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Influence of fabricating process on microstructure and properties of spheroidal cast tungsten carbide powder①

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Abstract: A super-high temperature furnace was developed to fabricate spheroidal cast tungsten carbide powder with excellent flowability and fine feathery structure in a large scale. Optical microscope and scanning electron microscope were taken to characterize the morphology and microstructure of cast tungsten carbide powder. X-ray diffractometry was used to analyze the phase composition of powders involved. It is found that the carbon potential in the furnace and feeding speed play an important role on the microstructure, morphology and properties of the spheroidal cast tungsten carbide powder. As carbon potential is between 0.3% and 0.9% in the furnace, cast tungsten carbide powder with hardness over 2800($HV_{0.5}$), flowability over 7.1 s/50 g and tap density over 10.3 g/cm^3 is obtained.

Key words: spheroidal cast tungsten carbide; fine feathery structure; processing parameter; flowability

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1 INTRODUCTION

Cast tungsten carbide, an eutectic mixture of WC and W_2C, was extensively used as a hard-facing material due to its unique properties such as high melting point up to 2 525 ℃, high hardness up to 2 500 - 3 000 kg/cm^2, which is only next to that of diamond and high wear resistance, whose relative wear resistance is 4 when assuming that of YG6 cemented carbide is 1[1]. Cast tungsten carbide powder can be build-up welded or thermal sprayed onto the surface of articles subjected to wear to improve their wear resistance and anti-corrosion properties and to improve their service life by ten times or even a hundred times, so it is widely used in petroleum, geology, mine, metallurgy, machining, electric power, building materials, paper making industry and agricultural machinery industry[2-6].

Great attention from the market is given to spheroidal cast tungsten carbide powder, because spheroidal cast tungsten carbide possesses two distinguished advantages: the spheroidal morphology leading to better flowability, welding property and better surface finish, and the fine feathery microstructure resulting in higher hardness and better wear resistance[7, 8].

In China most researches for cast tungsten carbide are focused on grinding and screening technology to gain cubic particulates as possible restricted by the super-high temperature involved in the process. Foreign researchers focus on two aspects. One is to gain cast tungsten carbide of qualified content, microstructure and phase structure by improving melting process[9]. The other is to obtain spheroidal cast tungsten carbide powder from angular powder at a small scale in laboratories by new technologies[10-12], such as plasma and arc melting-rotary atomization[11-16]. Though they can produce spheroidal cast tungsten carbide powder, the production scale and efficiency is low and the cost for the equipment is as high as 2 million US dollars.

Spheroidizing cast tungsten carbide powder in large scale and with high efficiency was not reported until now. In this paper we will introduce a brand new way to spheroidize cast tungsten carbide powder. Influence of fabricating technology on the microstructure and properties of spheroidal cast tungsten carbide powder is also studied.

2 EXPERIMENTAL

2.1 Raw material

The raw material is angular cast tungsten carbide powder made by traditional way, whose chemical compositions are listed in Table 1.

2.2 Spheroidizing process

A self developed equipment was adopted and

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Table 1 Chemical compositions of angular cast tungsten carbide powder(mass fraction, %)

Total carbon	Impurity								W
	Free carbon	Cl	Fe	Cr	V	Si	Ti	Mo+ Co+ Ni	
3.9	≤0.08	≤0.12	≤0.30	≤0.10	≤0.05	≤0.02	≤0.10	≤0.20	Bal.

the spheroidizing process is shown in Fig. 1. The angular cast tungsten carbide powder was carried by carrier gas continuously through a pre-heated sector and a high temperature spheroidizing sector to spheroidize angular powder at an super-heated temperature up to 2 900 ℃. Influence of feeding rate and carbon potential in the furnace on the microstructure and properties of cast tungsten carbide was studied.

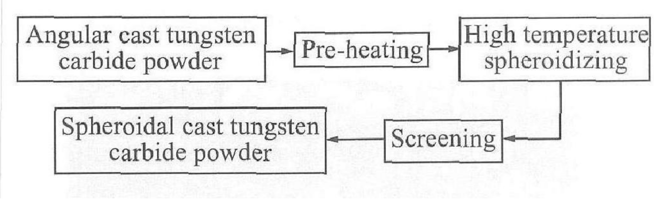

Fig. 1 Flow chart of spheroidizing process

2.3 Characterization

OM and SEM were used to observe the morphology and microstructure of cast tungsten powder. XRD was adopted to study phase composition; micro-indenter was used to measure hardness and ICP was taken to measure carbon content.

