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FRACTOGRAPHIC ASPECTS OF THE DENTAL CoCrMoTi ALLOYS

Alexandru GHIBAN[1], Mihai BUZATU[2], Brânduşa GHIBAN[3], Sorin CIUCĂ[4]

This paper presents the experimental results on the fracture behavior of several experimental dental alloys type CoCrMo, alloyed with different contents of titanium (0,1%; 1%; 3%; 3,5%; 4%; 4,5% and 5%). The alloys (about 100g) were elaborated in high vacuum induction furnace, and then centrifugal casted in cylinder samples about Φ10mm. The goal was to put in evidence the influence of titanium or/and zirconium alloying on fracture behavior of the CoCrMoTi alloys in different load conditions and defining the fracture mechanisms.

Keywords: dental cobalt alloys, titanium alloying, fractography

1. Introduction

Fractography is the study of fracture surfaces of materials [1,2]. Fractographic methods are routinely used to determine the cause of failure in engineering structures, especially in product failure and the practice of forensic engineering or failure analysis [3,4,]. In material science research, fractography is used to develop and evaluate theoretical models of crack growth behavior, which can be used to help identify the failure mode. The overall pattern of cracking can be more important than a single crack, however, especially in the case of brittle materials Optical fractography and Electron fractography are two more types of fractography. Optical fractography, either at stereomicroscope, or at optical microscope, need much less equipment in comparison with Electron fractography that needs an SEM (Scanning Electron Microscope) to be conducted. Complete fractography is done by scanning electron microscopy that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan

[1] PhD Student Depart. Engineering and Management of Metallic Materials Elaboration, University POLITEHNICA of Bucharest, România, e-mail: ghibi85@yahoo.com
[2] Prof.. Director of Depart. Depart. Engineering and Management of Metallic Materials Elaboration, University POLITEHNICA of Bucharest, Romania, e-mail: buzatu.mihai@yahoo.com
[3] Prof. habil., Depart. of Metallic Materials Science and Physical Metallurgy, University POLITEHNICA Bucharest, România, e-mail: ghibanbrandusa@yahoo.com
[4] Prof., Faculty of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania

pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography.

Cobalt-based alloys are widely used for manufacturing various devices either implanted in the body by surgery (their applications including hip prosthesis, knee plates and screws for osteosynthesis), or basic structures for heart valves [5,6], or prosthesis, with different applications in dentistry [7]. Removable partial dentures are such prosthesis, which can be inserted and take it out voluntary, by the patient, in and out from the oral cavity. These components consist from a metallic part and an acrylic one. Cobalt - chromium- molybdenum alloys used for partial removable dentures are known to have excellent corrosion resistance and outstanding mechanical properties (e.g. high stiffness). The cobalt dental alloys have diversified over time, aiming at creating both new products [8,9] and new technologies to process them [10-16]. The elaboration of Co-Cr-Mo alloys is usually carried out by centrifugal casting, or by the use of the laser sintering technique. Titanium is also known to be a very high biocompatible metal, with a very high corrosion resistance, used with great success as a biomaterial [16]. Despite of this, the influence of titanium on the properties of dental cobalt alloys is not well defined; only [17] mentioned this fact in the CoCr system. The aim of the present paper was to put in evidence the titanium or/and zirconium alloying influence on on fracture behavior of the CoCrMoTi alloys in different load conditions.

2. Materials and Methods

In order to put in evidence the fractographic features of different surfaces, loaded in different conditions, some CoCrMo base alloys were elaborated in a high vacuum induction melting furnace in ingots about 100g, and then centrifugal casted in cylindrical samples about Φ10 mm. The chemical composition of the experimental alloys is given in table 1. One may remark that the fractofraphic analysis was carried out on three compositions, such as: one with commercial composition for a CoCrMo dental alloys, one composition containing 2.5%Ti and 2.5%Zr in an matrix of CocrMo, and the other composition containing 5%Ti in the same matrix of CoCrMo. Investigation concerning mechanical loading of the surfaces were carried out including tensile test, bending test and compression test, made on different temperatures.

