Interface bonding performance of CuW alloy coating on Cu substrate

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Abstract. In this paper, CuW alloy is successfully coated on copper substrate by microwave sintering. A wedged load test and scanning electronic microscopy (SEM) are employed to investigate the interface bonding performance. The results show that the CuW coating bonds firmly to the copper substrate without any gap or crack. The interface bonding strength increases with the temperature increase, but doesn't show an obvious regularity changing with holding time increase.

Introduction

Cu-W is an important alloy which combines the features of tungsten and copper. CuW coating on copper substrate will enhance some properties of copper, such as higher melting point, welding resistance and arc erosion resistance, while this composite will retain the advantages of copper, such as high electrical conductivity, high thermal conductivity and well processing workability. CuW/Cu composite is widely used in high voltage switch, relays, EDM electrodes and other electronic applications.[1-3] Because tungsten and copper are immiscible and the melting point of tungsten is very high, conventional preparation of CuW alloy is to sinter the mixed powders of copper and tungsten. But traditional powder metallurgy methods have encountered some difficulties, such as longer sintering time, higher temperature and higher energy consumption.

Microwave sintering is an innovative process of powder metallurgy technology which has been used in preparing materials from 1980. Since Gavin Whittaker et al introduced this technology into metal powder sintering field, many alloys have been manufactured for many applications. [4, 5] Compared with conventional sintering technology, it has the advantages of lower temperature, shorter duration, higher efficiency and better properties of product in density, hardness and so on.

In this paper, we present a method to manufacture CuW coatings on copper substrate by microwave sintering. The interface between CuW coating and copper substrate is experimentally investigated. The influence of temperature and holding time on the interface bonding strength is also studied and discussed.

Experiment

Commercially available pure copper powders (purity>99.9%, particle size<25μm, provided by Shanghai Jingchun Ltd., China) and pure tungsten powders (purity>99.5%, particle size<2μm, provided by Xiamen Jinlu Ltd., China) were employed to prepare the coatings. The powders were mixed with different composition in a planetary ball mill (XQM-2L, Nanjing Daran Ltd. China) with 300r/min for 8h. 80°C vacuum drying for 4h is subsequent.

The pure copper substrates were cut in pieces with a size of 12mm*10mm*3mm by wire electrical discharge machine (WEDM). To ensure the good bonding performance between coatings and substrate, a series of post-process on copper substrate including degreasing, acid pickling, ultrasonic cleaning and vacuum drying was necessary. After that, the mixed CuW powders were pressed on the Cu substrate by a tablet machine (769YP-24B, Tianjing Keqi, China) with a pressure of 20MPa and a holding time of 2 min.

The green samples were covered with SiC pieces and sintered in a 2.45GHz 3kW high vacuum microwave sintering furnace (HAMiLab-HV3, Changsha Longtai co., Ltd., China). The pressure was less than 10^{-3}Pa and the heating rate was 15°C/min. The sintering temperature were set to 850°C, 880°C, 920°C and the holding time were set to 5 min, 10 min and 15min, respectively.

Detail process was illustrated in other paper. [6]

Optical microscopy (VHX-1000, Keyence, Japan) and scanning electronic microscopy (S-3500N, Hitachi, Japan) were employed to observe the interface morphology. The specimen used to observe was prepared under condition of 880°C, 10 min holding time.

Because the coating thickness is about 300-400 μm, conventional adhesion tests such as scratch test and shear test are unsuitable for this research. Adhesive strength test result also showed that the interface bonding strength is higher than the epoxy adhesive strength (20MPa). A wedged load strength test was employed to measure the interface bonding strength. [7] In additional, for avoiding slip and damage of the CuW coating, a copper block was introduced to enhance the damage resistance of CuW coatings. The block combined to the CuW coating surface with an epoxy binder. The test principle and process is schematically illustrated in Fig 1. The maximum shear strength of interface can be deduced and described as follow:

$$\sigma_{\max} = C\frac{p_{\max}}{2\omega h_2}\cot\frac{\alpha}{2} - 1.5p_{\max}\frac{(\frac{L_0}{2} - h_2\tan\frac{\alpha}{2})}{\omega h_1^{\ 2}} \tag{1}$$

In this equation: σ is the shear strength of interface which we are concerning; p is the load; α is the sharp angle of the stainless steel indenter; ω is the width; L_0 is the total length of complex; h_2 is the depth of initial slot; h_1 is height of specimens without count in h_2; C is a coefficient of correction which is 1.5 in this paper.

