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Preparation and properties of coated silica/aluminum cermet materials via powder metallurgy method

Jieguang Song[a,b,*], Yue Liu[b], Chunxiao Wu[a,*], Xueqing Yang[b], Huihui Luo[b], Chunyan He[b], Chengbin Li[b] and Haizhen Yang[b]

[a]*Engineering Technology Research Center for Sponge City of Pingxiang City, Pingxiang University, Pingxiang 337055 China*
[b]*Key laboratory for Industrial Ceramics of Jiangxi Province, School of Materials and Chemistry Engineering, Pingxiang University, Pingxiang 337055 China*

Cermet is a combination of metal and ceramic, it exhibits some special properties, so it is one of the most widely used engineering materials. In this paper, the properties of encapsulated SiO_2/Al cermet were prepared by powder metallurgy method. Results showed that the density of SiO_2/Al cermet is increased with an increasing Al content. When the Al content is high, and the high temperature is sintered, the liquid phase can fully bond the surrounding SiO_2 particles to form a relatively continuous and dense structure, thereby obtaining a high microstructure density. When the SiO_2:Al ratio is increased from 1:1 to 1:3, the hardness is gradually increased. The hardness and density of the sample are gradually increased with an increasing molding pressure. The surface hardness of the cermet is increased first and then decreased with an increasing sintering temperature. When the SiO_2:Al ratio is 1:3, the holding time is 10 min under molding pressure of 15 MPa, and the sintering temperature is 900 °C for 1 h, the surface hardness of the obtained coated SiO_2/Al cermet is high, the value is 175.2 HV.

Keywords: Cermet, aluminum, silica, surface hardness, powder metallurgy method.

Introduction

With the development and technological advancement of aerospace, electronics, automotive and other industries, the performance requirements for engineering materials are gradually increasing, and it is urgent to develop new materials with better performance [1-3]. Given that cermets are a combination of metals and ceramics, cermets exhibit several special properties. The properties of ceramic–metal composites depend on the metal and ceramic properties, the volume percentage of the two, the bonding properties, and the bonding strength of the phase interface. The solid particles in the cermet are combined with the metal phase to increase the strength and plasticity of the cermet. Cermet is an engineering material with excellent properties, and Al is one of the representative engineering materials [4-6].

SiO_2 ceramics have many excellent properties such as low thermal conductivity, low thermal expansion coefficient, low density, and good volume stability, which make them ideal for lightweight insulation. The SiO_2 material has a light weight and small volume to achieve the same thermal insulation effect. This feature account for the advantages of SiO_2 ceramic materials in aviation and aerospace [7-9].

The difference in melting point between SiO_2 and Al is relatively large. Thus, generally, using a conventional powder metallurgy process to make the obtained second phase Al particles small in size and uniform in distribution is difficult [10-11]. Preparation of coated composite powder by coating aluminum powder with silicon oxide by ball milling method is beneficial for uniformly dispersing silicon oxide in the cermet, uniformly improving its mechanical properties, and effectively regulating the conductivity of the cermet. Therefore, SiO_2 and Al powders were mixed according to certain ingredients, and ball milling is carried out in a ball mill by different ball milling processes to obtain composite powder with improved performance, which provides reference for the preparation of high-performance SiO_2/Al cermet.

Experimental Materials and Methods

The raw materials used in the experiment were pure Al powder (average particle size of approximately 50 μm) and analytically pure SiO_2 powder (average particle size of approximately 5 μm). A certain proportion of SiO_2 powder was mixed with Al powder, ceramic ball was used as ball milling medium, and the mixed powder was placed in a ball mill jar and placed on a GMS5-8 horizontal ball mill at a speed of 360 r/min for 6 h to obtain a package type. SiO_2/Al composite

*Corresponding author:
Tel : +86 799 6682178
Fax: +86 799 6682171
E-mail: sjg825@163.com (J. G. Song)
2974716855@qq.com (C.X. Wu)

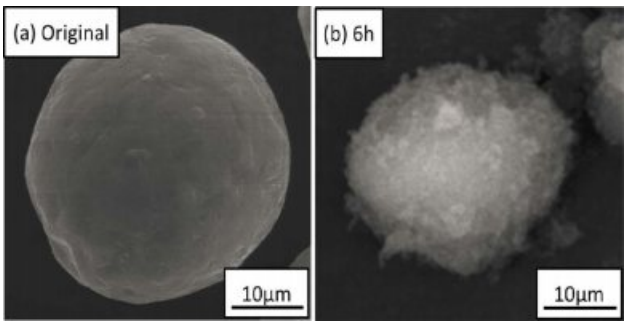

Fig. 1. Microstructure of Al and SiO_2/Al composite powder.

