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STRUCTURAL CHARACTERISTICS IN COBALT BASED ALLOYS

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ABSTRACT

In the present paper there are presented results of investigations on samples of partially removable denture made of cobalt base alloys (Co-Cr-Mo) regarding specific structural analysis: determination of structural phases by quantitative and qualitative microstructural analysis, microhardness determinations versus different casting parameters [1,2,3,4]. By metallographic analysis some important structural aspects may be pointed: the presence of lace eutectic and carbides with discontinuous precipitation in metallic matrix, non-uniform dendritic structure with interdendritic micro-porosities, interdendritic cracks in a structure with fine lace eutectic. Different types of welding were tested, which gave both structural modification and morphology of constituents. Structural modifications which can be made for repairing of prosthesis may diminish mechanical properties of prosthesis, microhardness values of two cobalt base alloys welded by laser technology being high, which may confer a brittle behaviour.

KEYWORDS: denture prosthesis, cobalt base alloy, structural analysis, microhardness

1. Introduction

Cobalt based superalloys continue to be used with great interest in dentistry due to simultaneous properties, such as: high mechanical characteristics (yielding strength, ultimate strength, hardness), biocompatibility, or wear resistance [1,2,3,4,5]. In dentistry cobalt is still used for realizing partial or total prosthesis. The most used cobalt base alloy for dentistry is Co-Cr-Mo with a carbon content of about 0,03%. The problems which are met during casting of prosthesis are connected to crack susceptibility and brittle behaviour after a rather short time of prosthesis working. Present paper is focused on structural modification analysis of different cobalt alloys used for denture prosthesis.

2. Experimental Methods

In the present paper there are presented results of investigations on samples of partiallz removable denture made of cobalt base alloys (Co-Cr-Mo) regarding specific structural analysis: structural phases (by X-Rays diffraction), quantitative and qualitative microstructural analysis, microhardness determinations versus different casting parameters [1,2,3,4]. Since the interdendritic phases are associated t reduced ductility and reduced corrosion resistance, cast Co-Cr-Mo is the typically solution annealed at approximately 1225°C. Such a thermal treatment results in the transformation of σ phase to $M_{23}C_6$ and the partial dissolution of the $M_{23}C_6$ phase. It was determined that 1225°C is the optimal temperature for annealing since, at this temperature, a complete and rapid transformation of the carbides $M_{23}C_6$ to M_6C or σ occurs. Solution annealing for extended times (24-48h) leads to a homogeneous microstructure. The CoCrMo alloy used in dentistry is particularly susceptible to work-hardening so that the normal fabrication procedure used with other metals cannot be employed.

The experimental alloys were cast by a investment casting method, following the steps:
1. A wax pattern of the desired component was made.
2. The pattern was coated with a refractory material, first by a thin coating with a slurry followed by complete investing after drying.
3. The wax was melted out in a furnace (100-150°C).
4. The mold was heated to a high temperature burning out any traces of wax or gas-forming materials.

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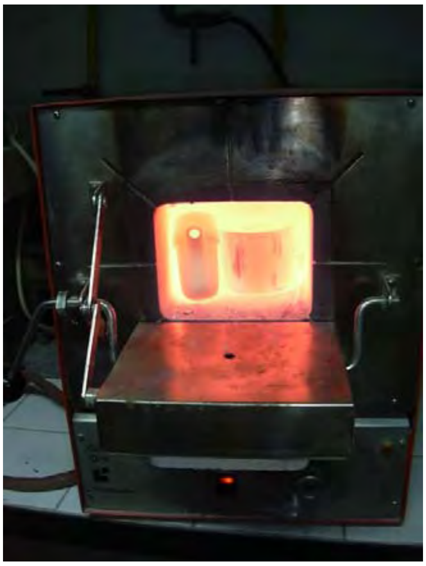

***Fig. 1**- Caloris CD 1016 Heating Furnace*

5. Molten alloys were poured with gravitational or centrifugal force. The mold temperature was about 800-1000°C and the alloy was at 1350-1400°C, in figure 1 being shown the experimental furnace.

Controlling the mold temperature will have an effect on the grain size of the final cast; coarse ones are formed at higher temperatures, which will decrease the strength. However, high processing temperature will result in larger carbides precipitates with greater distances between them resulting in a less brittle material.

