Investigation of Ni-Cr alloys in order to asses the quality of cast dental restorations

E. GÂTIN*, C. BERLIC, B. IORDACHE[a], L. CIOBANU[a]
University of Bucharest, Faculty of Physics, P.O. Box 11 MG, Magurele - Bucharest, Romania
[a]*"Carol Davila" Medicine and Pharmacy University of Bucharest, Faculty of Dentistry, Calea Plevnei 16, Sector 5, Bucharest, Romania*

In order to obtain fix or mobile dental prostheses, there are used a large variety of metal alloys, making difficult to evaluate technical, biological and clinical properties of these materials. The present study establishes the key role of heating and casting process for Ni–Cr alloys, in order to improve the physico-chemical properties and quality of the obtained physiognomic dental restorations. Using electron microscopy, we made first a comparison between qualities of the surfaces of crude and processed materials. Through EDX investigation method, there were evidenced and evaluated differences in composition between processed and unprocessed materials.

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1. Introduction

The partial or total loss of the dental substance requests the necessity of morphological and dental functional recovery with dental prosthesis support [1-3]. Dental prostheses are physical compounds obtained from aloplastic materials such as metal alloys, ceramics or polymers, through special technological processes. Physico – chemical properties and long time behavior of prosthetic dental works are influenced by material type and micro or macro structural changes that may take place during laboratory processing [4].

Most of the prosthetic works used in dentistry are obtained through a heating and casting process of different metal alloys, classified according to metal compounds [1, 5, 6]. Nowadays, are used no–noble metal alloys based on Ni–Cr, instead of noble metal alloys based on gold. Important advantages of Ni–Cr alloys are low cost, a good tolerance for lax and hard human tissues, improved mechanical properties (strength modulus), easy modeling process for dental prosthesis and improved mechanical resistance, being suitable even for very thin dental restoration works.

Despite the fact that properties and role of main compound elements of metal alloys (Fe, Ni, Cr) or micro – percentage added elements (Ni, Mo, W, Mn, Ti, Si) are well known [6], the present study emphasizes the importance of dental prosthesis heat processing. Composition and final structure of the dental prostheses material are connected to the initial metal alloy composition, heat and cast processing in the dental laboratory. Diffusion of Ni–Cr alloy compound elements, through the stage of melting phase during technological heat processing is an important aspect that regards the obtaining of improved performances for dental restorative prostheses [4,6].

2. Materials and methods

2.1 Materials and samples preparation

Iron-nickel-chromium based alloys have a major importance use in dental restoration works. Steels and alloys of this type have been systematically studied for their physico – chemical properties [7, 8]. For the present study, samples of Ni-Cr alloy of Vera Bond II from Alba Dent and Heraenium NA from Heraeus Kultzer were used. Samples used for the investigation were: (i) unprocessed Ni-Cr alloy buttons, (ii) Ni-Cr alloy disc shape obtained by heating and casting process in dental laboratory according to the manufacturer instructions and (iii) sample of Ni–Cr alloy processed as a usual patient dental prosthesis. Commercial name was preserved for the investigated materials, as they are known and frequently used on the market. Temperature melting point recommended for Ni – Cr alloys is around 1,500 K.

2.2 Methods and investigation

During prosthesis manufacturing process in the dental laboratory, alloy buttons melting phase is quite important. The Fe-Ni-Cr system exhibits the gamma phase over a large composition regions at temperatures above 1,273 K. Studies for temperatures of 1,373 K or 1,573K were performed as well, small changes for the range of the phase fields being observed [7] As the temperature melting point indicated for the investigated Fe-Ni-Cr samples is about 1,500 K, our interest is motivated for investigations performed before [7]. In order to understand the process of melting and casting for Ni–Cr dental restoration materials, we also need to take into account the interactions and the diffusive process in ternary phase Fe-Ni-Cr system alloy [7-10]. To predict specimen distribution on the sample surface, investigation concerning atomic weight of metal alloy compounds was performed, regarding the centrifugal process as an important stage before the cooling process - the final step of the manufacturing prosthesis process [7].

