Structural Characterization of Some CoCrMo Alloys with Medical Applications

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Cobalt alloys are difficult to make, which is why their use has been limited, but ongoing research led to the development of specialized hardware methods. CoCrMo casting alloys are used on a large scale for manufacture of various devices surgically implanted in the body, they have always continued to increase their area of applications.

Keywords: CoCrMo alloy, microstructures analysis, dilatometer analysis

Metal alloys based on chromium and cobalt are widely used in the dentistry field, as dental works and medical instruments. CoCrMo casting alloys have been used for many years to achieve partial dentures, replacing almost all gold alloys [1].

Metals and alloys used in dental applications should have, at least the following properties:

- chemical properties of the dental work should provide good resistance to corrosion and respectively no physical changes on contact with oral fluids [2];
- mechanical and physical characteristics, such as conductivity, melting point, strength and thermal expansion coefficient should be favorable, showing changes from one application to another, with certain minimum value;
- the chemical nature of the alloys should not cause toxic or allergic reactions to the patient;
- alloys, metals and materials must be easily accessible, in case of emergency and relatively inexpensive [3].

The cast CoCrMo alloys are used on a large scale on manufacturing of various surgical devices, which are implanted in the body [4].

Since 1949 it has been estimated that over 80% of partial dentures were made of CoCrMo alloy, and after 1969, more than 87%. In present almost all the metal plates of partial dentures are made of Co-Cr-Mo alloys [5].

Cobalt-based alloys generally have a good wear resistance, oxidation resistance, corrosion resistance and are less complex than the nickel-based alloys [6].

Cobalt-based super alloys are alloys with great refractory properties, they contain: cobalt, nickel, iron and small amounts of silicon, manganese, molybdenum, tungsten, tantalum, niobium, titanium, boron, [7]. Processing by forging cobalt-based superalloys are generally difficult, so that the products of these alloys are produced by precision casting [8].

Experimental part

Materials and methods

The alloy

In this work we have carried out studies on CoCrMo alloy with the following chemical composition, shown in table 1.

The technical details of this alloy, specified by the manufacturer, are presented in table 2.

Specimens used in the experimental test were subject to the following operations:

Heat treatment parameters

Samples who were obtained by casting were undergone the heat treatment homogenization, annealing, have complied with the following parameters: heating at a temperature of 1100°C, hold for 5 h, cooling with the furnace.

The heat treatment of the alloy was performed in an electrically heated treatment furnace, made by UTTIS [9].

Table 1
CHEMICAL COMPOSITION OF THE ALLOY

Co %	Cr %	Mo %	C%	Si%	Mn%
65	29	5	0.4	0.35	0.25

Table 2
TECHNICAL DETAILS OF THE ALLOY

The hardness	The density	The melting range	Casting temperature
370 HV	8.0 g/cm^3	1200 -1390°C	1600°C

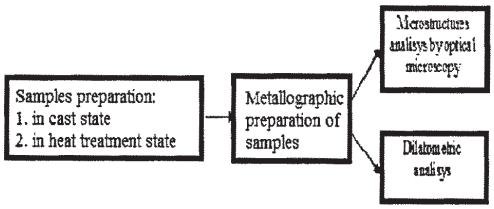

Fig. 1. The experimental processes flow chart

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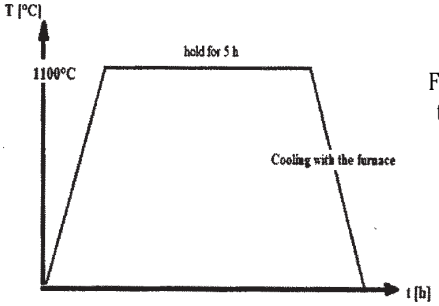

Fig. 2. Heat treatment temperature profile

Sample preparation

Preparing samples is a very important step for the microscopic research [10, 11]. On the quality of the metallographic samples depend the investigation processes and the results [12]. In metallography any imperfection that occurs in sample preparation may lead to incorrect or unsafe results.

