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Fabrication and properties of Al_2O_3-Al cermet materials using different raw material composition parameter

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Cermet application is extensive because it retains the characteristics of ceramic materials and has the advantages of metal materials. In this paper, alumina/aluminum cermet materials were prepared through powder metallurgy method. The influence of raw material formula on the properties of alumina/aluminum cermet was investigated on the basis that ceramic materials have good wear resistance and high thermal conductivity. Results show that when the mass ratio of alumina to aluminum is 1:3, the prepared cermet samples have excellent properties, highest density, and uniform distribution of aluminum and alumina. MgO addition exhibits better effect, higher degree of densification, and renders higher hardness and strength for the sample as compared with SiO_2 and Y_2O_3 addition. The sintered cermet with composite powder prepared via precipitation has better properties and higher densities and surface hardness than that prepared via the ball mill method. The relative density was 97.1%, surface hardness was 875 HV, and electric resistance was 0.0169 Ω·m.

Keywords: Cermet materials, alumina, aluminum, raw material, electric resistivity.

Introduction

Cermet is a heterogeneous composite material composed of metal or alloy and one or more ceramic phases, in which the latter accounts for approximately 15 ~ 85% of material volume. When prepared at a certain temperature, cermet's metal and ceramic phases are weakly dissolved [1-3]. The ceramic part of cermet makes it extremely hard, wear, corrosion, heat, and oxidation resistant, and chemically stable, and its metal composition makes it very strong, tough, thermally and electrically conductive, the solid particles in cermet combined with the metal phase provide its high strength and plasticity and make it 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 components, alumina ceramic is an abundant raw material that is extremely strong and hard, less dense, and chemically stable. However, its brittleness hinders its application. Strong metal toughening is most commonly used for alumina ceramic. Aluminum (Al)-based composite has Al or Al alloy as the matrix and its fiber or particle as a reinforcement of the homogeneous mixture. This material has highly specific strength, specific modulus, fatigue resistance, extreme toughness and impact resistance, high temperature, and excellent wear resistance. 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 preparation of cermet through the preparation of sintered powders can significantly improve the sintering densification effect and the uniform distribution of the reinforcing phases. the compactness of Al_2O_3/Al cermet was improved to enhance its wear resistance and low thermal conductivity.

Experimental Materials and Methods

The raw materials were Al powder, analytically pure Al_2O_3 powder, aluminum nitrate nonahydrate crystal, and ammonia water. Al_2O_3 powder, Al powder and 5

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wt.% sintering aid were mixed in a ball mill at a mixing speed of 100 rpm and mixing time of 2 h. One composite material was prepared through the mechanical method, and another through coprecipitation. The weighed Al powder was poured into deionized water and stirred with a stirrer to form suspension slurry. An aluminum nitrate solution configured with aluminum nitrate nonahydrate crystals was dropped by a precipitation method. Ammonia water was added in the suspension of Al powder, and the pH value of the suspension was maintained at 9 at all times. After the titration of the aluminum nitrate solution, stirring was continued for 1 h. The suspension was filtered, washed three times with deionized water, washed once with anhydrous ethanol, and finally dried to obtain a composite powder, and set aside. The composite powder prepared through precipitation was added with a 5 wt.% sintering aid. A ball mill mixture was used to obtain another composite raw material, which was reserved for further analysis. The mixed powder was placed in a Φ20 mm × 10 mm mold and dried at 60 MPa. After formation, the blank was placed in a vacuum carbon tube furnace for high-temperature sintering. The sintering temperature was 800 °C, the holding time was 2 h, and the heating rate was 5 °C/min. The sintered sample was surface polished on a metallographic polisher for further use. The sintered sample was subjected to density test using a BSA224S-CW type electronic balance, and the density of the sample was calculated by the relationship with the theoretical density. The surface hardness of the sample was tested by the HV-1000 type Vickers hardness tester, using TESCAN VEGA II. The microstructure and volume resistivity of the sample were observed and measured using scanning electron microscopy and CHT3540 DC resistance tester, respectively.

