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OBTAINING AND STUDYING TENSILE STRENGTH FOR NON-PRECIOUS ALLOYS BASED COBALT

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ABSTRACT

This paper presents aspects of obtaining non-precious dental alloys of Co-Cr-Mo alloys system and experimental tests to determine tensile strength, carried on standard flat specimens.

KEYWORDS: non-precious alloys, medical applications, casting, electrical discharge

1. Introduction

The use of metals and alloys in medicine applications has been known science ancient times, when they were designed and manufactured artificial substitutes that were implanted in the mouth.

Metals were used to fix the replacement teeth on the original teeth, with ligature wire from silver or gold, technique described by Hippocrates in the treatise "Epidemia" [1].

The oldest complete denture was made in Japan and it was found at Ganjyoji Temple (Kii Province). It was made of Buxus wood [2].

In 1932 was obtained the first alloy from Co-Cr-Mo alloys system, and since that time, the conditions of use of materials in medicine have been determined by three main factors [3]:

- Increasing the share of use of non-precious dental alloys due to the increasing price of noble alloys;
- Ongoing improvements made in the creation of new dental materials with special properties;
- Continuously changing manufacturing technology prosthetic devices.

The developments that we see in medicine are due to specialists in areas such as materials engineering, mechanical engineering, chemistry, physics, electronics and so on, thus making the complex links between these scientific fields that have the common goal to improve the people's health [4].

Co-Cr-Mo alloys referred to as "stellite" system are cobalt-based alloys resistant to wear, abrasion, corrosion, oxidation and erosion.

At higher temperatures up to 800°C, they keep their properties including high hardness and are less complex than nickel - based alloys [5].

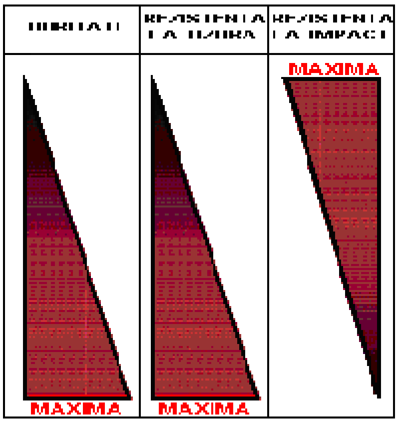

Fig. 1. *Values of properties of the alloys of cobalt* [6]

Cobalt-based alloys are difficult to manufacture and therefore their use has been limited but constant research has led to the development of specific casting methods [7].

Co-Cr-Mo system for casting alloys are widely used for making various devices surgically implanted in the body, their use always continues to extend [8].

Since 1949 it is estimated that over 80% of partial dentures were made of Co-Cr-Mo alloy system, and by 1969, over 87% [9].

Currently, almost all the metal plates of partial dentures are made of Co-Cr-Mo alloy systems.

2. The material used in experimental research

The material used in the research is a commercial alloy Co-Cr-Mo system, which belongs to the class of non-precious dental alloys, for medical applications.

The chemical composition of the alloy according to product data sheets is shown in Table 1.

Table 1. *The concentrations of the alloying elements for the Co-Cr-Mo commercial alloy*

Alloying element	Co	Cr	Mo	C	Si	Mn
% Mass	65	29	5	0.4	0.35	0.25

The materials used to produce these alloys of high purity and are appropriately selected in terms of chemical composition and grain size analysis.

The size of the ingots are chosen such that to be executed in well-positioned in the wells with water-cooled copper plate of the plant.

Mechanical characteristics for the studied alloy are the described in Table 2.

Table 2. *Mechanical characteristics for the studied alloy*

Yield stength	$R_{p0,2}$	560 N/mm^2
Tensile strength	R_m	760 N/mm^2
Elongation	A	3 %
Modulus of elasticity	E	219000 N/ mm^2
Hardness	HB	380
Density		8.26 g/cm^3
Melting range		1330…1400 ^{o}C

The process aims to achieve rapid melting to a maximum allowable current.

In terms of melting intensities we took into account a number of metallurgical considerations related to gas metal purification and non-metallic inclusions. The melted cobalt-based ingots have a good chemical and structural homogeneity [13].

