Hot Working Behaviour of a New Dental Alloy

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Cobalt based alloys are widely used in medicine, the system CoCrMo being used for partial removable dentures realization. The extension of the applications for these alloys is based either on alloying of the tertiary system with new elements, or to the using of the plastic forming components. Titanium, which is well-known for its biocompatibility property, was used as an alloying element for the system CoCrMo in order to increase the physical-chemical properties of these alloys. Present paper has the aim of establishing the plastic forming behavior of the new alloy from the system CoCrMoTi, with 5.5%Ti, which will be possible used in dentistry. The experiments were realized in laboratory conditions, on a free falling dawn hammer, with high of free falling about H = 0.2 m,, and the falling dawn mass about 71 kg. The determinations were made in the range of temperatures about 1100 – 1250°C, at every 50°C. Finally, the graphics of plastic forming versus temperature and mechanical working versus temperature were drawn. The final conclusion was that the optimum range of temperature for hot working of the CoCrMoTi alloy is 1150 ÷ 1250°C, in which the plastic forming resistance and specific hot working are optimum.

keywords: cobalt based alloys, deformability, optimum range for plastic forming, partial removable dentures

The physico-mechanical properties of a metallic material, in correlation with the chemical composition and structure may condition the behavior of the material during plastic deformation. Deformability is a complex technological feature that depends on the value of plasticity index and resistance to plastic deformation of the metal material analyzed and how the two parameters change depending on the material factors or specific deformation conditions.

The obtaining of the plastic forming products [1-3], with no internal or external defects and with precised mechanical properties could be realized by applying some corect establishing technologies, where the properties which characterize the formability of the metallic materials, such as plasticity or forming resistance must ne known at design. Knowing the plastic forming resistance in connection with the nature of the metallic material and the plastic conditions by pressure represents one of the main problem which must be taken into account at the selection of the forging device and the heating range of temperatures.

In turn, the resistance to plastic deformation is determined either by tensile testing, by compression or upsetting test. Because the external force is transmitted through the metallic material that acts in the same direction and the same sense, sometimes by plastic deformation one may understand the required load for metals and alloys to pass from the elastic to plastic state.

Cobalt based alloys are widely used in medicine[4-9], the system CoCrMo being used in dentistry, respectively for partial removable dentures realization. Extending the applications of these alloys are based either on alloying the system with new elements, or the use of deformable components. Titanium, known for its biocompatibility has been used as an alloying element in CoCrMo system to increase the physic-chemical properties of these alloys. Many papers indicate the possibility alloying with titanium of the CoCrMo dental alloys [8-14, 17].

This paper aims to establish the plastic deformation behavior (ie determining the optimum hot plastic deformation) of a new alloy CrCoMoTi system with possible application in dentistry.

Material and research procedure

The metallic materials used during the experiments is an alloy from the system CoCrMoTi , which was obtained in special conditions, in an melting furnace type Fives Celes, wi neutral atmosphere, by levitation [9,10]. The chemical composition of the alloy was: 28%Cr; 4.5%Mo; 5.5%Ti; 1%Si; 0.33%C and rest Co.

Since direct measurement of forming stress is difficult, requiring special equipment performance to determine the optimum of forging temperatures, resistance to deformation of the material at the test temperature was determined indirectly based on the relationship of deformation work:

$$L = \sigma'_c \cdot \left(1 + \frac{1}{3} \cdot \mu \frac{d_1}{h_1}\right) \cdot V \cdot \varepsilon_u \qquad (1)$$

where:

L – forming mechnical work [J, Nm];

σ'_c – forming resistance of the materials at the test temperature [N/m²];

μ – external friction coefficient (in accordance with the table 3.6);

d_1, h_1 – average diameter and sample high after forming [mm];

V – material volume which is plastis formed [m³];

ε_u – unit plastic forming degree obtained at one blow, calculated with the relation:

$$\varepsilon_u = \frac{h_0 - h_1}{h_0} \qquad (2)$$

where h_0 is initial high of the sample.

The average diameter of the plastic formed sample by upsetting may be established with the help of the equation from the constant volume law:

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Table 1
VALUES OF THE RATE COEFFICIENT w AND EXTERNAL FRICTION COEFFICIENT μ

Type of device		Mechanical pressure			Hammers	Hammers with free blow
Platic forming rate $W_a = \frac{h_0 - h_1}{t^*}$		10...25	25...75	>75	4...8	5
Unit measure		cm/s			m/s	m/s
Rate Coefficient *w*		1.2...1.6	1.6...2.0	2.0...2.5	2.0...4.0	3
Friction coeficientul μ	hot	0.25...0.5			0,2...0,4	
	Cold with lubrication	0.12...0.06			0.12...0.06	

t^* - time at the deformation occurs from h_0 to h_1.
Note: If using grease, the hot friction coefficient is reduced by 15÷25%.

$$d_1 = d_0\sqrt{\frac{h_0}{h_1}} \quad (3)$$

The work of equation (1) can be replaced with energy falling part of the hammer hitting the free fall. This energy can be expressed by the formula:

$$E = G \cdot H \cdot \eta \quad (4)$$

where:

G – the mass of the falling part of the hammer, [N];
H – height of the hammer fall, [m];
η – hammer return.