Table 1

Chemical composition of the experimental dental alloys, wt.%

Alloy	**Element**									
	C	Si	Mn	S	Cr	Ni	Mo	Ti	Zr	Co
CoCrMo	0,276	1,8	0,64	0,0011	24,51	0,098	7,29	0,08	0.0	ball
CoCrMoTi2.5Zr2.5	0,407	0,030	1,14	0,0017	23,87	0,073	7,61	2,50	2.5	ball
CoCrMoTi5.5	0,334	0,025	1,18	0,0062	22,45	0,069	7,96	5,46	0.0	ball

Fractographic analysis of mechanical tested samples were made both by macrostructural analysis on a stereomicroscope type Olympus type SZX7, equiped with image processing soft QuickphotoMicro 2.2 and by microstructural analysis on a scaning electron microscope type Philips. All the investigations were made at longitudinal and transversal surfaces perpendicular to the fracture surface.

3. Results and Discussion

In general terms, there are three basic crack growth mechanisms possible in fast fracture - intergranular along grain boundaries (or interdendritic fracture), brittle fracture via cleavage along crystallographic planes (or through pearlite lamellae), and transgranular ductile fracture via microvoid coalescence.

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area.

The results concerning structural analysis of the fractographic samples after tensile tests are given in Figs. 3-10, and after compression tests.

Fractographic aspects of the experimental cobalt alloys fracture surfaces after tensile tests are specific to brittle cleavage breakdown without stretching before breaking. Cleavage is characteristic of transgranular brittle fracture. Analyses carried out both stereo and scanning electron microscope (Fig. 1) showed brittle fracture character. Such surfaces are bright with advancing front breaking the plane of cleavage. On the fine structure by scanning electron microscopy analysis, all alloys present similar aspects of the fracture zone, the brittle nature of the fracture, with cleavage fracture zones with intergranular cracks and numerous interdendritice secondary cracks, which by coalescence have allowed and facilitated the movement of fracture front propagation. The fractography put in evidence in this paper is in accordance with structural aspects observed by other researchers [18-20].

In CoCrMo alloy after tensile test one may remark in macroscopic appearance a zig-zag manner of the fracture front (Fig. 1a) with great deviation of propagation, up to 2000 μm of the affected fracture zone. Analyzing the transversal cross section, either at macro or microscopic scale, one may remark no matter the loading is, the existence of two zones: one zone, which generates the fracture, consisting in compactness defects and the other zone with no defects. So, the existence of these zones and the different two loading tests may determine different fractographic aspects. There must be remark that all the alloys have similar aspects, in the same conditions of loading, with very small differences between them. At tensile testing all the alloys with compactness defects have an interdendritic aspect, with clear evidence of principal or secondary axes, this behaviour having a mixed brittle-ductile manner of fracture. In free defects zones the fracture front migrate by micro dimples coalescence on slip twin boundaries (Figs. 1c). Also, one may remark numerous secondary cracks, which may determine the step movement of fracture front. In compactness defects zones, the fracture front is interdendritic, with clear evidence of dendrites and axes inside the microshrinkages (Figs. 1d).

