JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 15, No. 7-8, July - August 2013, p. 911 - 917

Structural characterization of a new cobalt alloy for dental applications

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Currently, the removable and/or fixed prosthesis are usually realised from Co-Cr-Mo alloys, which possess good corrosion resistance owing to the appropriate microstructure, but presents low machinability. Knowing that titanium is one of the best biocompatible metals, widely used as implant, due to its high biocombatibility, bioinert capacity and low density, the paper presents the results concerning structure and surface properties of new CoCrMoTi alloys. There were elaborated three composition of cobalt alloys, with 1%, 3% , respectively 5% Ti. The main structural features were put in evidence, by metallographic analysis, scaning electron analysis and X-Rays diffraction. Finally, the isometric aspects by atomic force microscopy (AFM) were shown, revealing the level of roughness in milled and polished state.

(Received March 25, 2013; accepted July11, 2013)

Keywords: Cobalt, Titanium alloying, Dental alloy, Roughness, Milling, Polishing

1. Introduction

Cobalt based superalloys are continuously used with great interest in dentistry due to simultaneously properties, such as: high mechanical characteristics (yielding strength, ultimate strength, hardness), biocompatibility, or wear resistance [1,2,3,4]. Currently, the prosthesis, both removable and fixed, are usually realised in Co-Cr-Mo alloys, which possess good corrosion resistance owing to the appropriate microstructure, but presents low machinability. Occasionally also allergic responses to the constituents of base metal alloys are observed. Most adverse tissue reactions attributed to the wearing of a base metal removable prosthesis, however, are manifestations of improper design or poor fit. Being the major component, cobalt imparts to the alloy its intrinsic corrosion resistance. Different alloying elements are introduced to modify one or the other property. Titanium is one of the best biocompatible metals and is widely used as implant [5,6,7] due to its high biocombatibility, bioinert capacity and low density. The purpose of this paper is to characterize from the structural piont of view a new dental cobalt alloy with titanium adition.

2. Material and method

The experimental dental alloys were elaborated in cold crucible melting furnace, with high vacuum by RAV method, starting from the base CoCrMo system and adding different amounts of titanium. The chemical composition of the experimental alloys are given in Table 1. The obtained samples were cylinders from which different samples were cut for experiments. The following investigations were done:

- Metallographic analysis- using a Reichert microscope type Univar, equipped with soft for imagines “Materials - Pro Analyzer”,
- Macroscopic analysis- using steremicroscope type Olympus SZX7, equipped with soft QuickMicroPhoto 2.2,
- X-Ray diffraction, in order to determine the phases constitution of the dental experimental alloys,
- Milling with polipanto gums ang polishing (exactly as in ordinary orthodontics clinics) of the obtained surfaces in order to examine the machinability of the titanium cobalt experimental alloys and analyzing these surfaces with atomic force microscope (AFM).

Table 1. Chemical composition of the experimental dental cobalt alloys.

Alloy	**Chemical composition, % wt.**									
	C	Si	Mn	P	S	Cr	Ni	Mo	Ti	Co
CoCrMo	0,276	1,800	0,64	0,0006	0,0011	24,51	0,098	7,29	0,08	rest
$CoCrMoTi_1$	0,356	0,510	0,67	0,0010	0,0068	26,87	0,109	7,59	0,70	rest
$CoCrMoTi_3$	0,336	0,074	1,17	0,0006	0,0019	24,90	0,080	7,69	3,18	rest
$CoCrMoTi_5$	0,334	0,025	1,18	0,0006	0,0062	22,45	0,069	9,96	4,96	rest

