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EXPERIMENTAL RESEARCH REGARDING THE PRODUCTION OF CUTTING TOOLS THROUGH PIM TECHNOLOGY

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Abstract: *In the following experimental research studies the characteristics of the materials produced through powder injection moulding for cutting tools. The material utilized is a homogenous powder mix of WC powder and 6wt% Co. The injected parts were debinded in solvent vapor at a temperature of 75 °C for 8 hours and thermal debinded at a temperature of 70 °C for 8 hours. After debinding the samples were sintered in vacuum (10 $^{-4}$Torr). The parts had contractions of 19% and a density of 97%. The material has a homogenous structure, with low porosity with no discontinuous WC particle growth.*
Key words:*powder injection molding, cutting tools, tungsten carbide.*

1. INTRODUCTION

The current technology used for the production of cutting tools is the classic die pressing. For the production of complex shape tools with small dimensions a viable alternative is metal injection molding (PIM) [1-3].

For the injection molding purpose paraffin/polymer or polymer/polymer binder is added to the powder mix giving it the necessary viscosity [4, 5].

Problems that may occur in the production of cutting tools through powder injection molding are deformations during the debinding/sintering stages and obtaining the necessary density.

The WC/Co powder mixes are the materials most often used for the production of cutting tools. The WC/Co composite material is produced through liquid phase sintering.

An important factor in the liquid phase sintering of this kind of materials is the uniform distribution of cobalt in the powder mix.

During liquid phase sintering WC particle growth takes place, which is attributed to the solution – reprecipitation effect.

The excessive particle growth leads to a decrease in performance of the final product. There are two types of WC particle growth that can take place:

- continuous growth – dissolution of the small WC particles in the liquid cobalt phase and reprecipitation of the bigger WC particles ("Oswald Ripening") [6].
- discontinuous growth – increase in size of a single WC particle during all stages of sintering because of the chemical heterogeneity in the material [6].

On the surface of the powders there is a thin lair of oxides. During liquid phase sintering in vacuum part of the carbon is lost due to its reaction with these oxides. This leads to the modification of the W/C ratio and the formation of the W_2C phase. Because of this the properties of the final product can change, so the carbon concentration must be kept under control [11].

2. MATERIALS AND EXPERIMENTS

The material used in this experiment it's a homogenous mix of WC and 6wt% Co powders. The WC particle size range is between 0.5 and 2.5 μm.

The cobalt particle size varies between 0.7 and 10 μm. The particles have irregular shapes with rounded edges (fig. 2).

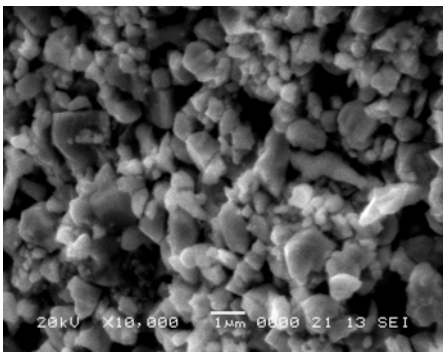


Fig. 1. WC powder (SEM x10000).

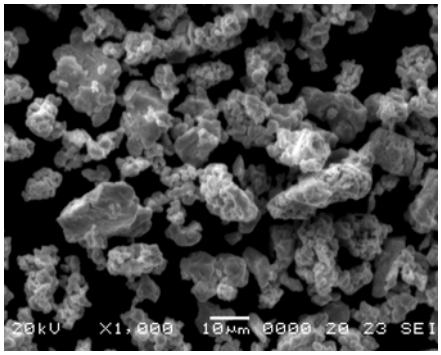


Fig. 2. Co powder (SEM x1000).

In order to reach the viscosity necessary for the injection process a binder with the following composition was added: 70wt% paraffin, 25wt% low density polyethylene, 5wt% stearic acid. The binder components were mixed for 90 minutes at a temperature of 120 °C. The WC/Co powder mix was added and the material was mixed for another 45 minutes at the same temperature. The material thus produced had a composition of 55 vol% powder. After the injection molding that was done at 150 °C,the parts were debinded in solvent vapors at a temperature of 75 °C for 4 hours followed by a thermal debinding at the same temperature for 8 hours.