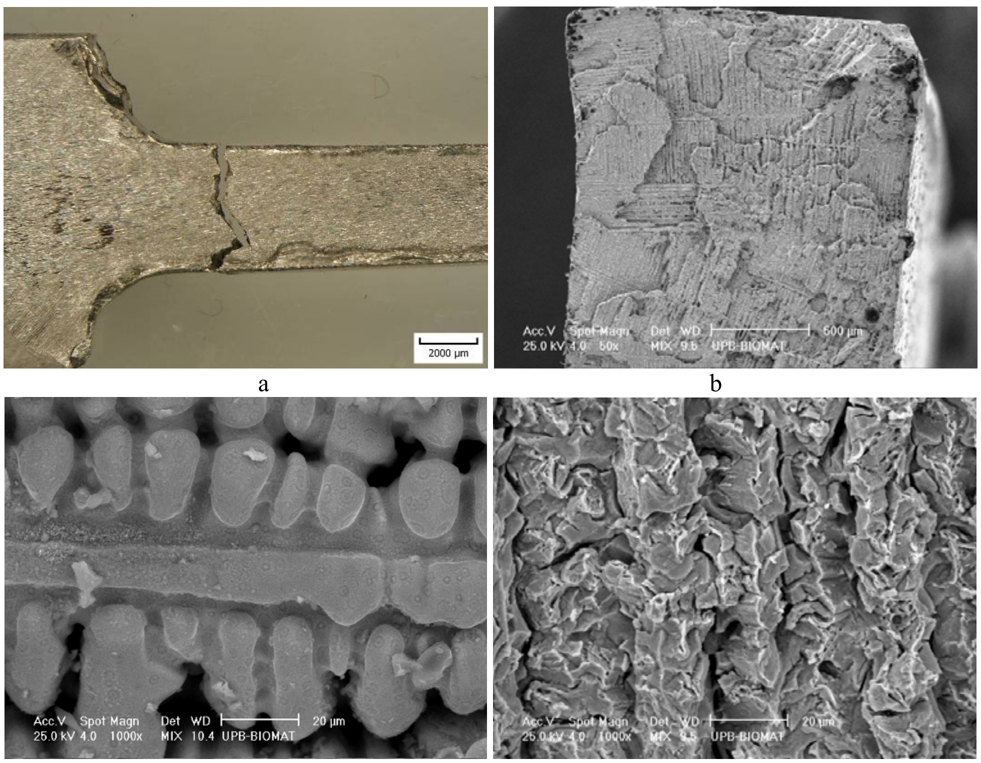
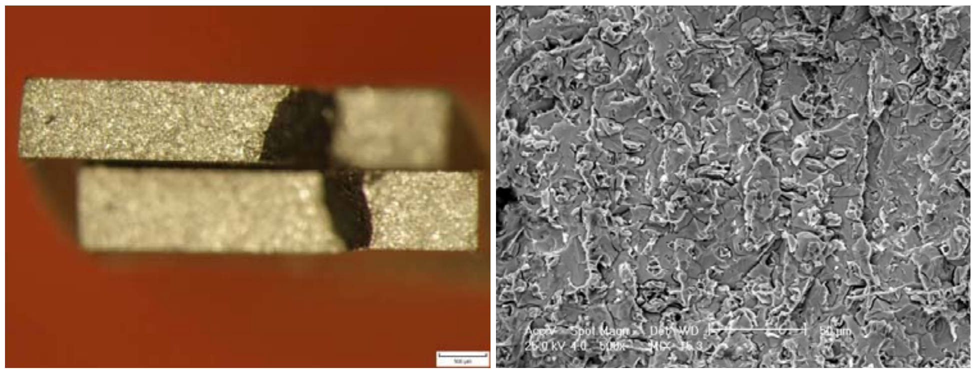


Fig. 1- Fractographic images of CoCrMo alloy after tensile test:
a- stereomacroscopic image of longitudinal section; b- macroscopic image of transversal section at SEM; c- microscopic image at SEM in free voids zone;
d- microscopic image at SEM in zone with voids and microshrinkage

In CoCrMoTi(Zr) alloys the aspects of the tensile test sample are quite different, the dendritic aspect being absent. The brittle behavior is more pronounced, as one may remark from Fig. 2 and Fig. 3. In both alloys, respectively CoCrMoTiZr and CoCrMoTi5 the macroscopic aspect obtained at stereomicroscope are the same, with shiny, brittle appearance. The SEM analysis reveals a cleavage aspect with flat, smooth surfaces through the grains. Evidence is seen of rivermarks, and the sharp edges of fracture planes (Fig. 2d and Fig. 3d). Also, one may remark that the cleavage have small flats, through small grains and also numerous secondary cracks inside the grains.