X-Rays diffraction was made on DRON 3 device, qualitative and quantitative microstructural analysis was made on REICHERT microscope equipped with IMAGE –Pro software for analysis. Different types of welding were tested, which gave both structural modification and morphology of constituents.

3. Results and Interpretations

Results concerning the chemical composition of the experimental alloys are given in table 1.
Macroscopic analysis of the experimental alloys is shown in figure 2.

***Table 1.** Chemical composition of the experimental cobalt base alloys*

Experimental alloys	**Chemical Composition, %**							
	C	**Cr**	**Mo**	**Ni**	**Fe**	**Mn**	**Si**	**Co**
A	0.29	26.5	5.35	0.60	0. 64	0.67	0.97	Rest
B	0.35	26.4	5.38	0.85	0.74	0.63	0.89	Rest
Welded prosthesis	0.05	28.9	5.6	0.21	0.17	0.79	0.49	Rest
IS0 5832 /4/	Max 0.35	26.5-30	4.5-7	Max 1.0	Max 1.0	Max 1.0	Max 1.0	Rest

alloy A

alloy B

Welded prosthesis

***Fig. 2.** Macroscopic aspects of experimental cobalt samples for dentistry applications.*

The microstructure results of the as - cast alloys are shown in **Figures 3 (a)**, consisted of cobalt-rich FCC matrix dendrites and a very fine interdendritic eutectic. In the high carbon alloy, slow cooling from below the eutectic temperature gave rise to relatively coarse grains, continuous grain boundary carbide films, and interdendritic blocky carbides. In alloy B it was observed non-uniform dendritic structure with interdendritic microporosities (figure 3 b, c). By welding of the samples of Co-Cr-Mo it can be studied the structural modifications which can be made for repairing prosthesis, it is given in **figure 3d** and **3e** interdendritic cracks in a structure with fine lace eutectic.

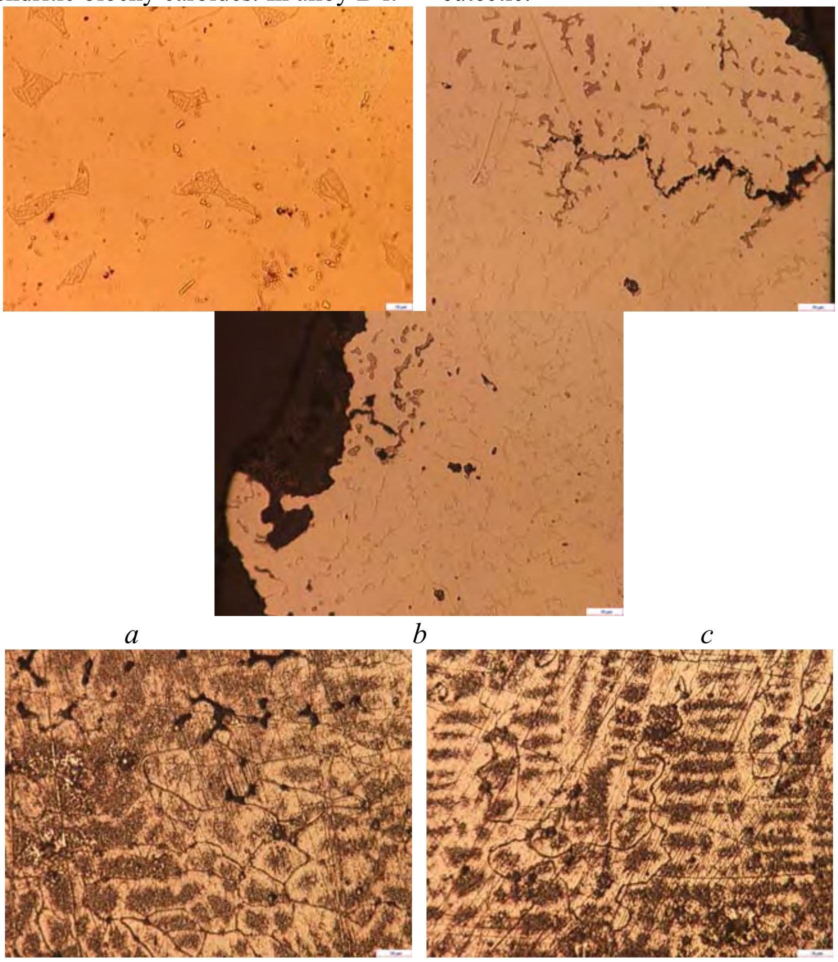

Fig. 3. *Microstructural aspects of different samples of Co-Cr-Mo alloys used for dental applications*

