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IS IT POSSIBLE TO PROCESS SINTERED CARBIDES BY SELECTIVE LASER MELTING TECHNOLOGY?

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ABSTRACT

The aim of this article is to introduce to the reader problems which is connected with processing of WC-Co composite material by the technology known as SLM (Selective Laser Melting Technology). The biggest problem associated with the material processing process is the porosity of the prototype builds. The work deals with what the final porosity of the product is affected by parameters of printing process and by raw material properties used for it. The presented results were obtained by performing metallographic analysis of builds made of various types of WC-Co powder mixtures under different processing parameters of them. Metallographic analysis was performed using light and electron microscopy techniques. These analyses were further supplemented by the evaluation of mechanical properties of prototypes by the test of hardness, compressive strength and dynamic resistance of the product by the impact test.

KEYWORDS

WC-Co, SLM, Porosity, Energy Density, Builds

INTRODUCTION

Sintered carbides are a material used in a wide variety of applications. . The most well-known applications are cutting tools for which these materials are most commonly used. Other non-conventional applications include, for example, abrasion applications, most commonly used for producing gaseous or liquid media nozzles. *(Sarin, 2014)* In addition, they are used, for example, for the production of blades or cutting rollers which are used in mass production, for example for the production of diapers for small babies. For each of the above applications, the material has to have different mechanical properties. Cutting tools require high hardness and dimensional stability. Against to for wear application parts where require, higher toughness and abrasion resistance. *(Sarin, 201;, Kriz and Bricin, 2017)* Sintered carbides can be used as a material for all of the above applications because their

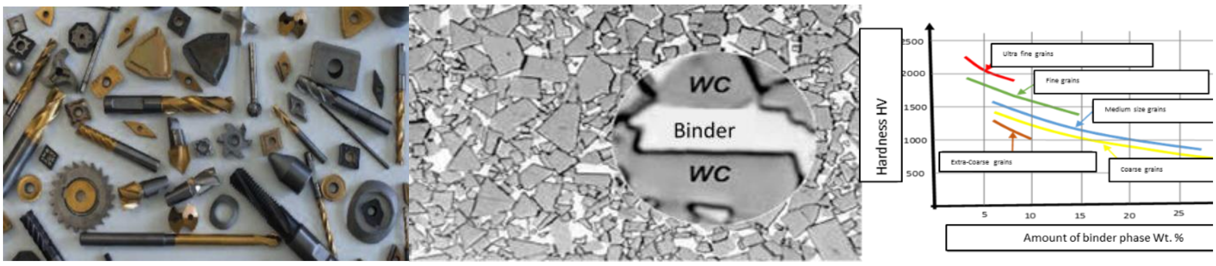

Fig. 1- Manufactured products left part of the figure, structure of cemented carbides centre of the figure and chart of influence of grain size and volume of binder on product hardness. *(Sarin, 2014)*

mechanical properties is possible changed by varying by the carbide grain size and changing the binder volume, thereby adapting them to the future application. Conventional pressing and sintering technology makes it possible to form simple shapes of product with its simple construction. In the case of more complex shapes of products with complicated internal structure, it is necessary to use more suitable technologies for it such as SLM technology. *(Venuvinod, 2010)* This article deals with the use of SLM technology for processing WC-Co materials. The principle of this technology is that the powdered material is gradually layered on a building platform. After each application of the powder layer, the laser melted powder bed in defined areas. In this way, the entire prototype product is gradually created. Thanks to the construction process, it is possible for the product to be made up of a highly intricate internal structure that can be used to reduce it weight or to control of status of the component. The aim of the article is to introduce the issue of achieving 100% density for samples printed from WC-Co powder mixtures. To this end, metallographic evaluation of samples printed from different types of WC-Co powder mixtures under various processing parameters was performed. As a result, different degrees of density and mechanical properties have been achieved of the builds.