3. Results and discussion

3.1 Metallographic analysis

Experimental cobalt alloys are part of the Co-Cr-Mo system where titanium was introduced as an alloying element in different proportions. Under equilibrium diagrams ternary alloy consists of a solid solution, with a nonhomogeneous structure in cast state and the presence of different carbides and a eutectic formed in turn from solid solution and carbides. Titanium, as an carbid former element, is primarily bonded by the carbon from based metal matrix during solidification, and the remaining amount unbound dissolve in solid solution. Microstructural analysis performed on experimental alloys is shown in the pictures from Fig. 1. Detailed analysis of metallographic structures is consistent with predictions from the literature. Thus, CoCrMo alloy (whose structure is shown in 1a) is in fact a classic alloy, the proportion of titanium is normally found in commercial alloys, consisting of a heterogeneous structure consisting of solid solution with segregation dendritic and eutectic finely dispersed in the matrix metal. $CoCrMoTi_1$ alloy (whose structure is shown in Fig. 1,b), where the proportion of titanium is increased from 1%, is almost a similar structure to the classical alloy, titanium alloy, in which there is a higher proportion of eutecticului, with a preferential orientation of it. The structure of alloy $CoCrMoTi_3$ (shown in Fig. 1,c) has a high dominant propotion of eutectic in which are defined many types of carbides, well developed and dispersed either in matrix or in eutectic. Scanning electron microscopy analysis is shown in the pictures of Fig. 2. Thus, the eutectic from the classic alloy with titanium addition, alloy CoCrMo, is well demonstrated in the SEM images in Fig. 2 (a), having a fine eutectic, laced with uniform matrix layout. Images similar to highlight and $CoCrMoTi_1$ alloy (Fig. 2 b), which is slightly higher proportion of eutectic. From 3% Ti (Fig. 3c and d) SEM analysis reveals carbides clear, well defined, shaped and rounded, darker, particularly present in the eutectic.

