MECHANICAL PROPERTIES OF POWDER CoCrW-ALLOY PREPARED BY AM TECHNOLOGY

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This study is focused on the evaluation of mechanical properties and microstructure of fabricating Ni-free CoCrW-alloy. Samples were prepared by additive manufacturing technology – selective laser melting. The chemical composition of used metal powder was – 60.5% Co, 28% Cr and 9%W. Parameters of SLM were given by powder supplier. The shape of thesampleis designed according to MPIF. After recommended heat treatment, the static tensile test was carried out at Tinius Olsen machine, the microstructure and porositywere observed, also. In results is interpreted the relations between porosity, microstructure, and mechanical properties. This report is the basis for further experiments aimed at improving the mechanical properties about manufacturing conditions.

KEYWORDS
powder CoCrW-alloy, selective laser melting, mechanical properties, porosity

1 INTRODUCTION

Generally, CoCr – alloys are used in dentistry for crowns, bridges, and frames for metal ceramic veneering and combined restorations.CoCr-based alloys have been utilized in thedentalprosthesis since they offer good resistance to corrosion [Ouerd 2008].It has been shown on one hand that chromium content inthese alloys is determining as for the corrosion resistance,and on the other hand, the presence of certain oxides at thealloy surface is very beneficial for a good adhesion of theceramic [Karaali 2005].Recently, alloys with high content of tungsten instead of molybdenum have been developed aiming a better ceramic-metal adhesion [Wang 2012].Co–Cr–Mo ternary alloys have been studied more as compared to Co–Cr–W ternary alloys which have received little attention, particularly, microstructure studies by transmission electron microscopy, which are not shown in the literature [Karaali 2005].
The amount of scientist research is focused on processing techniques and the production processes [Frazier 2014].However, focus on the mechanical properties of the resultant products of additive manufacturing (AM) products is needed. Only a little attention to machinability and its improvement is paid, but other relevant mechanical properties are not observed [Lindigkeit 2014].

Selective Laser Melting (SLM) is a generative production method in which the desired components are produced directly from 3D data. Based on the data at hand, even highly complex parts can be produced from different metallic materials.With the SLM method, the work pieceis constructed in a three-dimensional layer structure. To accomplish this, the metal is applied in thin layers of very fine powder and, using a laser beam, melted onto those areas where thework piece will be developed. Depending on the surface quality and production speed requirements, the powder is automatically applied with layer thicknesses of 20 to 100 µm. In the following step, a powerful fiberlaser selectively melts the designated areas. Sharp focusing provides the laser beam with a very high power density by which the material is melted in a very precise manner. Thus, workpieces with an absolute density can be produced with wall thicknesses from 40 µm on up [Udroiu 2012].Positioning and appropriate supporting of the model are crucial for the selective laser melting technology. This pre-processing step highly influences overall shape and size precision of the final product [Safka 2015].
A significant disadvantage of the PM processing methods is the presence of porosity,as well as the highly inhomogeneous microstructures. But it depends on the particular technology [Bidulska 2012].Most of the properties of PM materials are stronglyrelated to porosity. The pores act as crack initiators and due to their presence distribution of stress is inhomogeneous across the cross section and leads to areduction of the effective load bearing area. Both the morphology and distribution of pores have a significant effect on the mechanical behaviorof PM materials. The effect of porosity on the mechanical properties depends on several factors such as the quantity of pores, their interconnection, size, morphology and distribution[Bidulska 2010, Bidulsky 2014].Very important is the evaluation of formability, which is closely linked with the porosity and mechanical properties [Petrousek 2015].
This article intends to outline the mechanical properties, microstructure, and porosity of the common commercial CoCrW-alloy prepared by SLM technology. The relation between porosity and mechanical properties is also discussed.

2 MATERIAL AND EXPERIMENTAL PROCEDURES

As experimental material the powder CoCrW-alloy (Remanium®star CL powered by Dentaurum) was used. The chemical composition is given in Tab. 1.

Component	Mass [%]
Co	60,5
Cr	28
W	9
Si	1,5
Other elements < 1%: Mn, N, Nb, Fe. Free from Ni, Be and Ga.	