3 RESULTS AND DISCUSSION

3.1 Influence of carbon potential on microstructure and properties of cast tungsten carbide powder

The carbon potential in the furnace is adjusted by filling a certain flow rate of carbon containing gas such as methane, acetone or mono carbon oxide. It is found that carbon potential in the furnace plays an important role on the morphology evolution and properties of cast tungsten carbide powder. Fig. 2 and Fig. 3 reveal the relationship between carbon potential and hardness, flowability and tap density of cast tungsten carbide powders. It can be found that flowability, tap density and hardness of cast tungsten carbide powder increase with increasing carbon potential first, and then decrease. When carbon potential ranges from 0.3% to 0.9%, flowability, tap density and hardness of cast tungsten carbide powder possess the highest values. This is because over 2 000 ℃, WC will decompose into tungsten element and carbon under certain condition. Carbon is evacuated in the form of CO, leading to porous morphology, as shown in Fig. 4, reduced flowability and decreased hardness. XRD pattern of the spheroidal cast tungsten carbide power shows the presence of WC, W_2C and W (Fig. 5), proving the WC decomposing reaction. On the other hand, by filling a certain flow rate of carbon containing gas, carbon potential in the furnace is increased to restrain decomposing reaction of WC, leading to increased micro-hardness, wear resistance, better flowability and finishing powder surface. XRD pattern of qualified spheroidal cast tungsten carbide powder shows the presence of only WC and W_2C(Fig. 6). The micro hardness for those samples is around HV2900 and their morphology is shown in Fig. 7. The chemical compositions and properties of qualified spheroidal cast tungsten carbide powder are listed in Table 2. And too high level of carbon potential will lead to depo-

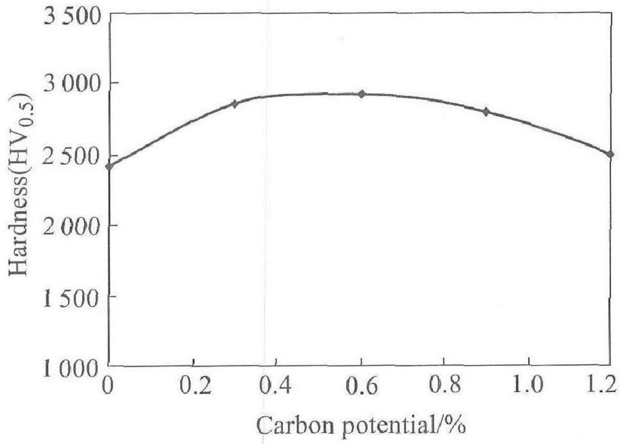

Fig. 2 Relationship between carbon potential and micro-hardness of cast tungsten carbide powder

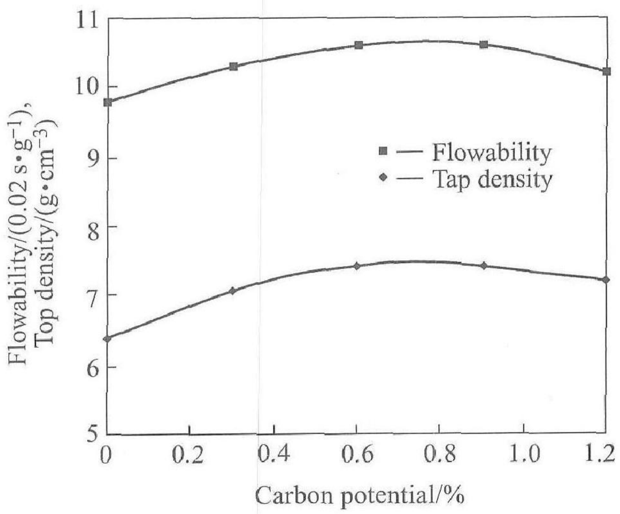

Fig. 3 Relationship between carbon potential and flowability, tap density of cast tungsten carbide powder

