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Microstructural and Mechanical Characterization of Alumina-Zirconia-Graphene Hybrid Nanocomposites

Solomon Duntu[1], Francis Tetteh[1], Iftikhar Ahmad[2], Mohammad Islam[2] and Solomon Boakye-Yiadom[1]

[1]York University, Toronto, Ontario, Canada, [2]King Saud University, Riyadh, Ar Riyad, Saudi Arabia

Advanced engineering ceramics such as alumina, silicon carbide and boron nitride have a growing interest in medical, aerospace, military and automotive applications due to their high stiffness, relatively low density, chemical inertness, thermal and electrical resistance and outstanding thermostability. However, nanocrystalline ceramics such as alumina are extremely brittle and therefore their potential for other structural applications are constantly limited. Through microstructural design, different nano-scale materials have been embedded in alumina in order to increase fracture toughness and other mechanical properties[1]. Commercial zirconia is commonly used to enhance the toughness property of alumina and make it suitable for structural applications such as implants and orthopedics. For a typical alumina-zirconia systems, the alumina matrix provides high strength, whilst the zirconia induces toughening effect due to the tetragonal-monoclinic(*t-m*) transformation [2]. Although many researchers have reported an improvement in property with the addition of certain amounts of ZrO_2 particles, other works have recorded a decline in the mechanical response such as hardness and wear behavior. For instance, adding high amount of ZrO_2 (above 8wt%) have been reported to enhance the fracture toughness but hardness is drastically decreased. This has been ascribed to the distribution of ZrO_2 particles and formation of micropores within the composite structure after sintering[3][4]. Therefore, there is a need to further tailor the microstructure of alumina-zirconia systems in order to improve their overall mechanical properties for higher structural performance. In recent years, carbon-based nano-inclusions such as graphene have been reported to have a promising effect on the mechanical attributes of ceramic matrix systems. It is perceived that the addition of small amount of graphene (between 0.1-1wt%) improve mechanical properties of matrix structures through grain refinement and toughening effects such as crack bridging, crack deflection and graphene pull-out[1]. Therefore, in the current study, an attempt has been made to enhance the mechanical property of alumina-zirconia nanocomposites with the addition of low content nano-structured graphene. The effect of the graphene on the microstructure and hardness behavior of the nanocomposites have been studied. The Al_2O_3/ZrO_2/Gn hybrid nanocomposite with compositions of 10wt%ZrO_2 and 0.5wt%Graphene were fabricated using colloidal mixing followed by hot-pressing at 1600 C, and at a constant pressure of 60MPa as described in previous works[5][4]. Vickers micro-hardness property of the processed nanocomposites was determined according to the ASTM C1327-15.

Figure 1 illustrates the evolution of the alumina matrix structure with the addition of ZrO_2 and graphene. The influence of the added 10wt%ZrO_2 shows a degree of grain refinement relative to the parent alumina which had a coarse-grained structure after sintering (Figures 1(a) and(b)). However, there is also evidence of micro-pores mostly occurring at grain junctions as shown in Figure 1(b). This might be attributed to the expansion of the interstitial ZrO_2 particles as a result of the *t-m* transformation during the high-temperature sintering. On the other hand, the hybrid nanocomposite of Al_2O_3/ZrO_2/Gn with the addition of 10wt%ZrO_2 and 0.5wt%Gn demonstrate even finer microstructure as compared to both Al_2O_3/ZrO_2 and monolithic Al_2O_3 samples. The homogeneous dispersion of graphene particles at the matrix grain boundary inhibits further diffusion during sintering to cause abnormal matrix grain growth and limits the presence of micro-pores in the hybrid structure. In addition, the refinement effect of the added graphene is also seen on the ZrO_2 particles of Al_2O_3/ZrO_2/Gn hybrid nanocomposite. Figure 2 illustrates the microstructural features on fractured surfaces of the processed nanocomposites upon high indentation loading. The uniform dispersion of zirconia particles and graphene at matrix boundaries is further demonstrated in Figure 2(b). The influence of ZrO_2 and graphene additions on the hardness property of the nanocomposite is shown in Figure 2(c). The addition of only 10wt%ZrO_2 led to about 24% decrease in the hardness whilst 0.5wt%graphene resulted in relatively 2.5%increase in micro-hardness. The high ZrO_2 content which exhibits lower hardness, as well as the presence of micro-pores resulted in the decline of the hardness property in Al_2O_3/ZrO_2 [7]. Meanwhile, the increase in hardness in the Al_2O_3/ZrO_2/Gn is due to the decrease in porosity, coupled with the effective load-bearing capacity of the tougher interstitial graphene particles which transfer applied load from the matrix during indentation.