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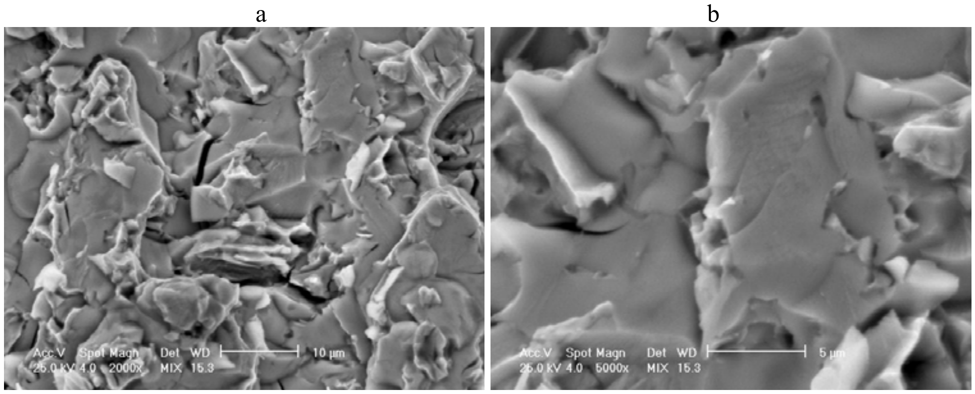

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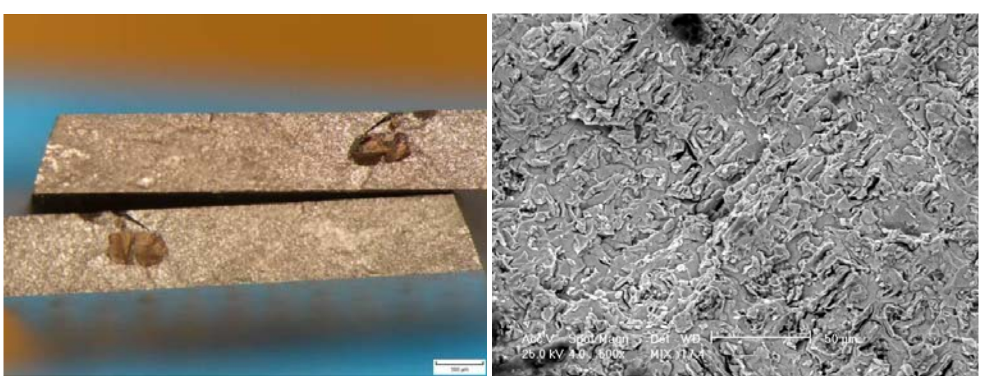
Fig. 2 -Fractographic aspects of surfaces after tensile test of the CoCrMoTiZr type alloy: a,b,c- macroscopic image at stereomicroscope; d,e,f- SEM images in transversal cross section



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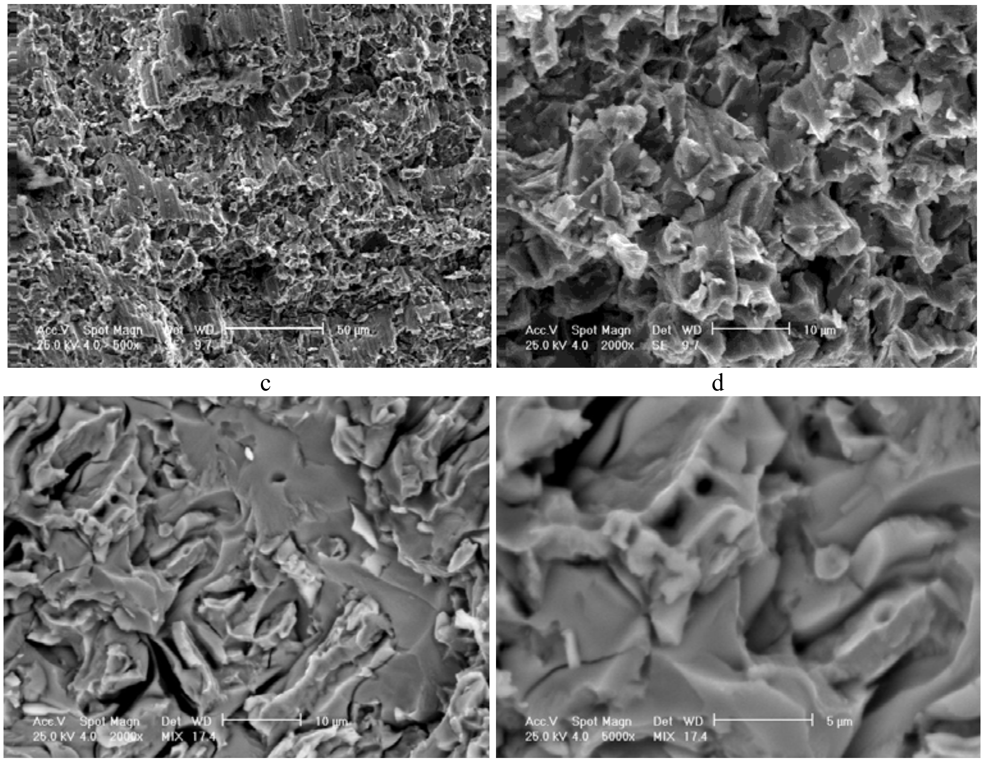

