



# Research on Ceramic/Steel Connection Using the Composite Interlayer Method

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**Abstract:** Ceramics are widely used in harsh environments due to their excellent mechanical properties such as hardness, high melting point and resistance to wear. However, due to their brittle nature, ceramics are difficult to process in engineering applications, which greatly limits their widespread use. Metals, on the other hand, have superior plasticity and toughness, allowing for on-demand design and shaping in practical production. Therefore, by combining the wear and corrosion resistance of ceramics with the plasticity and ductility of metals, composite structural components are able to meet the requirements for the normal performance of material properties in harsh environments. The composite sandwich method is an ideal method for joining ceramics and metals, and shows superior mechanical properties when joining ceramics and metals. The use of composite interlayers not only realizes stable ceramic/metal joints, but also effectively mitigates the damage to ceramics caused by residual thermal stresses in the weld. This paper summarizes the research progress in recent years on the application of composite sandwich method to prepare ceramic/steel joints, and describes in detail the interfacial composition and mechanical properties of ceramic/metal joints. The effects of welding time and welding temperature on the interfacial composition and mechanical properties of the joints by the composite sandwich method are summarized.

**Keywords:** Composite Interlayers, Ceramic/Metal, Interfacial Composition, Mechanical Properties

## 1. Introduction

In recent years the rise and rapid development of aerospace, electronics industry, instrumentation and military equipment and other fields, the use of material properties put forward new requirements. With the continuous development of science and technology new materials, new structures, new devices continue to emerge, so the need for dissimilar materials connected together, including ceramics and metal connection is more common, and has always been the domestic and foreign theoretical and applied research in the field of hotspots and difficulties. Engineering ceramics due to excellent high temperature resistance, corrosion resistance, wear resistance, has developed into a generally recognized high-performance structural materials, but the ceramic parts of poor plasticity, poor impact resistance, which limits the use of ceramic materials. Therefore, only the toughness of the metal

and ceramic wear resistance, corrosion resistance, high temperature resistance combined, in order to become an ideal structural material, so as to give play to the excellent performance of ceramics and metal respectively.

With the continuous development of materials science and technology, more and more ceramics and their composite materials are used in major projects. Due to the large differences between ceramics and metals in physical, chemical and mechanical properties, especially ceramics can not be melted into liquid state, which increases the processability of ceramics and limits its wide use. Conventional melt welding methods, such as arc welding, electron beam and laser welding, cannot effectively join ceramics and metals. In recent years researchers have lassoed in addition to many different methods of joining ceramics/metals [1], such as ultrasonic welding, SHS and partially transient liquid phase welding. Current literature and

practical applications show that brazing and diffusion welding are still the main methods for joining ceramics and metals.

The rapid development of modern material science and technology has put forward higher requirements on materials to ensure their normal operation under various severe environments. Composite structural workpieces of metallic steel and ceramics are new structural materials that are currently receiving attention, combining the respective advantages of both materials, with excellent properties such as high strength, wear and corrosion resistance, which have broad application prospects in aerospace, marine, metallurgy and chemical industries [2, 3].

The thermophysical properties of the two base materials, ceramic and steel, are quite different, which makes them both generate large residual stresses during heating and cooling [4]. Therefore, it has become a key technical problem that needs to be solved urgently by eliminating the residual stress at the interface between ceramic joints and steel joints to effectively improve the service performance of the joints. The use of composite sandwich method to add multilayer metal foil as a stress relief layer in the middle of ceramic and metal is one of the most widely used methods [5]. The incomplete melting of the intermediate metal material during the heating process can inhibit some negative reactions at the interface and stabilize the interfacial reaction process, thus playing a role in eliminating the residual thermal stresses in the ceramic and steel joints.

