The research state of Al$_2$O$_3$ ceramic toughening

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Abstract: Al$_2$O$_3$ ceramic has the advantages of high mechanical strength, high temperature resistance, oxidation resistance, high hardness, chemical resistance and so on, due to its brittleness, that has restricted the more wilder application. This paper introduces the research state of Al$_2$O$_3$ ceramic toughening, including phase transformation toughening, particle toughening, fiber (whisker) toughening, self-toughening and other methods, and the further development of Al$_2$O$_3$ ceramic toughening.

Introduction

Al$_2$O$_3$ ceramic has the excellent properties, such as high mechanical strength, high resistivity, good electrical insulation, high hardness and melting point, good corrosion resistance, good oxidation resistance, small thermal expansion coefficient and so on, and has been wildly used in mechanical, electronic power, chemical, textile, medicine, construction, food, aerospace and other fields[1].

Ceramic material has many advantages, but brittleness is the main disadvantage that limits the more wilder application. Because the combination bond of ceramic is composed of ionic bond and covalent bond, compared with the metal material based on metal bond, which hasn’t had the plastic deformation ability and the dislocation system of which the sliding can be produced. Because the materials hasn’t had the ability to absorb additional energy, once the energy is beyond a certain range, it will form a new surface to absorb the energy, then the material will show a brittle damage[2]. In recent years, many researchers at home and abroad have devoted to the research of Al$_2$O$_3$ ceramic toughening, and achieved certain results, this paper describes the research status of Al$_2$O$_3$ ceramic material toughening, and the development trend of Al$_2$O$_3$ ceramic material toughening in future.

The research status of Al$_2$O$_3$ ceramic toughening

As we all know that improving the toughness of Al$_2$O$_3$ is the main direction of the development of Al$_2$O$_3$ ceramic matrix composites, because the Al$_2$O$_3$ ceramic shows the big brittleness defect at
room temperature, and the sensitive brittleness to a crack, porosity, and such tiny defects. Therefore, in order to improve the toughness of Al₂O₃ ceramic materials, scientific research workers have conducted a number of scientific experiments, the method has been studied and applied to Al₂O₃ ceramic material toughening are phase transformation toughening, particle toughening, fiber toughening, self toughening, and so on.

The phase transformation toughening

The phase transformation toughening is one of the main ways of Al₂O₃ ceramic toughening, and there are many kinds of materials can be used by the phase transformation to toughen the Al₂O₃ ceramic, among which using ZrO₂ to toughen the Al₂O₃ ceramic is the most common one. In 1975, Australian scholar K.C.Garvie[3] has initially proposed the concept of using ZrO₂ phase transformation to toughen the Al₂O₃ ceramic, that is, the quartet zirconia is transformed into the stable monoclinic zirconia, absorbing energy during the phase transformation process, and the fracture toughness of ceramics is increased. The relative research shows that, The ways of ZrO₂ accomplishing of ceramic toughening include stress-induced phase transformation toughening, microcrack toughening, crack deflection toughening and so on, and the phase transformation is the main toughening mechanism[4].

The single ZrO₂ phase transformation toughening Al₂O₃ can not meet the actual needs, in order to further improve the performance of ZrO₂ phase transformation toughening Al₂O₃, need to introduce the other materials to improve the performance of ZrO₂ phase transformation toughening Al₂O₃. By adding 0%-10% TiO₂ to ZTA ceramic composites, Manshor H[5] has studied the mechanical properties and microstructure changes. The experiment shows the toughening effect will be the best when adding 3% TiO₂ to ZTA ceramic composites, because the new thin apperance ( Al₂TiO₅ ) has been produced, which makes the toughening effect more better due to the deflection of the cracklines.

The particle toughening

Al₂O₃ ceramic particle toughening is mainly used the dispersion role of the second phase particles, and by using the particle’s plasticity, toughness, particle as a toughening agent interact with matrix to produce the creep, microcrack, crack to improve the performance of particle reinforced Al₂O₃ ceramic[6]. At present, the particle adopt as the toughening materials mainly include metal, intermetallic compound, ceramic particles, and so on.