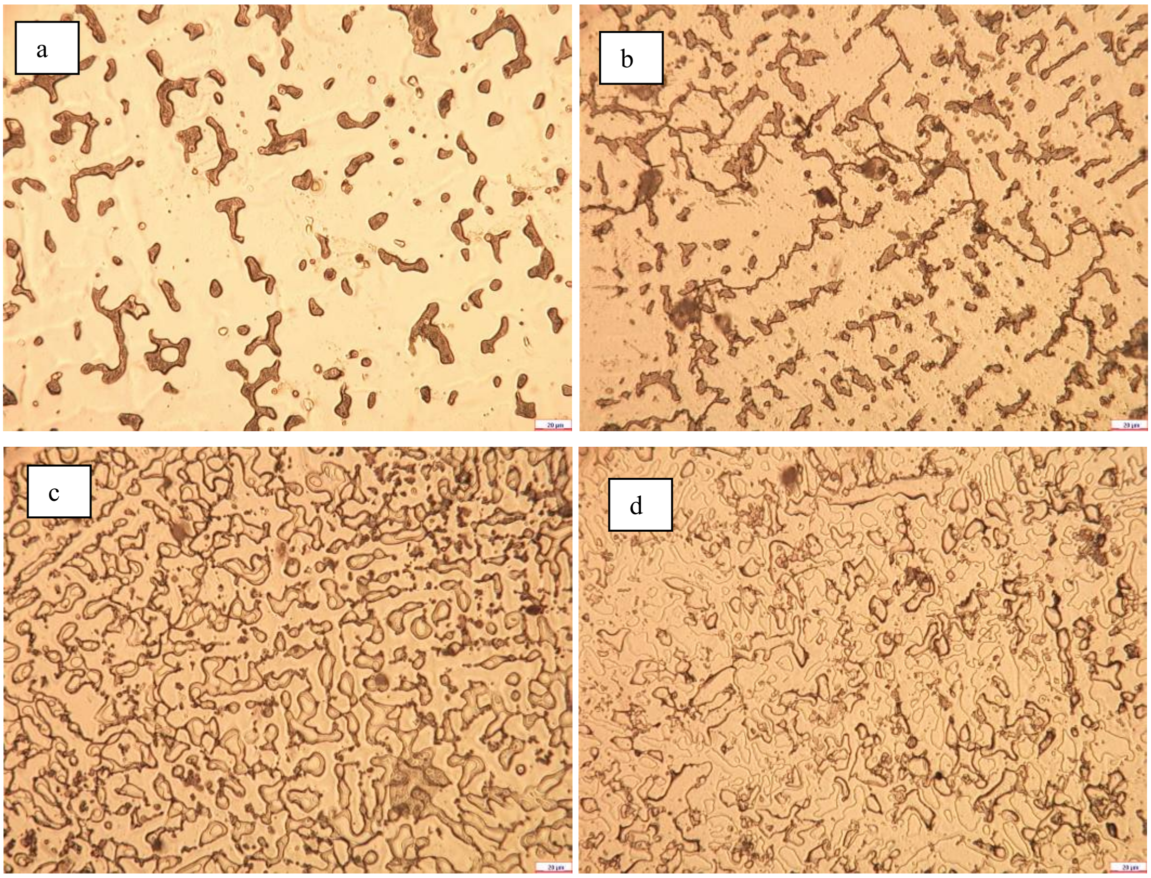


Fig. 1. Microstructural analysis of the experimental cobalt alloys (electrolitic atac $HCl+HNO_3+H_2O_2$): a- alloy CoCrMo; b- alloy $CoCrMoTi_1$; c- alloy $CoCrMoTi_3$; d- alloy $CoCrMoTi_5$.

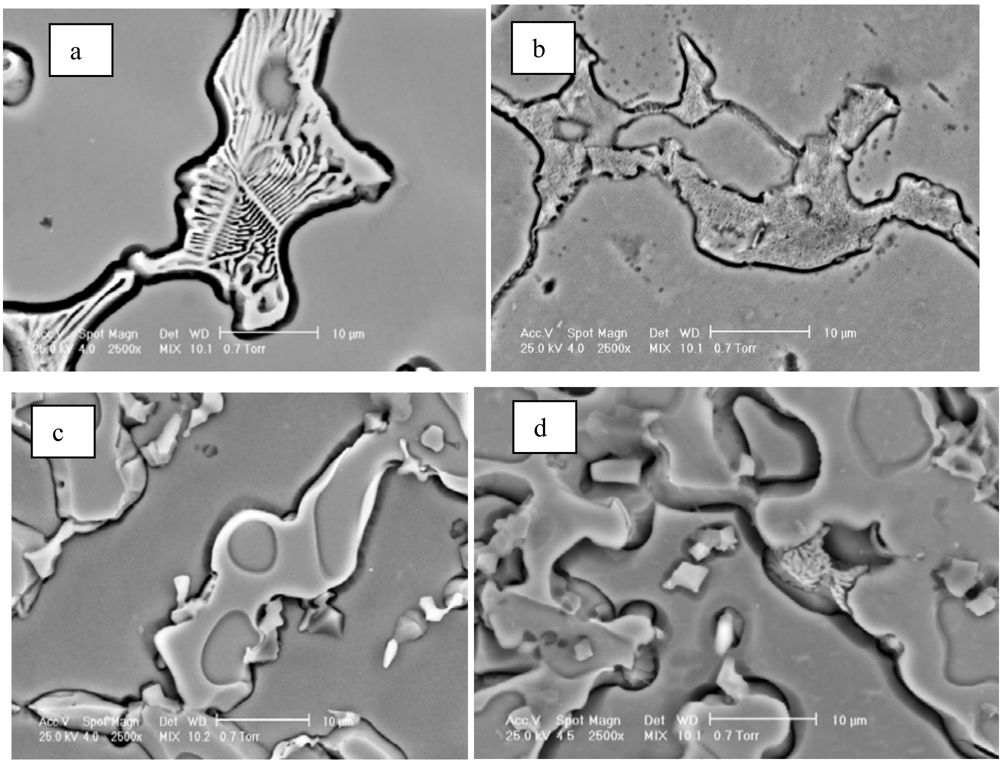


Fig. 2. SEM images of the experimental cobalt alloys (electrolitic atac $HCl+HNO_3+H_2O_2$):
a- alloy CoCrMo; b- alloy $CoCrMoTi_1$; c- alloy $CoCrMoTi_3$; d- alloy $CoCrMoTi_5$.