Results and Discussion

Effect of aluminum content on properties of Al_2O_3-Al cermet materials

Fig. 1 shows the macroscopic morphology of the alumina/aluminum cermet material sample. Fig. 1a reveals that the surface of the sample has defects, and the edge portion has a missing angle. The integrity of the sample is not high, indicating that the bonding strength between the aluminum and alumina particles is not high, and the strength of the sample is low. The overall integrity of the sample is high (Fig. 1b), indicating a high bond strength between the aluminum and alumina particles. A defect is found in the edge of the sample (Fig. 1c), indicating low strength of the sample and low bonding strength between the aluminum and alumina particles. Adopting dry pressing technology, due to uneven force or small force at the corners, it is easy to reduce the density of the corners and corners. The effect of raw material ratio on the density and surface hardness of Al_2O_3-Al metal ceramic materials is shown in Fig. 2. When the aluminum content in the raw material increases, the density of the cermet increases first and then decreases. Surface hardness is greatly related to the hardness of the material. The influence of density on surface hardness is direct and important [11-13]. Therefore, the surface hardness of the cermet material also shows a trend of increasing first and then decreasing. When the alumina/aluminum

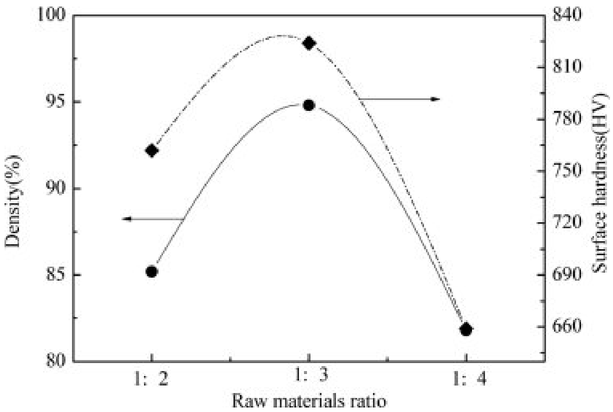

Fig. 2. Effect of raw materials ratio on the density and surface hardness of materials.

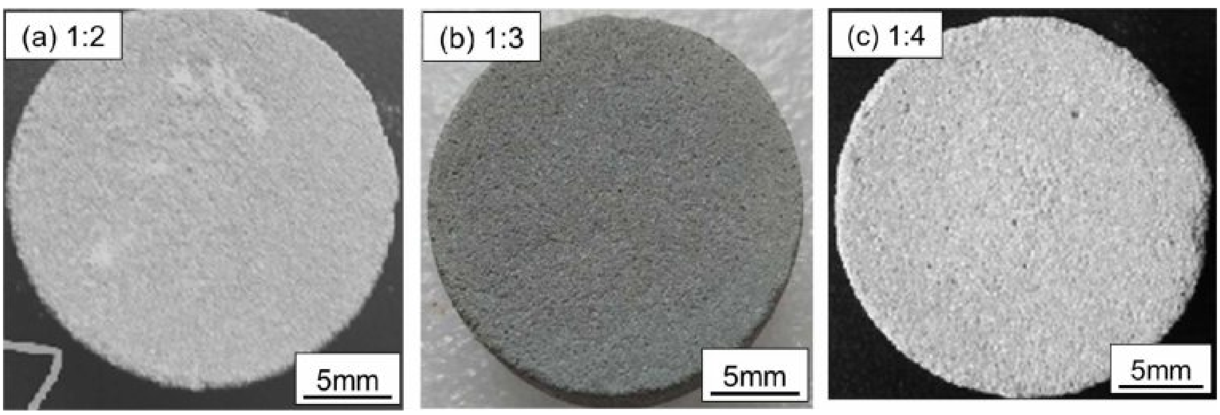

Fig. 1. Effect of raw materials ratio on the surface topography of materials.

raw material ratio is 1:3, the material has the highest compactness at density reaching 94.8% and highest surface hardness among the three ingredients. The microstructure of the sample is analyzed and shown in Fig. 3. The internal pores of the sample can be seen. When the ratio of raw materials is 1:3, the distribution of aluminum and alumina is uniform, the size of the powder is uniform, and the internal density is high, indicating that the bonding strength between alumina and aluminum is high. The hardness and strength of the sample.

