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# Zirconia toughened alumina (zta)

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Zirconia toughened alumina (ZTA) is one of the most widely used composite oxide structural ceramics. In fact, for several years, ZTA composites have been used for wear parts and cutting tools, due to their excellent mechanical properties, such as high strength, hardness, toughness and abrasion resistance. More recently, ZTA has become increasingly important as a structural material for biomedical implants, such as hip prosthesis. A key issue for such implants is to increase their lifetime, which is nowadays about 10 years. In fact, considering the increased life expectancy, as well as the growing demand of orthopedic surgery for younger and more active patients, implants should exhibit a lifetime of more than 30 years. For these reasons, research efforts currently focus on long-lasting devices based on new materials characterized by superior strength and toughness, optimal tribological properties and long-term biocompatibility [1].

In this frame, ZTA composites have demonstrated their effectiveness for orthopedic applications, and recently, the first composite femoral heads have been developed and commercialized. In this system, alumina provides high strength and hardness, whereas tetragonal zirconia exerts a toughening effect, thanks to its controlled transformation into the monoclinic phase [1]. In spite of the t → m transformation around advancing cracks having been recognized as the main toughening effect, other mechanisms can play a role, such as microcracking, crack deflection and bridging. Microcracking is favored in ZTA with large un-stabilized zirconia inclusions, which become monoclinic during cooling. This leaves a network of microcracks in the alumina matrix, which enables high toughness, but limits strength. On the other side, stress induced t → m transformation occurs in ZTA if the dispersion is kept tetragonal and transformable.

Generally, ZTA composites are prepared by the powder mixing route, whose main issue is keeping a homogeneous microstructure in the final, sintered materials. In fact, zirconia aggregates can lead to localized aging phenomena [2], whereas alumina ones could behave as preferential sites for crack propagation (figure 1).

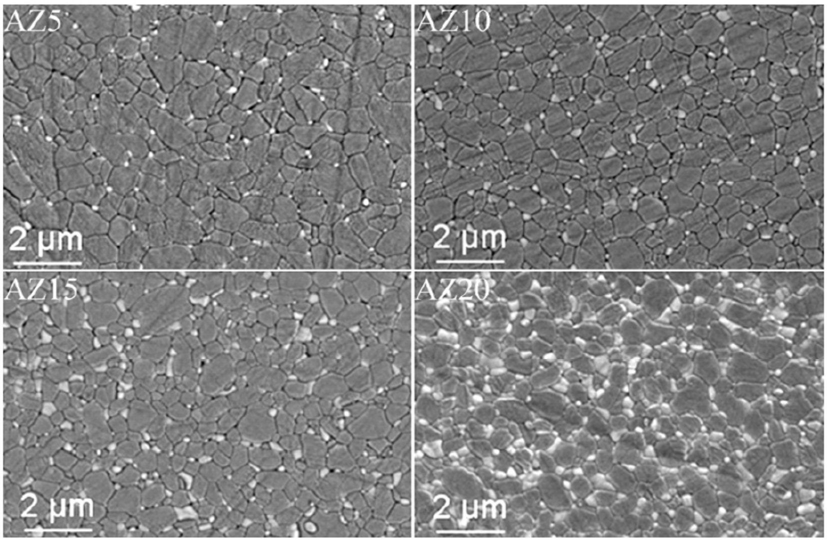


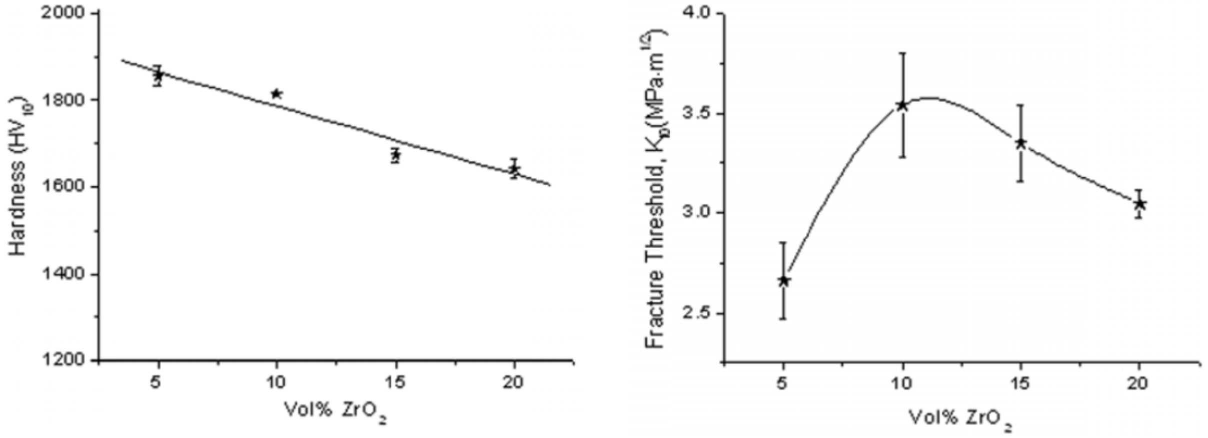
Figure 1 - Environmental scanning electron microscopy (ESEM) images of sintered materials obtained by slip casting (observations on polished and thermally etched surfaces).

Image analysis, carried out on several ESEM micrographs, allowed to evaluate the alumina and zirconia size distribution. Their mean size, as a function of the $ZrO_2$ content, is collected in Table 1. The zirconia mean grain size increased by increasing the $ZrO_2$ content in the composites. On the opposite, the alumina grain size is inversely proportional to the zirconia content: the well-known *pinning* effect exerted by zirconia on the alumina grain size was effective in limiting the matrix grain growth, as already stated in the literature.

**Table 1.** Alumina and zirconia mean grain size, as obtained by image analysis.

| № | Sample | $Al_2O_3$ mean size (μm) | $ZrO_2$ mean size (μm) |
|---|---|---|---|
| 1 | AZ5 | 0,88 | 0,26 |
| 2 | AZ10 | 0,81 | 0,31 |
| 3 | AZ15 | 0,75 | 0,31 |
| 4 | AZ20 | 0,70 | 0,36 |

Figure 2a collects the Vickers Hardness (*HV10*) as a function of the zirconia volume content. In spite of the decreased alumina grain size in the $ZrO_2$-reacher composites, the hardness decreased from AZ5 to AZ20, as expected on the grounds of the rule of mixture [2]. The length of the indentation cracks were also measured, in order to evaluate the threshold for slow crack propagation. In fact, the radial cracks originated from the indentation grown under the driving force, due to the residual stresses, introduced by applying the load during measurements. Figure 2b depicts the fracture threshold, $K_{IO}$, as a function of the zirconia content, showing a maximum for AZ10. This result is in agreement with previous literature data: in fact, a maximum is frequently observed in $K_C$ as a function of the zirconia content in ZTA materials, containing un-stabilized zirconia.



a) b)

Figure 2 - a) Vickers hardness; b) threshold for slow crack propagation obtained by the indentation test, as a function of the $ZrO_2$ volume fraction in the composites

## Literature

1. Wang, J.; Stevens, R. Review: Zirconia-toughened alumina (ZTA) ceramics. J. Mater. Sci. 1989,34, 3421–3440.

2. Rühle, M.; Claussen, N.; Heuer, A. Transformation and microcrack toughening as complementary processes in ZrO2-toughened Al2O3. J. Am. Ceram. Soc. 1986, 69, 195–197.