Research on Microstructural and Chemical Inhomogeneity in Cast Metal Crowns Made of CoCrMoW Alloy

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Non-compliance of the technology for making of prosthetics restorations can induce some phenomena appearance which can cause, during the use, failures of the dental materials properties.
This study target was the verification of structural and chemical homogeneity in the characteristic parts of the mold for a dental crown made of CoCrMoW alloy. The samples from the metallic crown, gate runner and pouring gate were investigated. The general microstructural aspect is characteristic to a mold metal state and, without a homogenization, the life time of the prosthetic crown could be reduced. The differences between the three characteristic zones prove that just the prosthetic crown, which is the thinner element, has also the most vicious microstructure in the rough cast state.

Keywords: CoCrMoW alloy, metallic crown, pouring gate, gate runner

Biocompatibility [1] is a complex concept which consider s all the processes that occur between biomaterial and living organism. Biocompatibility is the property of a material to be permanently accepted by the organism without generating adverse reactions and without any chemical or mechanical deterioration. A material is considered biocompatible if it does not harm or generates toxic or systemic adverse reactions. The materials for prosthetics restorations, in addition to mechanical, physical and chemical conditions, must have also biological compatibility [2].

Conformation of technological steps for dental restorations manufacture [3] is of tremendous importance for obtaining a finite product with a long life time.

The quality and performances of dental materials are, beside the proper composition of dental alloy, the good mechanical properties, the corrosion resistance and the biocompatibility [4]. Casting failures should be the exception, not the rule, and must be detected in time and associated with possible causes [5]. The cast CoCrMo alloys are used on a large scale on manufacturing of various surgical devices, which are implanted in the body [7]. CoCrMo casting alloys have been used for many years to achieve partial dentures, replacing almost all gold alloys [8]. The prognostic of fixed partial prosthetics restorations is extremely difficult to be evaluated [9-19], because there is a very large scale of implied factors in their integration.

This study target was the verification of structural and chemical homogeneity in the characteristic parts of the mold for a dental crown made of CoCrMoW alloy. The microstructures and compositions of samples from the metallic crown, gate runner and pouring gate and were investigated.

Experimental part

The experimental study was performed on a mixed metal-ceramic crown of CoCrMoW alloy, to detect the eventual deficiencies. The samples (fig. 1) were cut from the dental crown, the gate runner and the pouring gate, were warm-embedded in bakelite and polished. Then they have been electrochemically etched in a solution of 10 mL 37% hydrochloric acid mixed with 200 mL ethanol. The electrolysis was carried out on 2 V a.c., at 20°C, for 10 s. After washing and drying, the samples were microstructurally examined using an optical microscope Olympus BX5 and scanning electronic microscope Philips ESEM XL 30 TMP.

The Girobond alloy that was used presents, accordingly to producer specifications, the following characteristics:

-chemical composition: Co (62.5%), Cr (22.5%), Mo (5%), W (5%);

-density: 8.6 gcm^{-3};

-melting range: 1350 – 1422°C;

-casting temperature: 1510°C;

-Vickers hardness: 310 HV;

-thermal linear expansion coefficient: 14.1 μm mK^{-1} (in the range 25–500°C).

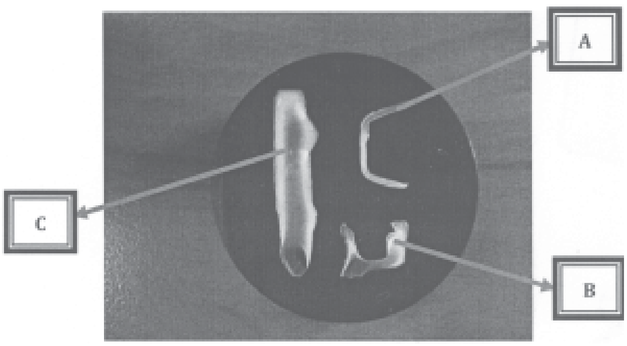

Fig. 1 Samples embedded in bakelite: (A) – metallic crown for metal-ceramic restoration, (B) – gate runner and (C) – pouring gate

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Results and discussions

Optical microscopy analysis of sample from the metallic crown (fig. 2) reveals a great amount of intermetallic compound particles in a matrix with dendritic microstructure (assigned to a solid solution) with cellular shape; clear interdendritic separations of intermetallic compounds are observed.