powder (Fig. 1) was ready for use. The packed SiO_2/Al composite powder was obtained by a dry pressing method by using a YP-15A powder tableting machine to obtain a blank with the size of Ø30Í10 mm, and the blank was placed in a corundum crucible and coated with alumina powder. The blank is embedded, and then buried in a SGM-2882SA high-temperature furnace to obtain a cermet material for use. SU8010 field-emission scanning electron microscope was used to observe the microstructure of composite powder and cermet samples. The density of the cermet samples was measured by the Archimedes principle drainage method via BSA224S-CW density balance. HVS- the surface hardness of the cermet sample was measured by a 1000 microhardness tester.

Results and Discussion

Effect of molding pressure on properties of SiO_2/Al cermet materials

Table 1 and 2 show that as the molding pressure increases, the surface hardness and the density of the cermet gradually increase. The effect of molding pressure on the microstructure of SiO_2/Al cermet material can be seen from Fig. 2. When the molding pressure is 5 MPa, the gap between the two phases becomes increasingly large (Fig. 2(a)). When the molding pressure is 15 MPa, the cermet particles are tightly bonded, with relatively few gaps and high density (Fig. 2(c)) because

Table 1. Hardness test of samples prepared by different forming pressure.

SiO_2:Al	Molding process		Sintering process		Hardness (HV)
1:2	5 MPa	10 min	800 ºC	1 h	84.2
1:2	10 MPa	10 min	800 ºC	1 h	114.3
1:2	15 MPa	10 min	800 ºC	1 h	119.5

Table 2. Density test of samples prepared by different forming pressure.

SiO_2: Al	Molding process		Sintering process		Density (%)
1:2	5 MPa	10 min	800 ºC	1 h	85.1
1:2	10 MPa	10 min	800 ºC	1 h	91.1
1:2	15 MPa	10 min	800 ºC	1 h	92.6

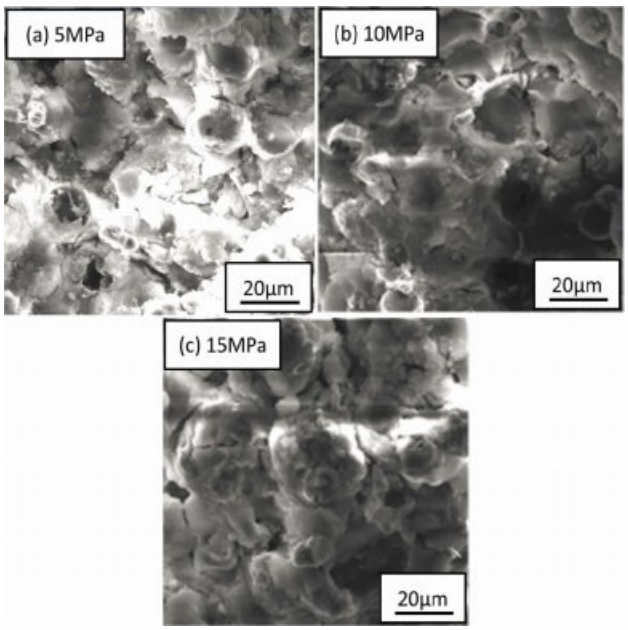

Fig. 2. Microstructure of SiO_2/Al cermet material prepared by different forming pressure.

when the cermet sample is sintered at a high temperature and the molding pressure is relatively small, the degree of tightness between the particles is small, the crack is easily generated at the interface, and the gas in the body is relatively high [12-15]. The smaller pressure of the surrounding particles is the more likely that the gas will overflow the body during the sintering process, thereby forming a porous gap in the body and reducing the density of the cermet. During the sintering process, the molten Al liquid phase will follow. The cavity flows out and collects on the surface of the blank. When the density is low, effect on the fluidity of the molten Al liquid phase is low, and the molten Al liquid in the outer flow is high, which cause the density to decrease. The density decreases, and the bonding strength between the particles and the particles decreases, which in turn increases the possibility of initiation and growth of cracks at the interface. On the contrary, when the molding pressure is large, the initiation of cracks at the interface is affected, the gas in the sample is low, and the pressure of the surrounding particles is larger During the sintering process, the molten Al liquid phase is not easily overflowed, and effect on density is low. At the same time, the fluidity of molten aluminum will be considerably hindered, thereby reducing the outflow of molten Al liquid phase, and the decrease in density. The bonding strength between particles is large, and the initiation and growth of cracks at the interface will be decreased.

