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Research on Non-Reactive Brazed Connections of Steel/Ceramics

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Abstract: The joining of dissimilar materials of ceramics and metals has been a hot research topic for both theoretical and practical applications at home and abroad. Connecting ceramics and metals together can combine the wear resistance, corrosion resistance and high temperature resistance of ceramics with the strong toughness of metals, becoming an ideal structural material and expanding the application fields of ceramics. The results of decades of research on ceramic and metal welding methods by countless scholars have shown that some of the joining problems have been solved, but the strength and heat resistance of ceramic/metal joints are still far from the requirements of using ceramic/metal joints. This paper reviews the current literature and practical applications, and after analysis, it is concluded that the effective methods for realizing ceramic-metal joints are mainly brazing, which has a very wide range of potential value in practical applications. However, these methods also have obvious drawbacks, leading to limitations in their own applications. For example, brazing generally requires a high surface quality of the workpiece, and this method of welding is only suitable for small workpieces and most lap joints, thus limiting its use in industrial production and making it unsuitable for high-temperature applications. On the other hand, inactive brazing permits effective ceramic/metal joining at high temperatures, which compensates to some extent for the disadvantages of brazing.

Keywords: Ceramic/Metal, Connections, Brazing, Inactive Brazing

1. Introduction

Nowadays, modern materials science and industry are continuing to evolve, thus placing higher demands on the performance of materials. A single material, due to its own limitations, has become difficult to meet the increasingly complex working conditions. Heterogeneous composite structural materials can combine the advantages of multiple materials to improve the overall performance of materials and also reduce the cost of materials to some extent [1]. Ceramics have superior resistance to corrosion and wear, as well as more stable thermal and chemical properties, etc., however, they have major limitations in terms of elongation, brittleness and workability [2, 3]. Steel has excellent mechanical properties with welding and processing properties and is inexpensive. However, its specific gravity is large and its corrosion resistance is not outstanding enough [4, 5]. The use of ceramic/steel composite structural materials not only combines the excellent toughness and ductility of stainless steel, but also gives full play to the advantages of ceramic wear and corrosion resistance, forming a complementary advantage of the both.

2. Inactive Brazing

The wettability of the substrate should be considered during brazing. When joining a ceramic material to a metal, the filler metal must be sufficiently wetted and diffused into the substrate by melting at elevated temperatures [6]. This case is mainly about the wetting of the ceramic, because the filler metal which may wet the ceramic may also wet the metal. It is important to avoid mutual dissolution or overreaction between the filler metal and the substrate so that many brittle compounds can not form, which would decrease the strength of the joint. By brazing ceramics to metal, it is possible to obtain reactive wetting, as with adhesives, diffusion and impregnating wets that are present in various joints. In the process of ceramic-to-metal joining, the liquefilled metal attracts to the ceramic and metal interfaces, and gradually solubilizes and becomes chemically reaction, which then achieves the wetting and spreading of the substrates [7]. From a thermal-mechanical viewpoint, wetting during brazing involves the reduction of the free energy of the system (solid+liquid) after the exposure of the liquid metal to the solid substrate [8].

Metals' wettability is by no means the only factor to be considered in the ceramic-to-metal joining process. In special cases, the solder must fulfill its unique requirements. For example, high-temperature structural components require filler metals with high-temperature properties [9-11]. For sealing components, the filler metal must not contain significant amounts of Zn, Zn, Mg, Li, Bi, and other high-pressure components to avoid leakage [12, 13].

Currently, most popular filler metals do not wets ceramics and metals at the same time [14]. By adding reactive elements to metals that are traditionally used as fillers, wettability can be improved. For example, transition metal elements such as Ti, Zr, Hf, and V [15-17] are chemically active, react with metals (e.g., Fe, Co, Cu, Cr, Ni, and Ag), and have a strong affinity for a wide range of oxides, silicate materials, and ceramics. After these brazing filler metals are melted, the active elements in the molten metal diffuse into the ceramic and metal surfaces at high temperatures, interacting with them and causing chemical reactions or dissolution. Through the reaction products generated, the filler metal can effectively wet and diffuse into the ceramic surface. During the subsequent cooling process, the molten solder solidifies to reliably join the ceramic and metal [18].

From the above analysis, it can be concluded that the effective connection of ceramics to metals has the following three problems in the current research.

(1) A variety of difficult and very brittle compounds can forms easily at the interfaces of ceramics and metals. Ceramics and metals have different physical and chemical properties. Bond transformations and chemical reactions occur during the joining process. The formation of numerous oxide, carbide, nitride, silicide and multicomponent compounds takes place on ceramic-metal interfaces. While these compounds are typically hard and brittle, their complex distribution at the interface often leads to brittle fractures in the joints.