PROBLEM SOLVING

The main problem in the processing of WC-Co powder by SLM is the porosity of the product. The amount of pores and the shape of the pores in the product structure are then dependent on several parameters. *(Bricin and Kriz, 2018; Uhlmann, 2015; Wang, 2002;Gu, 2006;Kumar, 2009; Zhou, 2015; Pacurar, 2016)*

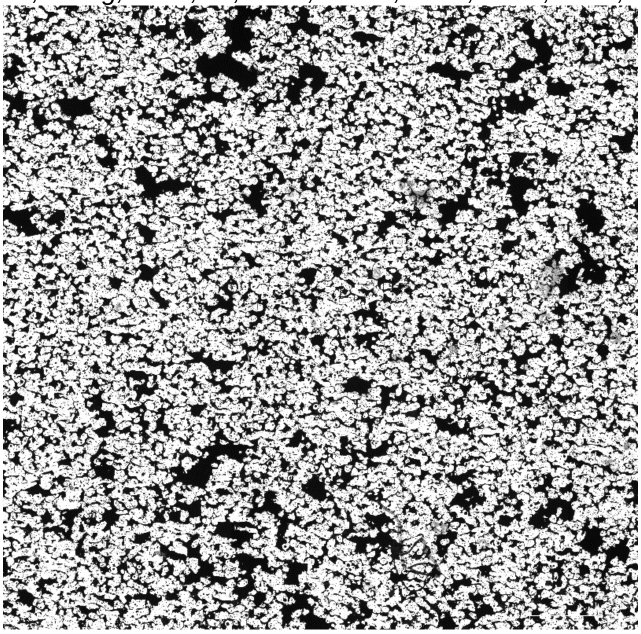

Fig. 2- Porosity of the printed sample made of WC-Co powder

During the interaction of the laser beam with the powder layer it melts. As it melts, new particles are formed that fly off the melt formed. In addition, material evaporation and structural changes in the molten material volume occur.

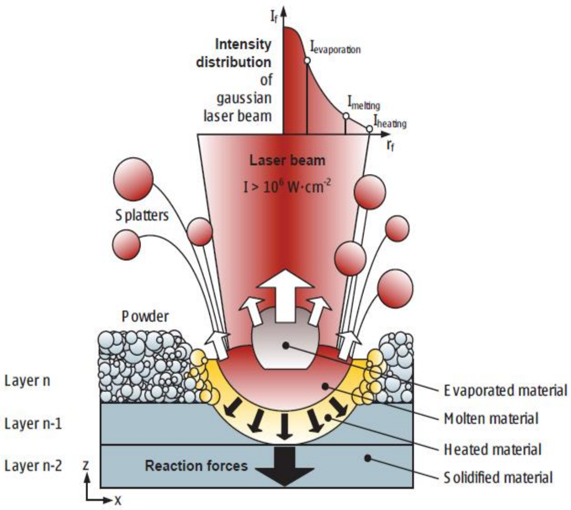

Fig. 3- Diagram of interaction of laser with powder bed. The figure shows areas in which heat is affected by the powder, melts, evaporates, and generates flying particles. *(Uhlmann, 2015)*

The amount of newly formed melt blown particles is directly dependent on the parameters used to process the powder bed. Their origin is caused by surface tension, which occurs when the temperature gradient between the particle surface and its centre is high. This gradient can be expressed by Maragoni's equation. *(Zhou, 2015)*

$$M_a = \frac{\left(\frac{dy}{dx}\right)\cdot\left(\frac{w}{\eta}\right)}{\left(\frac{\kappa}{w}\right)} = \frac{\left(\frac{dy}{dT}\right)\left(\frac{dT}{dx}\right)\left(\frac{w}{\eta}\right)}{\left(\frac{\kappa}{w}\right)} \tag{1}$$

Generally, flying particles are generated when the laser power is high to create sufficient liquid phase, but the velocity of the laser is too high, and so the surface tension packs the melt into spheres that leave the melt due to the applied laser energy. The amount of these particles is higher if the higher the speed of motion of the laser spot. The flying particles can then be found in the volume of the printed samples. This is one of the reasons why the cracks are possible found in the volume of the builds.