Effect of sintering temperature on properties of SiO_2/Al cermet materials

When the SiO_2:Al ratio is 1:2, the forming pressure is 10 MPa, the holding pressure for 10 min, sintering

and heat preservation for 1 h, Table 3 shows the hardness test results of the sample after sintering at different sintering temperatures. With the increase in sintering temperature, the surface hardness of the cermet is first increased and then decreased. When the sintering temperature is 900 °C, the surface hardness of the cermet is the highest. As the sintering temperature increases, the degree of aluminum melting increases, and the amount of liquid phase in the body increases, thereby filling the pores between the particles [16-18], making the body denser (Table 4 and Fig. 3), and improving performance. When the sintering temperature is extremely high, the amount of liquid phase is exceedingly large, and the molten aluminum liquid is deposited on the surface of the green body (Fig. 3(c)), which in turn decrease the density of the green body, thereby a decreasing the surface hardness. Fig. 4 shows that the sintering temperature affects the surface morphology of the SiO_2/Al cermet material. When the sintering temperature is 800 °C, the bonding strength of the grains in the sample is low, and most of the particles remain in the state of the particles before sintering. However, several grains combine to form large particles, and most grains have additional cracks at the joints, thereby resulting in a sample that is not dense. At the same time, distinguishing SiO_2 particles from Al particles is impossible. When the sintering temperature is 900 °C, the combination of particles, the strength is relatively high, the interface is clear, and the sample is extremely dense. When the sintering temperature is 1,000 °C, the bonding strength of the particles is relatively high, the interface is uneven, the local area is relatively loose, and many cracks are observed at the interface. In summary, when the sintering temperature is 900 °C, the density of the sample after sintering is relatively good.

Table 3. Surface hardness of samples prepared at different sintering temperatures.

SiO_2 : Al	Molding process		Sintering process		Hardness (HV)
1:2	15 MPa	10 min	800 °C	1 h	119.5
1:2	15 MPa	10 min	900 °C	1 h	145.1
1:2	15 MPa	10 min	1,000 °C	1 h	91.0

Table 4. Density of samples prepared at different sintering temperatures.

SiO_2 : Al	Molding process		Sintering process		Density (%)
1:2	15 MPa	10 min	800 °C	1 h	92.6
1:2	15 MPa	10 min	900 °C	1 h	94.1
1:2	15 MPa	10 min	1,000 °C	1 h	80.5

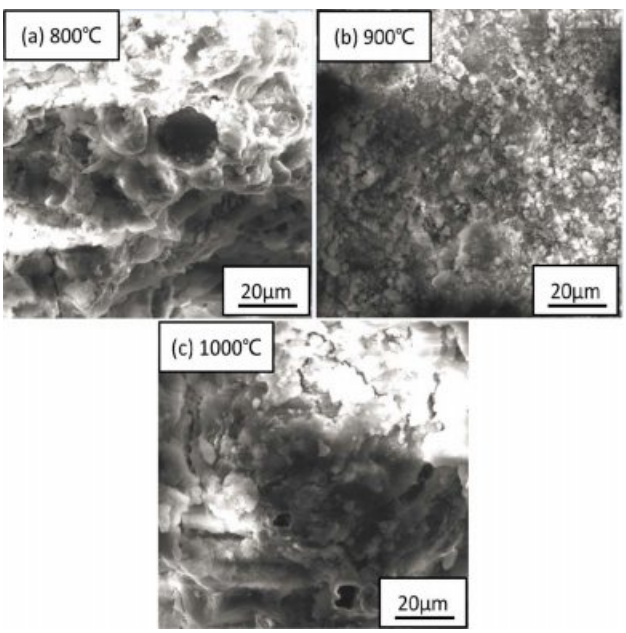

Fig. 3. Effect of sintering temperature on microstructure of SiO_2/Al cermet.

