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Sintering densification and properties of Al_2O_3/Al cermet materials via powder metallurgy method

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Cermet materials are important new engineering materials with combined advantages of ceramics and metals. In this study, Al_2O_3/Al cermet materials were prepared through powder metallurgy. The effect of sintering technology on the properties of Al_2O_3/Al cermet materials was analyzed as basis for preparing high-performance cermet materials. Results showed that when the sintering temperature was increased from 700 °C to 1000 °C under holding time for 1 h, the densification degree and hardness of Al_2O_3/Al cermet materials decreased and the electric resistivity increased. In the microstructure of Al_2O_3/Al cermet materials, Al particles were larger and continuously distributed, whereas the Al_2O_3 particles were smaller and discontinuously distributed. When the holding time was increased under sintering temperature of 700 °C, the densification degree and hardness of Al_2O_3/Al cermet materials also increased, and the electric resistivity decreased. When 25 wt% Al_2O_3/Al cermet materials were sintered at 700 °C for 3 h, the densification degree was higher, with hardness of 2203 HV and electric resistivity of 0.0159 Ω • m.

Key words: Cermet materials, Alumina, Aluminum, Sintering densification, Electric resistivity.

Introduction

Cermet is a heterogeneous composite material, composed of metal or alloy and one or more ceramic phases, wherein the latter accounts for about 15%-85% of the volume of the material. When prepared at a certain temperature, the metal and ceramic phases dissolve extremely weak [1-3]. Cermet ceramic maintains to be extremely hard, wear-resistant, corrosion-resistant, heat-resistant, oxidation-resistant, and chemically stable, whereas its metal material allows it to be extremely strong, tough, and thermally and electrically conductive; non-metallic composition makes the ceramic–metal composites extremely hard, thermally strong, and wear-resistant; solid particles in cermet, combined with the metal phase, provides high strength and plasticity, thereby creating a high-performance engineering material [4-5]. The performance of ceramic-metal composites depends on the properties of the metal and ceramic, their volume percentages, bonding properties, and bonding strength of the phase interface [6-7].

As one of the most widely used ceramic materials, alumina ceramic, which has abundant raw materials, is extremely strong and hard, less dense, and chemically stable. However, its brittleness hinders its application. Strong metal toughening of alumina ceramic is the most commonly used technical means. Aluminum (Al)-based composite material is based on Al or Al alloy as the matrix and its fiber or particle as a reinforcement of the homogeneous mixture, with highly specific strength, specific modulus, fatigue resistance, extreme toughness and impact resistance, high temperature, excellent wear resistance and more. Al_2O_3/Al metal-ceramic matrix composites are lightweight, extremely strong, ductile, tough, and aluminum-processed; alumina ceramics are extremely strong, hard, heat-resistant, wear-resistant, corrosion-resistant, and chemically stable; therefore, the Al_2O_3/Al metal matrix composites in the modern industrial production have an increasingly important role [8-10]. In this paper, the compactness of Al_2O_3/Al cermet was improved for the development of its wear resistance and low thermal conductivity characteristics.

Experimental Materials and Methods

The raw materials used for the experiment were Al powder, produced by Tianjin Kemico Chemical Reagent Co., Ltd., with an average particle size of 40 μm and an analytical grade of pure Al_2O_3 powder, produced by Shanghai 54 Chemical Reagent Factory, with an average particle size of 10 μm. To make a batch, 25% of Al_2O_3 powder and 75% of Al powder were mixed

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on a mixer at 100 r/min for 2 h, and the agate ball was used as the milling medium. The mixed powder was dry pressured into Ø 10 × 10 mm mold at 10 MPa for 15 min. The molded sample was placed into the ZT-50-22 vacuum sintering furnace using different sintering processes for densification. The sintered sample is prepared into a rectangular parallelepiped, placed vertically when inlaid, and coarsely ground on both upper and lower surfaces of the embedded sample, so that the cermet is exposed on both surfaces of the embedded sample, and finally polished for use. The microstructure of the sample was observed with TESCAN VEGA II scanning electron microscope. The surface hardness of the sample was measured by HV-1000 Vickers hardness tester. The Electric resistivity of the sample was measured by CHT3540 DC resistance tester.