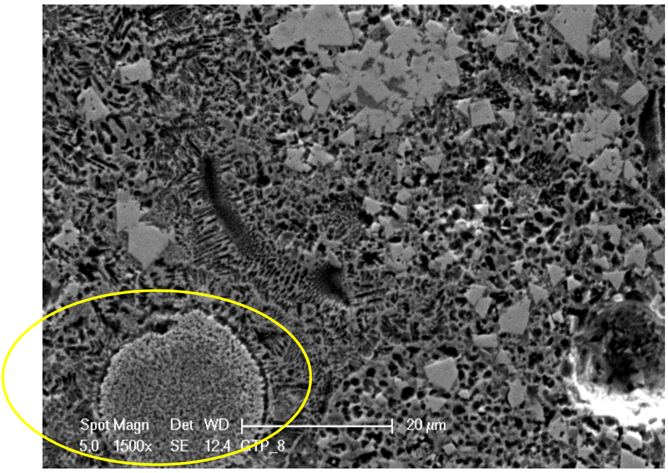

Fig. 4- Departure droplet trapped in product during solidification

The material processing process further evaporates the material. The size of the area in which this occurs depends again on the parameters used to process the powder material. The amount of vaporized material can be expressed by the Cahn-Hillard equation. *(Leitz, 2016)*

$$Q_v^{'} = \dot{m} \cdot \Gamma \cdot \left(\frac{1-\phi}{\rho_{vapor}} + \frac{\phi}{\rho_{metal}}\right) \tag{2}$$

Generally, the amount of vaporised binder is greater the higher the power of laser used or the lower the speed of the motion of the laser spot.

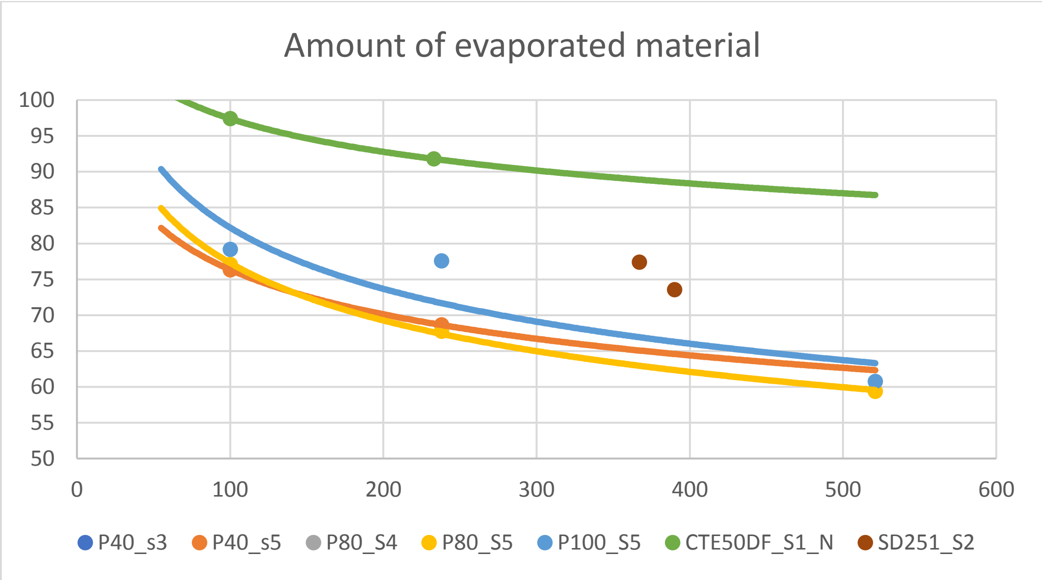

Fig. 5- Influence of applied energy on amount of evaporated material

Evaporation of material is one of the possible reasons why circular pores of microscopic dimensions are formed. In addition to the two aforementioned reasons for the formation of pores in the product structure, their proportion depends on the structural changes that are caused by the material processing process.

