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RESEARCH ON INFLUENCE OF METALLURGY FACTORS ON THE QUALITY OF METAL COMPONENTS IN METAL-CERAMIC PROSTHETIC RESTORATIONS

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ABSTRACT

The paper summarizes the characteristics of the metal component in the structure of metal-ceramic fixed prostheses and the technological conditions for obtaining it. The paper presents partial results of an experimental study on identifying the causes that favor the generation of defects during the stages of metal melting-casting, defects which in turn may be causes of failure in metal-ceramic restorations. The type of defect identified elucidates both the cause of and effects on the quality of metal-ceramic bond. The study was conducted by light and electron microscopy analysis of samples from two non-noble dental alloys (Co-Cr and Ni-Cr), samples taken from casting network, supply channels and metal crown. Results of the analysis performed with a scanning electron microscope SEM fitted with an energy spectrometer EDAX revealed the presence of oxide inclusions, chemical and structural heterogeneity, alloy solidification shrinkage voids and discontinuities caused by lack of technological discipline in the steps of metallurgical alloy processing, particularly the lack of rigorous assessment of temperature and optimum casting time and exposure of the molten alloy into contact with the atmosphere for a long time.

KEYWORDS: alloy, melting, casting, metal - ceramic, metal parts, impurities, chemical non-homogeneity

1. Introduction

Prosthetic treatments commonly used in solving partial edentulous are fixed metal ceramic restorations, partly or wholly physiognomic. Fixed metal-ceramic prostheses made of a metallic component and a ceramic part combine the aesthetics of the ceramic crown through natural physiognomic effect, mechanical strength and marginal adaptation of the metal (casting) component [1-5]. A particular problem raised by the metal-ceramic crown or bridge restoration is the alloy compatibility with the ceramic material to ensure a proper connection [6, 8-10]. It is undoubtful that a successful metal-ceramic restoration depends essentially on the compatibility of the two components which in the long run determine the firmness of the bond between the metal component and ceramic mass. The strong bond between ceramic and alloy surface is a condition for metal-ceramic prosthetic work to keep their integrity in any situation. Given the strong bond between metal and ceramic, the strain (tension) acting on ceramic is transmitted to the metal substructure. This connection is based on the chemical interaction of metal and ceramic and the ionic bond between oxides (Al_2O_3 and SiO_2) from the ceramic phase and the oxides on the metal surface. The oxide layer formed by the addition of alloy elements is usually closely linked to the alloy surface and achieving good chemical adhesion between metal and ceramic is determined by optimal wetting of the metal surface by the ceramic mass. This requires maximum contact surface between metal and ceramic, i.e. lack of macromechanic retentions on the metal surface, fluidity of the ceramic when applying it onto the metal and lack of porosity, obtained from burning ceramic in vacuum which favors the elimination of porosity in the interface area. Also to achieve a good connection between metal and ceramic involves conditions related to the metal structure which must be sufficiently rigid so as to prevent the occurrence of bending forces in the ceramic plating and therefore in the interface. Generally failures in obtaining adhesion of the ceramic to the alloy range from the design and casting conditions of the metal component, but they can also occur in any of the stages of the physiognomy composition, such as the paste, depositing and burning the ceramic layers, preparation of the teeth when contact is made uneven between the abutment tooth and the metal component, carrying out the working arch impression with gaps at cervical level, or when making an incorrect occlusal adaptation. In the production technology of metal-ceramic bridges, several versions are known, as follows: bridged with metallic infrastructure obtained by single molding, bridge with body deck infrastructure and aggregation elements poured independently and then bonded together, large bridges consisting of several segments to be subsequently put together by gluing or sliding systems.

The metal construction of the intermediate elements must be designed so as to obtain a uniform layer of ceramic mass to fit the outer contour of the final prosthetic parts. This requires strict control of the cast metal component (without casting defects that will affect adhesion of the superjacent ceramic mass after sintering).