## 2. Composite Intermediate Layer Method

The single interlayer can relieve the residual thermal

stresses generated at the joint interface during the heating and cooling process to a certain extent. However, due to the simpler structure of a single metal layer, stress concentrations still form in the interlayer material [6]. Therefore, the method of composite interlayer is used here to further relieve the residual stresses at the joint interface and improve the performance of the joint [7]. The composite interlayer is generally a combination of different single interlayer layers in various forms, and this method can significantly relieve the residual thermal stresses [8]. X. P. Xu et al. [9] joined silicon nitride ceramics with stainless steel by Cu/Ag-Cu/Ti composite interlayer brazing. As shown in Figure 1a, the interface generated  $\text{TiFe}_2$ , Ag-Cu eutectic organization, Cu solid solution, and  $\text{Cu}_3\text{Ti}$  compounds in turn. It was found that the plastic deformation of the Cu foil relieved the residual stresses in the brazed joints with a maximum bending strength of 53 MPa. G. W. Liu et al [10] achieved a brazed joint of molybdenum-manganese surface metalized  $\text{Al}_2\text{O}_3$  ceramics with stainless steel by AgCu brazing material. As shown in Figure 1b, small holes appeared at the weld,  $\text{MnAl}_2\text{O}_4$  phase appeared in the molybdenum-manganese metalized layer, and the maximum shear strength of the joint was about 110 MPa. P. MISHRA et al [11] achieved the joining of 304L stainless steel with hot isostatic alumina using AgCu brazing material. It was found that Ag-Cu eutectic organization appeared in the brazed region and a thin layer of molybdenum-rich and nickel-rich phases appeared on the ceramic side.

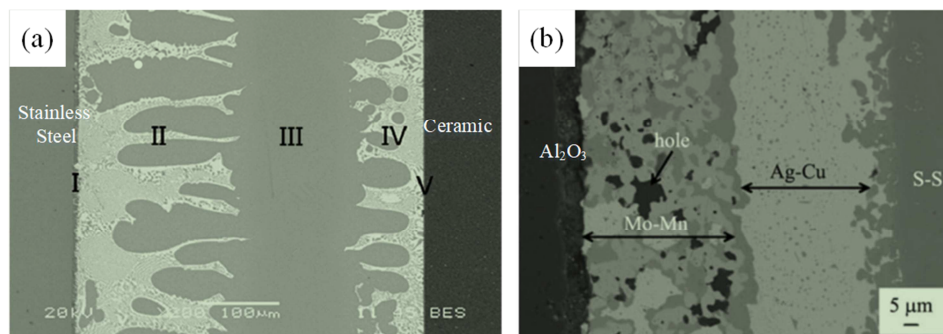


Figure 1. Composite Intermediate Layer: (a) SS/Cu/AgCu/Ti/Si<sub>3</sub>N<sub>4</sub>. (b) (Mo-Mn)Al<sub>2</sub>O<sub>3</sub>/AgCu/SS.

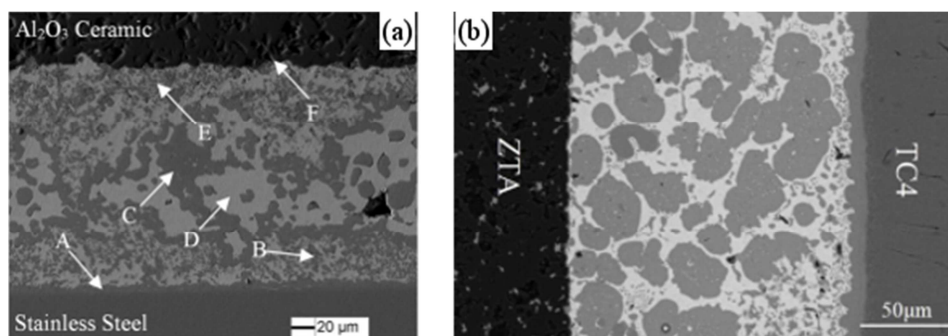


Figure 2. Porous material interlayer connecting ceramic to metal: (a)  $\text{Al}_2\text{O}_3$ /Ni foam/stainless steel; (b) ZTA/AgCu/Cu foam/AgCu/TC4.

It involves the using of metal powder and fiber sintered porous material or metal fiber mesh as an intermediate layer.

There are different common metal foams which are available like copper, nickel and stainless steel are available foams.