To analyze the effects that different solvents have on the quantity of the paraffin removed two solvents were used: one base on aliphatic hydrocarbons and one on xylene. The solvent vapor debinding diagram is presented in fig. 3.

The samples were presintered at a temperature of 1000 °C for 30 minutes, followed by a sintering at 1350 °C for 30 minutes.

The temperature was slowly raised until 500 °C to allow the elimination of the polyethylene from the samples to avoid deformation and cracking.

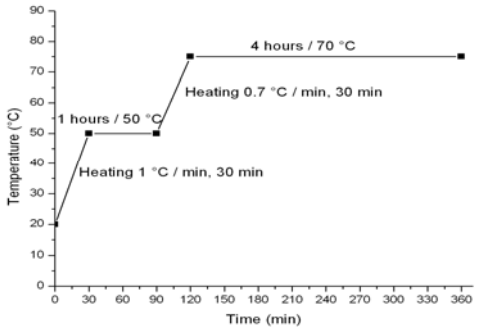


Fig. 3. Debinding diagram.

After sintering, XRD and SEM analysis were done on the parts. The density of the sintered samples was determined with the Archimedes method.

3. RESULTS AND DISCUTIONS

In order to analyze the efficiency of the debinding process, the paraffin percentage eliminated from the parts was calculated using the following equation [5]:

$$p_w = \frac{(g_o - g_u)\cdot 10^6}{g_0 \cdot g_l \cdot g_w}[\%] \quad (1)$$

where:

- p_w – is the eliminated paraffin [vol%];
- g_o– initial weight of the samples [g];
- g_u– the parts weight after debinding [g];
- g_l–the binder percentage in the samples[wt%];
- g_w– the paraffin percentage in the samples [wt%].

Table 1 presents the paraffin percentage eliminated from the parts after debinding using different solvents.

Table 1 The quantity of paraffin eliminated from the samples.

Solvent	Paraffin eliminated[vol.%]
hydrocarbon	**96.4**
xylene	**68.2**

For the debinding process the hydrocarbon proved more appropriate, removing 96.4 vol% of paraffin, while using the xylene based binder only 68.2 vol% was eliminated. After debinding the polyethylene is still present in the parts holding their integrity until sintering.

After sintering the samples had a contraction of 19% and a density of 97%. Defects of the

parts (cracking, deformation) can be avoided through a good debinding and slow heating rate during sintering to allow a gradual elimination of the polymer.

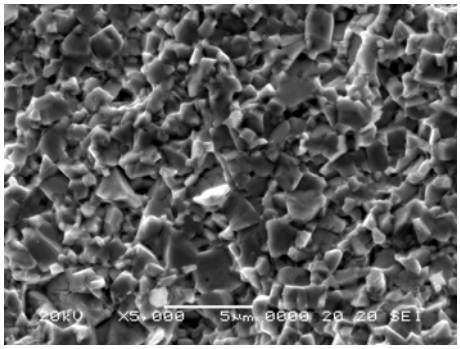
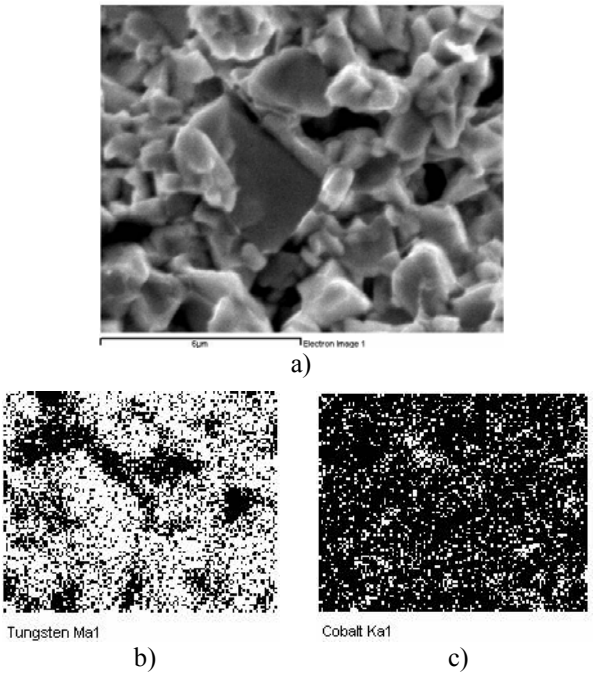


Fig. 4. Microstructure of the parts sintered at 1350 °C (SEM x2000).

