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INVESTIGATION ON FEEDSTOCK PREPARATION FOR MICRO-CEMENTED CARBIDE INJECTION MOLDING

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Abstract

This research was focused on mixing of submicron cemented carbide (WC-Co-VC) powder and binder. WC-Co-VC powder particle size and morphology were analyzed by laser diffraction and field emission scanning electron microscopy. The WC-Co-VC powder was kneaded with a paraffin wax based binder system. Based on critical solid loading, the feedstock with different solid loadings between 49 to 51 vol.% was prepared. Finally, the flow behavior of different feedstocks was investigated. Morphology of powder revealed that the particles of powder are slightly agglomerated and irregular in shape. The result of mixing indicted that the torque value increases as the solid loading increase from 49 vol.% to 51 vol.%. The feedstock exhibited homogeneity and the powder particles are homogenously coated with binder. The feedstock with solid loading of 51 vol.% is sensitive to temperature and showed high viscosity values. The feedstock with solid loadings of 49 and 50 vol.% had good compatibility and flow characteristics.

Keywords: Micro-cemented carbide injection molding, Mixing, Feedstock

INTRODUCTION

Cemented Carbide is a hard metal included a binder metal such as Nickel (Ni), Cobalt (Co) or Iron (Fe) and carbide usually either tungsten carbide (WC), VC (Vanadium Carbide), Cr_3C_2 (Chromium Carbide) and TiC (Titanium Carbide). It presents high hardness, high compressive strength, suitable thermal conductivity, and retains its hardness values at high temperatures. These properties cause to wide application of cemented carbide as mining, machining, metal cutting, metal forming and mold making [1-3].

In the recent years, many attempts have been undertaken to use powder injection molding (PIM) process technology for the manufacturing of micro parts, as called micro-powder injection molding (micro-PIM). Micro-PIM is a process used to fabricate metal, ceramic and carbide components and has several advantages such as shape complexity, near net-shape capability and high performance. This process has gained attractive processing technology in micro system manufacturing [4,5].

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Micro-PIM has high potential for manufacturing complex cemented carbide (WC-Co) micro parts without subsequent finishing processes as known micro-cemented carbide injection molding (micro-CCIM) [6,7]. The processing steps of micro-CCIMM included four main steps. The process begins with kneading fine WC-Co powders with a binder to form a feedstock. Then feedstock inject into the mold, as called green part. After that, the binder removes from green part in debinding stage. In the next step, debinded part sintered to obtain final part with high physical and mechanical properties [6,8]. The mixing of powder and binder require special considerations in the micro-PIM, as the fine powders typically are more prone to agglomerate. For preparing feedstock from fine powder, higher shear needs to be applied to obtain homogenize feedstock, as the uniformity of the feedstock influences the rheological properties of powder-binder mixture. The success of injection molding in the micro-PIM is highly dependent on flow characteristics of the feedstock. The binder systems should provide low viscosity of feedstock and ensure the fluidity of feedstock to fill the die cavity completely [9,10]. Evaluation of rheological properties of the feedstock is the simplest method for prediction of feedstock behavior during injection molding [11]. Therefore, the present research attempted to investigate the mixing process of fine WC-Co powder and binder. The homogeneity and rheological properties of the feedstock, that are critical character in micro-CCIM process, are also studied.

EXPERIMENTAL MATERIALS AND METHODS

A composition of submicron WC-10Co-0.8VC powder was prepared as powder mixture for the present study. This hardmetal composition normally utilized in the hardmetals industry for tools application such as precision drills in dental application. The VC was doped in the powder mixture as grain growth inhibitor. The paraffin wax (PW) based was selected as binder system. It included (PW), polyethylene (PE) and stearic acid (SA). The weight percentage ratio of PW:PE:SA was 65:30:5. The properties of selected binder systems are listed in Table 1.

Tab.1. Properties of binder system components.

Binders	Melting point (°C)	Decomposition range (°C)
PW	63	205–375
PE	125	425–495
SA	61	165–305

Mixing of WC-10Co-0.8VC powder and binder components were performed using a twin-screw Brabender mixer W50 EHT with a volume of chamber 55 cm^3 as shown in Fig.1. The mixing temperature was selected 140°C. This temperature was above the highest melting temperature of (125°C) and less than the lowest decomposition temperature (165°C) of the selected binder system components. Feedstock with solid loading between of 49 vol.% to 51 vol.% were prepared based on critical solid loading. Detailed information about critical solid loading is reported elsewhere [10].

Fig.1. Twin-screw Brabender mixer W50 EHT.

