Effect of welding time on microstructure and properties of Al2O3/AlSiMg/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 time 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℃×30 min, the boundary between AlSiMgLa solder and aluminum alloy disappears; the interface between Al2O3 ceramic and solder is well bonded, and the shear strength reaches 65.12 MPa. 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]. However, due to the inherent shortcomings of ceramic materials such as brittleness and poor cold workability, it is difficult to process and prepare large ceramic complex parts, which greatly limits its application in many fields[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 high specific strength, high fracture toughness, and good casting performance[5]. Therefore, realizing the reliable connection of ceramics and aluminum alloys, applying them to complex components, and giving full play to their respective advantages, is of great significance to 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 alloy more difficult[6]. In addition, due to the different bonding types of ceramic materials and aluminum alloy materials, the linear expansion coefficients are quite different, and there are many characteristics and difficulties in the connection of aluminum alloys and ceramics[7].
Two methods are usually used to solve 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]. Hou et al.[9] After Al2O3 ceramics were Mo-mnized and Ni-plated surface treatment, they studied the Al-Si-Mg brazing filler metal vacuum brazing Al2O3 ceramics and 1A95 aluminum alloy joints, and the shear strength of the joints reached 74 MPa. Due to the requirements of energy saving and environmental protection in recent years, 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 materials has become a key factor in solving the direct brazing of ceramics and metals. In this study, the rare earth element La was selected to be added to the Al-Si-Mg alloy to form an Al-Si-Mg-La low melting point polyeutectic solder. On this basis, the influence of welding temperature and holding time 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, as shown in Fig.1. It can be seen from Fig.1 that 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-url)

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.

![Figure 2. Schematic illustration of test of brazed specimen and shear strength](image-url)
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 directly brazed, at the same brazing temperature of 590℃, with the extension of brazing time, Al-Si-Mg-La brazing filler metal is on the aluminum alloy. The larger the wetted spreading area, the better the wettability of the solder. At the same time, it can be observed that when the brazing time is 60min, the upper surface of the aluminum alloy base material is slightly dissolved.

Figure 3. Macro-morphology of Al2O3/AlSiMgLa/1A95 joints at different brazing time

3.2. The effect of welding time on the micro-appearance of joints
Fig.4 shows the effect of holding time at 590℃ brazing temperature on the micro-morphology of the interface reaction layer of Al2O3/Al-Si-Mg-La/1A95 aluminum alloy joints. When the welding holding time is 5 minutes, the interface line between Al-Si-Mg-La solder and aluminum alloy is clearly visible, while the interface line between Al2O3 ceramic and solder is more tortuous, and fine gaps can be observed at the joint interface exist. With the extension of the brazing holding time, the diffusion between the brazing filler metal and the aluminum alloy becomes more and more sufficient, and the composition at the joint is gradually uniform, and the boundary between the Al-Si-Mg-La brazing filler metal and the aluminum alloy is also increasing. When the brazing holding time is 60 minutes, the ceramic fracture appears at the interface between the ceramic and the solder, and the interface between the Al2O3 ceramic and the solder appears fine cracks. Therefore, when the brazing temperature is 590℃ and the holding time is 30 minutes, a dense and defect-free brazing joint can be obtained.

Figure 4. Morphology of interface at different holding time

Fig.5 shows the micro-interface structure and EDS analysis results of Area 1 and 2 of the reaction layer at the joint between Al-Si-Mg-La solder and Al2O3/1A95 aluminum alloy when the brazing
temperature is 590°C and the holding time is 5min. It can be seen from Fig.5 that there is a relatively obvious boundary line at the joint interface between the solder and 1A95 aluminum alloy. It can be seen that the joint area cannot achieve sufficient diffusion under a short welding holding time; the interface area between the solder and the Al2O3 ceramic can be a small amount of cracks were observed and extended to the entire joint area, and the ceramic and the interface layer were relatively poorly bonded.

3.3. The influence of holding time on the strength of joints

Fig.6 shows the change curve of the shear strength of the brazed joint under the same brazing temperature of 590°C and different brazing holding time. It can be seen that as the brazing holding time increases, the shear strength of the joint first increases and then decreases. When the holding time is 30 minutes, the maximum shear strength of the joint is 65.12Mpa. The analysis reasons are: the brazing time is short, the solder is not fully melted and spread, and the interface reaction is not sufficient. With the extension of the welding holding time, the melting and spreading of the brazing filler metal will be more sufficient, and the interface reaction will be more intense, thereby increasing the shear strength of the joint. When the brazing heat preservation time is too long, the base metal near the brazing seam will partially dissolve, causing over-burning. With the extension of the welding holding time, the brittle compounds generated at the joint accumulate and grow in the interface area, which then affects the mechanical properties of the joint[10].

3.4. Fracture appearance analysis of brazed joints

Fig.7 shows the fracture morphology of the joint specimens with a welding temperature of 590°C, a holding time of 5min and 20min. Table 2 lists the corresponding energy spectrum analysis results of the fracture characteristic area of the joint. It can be seen from Fig.7(a) that when the welding holding time is 5 minutes, the fracture form of the joint is brittle fracture. The energy spectrum analysis of the two fracture areas in the Fig.7 (see Table 1) shows that both the A and B areas contain a large amount of aluminum, indicating that the fracture location should be located at the interface layer between the...
aluminum alloy and the brazing filler metal layer at this time. When the holding time was extended to 20min, as shown in Fig.7(b), 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.

| Zone | O  | Mg  | Al  | Si  | Zn  | Possible phase     |
|------|----|-----|-----|-----|-----|-------------------|
| A    | 1.97 | 88.73 | 7.63 | 1.67 |     | α(Al)             |
| B    | 0.96 | 94.91 | 1.59 | 2.54 |     | α(Al)             |
| C    | 5.76 | 84.87 | 5.03 | 4.24 |     | α(Al)             |
| D    | 26.23 | 3.67 | 65.28 | 1.90 | 2.92 | α(Al)+Al2O3       |

4. Conclusion
(1) At the same brazing temperature of 590℃, with the extension of the brazing holding time, the shear strength of the Al2O3/Ag-Si-Mg-La/1A95 joint first increases and then decreases. The Al2O3 ceramic matrix is embedded in the solder by mechanical fitting, and the joint is sheared. The maximum strength is 65.12MPa.

(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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