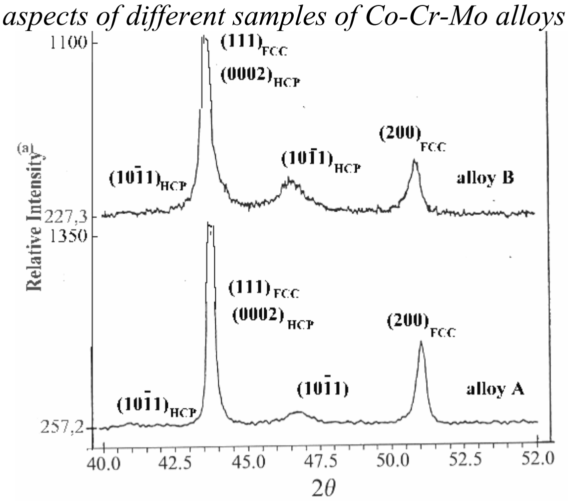

Fig. 4. *X-Ray Diffractions of experimental alloys.*

The eutectic presented in experimental alloys was identified as a mixture of $M_{23}C_6$, σ phase and FCC Co-rich phase, it is illustrated in **figure 4**. By heating the cobalt sample at different temperatures, respectively 825°C, 950°C and 1100°C two structural parameters were studied. Results concerning the influence of heat treatments on grain size are given in **figure 5** and results concerning the influence of heat treatments on precipitation size are shown in **figure 7**. Results concerning microhardness values of two cobalt base alloys welded by laser technology are illustrated in **figure 7**.

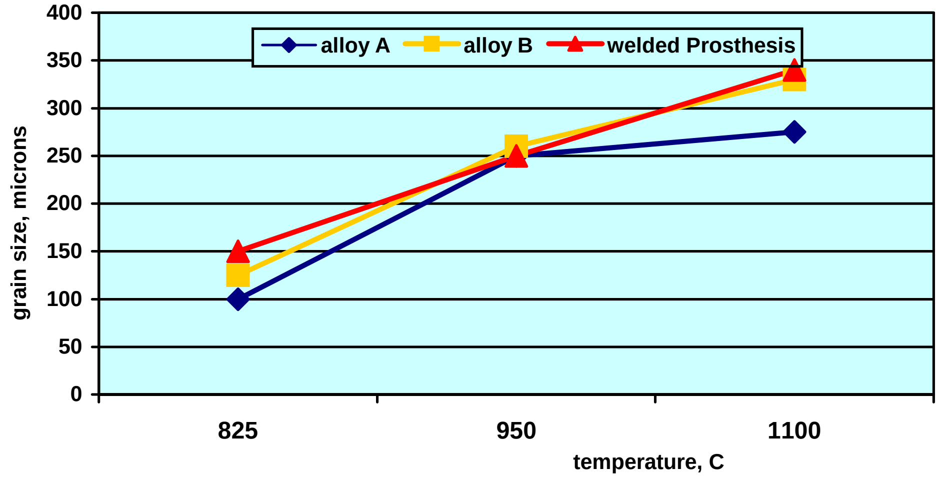

Fig. 5. *Influence of heating temperature on grain size of experimental cobalt alloys*

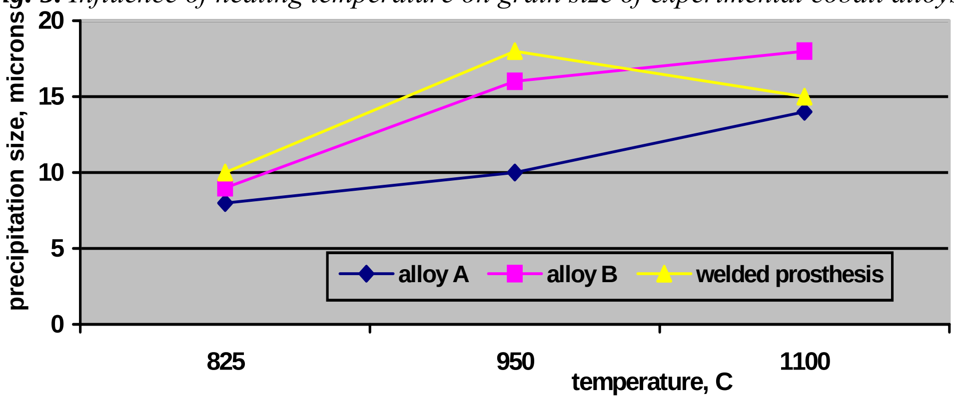

Fig. 6. *Influence of heating temperature on precipitation size of experimental cobalt alloys*