Achieving a homogenous metal component depends on how the casting rods (channels) of the molten alloy flowing are fixed. Also important is the layout and positioning of the model packaged into the cast plug and the insertion direction of the molten alloy [5-7, 12]. The pattern must be filled as rapidly as possible with the molten alloy without hot crystallization -phases in the plug. Dental practice shows that the flow channels which have a spherical profile tank (5mm in diameter) are very effective because the layout of the junction place of the cast channel (rod) with the denture model is in spots. Along with the casting rod shape, position and number of junctions between the cast channels layout and metal component model can be particularly important to achieve the final denture. A wrong position can cause pores or stress concentrations in regions with variable thicknesses of the future metal structure. Some experts recommend setting an oversized channel as tank for the molten alloy. If a correct location of the casting rods is complied with it can be obtained a homogeneous metal structure that is favorable to the ceramic mass coating.

The alloys used in metal-ceramic technology are gold and palladium -based noble alloys and non-noble alloys [20, 22].

Noble alloys were developed as an alternative to noble alloys that became expensive and inaccessible. They were first used for casting metal on the prostheses partial skeleton, but the benefits in terms of their characteristics (higher mechanical properties, low density, low cost) have imposed them in other technologies as well, such as casting dental crowns and bridges. Among these alloys the most commonly used in metal-ceramic technology are: alloys Ni-Cr (50-80% Ni; 20-25% Cr), alloys Ni-Cr-Fe (48-66% Ni; 14-27% Cr; 8-27% Fe), alloys Ni-Cr-Co (40-62%Ni; 10-21%Cr; 5-34%Co), alloys Co-Cr-Ni and Ti-base alloys.

Non-noble alloys meet superior characteristics in terms of tensile modulus and ultimate strength compared to the noble ones, which means that it requires minimum thickness of the metal frame compared to the noble alloys. To improve the properties of these alloys, additions should be made of elements like Mo, Al, Mn, Si, Be, Cu, Co, Ga, Fe, such as modern Ni-Cr alloys (Ni - 60-70% and Cr - 15-20%).

Corrosion and oxidation resistance of these alloys is due to the formation of the protective chromium oxide microlayer on the surface of the ingot or cast.

These advantages, however, are overshadowed by certain disadvantages such as: casting is much more difficult and solidification shrinkage coefficient can create big problems in the marginal adapting of the metal substructure.

There are studies that demonstrate significant differences in terms of quality of the metal-ceramic bond between the various commercial Ni-Cr alloys. These differences occur for reasons such as variations in the mechanical properties of these alloys, the method used for melting and the design of the metal structure.

Titanium and titanium-based alloys are an interesting alternative due to their excellent biocompatibility, low specific weight and a cost price lower than that of noble alloys. However, titanium alloys also feature a number of disadvantages of the metal-ceramic technique. The oxide layer formed on the surface of titanium alloys during casting is extremely thick and it may grow during the heating to sinter the ceramic. To avoid these problems various solutions have been proposed, from sanding to the use of CAD-CAM system for producing metal components.

The Co-Cr alloys have advantages over the Ni-Cr alloys due to their biocompatibility (highly resistant to corrosion due to chromium which forms a protective oxide layer on the surface) and the lack of allergic reactions that they can develop. The corrosion resistance of the alloy is extremely important in avoiding crevicular corrosion that will undermine the plating ceramic. That is why it is indicated to use gold-based alloys or those of high corrosion resistance. Non-noble alloys show a lower resistance to corrosion than noble alloys, but they feature higher hardness and higher elastic modulus. The alloys that possess elastic modulus and therefore high elastic resistance are rigid thereby preventing the transmission of excessive occlusal stress onto the ceramic. At the same time the metal structural rigidity is maintained even while reducing its size to achieve a proper aesthetic effect (thicker ceramic layer).

2. Materials and experimental conditions

The investigations were conducted on samples from two kinds of non-noble alloys commonly used in metal-ceramic restorations or Ni-Cr (NIADUR) alloy and Co-Cr (ADORON LX) alloy, samples taken from the alloy delivered, samples cut from the casting network, supply channels/rods and crowns.

The study of the samples was performed by microscopic analysis (optical and electron scanning spectrometer equipped with a diffraction energy EDAX) able to reveal defects in material or those occurred while processing the alloy to make the prosthesis.

Table 1 illustrates the chemical composition of the alloys studied in their marketing phase.