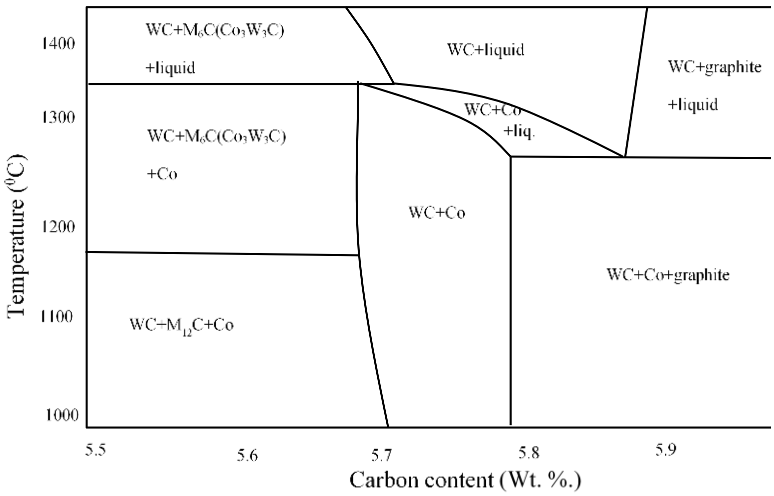

Fig. 6- Binary diagram of WC-Co *(Sarin, 2014)*

It can be seen from the WC-Co binary diagram that the structure of the builds can be form by both tungsten carbides and binder. This is the case if the carbon ratio between 5.7-5.8 wt. %. However, carbon is diffused into the molten material during processing of the powder mixture. In these molten regions it can then either form the phase of the eta or be in the form of graphite. Since the process of melting and solidifying the powder bed is extremely fast, favourable conditions for the formation of the phase of the eta are established. The Eta phase may also be part of the powder mix. Its volumetric growth then tears the samples.