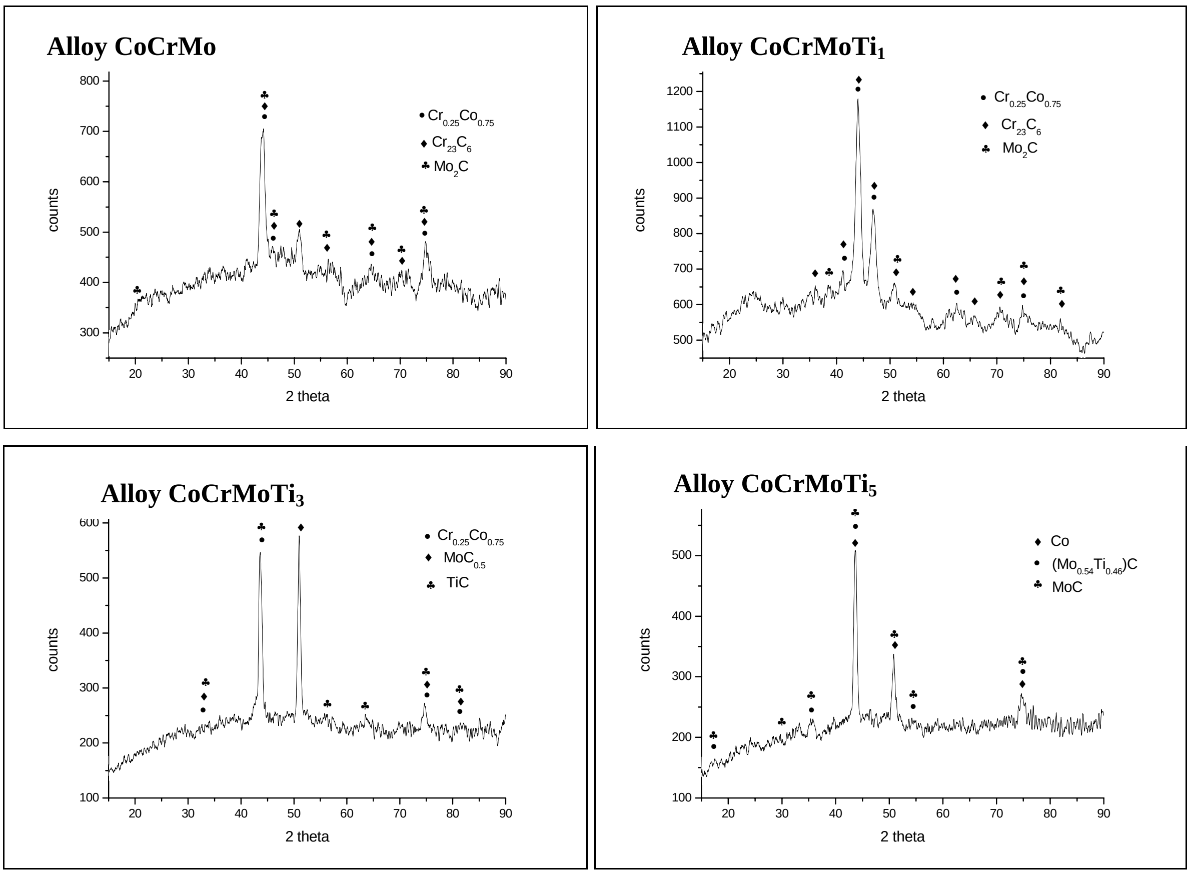


Fig. 3. X-Rays Diffraction of the experimental cobalt alloys.

3.3 Surfaces analysis of the of processed surfaces of the CoCrMoTi alloys

3.3.1 Macroscopic analysis

Results on surface topography of experimental cobalt alloys are displayed in Fig. 4 and Fig. 5. Macroscopic analysis, performed at magnifications of 56 times, highlights the milled surfaces with gum type polipanto (Fig. 4) and polished surfaces with abrasive agents used in dentistry (Fig. 5). Detailed analysis of the images reveals that the alloys have a similar topography, regardless of the proportion of alloying elements. Uneven surfaces milled macroscopic, with the broad direction of advancement of the cutter. Smooth surfaces with gum type polipanto have a higher degree of flatness, with macroscopically smooth tread also oriented towards the application of abrasive elements. Polished surfaces appear macroscopically as having characteristic gloss are identified numerous non-metallic inclusions (white). One can appreciate that these aspects are consistent with those obtained in the literature, cobalt dental alloys [7,8,9,10].