Casting network was sectioned by cutting. The sample thus obtained was embedded into resin to be prepared by paper metallographic grinding and felt polishing, followed by the chemical attack for subsequent microscope analysis. The metallographic attack was made with the reagent: 50 ml HCl + 1-3 ml H_2O_2 (for Ni-Cr alloy) and electrolytic attack in solution of 10 ml of HCl in 200 ml ethanol at 2V DC and a temperature of 200 °C for 10 seconds (for the Co-Cr alloy), followed by sample washing and drying. To highlight any changes that may occur during processing by alloy melting and casting in the dental laboratory, first it was analyzed the structure and composition of the samples before their processing (marketing alloys).

Table 1. *Chemical composition of the alloys studied*

Alloys/Elements	Co	Ni	Cr	Mo	Si	Nb	Al	Mn, C, N
Co-Cr	62.5	-	29.5	5.5	1.4	-	-	up to 1%
Ni -Cr	-	75.5	11.5	0.608	3.5	4.25	2.25	-

3. Experimental Results and Discussion

Microstructural aspects are shown in Figure 1, along with X-ray spectroscopy analysis of the chemical composition.

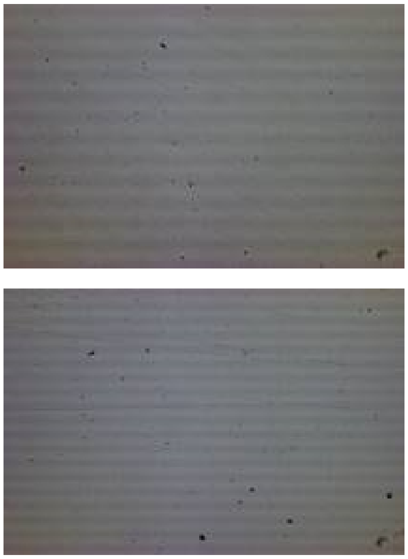
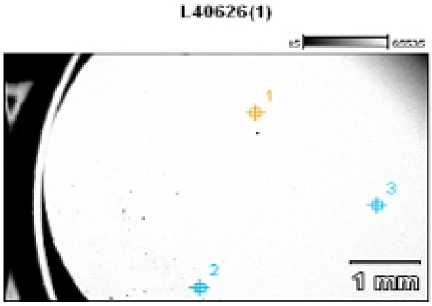


Fig. 1. *Microscopic appearance (optical microscopy without metallographic attack, magnification X50) of the Co-Cr alloy samples (ADORON LX40626) delivery/marketing state of alloy* [5]



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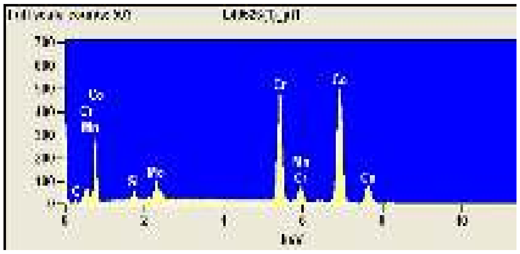

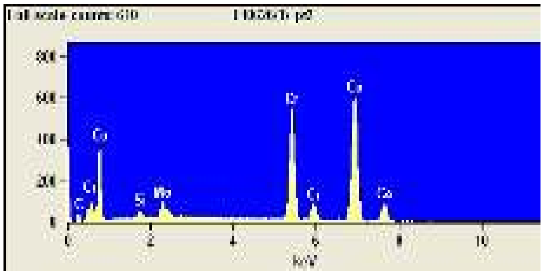

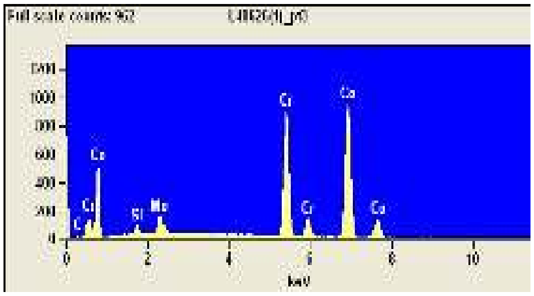

Fig. 2. X-ray spectroscopic analysis of chemical composition of samples of Co-Cr alloy (ADORON LX40626) delivery/marketing state of alloy [5]

The analysis results for the marketing samples, before their processing indicates an alloy of chemical composition according to the bulletin indicated by the manufacturer. It is found a high purity alloy, absence of inclusions, porosity and other defects.