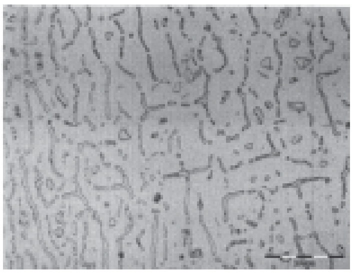


Fig. 2. Sample from metallic crown. Optical microscopy, 100x

Optical microscopy analysis of the gate runner (fig. 3) reveals a similar microstructure, with a matrix of dendritic shape (solid solution) and less pronounced interdendritic separations of intermetallic compounds. However optical micrographs of the pouring gate (fig. 4) reveals also a homogenous solid solution with evident intermetallic compounds separations. The possible cause of these microstructural differences may be determined by the different thickness of the corresponding zones of the cast material, which is the result of different cooling rates and so impeded the diffusion of alloy components.

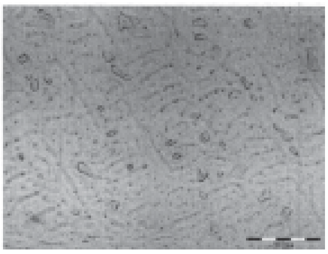


Fig. 3. Sample from gate runner. Optical microscopy, 100x

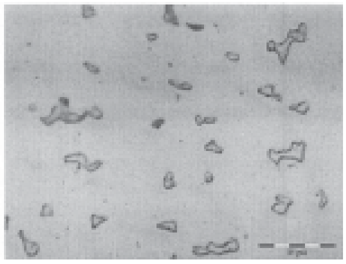


Fig. 4. Sample from pouring gate. Optical microscopy, 100x

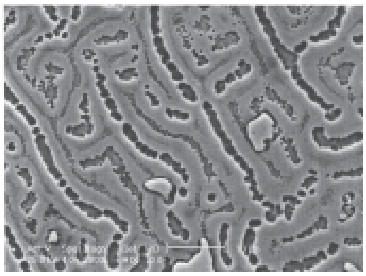


Fig. 5. SEM image (2000x) of sample from the metallic crown

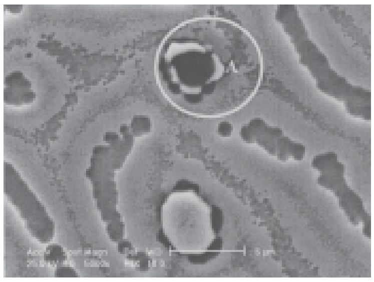


Fig. 6. SEM image at higher magnification (5000x) of sample from the metallic crown; in detail A is a different shape particle

To identify the chemical nature of these microstructural aspects we supplementary made SEM and EDS investigations on the three parts of CoCrMoW dental crown. SEM images for a sample from metallic crown are shown in figures 5 and 6.

As can be seen, the interdendritic separated compounds, with composition showed in table 1, present significant amount of cobalt, chromium, but also molybdenum, and tungsten; a content in niobium (unspecified by the producer) and silicon is found, too. The assumption that the particle in detail A (fig. 6) is made from silica (sand), with provenance from processing phases of the alloy at

Table 1
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR INTERMETALLIC COMPOUNDS IN METALLIC CROWN

Element	Wt %	At %
Si	2.87	6.4
Nb	4.26	2.88
Mo	13.08	8.55
Cr	24.65	29.72
Co	46.55	49.52
W	8.59	2.93
Total	100	100

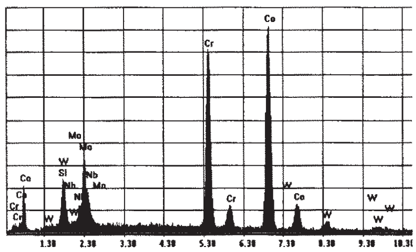


Table 2
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM IN INTERMETALLIC COMPOUND IN METALLIC CROWN, IN DETAIL A

Element	Wt %	At %
O	16.07	35.88
Si	22.54	28.66
Mo	3.73	1.39
Cr	17.87	12.27
Fe	0.43	0.28
Co	33.71	20.43
W	5.66	1.1
Total	100	100

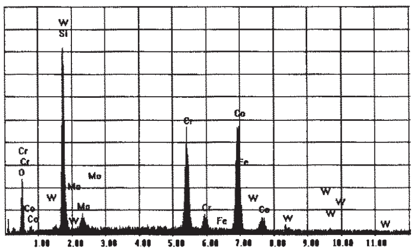


Table 3
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR DARK-GREY ZONES IN DENDRITES IN METALLIC CROWN