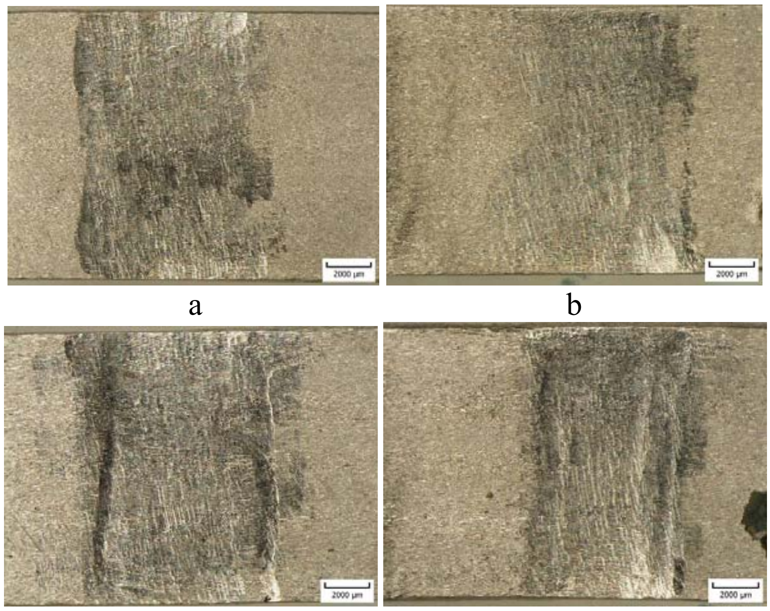


Fig. 4. Steremacroscopic aspect of polipanto gums milled surfaces of the experimental cobalt alloys: a- alloy CoCrMo; b- alloy $CoCrMoTi_1$; c- alloy $CoCrMoTi_3$; d- alloy $CoCrMoTi_5$.