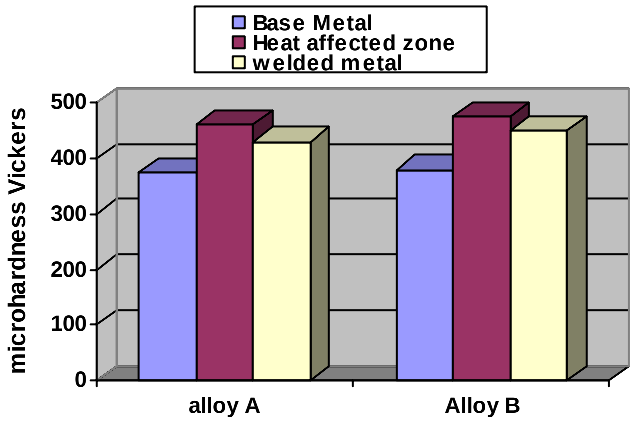

Fig. 7. *Microhardness Vickers values of the investigated cobalt samples*

4. Discussions

For both carbon contents, alloy heating at 815˚C produced a fine carbide precipitate and fine –grained structure with a relatively large volume fraction of precipitates confined to the grain boundaries. The obtained microstructures were in agreement with those reported in a previous work. Furthermore, heating at 815˚C led to relatively large stacking fault densities coupled with intragranular striations. These striations became apparent after preferential precipitation of carbides on the stacking faults. The precipitation reactions can be attributed to preferential solute diffusion to the stacking faulted regions due to the local hexagonal crystal structure. Also, carbide precipitation in favoured at hcp Co{0001} planes, which are nearly identical to $M_{23}C_6${111} planes. Alloy heating at 950 ºC induced a transition in the precipitate morphology, nucleation seems to occur at undissociated dislocations, whereas growth takes place along distinct crystallographic planes, predominantly of the {111}type. During heating at 1100ºC, precipitate spheroidization is dominant in both alloys.

The different precipitate morphologies associated with the implemented heats are responsible for the final microstructure obtained after solutioning at 1225ºC. Apparently, heating at 815ºC prior to solutioning inhibited, up to a certain extent, grain growth in both alloys. It is well known that a fine distribution of precipitates can effectively pin grain boundaries during grain growth, in so far the particles do not dissolve nor coarsen at the temperatures of interest. Assuming that appreciable carbide dissolution occurs at 1225ºC the interaction between moving boundaries and solute also contributes to limiting grain growth. Grain growth was effective in the alloys previously heated at 950ºC or 1100ºC. Apparently, in these heats, the intrinsic differences in carbide morphology (type) and distribution were responsible for the lack of substantial grain boundary pinning. Furthermore, at 1225ºC, grain boundaries become preferred sites for carbide coarsening, promoting the development of continuous films in the 950ºC and 1100ºC annealing.

These structural changes may explain the grain size and precipitation size modifications at different temperatures heating.

That is why by increasing the temperature, both grain size and precipitation size may increase, due to fill forming and grain growth.

5. Conclusions

- Optical microscopy observations indicated that Co-Cr-Mo-C alloys fabricated by investment castings exhibited large microstructural defects, which included interdendritic carbides, solute segregation, relatively large grains, and porosity. These microstructural defects tend to promote crack initiation and growth and explain the poor ductility and strength exhibited by as-cast alloys.
- The tensile properties of the heat-treated alloys exhibited significant improvements in ductility and strength when compared with the as-cast counterparts. The main effect of alloy preheating was manifested as a removal of the extensive interdendritic carbide precipitation and appreciable break-up of the dendritic grain structure. This leads to the development of a homogenous equiaxial grained structure and the consequent improvement in mechanical behaviour (by microhardness measurements).
- By welding with different laser technology, the materials for dental applications may be repaired. Cracks may appear either due to casting technology, or to welding by laser.

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