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Research on Fusion Brazing Welding of Steel/Ceramic Connections

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Abstract: Ceramic/metal joints combine the high wear resistance of ceramics with the good ductility of metals to meet the conditions of use in harsh environments, avoiding the drawbacks of individual materials, and are used in a wide range of mechanical and heavy engineering applications such as aerospace, military instrumentation and nuclear energy. Due to the large difference between the density, specific heat capacity and coefficient of thermal expansion of ceramics and metals and other thermophysical properties, the residual thermal stresses generated during the connection will cause damage to the joints, which makes it difficult to realize the connection between ceramics and metals. Fusion brazing can alleviate the defects caused by the differences in thermophysical properties, and is an important method for the preparation of ceramic/metal composites. A molten liquid metal is used to wet the ceramic/metal surface and undergo a metallurgical reaction. Brazed connections are made at low temperatures, the base material does not melt during the brazing process, and there is minimal effect on the structure and properties of the base material. Therefore, hard brazing has been the main method of joining different materials for many years. This paper reviews the application of melt brazing in ceramic/metal joints in recent years and analyzes the structure, mechanical properties and constituent parts of the ceramic/metal interface.

Keywords: Fusion Brazing, Thermal Expansion, Ceramic/Metal Joints, Interface

1. Introduction

Ceramic materials are widely used to make cutting inserts, wear and corrosion resistant parts, etc. due to their high hardness, excellent wear and corrosion resistance, and high temperature stability [1, 2]. However, ceramic materials are inherently brittle and difficult to prepare into large-sized components with complex structures. In contrast, steel possesses excellent toughness and plasticity and is machinable [3], so it is possible to join steel and material materials together to obtain composite parts with complementary advantages. However, there are difficulties in joining steel and ceramic materials together [4, 5]. Ceramic materials are chemically mismatched with steel and generally require an active metal braze to achieve a good metallurgical reaction, but it is difficult to form a metallurgical bond with ceramics. Also, the interaction of ceramics with reactive elements usually generates a continuous brittle reaction layer, which reduces the reliability of the joint. The physical properties of steel and ceramic materials do not match, and the coefficient of thermal expansion and modulus of elasticity of the two usually have large differences, so that during the heating and cooling process, large residual stresses are generated in the joint, weakening the performance of the joint.

Techniques for joining ceramics to metals have been investigated by many scholars to obtain composites having outstanding properties. For example, the application of ceramics to tanks and other such armored vehicles can effectively prevent weapons from erosion, improve abrasion resistance, and meet the lightweight requirements of high-performance tanks and armored vehicles. Ceramics are commonly used in motor vehicle engines for their high temperature resistance, light weight and other excellent properties, which can reduce loads, increase thrust and operating temperatures, and improve service life. The application of ceramics in military machinery and aircraft carriers can significantly improve its corrosion resistance in the marine environment, thereby greatly increasing its service life [6-8].

2. Fusion Brazing Welding

Ceramics not only have good strength, hardness, wear and Corrosion resistance, so it has a wide range of applications in the harsh environment as a structural material and electrical insulation material. However, the hardness and brittleness of ceramic materials make them difficult to process and manufacture. However, ceramic materials have the disadvantages of hardness and brittleness that make them difficult to be processed and manufactured, and it is necessary to connect them with steel and other metals to realize the complementary properties with metals, so as to obtain ceramic-metal composite components with excellent properties of both ceramics and metals, and to give better play to the superior performance of ceramics in harsh environments. Currently there are many welding methods that can be applied to ceramics and steel, the main ones being diffusion welding and brazing. Diffusion welding has a connection temperature. Diffusion welding has a connection temperature is low, small residual stress and small impact on the performance of the matrix and other characteristics, especially laser diffusion welding to workpiece deformation is small, high quality of the weld has become one of the preferred technology to connect ceramics and steel [9].

Fusion brazing is a method that uses an electric arc, laser, or electron beam as the heat source to partially or completely melt the interlayer material and then cools and solidifies to join the base material on both sides. Laser brazing can achieve localized melting through its high density of energy to complete the brazing process. The key to laser brazing is the reasonable control of the laser power. When the laser beam is focused on the brazing material, too high a temperature can cause the brazing material to melt directly, which can affect the filling effect in the molten state and lead to poor brazing seam formation [10]. When the laser beam is focused on the base material, the temperature of the brazing material may be too low at this time, resulting in low fluidity and difficulty in wetting the surface of the base material [11]. Y. Hadji et al. [12] achieved a tungsten inert gas brazed joint of Ti3SiC2 ceramic to 308 stainless steel using Al brazing material. As shown in Figure 1a, the interfacial organization of the Ti3SiC2/Al joint consists of a brazing zone and a decomposition zone. Compounds such as Ti4AlC3, TiAl3 and TiCX may be formed at the interface, and fracture occurs mainly along the decomposed Ti3SiC2/undecomposed Ti3SiC2 interface. M. Rohde et al. [13] used to achieve a laser brazed joint between Al2O3 ceramics and 100Cr6 steel. A narrow, continuous Ti-rich zone can be observed near the ceramic-metal interface with the presence of Ag-rich zone and Ag-Cu phase between the Ti-rich reaction zone, as shown in Figure 1b. The ceramic cracked and fractured internally with a bending strength of only 40-80 MPa. Y. Zhang et al. [14] applied AgCuTi brazing material to laser join Al2O3 ceramic and 304 stainless steel. As shown in Figure 1c, a distinct reaction layer was generated on the stainless steel side, and compounds such as Ti2Fe, TiFe, Ti3Al, and TiO were formed inside the joint. Fracture of the joint occurred at the AgCuTi/Al2O3 interface, and the maximum tensile strength reached 132 MPa. Z. J. Guo et al. [15] used AgCuTi brazing material to laser join ZrO_2 ceramics with 304 stainless steel, and the tensile strength of the joint reached 71 MPa. As shown in Figure 1d, the interface was tightly joined without defect generation, and the brazed region generated TiFe, TiCu and TiO compounds.