Such interlayers are more effective in relieving residual stresses than pure metal interlayers. Yu Zhang *et al* [12], used Ag-Cu-Ti/Ni foam/Ag-Cu-Ti as an interlayer for vacuum brazing of  $\text{Al}_2\text{O}_3$  ceramic into 1Cr18Ni9Ti alloy as showed in Figure 2a. The fracture location of the joint was on the ceramic side when there is no interlayer added and the shear strength was only 7.7 MPa. The interface between the ceramic and Ni foam fractured when a Ni foam interlayer was added and the shear strength of the joint was 101.7 MPa. Wang *et al* [13] used an AgCu/Cu foam/AgCu interlayer to join ZTA ceramics to TC4 as shown in Figure 2b. The interfacial structure of this joint is  $\text{ZTA/TiO}+\text{Ti}_3(\text{Cu}, \text{Al})_3\text{O}/\text{Ag}(\text{s},\text{s})+\text{Cu}(\text{s},\text{s})/\text{Ti}_2\text{Cu}_3/\text{TiCu}/\text{Ti}_2\text{Cu}/\alpha + \beta\text{-Ti}/\text{TC4}$ . The maximum shear strength of this joint is 84.5 MPa.

### 3. Effect of Holding Time on Joint Properties

Xia *et al* [14] attached  $\text{Ti}_3\text{SiC}_2$  ceramics to TC4 alloy through Ni interlayer. It was found that the width of the brazing layer increased and the number of  $\text{Ti}_2\text{Ni}$  phases decreased with increasing brazing temperature and holding time. When the temperature was  $1040^\circ\text{C}$ , micropores appeared near the TC4 substrate in the joint, resulting in the joint with minimum strength. Feng *et al* [15] used AgCuZn filler metal to join TiC ceramics to stainless steel. The interfacial structure of this joint was  $(\text{Cu}, \text{Ni}) / \text{Ag}(\text{ss}) + \text{Cu}(\text{ss}) / (\text{Cu}, \text{Ni}) / (\text{Cu}, \text{Ni}) + (\text{Fe}, \text{Ni})$ . With the increase of brazing temperature or time, the amount of  $(\text{Cu}, \text{Ni})$  phase on the ceramic side and  $(\text{Cu}, \text{Ni}) + (\text{Fe}, \text{Ni})$  phase on the steel side increased, while the amount of  $\text{Ag}(\text{s},\text{s}) + \text{Cu}(\text{s},\text{s})$  phase decreased. The maximum shear strength was 120.7 MPa. Shi *et al* [16] used AgCuTi filler metal to realize the joining of ZrC-SiC ceramics with TC4 by brazing. both Ti in AgCuTi and TC4 reacted with ZrC in ceramics to create TiC crystals of different shapes. As brazing temperature and holding time increase, a great amount of Ti is dissolved in TC4. Due to the high affinity from Cu to Ti, Cu and Ti reacted to form a series of Cu-Ti compounds in the filler metal in AgCuTi. The Cu-Ti compounds added to the hardness and brittleness of the joint, which decreased the performance of the joint, which had a maximum shear strength of 39 MPa. Liu *et al* [17, 18] used Ag/Cu and  $\text{TiH}_2$  powders as filler metals to realize the joint of zirconium dioxide ceramics with stainless steel by brazing method. Further study of this joint showed that the strength of the joint first increased and then decreased within a certain range of brazing temperature and holding time, with a maximum strength of 90 MPa. the effect of brazing temperature on the strength of the joint was more significant than the holding time. Liu *et al* [19] used AgCuTi filler metal to realize the joining of Cf/LAS composites with TC4 alloy. It was found that the thickness of the diffusion,  $\text{Ti}_3\text{Cu}_4$  and  $\text{TiSi}_2+\text{TiC}$  layers increased with the increase of holding time. On the contrary, the thickness of the Ti-Cu intermetallic compound layer decreases. In addition, when the joints were brazed at  $890^\circ\text{C}$  for 20 min, a large amount of  $\text{Ti}_3\text{Cu}_4$  phase

coarsened, which greatly reduced the mechanical properties of the joints.

### 4. Conclusion

A review of previous studies shows that the introduction of composite interlayers into ceramic/metal joints is highly effective in relieving residual stresses at the joint interface and within the ceramic. The method of composite interlayer can effectively reduce the residual thermal stress at the steel/ceramic joint interface and improve the microstructure at the interface, which effectively improves the performance of the joint. However, it is tedious in the loading process and still has some limitations.

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