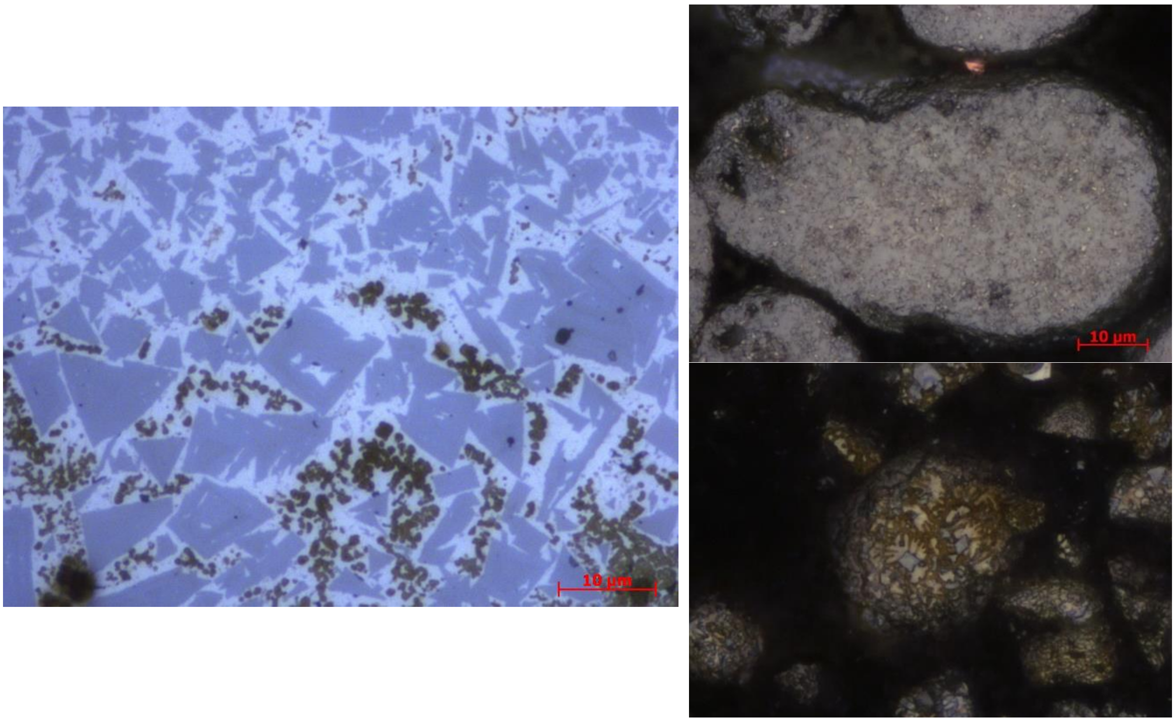

Fig. 7- Left part of the image shows structure of the printed pattern . The right part of the image shows particles of two types of WC-Co powders. Powder particles differed in phase composition. The brown-orange areas are areas of the eta phase. White areas occurrence of binder Co. The light gray areas are tungsten carbide grains.

CONCLUSION AND RECOMMENDATIONS

It follows from the above that it is possible to form the body of the WC-Co powder blend by the additive SLM technology. However, in this body it will be very difficult to achieve a density that is close to the full density of a conventionally produced cemented carbide. However, in this body it will be very difficult to achieve a density that is close to the full density of a conventionally produced cemented carbide. The full density of the product is really hard to achieve. One of the reasons is that the full density is affected by the increasing volume of vaporised binder if increasing the applied energy density which is necessary to neck growing among the particles. By reducing the amount of applied energy, for example, by increasing the speed of the laser spot movement, beads are formed that fly away from the melt, again increasing the amount of porosity of the builds and it case their volume deformations. In addition to these two reasons, formation of new structural phases in the volume of the prints due to carbon diffusion increasing porosity of the builds. The volume of the newly created phase is dependent, in addition to the parameters used to process the powder mixture, on its properties, i.e. the phase composition which were achieved by process of manufacturing of the powder.

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REFERENCES

1. Venuvinod, P. and Ma, W. (2010). Rapid prototyping. Boston: Kluwer Academic
2. Uhlmann, E., Bergmann, A. and Gridin, W. (2015). Investigation on Additive Manufacturing of Tungsten Carbide-cobalt by Selective Laser Melting. Procedia CIRP, 35, pp.8-15.

3. Wang, X., Laoui, T., Bonse, J., Kruth, J., Lauwers, B. and Froyen, L. (2002). Direct Selective Laser Sintering of Hard Metal Powders: Experimental Study and Simulation. The International Journal of Advanced Manufacturing Technology, 19(5), pp.351-357.

4. Bricín, D., Špirit, Z. and Kříž, A. (2018). Metallographic Analysis of the Suitability of a WC-Co Powder Blend for Selective Laser Melting Technology. Materials Science Forum, 919, pp.3-9.

5. Bricín, D. and Kříž, A. (2018). Assesment of usability of WC-Co powder mixtures for SLM. Manufacturing Technology.18(5), pp. 727-731

6. Gu, D., Shen, Y., Dai, P. and Yang, M. (2006). Microstructure and property of sub-micro WC-10 %Co particulate reinforced Cu matrix composites prepared by selective laser sintering. Transactions of Nonferrous Metals Society of China, 16(2), pp.357-362.

7. Kumar, S. (2009). Manufacturing of WC–Co moulds using SLS machine. Journal of Materials Processing Technology, 209(8), pp.3840-3848.

8. Zhou, X. Liu, X., Zhang, D., Shen, Z. and Liu, W. (2015). Balling phenomena in selective laser melted tungsten. Journal of Materials Processing Technology, 222, pp. 32-44

9. Pacurar, R. and Pacurar, A. (2016). Applications of the Selective Laser Melting Technology in the Industrial and Medical Fields. New Trends in 3D Printing.

10. Sarin, V. (2014). Comprehensive Hard Materials. Elsevier.

11. Kríž, A. and Bricín, D. (2017). Properties and Testing of Cemented Carbides. Powder Metallurgy - Fundamentals and Case Studies.

12. Leitz, K.-H., Singer, P., Plankensteiner, A., Tabernig, B., Kestler, H., Sigl, L.S. (2016). Fluiddynamical Modelling of Laser Beam-Matter Interaction in Selective Laser Melting. DOI: 10.13140/RG.2.2.25651.02087.