(2) There is a large amount of residual stress at the interface between the ceramic and the metal. The modulus of elasticity and the coefficient of thermal expansion of the ceramic and the metal are changed. In the connection process and the subsequent cooling process, the thermal stress distribution is extremely uneven, and a large amount of residual stress is easily generated. This leads to stress concentration at the connection interface and reduces the adhesive strength of the joint.

(3) Lack of basic parameters that can be analyzed by numerical simulation. When ceramics are joined to metals, it is easy to form multiple composite layers. Although these composite layers are thin, they have a considerable effect on the joint properties. Due to the lack of room and high temperature parameters for the interfacial phases, numerical simulation analysis of the interfacial reaction and the growth pattern of the reactive phases and calculation of the stress distribution are difficult. Consequently, numerical simulation analysis of ceramic-metal joints also becomes difficult.

To solve these problems scholars usually use hard brazing for steel/ceramic joints. Inactive brazing is based on the principle that under the action of high temperatures, the active elements within the base material diffuse through the molten solder to the surface of the other base material, resulting in a wetting effect. Therefore, it has obvious limitations on the base materials due to the lack of active elements in filler materials, so it is only suitable for ceramics containing active elements such as ZrO_2 ceramics and TiC ceramics [19]. J. C. Feng et al. [20] used AgCuZn braze alloy foil to join TiC cermet and steel. Ag, Cu solid solution and (Cu, Ni)+(Fe, Ni) phase were formed at the interface after holding at 850°C for 15 min. As shown in Figure 1a, the interface structure is TiC cermet/(Cu, Ni)/Ag(s.s.)+Cu(s.s.)/(Cu, Ni)/(Cu, Ni)+(Fe, Ni)/steel. The maximum shear strength of the joint was 120.7 MPa. YE. Dameng et al. [21] obtained firm joining between Ti(C,N)-based cermet and steel with Ag-Cu-Zn-Ni filler metal by vacuum brazing. As shown in Figure 1b, the interfacial reaction layer formed Ag-based solid solution, (Fe,Ni) solid solution, (Cu,Ni) solid solution and Cu_5Zn_8. The maximum shear strength of the brazing joint achieved 176.5 MPa. F. Z. Wang et al. [22] achieved good bonding between Ti(C,N)-based cermets and 17-4PH stainless steel by vacuum brazing, as shown in Figure 1c. It was found that with the increase of brazing temperature, the fracture of the joint began to occur on the brazing seam near the Ti (C,N)-based cermet, and then occurred inside the Ti(C,N)-based cermet. The fracture surface had obvious plastic deformation, indicating that the crack propagated with high resistance and the joint had high strength. The maximum shear strength of joint reached 690 MPa. M. F. Wu et al. [23] brazed Ti (C,N)-based cermets to 45 steel with copper foil interlayer. The results showed that the addition of copper foil can effectively release the residual stress of the joint. However, due to the dissolution of copper foil in the brazing process, as shown in Figure 1d. The chemical compatibility between the brazing filler metal and Ti (C,N)-based cermet was weakened, and the interface bonding force is reduced, resulting in a decrease in the strength of the joint. The bending strength of the joint reached 285 MPa.

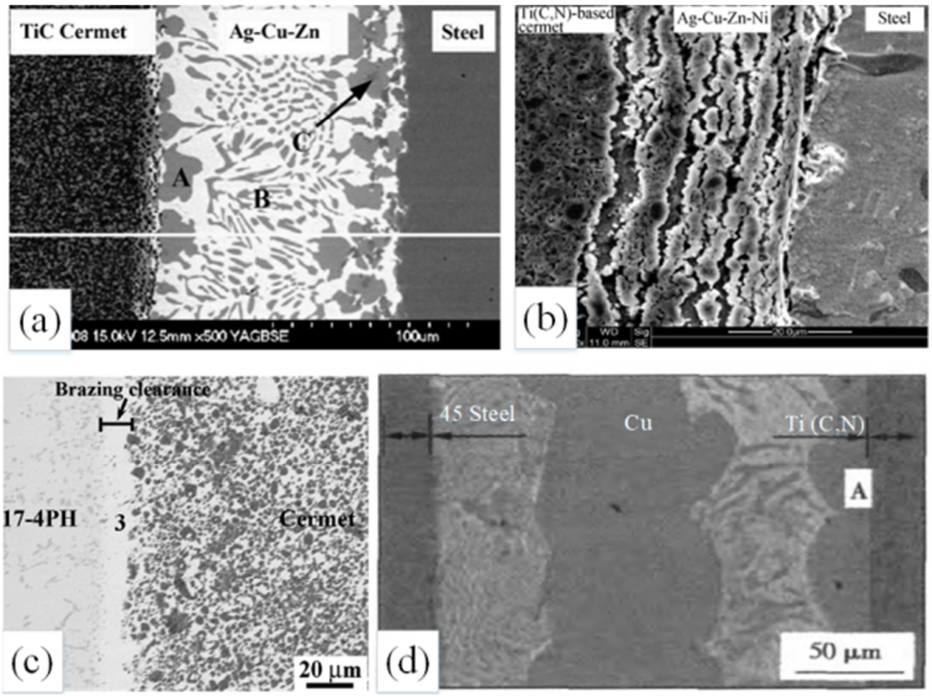

Figure 1. *Inactive brazing of ceramics and metals: (a) TiC/AgCuZn/Steel. (b) Ti(C,N)/AgCuZnNi/Steel. (c) 17-4PH/BNi-2/Ti(C,N). (d) Ti(C,N)/AgCu/Cu/45Steel.*