Regarding the interest for the mentioned materials, we used surface electron microscopy, EDX methods for investigation of the quality of the surfaces and determination of specimen composition, changes during heating and casting process [11, 12].

3. Results and discussion

3.1 Surface electron microscopy investigations

For prosthesis metal infrastructure, surface quality of the restoration work is quite important [6, 13]. In that sense, first, we have investigated the quality of the surfaces of the unprocessed materials using the electron microscopy. We used an electron microscope SEM model – Fei -Inspect S.

In the following two figures we have the surface electron microscopy results, for Heraenium NA, respective Vera Bond II at magnitudes of 1000× and 10000×.

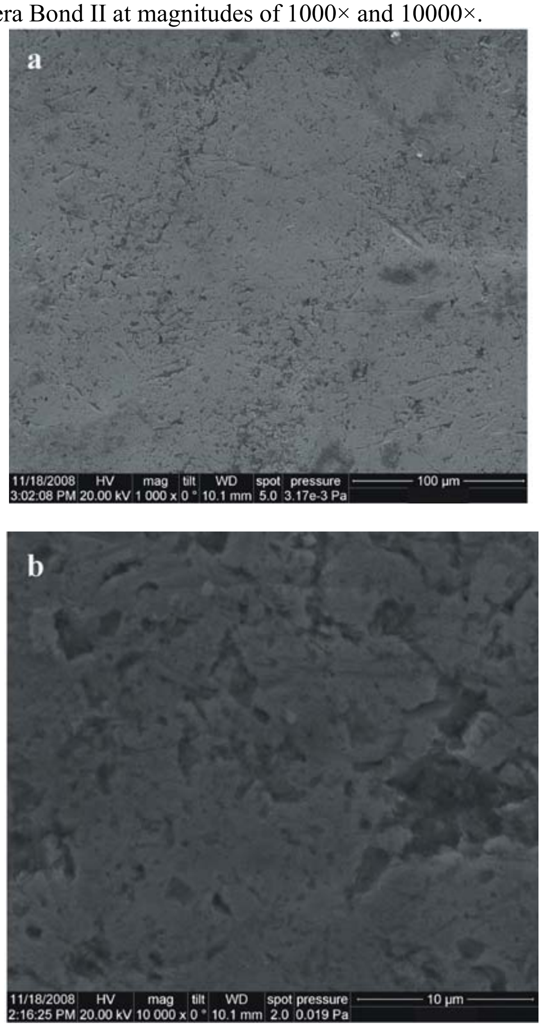

Fig. 1 Surface electron microscopy for Heraenium NA at magnitudes of 1000x (a) and 10000x (b).

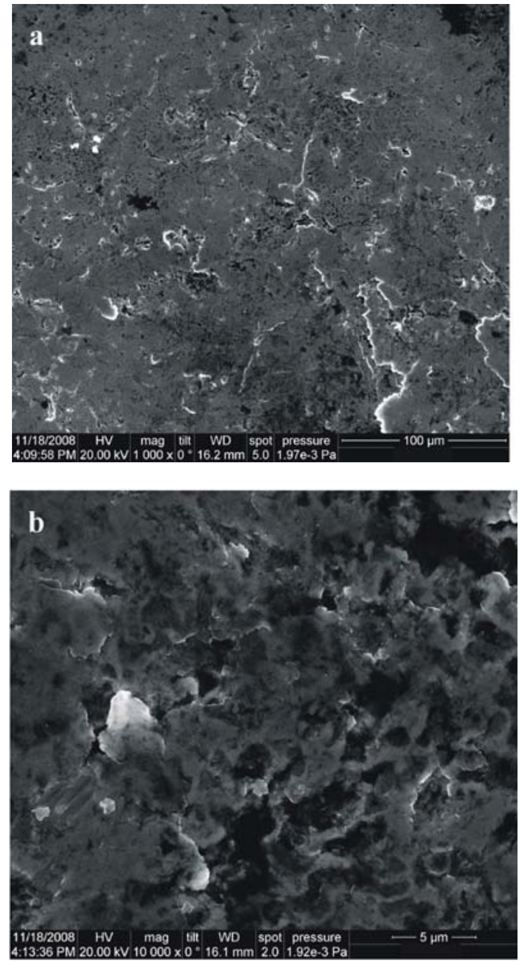

Fig. 2 Surface electron microscopy for Vera Bond II at magnitudes of 1000x (a) and 10000x (b).

