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The Influence of (Ti,W)C and NbC on the Mechanical Behavior of Alumina

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Recent studies published in the literature have focused on reinforcing alumina with different refractory carbides and nitrides in order to improve hardness, fracture toughness and wear resistance. The incorporation of hard particles as WC, (Ti,W)C and NbC on alumina matrix has shown to be a good alternative in improving the mechanical properties of the composite material. The present work reports some preliminary results obtained reinforcing alumina with 20 wt. (%) (Ti,W)C and 10 wt. (%) NbC. Alumina, (Ti,W)C and NbC powders were homogenized and mixed in a planetary ball mill and subsequently hot-pressed at 1650 °C under 20 MPa in flowing argon. Specimens were characterized by Vicker`s microhardness (H_V), fracture toughness (K_{IC}), X ray diffraction and scanning microscopy. The composite material showed hardness values of 19.5 GPa and fracture toughness values ≈ 5.2 $MPa.m^{1/2}$. The high fracture toughness encountered in this work is related to the crack deflection mechanism.

Keywords: *ceramics, composite materials, hardness, fracture toughness*

1. Introduction

Cemented carbides such as WC-Co are the most widely used cutting tool material[1]. However, hot-pressed alumina-based ceramic composite reinforced with refractory carbides and others elements have been developed as technological alternatives to cemented carbides[2-5]. Studies published in the literature relevant to alumina ceramics reinforced with (Ti(C,N), WC, TiB_2/SiCwhisker, TiC and MgB_2 particles have shown increase of the wear resistance, hardness, fracture toughness and thermal shock resistance[3,6-10]. The alumina-based composite materials present good mechanical properties, in order to replace WC-Co in some special applications, such as machine cast iron and other metals and alloys. Despite such good properties the ceramic materials only represent up to 5% of the indexable cutting tool market[1]. Table 1 summarizes some typical properties of alumina and other reinforcing carbides published in the literature[5,11-13]. Although all carbides show similar hardness, WC features higher fracture toughness and elastic modulus, when compared to alumina, NbC and TiC. This may play a role in improving the mechanical properties of alumina, particularly in regards to its fracture toughness. Studies reported in the literature have shown that the presence of WC or NbC in a alumina matrix causes a pinning effect and reduces the alumina grain growth, which improves the mechanical properties of the composite material[4,5]. However, literature data on the properties and microstructure aspects of alumina reinforced with mixed carbides are still scant. Recent works[4,14-15] show that the presence of NbC and (Ti,W)C in an alumina matrix have improved the hardness value up to 19.7 and ≈ 22 GPa, respectively. The Ti-W and Ti-Nb phase diagram (Figure 1) shows that a formation of a solid solution between titanium and tungsten and titanium and niobium exists over a wide range of stoichiometry[16]. The incorporation of (Ti,W)C and NbC could possibly form a dispersion of a solid solution of (Ti,W)C and (Ti,Nb)C or (Ti,W,Nb)C in alumina, which may improve the mechanical properties when compared with the monolithic matrix. This study reports the influence of adding mixed carbides ((Ti,W)C + NbC) on the mechanical properties of a hot-pressed alumina.

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2. Experimental Procedure

Alumina APC-2011 SG (Alcoa, Brazil), (Ti,W)C (Herman Starck, Berlin, Germany) and NbC (Herman Starck Berlin, Germany) powders with an average grain size of 2.3 µm, 1.6 µm and 2.5 µm, respectively, were used as starting materials. Alumina powder was dry mixed with 20 wt. (%) (Ti,W)C and 10 wt. (%) NbC for four hours in a planetary ball mill using alumina grinding-balls. The concentration used in this work was chosen owing to the fact that the better results published in the literature were obtained with 30 wt. (%)[4,5,15]. Dense Al_2O_3 - (Ti,W)C - NbC samples were prepared by hot-pressing the powder mixtures at 1650 °C under 20 MPa for 30 minutes in flowing argon. The density of the sintered specimens was measured by the Archimedes method in water. The crystalline phases present in the sintered samples were identified by X ray diffraction (Shimadzu XRD-600) in the range of 10 to 80. Vicker's microhardness (H_V) and fracture toughness (K_{IC}) were obtained by means of the indentation method by measuring the length of the cracks and diagonal of the impression produced on diamond polished surfaces of sintered samples under a load of 50 N for 15 secods, as described elsewhere[17]. Scanning electron microscopy (SEM) was used to investigate the crack propagation mechanism.