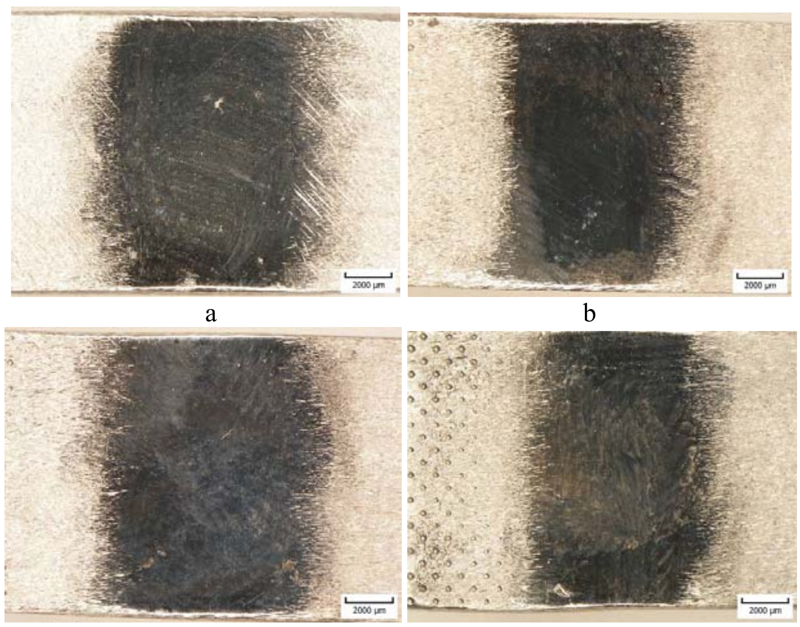


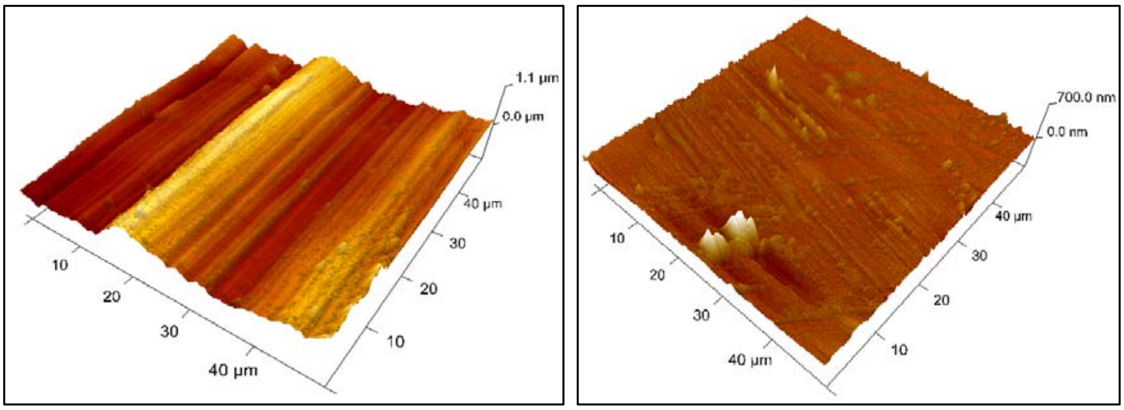
Fig. 5. Steremacroscopic aspect of polished surfaces of the experimental cobalt alloys:

a- alloy CoCrMo; b- alloy $CoCrMoTi_1$; c- alloy $CoCrMoTi_3$; d- alloy $CoCrMoTi_5$.

3.3.2. Atomic Force Microscopy of the processed surfaces of CoCrMoTi alloys

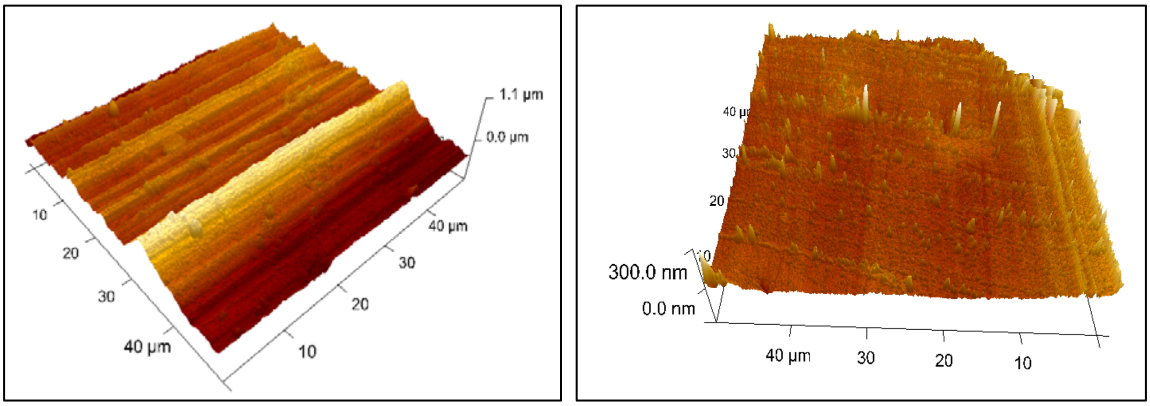
Isometric representation of the Atomic Force Microscope (AFM) surface topography of the alloy CoCrMo is shown in Fig. 6. Representation of the alloy sample surface milling, Fig. 6 (a) shows an ordered distribution of parallel grooves, oriented towards processing and appear slightly wavy. In the image the same surface after polishing Fig. 6 (b) tendency to flatness is evident. However, feel any distribution oriented along the old grooves, which were mitigated by polishing. Flatness is prominent local distrurbing grouped preferential distribution, suggesting a macroscopic distribution of particles in the surface hard. Isometric representation of the AFM surface topography for CoCrMoTi1 alloy is shown in Fig. 7. The alloy has a milled surface topography Fig. 7 (a) similar to the alloy CoCrMo. The difference is more pronounced wavy appearance. Can also be seen along the striae unequal spherical average diameter of 1.3 µm. Polished surface, Fig. 7 (b), has a slightly rough, but with a higher density distribution of prominences and found where CoCrMoTi1-polished alloy. It is assumed that affiliation is linked to inequality in spheroidal found preliminary evidence processed by milling and whose existence is made whole at the expense of hard particles from the surface. Isometric representation of the AFM surface topography for $CoCrMoTi_3$ alloy is shown in Fig. 8. Topography after preliminary processing by milling, Fig. 8 (a) shows an uneven appearance of the surface with parallel grooves, alternating with goals (even pulling) of material lengths of 8-10 µm. Local points and protrusions are strong enough, the general appearance suggesting dense and uneven distribution in particulate hard surface. The appearance of the surface after the final polishing, Fig. 8 (b) shows the same character uneven, the operation failed to provide surface flatness. As the area selected for detailed morphological analysis reveals a rough character, with protrusions major the high density whose origin can be attributed to the harsh surface of macroscopic particles. Isometric representation of the AFM surface topography for CoCrMoTi5 alloy is shown im Fig. 9. The topography surface of $CoCrMoTi_5$ after milling, Fig. 9 (a) reveals the general appearance striated, with a major hole in the upper zone of 15-18 µm width very well shaped dense projections suggesting an agglomeration of particles tough. Polished surface image, Fig. 9 (b) maintain uneven appearance: rough appearance is largely and prominent particles have a much higher density and are well defined. Thus, comparative analysis of observations obtained from atomic force microscope experimental cobalt alloys concluded that the alloying of titanium alloy retains machinability properties, recorded a higher concentration of titanium noticeably rough surface with a more uneven, which generated intense agglomeration of particles of titanium carbide hard alloy. Although we can say that by increasing the proportion of titanium surface roughness increases CoCrMo system processing.