The sample was embedded in phenolic powder with a Metapress-Machine. After embedding the samples were polished. Grinding was carried on the belt sander and polisher Forcipol 2 V, with 8 metallographic papers from 180 to 2000 grit [13]. For contrast a reaction with a $FeCl_3$ solution at 300°C was carried.

Characterisation methods

The characterization methods involved are Optical Microscopy, using an optical inverted Zeiss microscope and Dilatometer analysis, using a differential dilatometer LINSEIS, type L75H/1400.

Results and discussions

Microstructural analysis

We've analyzed the structure of CoCrMo samples using optical microscopy [14, 15]. The microstructure of a metal material is the relationship between material processing and its behaviour during use. The microstructure is defined by the crystallographic orientation, texture, morphology, distribution, size and number of existing phase, [16].

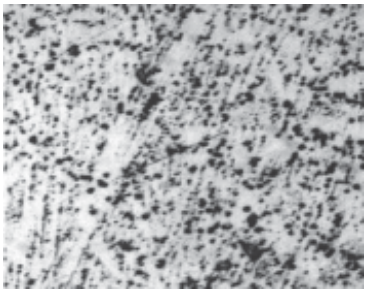

Fig. 3. CoCrMo Alloy - cast condition, heat untreated, 100X, attack solution: $FeCl_3$

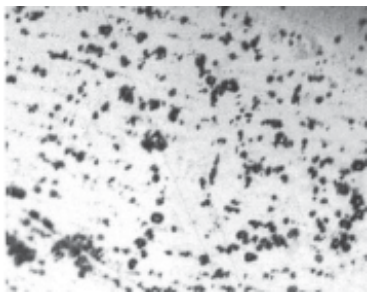

Fig. 4. CoCrMo Alloy - cast condition, heat untreated, 200X, attack solution: $FeCl_3$

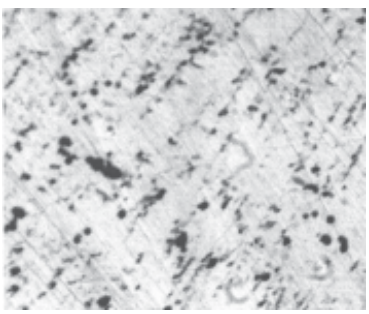

Fig.5. CoCrMo Alloy - cast condition, heat untreated, 320X, attack solution: $FeCl_3$

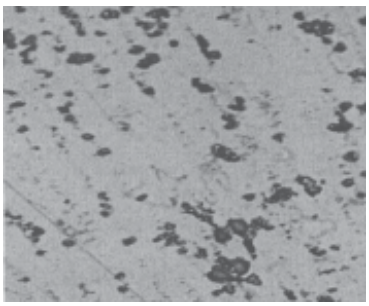

Fig. 6. CoCrMo Alloy - cast condition, heat untreated, 500X, attack solution: $FeCl_3$

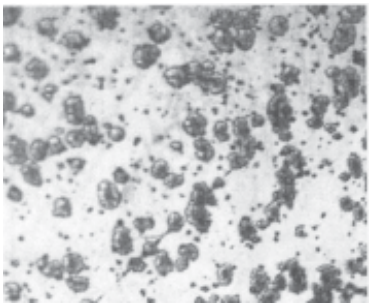

Fig. 7. CoCrMo alloy after homogenization annealing, 100X

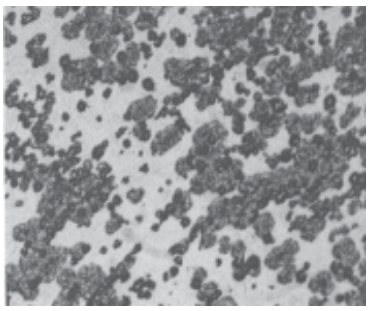

Fig. 8. CoCrMo alloy after homogenization annealing, 200X

Microstructural aspect of a untreated CoCrMo alloy (fig. 3) is a coarse structure, relatively uniform, with interdendritic separation of carbides and eutectic with spot arrangement (due to $FeCl_3$).