The research conducted on samples from the same alloy after their processing, namely Co-Cr alloy samples taken from the casting network indicates the presence of oxide inclusions. A comprehensive analysis providing information on the nature of the inclusions was performed by spectroscopy EDAX, the analysis indicating high oxygen content along with silicon and aluminum, the proportion of the basic elements (Cr and Co) decreasing significantly in these areas (Figure 3). It may be noted that determinations in the basic mass indicate the initial composition of the alloy within the limits prescribed by the manufacturer.

Table 2. *The chemical composition of the alloy Co-Cr (ADORON LX40626) %, delivery/marketing state of alloy* [5]

	C-K	Si-K	Cr-K	Mn-K	Co-K	Mo-L
L40626(1)_pt1	2.23	0.94	29.11	1.26	62.13	4.33
L40626(1)_pt2	5.47	0.77	27.53		62.64	3.59
L40626(1)_pt3	1.94	0.93	30.03		63.02	4.09

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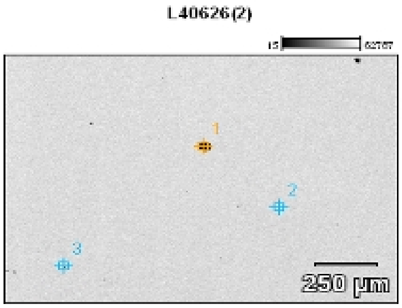

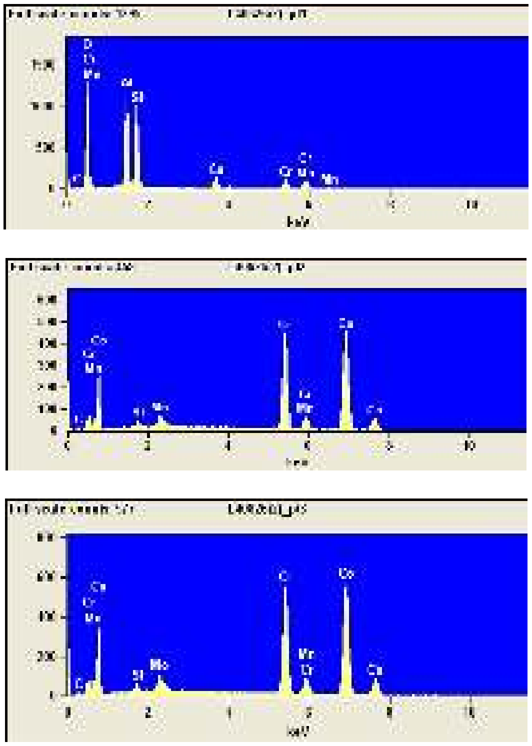

Fig. 3. X-ray spectroscopic analysis of chemical composition of samples of Co-Cr alloy (ADORON LX40626), the sample taken from casting network [5]

Table 3. *Chemical composition (%) of the alloy Co-Cr (ADORON LX40626), samples taken from the casting network* [5]

	C-K	*O-K*	*Al-K*	*Si-K*	*Ca-K*	*Cr-K*	*Mn-K*	*Co-K*	*Mo-L*
L40626(2)_pt1	3.58	61.18	11.43	12.32	2.76	4.49	4.25		
L40626(2)_pt2	3.02			1.01		28.74	0.83	62.44	3.95
L40626(2)_pt3	2.30			0.96		29.33	1.00	61.63	4.78

