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Preparation and Properties of Cu-Ti_3AlC_2 Composites by Cu-coated Ti_3AlC_2

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Abstract: Cu-Ti_3AlC_2 composites (CTCS) are a potential electrical contact material, but Ti_3AlC_2 tends to agglomerate, which is detrimental to the density of CTCS. In this work, to prepare CTCS with high density and high Ti_3AlC_2 content, a uniform Cu coating was applied to the surface of Ti_3AlC_2 using rotating electroless plating. The effects of sintering temperature on the microstructure and properties of CTCS fabricated with Cu-coated Ti_3AlC_2 were investigated. The results show that Ti_3AlC_2 particles are evenly distributed within CTCS. The relative density and compressive strength of CTCS are optimal at a sintering temperature of 1000 °C, with values of 97.6% and 654.7 MPa, respectively. In contrast, at a sintering temperature of 950 °C, CTCS exhibit the highest hardness and tribological properties, with a hardness value of 314.7 HV, a friction coefficient of about 0.35, and a wear rate of 1.08×10^{-7} $mm^3/N\cdot m$.

Keywords: Composite materials; Microstructure; Powder technology.

1. Introduction

As a typical MAX phase material, Ti_3AlC_2 not only has excellent lubrication properties but also possesses good mechanical properties and electrical conductivity [1-3]. When combined with Cu, which has good electrical and thermal conductivity, Ti_3AlC_2 shows great potential for use in electrical contact materials [4-5]. Relevant studies have shown that in the Cu-Ti_3AlC_2 material system, Ti_3AlC_2 decompose at high temperatures, and the lower the content of Ti_3AlC_2, the more likely it is to decompose completely [6-8]. To ensure that most Ti_3AlC_2 does not decompose during the sintering process of Cu-Ti_3AlC_2 composites (CTCS), the amount of Ti_3AlC_2 should be increased. However, due to the density difference between Cu and Ti_3AlC_2, Ti_3AlC_2 is prone to agglomeration. When the amount of Ti_3AlC_2 increases, it becomes more difficult to achieve high-density CTCS.

In order to prepare CTCS with high density and a high content of Ti_3AlC_2, Ti_3AlC_2 powders coated with a uniform Cu coating were prepared by rotating electroless plating. CTCS were then fabricated using powder metallurgy with Cu-coated Ti_3AlC_2 as the raw material. Furthermore, the effects of sintering temperature on the microstructure, relative density, mechanical properties, and tribological properties of CTCS were investigated.

2. Experimental

The Ti_3AlC_2 powder, with an average particle size of 30 μm, was sourced from Foshan Xinxi Technology Co., Ltd (Foshan, China). Table 1 details the composition and relevant information of the solution used for electroless copper plating on the Ti_3AlC_2 surface. Specifically, the reaction solution and Ti_3AlC_2 are placed in a ball mill tank and subjected to rolling conditions in a planetary ball mill for copper plating. Importantly, Ti_3AlC_2 powder does not require sensitization or activation prior to electroless plating, and the copper content in the Cu-coated Ti_3AlC_2 was 40 wt.%. Post-plating, the Cu-coated Ti_3AlC_2 was cleaned, vacuum dried, and treated with hydrogen at 350 °C for 3 hours.

Table 1. Composition of the solution and electroless plating parameters

Reagent	Concentration/($g\cdot L^{-1}$)
$CuSO_4\cdot5H_2O$	12
HCHO	12 ml/L
$C_{10}H_{14}N_2Na_2O_8$	16
$C_4H_4O_6KNa\cdot4H_2O$	22
pH regulator	NaOH
pH	14
Temperature	40 °C

A hydraulic press was employed to form Cu-coated Ti_3AlC_2 powder at a load of 400 MPa and hold pressure for 2 minutes. Subsequently, the compact was sintered using a tubular furnace (OTF-1200X-HP30) at different temperatures (800, 850, 900, 950, and 1000 °C) for a holding time of 2 h with a 3 MPa argon atmosphere.

The phase structure and micromorphology of Ti_3AlC_2, Cu-coated Ti_3AlC_2, and CTCS were characterized by X-ray diffraction (D/max-Rc, Japan) and scanning electron microscope (Tescan Mira4), respectively.