As it can be seen, for Figures 1 and 2, we remark that surface quality is better (smoother) for Ni–Cr alloy unprocessed sample from Herenium NA compared with Vera Bond II.

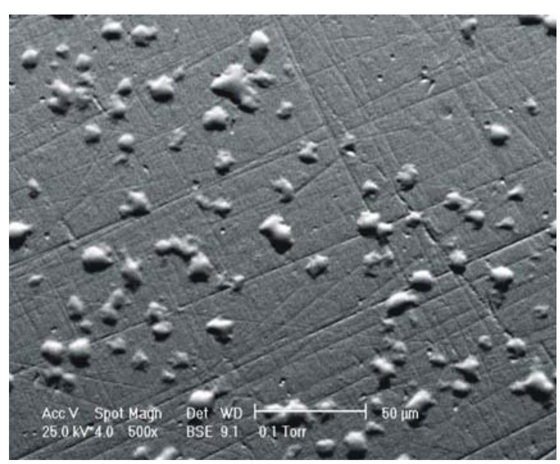

Fig. 3. Colonies of Streptococus mutans on the Ni–Cr alloy processed surface.

No evident defects or rift are observed, the surfaces are clean. A small part of the metal – ceramic dental restoration crown is ending as a metal area of (Ni – Cr), named colereta. For this area, actions of corrosion and bacteria deposits may occur [11, 15]. The presence of the surface defects stimulates bacteria deposits, causing corrosion and early decay of prosthesis metal infrastructure. If there are larger metal dental restoration works, the process is more evident and aggressive [11, 15]. In that sense, we present in the next figure, colonies of Streptococcus Mutans on Ni–Cr alloy surface. The investigation was performed during an experiment concerning corrosion and bacteria activity on Ni–Cr metal alloy. For investigation it was used a medium of artificial saliva Fusayama - Meyer improved with yeast extract from Difco Laboratories – Detroit, USA at temperature 310 K ($\pm$0.1 K) with added bacteria of Streptococcus Mutans from ATCC 700610 (American Type Culture Collection). The investigation was performed to the Dental Laboratory from Faculty of Dentistry, “Carol Davila” University of Bucharest.

Our interest was focused on Ni–Cr alloy Vera Bond II from Alba Dent, because of its large use and interest on the market. In such sense, we have investigated the surface of a material sample from a patient restoration work, Figure 4 and a disc of Vera Bond II, Figure 5, obtained from an alloy buttons processed as final dental restoration work in the dental work laboratory from the Faculty of Dentistry, „Carol Davila” University of Bucharest.

