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RESEARCH ARTICLE

CAUSES OF FRACTURE OF METAL ALLOY CHASSIS COBALT-CHROME-MOLYBDENUM (EXPERIMENTAL STUDY)

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ABSTRACT

The laboratory realization of the removal partial denture casting is often accompanied by casting defects. Among these casting defects, there are defects of structures that cause changes in the initial properties of the Cobalt chromium molybdenum alloy. 15 samples of Cobalt chromium molybdenum alloy metal frame fractured were recovered from dentists and prosthetists (some metal frames were used in the mouth; others not). They have been analyzed in the scanning electron microscope. The results of this study demonstrate the involvement of these defects of structures in the appearance of the fracture of the metal frame. Thus, we can conclude that to avoid this fracture, we need to improve manufacturing techniques of the metal plate in the laboratory.

INTRODUCTION

The cast removable partial prosthesis still occupies a preponderant place in our Moroccan therapeutic arsenal of treatments for partial edentulous patients due to:

- Morocco's low purchasing power.
- The Moroccan social protection system, the reimbursement of which remains partial.

Cobalt-Chrome-Molybdenum or stellite alloys are the most comm only used for the manufacture of metal chassis of cast partial removable prostheses because of their various advantages (cost, Excellent rigidity, Good biological tolerance...).

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The defects of this type of alloy are its low ductility, high hardness and low fatigue strength. These defects will be increased during the casting of the metal frame by the creation of structural defects: segregation and porosity. The purpose of this study is to study the distribution of structural defects with in the analyzed fractured metal chassis in order to better underst and the causes of fracture of Co-Cr-Mo alloy metal chassis and to increase the longevity of cast partial removable prostheses.

MATERIALS AND METHODS

During the one year period, we collected 15 Co-Cr-Mo metal chassis from dentists and prosthetists. Some of these samples are fractured in the dental technician during the control of the adaptation of the frame on the model from the secondary impression, others in the patient after a period of use in the mouth. 15 samples were studied according to the type of fracture at different levels. These samples were analyzed under a scanning electron microscope. In order to be able to analyze the sefractured metal frames, we cut them 1 cm from the fractured area with a cutting pliers (figure 1). Then we put the sample on a sample port using double-sided tape (Figure 2). Afterwards, we brought the twos ample holders to the analysis chamber (Figure 3).

We carried out the analysis as follows:

- Overall observation of the surface state of the sample.
- Observation of the surface state + chemical analysis of the fractured area.
- Observation of the surface state + chemical analysis of the fractured edge.
- Observation of the surface state + chemical analysis of a zone close to the fractured zone.
- Observation of the surface state + chemical analysis of an area far from the fractured area.

A1: Image + spectrum of analysis at the fractured area.
A2: Image + spectrum of analysis at the fractured edge.
A3: Image + spectrum of analysis at the area near the fractured area.
A4: Image + spectrum of analysis at the level of the area far from the fractured area.

At the level of the fractured zone

We observe the presence of structural defects in all samples in the fractured zone. These structural defects can take different forms:

- Porosities: Blows and solid inclusions (or impurities).
- Segregation.
- Structural heterogeneity: Presence of dendrites of variable composition and coarser grains.(Figure 5)

The regions where the blowing and impurities are concentrated are in the form of black areas on the images from the SEM (Figure 6). The regions where the initial alloy or modified alloy is located are white areas on the SEM images.(Figure 7)

Black area

Figure 8**:** The chemical elements that compose the black zone of the fracture zone

A:[c] high Carbon +[c] average Oxygen.
B :[c] high Carbon +[c] low Oxygen
C:[c] high carbon content +[c] medium oxygen content +[c] low sodium content +[c] low chlorine content +[c] low sulphur content +[c] low calcium content.
D:[c] high Carbon +[c] medium Oxygen +[c] low Sodium +[c] low Chlorine.
E:[c] high Carbon +[c] high Oxygen +[c] medium Copper +[c] low Sodium +[c] low Chlorine.
F : c] high carbon content + average oxygen content +[c] low sodium content +[c] low chlorine content +[c] low aluminium content +[c] low silicon content.
G:[c] high carbon content +[c] average phosphorus content +[c] average sulphur content +[c] average calcium content +[c] low sodium content +[c] low chlorine content.
H :[c] high Oxygen +[c] high Sulphur +[c] average Calcium +[c] average Carbon.
I:[c] high Carbon +[c] medium Oxygen +[c] low Sulphur +[c] low Calcium.
J:[c] high Carbon +[c] average Oxygen +[c] average Molybdenum +[c]
K :[c] high Carbon +[c] medium Nitrogen +[c] low Oxygen +[c] low Titanium.
L:[c] high Carbon +[c] medium Oxygen +[c] low Silicon.
M:[c] high Carbon +[c] average Oxygen +[c] average Silicon.
N:[c] high Oxygen +[c] high Silicon.
O:[c] high Silicon +[c] average Oxygen.