The micro hardness values of the tested samples ranged between 1650 and 1700 [HV 10/15] and it was comparable with those of the parts produced through classic die pressing technology [8].

Figure 4 presents the SEM image of a sintered sample. The material has a homogenous structure, and low porosity.



a) b) c)

Fig. 5. Elements distribution map in the material sintered at 1350°C: a) SEM x10000, b) W distribution, c) Co distribution.

EDX analysis showed that the cobalt matrix is relatively homogenously distributed in the samples body (fig. 5).

The XRD analysis revealed in the sintered samples the presence of two phases: the WC phase and the pseudo binary phase Co_3W_3C (fig. 6).

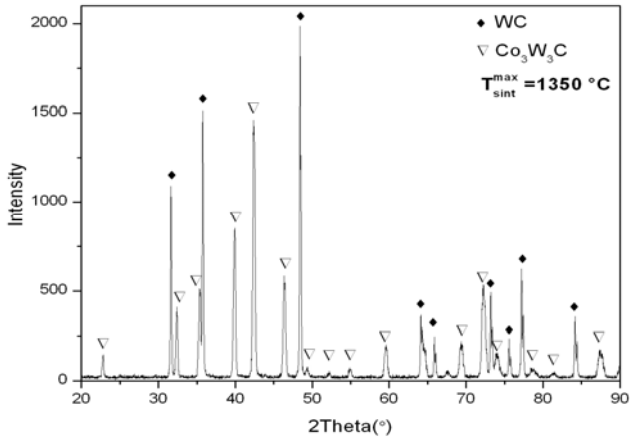


Fig. 6. RXD diagram of the parts sintered at 1350°C

The cubic phase Co_3W_3Cit's a stable phase that forms at temperatures over 1200 °C [9, 10]. Through complete removal of the binder during the debinding and presintering of the samples, the modification of the carbon concentration was avoided. The carbon content it's an important factor that must be taken in consideration. Variations in the carbon content can lead to modification of the properties of the final product. The ideal WC/Co ratio is 1:1 [11].

The WC particle growth was determined through image analysis measurements. The particle size varied between 0.5 and 3.5 μm. The material had a low, continuous particle growth that didn't affect the properties of the final part. There was no discontinuous WC particle growth. In order to reduce the particle growth the powder mix can be doped with vanadium carbide. In this case that wasn't necessary (fig. 4).

4. CONCLUSION

The best results of the debinding process were obtained using hydrocarbon based solvent.

The hardness and density of the parts are comparable with those of the parts produced through classic die pressing methods.

The defects (fissures, cracks) can be avoided through a good binder removal during the debinding process and a slow heating rate until

the temperature of 400 – 500 °C is reached during the sintering process to allow the polyethylene to be slowly removed. The growth of the WC particles was low and it didn't affect the properties of the sintered material. There was no discontinuous WC particle growth.

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Cercetări experimentale privind producerea sculelor aşchietoare prin tehnologia PIM

Abstract: Cercetările experimentale urmăresc studierea caracteristicilor materialelor obținute prin procedeul injectării pulberilor metalice în vederea obținerii de scule aşchietoare. Materialul utilizat este un amestec omogen din pulberi de WC cu 6 wt% Co. Probele injectate au fost deliate în vapori de solvent la temperatura de 75 °C, timp de 4 ore şi apoi deliate termic la temperatura de 70 °C timp de 8 ore. În urma delierii, probele au fost sinterizate în vid (10^{-4} torr). Probele au avut contracții de 19% şi densitatea de 97%. Structura este uniformă, cu porozitate redusă, fără creştere discontinuă a particulelor de WC.

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