Results of measurements of roughness, Ra, which is the average value of successive points of the profile heights are given in Fig. 10. The results are consistent with observations made at stereomicroscope and atomic force microscope. Thus, the state milling roughness values are much higher than the polished state. However, it is noted that by alloying with titanium alloy roughness increases, regardless of the surface are investigated, namely milling or polishing.



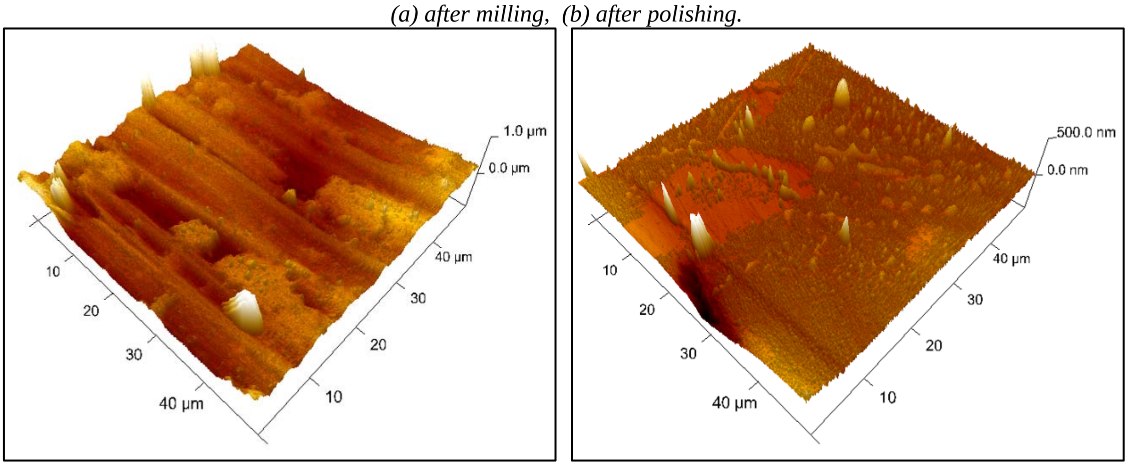
a b

Fig. 6. Isometric reprezentation by atomic force microscopy (AFM) of the CoCrMo alloy topographic surface: (a) after milling, (b) after polishing.