The mechanical properties of intermetallic compounds is located between metal materials and ceramic materials, and the intermetallic compounds as the second phase to toughen ceramics have great potential for development. Kangning S[7] has studied the strong toughness of Fe-Al/Al₂O₃ ceramic composite materials, and research shows that the strength of ceramic composite as 860MPa, the fracture toughness reaches 12.5 MPa, the hardness reaches 92.5HRA to accomplish the excellent toughness property, and by observing the compond construction, the nanostructure and rod-crystal inside of crystal are found, and the bridge-joint toughening mechanisms appear. By adopt non-pressure sintering process, Gao pengzhao[8] has made the Nano SiC to toughen Al₂O₃ ceramic composite materials, and has studied the toughness effect of the SiC on the composite materials. The results show that 4% SiC has the best toughening effect on Al₂O₃ ceramic composites, the bending strength is 480 MPa, the fracture toughness is 5.12MPa·m¹/₂, and the
Vivtorinox hardness is 16.2 GPa after the sintering in oxidizing atmosphere. The nano SiC particles are located at the crystal boundary, which forms the bridge-connected crystal boundary, which improves the strength of the crystal boundary and arouses the crack to propagate in the crystal.

**The fiber toughening**

To add the fiber into the ceramic materials, the high strength fiber can not only bear the part of external load but also form a weak interface between the fiber and the ceramic matrix, and using the combination degree of the weak interface to absorb external energy, improves the fracture property of the ceramic materials, and further improves the strength of the ceramic materials[9]. The fiber reinforced ceramic matrix composites, the main toughening mechanism of fiber bridging includes fiber bridging, crack deflection, fiber pullout, micro-crack energy absorption[10].

In the fiber reinforced Al\(_2\)O\(_3\) ceramics aspect, the researchers has conducted a carbon nanotube toughening (CNTs) research, and by using heat and other static-pressure technology, Ahmad I[11] has studied the properties of carbon nanotube reinforced Al\(_2\)O\(_3\) nanocomposite materials. The experiment proves that when adding 4% carbon nanotube to toughen the Al\(_2\)O\(_3\) nanocomposite materials, fracture toughness, hardness, bending strength of the composite materials are increased by 94%, 13%, 6.4% respectively compared with the pure Al\(_2\)O\(_3\), and when adding 10% carbon nanotube, the fracture toughness is increased by 66%, therefore, adding 4% carbon nanotube is the proper to toughen the property of Al\(_2\)O\(_3\).

**The self-toughening**

The self-toughening of Al\(_2\)O\(_3\) ceramic is to form self-toughening effect by adding additive or crystal-seed promoting the abnormal growth of Al\(_2\)O\(_3\) ceramic crystal-particles, and the main shape of abnormal growth includes rod, long column, plate, sheet, and so on. The self-toughening can not only reduce the cost and simplify the process, but also be conducive to the compatibility of the reinforced phase and matrix, therefore, the self-toughening Al\(_2\)O\(_3\) ceramic is a kind of ideal toughening method[12]. The mechanism of self-toughening mainly include pullout, bridging and crack deflection.

The effect of crystal-seed introduced and sintering method on the growth of Al\(_2\)O\(_3\) long-column crystal-particle and fracture toughness of Al\(_2\)O\(_3\) ceramic has been studied by Xie zhipeng[13]. By the wet-milling of high-purity Al\(_2\)O\(_3\), Al\(_2\)O\(_3\) grinding chip is introduced into Aluminum-hydroxide powder and sintered under the pressure of 40MPa and the high temperature of 1600\(^\circ\)C , and the fracture toughness reaches 7.10MPa-m\(^{1/2}\) and the bending-resistance strength is 630.73MPa.

**The development trend of Al\(_2\)O\(_3\) ceramic toughening**

The brittleness of Al\(_2\)O\(_3\) ceramics is the main factor that restricts its development. Because many factors can effect the toughness of Al\(_2\)O\(_3\) ceramics, the toughening methods have many kinds. According to the present research status, it can be clearly found that the main development direction of Al\(_2\)O\(_3\) ceramics materials reinforced is the development from single-phase to multiphase composite and from micro to nano scale. With the development of the technology and the improvement of the craft level, the strengthening method of Al\(_2\)O\(_3\) ceramic material will be further developed, and the application of Al\(_2\)O\(_3\) ceramic material will have a great leap forward.
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