Effect of welding temperature on microstructure and properties of Al2O3/AlSiMgLa/1A95 aluminum alloy direct brazing joint

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Abstract. Al2O3 ceramic and 1A95 aluminum alloy vacuum brazed joints were prepared with Al-Si-Mg-La solder. The effects of brazing temperature on the structure and shear properties of brazed joints were studied, and the interface of the joints was analyzed. Studies have shown that the shear strength of Al2O3/Ag-Si-Mg-La/Al joints all show a trend of increasing first and then decreasing with the increase of brazing temperature and holding time; when the best brazing process is 590℃×20 min, the boundary between Al-Si-Mg-La solder and aluminum alloy disappears; the interface between Al2O3 ceramic and solder is well bonded, and the shear strength is 56.74MPa. The fracture form of the joint is brittle fracture. Under different brazing process parameters, the fracture position of the joint is mainly divided into two types: when the joint strength is low, the fracture occurs near the interface between the aluminum alloy and the brazing filler metal layer; when the joint strength is higher, the fracture occurs at the interface between the Al2O3 ceramic and the solder.

1. Introduction
Al2O3 ceramics have excellent wear resistance, high temperature resistance, high strength, corrosion resistance and insulation properties, and have good application prospects in aerospace, automotive electronics and other fields [1,2]. Due to the high strength of ceramic materials, poor plasticity and toughness, poor machining and cutting performance, simple manufacturing process, it is difficult to make large or complex ceramic components. This status quo also limits the use and promotion of ceramic materials on the one hand [3]. A large number of studies have shown that combining the advantages of high strength, high toughness and excellent cold workability of metal materials with ceramics can make up for the shortcomings of ceramic materials [4]. Among many metals and alloys, aluminum and aluminum alloys can be widely used in transportation, aerospace, auto parts and other fields because of their higher specific strength, higher fracture toughness and good casting properties [5]. Therefore, realizing the reliable connection of ceramics and aluminum alloys, applying them to complex parts, and exerting their respective advantages is of great significance for expanding the application range of ceramics and metals.

Aluminum has a strong oxygen affinity, and it is easy to form a dense oxide film on the surface during welding, which hinders the diffusion of atoms between the base metal and the brazing filler metal, making the brazing of aluminum alloys more difficult [6]. In addition, due to ceramic materials Different from the combination of aluminum alloy materials, the linear expansion coefficient is quite
different, and the combination of aluminum alloy and ceramic has many characteristics and difficulties [7].

Two methods are usually used to solve many welding problems in ceramics and metals. One is to pre-metallize the ceramic surface, and the other is to add active elements to the solder [8]. Zhu et al. [1] used Al-Si solder to vacuum braze Al2O3 ceramics and 5005 aluminum alloy after active metallization of Ag-Cu-Ti powder. The maximum shear strength of the joint was 15MPa; Hou et al. [9] After Al2O3 ceramics were treated with molybdenum-manganese and nickel-plated surface treatment, vacuum brazing of Al2O3 ceramics and 1A95 aluminum alloy joints with Al-Si-Mg brazing filler metal was studied, and the joint shear strength reached 74 MPa. Compared with direct brazing, the method of plating nickel on the ceramic surface can significantly improve the joint strength. However, in recent years, due to the requirements of energy saving and environmental protection, the research on direct brazing of ceramics and metals has also begun to attract attention. Among the influencing factors of the direct brazing of ceramics and metals, the development and modification of brazing filler metals has become a key factor in solving the direct brazing of ceramics and metals. In this study, the rare earth element La was added to Al-Si-Mg alloy to form Al-Si-Mg-La low melting point eutectic solder. On this basis, the influence of welding temperature on the structure and properties of Al2O3 ceramic/ Al-Si-Mg-La/1A95 aluminum alloy brazed joints was studied.