3. The technological flow for the obtaining of cobalt-based alloys

The obtaining of material, submitted to research, was performed using arc remelting facility, MRF vacuum ABJ 900, followed by remelting of the alloy for 7 times for refining and homogenizing the structure in the same installation.

Work parameters for RAV installation are the following:

- Pressure on site 10^{-4} mbar;
- "Flooding" of the working chamber with argon purity 99.99%, which carries out an on-site oxygen content of approx. 60 ppm;
- Melting power: 55 kVA;
- Melt flow of 650 A.

Advantages of this furnace are:

- High temperatures are reached in just a few seconds;
- Creating alloys with a uniform composition due to the strong stirring effect realized by an electric arc melting;
- Possibility of mixing the components with different melting temperatures.

Fig. 2. *Remelting installation with electric arc, under vacuum, type MRF ABJ 900*

During the melting and casting operations can be achieved an atmosphere of vacuum or inert gas to prevent reaction with oxygen or nitrogen in the furnace atmosphere.

The technological flow of obtaining cobalt-based alloys consisted of the following steps:

- Preparation of commercial CoCrMo alloy;
- Degreasing volatile organic solvents to remove the surface grease, which could affect the quality of the protective atmosphere inside the kiln and the quality of the alloy obtained by casting process;
- Weighing "ingots" of commercial Co-Cr-Mo alloy under the charge calculation;
- Loading of raw materials in the crucible furnace;
- A vacuum system and achieving controlled argon atmosphere inside the melt;
- Batch melting by the heat of the arc, followed by remelting for 7 times;
- Extraction of molded samples obtained.

4. Commercial Co-Cr-Mo alloys remelting

This phase included the remelting of commercial alloy, from Co-Cr-Mo system. Melting was performed by using the arc created between the tungsten-thorium electrode and metal charge placed in the wells of different sizes, formed in the base made of copper and cooled with water.

Co-Cr-Mo alloy system has been introduced under the form of "ingot", which has been melted by the heat from the electric arc. To ensure a high homogeneity of the alloys, the load was remelted at least 7 times with successive turns of micro-ingot formed in each well after each remelting.

Fig. 3. *Commercial Co-Cr-Mo alloy prepared during elaboration process*

The alloys obtained were classified by sample weight, keeping weight to a quasi-constant value in each category.

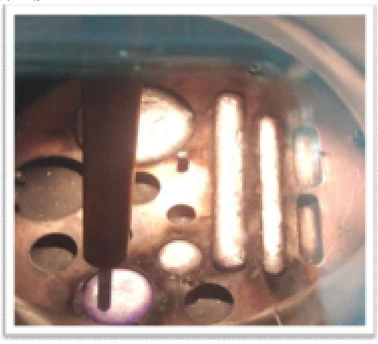

Fig. 4. *Melting of commercial Co-Cr-Mo alloy*

After solidification of the commercial alloy, from Co-Cr-Mo system, we obtained five samples of various weights and shapes (Figure 5).

Fig. 5. *Commercial Co-Cr-Mo alloy after solidification – casting samples*

The structure of remelted samples is compact, uniform, with dendrites oriented in direction of the sense thermal gradient.

Concentric zonal segregation showed that a difference in grain occurs at melting with higher intensities. To limit the formation of casting losses at the end of ingot, remelting has dwindled towards the end of the current intensity.

To calculate the metal load (load dosing) levels were taken into account theoretical assimilation of the elements melt and vaporization any losses. The metallurgical process takes place in vacuum or controlled atmosphere of argon.

Evaporation losses are reduced because "ingots" do not contain impurities, development performed in controlled atmosphere of vacuum and argon.

Melting occurred evenly and smoothly throughout its duration and at the end of the process, with a gradual reduction for the current intensity and in the work chamber was introduced an inert gas (argon), until the pressure reached about 10^{-4} mbar.

After elaboration of the first batch molded samples were obtained various sizes. Batch size has been chosen so that, after each sample, preparation can be used for different tests.

