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Influence of Homogenization on the Phase Composition of the Cast Cobalt Super-Alloy

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Abstract.
An alloy based on Co-Cr-Mo with no Ni content used for prosthetics is investigated. Data for the structure and the phase composition during homogenization regimes are obtained. An ability to use the high temperature as a method for increasing operational capacities of the alloy is demonstrated.

Keywords: cobalt super alloy, homogenization, structure, phase composition, high temperature treatment, X-Ray, cobalt super-alloy, prosthesis, high temperature treatment, γ-Co, ε-Co,

1. Introduction

The cobalt-base nickel free alloys used generally for manufacturing dental and surgical prostheses and implants possess a good biological tolerance and biocompatibility within the human body tissues [1-6] because of the absence of dangerous for the human health nickel ions [1].
Due to their complex configuration and individuality of the implants, they are made mainly by the methods of precision casting. The application of plastic deformation to improve their properties is excluded. Therefore, the alloy has lower mechanical properties and does not use its full working and technological life.
The aim of the work is to study some technological features that a cast cobalt-based alloy used for medical implants offers us. Influence of homogenization on the phase composition of the cast cobalt super-alloy.

2. Material and methods

A cobalt alloy containing 31% chromium, 4% molybdenum and the rest of the cobalt obtained at IMSETHA-BAS was studied. The technology of sample preparation is described in detail in [9].
Samples for metallographic and X-ray structural examinations with dimensions – diameter 15 mm and thickness 2 mm, which are cut from cast cylindrical blanks. To avoid changes in the structure of the test specimens, they were cut by a wire machine by electro-sparking in a water bath.
In order to monitor the possible phase states of the investigated alloy after casting, one part of the samples was examined in the cast state, and another – after homogenization of the cast ingot at 1250°C for 6 hours with air cooling. The same samples were tested after subsequent hardening of 110ºC /15 min / in water / without and with homogenization / and aging at 730ºC – 4 hours.
The aging temperature was determined by other dilatometric studies [9].
The results of preliminary metallographic studies of pre-prepared sections in different structural states after casting, homogenization, hardening and aging are published in [9].

The X-ray diffraction analysis was performed with Philips-Mikro 111 computerized equipment. The diffraction spectra were studied in the range of reflection angles 15-115°, with $Co_{K\alpha}$-radiation, step 0.02 o/min, time constant 10 sec. The “Origin 5.0 Professional” program was used to record the diffraction pattern and process the results.

3. Experimental results and discussion

In Fig. 1 shows the phase diagram of the two-component Co-Cr alloy [10], including the alloy studied by us in the temperature range up to 1100°C.
According to the state diagram, the following solid-phase reactions and phases are typical for the Co-Cr binary system:

- High temperature modification rich in cobalt phase, with wall-centered cubic lattice (FCC), s.c. γ-Co;
- At temperatures below 900°C (for the alloy we studied) it turns into a cobalt-rich phase with a hexagonal lattice, etc. ε-Co;

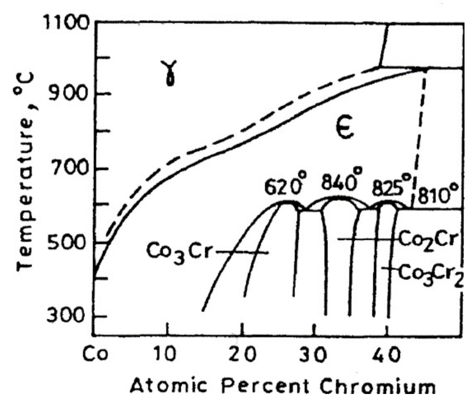

Fig.1. Phase diagram of Co-Cr [9]

- At temperatures below 840°C ε-Co decomposes into sigma phase (σ-phase) and chromium-rich volume-centered cubic lattice, so. α-Co. The sigma phase is an inter-metallic compound that has an approximate Co_2Cr_3 composition.

This is valid for the dual Co-Cr system, but the presence of molybdenum of the order of 4% changes the equilibrium of the system.
According to the literature, in the presence of molybdenum, the σ-phase is already a triple inter-metallic compound of the $Co_xCr_yMo_z$ type [10].
The state diagram reflects the equilibrium states of the metal system, which are reached after prolonged tempering, which are not typical of the applied in practice technological regimes for obtaining products that are the subject of our research. However, it shows the possible pathways for one or another phase reaction and the possibilities for obtaining a certain phase composition.
The results of the diffraction X-ray diffraction analysis of cast, hardened and aged samples, without and after homogenization, are shown in Fig. 2 and Fig. 7.
The analysis of the obtained radiographs processed with the database of [11,12] showed that the phase composition of the cast samples is γ-Co.
The homogenization of the cast samples does not lead to changes in the phase composition of the alloy, but only increases the intensity of the diffraction lines and the reduction of their width. This means that the homogenization leads only to structural changes related to the reduction of the internal micro-stresses in the material and the increase of the crystal domains, which is an expected and logical result – Fig. 2 and Fig.3.