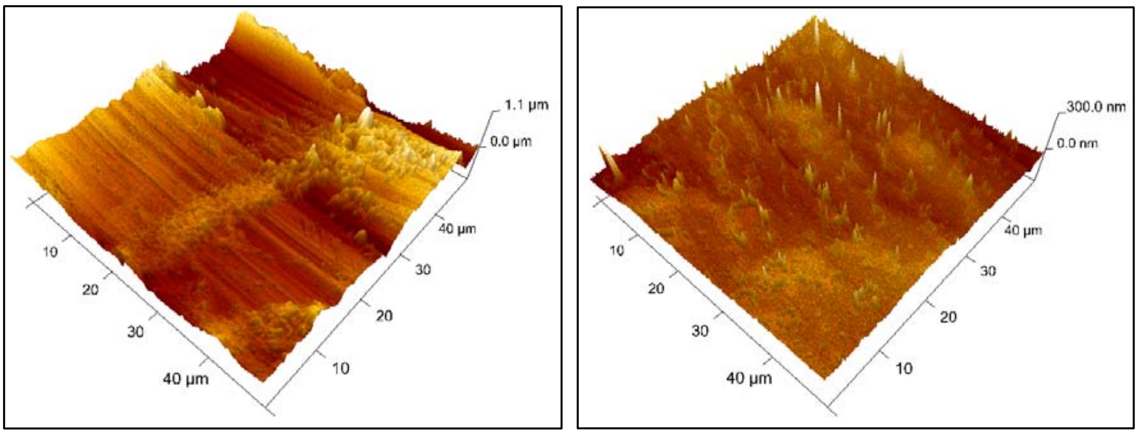
a b

Fig. 7. Isometric reprezentation by atomic force microscopy (AFM) of the CoCrMoTi$_1$ alloy topographic surface: (a) after milling, (b) after polishing.



a b

Fig. 8. Isometric reprezentation by atomic force microscopy (AFM) of the CoCrMoTi$_3$ alloy topographic surface: (a) after milling, (b) after polishing.
(b)



a b

Fig. 9. Isometric reprezentation by atomic force microscopy (AFM) of the CoCrMoTi$_5$ alloy topographic surface: (a) after milling, (b) after polishing.

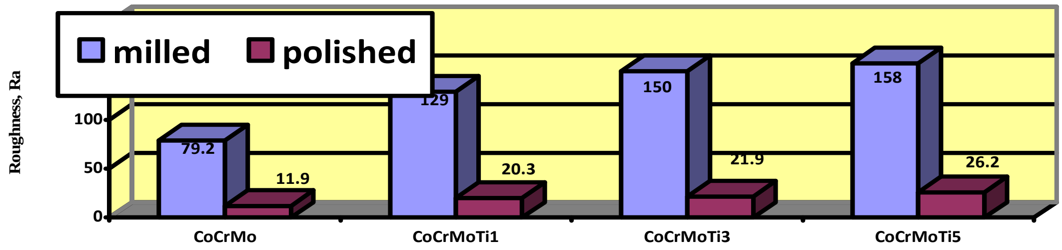


Fig. 10. Roughness average values of the experimental dental cobalt alloys after milling and polishing.

4. Conclusions

Titanium alloying of the dental alloys from the system CoCrMo may lead to the following conclusions:

- The structure of a CoCrMoTi depends mainly on the amount of titanium and carbon. The higher titanium content is, the higher complex carbides of titanium and molyndenum are in the alloy matrix.
- The X-Rays diffraction analysis show a matrix of γ solid solution of chromiunm and molybdenum in cobalt, with complex carbides of molybdenum and titanium, type (Mo_xTi_y) .
- By titanium alloying, the isometric aspects of the cobalt alloys surfaces is the same, no matter the titanium amount is. So, the milling roughness values are much higher than the polished surface values. And also, by titanium alloying, the roughness of the alloys may increase regardless of the surface (milled or polished).

Acknowledgement

The work has been funded by the MANUNET Project with acronim DENTICO.

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