We notice that:

- 92% of the samples contain Carbon at a high or medium concentration + Oxygen at a high, medium, low or zero concentration in this area.
- 28% of the samples contain Sodium and Chlorine at a low concentration in this area.
- 23% of the samples contain Oxygen at a high, medium or zero concentration + Sulphur at a high, medium, low or zero concentration + Calcium at a medium or low concentration in this area.
- 18% of the samples contain Oxygen at a high or medium concentration + Silicon at a high, medium or low concentration in this area
- 3% of the samples contain Copper at an average concentration and 3% of the samples contain Aluminium at a low concentration so 6% of the samples contain metallic elements outside the Co-Cr-Mo alloy at this zone.
- 4% of the samples contain Phosphorus at an average concentration in this area.
- 4% of the samples contain Molybdenum at an average concentration in this zone.
- 4% of the samples contain Nitrogen at an average concentration in this area.

White zone

We note that:

- 46% of the samples contain the elements of the Co-Cr-Mo alloy at a normal concentration with or without other elements.
- 54% of the samples contain the elements of the Co-Cr-Mo alloy with a higher concentration of Chromium and with or without the presence of other elements.
- 20% of the samples contain elements other than the basic elements of the Co-Cr-Mo alloy.

At the edge of the fracture: It can be seen that the elements of the Co-Cr-Mo alloy are present at a normal concentration in the majority of samples in this zone.

In the area near the fracture area: In this area, we observe the presence of cracks in 96% of the samples. These cracks are the initiation and propagation areas of the fracture.

A: Presence of the Co-Cr- Mo alloying elements at normal [c].
B: Presence of the elements of the Co-Cr-Mo alloy at [c] normal +[c] low Carbon +[c] low Oxygen.

Figure 1. Cutting the sample

Figure 2. Sample placed on the sample holder

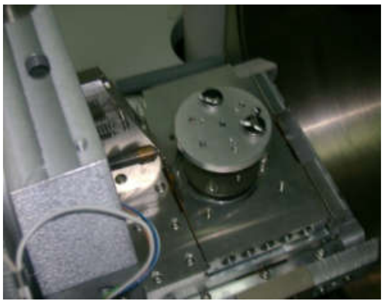


Figure 3. The two sampleholdersplaced in the analysis chambrer

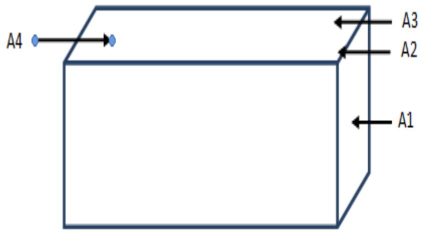


Figure 4. Scanning electron microscope analysis procedure

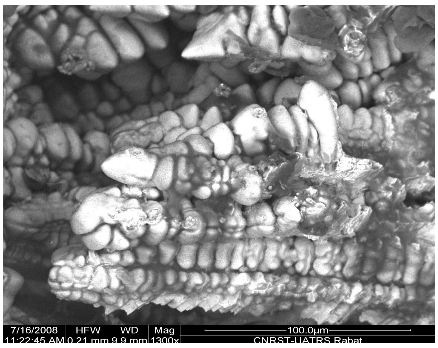


Figure 5. Structural heterogeneity

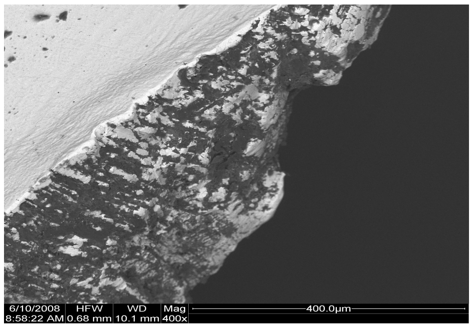


Figure 6. Areas where blowholes and impurities are concentrated are in the form of black areas