Results and Discussion

Sintering Densification of Al_2O_3/Al Cermet Materials

Table 1 shows the relative density of Al_2O_3/Al cermets prepared under different sintering conditions. The microstructure of Al_2O_3/Al cermets prepared at different sintering temperature for 1 h is shown in Fig. 1. As shown in Tab.1, the sintering temperature gradually rose from 700 ºC to 1000 ºC, and in the microstructure of Al_2O_3/Al cermets, the degree of densification gradually reduced. As shown in Fig. 1, the particles, which were larger and continuously distributed, were metal Al,

Table 1. Relation density of prepared sample under different sintering temperatures.

Temperature /ºC	700	700	700	800	900	1000
Holding time/h	1	2	3	1	1	1
Relative density/%	92.52	95.18	96.21	90.59	87.46	85.27

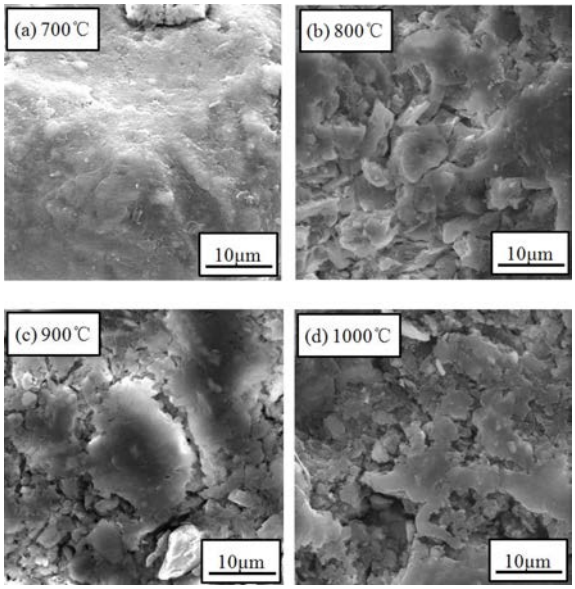

Fig. 1. Effect of sintering temperature on the microstructure of Al/Al_2O_3 metal ceramics.

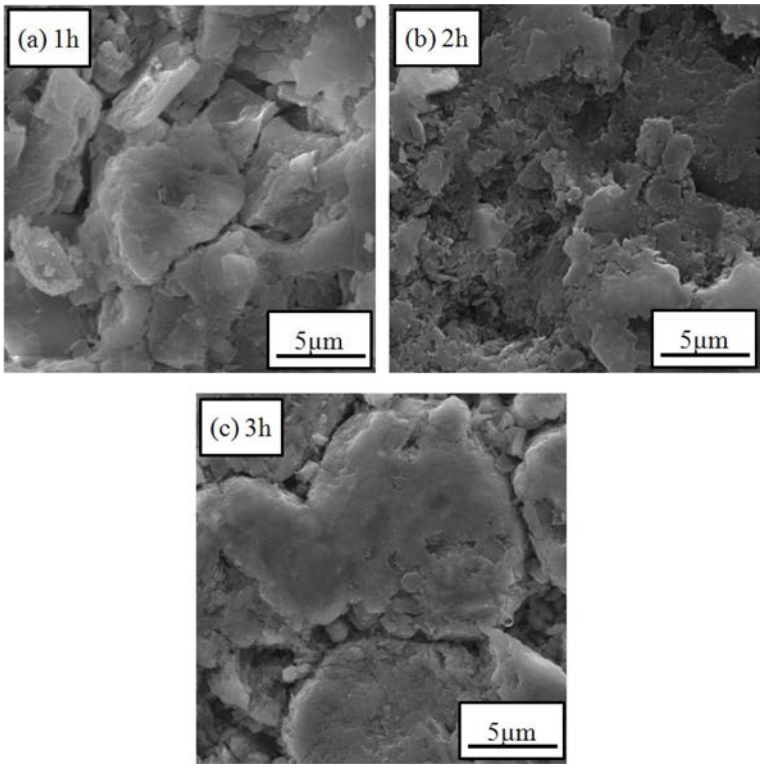

Fig. 2. Effect of holding time on the microstructure of Al_2O_3/Al metal ceramics.

distributed, were Al_2O_3. The Al particles served as the matrix phase, and the Al_2O_3 particles served as the enhanced phase. As the temperature rose from 700 ºC, the densities decreased. Because the melting point of Al was 660 ºC and the melting point of Al_2O_3 was 2,050 ºC [11-12] above sintering, Al powder completely melted, while the Al_2O_3 powder did not. The powders bonding along the way without sintering densification were combined loosely. In this case, Al was a dense phase relative to Al_2O_3, and Al_2O_3 was a non-dense phase relative to Al. The melted Al enveloped the Al_2O_3 powder to form an Al-based cermet. Al content in higher cases could fully wrap Al_2O_3, which formed a more continuous distribution of the block, resulting in a higher density of the organizational structure. The Al was set to 700 ºC just over its melting point to ensure that the Al was both molten and suitable. Therefore, as the temperature increased, the more compact and the more mobile the Al was. This phenomenon is due to the vacuum sintering of negative green body pressure being more negative, making molten Al precipitation easier and subsequently resulting in a looser microstructure of the metal ceramics.