Table 1. Chemical composition of powder CoCrW-alloy

Samples for thestatic tensile test were produced by SLM (selective laser melting). Dimensions of the sample according to the MPIF Standard Test Methods Edition 2007are shown in Fig.1.The thickness of samples was 2,67mm. Thegrayarrow in Fig.1 shows thedirection of thebuilding. All samples were produced in one batch.

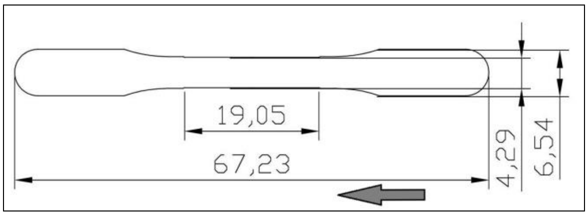

Figure 1.Sample for statictensile test

Thermal conditions of heat treatment replied to recommended conditions by themanufacturer of metal. For optical microscopy, the 50/100 magnification was used (Zeiss andAxio Vision software).Total porosity of studied material was calculated by equation (1) [Bidulska 2013]:

$$P = \left(1 - \frac{\rho_g}{\rho_t}\right).100[\%] \qquad (1)$$

where P – total porosity,
ρ_g – green density [kg.m^{-3}]
ρ_t – theoretical density [kg.m^{-3}].

For second way to evaluate porosity was Archimedes method used, and ImageJ software was used. Then the results were compared.
The tensile test was carried out with static strain rate – 0,002s^{-1} on Tinius Olsen machine – H300KU.

3 RESULTS AND DISCUSSION

3.1 *Optical microscopy and porosity*

Optical microscopy was observed in three directions, Fig. 2.Porosity was determined in each direction separately – on edge and in the middle of samples.

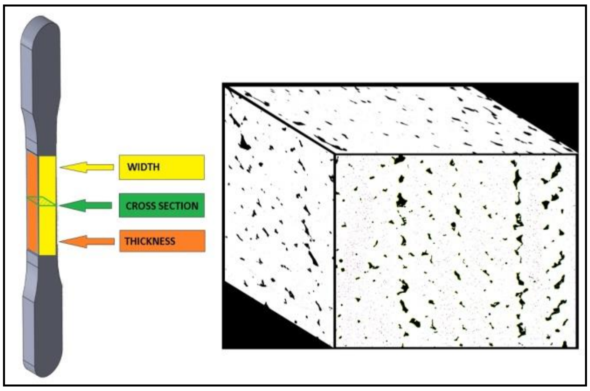

Figure 2. The directions of structure observation

Based on observation, it is possible to say that distribution of pores is non-uniform. Especially around the edges of the samples huge inclusions were observed. Their definition will be discussed later.
In Fig.3 the significant line spacing is visible, mainly in areas close to samples surface. Line spacing direction corresponds to building direction of samples. It is questionable if this is due to the material properties or additive manufacturing technology.
Each figure of themicrostructureis taken in the same direction on the direction of building shown in Fig. 3.

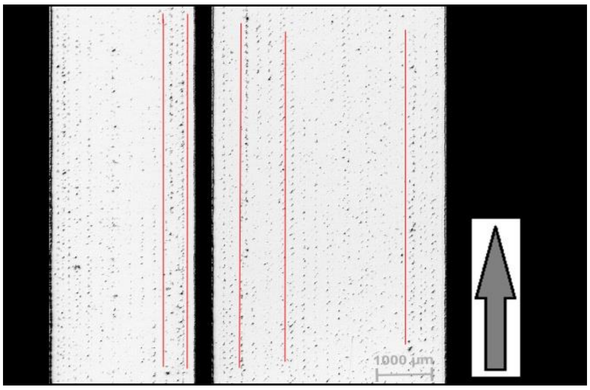

Figure 3. The directions of structure observation

In Fig. Four non-uniformity of porosity is obvious. Despite the facts that areas highlighted by arrow supposed to be the pores, according to the literature, it can be said that it is an inclusion [Bidulsky 2014]. Some authors define it as pores [Slotwinski 2014] others like Si-rich inclusions[Kim 2016] Compared with typical pores (blue marks in Fig. 5) and its dimensions it can be assumed that this is not pores. Distribution of inclusions is line spaced also.

