MME SEE CONGRESS 2023

5th Metallurgical & Materials Engineering Congress of South-East Europe
Trebinje, Bosnia and Herzegovina
7-10th June 2023

CONGRESS PROCEEDINGS

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MICROSTRUCTURE ASSESSMENT OF Co ALLOY INTENDED FOR DENTISTRY

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Cobalt–chromium–molybdenum (CoCrMo) alloys are known for medical use due to their biocompatibility, corrosion and wear resistance. The chemical and phase composition, as well as microstructure of the alloy directly affect the mechanical properties. In this investigation, CoCrMo alloy samples were obtained by vacuum precise casting. The procedure of melting and casting process as well as their parameters are given. Molds fabricated of copper, gray iron, steel, ceramics and graphite were used during the casting process. In this way, the cooling rate influence on the obtained microstructure was examined. Besides, different casting temperatures (1400°C, 1450°C and 1500°C) were applied for each kind of mold. After metallographic preparation, the microstructure was examined on the cross section of samples by optical microscopy. The obtained results show that by increasing the cooling rate, the microstructure of samples become finer and more homogeneous.

Keywords: CoCrMo alloy, vacuum precise casting, cooling rate

Introduction

Co-Cr-Mo alloys are distinguished by their high strength, biocompatibility, non-corrosiveness, and exceptional wear resistance [1, 2]. These alloys exhibit high fluidity and low viscosity at elevated temperatures, which allows for the casting of complex shapes [3]. These properties make them well-suited for use in dentistry for the manufacture of various dental components, including prostheses, bridges, dental crowns, and orthodontic appliances. Additionally, their resistance to tarnishing also makes them ideal for dental applications [4, 5]. Being in the aggressive environment of the oral cavity, Co-Cr-Mo alloys must be biocompatible [6]. Cobalt, chromium, and molybdenum are microelements in the human body, and these alloys are recognized as hypoallergenic [2]. They exhibit excellent corrosion resistance, owing to the formation of a passivating layer that inhibits the release of metal ions into the oral cavity [2, 7].

The microstructural characteristics of a material have a profound effect on its mechanical properties, thus defining its suitability for a given application [8]. A heterogeneous and coarse-grained microstructure usually results in low strength and increased brittleness, while a fine-grained, uniform morphology is a good indicator of superior strength. The final obtained structure largely depends on the processing temperature and cooling rate. Elevated processing temperatures are more likely to yield a homogeneous and coarse-grained structure, with a higher density of dislocations, compared to lower cooling temperatures [9]. Rapid cooling leads to the formation of fine crystals, which contributes to increased strength and ductility [10]. Different molds have different coefficients of thermal conductivity, with higher values corresponding to faster cooling [11].

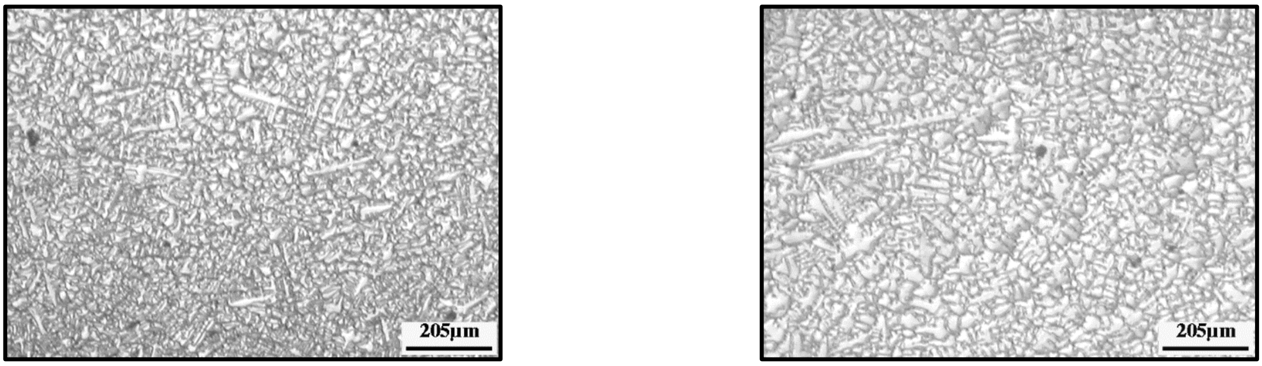
Materials and methods

Alloy was prepared from the following elements Co (99.99 wt.%), Cr (99%), Mn (99.9%), Mo (99,8%), Si (98%) by vacuum precise casting in a vacuum induction furnace. Cobalt chromium and manganese are integral components of alloys, while manganese and silicon are important for detoxification and cleaning of alloys during melting. Granulation of raw materials is 0.5-5 *mm*.