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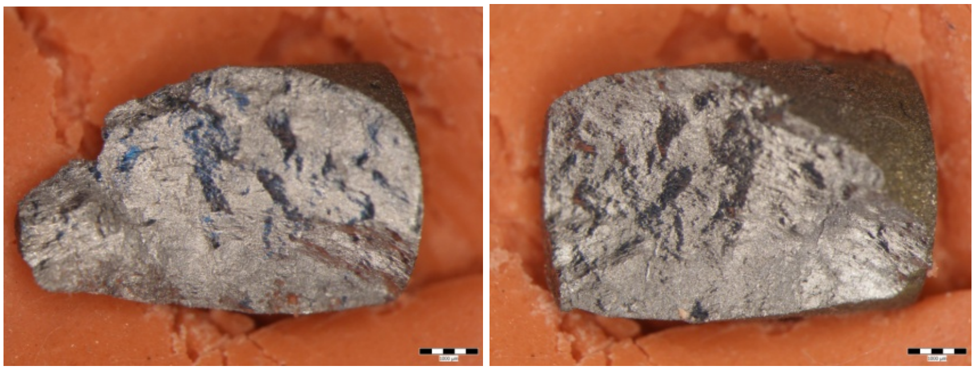
Fig. 3- Fractographic aspects of surfaces after tensile test of the CoCrMoTi5 type alloy: a-macroscopic image at stereomicroscope; b,c,d,e,f- SEM images in transversal cross section

In compressions tests the aspects of the surface sample are completely different, both at room temperature or at high temperature, as is given in Fig. 4÷7. When compression is take place at different high temperatures the aspect of the surface sample is oxidized, with fine faceted cleavage [transgranular brittle fracture (cleavage)], as is shown in Fig. 4 and Fig. 5. The propagation of the fracture front is at 45◦ plane, in according with Schimdt's law. If at the alloy CoCrMo the dendritic aspect is very dominant, Fig. 4d, at CoCrMoTi5 alloys this dendritic aspect is absent (as is shown in Fig. 5), but very fine-faceted crack structure may be seen.

At severe compression tests, at forming degree higher than admitted degree (Fig. 6 and Fig. 7), the same fine faceted crack structure may be seen, with dominant brittle aspect. Of course, at severe compression at room temperature (Fig. 6) the aspect of the sample is shiny, with numerous cracks along the facets. Also, one may be seen at higher magnification, Fig. 6d, the traces of particles route, with breaking friction surfaces.



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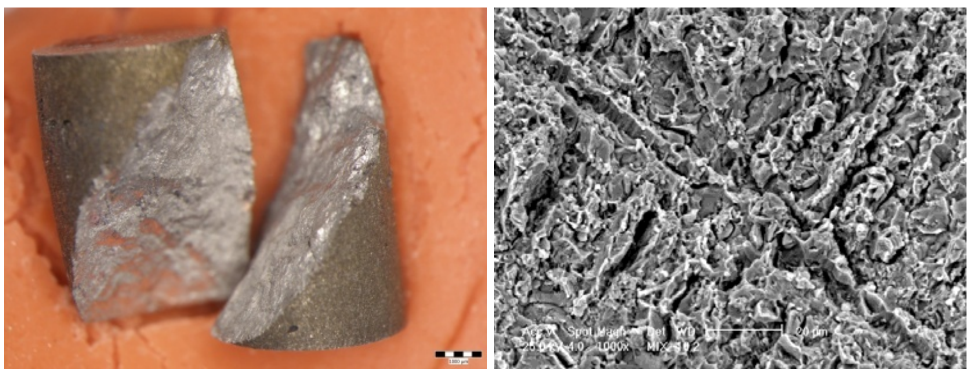