3. Results and Discussion

Figure 2 shows a typical X ray pattern of alumina + 20 wt. (%) (Ti,W)C + 10 wt. (%) NbC composite material, subsequent to hot-pressing at 1650 °C. This analysis shows the presence of the Al_2O_3, TiC and $(Ti,W)C_{1-x}$ phases. The presence of other new crystalline phases was not detected, in agreement with the Ti-W and Ti-Nb phase diagram (Figure 1). This agrees with the results reported in the literature for alumina reinforced with (Ti,W)C[14,15]. The absence of the niobium peak in the diffraction analysis can be associated to the low content of niobium carbide applied in this work. The low niobium content used in this work probably forms a solid solution with Ti and W, as suggested in the phase diagram (Figure 1) and not a new crystalline phase. The ionic crystal radii of tungsten (0.066 nm), titanium (0.061 nm) and niobium (0.064 nm) are very similar[18], which contributes to the formation of a solid solution between these three elements. The presence of a solid solution of titanium and tungsten carbide $(Ti,W)C_{1-x}$ and probably between titanium, tungsten and niobium carbide can strongly influence the mechanical properties of the alumina matrix. Table 2 summarizes the properties found in this work. The hot-pressed Al_2O_3 + 20 wt. (%) (Ti,W)C + 10 wt. (%) NbC composite samples have shown samples with densities values at around 99% of the theoretical density. Similar density values to those obtained in this work have been reported for hot-pressed alumina reinforced with NbC[4], WC[5,7], (Ti,W)C[14,15], TiC[2,10] and TiB_2 + SiCwhisker[8]. The hardness and fracture toughness obtained were consistent with the composite method, displaying values of 22 GPa and 5.2 $MPa.m^{1/2}$, respectively. Figure 3 shows the effect of (Ti,W)C + NbC presence on hardness and fracture toughness of alumina composites. Results found on both properties performed on similar hot-pressed Al_2O_3 reinforced composite material, which are also presented for comparison purposes[2-8,10,15]. The hardness obtained in this work was lower than that for alumina + (Ti,W)C, alumina + TiC, alumina + WC + Co, alumina + MgB_2 and alumina + TiB_2 + SiCwhisker. The addition of niobium carbide in the alumina + (Ti,W)C caused a decrease of the hardness value, (stretching) from 22 to 19.5 GPa. This effect can probably be attributed to the lower density of the material when compared to other composite materials. The hardness values could be improved by adding hard particles and decreased as the microstructure becomes coarser and more porous[4,6,7]. Al_2O_3 + (Ti,W)C composite material has shown a maximal density value of 99.7% TD15, significantly higher than the material with niobium carbide (98.5% TD). But the hardness value now obtained (19.5 GPa) is comparable to those reported for alumina + Ti(C,N) (20 GPa)[6], alumina + WC (19 GPa)[15] and alumina + NbC (19.7 GPa)[4]. Contrary to what was observed regarding hardness, the fracture toughness shows a pronounced improvement in the Alumina + (Ti,W)C system by an addition of niobium carbide.

Table 1. Typical mechanical properties of alumina and some refractory carbides[5,11-13].

Material	H_V (GPa)	K_{IC} ($MPa.m^{1/2}$)	E (GPa)
Alumina	18 - 20	2.5 - 3.5	310 - 410
WC	17 - 24	10 - 12	520 - 700
TiC	18 - 23	3.5 - 4.3	310 - 410
NbC	18 - 24	3.0 - 4.0	340 - 400