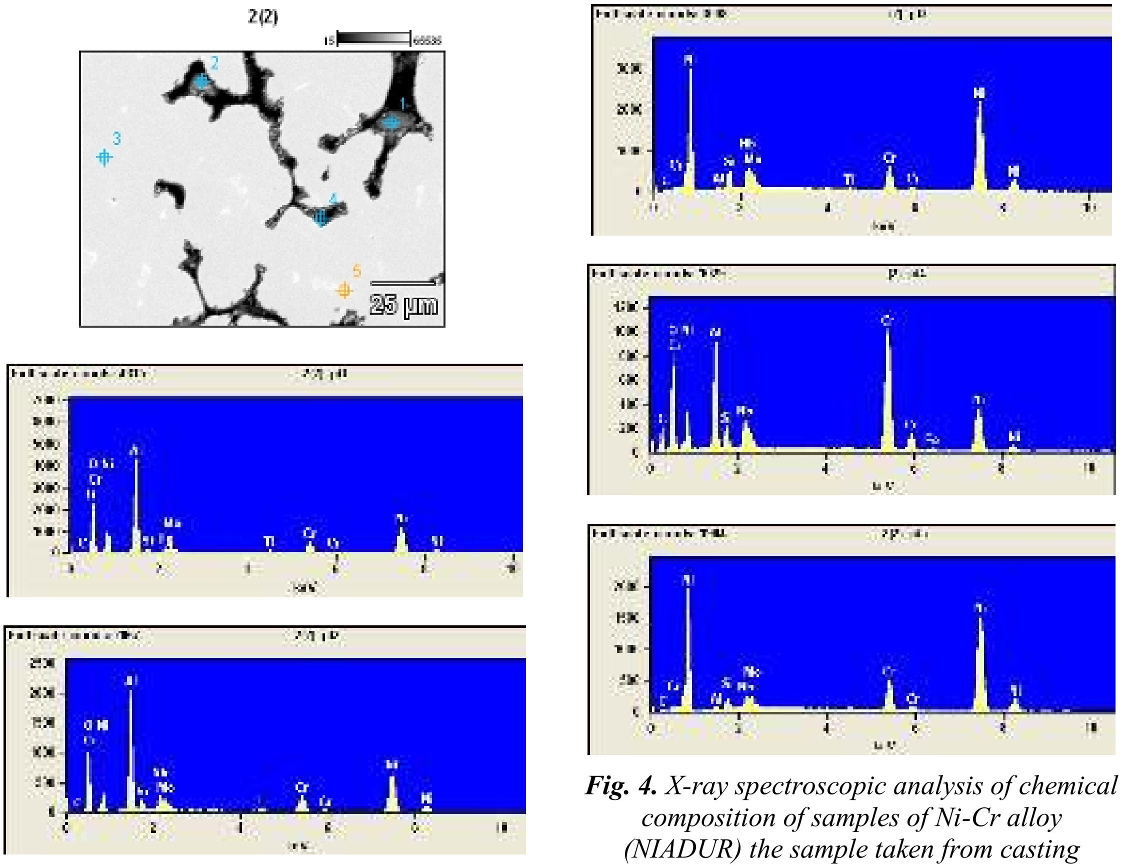

Fig. 4. *X-ray spectroscopic analysis of chemical composition of samples of Ni-Cr alloy (NIADUR) the sample taken from casting network*

Tabel 4. *Chemical composition (%) of the alloy Ni-Cr (NIADUR), samples taken from the casting network*

	C-K	O-K	Al-K	Si-K	Ti-K	Cr-K	Fe-K	Ni-K	Nb-L	Mo-L	Hg-L
TURNATE 1-PLIC 2(2)_pt1	2.78	37.55	19.57	0.50	0.88	5.71		30.85		1.69	0.46
TURNATE 1-PLIC 2(2)_pt2	2.66	35.30	17.18	1.64	0.71	5.70		30.10	4.99	1.71	
TURNATE 1-PLIC 2(2)_pt3	3.17		0.62	3.21	0.32	8.65		72.17	8.32	3.54	
TURNATE 1-PLIC 2(2)_pt4	12.45	30.09	7.85	1.69		23.98	0.44	18.56	4.94		
TURNATE 1-PLIC 2(2)_pt5	3.02		0.61	1.81		11.01		76.11	4.21	3.22	

The high content of oxygen and the presence of inclusions indicate that the alloy was oxidized during the casting in contact with the atmosphere for a long time. With Ni-Cr alloy samples (Figure 4) oxide inclusions are highlighted.