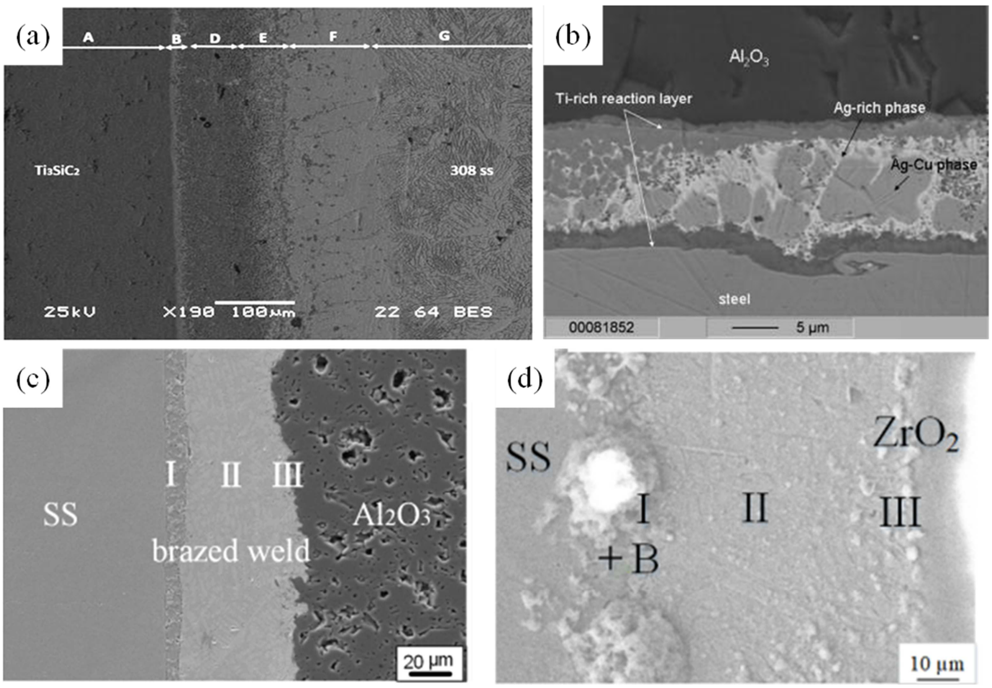

Figure 1. *Microstructure of joints: (a) $Ti_3SiC_2/Al/308SS$. (b) $Al_2O_3/AgCuTi/100Cr6$. (c) $SS/AgCuTi/Al_2O_3$. (d) $304SS/AgCuTi/ZrO_2$.*

3. Active Brazing

Reactive brazing is a primary method of joining dissimilar materials in brazing. The process of brazing ceramics for metal with a reactive filler metal is known as reactive brazing. For matrials which do not have reactive elements in the base material, like alumina, silicon carbide ceramics and metals, there is a need to consider the wettability of the parts to be joined.