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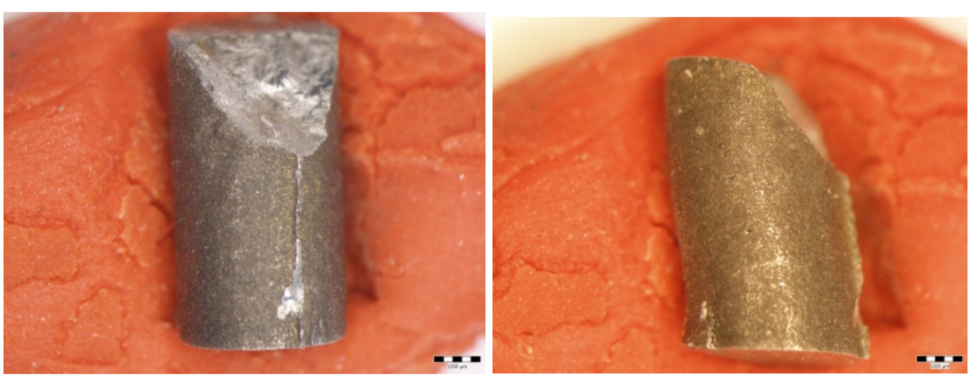
Fig. 4- Fractographic aspects of surfaces after compression at room temperature of CoCrMo type alloy: a,b,c- macroscopic image at stereomicroscope; d- SEM images in transversal cross section



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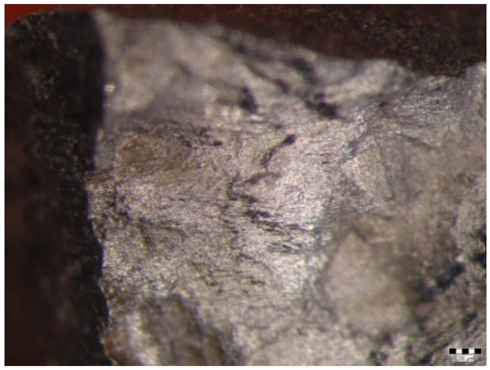

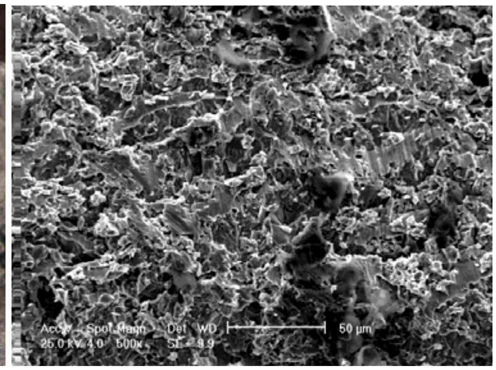

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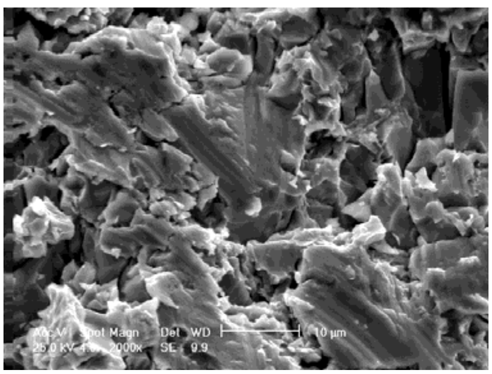