Effect of raw material ratio on properties of SiO_2/Al cermet materials

The results of the density test of the SiO_2/Al cermet material are shown in Table 5, Fig. 5 and Fig. 6 presents a XRD and SEM photograph of the cermet sample, respectively. Table 5 shows that as the Al powder content increases, the SiO_2/Al cermet material density gradually increases. It can be seen from Fig. 5 that the characteristic peaks of the Al after sintered

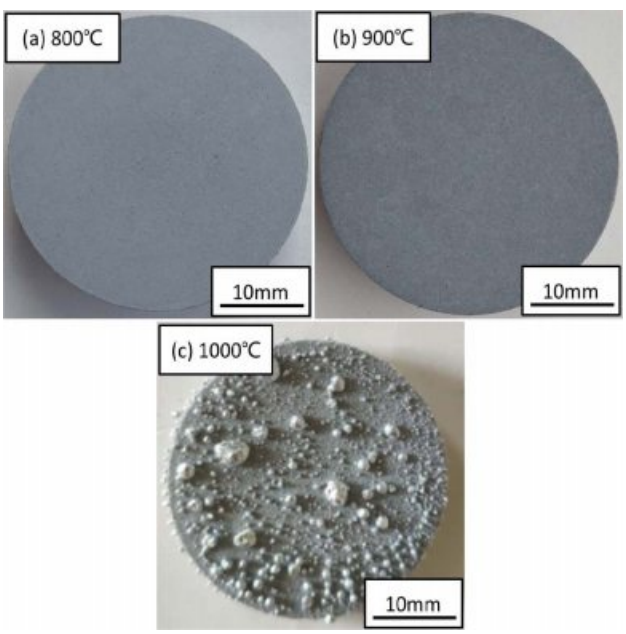

Fig. 4. Effect of sintering temperature on surface macroscopic morphology of SiO_2/Al cermet.

Table 5. Density of samples prepared by different raw materials.

SiO_2:Al	Molding process		Sintering process		Density (%)
1:1	15 MPa	10 min	900 °C	1 h	85.6
1:2	15 MPa	10 min	900 °C	1 h	94.1
1:3	15 MPa	10 min	900 °C	1 h	97.8

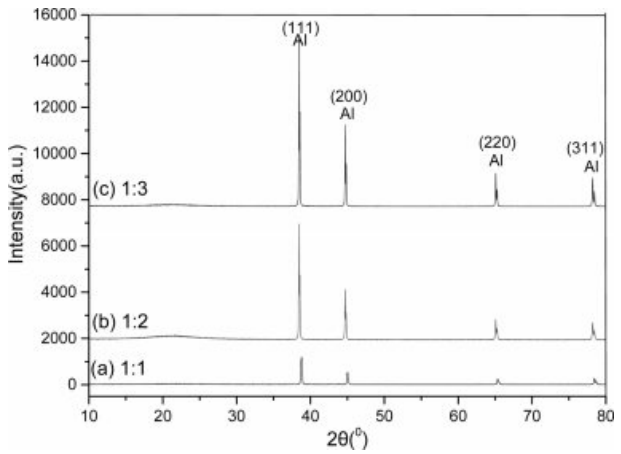

Fig. 5. XRD of samples prepared by different raw materials.

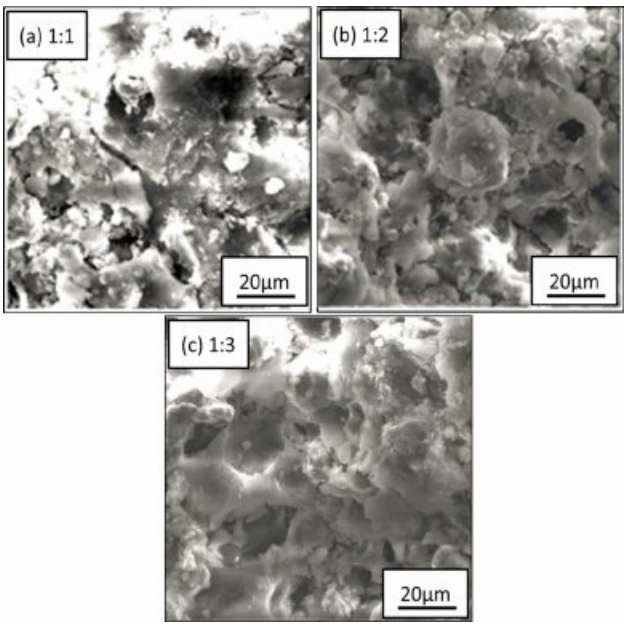

Fig. 6. Microstructure of samples prepared by different raw material ratio.