Effect of sintering aid on properties of Al_2O_3-Al cermet materials

Fig. 4 shows that the surface of the sample has good flatness. The aluminum and alumina powders have high bonding strength, hardness, and strength. The surface of sample b has defects. The occurrence of delamination cracking indicated that the bonding strength and surface hardness of sample a are not high, and the toughening effect of SiO_2 as a sintering aid on cermet is poor. Compared with sample a, sample c has low surface flatness, and low strength, indicating that the toughening effect of Y_2O_3 is not as good as that of MgO.

Fig. 4 shows that adding a sintering aid can significantly increase the sintering density of the sample. With the sintering aid, the sintering activity of the surface of the alumina and aluminum powder particles can be improved during the sintering of the green body; hence, the sintering neck between the particles is easily formed, and the sintering aid is added to reduce the minimum eutectic point of the sample [14, 15]. Under the same temperature conditions, the amounts of particles migrating to the sintered neck increases, and the ability to eliminate pores between the particles is enhanced in the green body. The sintering aid can improve the cohesiveness between the alumina and aluminum particles to ensure that they are bonded by effective grain boundary substances [16, 17], thus promoting the reduction of porosity and increasing the alumina/aluminum ratio. The densification degree of the cermet material is shown in Fig. 5. The surface hardness of the material increases with its density. Fig. 5 and 6 show that the sintering effect of MgO is better than that of SiO_2 and Y_2O_3; the sample with MgO has higher hardness and strength and better densification degree than those with SiO_2 and Y_2O_3. The surface hardness is 824 HV, and the density is 94.8%. Fig. 7 shows that the samples added with the sintering aid have high densities and less pores in their microstructure. Moreover, the samples with sintering aid have a wrapping structure, indicating that the grain boundary particles migrate during sintering, the grain boundary is

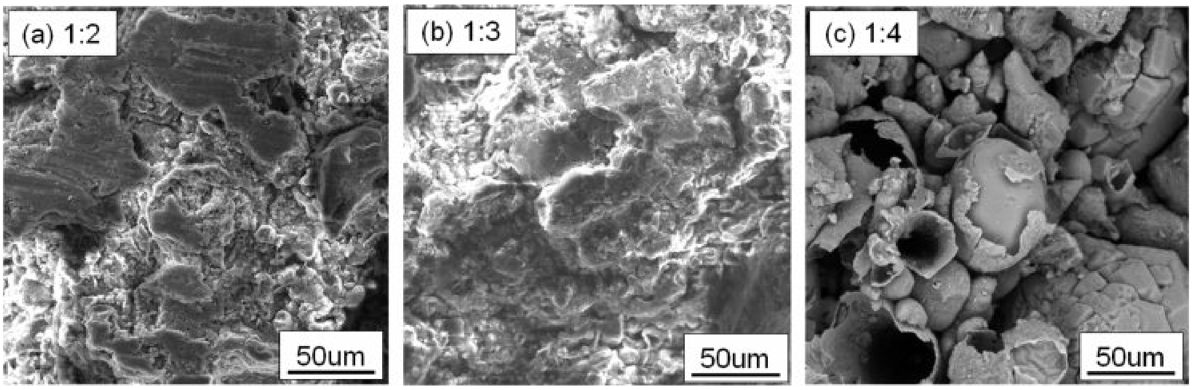

Fig. 3. Effect of raw materials ratio on the microstructure of materials.

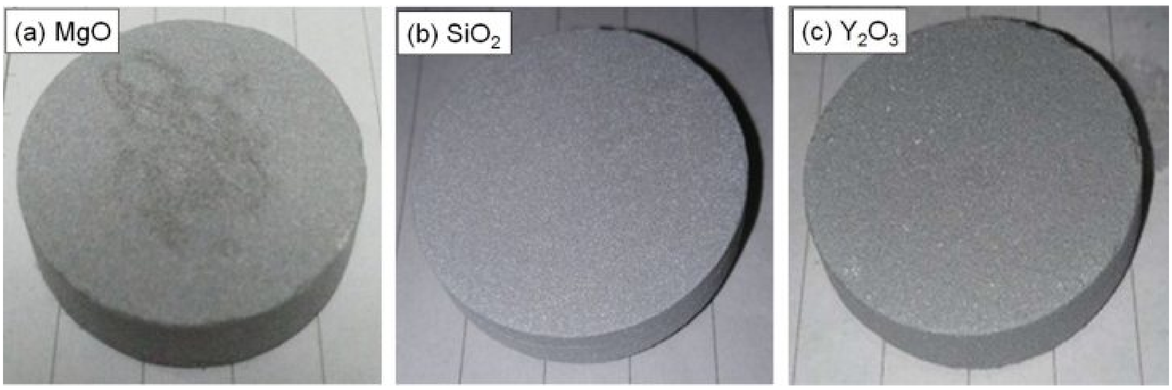

Fig. 4. Effect of sintering aids type on the surface topography of materials.