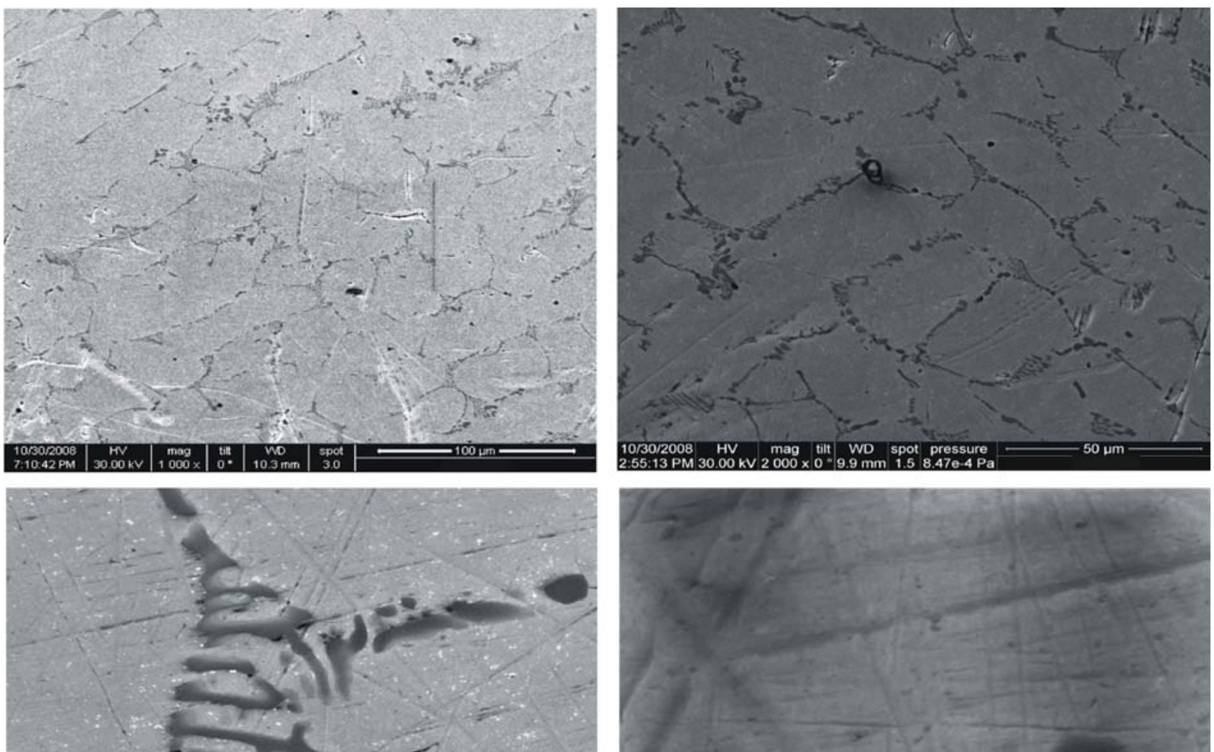

Fig. 4 Surface electron microscopy of a sample from a patient restoration work.

Microstructure of the metal alloys is the main parameter, with a strong influence on chemical, physical and surface properties. Ni–Cr and Co–Cr alloys have not a very simple microstructure and are very sensitive to various manipulation conditions. According to the type of Ni–Cr alloy, during manipulation for heating, melting and casting process, various kinds of surface defects were observed [16 - 18]. In Fig. 4, we noticed traces of carbon compounds, very well presented like dots, surface defects situated at the grains limit. The surface quality is very low, looking similar to that for Co–Cr metal alloy, even if the metal alloy is Ni-Cr. The result is caused by material overheating (about 100 K, above the recommended melting temperature) and very slowly poured during the casting process [7, 19, 20]. At least double times melting process before casting is recommended, in order to homogenize the material. As we noticed, various factors interfere during melting process, but quite important is the centrifugal process and its result is shown in Fig.5, where a microscope image of the processed disc is presented. As the disc of Ni–Cr alloy sample was prepared respecting strict the manufacturing manual stages and taking in account the above mentioned advices, the improved results for Vera Bond II are evident in Fig 5.

