The research state of Al_2O_3 ceramic toughening

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Abstract：Al_2O_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_2O_3 ceramic toughening, including phase transformation toughening, particle toughening, fiber(whisker) toughening,self-toughening and other methods, and the futher development of Al_2O_3 ceramic toughening.

Introduction

Al_2O_3 ceramic has the excellent properties, such as high mechanical strenghth, 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_2O_3 ceramic toughening, and achieved certain results, this paper describes the research status of Al_2O_3 ceramic material toughening, and the development trend of Al_2O_3 ceramic material toughening in furture.

The research status of Al_2O_3 ceramic toughening

As we all know that improving the toughness of Al_2O_3 is the main direction of the development of Al_2O_3 ceramic matrix composites, because the Al_2O_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 Al_2O_3 ceramic materials, scientific research workers have conducted a number of scientific experiments, the method has been studied and applied to Al_2O_3 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 Al_2O_3 ceramic toughening, and there are many kinds of materials can be used by the phase transformation to toughen the Al_2O_3 ceramic, among which using ZrO_2 to toughen the Al_2O_3 ceramic is the most common one. In 1975, Australian scholar K.C.Garvie[3] has initially proposed the concept of using ZrO_2 phase transformation to toughen the Al_2O_3 ceramic, that is, the quartet zirconia is transformed into the stable monoclinic zirconia, absorbing energy during the phase transformation process, and the fracture toughtness of ceramics is increased. The relative research shows that, The ways of ZrO_2 accomplishing of ceramic toughening include stress-induced phase transformation toughening, microcrack toughening, crack deflection toughening and so on, and the phase transformaton is the main toughening machanism[4].

The single ZrO_2 phase transformation toughening Al_2O_3 can not meet the actual needs, in order to further improve the performance of ZrO_2 phase transformation toughening Al_2O_3, need to introduce the other materials to improve the performace of ZrO_2 phase transformation toughening Al_2O_3. By adding 0%-10% TiO_2 to ZTA ceramic composites, Manshor H[5] has studied the mechanical properties and microstructure changes. The experienment shows the toughening effect will be the best when adding 3% TiO_2 to ZTA ceramic composites, because the new thin apperance (Al_2TiO_5) has been produced, which makes the toughening effect more better due to the deflection of the cracklines.

The particle toughening

Al_2O_3 ceramic particle toughening is mainly used the dispension 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 Al_2O_3 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/Al_2O_3 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 Al_2O_3 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 Al_2O_3 ceramic composites, the bending strength is 480 MPa, the fracture toughness is 5.12MPa·$m^{1/2}$, 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_2O_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_2O_3 nanocomposite materials. The experiment proves that when adding 4% carbon nanotube to toughen the Al_2O_3 nanocomposite materials, fracture toughness, hardness,bending strength of the composite materals are increased by 94%, 13%, 6.4% respectively compared with the pure Al_2O_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_2O_3.

The self-toughening

The self-toughening of Al_2O_3 ceramic is to form self-toughening effect by adding additive or crystal-seed promoting the abnormal growth of Al_2O_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_2O_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 introducted and sintering method on the growth of Al_2O_3 long-column crystal-partical and fracture toughness of Al_2O_3 ceramic has been studied by Xie zhipeng[13]. By the wet-milling of high-purity Al_2O_3, Al_2O_3 grinding chip is introduced into Aluminum-hydroxide powder and sintered under the pressure of 40MPa and the high temperature of 1600℃ ,and the fracture toughness reaches 7.10MPa·$m^{1/2}$ and the bending-resistance strength is 630.73MPa.

The development trend of Al_2O_3 ceramic toughening

The brittleness of Al_2O_3 ceramics is the main factor that restricts its development. Because many factors can effect the toughness of Al_2O_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_2O_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_2O_3 ceramic material will be further developed, and the application of Al_2O_3 ceramic material will have a great leap forward.

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