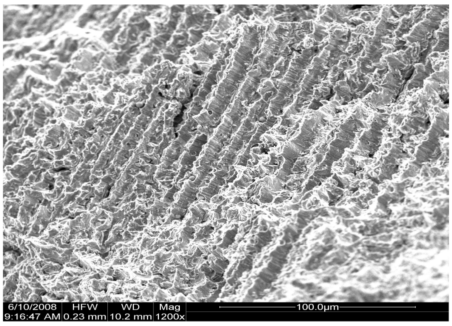


Figure 7. The regions where the initial alloy or modified alloy is located are white areas

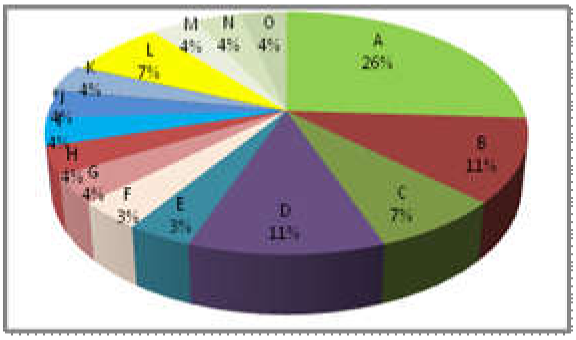


Figure 8. The chemical elements that compose the black zone of the fracture zone

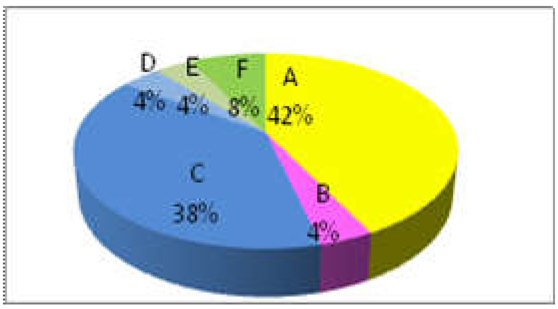


Figure 9. The chemical elementsthat compose the white zone of the fracture zone

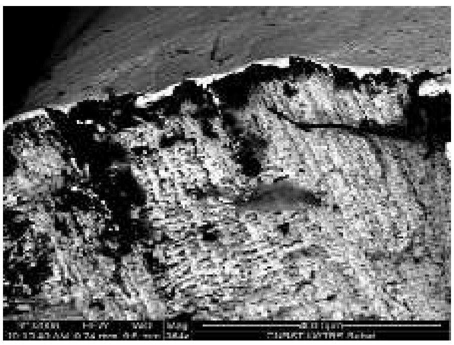


Figure 10. Image at the edge of the fracture

