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Research on Diffusion Welding Connection of Steel/Ceramics

Yuqiang Liu[1], Yan Zhang[1, *], Jianping Zhou[1], Daqian Sun[2], Hongmei Li[2]

[1]School of Mechanical Engineering, Xinjiang University, Wulumuqi, China

[2]Key Laboratory of Automobile Materials, School of Materials Science and Engineering, Jilin University, Changchun, China

Email address:

yanzhang4967@163.com (Yan Zhang)

[*]Corresponding author

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Abstract: Ceramics have been widely used in engineering applications due to their excellent hardness and wear resistance. Connecting ceramics and metals into composite parts and applying them to high temperature and corrosive use bar environments not only allows for normal use in harsh environments, but also improves the service life of the materials. The connection of ceramic and metal due to the large difference in the coefficient of thermal expansion between the dissimilar materials, will produce large residual thermal stress, thus hindering the further development of ceramic/metal dissimilar materials connection. At present, diffusion welding can not only realize the connection between them, but also can effectively alleviate the residual thermal stress between ceramics and metals due to the large difference in the coefficient of thermal expansion, which has a great protective effect on ceramics, and protects the integrity of the dissimilar materials connectors. Therefore, diffusion welding is used for the connection of ceramics and metals. This paper reviews the research progress in the realization of ceramic/metal composite parts using solid-phase diffusion welding, liquid-phase diffusion welding and partially transient liquid-phase diffusion welding, and analyzes the microstructure and mechanical properties of the interface. Finally, the advantages and disadvantages of solid-phase diffusion welding, liquid-phase diffusion welding and partially transient liquid-phase diffusion welding are briefly analyzed.

Keywords: Ceramic/Metal, Solid-Phase Diffusion Welding, Liquid-Phase Diffusion Welding, Residual Thermal Stress, Transient Liquid-Phase Diffusion Welding

1. Introduction

Ceramics have excellent properties such as high hardness, high temperature resistance, wear resistance, and corrosion resistance, but their inherent brittleness makes them difficult to process into structurally complex components [1, 2]. Metal materials have excellent plasticity and toughness, good machinability and welding properties, but their mechanical properties at high temperatures are poor [3, 4]. Therefore, connecting ceramics and metals into composite components can form a good complementary performance, which is important to meet the needs of engineering applications and expand the range of material applications. For example, Ceramic-steel composite bearing is made of ceramics and steel. On the one hand, ceramic has the properties of ceramic wear resistance, corrosion resisting and electrical insulation, so it can reduce the risk of fire due to static electricity, so as to protect the safety of users. On the other hand, Some of them are made up of steel. They have certain toughness and strength. They can make up for the defects of brittleness and easy fragmentation of ceramics, which can prolong the service life of these bearings [5].

The preparation of the bearing of ceramic-steel composite materials can give full play to the complementary advantages of the two kinds of materials in performance and economy. It can not only play to the excellent properties such as wear resistance, corrosion resistance, thermal insulation and electrical insulation of ceramics, but also make full use of the characteristics of good plasticity, good toughness and high strength of steel, which is of great research significance.