2. Experiment

2.1. Determination of brazing process
The determination of the brazing process includes the selection of brazing temperature and holding time. The brazing temperature should be selected in the temperature range higher than the melting point of the solder but lower than the melting point of the base material aluminum alloy. Using DSC melting point test equipment, test the melting point of base material 1A95 aluminum alloy and Al-11.5Si-1.5Mg-0.5La solder, the melting point of the base material 1A95 is 639℃, and the melting point of the brazing filler metal is 580℃ (solidus 556℃). Therefore, the brazing temperature is chosen at 570℃, 580℃, 590℃, 600℃ and 610℃ , and the holding time is chosen at 20min. The specific brazing process curve is shown in Fig.1.

![Figure 1. Graph of brazing process](image)

By measuring the spreading performance of the brazing filler metal on Al alloys and ceramics at different times at the brazing temperature, the appropriate brazing time can be selected. The optimal brazing process needs to be selected in the determination of the mechanical properties of the brazed joint. The schematic diagram of sample brazing and the schematic diagram of the joint shear test is shown in Fig.2.
2.2. Microstructure analysis of brazed joints

Cut the brazed sample from the cross section, and then cold-set and solidify the cut sample. The cross section of the sample is polished with 200#, 400#, 600#, 1000#, 2000# sandpaper in turn, and then use 2μm diamond polishing paste to polish the cross section to a mirror surface. Immediately after polishing, etched with 95%H2O-2.5%HNO3-1.5%HCl-1HF (volume ratio) etching solution for 5-10s, sprayed the etched sample with gold, and analyzed the microscopic morphology and the interface of the sample by scanning electron microscope.

3. Experiment

3.1. The effect of welding temperature on the macroscopic appearance of joints

It can be seen from Fig. 3 that when 1A95 aluminum alloy and Al2O3 ceramics are welded by direct brazing, under the same welding holding time (20min), as the welding temperature continues to rise, Al-Si-Mg-La solder The larger the spread area on 1A95 aluminum alloy, the better the wettability. With the increase of welding temperature, at the brazing temperature of 610℃, the surface of 1A95 aluminum alloy has micro-dissolution phenomenon. When the brazing temperature of 610℃ is used, due to the temperature uniformity of the furnace and the dissolution of the molten solder on the base metal at high temperatures, the micro-dissolution phenomenon on the upper surface of the aluminum alloy can be observed.

3.2. Effect of the welding temperature on the micro-morphology of the joints

Fig. 4 shows the effect of brazing temperature on the micro-morphology of the interface reaction layer of Al2O3/Al-Si-Mg-La/1A95 aluminum alloy joint when the holding time is 20min. It can be seen when the brazing temperature is 570℃, the interface between Al-Si-Mg-La solder and aluminum alloy is clearly visible, while the interface area between Al2O3 ceramic and solder is more tortuous, and the interface can be observed to a few holes. When the brazing temperature rises to 590℃, the diffusion between the brazing filler metal and the aluminum alloy is more complete, the composition of the joint area is uniform, and the interface line between the Al-Si-Mg-La brazing filler metal and the aluminum alloy disappears; the interface between the Al2O3 ceramic and the brazing filler metal is well bonded, and the Al2O3 ceramic is embedded into the brazing filler metal matrix by mechanical interlocking. With the further increase of the brazing temperature, especially when the brazing temperature is 610℃, the thermal expansion coefficients of Al2O3 ceramics and brazing filler materials are too different,
and too high brazing temperature will inevitably produce larger joint residues. Stress causes micro-cracks to appear in the interface area and further develop into macroscopic joint cracks.

![Figure 4. Morphology of interface at different brazing temperatures (Insulation 20 min)](image)

In order to determine the distribution of the elements in the interface area of the joint, scan the energy spectrum of the area where the red line shown in the figure passes, and the result is shown in Fig. 5. It can be seen that the aluminum element is mainly distributed in the brazed alumina ceramic, the brazing filler metal layer and the 1A95 aluminum alloy matrix; the Si element is mainly distributed in the Al2O3 ceramic/brazing filler interface and the brazing filler/1A95 aluminum alloy interface.

![Figure 5. Distribution of Elements in the Area of Al2O3/Al-Si-Mg-La/1A95 Joints](image)

Except for Al and O elements, none of the other elements were observed to be concentrated on the ceramic matrix. In addition to a large amount of aluminum elements observed in the 1A95 aluminum alloy matrix, some Mg and Si elements can also be observed at the junction with the solder interface. It can be seen that after the solder is melted, the active atoms in the solder have achieved good diffusion at the interface between the 1A95 aluminum alloy and the solder, but have not formed a good diffusion with the ceramic.