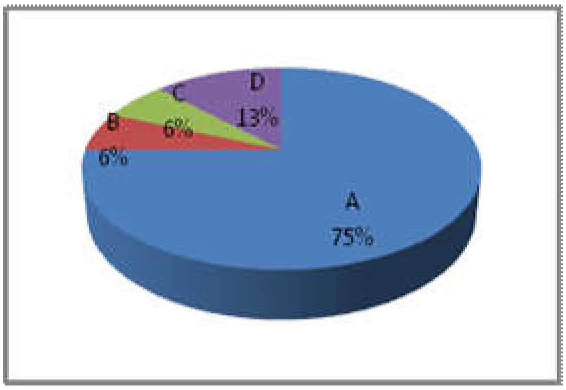


Figure 11. The chemical elements that compose the edge of the fracture

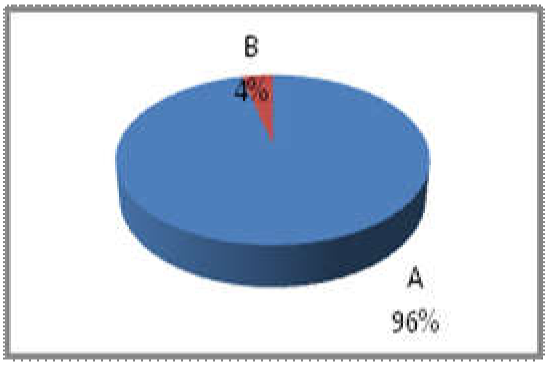


Figure 12. Percentage of cracks in samples

A: Presence of cracks. B: No cracks

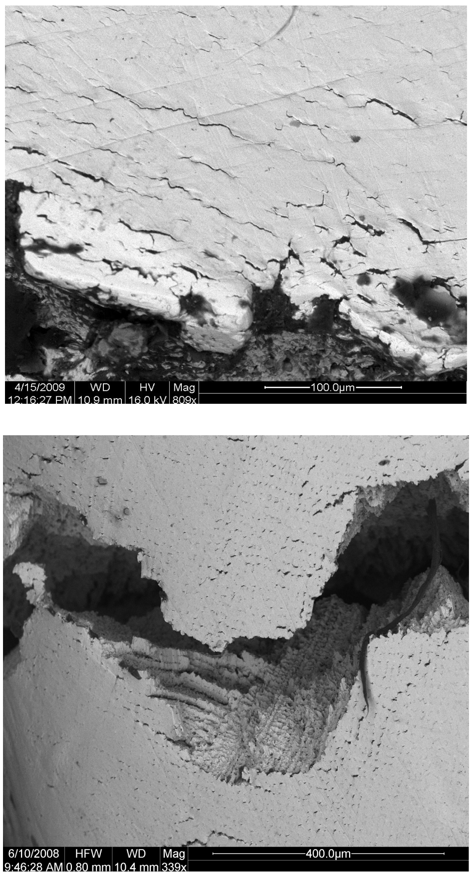


Figure 13. Image of the crack

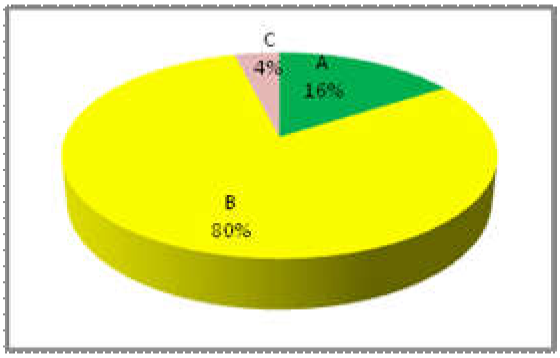


Figure 14. The chemical elements that compose the area outside the crack

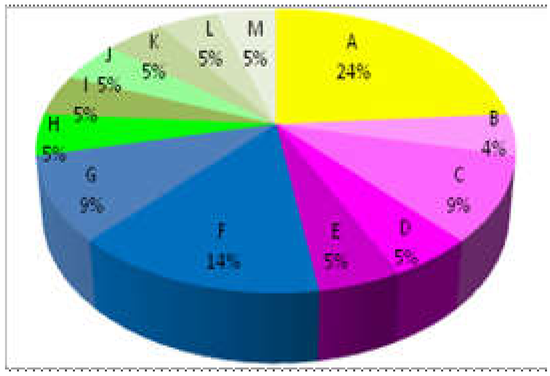
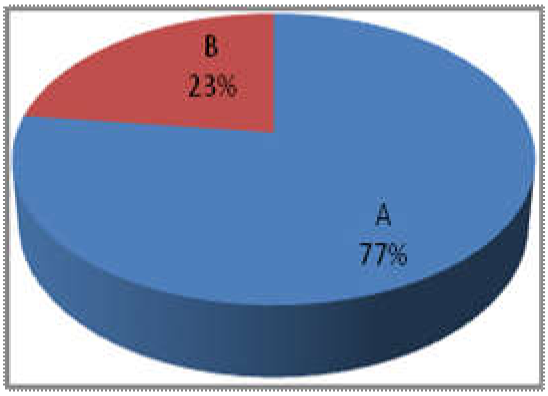