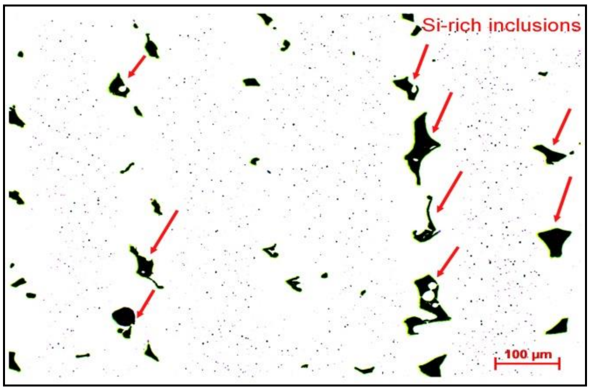

Figure 4.Line spaced inclusions, magnification 100x

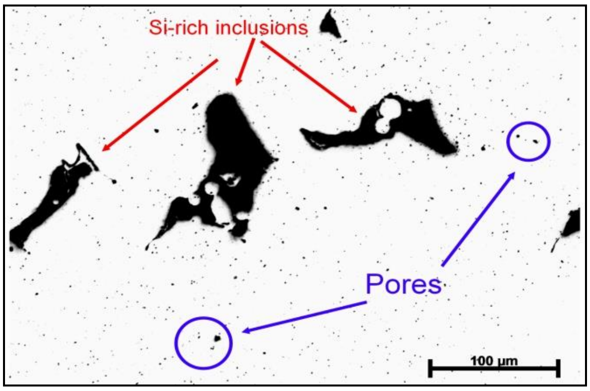

Figure 5.Si-rich inclusions in detail, magnification 200x

The porosity was observed by two different ways, by mathematical calculation (equation 1) and by thegraphic method. Statistically, for evaluation of porosity ten different samples were used. The average values for each methodare given in Tab. 2.

Method	Porosity [%]
Mathematical calculation	2,85
Graphical method	2,28

Table 2. Results of porosity evaluation

For assessment by graphical method100x magnificationwas used.Inclusions are excluded and only obviously pores are evaluated. For porosity evaluation

3.2 Static tensile test

Results of thestatic tensile test are showed in Fig. 6. Ten representative strain-stress curves were selected to show differences in mechanical properties. These differences were observed despite the identical conditions of production.

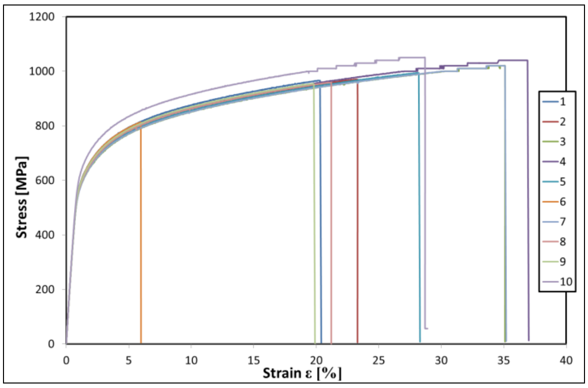

Figure 6. Strain-stress curves of CoCrW-alloy

In Tab. Three values of yield strength (YS) and ultimate tensile strength (UTS) for each sample are presented. The variations range of measured YS values is 48 MPa, the variations range of measured UTS values is 237 MPa. These values correspond evaluated porosity.

	YS [MPa]	UTS [MPa]
1	564	966
2	556	970
3	550	1020
4	558	1040
5	553	994
6	556	813
7	538	1020
8	555	959
9	563	954
10	598	1050

Table 3. Mechanical properties of CoCrW-alloy

Other problems arise during atensiletest, the cracks were created near to the heads of samples. This is undesirable phenomenon due to thepossibility of plastic properties evaluation. Based on Fig. 6 is clear that elongation of each sample is incomparable. This iscauses by non-uniform porosity and the presence of inclusions.

4 CONCLUSIONS

According to the literature, experimental results and its evaluation the following conclusions can be formulated:

- Even though additive manufacturing technology (SLM) is suitable for powder CoCrW-alloy, it is necessary to pay more attention to resulting properties – mechanical and plastic properties, microhardness, machinability, etc.
- Evaluation of porosity in two different ways showed comparable results.
- Porosity is inhomogeneous and has aninfluence on mechanical properties. This was reflectedin different values of UTS and location of fracture during atensile test.

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