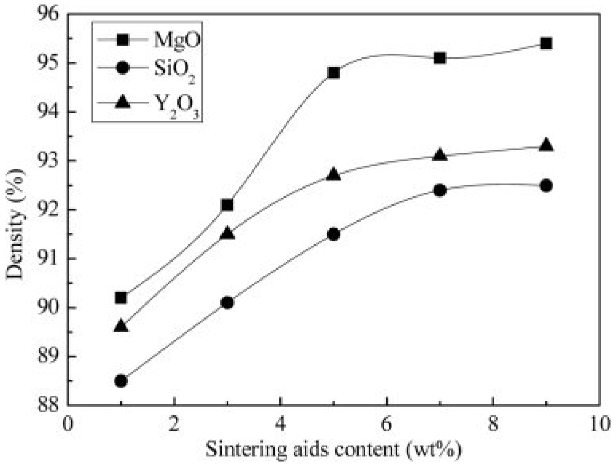

Fig. 5. Effect of sintering aids on density of materials.

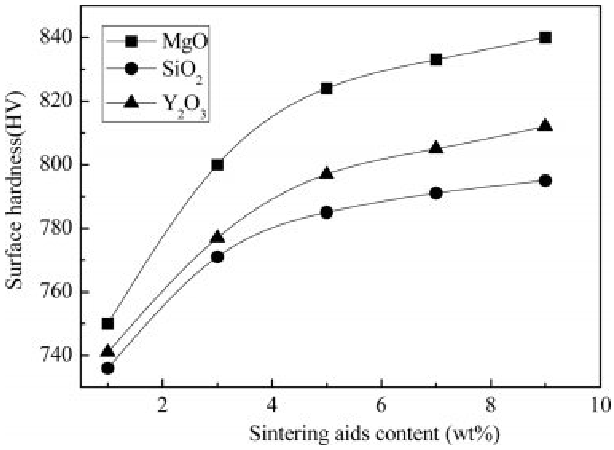

Fig. 6. Effect of sintering aids on surface hardness of materials.

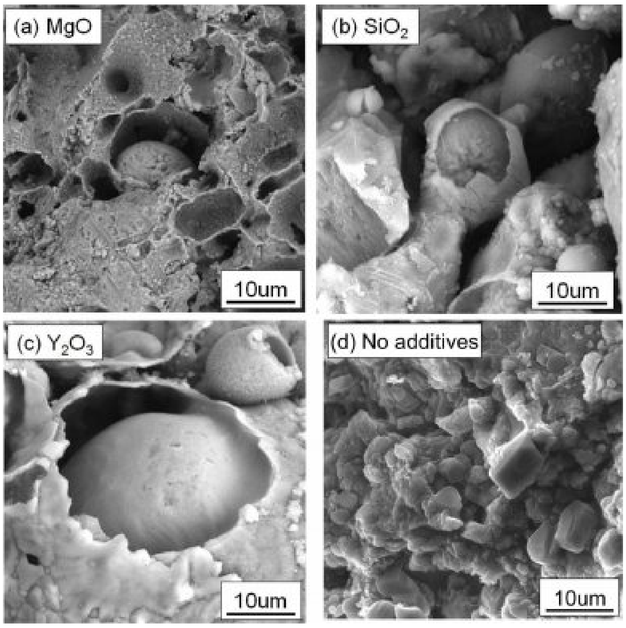

Fig. 7. Effect of sintering aids on the microstructure of materials.