The density of CTCS was measured using an electronic balance (MSA324S-000- DU, Germany). The relative density of CTCS was calculated as the ratio of the true density to the theoretical density. A Vickers hardness tester (Leco-LV700AT) was used to evaluate the hardness of CTCS, with the average of five test points taken. A universal testing machine (INSTRON 3369) was employed to measure the compressive strength of CTCS, with a compression speed of 0.5 mm/min. A friction and wear testing machine (GF-1) was used to measure the tribological properties of CTCS. The counterpart was a CuCrZr alloy ball, with a friction speed of 400 r/min and a load of 20 N.

3. Results and Discussion

Fig. 1(a) shows the micromorphology of Ti_3AlC_2, which

exhibits the typical layered structure characteristics of MAX phase materials. From the surface and cross- sectional morphology of Cu-coated Ti_3AlC_2 powder, it can be observed that Cu coating can be uniformly and completely coated on the surface of Ti_3AlC_2, as shown in Figs. 1(a) and (b). This will effectively avoid the aggregation phenomenon of Ti_3AlC_2, thus obtaining highly dense CTCS. Besides, the morphology of Cu-coated Ti_3AlC_2 powder shown in Figs. 1(a) and (b), provides a strong support that the rotating electroless plating process used in this study can prepare good Cu coating on the surface of Ti_3AlC_2 powder. The XRD pattern of Cu-coated Ti_3AlC_2 shows that the raw material of Ti_3AlC_2 has a good purity, and no obvious oxides of copper, as shown in Fig. 1(d).

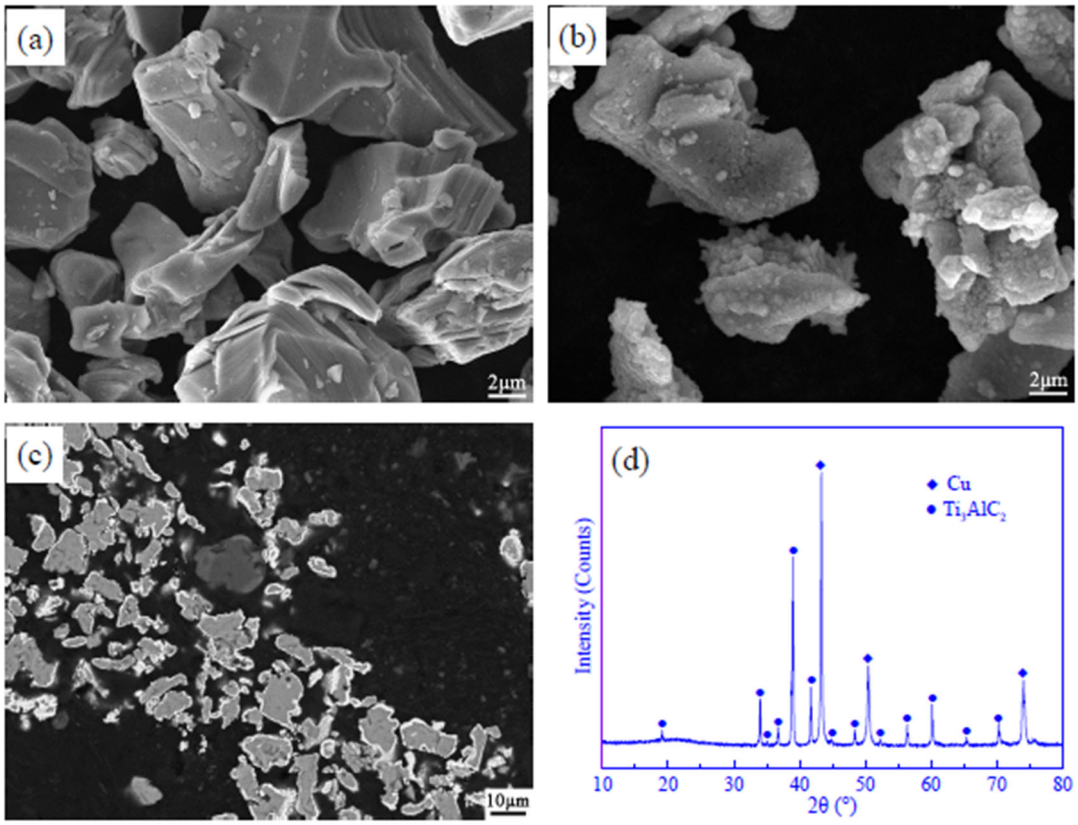

Figure 1. (a) The micromorphology of Ti_3AlC_2; (b) Surface morphology of Cu-coated Ti_3AlC_2; (c) Cross-section morphology of Cu-coated Ti_3AlC_2; (d) The XRD pattern of Cu-coated Ti_3AlC_2