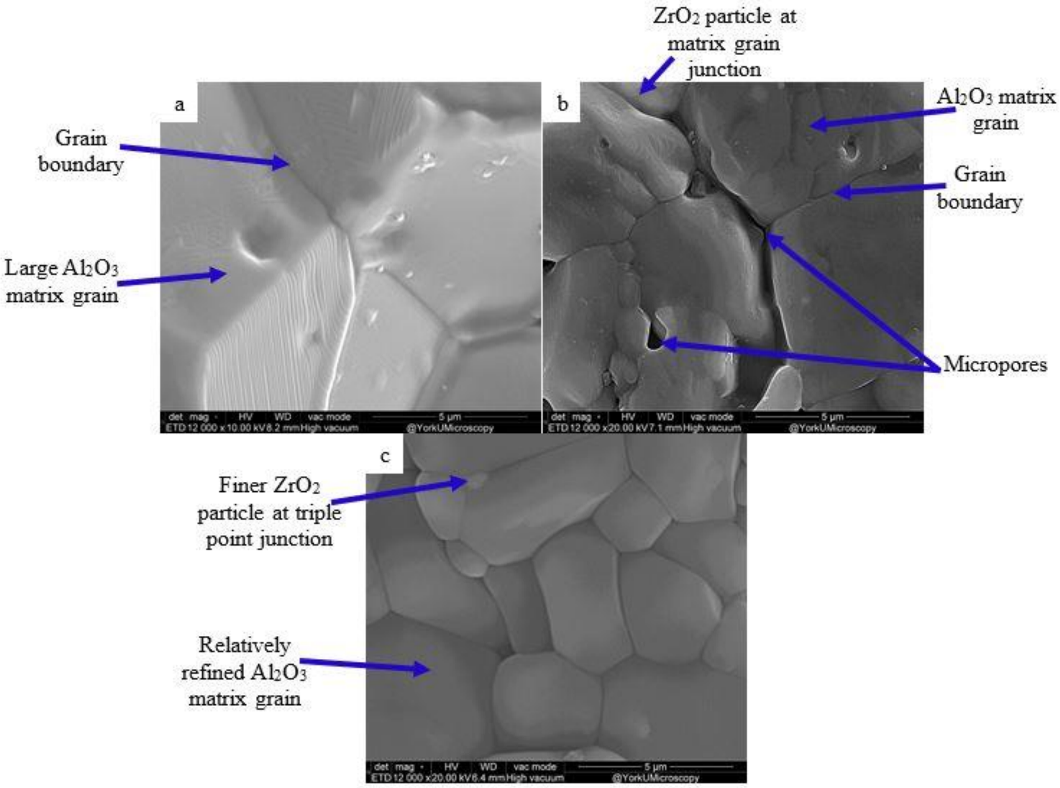

Figure 1. SEM micrographs showing the evolution of microstructure with the addition of ZrO_2 and graphene (a) Monolithic Al_2O_3 (b)Al_2O_3-10wt%ZrO_2 (c) Al_2O_3-10wt%ZrO_2-0.5wt%Gn showing relatively finer matrix structure.

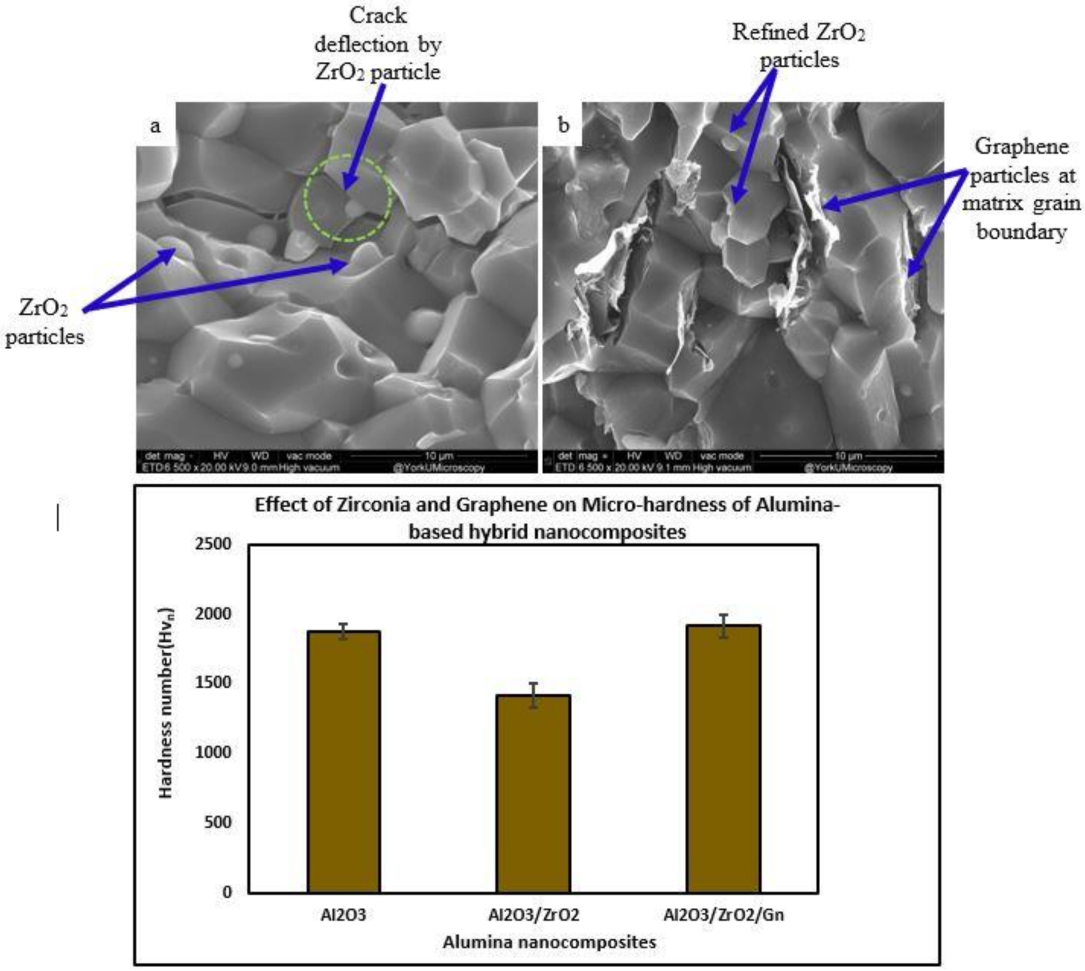

Figure 2. (a)-(b) Fractured surfaces of nanocomposites showing the distribution of ZrO_2 and graphene particles, and their load-bearing effects within matrix (c) Variation of micro-hardness property of Al_2O_3 with the addition of 10wt%ZrO_2 and 0.5wt%Graphene

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