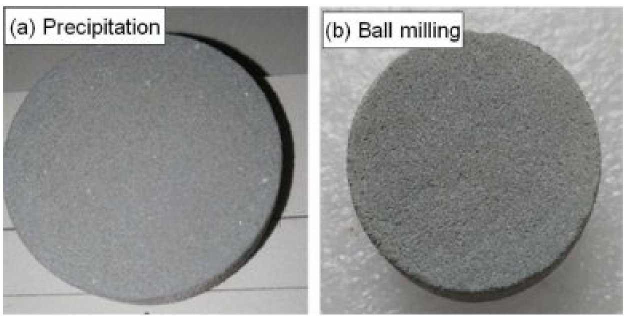

Fig. 8. Effect of raw materials type on the microstructure of materials.

coated, and the particles are effectively bonded to the particles, thereby lifting the sample.

Effect of raw material types on properties of Al_2O_3-Al cermet materials

Fig. 8a shows the materials sintered using the composite powder prepared through chemical precipitation, and Fig. 8b displays the materials sintered using mixed aluminum and alumina powders via the ball mill method. The composite powder is prepared with a stable mass ratio of alumina to aluminum of 1:3. According to the comparison of Fig. 8a and b, the surface of the sample in Fig. 8a is flatter, and the sample is intact without defects. No cracking or delamination occurs, no pores are found on the surface, and the sample is no powder drop after demolding and sintering. These findings indicated that the bonding strength of aluminum powder and alumina powder in the sample is high, which is reflected in the hardness test data. As shown in Table 1, the voids are high in the material due to the low density, thus resulting in the high resistivity and conversely low resistivity of the metal. The alumina powder coated on the surface of the aluminum powder by the precipitation method has a finer particle size, a more uniform coating, and a lower driving force for sintering. Sintering under the same conditions can make the cermet densification better. However, fine pores are found on the surface of the sample in Fig. 8b, the distribution range is relatively wide, the surface flatness is not high, and the density is relatively low. Fig. 9 shows that the alumina particles in the sample of Fig. 9a are fine and have a uniform size and distribution around the large particles; in addition, the filling ability is strong, the sintering activity is high, and the degree of material compactness is high [18-20]. Given that the

Table 1. The properties of materials using different raw materials type.

Type	Precipitation method	Ball mill method
Density(%)	97.1	94.8
Surface hardness (HV)	875	824
Electric resistance (Ω·m)	0.0169	0.0371

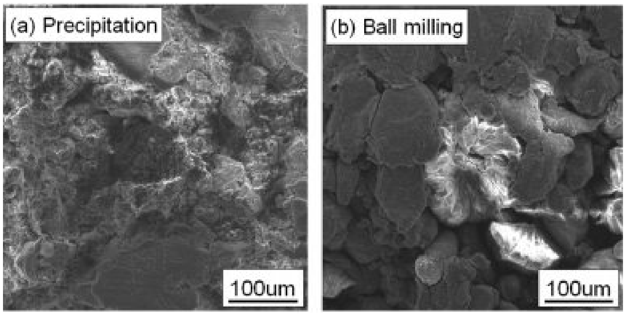

Fig. 9. Effect of raw materials type on the microstructure of materials.

fine alumina particles can be uniformly distributed around the aluminum particles, the surface hardness of the sample is high. The sample in Fig. 9b is a powder that can be directly purchased from the factory. The uniformity of the powder particles is poor, the particle size is large, the sintering property of the particles is relatively poor, and the filling ability between particles is poor. The microstructure also shows that a part of the void remains inside the material and forms pores, resulting in a decrease in the density and surface hardness. The surface hardness of die-cast aluminum is about 120. By adding alumina powder to enhance the surface hardness, the surface hardness can reach more than 800. It can be seen that the enhancement effect is quite obvious.

Conclusion

The following conclusions were obtained, the density of the cermet is increased first and then decreased with an increasing the ratio of raw material aluminum, the surface hardness shows a similar trend. When the mass ratio of alumina to aluminum is 1:3, the prepared cermet is intact. The better properties, density, and surface hardness of cermet are obtained using this ration, and aluminum and alumina are evenly distributed. MgO as a sintering aid has better sintering densification than SiO_2 and Y_2O_3, thereby the cermet shows the better excellent densification degree and high hardness. The cermet with composite powder prepared through precipitation has better performance than that prepared by ball milling method. The internal alumina particle size is fine and uniform, and the density and surface hardness are higher. The density is 97.1%, the surface hardness is 875 HV, and the electric resistivity is 0.0169 Ω·m.

Acknowledgments

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