Element	Wt %	At %
Si	0.99	2.09
Mo	3.48	2.16
Cr	25.28	28.92
Fe	0.55	0.58
Co	63.71	64.31
W	5.99	1.94
Total	100	100

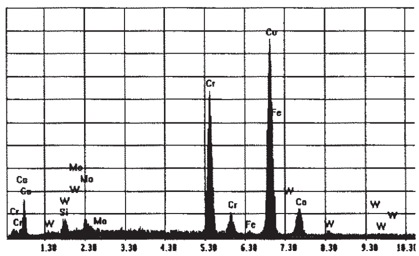


Table 4
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR LIGHT-GREY ZONES IN DENDRITES IN METALLIC CROWN

Element	Wt %	At %
Si	1.39	2.93
Mo	3.69	2.28
Cr	25.86	29.51
Fe	0.78	0.83
Co	62	62.43
W	6.28	2.03
Total	100	100

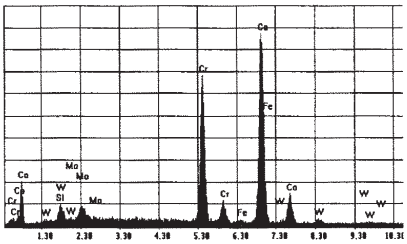
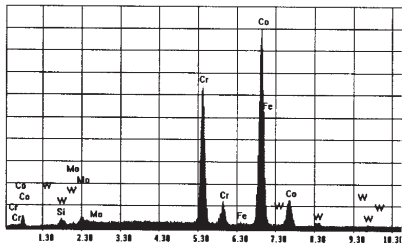


Table 5
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR DARK-GREY INTERDENDRITIC ZONES IN METALLIC CROWN

Element	Wt %	At %
Si	0.44	0.92
Mo	1.9	1.17
Cr	25.61	29.1
Fe	0.65	0.69
Co	66.28	66.47
W	5.11	1.64
Total	100	100



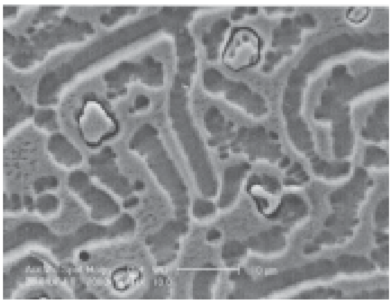


Fig. 7 SEM Image of sample from gate runner, 2000x

Table 6
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR INTERMETALLIC COMPOUNDS IN GATE RUNNER

Element	Wt %	At %
Si	2.86	6.39
Nb	3.5	2.36
Mo	14.41	9.42
Cr	25.72	31.04
Fe	0.74	0.83
Co	44.16	47.01
W	8.6	2.94
Total	100	100

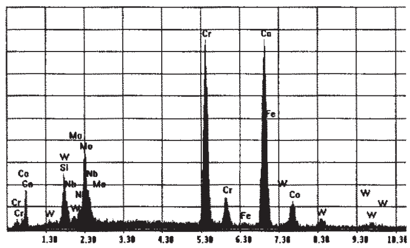


Table 7
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR LIGHT-GREY ZONES INSIDE DENDRITES IN GATE RUNNER

Element	Wt %	At %
Si	1.76	3.76
Mo	7.05	4.41
Cr	26.01	30
Fe	0.6	0.64
Co	58.02	59.05
W	6.56	2.14
Total	100	100

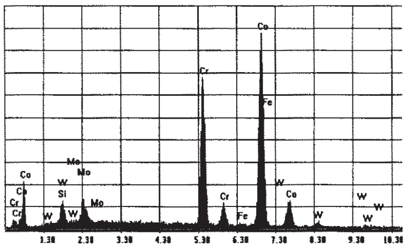
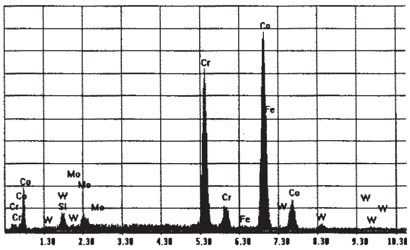


Table 8
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR DARK-GREY INTERDENDRITIC ZONES IN GATE RUNNER

Element	Wt %	At %
Si	0.89	1.88
Mo	3.41	2.12
Cr	27.28	31.27
Fe	0.8	0.86
Co	61.06	61.75
W	6.55	2.12
Total	100	100



the producer, is justified from the simultaneous EDS identification of silicon and oxygen (table 2). Dark-grey zones inside the dendrites (table 3) contain cobalt, chromium, tungsten and molybdenum, and also silicon and iron as remains. Light-grey zones inside the dendrites (table 4) contain cobalt, chromium, molybdenum and tungsten, and also silicon and iron. In interdendritic (dark-grey) zones (table 5) were identified the same elements, but the molybdenum content is lower, as well as for silicon and iron.

