Ultrasonic-assisted soldering of Cu/Ti joints

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Abstract. Cu/Ti joints are expected to be used in various applications, while reliable joining method is still to be developed. It is commonly not possible to solder Ti alloys using Sn-based solder alloys because of their poor wettability. In this study, Sn-Ag-Cu soldering filler metal was used to joining TC4 titanium alloy and pure copper using ultrasonic-assisted soldering. The influence of different temperature and different ultrasonic time on the welded joint is studied and explored. Microstructure of the joints was investigated. Shear strength of the joints reached the maximum value, i.e. 38.2MPa. Relationship between the sonication parameters and the microstructure and strength of the joints was discussed. Thus, it is verified that dissimilar metal brazing of TC4 and copper is suitable for low temperature soldering.

1. Introduction

Titanium alloys have remarkable strength and high-temperature performance[1]. They are expected to be widely used in various industries, such as aerospace, automotive engineering, biomedical engineering and military fields. Comparatively, copper alloys have high heat conduction rate, low electric resistance, remarkable ductility and satisfactory corrosion resistance [2]. Joints made of titanium and copper have advantages of both of the two materials, and can be used in various applications which is not suitable for components mad of single material in the aerospace, shipbuilding, et. al. However, weldability of them is commonly considered as very poor because of their very limited mutual-solubility. Moreover, thermos-properties of them are very different, which can be a negative fact for the joining.

Much efforts have been devoted to joining titanium alloys to copper alloys. Shiue et al.[3] reported joining pure Ti plates and Cu plates by vacuum brazing. The brazed seam was basically composed of brittle intermetallic compounds (IMCS), which may lead to low ductility. Aydin et al.[4] joined TC4 Ti alloy and Cu by diffusion welding. Kimura et al.[5] welded Ti and Cu by friction welding. Kahraman et al. [6] and Miao et. al. [7] joined Cu-Ti using explosive welding. Liu et al. [8] joined Ti6Al4V alloy and QCr0.8 copper alloy using electron beam. Cao et. al. [9] made TA2 titanium alloy/copper T2 joints by cold metal transfer technology.

Most of the previous research used joining methods involving high energy input in the joints, i.e. friction or high temperature, which may promote formation of intermetallic compounds (IMCs) in the joints. IMCs are usually brittle and may lead to brittle fracture in service. On the other hand, the very complicated assembling of the previously reported research can lead to very high cost which may
significantly limit the wide application of Cu-Ti joints. Thus, a convenient method for joining copper alloys and titanium alloys is highly in need.

Soldering is a very widely used method for low-temperature joining and Sn-based alloys are most commonly used in this method. Joining copper with Sn-based alloys is very convenient. However, it is commonly very difficult to join Ti alloys by soldering because wettability between them is very poor in ordinary conditions. In our previous studies, it was found that ultrasonic can be used to promote wettability and bonding between various materials. Here we present that ultrasonic was used to achieve wetting between Sn and TC4 titanium alloy, and thus copper-titanium joints were made by ultrasonic coating and soldering.

2. Materials and experiments

Commercial pure copper and TC4 titanium alloy were cut into 2mm×10mm×50mm pieces and used as the base metal. Chemical composition and mechanical properties of the TC4 alloy is listed in the table 1 and 2. Commercial Sn-3.5Ag-0.5Cu were used as the solder alloy and rosin was used as flux.

A coating-soldering procedure was used to join the base metals. The copper and titanium alloy pieces were cleaned by ultrasonic washing and then grinded by abrasive paper so that oxide films on them were removed. Then, the end to be soldered were merged in to a solder pool with liquid Sn-3.5Ag-0.5Cu alloy. Ultrasonic radiation was then applied to the liquid solder so that the merged base alloy pieces were coated by a layer of solder. The sonication time was 10s, 30s, and 60s. And the coating temperature was 250-280°C. Then, the coated base-metals were assembled in a holding instrument and heated to 250°C and joined by a common soldering procedure, as shown in the Figure 1.

| Table 1. Chemical composition of the TC4 alloy (wt%) |
|--------|--------|--------|--------|--------|--------|--------|--------|
| Fe     | C      | N      | H      | O      | Al     | V      | Ti     |
| 0      | 0      | 0      | 0      | 0      | 5.5    | 3.5    | B      |
| 0.30   | 0.10   | 0.05   | 0.015  | 0.20   | ~6.8   | ~4.5   | al.    |

| Table 2. Chemical composition of the pure copper (wt%) |
|--------|--------|--------|--------|--------|--------|
| Cu+Ag  | Bi     | Pb     | Sn     | O      | Fe     |
| 99.5   | 0.002  | 0.01   | -      | 0.005  | -      |

Cross-sections of the joints were made by cutting, polishing and corroding by 1wt% HNO₃ aqueous solution. Microstructure of the joints were observed by optical microscope. Tensile shear strength test were used to evaluate mechanical properties of the joints.