Fig. 2(a) shows the XRD pattern of CTCS sintered at different temperatures. The strength of the Ti_3AlC_2 characteristic peak gradually decreases with increasing sintering temperature, while the TiC characteristic peak shows the opposite trend, gradually increasing with temperature. Additionally, a significant diffraction peak of Ti_3C_2 appears in CTCS sintered at 800 °C, but this peak gradually decreases as the sintering temperature rises. Furthermore, the diffraction peak of the copper matrix shifts to the left with increasing sintering temperature, due to the diffusion of Al from Ti_3AlC_2 into the copper matrix. This is supported by EDS results from points 1 to 5, which show that as the sintering temperature increases from 800 °C to 1000 °C, the Al content in the copper matrix rises from 14.63 At% to 19.27 At%. Notably, at 800 °C and 850 °C, the Ti content in the copper matrix is relatively low, at 2.52 At% and 2.73 At%, respectively. However, with rising temperature, the Ti content increases rapidly, reaching 10.50 At% at 1000 °C. Thus, at lower sintering temperatures (800 °C and 850 °C), Ti_3AlC_2, primarily decomposes into Ti_3C_2 with minimal Ti diffusion into the copper matrix. In contrast, at temperatures above 900 °C, Ti_3AlC_2 decomposes into TiC, resulting in a larger amount of Ti diffusing into the copper matrix.

Figs. 2 (b)-(e) show the micromorphology of CTCS sintered at different temperatures. It can be observed that Ti_3AlC_2 particles are uniformly distributed within the CTCS structure. This uniform distribution is attributed to the well-coated copper layer on the surface of Ti_3AlC_2. Due to insufficient diffusion at a sintering temperature of 800 °C, a few pores are present in the copper matrix of CTCS, as indicated by the red arrow in Fig. 2 (b). Additionally, there are some cracks in the Ti_3AlC_2 particles, caused by the fracture of Ti_3AlC_2 during the pressing process, as indicated by the blue arrow in Fig. 2 (b). However, as the sintering temperature increases, diffusion between powders is enhanced, leading to a gradual reduction in pores within the copper matrix and a decrease in cracks in Ti_3AlC_2, as shown in Figs. 2 (c)-(f). Moreover, the light gray areas surrounding Ti_3AlC_2 particles increase with the sintering temperature, which are attributed to the in-situ decomposition of Ti_3AlC_2 into Ti_3C_2 or TiC. This phenomenon is consistent with the XRD results of CTCS shown in Fig. 2 (a).