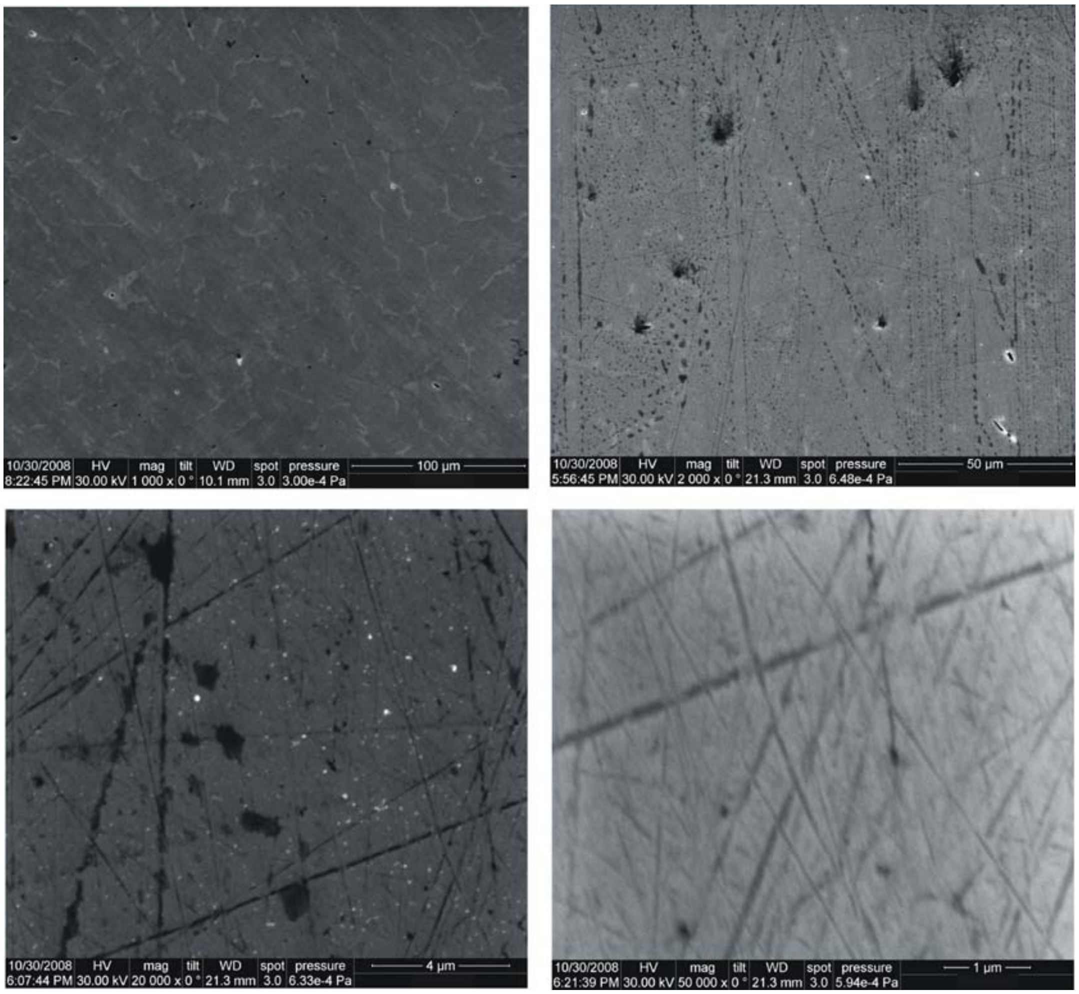

Fig. 5 Surface electron microscopy of a sample from processed Vera Bond II.

Microstructure Even the sample surface is processed (polished, sandblasted), results obtained are limited and do not compensate the material structure defects during the casting process. We noticed that surface defects do not disappear, very visible for a larger magnitude for a patient sample restoration work, as it is shown in Fig. 3. Comparing with Vera Bond II disc sample results from Fig. 5, we conclude that a longer time for centrifugal process and a slowly cooling after casting process is recommended, to permit the formation of larger grains in order to obtain a clean surface [6, 21].

3.2 The role of the material processing in establishing physical properties and composition of the dental restoration work.

In order to asses the role of the manufacturing process in obtaining the final restoration work, was used EDX analysis method for identification of the material composition before and after processing the material.

It was performed an investigation regarding composition and weight percentage for the Vera Bond II samples, using EDX analysis that stands for Energy Dispersive X – ray analysis. The EDX analysis system works as an integrated feature of a scanning electron microscope. SEM Fei – Inspect S, is the microscope used for our surface investigation, fitted with a Li-Si radiation detector. The output of EDX analysis is the EDX spectrum, which identify the composition of the samples and also estimates the elements concentration on the surface of the specimen.