3. Results and Discussion

In the first situation, the sonication took place at 280°C. Interfaces between the TC4 alloy/solder and Cu/solder is shown in the figure 2. When the sonication was 20s, a 5-10µm thick IMCs layer formed. When the sonication was 40s, thickness of the IMCs layer increased into 10-15µm. When the sonication was 60s, thickness of the IMCs layer increased into 20-25µm. Thus, it is clear that
sonication has a significant impact on the interfacial reaction between Cu base metal and the solder. IMCs layer was not found at the Ti alloy/solder interface. This is because Ti alloy is much harder than copper, and diffusion is very limited. Maximum shear strength of the joints with sonication of 20s, 40s and 60s was 17.9Mpa, 24.3Mpa and 26.7Mpa, respectively.

![Figure 2. Microstructure of the joints with sonication at 280°C. (a) Cu/solder interface, sonicated 20s; (b) Cu/solder interface, sonicated 40s; (c) Cu/solder interface, sonicated 60s; (d) Ti/solder interface, sonicated 20s; (e) Ti/solder interface, sonicated 40s; (f) Ti/solder interface, sonicated 60s.](image)

In the second situation, the sonication took place at 250°C. Interfaces between the TC4 alloy/solder and Cu/solder is shown in the figure 3. When the sonication was 20s, a 5~8μm thick IMCs layer formed. When the sonication was 40s, thickness of the IMCs layer increased into 8-12μm. When the sonication was 60s, thickness of the IMCs layer increased into 15-20μm. The IMCs' thickness was less than that obtained at 280°C, which indicates the significant influence of temperature on the interfacial reaction. IMCs layer was neither found at the Ti alloy/solder interface. Maximum shear strength of the joints with sonication of 20s, 40s and 60s was 18Mpa, 32.7Mpa and 38.2Mpa, respectively.

![Figure 3. Microstructure of the joints with sonication at 250°C. (a) Cu/solder interface, sonicated 20s; (b) Cu/solder interface, sonicated 40s; (c) Cu/solder interface, sonicated 60s; (d) Ti/solder interface, sonicated 20s; (e) Ti/solder interface, sonicated 40s; (f) Ti/solder interface, sonicated 60s.](image)
Relationship between shear strength and sonication time and temperature is shown in the Figure 4. It is clear that the shear strength increased along with the sonication time at both 250°C and 280°C. This may be caused by better interface reaction between the Ti alloy and the solder. On the other hand, shear strength of the joints sonicated at 250°C was obviously higher than that sonicated at 280°C. This may be caused by the growth of IMCs between the copper and the solder. Proper chemical reaction at the interface is beneficial to the joining strength. Further study on the relationship between the microstructure and strength is to be carried out later.

![Figure 4](image.jpg)

**Figure 4.** Relationship between shear strength and sonication time and temperature

And the maximum shear strength of the copper/Ti alloy was 38 MPa, which was very close to the shear strength of the Sn-3.5Ag-0.5Cu alloy, i.e. 48.5Mpa. This indicates that the bonding strength of the joints was relatively high, which is very close to the theoretical limit. Xu et. al. [10] soldered pure copper and pure titanium with In as the filler metal and the maximum shear strength was 6.07Mpa. Thus it is reasonable to state that the joining strength is satisfactory. Wang et. al. [11, 12] joined copper and titanium by resistance brazing with Ag50CuZn alloy as the filler metal and the maximum strength reached 70MPa. Shear strength of Ag alloy is commonly much higher than that of Sn-based alloys. So the very high shear strength was caused by the stronger filler metal. To date, the strength in this study is the highest in the studies of low temperature soldering of copper and titanium alloys.

4. **Conclusion**

Pure copper and TC4 Ti alloy were joined by ultrasonic-assisted soldering using Sn-3.5Ag-Cu solder alloy. The following conclusion can be drawn:

(1) Wetting and bonding between TC4 Ti alloy and Sn-3.5Ag-0.5Cu can be achieved by the aid of ultrasonic sonication.

(2) Temperature and sonication time influence interaction between copper and the solder significantly, but not that at the Ti alloy/solder interface.

(3) Maximum shear strength of the joints was ~38MPa, which was obtained when the ultrasonic sonication temperature was 250°C

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