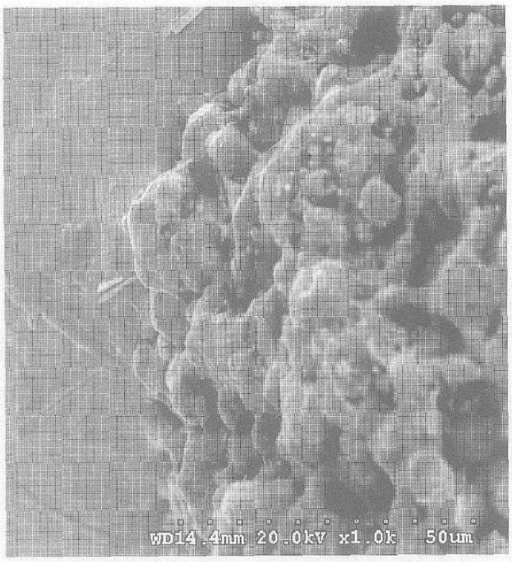

Fig. 4 Morphology of porous surface of cast tungsten carbide

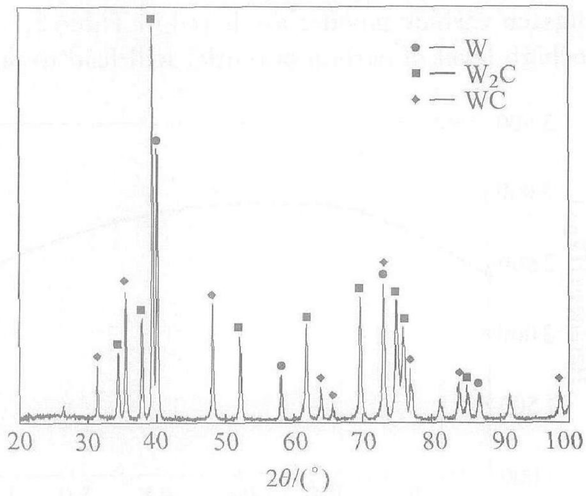

Fig. 5 XRD pattern of spheroidal cast tungsten carbide with decomposed tungsten element

sition of carbon and free carbon in the powder, reduced tap density, hardness and flowability.

3.2 Influence of feeding rate on microstructure and properties of cast tungsten carbide

Feeding rate also plays an important role on the microstructure and properties of cast tungsten carbide powder. Under a constant temperature and length of high temperature sector over 2 m, feeding rate decides the residing time of cast tungsten carbide powder in the high temperature sector. With suitable feeding rate, powder in carrier gas

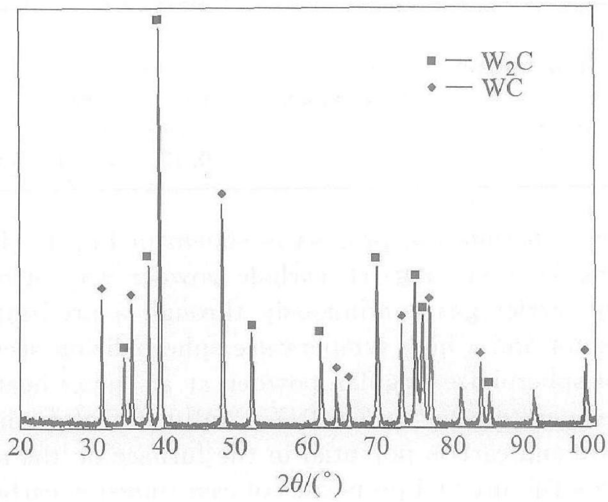

Fig. 6 XRD pattern of qualified spheroidal cast tungsten carbide powder

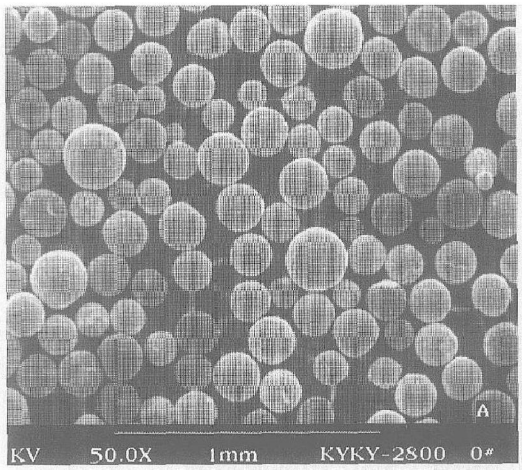

Fig. 7 SEM image of qualified spheroidal cast tungsten carbide powder

has enough time to adjust microstructure, homogenize and rapidly consolidate, leading to changing from angular morphology into spheroidal one driven by the surface tension force, as shown in Fig. 8 and microstructure evolution from coarse structure into fine feathery one, as shown in Fig. 9.

Reducing the feeding rate to certain degree, powder in the carrier gas does not have enough time to adjust microstructure, homogenize and rapidly consolidate, so only local re-melting takes place. Partial spheroidizing takes place as shown in Fig. 8(b). The inner microstructure of those powders remains as coarse structure, and only surface has feathery structure, as shown in Fig. 10.