In figure 4 the untreated CoCrMo shows grains with fine separations, uniform, interdendritic with pointlike eutectic. In figure 5 untreated cast CoCrMo we notice the grain boundary, separation of dendritic eutectic and fine carbides. In figure 6 the untreated cast CoCrMo (x500) shows fine carbides and eutectic dendritic separations.

CoCrMo alloy microstructure after homogenization annealing which consisted of heating at a temperature of 1100°C, maintaining for 5 h, and cooling with the furnace is shown in figures 7-10. For contrast a $FeCl_3$ solution was used.

The aim of treatment is to homogenize the initial structure of castings, and its role is to remove dendritic and interdendritic segregation [17]. By using this method, uneven dendritic structure of the alloy returns to the regular polyhedral structure [18]. At high temperatures material oxidation may occur, with formation of iron oxide films intergrains which reduces the material corrosion.

The CoCrMo alloy (fig. 7) unde homogenized heat treatment condition (x100) shows the alpha non-homogenous solution with dendritic arrangement, oblong with interdendritic oriented precipitates, due to $FeCl_3$ attack. In Figure 8 we can observe agglomeration of coarse and fine carbides.

The microstructural aspect of CoCrMo alloy with homogenization heat treatment at 1100°C (x320) shown in figure 9 shows agglomeration of coarse and fine

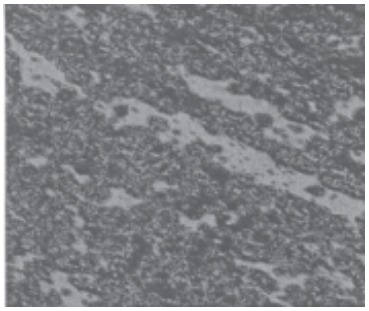

Fig. 9. CoCrMo alloy after homogenization annealing, 320X

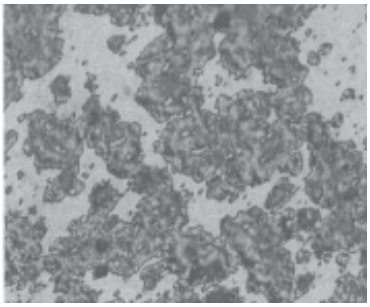

Fig. 10. CoCrMo alloy after homogenization annealing, 500X

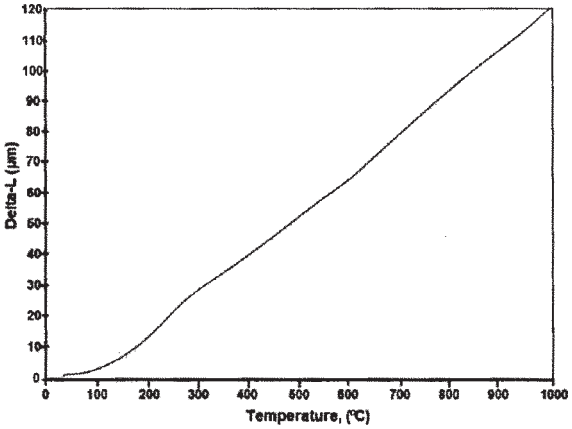

Fig. 11. Variation of temperature coefficient of expansion for CoCrMo alloy, cast condition

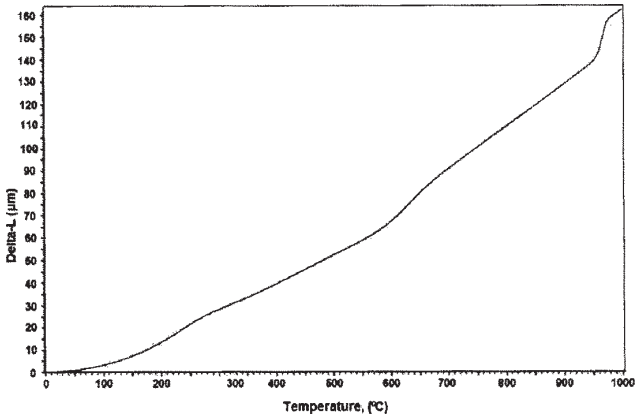

Fig. 12. Variation of temperature coefficient of expansion for CoCrMo alloy, state after homogenization annealing treatment.