Singh M et al. [24] studied the effects of various solders containing Pd on the properties of YSZ/stainless steel joints. As shown in Figure 2a, there was a distinct interface layer in YSZ basement, unexpectedly, no Co was detected on YSZ or steel. As shown in Figure 2b, The interface of YSZ/steel was irregular which mean Fe, Cr element diffused. As shown in Figure 2c, There was no reaction layer in the steel/YSZ interface, forming silver-rich phase and rich-pass phase. However, there were Ag-rich and Cu-rich phases, also formed Ag-Cr and Ag-Pd phases in Figure 2d. The oxidation rates of 65Pd-35Co and 60Pd-40Ni joints are the fastest and slowest, respectively. The area of 59Ag-31Cu-10Pd and 5Ag-20Cu-15Pd brazed joints contains Ag-rich phase, Cu-rich phase and elements such as Zr, Y and Pd, which was the key to forming good metallurgical bonding. Kun-Lin Lin et al. [25] conducted a further research on YSZ/Ag-Cu-Pd/Steel brazed joint. As shown in Figure 2e, It was found that Ag particles precipitated within the Cu_3Pd phase in 58Ag-32Cu-10Pd. However, a Fe(Cr) needle-like phase, instead of Ag particles, precipitated within the Cu_3Pd phase in 65Ag-20Cu-15Pd, as shown in Figure 2f. The interlayer-YSZ interface formed SiO_2 and Ti_3O_5 reaction products but no reaction products were found at the interlayer-steel interface.

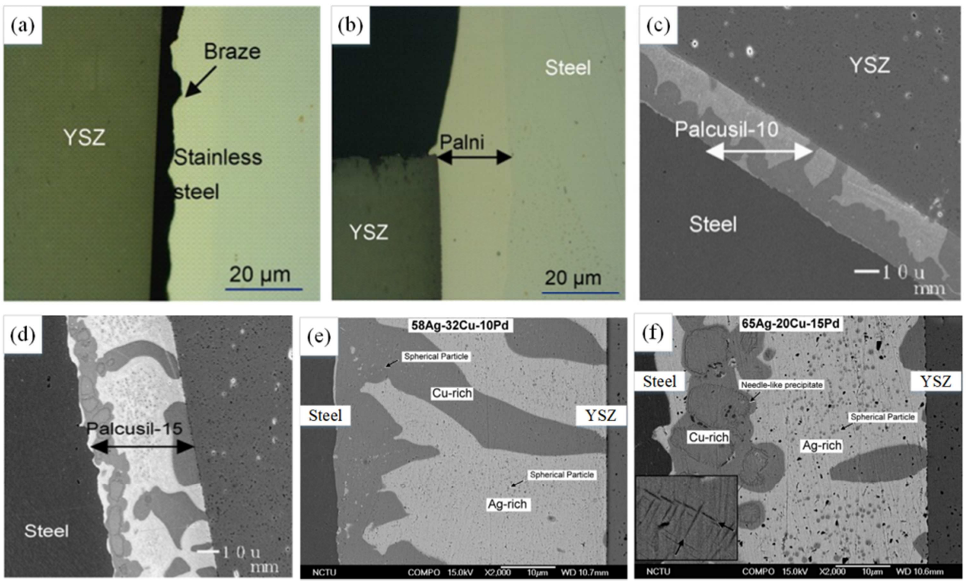

Figure 2. *Microstructure of YSZ/stainless steel joint: (a) 65Pd-35Co. (b) 60Pd-40Ni. (c) 59Ag-31Cu-10Pd. (d) 65Ag-20Cu-15Pd. (e) 58Ag-32Cu-10Pd. (f) 65Ag-20Cu-15Pd.*

3. Conclusion

A reliable link between ceramics and metals makes it possible to fully utilize the complementary performance and economic advantages of these two materials. The outstanding ceramic corrosion and high-temperature wear resistance takes full advantage of the good plasticity, ductility and high strength of metals. Although inactive brazing allows the joining of ceramics and steel, the requirements for the base material are high and require the base material to have active metal elements or modified treatment of the base material, which has major limitations. During inactive brazing, the active elements within the base material usually precipitate less and diffuse more slowly, which makes the connection of the joint more difficult.

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