The examination of the gate runner for restoration dental crown reveals the same cellular shape of the microstructure, with casted solid solution as matrix with interdendritic separations of intermetallic compounds. The microstructure is somehow homogenous because this sample material has cooled slower, being thicker than the prosthetic crown. The interdendritic compounds (table 6) contain cobalt, chromium, molybdenum and tungsten in somehow expected quantities, but also silicon, niobium and iron. Light-grey zones inside dendrites (table 7) contain as well cobalt, chromium, molybdenum and tungsten as expected, with some variations, but also silicon and iron. Dark-grey interdendritic zones (table 8) in the gate runner contain cobalt, chromium, molybdenum and tungsten, but also silicon in small amount and iron.

We also have found that the metallic bulk mass (the matrix) inside the pouring gate (table 9) contains the same elements as the other samples analysed, with little variations in different zones. For instance, the dark-grey zones inside dendritic arms (table 10) contain cobalt, chromium, tungsten, molybdenum, silicon and iron.

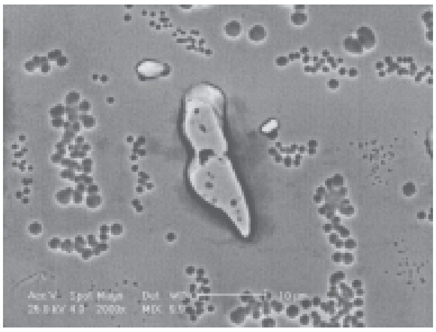


Fig. 8 SEM Image of the sample from pouring gate. 2000x

Table 9
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR METALLIC MATRIX (DENDRITIC SOLID SOLUTION) IN THE POURING GATE

Element	Wt %	At %
Si	1.56	3.33
Mo	4.44	2.77
Cr	25.93	29.92
Fe	1.43	1.54
Co	58.82	59.88
W	7.81	2.55
Total	100	100

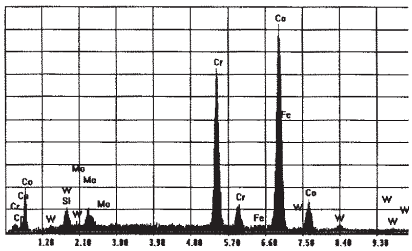
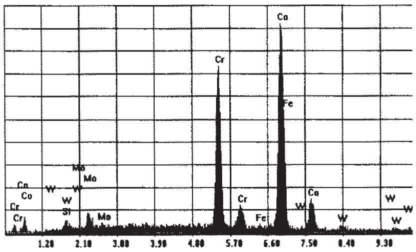


Table 10
LOCAL CHEMICAL ANALYSIS AND EDS SPECTRUM FOR DARK-GREY SITES INSIDE DENDRITIC ARMS IN THE POURING GATE

Element	Wt %	At %
Si	1.17	2.48
Mo	4.2	2.6
Cr	26.48	30.25
Fe	0.53	0.56
Co	61.7	62.19
W	5.93	1.92
Total	100	100



Conclusions

The general microstructure of the samples collected from the three characteristic zones (metallic crown, gate runner and pouring gate) reveals similar aspect, as expected for the case of a casted material. Nevertheless, the casting without microstructural and chemical homogenization could create problems related to the lifetime of corresponding prosthetic crown. The observed differences between the characteristic zones demonstrated that the prosthetic crown, which is the piece of interest with the thinner wall thickness, has the worst possible microstructure in this rough cast state. The thickness of the corresponding element of the cast determines the magnitude of solidification/cooling rate. In this situation, the solidification is as rapid, thus the dendrites have no time for developing themselves, and the oversaturated liquid between solidified arms precipitates intensively the intermetallic compound.

One can observe a relative finishing of the dendritic structure, which has fine arms. The effect of cellular separation of the compounds will be still disadvantageous, in spite of the finished structure, because it will determine a lower corrosion resistance of the prosthetic crown. Even the prosthetic crown toughness will be affected because of microstructural and chemical inhomogeneity. As a consequence, it will be necessary to correct these microstructural and chemical aspects.

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