Table 3

ELONGATION VALUES FOR Co-Cr-Mo ALLOY CASTINGS AND SPLINTERING PROCESSING CONDITION

Temperature [°C]	30.0	67.8	143.0	212.5	270.0	360.4	458.0	547.8	676.5	737.0	824.0	1000.0
Expansion coefficient [µm]	0.0	1.4	6.1	14.9	24.4	35.1	46.8	58.0	75.2	84.1	96.5	120.0

Table 4

VALUES OF THE ELONGATION FOR THE SAMPLES AFTER THE HOMOGENIZATION ANNEALING

Temperature [°C]	24.3	163.0	268.1	372.0	448.5	568.0	609.0	688.2	756.7	853.5	902.2	1000.0
Expansion coefficient [µm]	-0.2	8.3	23.9	35.7	45.3	6.1	68.9	88.0	101.2	119.4	128.7	161.8

carbides. In figure 10 we have an eutectic with dentrites and fine carbides precipitated in matrix.

Dilatometer analysis

The phase transformations in solid phase can be analyzed by means of dilatometry, which measures the change in size of a sample, with the help of displacement sensor by means of a quartz rod [19].

In the case in which a phase transition material occurs, at variation curve of the thermal expansion coefficient with temperature discontinuities will occur, due to the fact that the new phase has a different volume than of the original [20-23].

Changing the volume of material at the temperature has a great practical significance, especially in the case of important processes such as: welding, casting, or heat treatment [21]. Generally, the solidification and melting phenomena have a great importance as they are responsible for macroscopic or microscopic defects in crystals [22].

Dilatometer analysis is used to determine the points of transformation in solid state materials and thermal expansion coefficient. Dilatometer analysis is based on the appearance of deviations of expansion-temperature curves, from the normal appearance of these curves, from the transformation temperatures, deviations caused by dimensional changes of the samples.

Using large sample favour good accuracy in determining elongation, instead using small samples gives us a good temperature control accuracy and repeatability of results.

To analyze dilatometer samples were processed by cutting at dimensions that fall in the class of measuring device: cylindrical samples with the diameter between 3 and 6 mm and length with values between 10 and 50 mm.

Our samples have diameter of 4 mm the length of 14.97 mm for the casted sample and respectively, 14.56 mm for the sample annealed for homogenization.

The heating rate was required for the experiment at 10°C / min. This rate was used to obtain accurate and repeatable experimental data.

Characteristic curve of the CoCrMo alloy in casting sate and processed by cutting is shown in figure 11.

Table 3 presents the expansion coefficient variation of a CoCrMo casted sample.

The characteristic curve of CoCrMo alloy in homogeneous state is shown figure 12.

Table 4 shows the changes in temperature and thermal expansion coefficient for a CoCrMo alloy sample, after the homogenization heat treatment (heating at 1100°C and hold 5 h with slow cooling in furnace).

Conclusions

The microstructure of a metal material represents the relationship between material processing and its behaviour during use. Structural investigations performed on CoCrMo alloys dental emphasize structural changes caused by temperature homogenization parameters.

We can see that there are differences between the micstructure of untreated CoCrMo alloy and the heat-treated for homogenization. Untreated CoCrMo alloys have a coarse structure, relatively uniform, compared to the heat treated ones where the structures are composed of coarse and fine carbides.

The microstructure of casted CoCrMo presents interdendritic separation and eutectic carbides with pointlike arrangement, compared to the treated samples that presents non-homogenous alpha solution with dendritic arrangement, elongated, with precipitates and with interdendritic orientation.

The chemical etching was done with a solution of $FeCl_3$.

The purpose of the homogenization treatment is to improve the structure of the initial heterogeneous casting, and its role is to remove the interdendritic and dendritic segregations. Using this method, uneven dendritic structure of the alloy returns to the regular polyhedral structure.

From the dilatometer analysis of the samples we can observe that our alloy has a good dimensional stability stability in low temperature range (up to 6 ... 8 microns - maximum temperature 200° C) and in rest it behaves like superalloys with a linear increase with the rising of temperature.

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