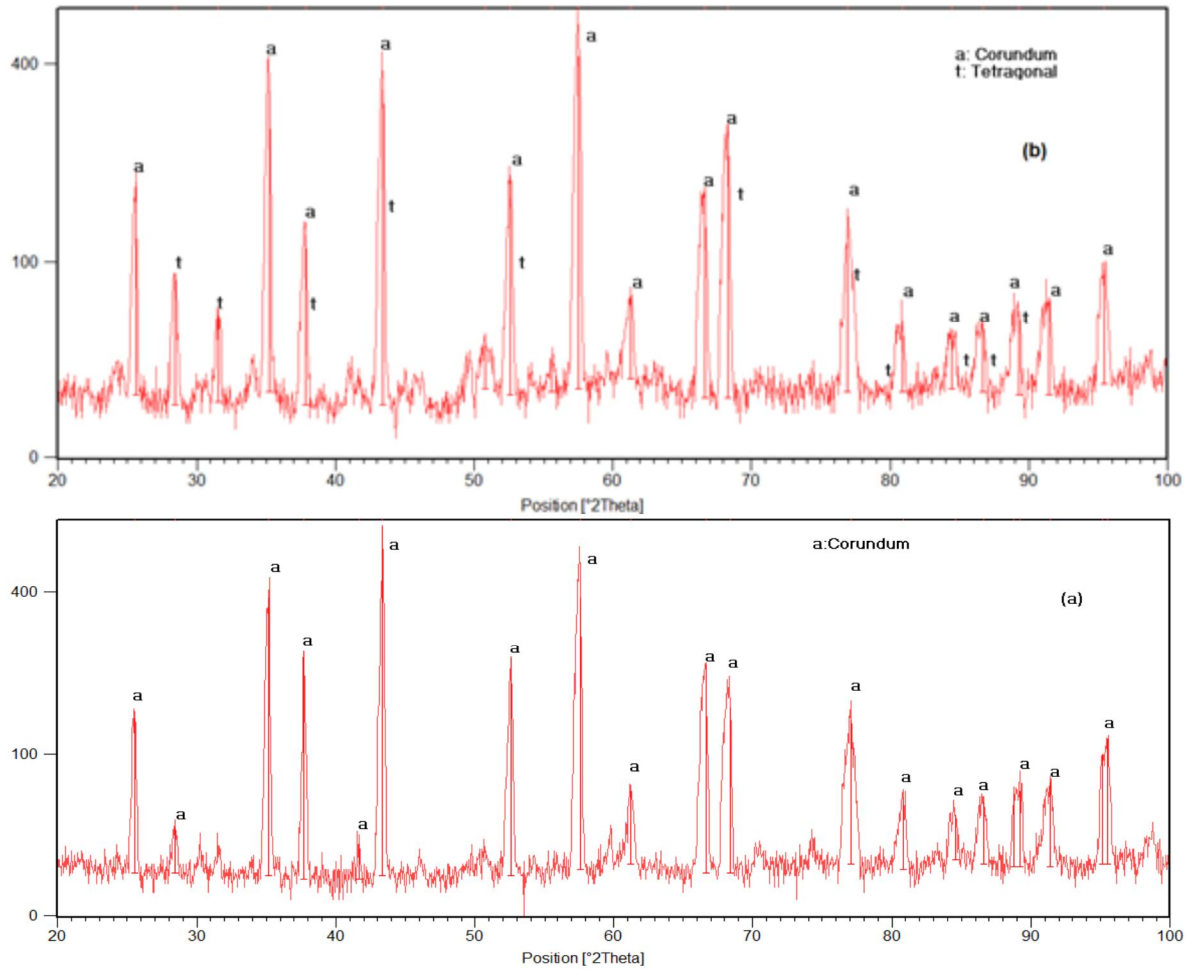


Figure 9: pattern of XRD a. alumina including 2 percent of stabilized zirconia with 10 percent of titania b. alumina including 8 percent of stabilized zirconia with 10 percent of titania

Figure (8,b) and (9,a) includes 2 percent of zirconia, XRD machine does not show phases of elements under 3 percent, therefore, corundum phase is the only observed phase.

With increase of zirconia, tetragonal phase has been observed, absence of new phase after sintering shows that there is no reaction between $\alpha\text{-Al}_2\text{O}_3$ and stabilized zirconia.