For the unprocessed sample of Vera Bond II Ni-Cr alloy, were obtained the fluorescence spectra for three points of the surface. Composition and weight percentage results are depicted in Table 1:

Table 1. Weight percentage composition of the unprocessed Ni-Cr alloy from Vera Bond II.

%wt	C	O	Al	Si	Nb	Mo	Ti	Cr	Fe	Ni
1	3.55	9.51	4.04	4.05	6.18	1.59	2.68	6.08	18.90	43.42
2	2.79	3.54	2.41	3.68	5.39	2.37	1.52	7.87	14.34	56.10
3	3.97	7.51	3.22	4.87	8.13	2.10	2.92	6.14	9.29	51.85
Average	3.44	6.85	3.22	4.20	6.57	2.02	2.37	6.70	14.18	50.46

It is very clear that an investigation concerning only three measurement points it is not sufficient to have a clear map of the surface composition of the material, but in this table we remark some notable differences between weight percentage on the sample surface. We believe that these weight percentage variations along the surface are connected with the defects illustrated in the above figures for the electron microscope investigation of the Vera Bond II alloy. We also did same investigations in three points on the surface of the dental processed material, for the disc sample of Vera Bond II. The obtained results according fluorescence spectra, regarding composition and weight percentage are presented in Table 2.

Table 2. Weight percentage composition of the processed Ni-Cr alloy from Vera Bond II.

%wt	O	Al	Si	Nb	Mo	Ti	Cr	Fe	Ni
1	2.13	2.34	3.87	4.73	3.80	0.46	11.59	0.38	70.69
2	2.40	2.37	4.28	5.14	4.25	0.55	11.43	0.36	69.22
3	2.03	2.44	3.89	5.05	4.06	0.69	11.68	0.35	69.80
Average	2.19	2.38	4.01	4.97	4.04	0.57	11.57	0.36	69.90

From the above table we may notice that there are notable differences for some chemical elements like: Fe, Ni, Cr, Mo and Ti. Very important is the fact that, the composition determined for processed material is very close to the composition given by the producer for Vera Bond II.

Another interesting fact is that Carbon is almost totally missing in the processed sample, because of temperature of 1,500^{o}K used during the alloy melting process, but some traces of different carbon compounds may be identified [6,22]. Also, the presence of some chemical elements like Mn, Ti, Si and Mo was noticed, purpose for limiting the formation of carbon compounds for Fe and Cr [6, 23].

A similar, but not so strong tendency was also observed for the Oxygen. The presence of the two last elements is causing crystal network defects, affecting the resistance and hardness of the dental restoration work. Thus, we believe that the decreasing tendency is closely related to the improved quality surface with no defects.

4. Conclusions

There is a high interest for producing and investigation of Ni–Cr metal alloys, regarding their interaction with human tissues, especially biocompatibility and bounding reactions with other dental restorative materials. For a complex medium, like the oral cavity, very important are side effects, stability and long time resistance of the metallic prosthetic structure [6,12]. The present investigation evidenced the key role of the manufacturing process of heating, melting and casting steps in obtaining a higher quality work for the final patient dental restoration. Important is the recommendation for the melting stage: at least two times melting process is advisable before casting the material. Next, a long centrifugal process must take place, for about 40 min, attended by a long time cooling process [7]. The final composition, structure, surface quality and physico–chemical properties are established during the manufacturing process in the dental laboratory, same Ni–Cr metal alloy material but obtaining different quality dental restoration works. For a complete investigation, a deep structure mapping of metal alloy sample is recommended [24, 25]. Concluding, we hope that the present study opens a different way to understand the metal alloy manufacturing process and, in the meantime, a new trend to improve metal alloy dental prosthetic restorations.

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*Corresponding author: edgatin@netscape.net