Table 2. *Calculation of charges for commercial alloy from Co-Cr-Mo system*

Nr.	Charge	Co	Cr	Mo	Ni	Si	Mn	Fe	W	S	P
	[g]										
1	171.34	107.410	45.924	10.217	4.974	1.371	0.723	0.550	0.195	0.009	0.002
2	105.48	66.123	28.272	6.290	3.062	0.844	0.445	0.339	0.120	0.005	0.001
3	253.78	159.090	68.021	15.133	7.367	2.030	1.071	0.815	0.289	0.013	0.003
4	72.36	45.361	19.395	4.315	2.101	0.579	0.305	0.232	0.082	0.004	0.001
5	33.56	21.038	8.995	2.001	0.974	0.268	0.142	0.108	0.038	0.002	0.000

5. Samples cutting by electric discharge

Processing of specimens, required for this study, was done by electric discharge and the removal of excess material is based on the erosive effects of electric discharges impulse, primed repeatedly between object processing and electrode.

Processing plant Japax electro JAPTI (Fig. 6) is composed of: machine itself, the water basin with a capacity of 120 liters and control panel.

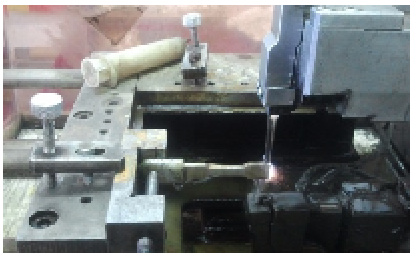

Fig. 6. *Japax Japt with wire cutting machine, to cut the samples*

During the electric discharge processing, dielectric (de-ionized) water is heated and thus it pollutes the particles collected, with the possibility of short circuits.

To remove these unwanted phenomena, the plant has in its system cooling and filtering the dielectric and washing the work gap.

6. Tensile tests

We used tensile testing because we can determine many mechanical properties that allow us to make an accurate assessment of the behavior of the material that will be used in the application [15].

To highlight the differences between the various parameters obtained as a result of tensile testing, investigations were conducted on flat specimens with a total length of 54 mm in accordance with specific standard tests.

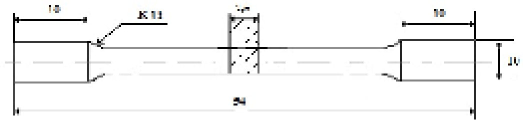

Fig. 7. *Flat sample which used tip tensile test [16]*

Determination of mechanical testing was performed on Instron 3382 machine, computer-aided record tensile curves being automatically made according to the established protocol traction experiment, monitored by the traction machine program.

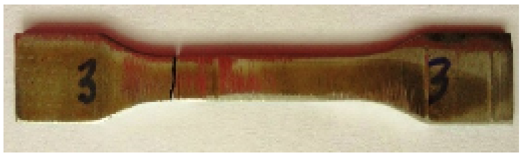

Fig. 8. *Samples after tensile test*

The tests were carried out at ambient temperature. Curves of tensile stress (MPa) were plotted function of tensile strain (%).

For each alloy were performed 4 tensile tests to reveal better mechanical properties and to obtain the most accurate results.

Table 3 contains the values provided by the traction machine program for the mechanical properties of commercial CoCrMo alloy samples.