Figure 15. The chemical elements that compose the crack



A: Presence of precipitation.
B: No precipitation

Figure 16. Percentage of precipitation at sample level

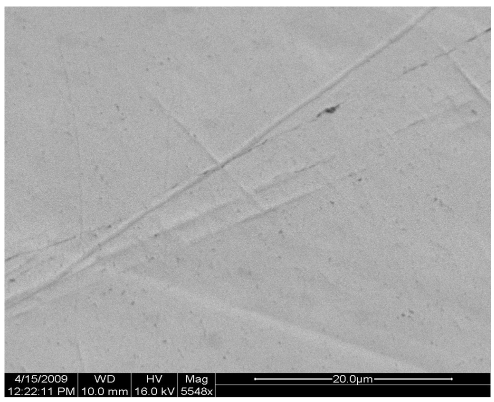


Figure 17: Image of the area far from the fracture area: No precipitation

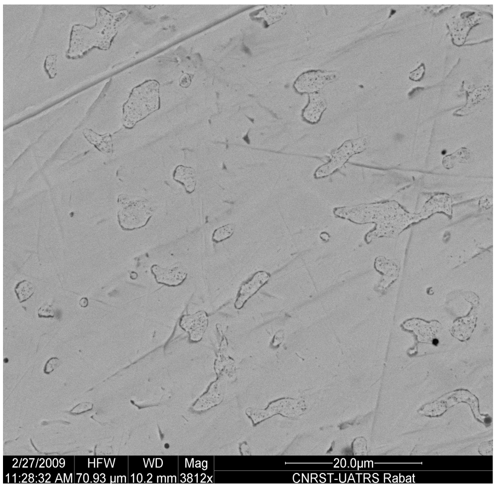
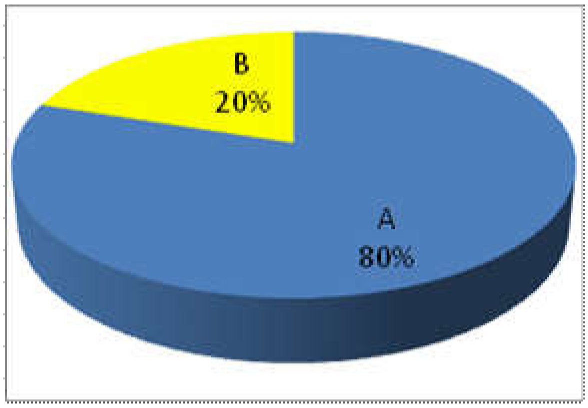


Figure 18. Image of the area far from the fracture area: Présence de précipitations



A: Elements of the Co-Cr-Mo alloy at normal concentration.
B: Elements of the Co-Cr-Mo alloy at a normal concentration+ of carbon and oxygen at a low concentration.

Figure 19. The chemical elements that compose the area outside of the precipitation

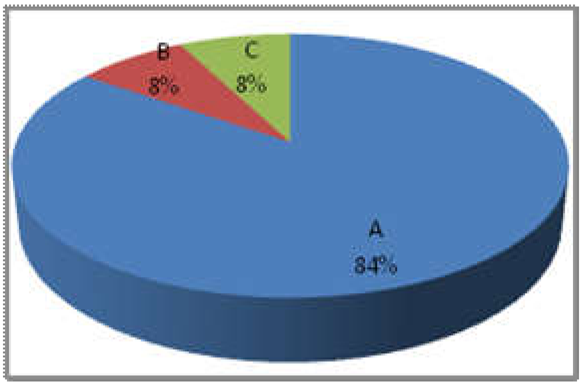


Figure 20. Chemical elements that compose precipitation

C: Presence of Co-Cr-Mo alloy elements with [c] high Chromium, [c] lower Cobalt and above normal molybdenum (high) +[c] medium Oxygen +[c] low Carbon.

A: Presence of the elements of the Co-Cr-Mo alloy with a higher[c] of Chromium +[c] low Carbon and Oxygen.
B: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Molybdenum, lower of Cobalt (average) and normal of Chromium +[c] low of Carbon.

C: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] average of Molybdenum and a low[c] of Cobalt +[c] low of Carbon and Oxygen.

D: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] average of Cobalt,[c] normal of Molybdenum and[c] low (above normal) of Silicon +[c] low of Carbon +[c] average of Oxygen.