2. Solid Phase Diffusion Welding

Solid-phase diffusion welding is achieved by pressing ceramics and metals together and adding an intermediate layer of metal between the base materials on both sides, and then metallurgically joining them by maintaining a high temperature environment and diffusing the metal elements into the opposite base material [6]. The addition of an intermediate layer not only relieves the residual stresses caused by the difference in coefficient of linear expansion between the base materials during the heating of the joint, but also generates the desired compound. X. Q. Shen et al [7, 8] achieved diffusion connection of composite ceramics with HSS using Ti/Cu/Ti multilayer interlayer. As shown in Figure 1a, Ti_3Al, Ti_2O and TiC may be formed near the Al_2O_3-TiC/Ti interface, Cu-Ti solid solution is formed in the transition zone, and FeTi and $FeTi_2$ intermetallic compounds are formed near the steel side. The use of Ti-Cu-Ti interlayer can significantly reduce the maximum shear residual stress in the joint, however, the maximum axial residual stress does not change much. J. Wang et al [9] achieved a diffusion connection of alloyed steel and composite ceramics by a Ti/Cu/Ti composite interlayer. The experiments showed that the Ti-Cu-Ti composite intermediate layer dissolved and diffused sufficiently at high temperature to generate a continuous and dense reaction layer (thickness about 100 μm) near the base of the base material on both sides, and the intermediate reaction layer was present with Ti_3AlC_2, TiC, Cu and Fe_2Ti products, as shown in Figure 1b. The test fracture occurred close to the side of the Al_2O_3-TiC interface, and the maximum shear strength was 122 MPa. Z. H. Zhong et al [10] achieved a diffusion joint between silicon carbide ceramics and stainless steel by means of a W/Ni multilayer interlayer. As shown in Figure 1c, the joining of the joint was accomplished in two main steps, firstly, W_5Si_3 with WC metal compound was generated on the ceramic side, followed by Ni(W) solid solution and Ni_4W in the diffusion region, however, no metal phase was found at the Ni/SS interface. The joint fracture location was the SiC/W interface with an average strength of 55 MPa in tension. W. Q. Huang et al [11] successfully achieved the diffusion connection of Al_2O_3-TiC ceramics with Cr18-Ni8 steel through Ti/Cu/Ti interlayer. During the diffusion process, the brazing material and the base material on both sides reacted and a distinct transition layer was formed at the bonding interface, resulting in a tight connection between the brazing material and the base material, as shown in Figure 1d. The experimental results showed that TiO, TiC, α-Cu, CuTi, FeTi and Cr_2Ti were generated in the weld region. the joint fractured at the Al_2O_3-TiC ceramic interface and was characterized as a brittle fracture with a shear strength of 106 MPa.

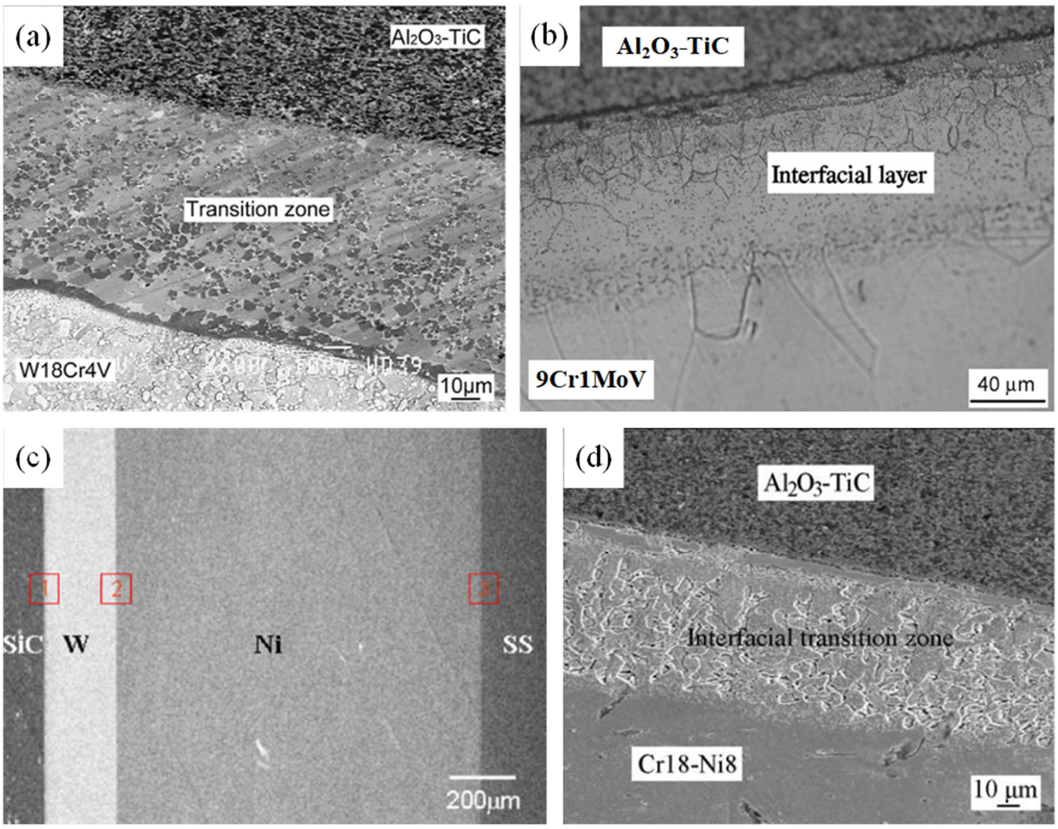

Figure 1. *Microstructure of joints: (a) Al_2O_3-TiC/Ti/Cu/Ti/Steel. (b) Al_2O_3-TiC/Ti/Cu/Ti/Steel. (c) SiC/W/Ni/SS. (d) Al_2O_3-TiC/Ti/Cu/Ti/Cr18-Ni8.*