3.3. The influence of brazing temperature on the shear strength of joints

Fig. 6 shows the change curve of the shear strength of brazed joints at different brazing temperatures under the same welding holding time for 20 minutes. It can be seen with the increasing of the brazing temperature, the shear strength of the joint increase first and then decrease. The ultimate shear strength of the joint reaches the maximum at the temperature of 590℃, the maximum value is 56.74MPa. When the brazing temperature is low, the solder is not fully melted and diffused, and the interface reaction is not sufficient. As the temperature increases, the melting effect of the solder becomes better, and the interfacial reaction intensifies, thereby increasing the shear strength of the joint. When the brazing temperature is too high, the brazing filler metal will seriously dissolve the base metal, and the base metal near the brazing seam will burn excessively. The higher the welding temperature, the
greater the difference in thermal expansion coefficient between ceramics and metals, which ultimately results in greater internal stress between ceramics and aluminum alloys. The main reason may be that the resulting brittle compounds accumulate and grow in the interface zone, thereby reducing the performance of the joint [3,10].

Figure 6. Effect of direct brazing temperature on shear strength (insulation 20 min)

3.4. Fracture appearance analysis of brazed joints

Fig.7 shows the fracture morphology of the joint specimens with a welding temperature of 590℃, a holding time of 20min, and a connection temperature of 610℃ and a holding time of 20min. Table 1 lists the corresponding energy spectrum analysis results of the fracture characteristic area of the joint. It can be seen from Fig.7(a), the joint fractured in two obvious areas. After observation, the fracture was also brittle fracture. The energy spectrum analysis results show that the C zone contains a large amount of Al element, and the D zone is mainly α(Al)+Al2O3. Therefore, it shows that part of the fracture occurs at the interface between Al2O3 ceramic and solder. Fig.7(b) shows the fracture microscopic morphology of the joint when the connection temperature is 610℃ and the welding holding time is 20 minutes. It can be seen from Fig.7(b) that the fracture form of the joint is brittle fracture, and the fracture morphology shows that it is concentrated in two areas and fractures. The energy spectrum analysis of the joint area shows that the E area contains a large amount of Al2O3, and the F area contains a large amount of Al element. It is inferred that the fracture should occur partly in the interface layer between the Al2O3 ceramic and the solder, and partly in the interface reaction zone between the solder and the aluminum alloy.

Table 1. Energy spectrum analysis of each characteristic region of fracture surface

| Zone | O  | Mg  | Al  | Si  | Zn  | Possible phase   |
|------|----|-----|-----|-----|-----|------------------|
| A    | 5.76 | 84.87 | 5.03 | 4.24 |     | α(Al)            |
| B    | 26.23 | 3.67  | 65.28 | 1.90 | 2.92 | α(Al)+Al2O3      |
| C    | 56.08 | 1.46  | 42.46 |     |     | Al2O3            |
| D    | 1.37  | 86.20 | 12.42 |     |     | α(Al)            |

Figure 7. Fracture Morphology of Al2O3/Al-Si-Mg-La/1A95 Direct Brazed Joint
4. Conclusion

(1) When AlSiMgLa solder was used to braze Al2O3 ceramics and 1A95 aluminum alloy directly. Under the same welding holding time of 20 minutes, as the brazing temperature increases, the shear strength of the Al2O3/Ag-Si-Mg-La/1A95 joint first increases and then decreases. When the brazing temperature is 590°C, the maximum shear strength is 56.74MPa.

(2) The fracture form of the joint of Al2O3/Ag-Si-Mg-La/1A95 alloy is brittle fracture. The fractured parts at the joint are mainly divided into two types: when the joint strength is low, fracture occurs near the interface between the aluminum alloy and the brazing filler metal layer; when the joint strength is high, Al2O3 ceramics fracture occurred at the interface with the solder and at the interface between the aluminum alloy and the solder layer.

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