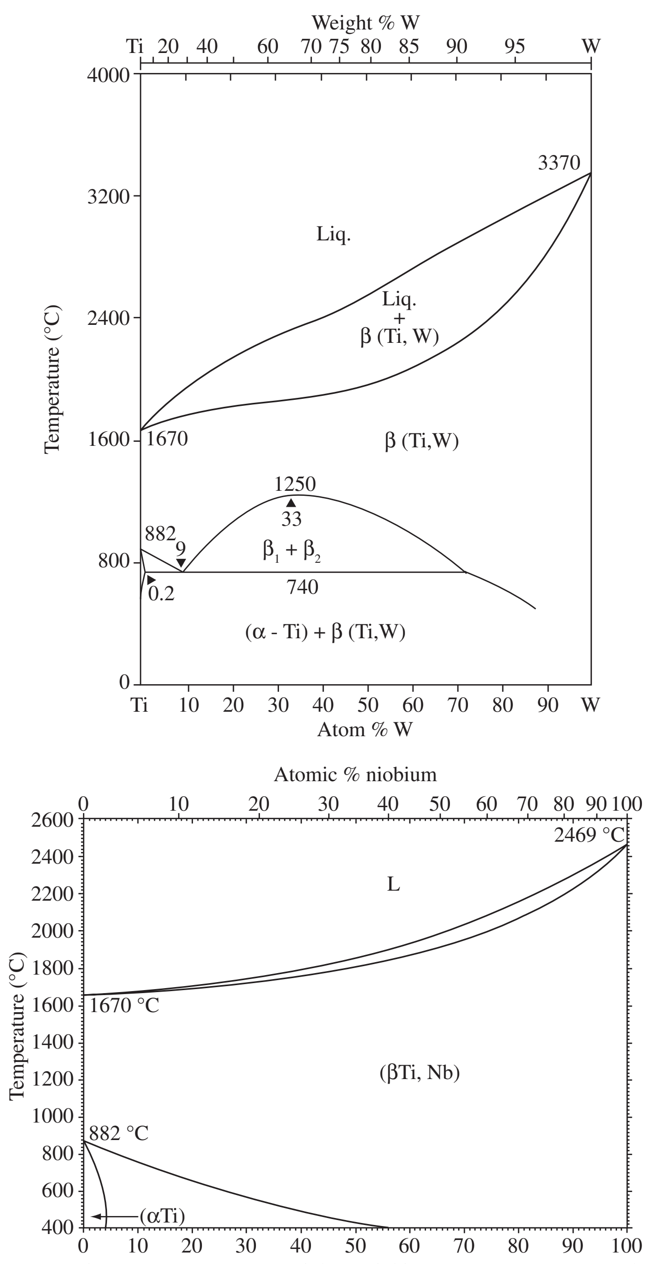

Figure 1. Phase diagram of (Ti,W)C and (Ti,Nb)C[16].

Table 2. Values of the properties, as obtained in this work.

Properties	Alumina + 20 wt. (%) (Ti,W)C + 10 wt. (%) NbC
Relative density (%)	99 ± 0.3
H_V (GPa)	19.5 ± 0.6
K_{IC} ($MPa.m^{1/2}$)	5.2 ± 0.4
Crystalline phases	Al_2O_3, TiC and $(Ti,W)C_{1-x}$

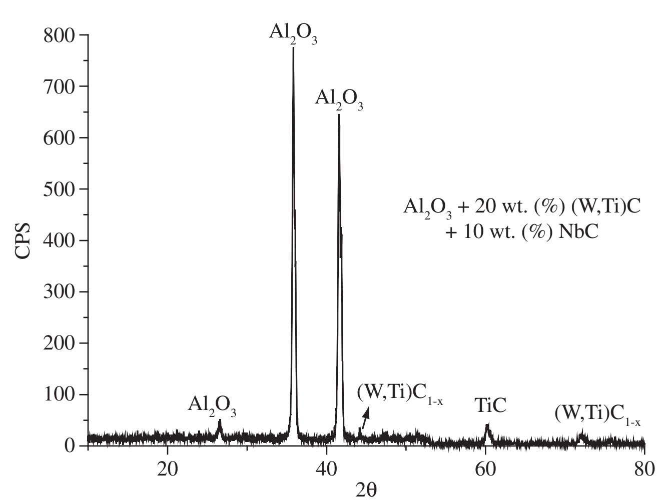

Figure 2. X ray diffraction pattern of the sample containing alumina + 20 wt. (%) (Ti,W)C + 10 wt. (%) NbC.

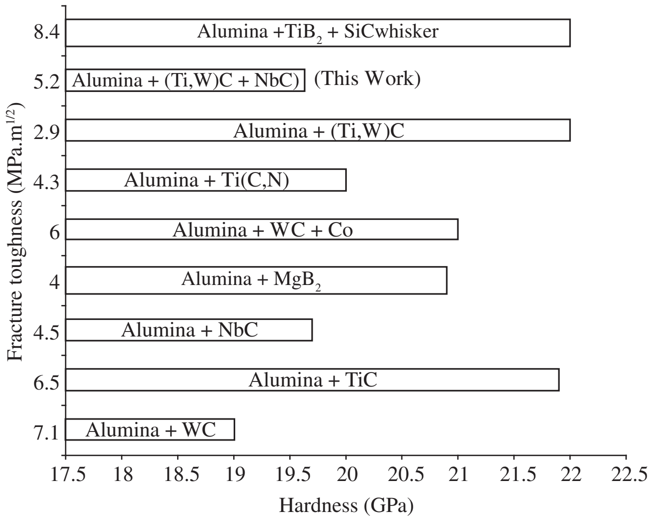

Figure 3. Comparison of the Vicker`s hardness and fracture toughness values obtained in this work, with those for other alumina composite materials[2-8,10,15].