Table 2 Compositions and properties of spheroidal cast tungsten carbide

Composition(mass fraction)/%			Property			
W	Total carbon	Free carbon	Hardness($HV_{0.5}$)	Apparent density/($g\cdot cm^{-3}$)	Tape density/($g\cdot cm^{-3}$)	Flowability/($2s\cdot g^{-1}$)
95.88	3.96	0.06	2 900	9.64	10.62	7.4

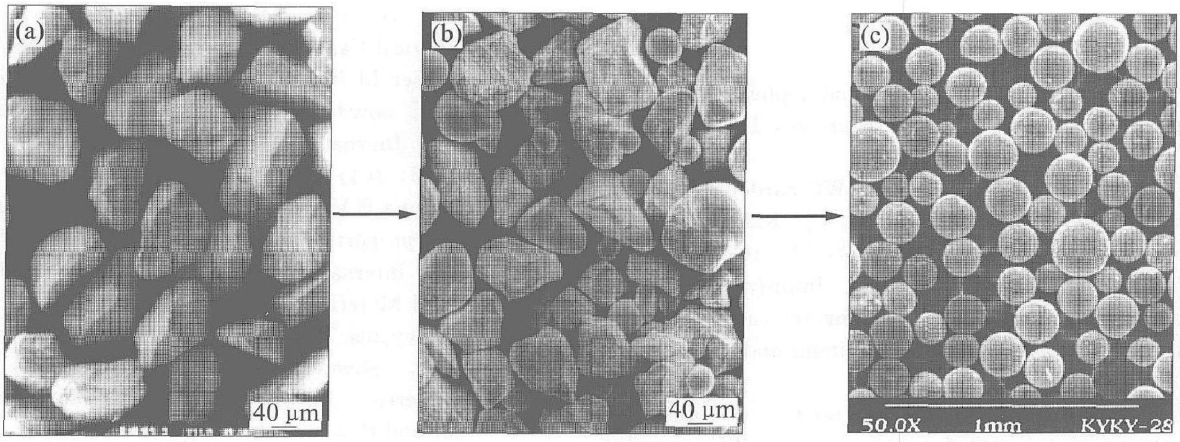

Fig. 8 Morphology change during spheroidizing process
(a) —Raw material; (b) —Partial re-melting; (c) —Spheroidization

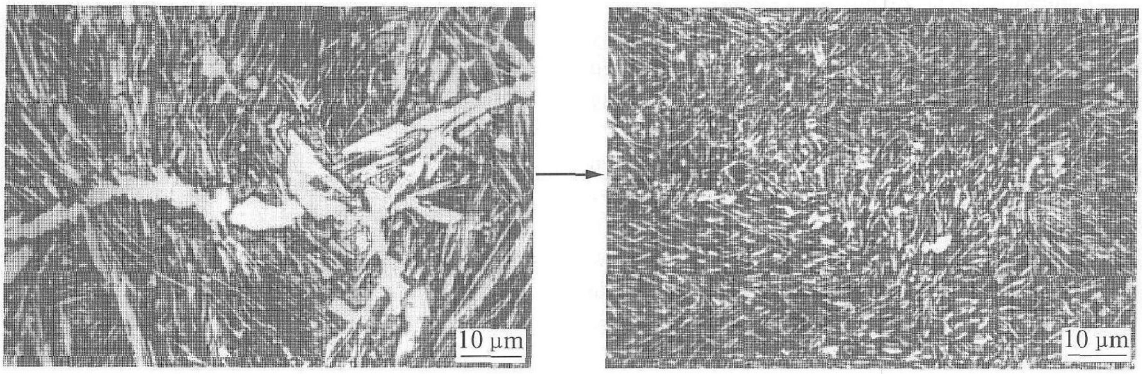

Fig. 9 Microstructure change during spheroidizing process

Fig. 10 OM image for inner and surface of cast tungsten carbide powder

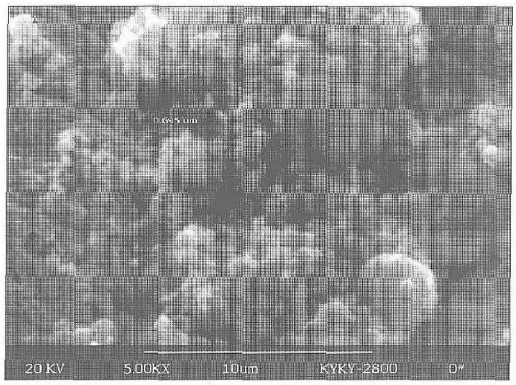

Fig. 11 Nano-structure formed on cast tungsten carbide powder surface

Because only the surface has enough time to adjust microstructure, homogenize and rapidly consolidate, and because very high cooling rate is involved in the process, a fine surface with particle size below 0.7 μm is obtained, as shown in Fig. 11. By adjusting feeding rate, angular powder can be modified into spheroidal powder with microstructure and hardness gradient specially with higher hardness and finer microstructure on the surface and with coarser structure and relatively lower hardness in the inner part of the powder.

4 CONCLUSIONS

Spheroidal cast tungsten carbide powder with excellent flowability and fine feathery structure was produced in a super-high temperature furnace. It is found that carbon potential in the furnace and feeding rate play an important role on the morphology and properties of cast tungsten carbide powder.

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