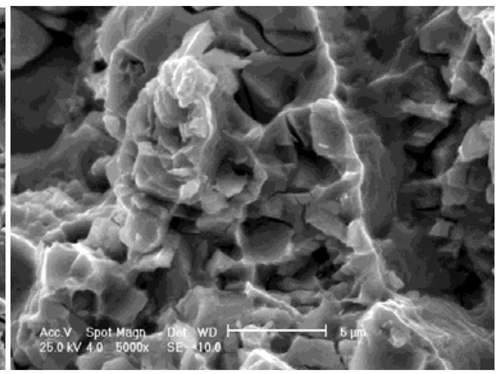

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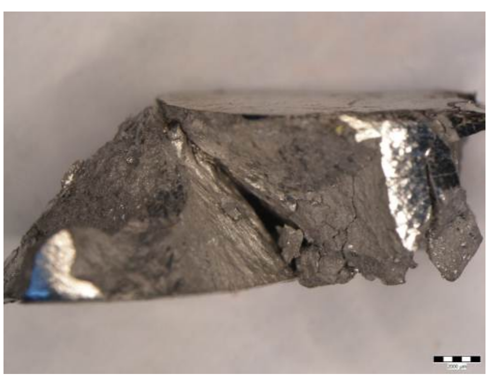
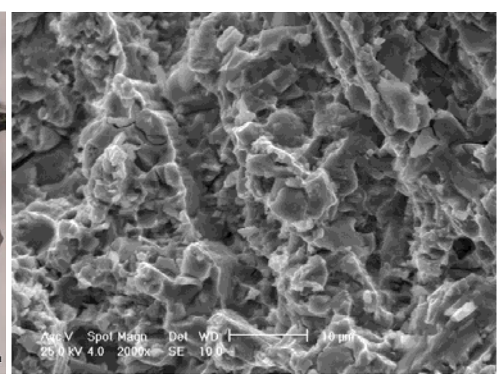
Fig. 5- Fractographic aspects of surfaces after compression at room temperature of CoCrMoTi5 type alloy: a,b,c- macroscopic image at stereomicroscope; d,e,f- SEM images in transversal cross section





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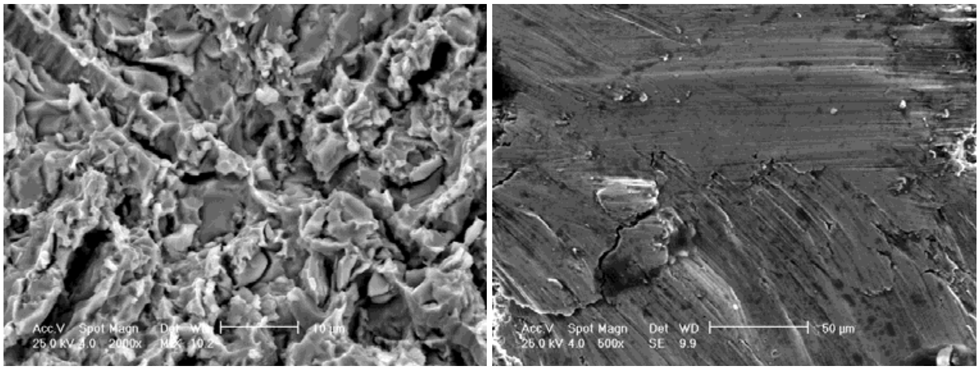

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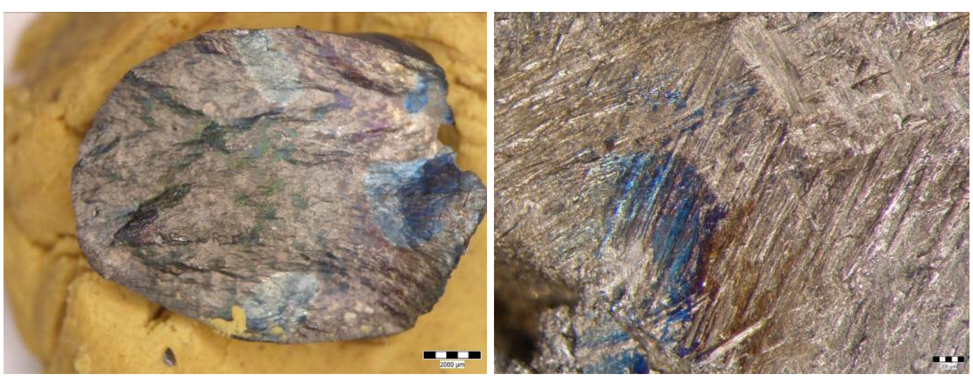
Fig. 6- Fractographic aspects of surfaces after severe compression at room temperature of CoCrMoTi5 type alloy: a- macroscopic image at stereomicroscope; b,c,d - SEM images in transversal cross section