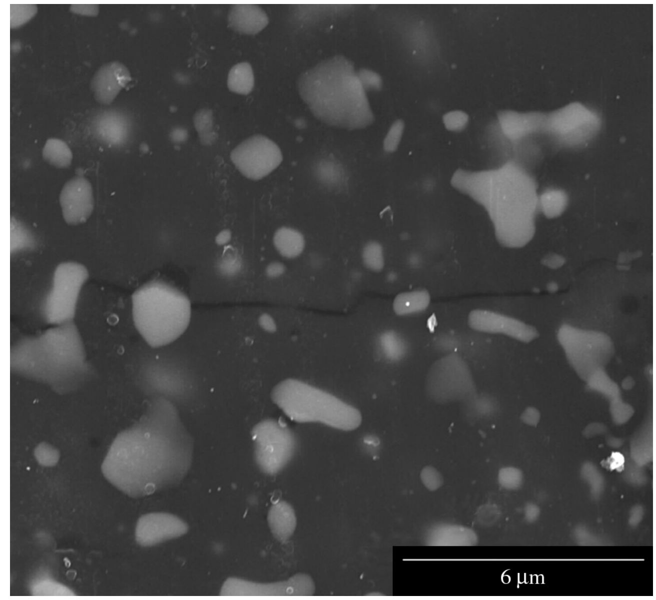

Figure 4. SEM micrograph showing the crack deflection due the presence of the refractory carbides particles.

The presence of NbC particles to Al_2O_3 + (Ti,W)C in this work, led to a fracture toughness increase ranging from 2.9 [15] to 5.2 $MP.m^{1/2}$. This behavior can be associated with the formation of a solid solution of (Ti,W)C and (Ti,W,Nb)C in the alumina matrix that can produce a more pronounced crack deflection mechanism than the material without niobium carbide. These values are slight higher than alumina + Ti(C,N) (4.3 $MP.m^{1/2}$), alumina + NbC (4.5 $MP.m^{1/2}$) and alumina + MgB_2 (4 $MP.m^{1/2}$). Higher K_{IC} values (6.5 - 8.4 $MP.m^{1/2}$) have only been obtained in alumina composites reinforced with WC, TiC and TiB_2 + SiCwhisker[2,3,5]. The mechanical results obtained in this work show that incorporation of mixed carbides such as (Ti,W)C + NbC in an alumina matrix has a good potential to be further investigated. SEM observation on indentation crack propagation paths are illustrated in Figure 4. The material showed a crack deflection mechanism, produced by hard carbides particles (bright particles in the microstructure). Deflection propagation of cracks and pinning of the carbides particles to cracks are the main factors increasing the fracture toughness value of the composite material investigated in the present work. Similar behavior was observed in alumina reinforced with WC[5,7] and NbC[4]. Figure 5 shows a SEM micrograph of a typical microstructure of the composite material. The composite material presented a homogeneous carbide distribution in the alumina matrix. The microstructure consists of irregularly shaped carbide particles (bright particles) within a dense alumina matrix. Further investigations are under way to assess the influence of niobium carbide content on the microstructure and its effect on hardness and fracture toughness of the composite material, in a way to fully understand the effect of mechanical reinforcing.

4. Conclusions

The present work submits the results obtained in a study of the mechanical properties of hot-pressed alumina reinforced with (Ti,W)C and NbC. The results show that hot-pressing resulted in relative dense specimens (98.5 %TD). The addition of niobium carbide particles causes a decrease of the hardness and significant improvement of the fracture toughness in the alumina + (Ti,W)C system, which ranges from 2.9 to 5.2 $MP.m^{1/2}$. SEM micrographs showed that the observed increase on the fracture toughness value can be attributed to the crack deflection mechanism produced by the hard carbides particles. Such results suggest that the hot-pressed alumina + (Ti,W)C + NbC composites can potentially be used as cutting tool material.

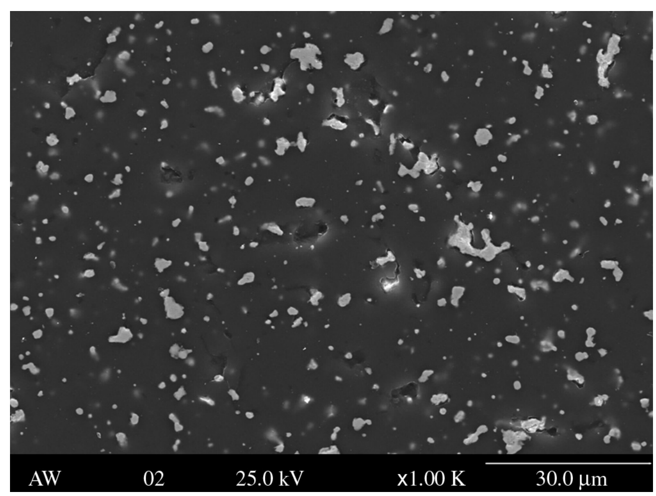

Figure 5. SEM micrograph of a typical microstructure of alumina + 20 wt. (%) (Ti,W)C + 10 wt. (%) NbC.

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