Average particle size and distribution of WC-10Co-0.8VC powder were measured by using Malvern Zetasizer nano zs particle size analyzer, based on laser scattering method. Morphology of the powder and feedstock were also investigated by using field emission scanning electron microscope (FE-SEM). The flow behavior of different powder-binder mixture was examined by using Shimadzu Capillary Rheometer CFT-500D.

RESULTS AND DISCUSSION

The Figure 2 indicates the microstructure of the WC-10Co-0.8VC powder. The powder exhibited an irregular and angular shape morphology and was agglomerated. The high agglomerated powder is not suitable for the PIM process. The irregular shaped particle lead injection molding more difficult compare to spherically shaped particle, because of the irregular particle cause to increase viscosity of feedstock [12].

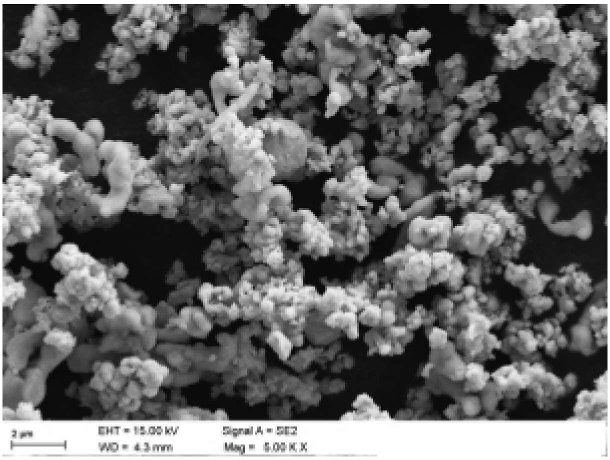

Fig.2. Microstructure of the WC-10Co-0.8VC powder.

The Figure 3 shows the distribution size of WC-10Co-0.8VC powder. The particle size analysis gave the distribution of WC-10Co-0.8VC powder, which presented D_{50} equal to 0.67 µm. Previous study was reported using WC-10Co powder with a 0.5 µm particle size to manufacture small tools by PIM [13]. So, the particle size of powder in this study is fine enough to manufacture small WC-Co parts with high surface quality.

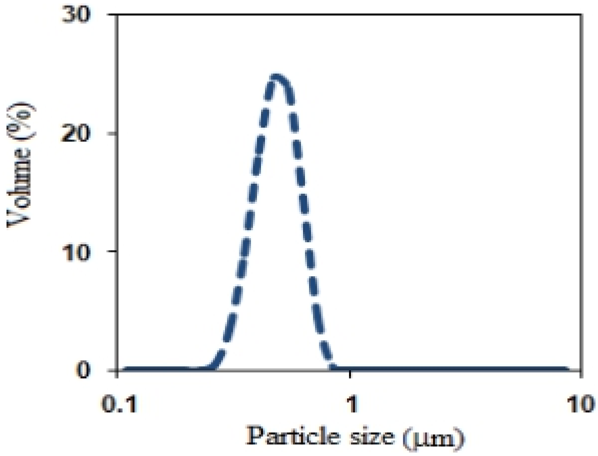

Fig.3. Particle size distribution of WC-10Co-0.8VC powder.

The preparation of feedstock that was performed through the kneading powder with binder is a critical process stage in PIM process, since the quality of feedstock influence on injection molding and debinding process. A proper mixed compound consists of a homogeneous powder which is dispersed among the binder.

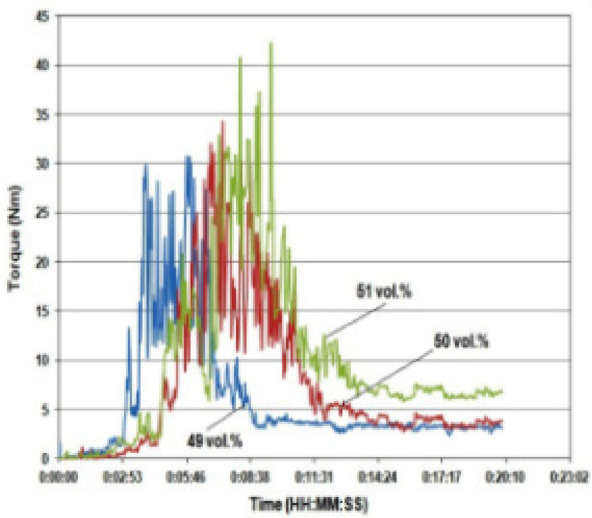

Fig.4. Torque variation versus mixing time of feedstock preparation different solid loadings.