In order to prevent the oxidation of the alloy and to obtain its appropriate chemical composition, the casting process was carried out in a vacuum induction furnace. Melting and casting process was performed under the vacuum of 0.04 mbar Five different kinds of molds with dissimilar thermal conductivity coefficients were prepared for casting alloys, from the following materials: copper (386 W/m.K), gray iron (52.5 W/m.K), ceramic (1.38 W/m.K), steel (50 W/m.K) and graphite (4180 W/m.K) [12, 13, 14, 15]. The molds should be preheated to the temperature of about 1000 ºC while the casting temperatures were in range of 1450-1550 ºC. After melting, casting and cooling, five series of samples cast in five different molds were made. The microstructure of samples (cast in five different molds) was examined after the usual metallographic preparation. The samples were ground and polished. Polishing was carried out using alumina suspension (Al_20_3) that was applied on a rotating self-adhesive disc. A mixture of potassium ferrocyanide, potassium hydroxide and water was used for samples etching. For the qualitative microstructure analysis the image analysis device Leica Q500MC was used.

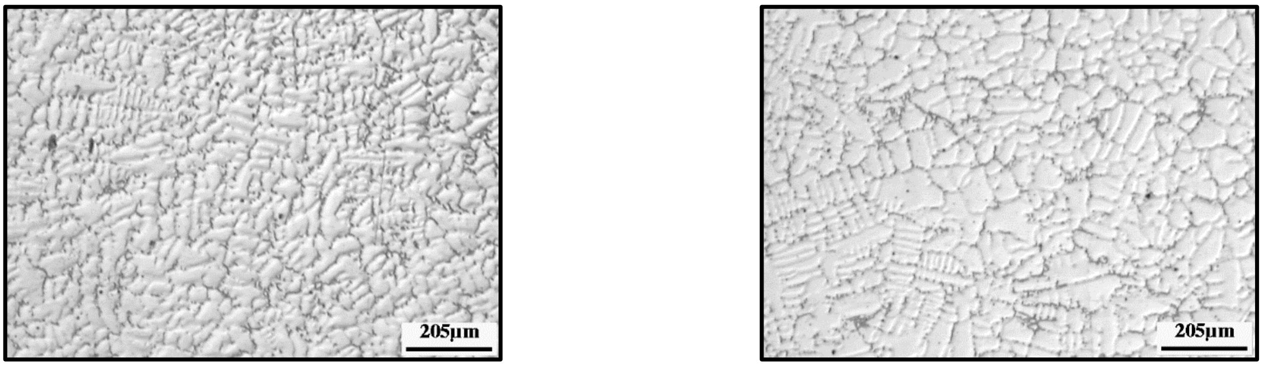
Results and discussion

The characteristic microstructure appearance at the cross section of samples casted in five different molds is shown in Figures 1, 2, 3, 4 and 5. Sample 1 was cast in graphite-base mold, sample 2 in copper mold, sample 3 in gray iron mold, sample 4 in steel mold and sample 5 in ceramic mold.



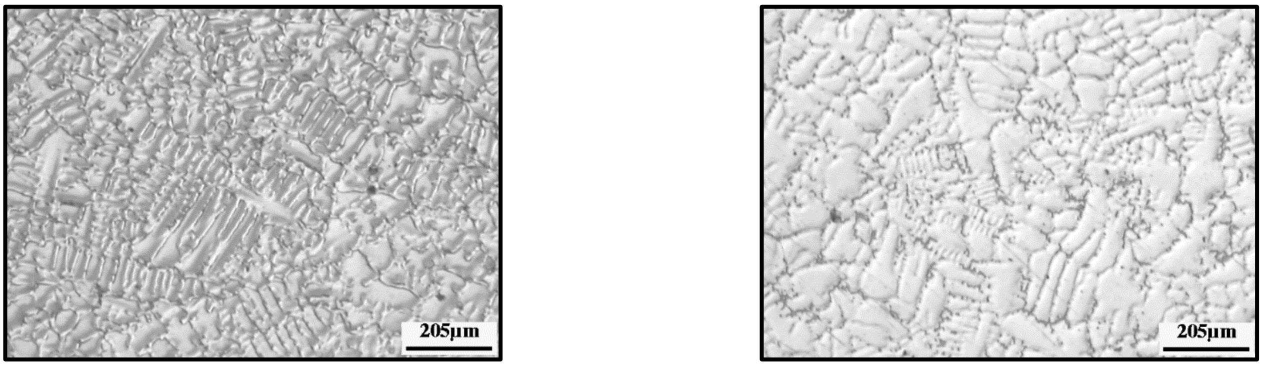
(a) (b)

Figure 1 Microstructure of sample 1 cross section, (graphite-base mold), surface area (a) center (b)