Diffraction pattern of X ray after abrasion of samples represented here:

91/5 wt% Al_2O_3 + 8 wt % ZrO_2 (3 mol % Y_2O_3)

97/5 wt% Al_2O_3 + 2 wt % ZrO_2 (10 wt % TiO_2)

DISCUSSION AND RESULTS

According to figure 1 while observing density pattern, we could observe that there is no difference in the pattern density in which titanium or yttria has been used to stabilize the zirconia. Also, according to figure 2 the pattern abrasion resistance in which yttria has been used to stabilize zirconia, is nearly 6 wt% more than while adding titanium to make the zirconia stabilized. 1 wt% or more than 1 wt% Al_2O_3 could be dissolved in ZrO_2 , and this is due to the point that Al^{+3} is so small, in which it could be substituted with Zr^{+4} and we have to notice that Stabilization of the tetragonal polymorph of zirconia over wider range of temperatures is accomplished by substitution of some of the Zr^{4+} ions.[8] phase amounts and their spatial arrangement or distribution depends on cooling rates and phase diagram of composition [7].finally we have to announce that high quality zirconia powder such as stabilized (PSZ) tetragonal composition doped with 10 wt% TiO_2 and 3 mol% Y_2O_3 as stabilizing oxide is key ingredient for the development of high temperature zirconia ceramics.

Results of linear analysis

Image of sample linear analysis:

97/5 wt% Al_2O_3 + 2 wt % ZrO_2 (10 wt % TiO_2)

In figures (10) and (11) it is been shown that red line, green line, and blue line respectively indicate O,Zr, AL in the combination. In the study of image, non- uniformed distribution of zirconia has been observed, in fact, based on method of mixture of powder, distribution is always non -uniformed. Therefore, one of the best ways is to make alumina in the form of suspension and then add zirconia to it.

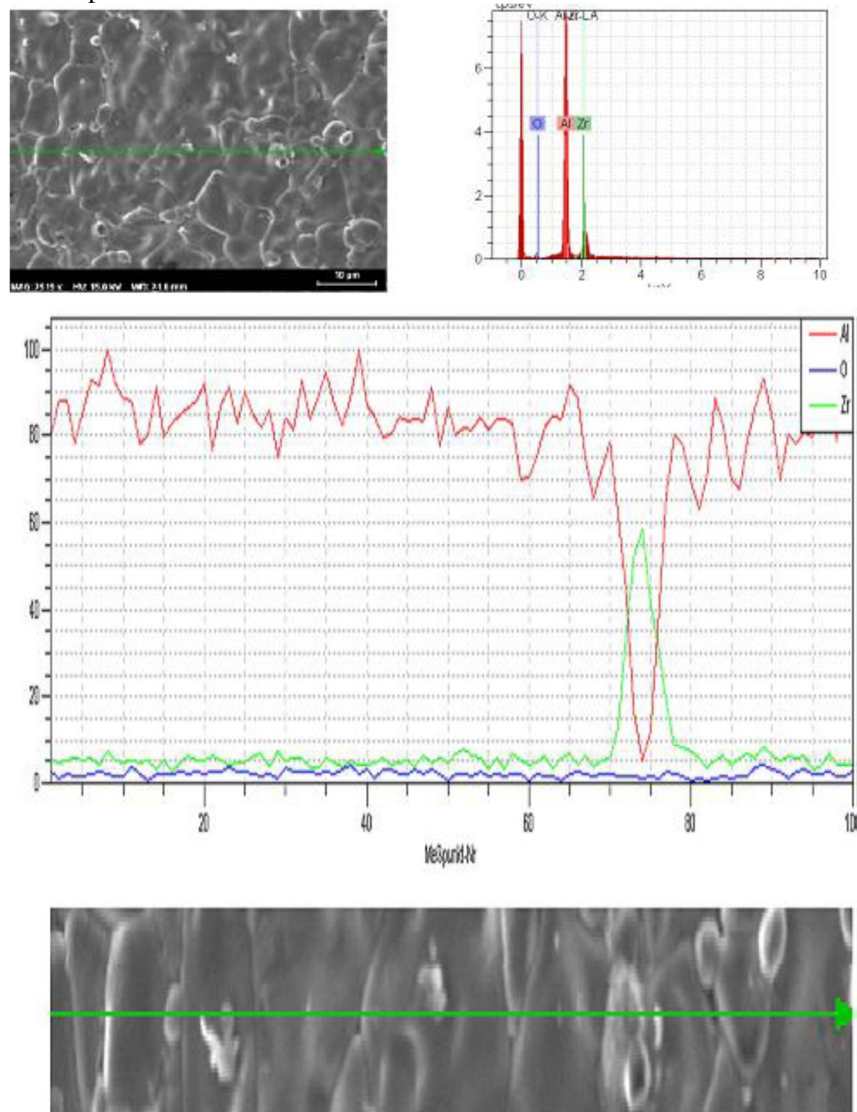


Figure 10: sample of image of linear analysis, 97/5 wt% Al_2O_3 + 2 wt % ZrO_2 (10 wt % TiO_2)