The mixing torque, proportional to the shear stress of the mixer, indicates that the work energy consumed to disperse and distribute the powder in the binder [14]. Fig. 4

shows the variation of torque as a function of mixing time for different solid loadings of binder system. As it can be seen, the torque value increases as the solid loading increase from 49 vol.% to 51 vol.%. This is attributed to higher powder content require higher torque to wetting surface of powder particles. Fig. 4 also shows, the torque becomes stable in a short time that demonstrating uniform mixing in low solid loading. However, low solid loading has high tendency to powder and binder segregation during injection molding and also can cause to higher shrinkage after sintering [12]. For 51 vol.% solid loading, the torque value increased significantly with the mixing time. This shows that the powder was not uniformly distributed within the binder in short time, due to the binder could not fill completely the voids between the particles.

The ideal homogenous feedstock indicated low viscosity and any in-homogeneity in feedstock also affects the properties of molded, debinded and sintered parts [10]. The Figure 5 illustrates the micrograph of the final feedstock was prepared after mixing. The micrographs indicate that the powder particles were surrounded by binder components, which verifies that the powder-binder mixture is homogeneous. It also revealing to proper selection of kneading parameters due to mixed compound consists of a homogeneous powder which is dispersed among the binder.

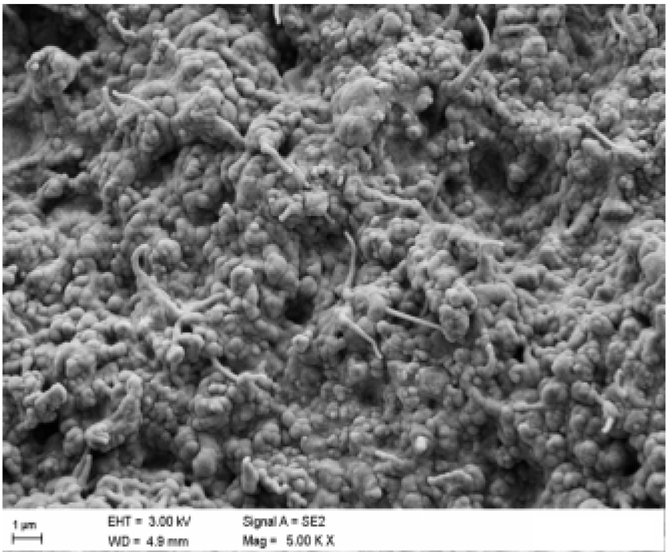

Fig.5. FESEM image of feedstock.

The success of the fabrication green part in the PIM is highly dependent on flow behavior of the powder-binder mixture. The binder systems should provide low viscosity of feedstock and ensure the fluidity of feedstock to fill the die cavity completely. The most important characteristics of the feedstock are its rheological properties, which relate mostly to viscosity [9]. Study of rheological properties is an important aspect for evaluation flowability of the feedstock. The variation of viscosity at different temperature in solid loading between 49 vol.% to 51 vol.% are presented in Table 2. The viscosity of feedstock decreases as the temperature increases. In this study viscosity of feedstock is very sensitive to temperature and when temperature increase, viscosity is low, especially at a high level of solid loading. As it found that the flow characteristics of feedstock with solid loading of 51

Vol.% is too much sensitive to temperature. The powder-binder mixture with solid loading 51 vol.% also indicated high viscosity at low temperature. Typically, the viscosity of a feedstock at the injection temperature should be in the range of 15-40 Pa.s for low pressure injection molding [15]. As can be seen from Table 2, the viscosity of feedstock with 49 vol.% and 50 vol.% solid loading indicate lower sensitivity to temperature. To compare the flow properties of different feedstocks, it indicates that the feedstock with solid loading 49 vol.% and 50 vol.% are within the suitable viscosity value for low pressure injection molding.

Tab.2.Viscosity at different temperature and solid loading.

Temperature (°C)	Viscosity [Pa.s] in different solid loading		
	42 vol.%	50 vol.%	51 vol.%
90	42	62	82
100	40	21	5
110	21	14	2

CONCLUSIONS

In the present work, the cemented carbide feedstock using submicron WC-10Co-V0.8C powder and the PW based binder system was produced for the micro-CCIM process of small components. The results show higher solid loading require higher torque to mixing powder and binder. The flow properties of the feedstock are used to predict the feedstock characteristics for fabricating micro part by micro-CCIM. The powder-binder mixture exhibited good homogeneity and the powder particles after mixing are surrounded with binder components. The feedstock with solid loading of 51 vol.% shows sensitivity to variation in temperature. It also found the powder-binder mixture shows high viscosity values at low temperature during the rheological test. The powder-binder mixture with solid loadings of 49 vol.% and 50 vol.% had good compatibility and flow characteristics. The lower solid loading also resulted in lower viscosity, therefore it is expected that injection process can carry out at lower temperature and fabricate green parts without any defects.

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