When compression tests are made at higher temperatures, over 1000˚C (Fig. 7), the oxidation phenomena may take place and coloring the surfaces in blue, due to the titanium alloying. Because the test is too severe, fracture appears at the same 45◦ orientation of the fracture front (Fig. 7c). Also numerous parallel slipping lines may be seen, with orientation given different from one grain to another (Fig. 7b, Fig. 7d). If the material was firstly in cast state, the aspect is transgranular brittle fracture- cleavage with river patters and cracking started from the gran boundary. The flatness of cleavage facets suggests the idea that only the two atomic planes forming the fracture surfaces are involved in the crack process. But in cleavage a plastic zone is also formed at the front of a running crack. This plastic zone consumes the main part of the work of fracture. Depending on the lateral extent of the plastic zone the material near the crack planes is plastically deformed. All our remarks are the same with other references, such as [18÷20].



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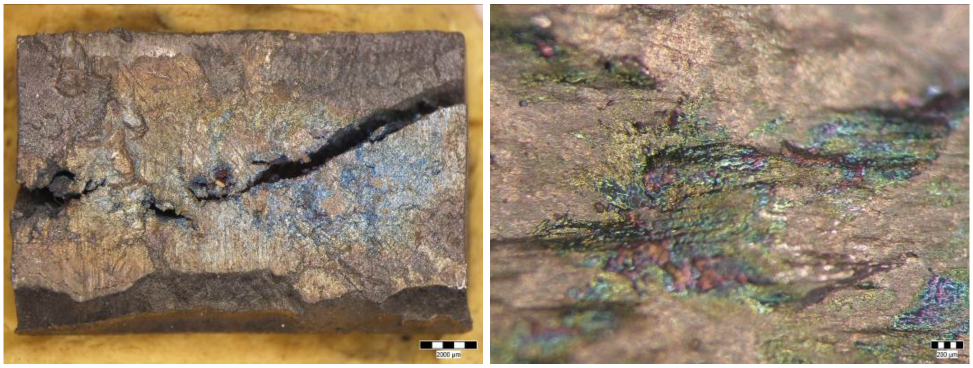

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Fig. 7- Macrofractographic aspects at stereomicroscope of surfaces after severe compression at 1100˚C temperature of CoCrMoTi5 type alloy in transversal cross section at different magnifications

4. Conclusions

Our structural analysis of fractography of new dental alloys from the system CoCrMoTi(Zr) could reveal the following considerations:

- Alloying with titanium of CoCrMo dental alloys could be made in the same manner as the elaboration process of commercial alloys;
- The structure of CoCrMoTi alloys consists in a mixture of solid solution and eutectic with dendritic segregation;
- Macrofractographic analysis of the alloys may reveal the presence of two different zones: with or without defects, which may deeply influence the aspect of fracture.
- Microfractographic analysis put in evidence the manner of propagation of the fracture front, which is similar to all the alloys, no matter the test is: at free defects zones numerous secondary cracks may determine the step movement of fracture front, at compactness defects zones, the fracture front is interdendritic, with clear evidence of dendrites and axes inside the microshrinkages or dimples.
- The fractography made on mechanically tested sample may reveal the brittle behavior of all alloys in cast state. The fracture surfaces consisted in cleavage aspect, with intergranular interdendritic cracks, which were developed by coalescence and displacement movement of the fracture front.
- At severe compression at high temperatures, besides the coloring in blue of the oxidated surfaces in blue, the aspect is transgranular brittle fracture- cleavage with river patters and cracking started from the gran boundary.

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