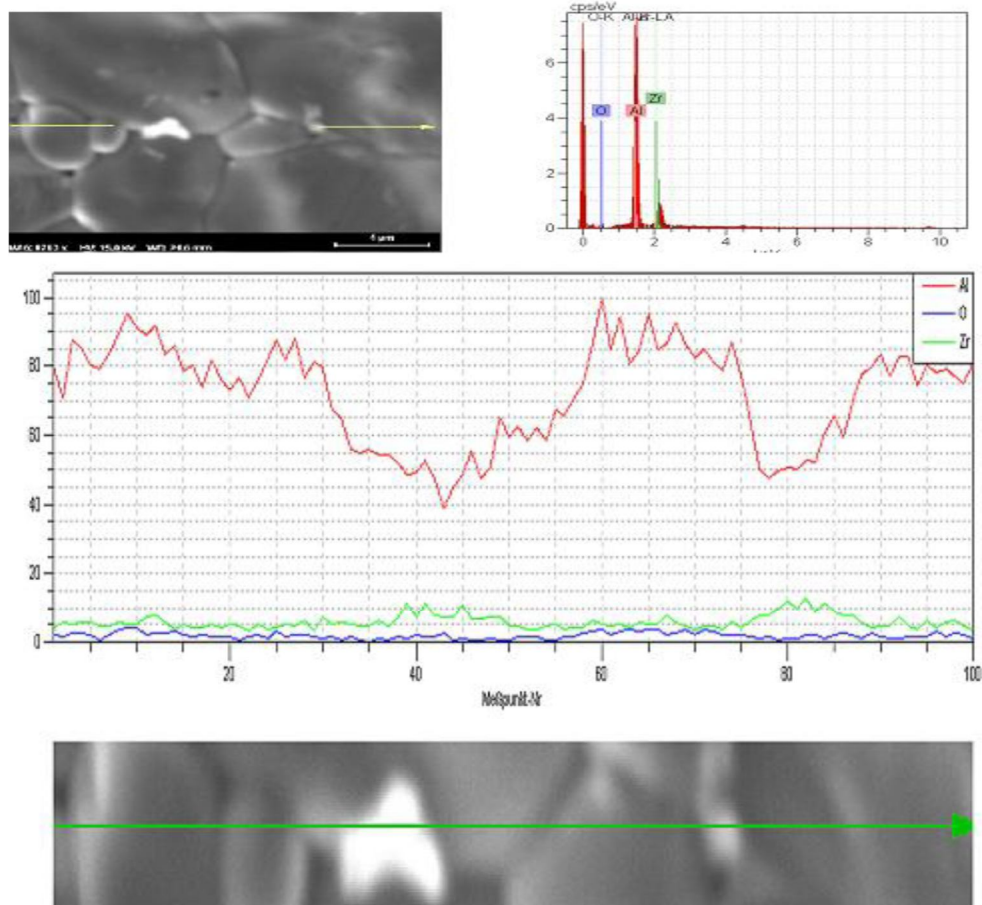


Figure 11: sample of image of linear analysis, 97/5 wt% Al_2O_3 + 2 wt % ZrO_2 (10 wt % TiO_2)

Conclusion

- 1-With increasing zirconia from 0 wt% to 8 wt%, Patterns density increases from 3.92 gr/cm^3 to 4.05 gr/cm^3 .
- 2- With increasing zirconia from 0 wt% to 8 wt%, the pattern volume decreases from 0.0969 cm^3 to 0.0074 cm^3 ; this means that abrasion resistance has been increased.
- 3-The properties of stabilized Alumina-Zirconia patterns with yttria is nearly equal with the properties of stabilized Alumina-Zirconia patterns with titanium.
- 4-In stabilizing zirconia, TiO_2 is preferred to be substituted with Y_2O_3 .

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