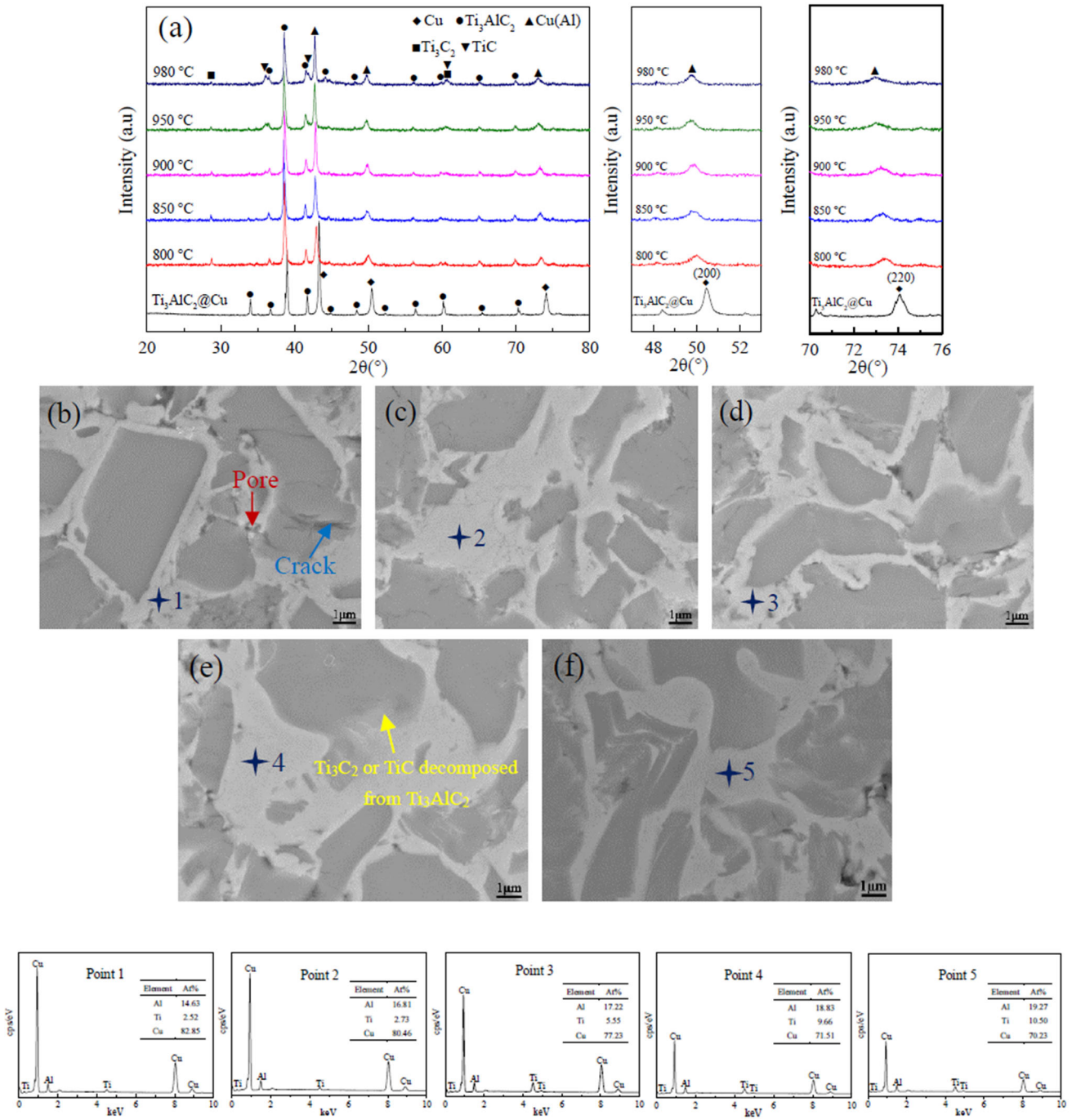

Figure 2. (a) The XRD pattern of CTCS sintered at different temperatures; (b)-(e) The micromorphology of CTCS sintered at different temperatures: (b) 800 °C, (c) 850 °C, (d) 900 °C, (e) 950 °C, (f) 1000 °C

Fig. 3 shows the properties of CTCS sintered at different temperatures. It can be found that the relative density of CTCS increases with the sintering temperature. When the sintering temperature rises from 800 °C to 1000 °C, the relative density of CTCS increases from 89.7% to 97.6%, as shown in Fig. 3(a). Besides, when the sintering temperature increases from 800 °C to 950 °C, the hardness of CTCS increases from 234.4 HV to 314.7 HV, due to an increase in relative density. However, when the sintering temperature is further increased to 1000 °C, the hardness of CTCS decreases to 301.1 HV. It is interesting that the compressive strength and strain capacity of CTCS increase with the sintering temperature, as shown in Fig. 3(b). When the sintering temperature gradually increases from 800 °C to 1000 °C, the compressive strength of CTCS increases from 266.8 MPa to 654.7 MPa, and the corresponding strain increases from 6.68% to 13.30%. The friction coefficient of CTCS sintered at different temperatures is between 0.3 and 0.6. When the sintering temperature is 950 °C, CTCS has a smaller friction coefficient, about 0.35, while at 1000 °C, CTCS has a higher friction coefficient, about 0.55, as shown in Fig. 3(c). The wear rate of CTCS first decreases and then increases with the sintering temperature. When the sintering temperature is 950 °C, CTCS has the lowest wear rate of 1.08×10^{-7} $mm^3/N\cdot m$, as shown in Fig. 3(d).