E: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] average of Cobalt and a normal[c] of Molybdenum +[c] average of Carbon +[c] low of Oxygen +[c] low of Sodium and Chlorine +[c] low of Calcium +[c] low of Potassium.

F :[c] high Carbon + [c] low Oxygen.
G :[c] high Carbon +[c] average Oxygen +[c] average Calcium.
H :[c] high Carbon +[c] average Oxygen +[c] average Calcium +[c] low Chromium.
I:[c] high Carbon and Oxygen content +[c] average Molybdenum content +[c] average Calcium content.
J:[c] high Carbon and Chlorine +[c] medium Oxygen +[c] low Calcium.
K :[c] high Silicon +[c] low Carbon +[c] low Oxygen .
L:[c] high Oxygen and Molybdenum +[c] average Calcium +[c] low Chromium +[c] low Cobalt +[c] low Carbon.
M:[c] high Aluminium +[c] high Oxygen.

We note that:

- 52% of the samples show a change in the proportions of the base elements constituting the Co-Cr- Mo alloy at the crack area.
- 63% of the samples show other elements at the crack level than the elements constituting the Co-Cr- Mo alloy.
- 15% of the samples show a change in the proportions of the base elements constituting the Co-Cr- Mo alloy and other elements than the elements constituting the Co-Cr- Mo alloy at the crack level.

So the cause of the cracks is:

- In 52% of the samples is segregation .
- In 63% of the samples is porosity.
- In 15% of the samples is segregation and porosity.
It can be seen that cracks caused by segregation have:
- In 83% of these cracks: Chromium at a high concentration.
- In 17% of these cracks: Molybdenum at a high concentration.
It can be seen that cracks caused by porosity have:
- In 84% of these cracks: Oxygen at a high concentration.
- In 60% of these cracks: Carbon at a high concentration.
- In 54% of these cracks: Oxygen at a low or medium concentration and Calcium at a low or medium concentration.
- In 16% of these cracks: Silicon in high or low concentration.
- In 8% of these cracks: Aluminium at a high concentration.
- In 8% of these cracks: Chlorine at high concentration.
- In 8% of these cracks: Chlorine at low concentration and Sodium at low concentration.

N.B.: We observe that Carbon and Oxygen are the most present elements in the porosities that cause cracks and porosities in the fracture region.

In the area far from the fracture: We observe the presence of precipitation in 77% of the samples at the area away from the fracture.

Area outside of precipitation: We note that the area outside the precipitation is composed of:

- In 80% of the samples: Elements of the Co-Cr-Mo alloy at normal concentration.
- In 20% of the samples: Elements of the Co-Cr-Mo alloy at a normal concentration+ of carbon and oxygen at a low concentration.

It can be seen that the elements of the Co-Cr-Mo alloy are present at a normal concentration in the majority of samples in this zone.

Precipitation zone

A: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] very low of Cobalt and a normal[c] of Molybdenum +[c] low of Carbon +[c] low of Oxygen.

B: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] low of Cobalt and an average[c] of Molybdenum (above normal) +[c] low of Carbon +[c] low of Oxygen.

C: Presence of the elements of the Co-Cr-Mo alloy with a high[c] of Chromium,[c] average of Cobalt (less important) and a normal[c] of Molybdenum +[c] low of Carbon +[c] low of Oxygen. In all samples, there is a modification in the proportions of the basic elements constituting the Co-Cr- Mo alloy in terms of precipitation.

DISCUSSION

The results obtained in our study on the causes of fracture of Cobalt-Chrome-Molybdenum metal chassis are in accordance with the data in the literature. They confirm the implication of structural defects (segregation and porosity) in the appearance of fractures. Harcourt 1961 examined 31 fracture zones of 23 metal frames of metal partial prostheses under an optical microscope and assumed that the cause of fracture of half of these samples is the presence of porosities (11) Arthur J. Lewis 1978 examined 41 metal partial dentures with a stereomicroscope. The results of this examination revealed the presence of 3 porosities at the fractured area, which shows that the cause of fractures of the metal frames of these prostheses is the presence of porosity inside the structure of the Co-Cr-Mo alloy (12). R. Van Noort and D. J. Lamb1984 examined the fractured surface of 12 metal frames of metal partial dentures under a scanning electron microscope. The results of this study showed that the most significant cause of metal frame fractures is the presence of structural defects. (20) These structure defects are introduced into the metal part during casting either by:

- Incorrect choice of coating material or mistakes in its preparation (4,10,17,19)
- Errors during the preparation of the mockup of the metal frame or casting rod system. (4,6, 16)
- Failure to respect the kinetics of the temperature rise when heating the cylinder (10,19)
- Mistakes in the choice of the alloy used. (1)
- The lack of cleaning of the crucibles after each use (17)
- Errors in the choice of fusion and casting method. (4,15,17,28,19)
- Errors during cooling (4, 3, 13)

The presence of structural defects in the cast part favours the appearance of fractures according to different processes: (4,5, 7, 8, 12, 13, 19, 20)

- The presence of segregation leads to an uneven distribution of the alloying elements, which contributes to a change in the mechanical characteristics of the cast-piece and makes it more susceptible to fracture.
- The development of porosity reduces the section of the prosthetic element it affects. The result is a local weakening of the part which, under the stress of the forces applied to it, appears more likely to fracture under tensile stress than an unscathed part.

A porosity also represents a site that initiates the fracture. The existence of a porosity leads to the concentration of stresses at its level causing the initiation of the fracture, the result of which is established by fatigue. The effects of these defects are all the more pronounced when their volume is large or when their location affects critical areas under heavy load.

- The formation of porosities during casting results in a change in the initial mechanical properties of the alloy.
- The development of porosity promotes the corrosion process of the alloy which can lead to a subsequent fracture.

In our study, samples where carbon is found at high or medium concentration, the fracture can be explained by the fact that the increase in carbon content increases hardness and decreases ductility, making the cast piece more fragile. (14,19). In samples containing Oxygen, sulphur and calcium, the fracture may be explained by the fragility of the cast piece due to the decomposition products of the plaster. (10). In samples where Silicon is found at high, medium or low concentration, the fracture can be explained by the fact that the presence of Silicon at a content higher than 1% weakens the alloy. (14,19). In samples containing Copper or Aluminium or Phosphorus or Molybdenum or Chlorine or Sodium, the fracture can be explained by the modification of the mechanical characteristics of the alloy by modification of its constituent elements. (20). The presence of the modification of the proportions of the base elements constituting the Co-Cr- Mo alloy in some samples can be explained by the phenomenon of segregation due to a cooling error: acceleration of the cooling process (3, 4, 5, 9). Chromium and Molybdenum increase the hardness and decrease the ductility of the Co-Cr-Mo alloy, which explains their high concentrations at the crack level (19,5, 2,14). In samples where the elements of the Co-Cr-Mo alloy are present at a normal concentration + Carbon and Oxygen at a low concentration, the fracture can be explained by the presence of porosities.

In samples where the elements of the Co-Cr-Mo Mo alloy with a higher concentration of Chromium are present, the fracture can be explained by:

- The presence of porosities.
- The modification of the mechanical characteristics of the alloy by modifying the proportions of these elements (6,1)
- The increase in hardness and the decrease in ductility by increasing the Chromium content (2,5,14)
- In samples where the elements of the Co-Cr-Mo alloy are present at a normal concentration + other elements, the fracture can be explained by:
- The presence of porosities.
- The modification of the mechanical characteristics of the alloy by modifying its constituent elements (19)
- In samples where the elements of the Co-Cr-Mo Mo alloy are present with a higher concentration of Chromium + other elements, the fracture can be explained by:
- The presence of porosities.
- The modification of the mechanical characteristics of the alloy by modifying the proportions of these elements and the presence of other elements (19)
- The increase in hardness and the decrease in ductility by increasing the Chromium content. (3,6,16)

In all precipitation, there is a change in the proportions of the basic elements constituting the alloy Co-Cr- Mo . So precipitation is a major segregation that can constitute a site of initiation and propagation of the fracture. (19,2)

Conclusion

To reduce the fracture rate of Co-Cr-Mo alloy metal chassis, it is necessary to try to reduce the quantity of structural defects by strictly respecting the technique chosen for casting the metal chassis and improving the casting techniques of the Co-Cr- Mo alloy. Wherever possible, use induction vacuum or neutral gas flux casting (Argon) and depressed-pressure casting which provide the low structural defect rate in the cast part.

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