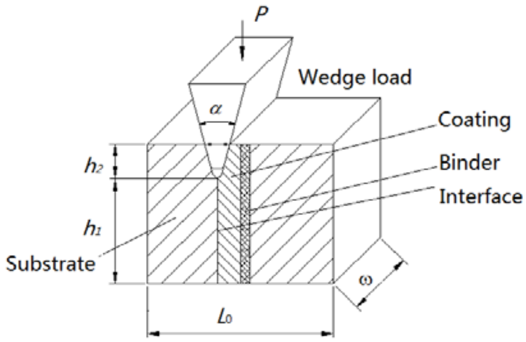


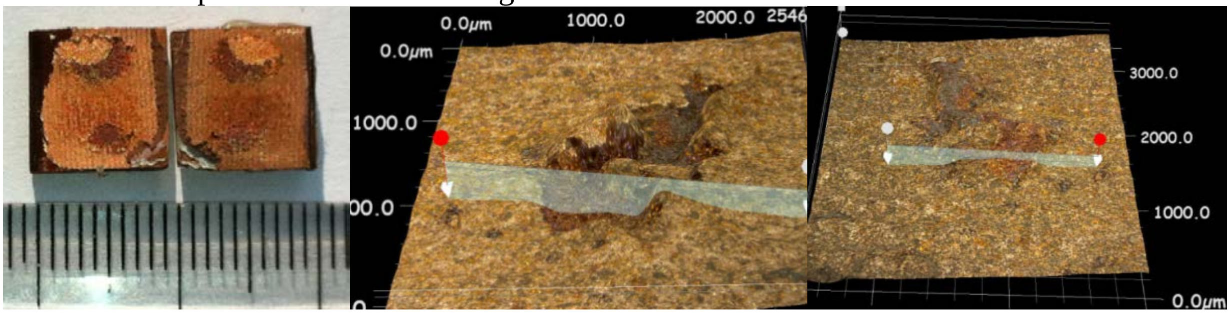
Fig.1 Schematic of the wedged load test

Results and discussion

Fig.2 shows the cross section morphology of the CuW coating on Cu substrate (880°C, 10 min). It can be seen that the white tungsten particles distribute in the coating dispersedly. The thickness of the CuW coating in this experiment is about 300-400 μm, according to the dosage of the CuW mixed powders. Not any gap or crack in the interface can be observed in this figure. This result indicates that the interface bonding performance is very well and the CuW coating can bond firmly to the copper substrate by the process we present.

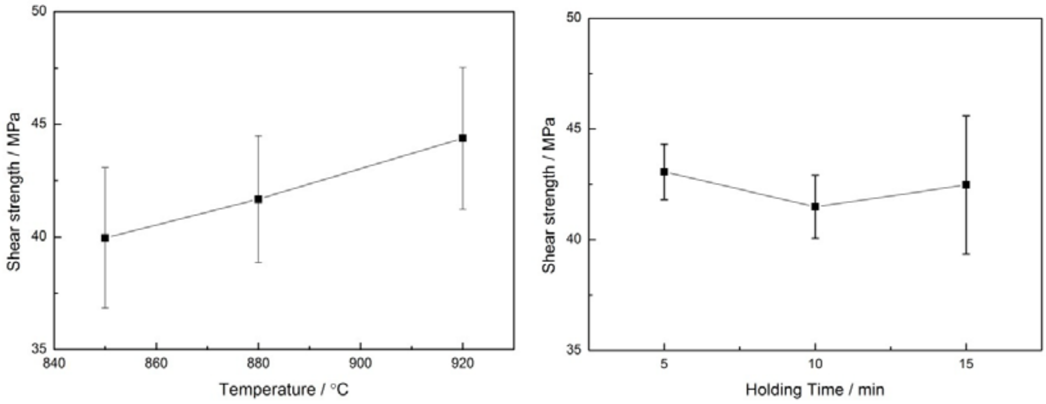
Fig.2 The cross section morphology of CuW coating on Cu substrate

After wedged load test, fracture morphologies of the specimen are shown in Fig.3. The CuW coating is cut off integrally from the copper substrate along the interface strictly. It can be seen some copper material transfer from the substrate to the CuW coating. The transfer pit can reach up to a depth of 150 μm and area of 20 mm^2. This result indicates that the bonding strength between CuW coating and Cu substrate is higher than the copper cohesion in some place, particularly the defects of copper substrate. Due to the good interface bonding performance, the defects (gaps or cracks) in copper substrate near the interface are going to grow up, even peel off in the loading procedure. Consequently, the copper exfoliation bonds to the CuW coating interface firmly and transfers in the separation of CuW coating and Cu substrate.



(a) The interface (b) Cu substrate (c) CuW coating

Fig.3 The fracture morphology of Cu substrate and CuW coating after wedged load test



(a) Different temperature (b) Different holding time

Fig.4 Bonding strength (shear strength) of the interface changed with different conditions

The sintering temperature and holding time impact on the bonding strength of interface is investigated and shown in Fig.4. It can be seen that the interface shear strength increases with the sintering temperature increase in Fig.4 (a). The explanation is: because of the press procedure before sintering, less cracks or gaps will be formed in the interface. With the sintering temperature increase, the copper inter-diffusion is more active. It results in the increase of interface bonding strength. Fig.4 (b) shows that the interface shear strength doesn't change apparently or regularly with holding time increase. It is a minor difference to the traditional point of view. The possible reason is the holding time in this experiment is too short to reveal the difference.

Further, microwave seems to devote a significant contribution to the high interface bonding strength. Due to the selective heating and the dense surface reflection characteristic of microwave, most heating energy is concentrated in the interface. It may also induce a local melt in some place of the interface. This will help to increase the bonding strength. The detail mechanism needs a further research in the future.

Conclusion

Base on the microwave sintering technology, CuW alloy is successfully coated on copper substrate. Morphology observation and wedged load test show that the CuW coating bonds firmly to the copper substrate without any gap or crack. The interface bonding strength increases with the temperature increase, but doesn't show an obvious regularity changing with holding time increase.

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