3. Liquid Phase Diffusion Welding

Transient liquid-phase diffusion welding of steel and ceramic materials is achieved by using some metallic materials with lower melting points, and by applying no or less pressure in a vacuum environment, interdiffusion between the intermediate metallic materials and the base material elements occurs, and finally a low-melting eutectic product is generated to achieve the connection. W. Q. Huang et al [12, 13] connected composite Ti/Cu/Ti multilayer intermediate metal liquid-phase diffusion ceramics with Q235 steel. As shown in Figure 2a, the joint was tightly connected and compounds such as TiO, Ti_3Al, Cu_2Ti_4O and Cu_3Ti_3O are produced. The fracture of the joint was located near the ceramic interface and the maximum shear strength reached 143 MPa. W. Q. Yang et al [14] used a Ti/Ni composite interlayer to achieve a diffusion connection between composite ceramics and stainless steel, as shown in Figure 2b. The experimental results showed that a reaction layer consisting of TiC, Zr-Ni, Ti-Ni, and Ti-Ni-Si was formed near the ceramic interface, while no compound was formed on the stainless steel side. The shear strength reached 117.2 MPa. M. F. Wu et al [15] used AgCuZr/Cu/AgCu composite brazing material and assisted pulse current liquid phase diffusion to join Ti(C,N)-Al_2O_3 composite ceramics and 40Cr steel, and the maximum bending strength of the joint was 272 MPa. As shown in Figure 2c, the weld region mainly generated Ag(s,s), Cu(s,s), Ti-Cu and Zr-Cu intermetallic compounds. Q. Hao et al [16] used CuTi/Cu/AgCu asymmetric interlayer liquid phase diffusion to join Ti(C,N)-Al_2O_3 composite ceramics and 40Cr steel, as shown in Figure 2d. The experimental results showed that the weld region was mainly composed of white titanium solid solution and gray as copper solid solution, and the bending strength of the joint was up to 260 MPa.

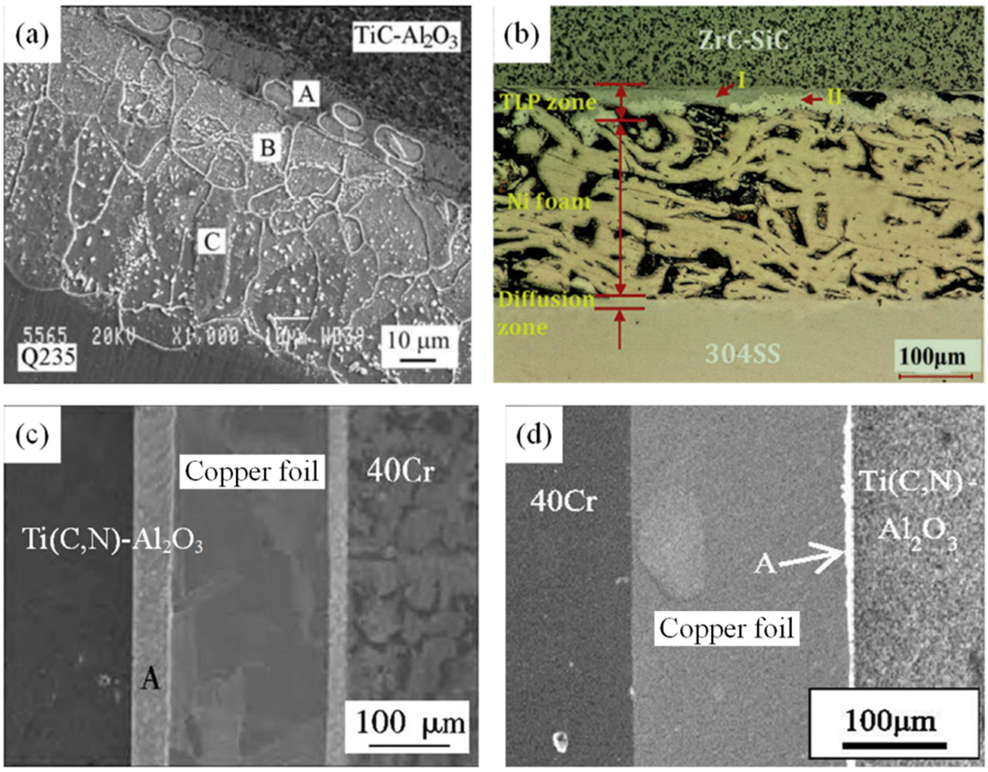

Figure 2. *Microstructure of joints: (a) Al_2O_3-TiC/Ti/Cu/Ti/Q235. (b) ZrC_3-SiC/Ti/Ni/304SS. (c) Ti(C,N)-Al_2O_3/AgCuZr/Cu/AgCu/40Cr. (d) 40Cr/CuTi/Cu/AgCu/Ti(C,N)-Al_2O_3.*