The microstructure of Al_2O_3/Al cermet obtained by sintering at 700 ºC for different time periods is shown in Fig. 2. As shown in Tab.1, the microstructure of Al_2O_3/Al metal ceramics was denser as the holding time was prolonged. The reason is that in the case of a certain sintering temperature, the amount of molten Al in the body is almost constant. With longer holding time, the Al liquid has enough time to enter the pores for filling for metal ceramic densification, as depicted in Fig. 2.

Hardness of Al_2O_3/Al cermet materials

Table 2 shows the results of the hardness tests of Al_2O_3/Al cermets with different sintering temperatures for 1 h. Tab.2 shows that the sintering temperature gradually increased from 700 ºC to 1000 ºC, and the hardness of Al_2O_3/Al cermets gradually decreased. The reason is that the hardness tested is the surface hardness, which depends on the density of the sample to some extent; thus, the tendency of the change is consistent with that of the microstructure of the Al_2O_3/Al cermet.

Table 3 shows the hardness test results of Al_2O_3/Al cermets with sintering temperature of 700 ºC under different holding time conditions. At 700 ºC, the longer the holding time, the higher the hardness value. With prolonged holding time, the melted Al fully encapsulated the alumina and formed a relatively continuous distribution of the blocks, resulting in a higher density of the organizational structure, thereby increasing the hardness.

Electric resistivity of Al_2O_3/Al cermet materials

Table 4 shows the results of the electric resistivity measurements of Al_2O_3/Al cermets obtained by holding at different sintering temperatures for 1 h. The electric resistivity of Al_2O_3/Al cermets gradually increased as the sintering temperature gradually increased from 700 ºC to 1000 ºC. Because of the low electric resistivity of Al and the high resistivity of alumina, the higher the temperature, the more suitable for Al melted at 700 ºC to form a continuous distribution of blocks with a high degree of densification of the microstructure. As a result, the resistance at a lower rate allowed the temperature of sintering samples to remain due to the worse degree of microstructure densification, resulting in higher resistivity.

Table 5 shows the Al_2O_3/Al cermet electric resistivity test results with sintering temperature of 700 ºC under different holding time conditions. At 700 ºC, the longer the holding time, the lower the rate of the electric resistance of Al_2O_3/Al cermet, which shows that with longer holding time, the resistivity decreased and the electrical properties improved. As the holding time prolonged, the melted Al fully encapsulated the alumina and formed a relatively continuous distribution of blocks, resulting in a higher density with high organizational structure and subsequently improved the electrical properties.

Table 2. Hardness of prepared sample under different sintering temperatures.

Temperature/ºC	700	800	900	1000
Hardness/HV	2056	824	647	503

Table 3. Hardness of prepared sample under different holding time conditions.

Holding time/h	1	2	3
Hardness/HV	2056	2125	2203

Table 4. Electric resistivity of prepared sample under different sintering temperatures.

Temperature /ºC	700	800	900	1000
Electric resistivity /Ω·m	0.0452	0.0547	0.0701	0.1099

Table 5. Electric resistivity of prepared sample under different holding time conditions.

Holding time/h	1	2	3
Electric resistivity /Ω·m	0.0452	0.0214	0.0159

Conclusions

To sum up, the microstructure densification degree of Al_2O_3/Al cermet decreases gradually as the hardness decreases and the electric resistivity increases under sintering temperature from 700 ºC to 1000 ºC for 1 h. In the microstructure of Al_2O_3/Al cermet materials, the Al particles are larger and continuously distributed, whereas the Al_2O_3 particles are smaller and discontinuously

distributed. At 700 °C with prolonged holding time, the microstructure becomes denser, and a higher hardness indicated lower electric resistivity. When sintered at 700 °C for 3 h, a 25 wt% of Al_2O_3/Al cermet was obtained. The microstructure densified to a high degree with a hardness of 2203 HV and a electric resistivity of 0.0159 Ω • m.

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