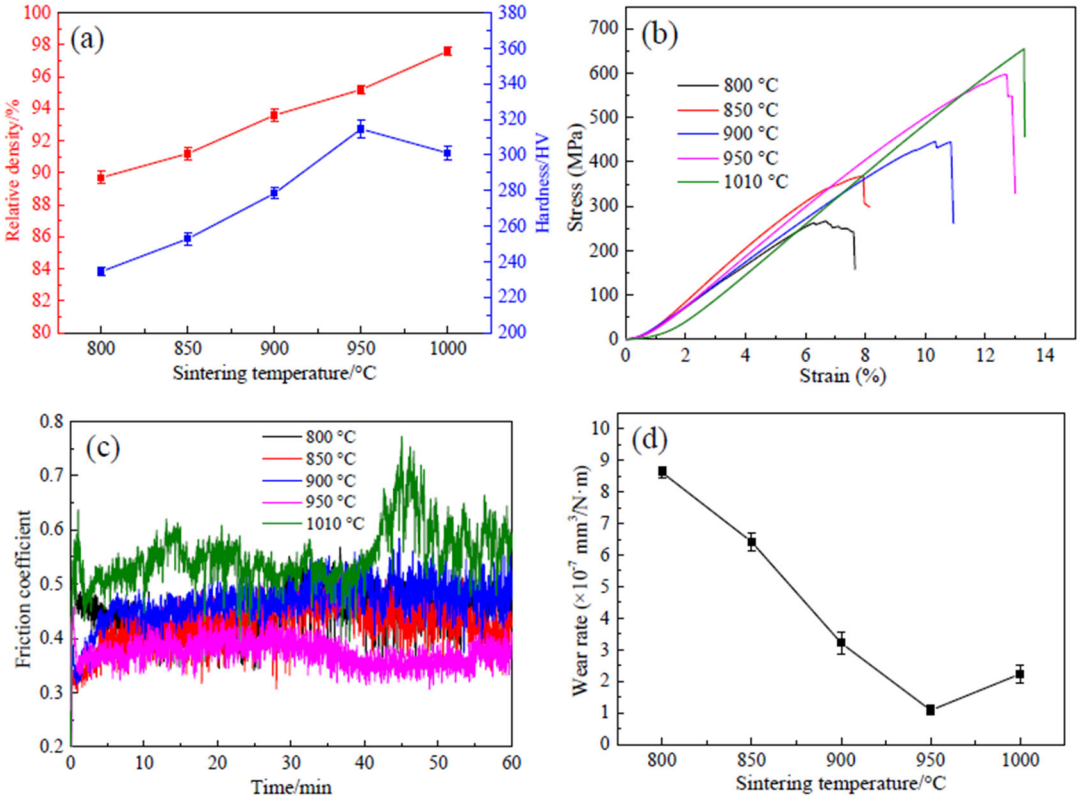

Figure 3. The properties of CTCS sintered at different temperatures: (a) Relative density and hardness, (b) Compressive stress-strain curve, (c) Friction coefficient, (d) Wear rate

4. Conclusions

In order to obtain CTCS with high density and high Ti_3AlC_2 content, Cu-coated Ti_3AlC_2 powder was prepared by rotating electroless plating method, and then CTCS were prepared by sintering at different temperatures. The conclusions are as follows:

(1) Due to the enhancement of diffusion, the relative density and compressive strength of CTCS increase with the sintering temperature, and they can reach 97.6% and 654.7 MPa, respectively, at a sintering temperature of 1000 °C.

(2) The decomposition degree of Ti_3AlC_2 increases with sintering temperature, and the decomposition products tend to be Ti_3C_2 at lower sintering temperatures (800 and 850 °C) but TiC at sintering temperatures above 900 °C.

(3) When the sintering temperature is 950 °C, the hardness and tribological properties of CTCS are better, with the hardness value, friction coefficient, and wear rate being 314.7 HV, 0.35, and 1.08×10^{-7} $mm^3/N\cdot m$, respectively.

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