One of the most widely used active elements in metal fillers is Ti. During the brazing process, Ti in the fused filler metal diffuses into the ceramic interface at high temperatures and undergoes a chemical reaction to form compounds such as TiO and TiC. The fused metal filler would also wet the ceramic interface and formation of bond. The AgCuTi reactive filler have been extensively used in ceramic-to-metal joining [16]. Li et al [17] successfully realized vacuum brazing of Ti_3AlC_2 ceramics and 40Cr steel using AgCuTi filler. As shown in Figure 2a, four phases were found at the brazing interface, i. e., $AlCu_2Ti$, Al_4Cu_9, Cu [s, s] and Ag [s, s]. The joint fractured at the interface between Ti_3AlC_2 and the filler metal, the shear strength of the weld was 196.4 MPa. Jin et al [18] used AgCuTi powder to realize the connection of carbon fiber reinforced silicon carbide (Cf / SiC) to TC4. As shown in Figure 2b, this joint has an interfacial structure consisting of Cf / SiC / Ti_3SiC_2 + TiC / Ti_2Cu + Ti_5Si_3 / Ag + Ti-Cu / Ti_3Cu_4 / TiCu / Ti_2Cu / Ti_2Cu + Ti / TC4, and the joint shear strength is 102 MPa. Ying et al [19] have realized the connection between infrared alloy and Si_3N_4 ceramics by AgCuTi filler metal and the interface morphology is shown in Figure 2c. The Ti element reacts with the alloy to form brittle compounds such as Fe_2Ti and Ni_3Ti, which form a TiN-Ti_5Si_3 reaction layer at Si_3N_4 ceramic interface, which gives the weld a shear strength of 92.8 MPa. Yan et al [20] studied the vacuum brazing of ZrO_2 ceramics and TC4 alloys by using AgCuTi filler metal and the interfacial structure is shown in Figure 2d. The interfacial structure of the joint was ZrO_2 / TiO + Cu_2Ti_4O + Cu_4Ti_3 / Ag + Cu_3Ti_3O / Ti_2Cu_3 / Ti_2Cu_3 + $CuTi_2$ / $CuTi_2$+ $CuTi_3$/TC4, which had a maximum strength of 191.9 MPa.

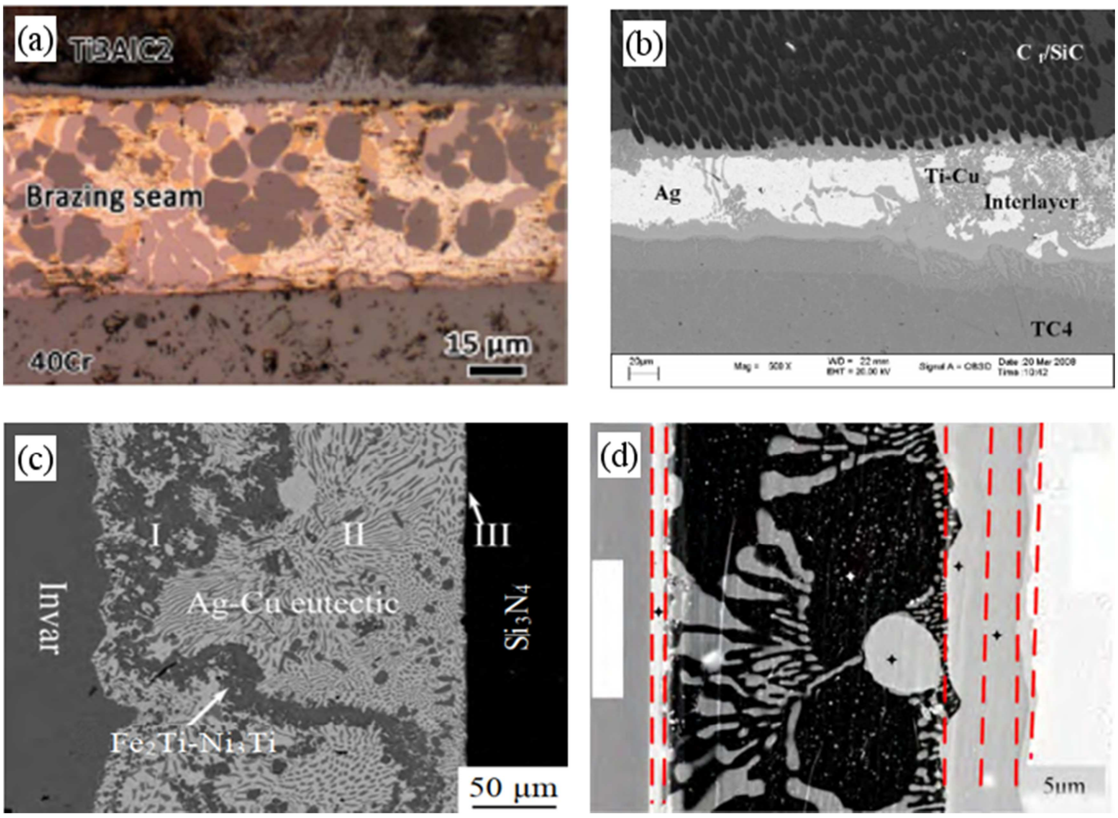

Figure 2. *AgCuTi brazing ceramic to metal: (a) Ti_3AlC_2/40Cr, (b) Cf/SiC/TC4, (c) Si_3N_4/Invar, (d) ZrO_2/TC4.*

4. Conclusion

The advantages of fusion brazing can be combined with the advantages of fusion welding and brazing. By precisely controlling the heat input, joints with low thermal deformation, narrow heat affected zones, and low welding stress and distortion can be obtained. At the same time, a wide range of materials can be joined without back fusion. Ceramic/metal joining by brazing is a major joining method in which the ceramic/metal surface is wetted with molten liquid metal and metallurgically reacted. Brazed connections are made at low temperatures, the base material does not melt during brazing, and there is little effect on the structure and properties of the base material. As a result, brazing has been the primary method of joining different materials for many years.

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