4. Partial Transient Liquid Phase Diffusion Welding

Partially transient liquid-phase diffusion welding combines the advantages of brazing and diffusion welding with only partial liquid generation in the bonding region of the ceramic interface to achieve brazing, but the metal bonding region exhibits a diffusion joint effect and a lower bonding temperature is typically used during the joining process to help relieve thermal stresses [17]. W. Tillmann et al [18] used Ni and CuNi braze liquid phase diffusion to join yttria-stabilized zirconia ceramics and Crofer22APU stainless steel. It was found that small amounts of Zr and Ti active elements deposited on the stainless steel surface promoted the brazing wet ceramic surface, resulting in good bonding, and also limited the formation of some brittle Ti_XO_Y and Zr_XO_Y phases. J. C. Lin et al [19] used Ti/Ni composite metal foil for diffusion joining of composite ceramics and stainless steel, as shown in Figure 3a. It was shown that Ti_2Ni, Ti_3Ni_2Si, $TiNi_3$ and Ni_5Zr phases were formed in the weld region. The joints fractured along the $TiNi_3$/Ni boundary with a maximum shear strength of 107 MPa. Li Jia et al [20, 21] connected TiC cermets and 304 stainless steel by partial transient liquid-phase diffusion of Ti/Cu/Nb multilayer interlayer. As shown in Figure 3b, there was a clear reaction layer formation at the interface and the brazing material was tightly connected to the base material on both sides. In the process of joint forming CuTi, $CuTi_2$ intermetallic compound, the maximum shear strength of the joint was 106.7 MPa.

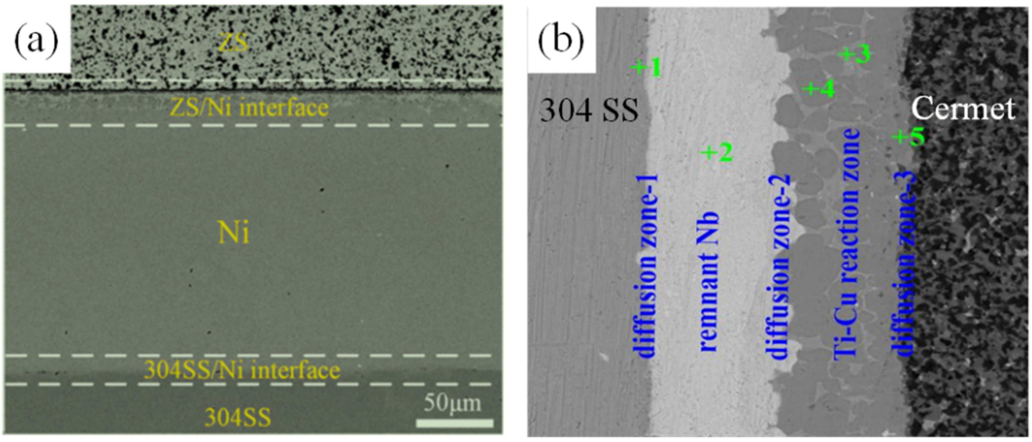

Figure 3. *Microstructure of joints: (a) ZrC-SiC/Ti/Ni/304SS. (b) TiC/Ti/Cu/Nb/304SS.*

5. Conclusion

Solid phase diffusion welding of steel and ceramics is also a convenient method for connection. However, solid phase diffusion welding has high requirements on the surface quality of the weldment, and the welding time is long. These problems still need to be further studied. The connection of steel and ceramics can be achieved by using the homeopathic liquid-phase diffusion connection. However, the reaction at the steel/ceramic interface is more complex, the analysis of residual stresses at the interface and the determination of the joint properties are yet to be studied in depth. Part of the instantaneous liquid-phase diffusion welding can reduce the stress generated during solid-phase connection by isothermal solidification, but in the interface connection will form holes and other defects, still need further in-depth study, and improve the performance of the joint.

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