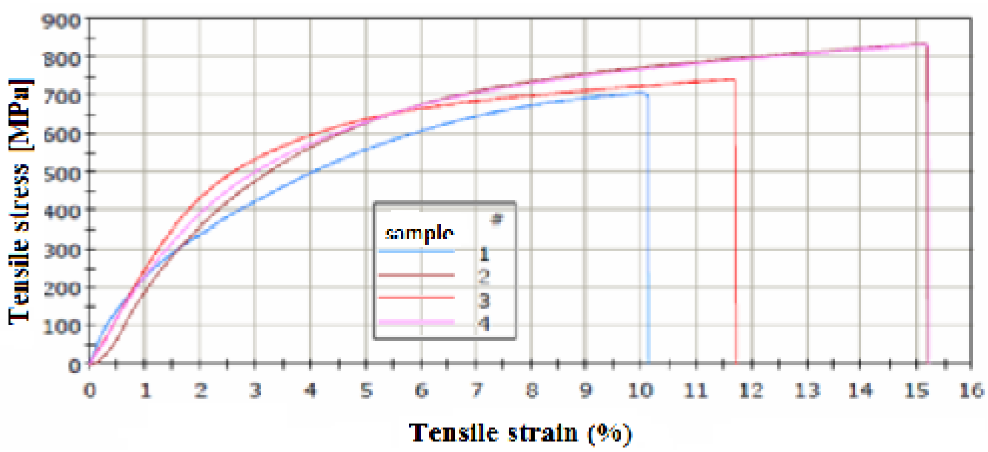

Fig. 8. *Tensile stress vs Tensile strain, curves obtained for commercial Co-Cr-Mo alloy*

Table 3. *Mechanical properties measured by tensile test for Co-Cr-Mo alloy*

Tensile stress vs. Tensile strain	**Maximum load**	**Tensile strain at Break (Standard)**	**Modulus (E-modulus))**	**Tensile stress at Tensile Strength**	**Tensile stress at Yield (Offset 0.2 %)**
	[N]	[%]	[MPa]		
CoCrMo (1)	7079.35	10.12	20059.03	707.60156	281.17
CoCrMo (2)	8343.83	15.17	21644.17	833.73578	358.56
CoCrMo (3)	7436.92	11.71	23809.56	742.39044	428.73
CoCrMo (4)	8316.70	15.20	20900.89	830.25531	386.32

The Co-Cr-Mo alloy system shows a linear behavior up to rupture. Given the behavior of the alloy, it belongs to the category of fragile materials which are characterized by the following traits:

❖ Rupture occurs suddenly and without prior plastic deformation;

❖ Characteristic tension-strain (σ-ε) is linear;

❖ They do not distinguish a deviation from linearity of the characteristic curve which means that plastic deformations, if they exists, are limited;

❖ As the elongation is observed that there is a greater dispersion of this size, probably due to sample processing defects;

❖ Maximum tension for Co-Cr-Mo alloy system is 833.73 [MPa]. At this level of deformation tension is relatively small, which implies that all deformation was elastic rupture, breaking effort with a maximum of 428.73 [MPa];

❖ Rupture occurred due to crack propagation from a preexisting defect and not due to displacement, dislocation accumulation and agglomeration planes additional obstacle;

❖ The examination and cross-sectional area measurement, after fracture, pointed out that they remain plane and perpendicular to the direction of application. The crystallographic plans do not change its original shape and very little his size;

❖ This aspect of the results, after fracture surfaces, is characteristic to the brittle behavior of materials;

❖ The modulus of elasticity was deduced from the slope of the voltage curve approximation - specific strain (σ - ε), given the linearity of the curve up to breaking;

❖ Thus, Co-Cr-Mo alloy system for the maximum elastic modulus was 23809.56 [MPa].

7. Conclusions

If Co-Cr-Mo alloys are commonly used in medicine, their detailed study has an important role in determining the structural stability, size and variation of properties in different processing conditions.

The study of the mechanical properties of the system of Co-Cr-Mo alloys was performed using dedicated laboratory tests to assess their potential use as biomaterials for medical applications.

Depending on the properties and areas of application, the study continues as cobalt -based alloys and their production technologies ensure the development of new applications of scientific and engineering requirements of the present time.

The modulus of elasticity is a controversial matter. It is a measure of the elastic deformation and is inversely proportional to its amplitude.

A high modulus of elasticity, the minimum deformation means and the forces are taken to full bridge abutments, and as such will be overworked.

On the other hand, a low modulus of elasticity means and the high deformations under the action of forces can lead to mobilization of abutments.

The modulus of elasticity of the alloy based on cobalt 200-234 GPa is two times higher than that of the noble alloys, which gives a certain advantage and aesthetic designs can be achieved at the same time soft and rigid.

As the modulus of elasticity is higher, with both the mechanical parts made from Co-Cr-Mo alloys, can be made thinner.

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