sample become higher and higher with the gradual change of the SiO_2-Al ratio, while the SiO_2 is basically invisible. Therefore, SiO_2 is not appeared in the XRD pattern. As shown in Fig. 6, when the Al content is high during the high-temperature sintering, the Al melts to form a liquid phase, which can fully bond the surrounding SiO_2 particles to form a relatively continuous and dense structure, thereby obtaining a highly dense network structure (Fig. 6(c)). When the SiO_2:Al ratio is 1:2, the liquid phase content of SiO_2 can be reduced, and the relative SiO_2 content is increased, which leads to a relative decrease in the dense phase content and a relative increase in the nondense phase content [19, 20]. This result shows decreased density with the SiO_2:Al ratio of 1:2 compared with that of 1:3 (Fig. 6(b)). As the Al content is further reduced, the SiO_2 content is increased, and the density is further decreased (Fig. 6(a)).

Table 6. Surface hardness of samples prepared with different raw materials.

SiO_2:Al	Molding process		Sintering process		Hardness (HV)
1:1	15 MPa	10 min	900 °C	1 h	65.1
1:2	15 MPa	10 min	900 °C	1 h	145.1
1:3	15 MPa	10 min	900 °C	1 h	175.2

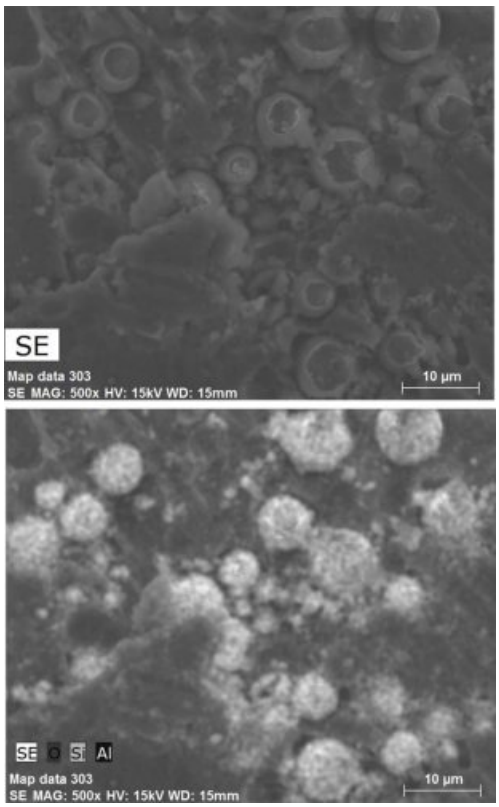

Fig. 7. SEM and EDS of samples prepared by 1:3 raw material ratio.

Table 6 shows that when the SiO_2:Al ratio is increased from 1:1 to 1:3, the surface hardness of the cermet is gradually increased. The metal Al is partially melted at 800 °C, while the SiO_2 powder is not melted, the molten Al liquid phase will still exhibit a granular SiO_2 powder encapsulation, and the matrix structure is an Al phase. The Al content is relatively high, the matrix is relatively large, and the SiO_2 powder is relatively small. Al can enclose SiO_2, and the densification effect is good (Fig. 6(c)), the EDS of SiO_2/Al cermet material prepared by 1:3 raw material ratio is shown in Fig. 7. It can be seen from the internal distribution of Si and Al that the two-phase material is evenly distributed and tightly bound. Hence, the sample has a high hardness as a whole. When the SiO_2:Al ratio is 1:2, the molten liquid phase of the Al cannot sufficiently enclose the SiO_2 powder, and several SiO_2 powders are not wrapped by A1 and cannot form a dense phase continuously, thereby decreasing the densification degree of the cermet and in the surface thereof. The hardness has

decreased to some extent. As the Al content is further decreased, the degree of densification of the green body is weakened, and the surface hardness is further reduced.

Conclusion

The experimental research and analysis results showed that the density of SiO_2/Al cermet material increases with the increase in the Al powder content. When the Al content is high, and the high temperature is sintered, the liquid phase can fully bond with the surrounding SiO_2 particles to form a relatively continuous and dense structure, thereby obtaining a high microstructure density. When the SiO_2:Al ratio is increased from 1:1 to 1:3, the hardness gradually increases. As the molding pressure increases, the hardness and density of the sample gradually increase. As the sintering temperature increases, the surface hardness of the cermet increases first and then decreases. When the SiO_2:Al ratio is 1:3, the molding pressure holding time of 15 MPa is 10 min, and the sintering temperature is 900 °C for 1 h, the surface hardness of the obtained encapsulated SiO_2/Al cermet is high, with the value of 175.2 HV.

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