It was found that the phase composition of the hardened samples is γ-Co and ε-Co-Fig. 4 and Fig.5. Again, it can be seen that the homogenization of the samples before quenching does not qualitatively change their phase composition.

After aging of the hardened samples for 6 hours at 730°C, the phase composition of the alloy is γ-Co and σ-phase – Fig. 6. The phase composition of the homogenized samples is similar – Fig. 7, after hardening and aging.

Table. Volume percentage of ε-Co and σ-phase in the studied alloys after heat treatment

№	Heat treatment	Volume percentage ε-Co	Volume percentage σ-phase
1	Hardening – without homogenization	20,2%	0%
2	Tempering – after homogenization	15,4%	0%
3	Tempering – without homogenization	0%	20,08%
4	Tempering – after homogenization	0%	14,45%

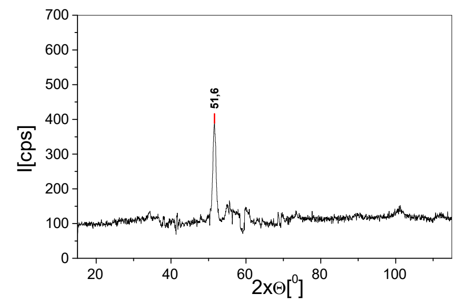

Fig. 2. Cast sample

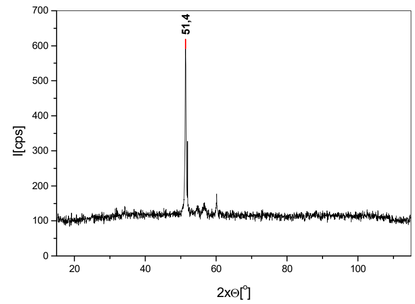

Fig. 3. Cast and homogenized sample

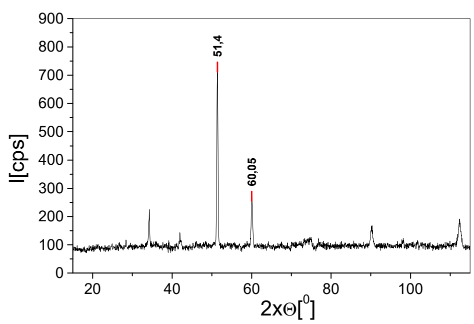

Fig. 4. Hardened without homogenization

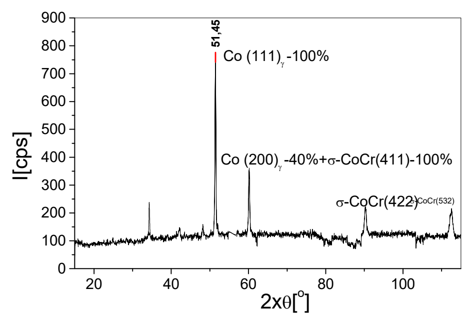

Fig. 5. Hardened after homogenization

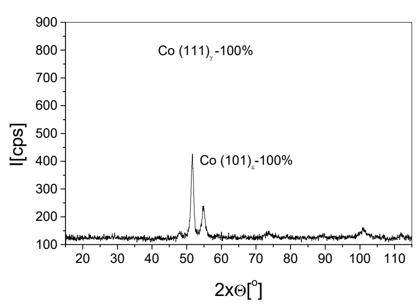

Fig.6. Hardened and aged without homogenization

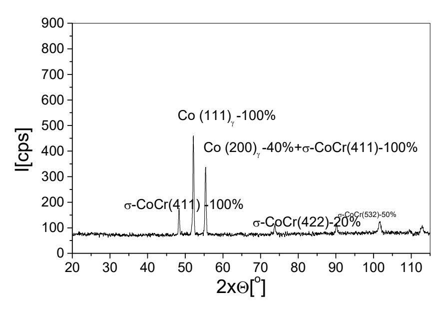

Fig.7. Hardened and aged after homogenization

To obtain a quantitative idea of the influence of homogenization on the amount of available phases in the studied alloy after heat treatment, the dependence proposed in [13] was used, which connects the volume percentage of ε-Co in the alloy Vg (ε-Co) with the intensity 100% line reflection of ε-Co and γ-Co:

$$Vg(\varepsilon\text{-}Co) = g(\varepsilon)(101) / [g(\varepsilon)(101) + [3/2.g(\gamma)(200)] \times 100\%$$

A similar dependence was used to calculate the amount of σ-phase in the studied samples after aging. The results are shown in the table below.

The results show that the homogenization of the alloy before heat treatment leads to a reduction in the amount of ε-Co and σ-phase in the alloy. The obtained practically identical values of the volume percentages of two phases after hardening and aging show that most probably the σ-phase in the studied alloy is obtained from γ-Co and necessarily passes through ε-Co. It should be mentioned that from our other studies of such alloys it was found that in terms of crystallography such a path of phase reactions is crystallographic and energetically completely justified.

4. Conclusions

Preliminary homogenization of the studied Co-Cr-Mo-alloy does not change its phase composition, but only reduces the volume of the converted and separate phases during heat treatment. It was found that the most probable path for separation of the σ-phase in the investigated alloy is through the ε-Co phase obtained during hardening.

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