EDAX analysis reveals, in addition to the basic elements (Ni and Cr), the presence of a high content of Si and other elements such as C, O, Al, Fe. The presence of oxygen in the inclusions suggests that the material studied oxidized for a long time during casting. The presence of carbon is explained as having come from the metallographic sample preparation process (particles of diamond paste). The predominant component is nickel as alloying element, to be found in a constant amount in the solid solution and in the eutectic, with an increase in the mass of the base metal (above 70%) and reduced inclusions (about 30%).

The analysis of the samples at different resolutions highlights the typical structure of dendritic casting aspect (Fig. 5 and Fig. 6).

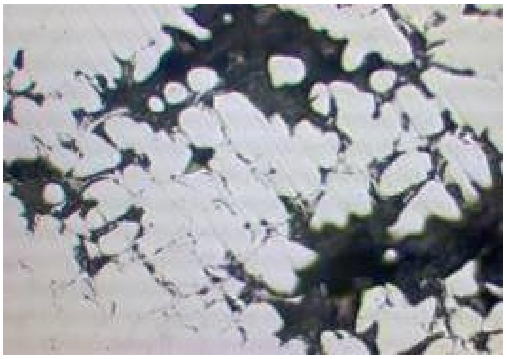

Fig. 5. *Microscopic appearance (optical microscopy, magnification X400) of the Co-Cr (ADORON LX40626), Samples from the casting alloy network* [5]

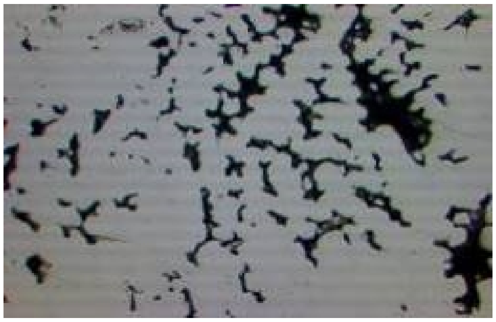

Fig. 6. *Microscopic appearance (optical microscopy without metallographic attack, magnification X100) of the Co-Cr alloy samples (ADORON LX40626), Samples from metal crown* [5]

Highlighting the chemical inhomogeneity in the studied samples reveals the existence of manufacturing processes at temperatures noncompliant with the specific alloy melting and casting ones. Also there are material discontinuities (alloy solidification shrinkage voids) and some areas of material overheating. The optical microscopy analysis of the metallic sub layer of metal-ceramic restoration reveals a cell-appearance dendritic structure and compound interdendritic separations. The presence of cell appearance is determined by the corresponding reduction in the thickness of the casting part, which further increase the solidification speed. In this situation, the solidification of the melt occurs quickly enough so that dendrites have no time to develop and the supersaturated interdendritic liquid precipitates intensely the intermetallic compound. The electron microscope examination of the metallic sub layer of the metal-ceramic crown highlights the same interdendritic inhomogeneities originated in the mold. The alloying elements are distributed unevenly. In terms of chemical composition, they have noticeable losses decreasing with respect to the gross alloy used, losses that take place in the melt. It is noted the presence of heterogeneous dendritic eutectic structure. The material was cast at a low temperature, which resulted the appearance of restoration.

4. Conclusions

Defects arising from failure to comply with the technological alloy foundry- casting conditions in the mold/pattern are generated on the one hand by not meeting the casting temperature requirements, causing either overheating (high temperature) or decreased fluidity and occurrence of the alloy solidification shrinkage voids (low temperature) and on the other hand there are defects caused by improper network design, incorrect sizing of the rods or supply channels which should provide a sufficient amount of metal into the mold cavity.

It is necessary to correctly size the system of rods to provide a quantity of molten metal in the mold prior to rapid quenching of the alloy. The channels will be wide and short to increase the pressure of the metal in the mold and its absorption from the metal tank.

Lack of rigorous assessment of the melt temperature and optimal timing of casting is possible because this is assessed only visually by loss of the geometric shape of the tablets and their collapse into the mold cone. Failure to comply with specific alloy melting range (as specified by the manufacturer) is another possible cause of occurrence of casting defects. Usually alloy melting is achieved with a high flame nozzle with many holes to quickly reach the melting point of the alloy.

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