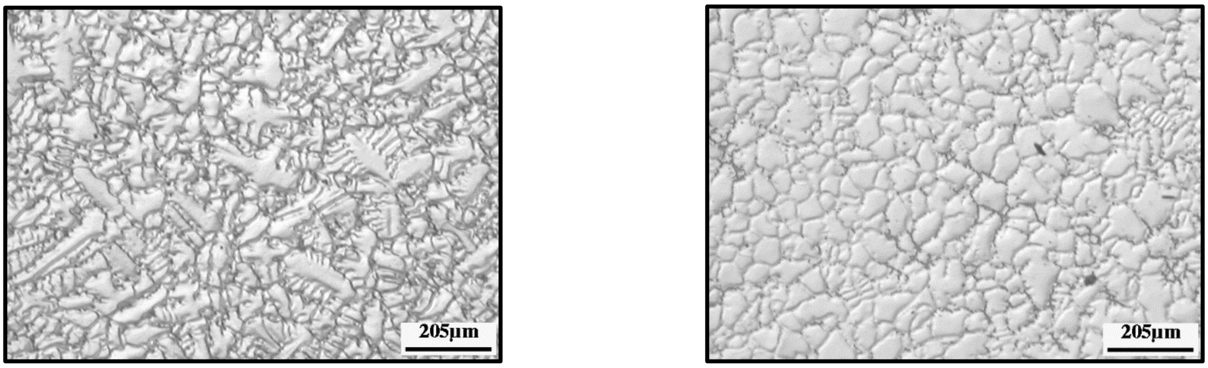
(a) (b)

Figure 2 Microstructure of sample 2 cross section, (copper mold), surface area (a) center (b)



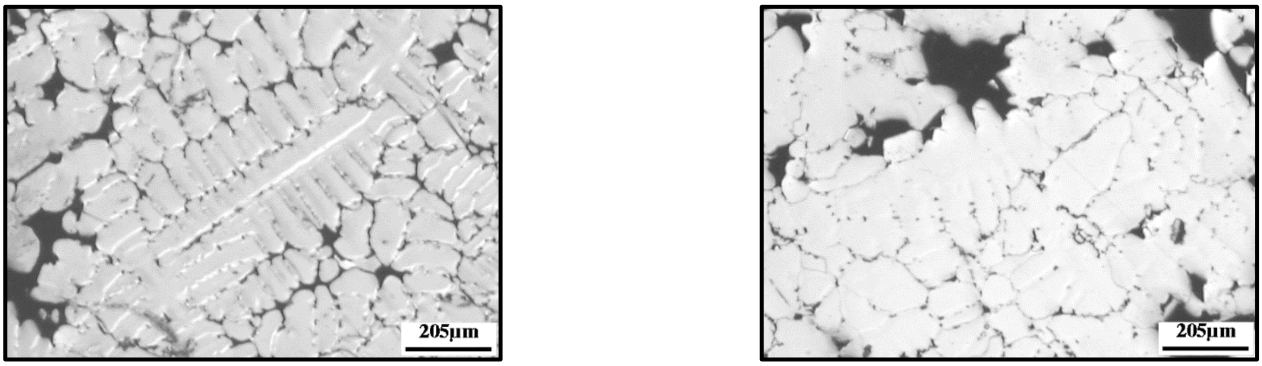
(a) (b)

Figure 3 Microstructure of sample 3 cross section, (gray iron mold), surface area (a) center (b)



(a) (b)

Figure 4 Microstructure of sample 4 cross section, (steel mold), surface area (a) center (b)



(a) (b)

Figure 5 Microstructure of sample 5 cross section, (ceramic mold),surface area (a) center (b)

As it can be seen, the cellular/dendritic morphology is the result of Co segregation from the solid solution during the solidification process. However, the morphology of the samples differs from one another. This is a consequence of the different cooling rate, because each material (five kinds of molds) has various thermal conductivity coefficients. If the thermal conductivity coefficient is higher, the cooling rate is also higher. The finest and the most homogenous is microstructure of the sample 1 and 2, cast in graphite-base mold and copper mold, because of the high cooling rate. With cooling rate decrease, the microstructure became less fine and more dendritic (samples 3 and 4).

Due to the small difference in thermal conductivity coefficients, the microstructure of samples 3 and 4, does not differ significantly. Sample 5 has the roughest microstructure with pronounced dendrites and a lot of porosity, because of the lowest cooling rate.

In all samples, a slightly larger grain can be observed in the center compared to the surface area. This is also a consequence of the cooling rate decreasing from the surface area to the center of samples.

Conclusion

Results of microstructure assessment of the samples reveal a difference in the morphology, size and shape of the grains. The cooling rate directly affects the obtained microstructure of the alloy. The higher cooling rate results in a finer and more homogeneous microstructure, which is the case with the samples 1 and 2 cast in graphite base mold and copper mold. Some less fine and less homogeneous microstructure has samples 3 and 4 cast in gray iron mold and steel mold. The poorest microstructure with porosity appears, has sample 5 cast in ceramic mold. It is clear that the cooling rate directly affects the microstructure and that the appropriate structure can be achieved by properly choosing the material from which the mold is made. This is very important because the mechanical properties depend on the microstructure, which will be the subject of study in our following researches.

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