By replacing of L cwith blow energy $E = G \cdot H \cdot \eta$ the forming resistance may be determined:

$$\sigma'_c = \frac{G \cdot H \cdot \eta}{\left(1 + \frac{1}{3} \cdot \mu \frac{d_1}{h_1}\right) \cdot V \cdot \varepsilon_u} \quad (5)$$

Sometimes, for simplicity, the plastic forming resistance τ'_c may be replaced with specific mechanical work. In turn, the specific plastic forming work is determined based on the plastic forming degree obtained with the same blow energy E at the upsetting of the cylindrical specimens heated at different temperatures. The calculation formula used is as:

$$A = \frac{E}{V_d} \cdot 1000, \text{ [J/mm}^3\text{, Nm/mm}^3\text{]} \quad (6)$$

where:

A – the specific plastic forming work ;
V_d – materials volume dislocated during upsetting (mm^3), which is determined by the relation:

$$V_d = V \cdot \varepsilon_u, \text{ [mm}^3\text{]} \quad (7)$$

For the determination of the two parameters σ'_c and A versus temperature, the blow energy is mentained constant, only test temperature being modified. The test specimens from the same charge have te same dimenions and different final plastic forming degreere. Obviously, all the rest of the conditions for the upsetting , such as forming rate, external friction forces may influence the plastic forming degree, respectively forming resistance and speciffic mechanical work etc. Therefore,in order to obtain comparable results it was necessary, outside forming temperature change, that the remaining conditions must be are maintained to the same values for all tests.

Experimental measurements were performed at a free fall hammer (pile driver) in the endowment *Forging, die-casting, extrusion laboratory* of the Faculty of Materials Science and Engineering of the University Politehnica of Bucharest. The appearance of this equipment is shown in figure 1. Falling height used was H= 0.2 m and the mass m = 71 kg shooting party; using three test pieces for each test temperature within the range 1100 - 1250°C, the determinations being made from 50 to 50 ° C. Heating the hot plastic deformation to the drop hammer has been carried out in an oven with forced heating rods, located in the immediate vicinity of the pile in figure 2 is shown the appearance of the specimens are in the oven. The samples were cut from the original cast specimens by electroerosion,having initial diameter d_o = 10 mm and height h_o = 15 mm; the appearance and dimensions shown in figure 3.

The main data considered working in experimental determinations were: the weight of the falling hammer G = 695.8 N (m = 71 kg); hammer drop height H = 0.2 m; the coefficient of friction μ = 0.3 (hot, without lubricant); free falling hammer yield, determined by the method of Heim was about η = 0.7 (70%).

According to Heim's method, the return hammer free fall is dependent on the size and height of the fall of the hammer. To determine this, they discharged several specimens of pure lead, with as few impurities, having the specific gravity equal to 11.3 kg / dm^3, the ratio of height and diameter cylindrical specimens was 1.5.

In order to determine the impact energy of the hammer the following relationship was used:

$$E = d_0^3\left[2,7\varepsilon + 4\left(\varepsilon^2 + \varepsilon^4\right)\right], \text{ [kgfm]} \quad (8)$$

Fig. 1. Free fall hammer (pile driver laboratory) used in the experimental determinations

Fig. 2. The image of the test specimens inside the heating furnace to the drop hammer plastic deformation

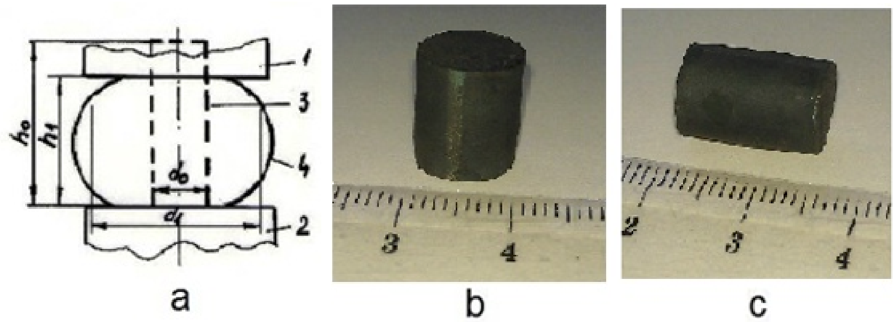

Fig. 3 a) Sketch with dimensions of specimens before (3) and after (4) upsetting between 1 and 2 grinding tools; b) The appearance of specimens prior to plastic deformation (d_0 = 10 mm); c) The appearance of specimens prior to plastic deformation (h_0 = 15 mm)

where:

d_0 represents the initial diameter of the sample [cm];

ε – upsetting degree at one blow, expressed by the relation:

$$\varepsilon = \frac{h_0 - h_1}{h_0}$$

h_0 °i h_1 – initial, respectively final high of the specimen which is upsetted.

The return of the free fall hammer was calculated with the relation:

$$\eta = \frac{E}{E_n} \cdot 100 = \frac{E}{G \cdot H} \cdot 100, \ [\%] \qquad (9)$$

where:

G represents the weight of the shooting, in kg; H - height of fall of the hammer, in m.

The return of the free-fall hammer (laboratory pile driver) used in the experimental measurements, determined according to the method of Heim, the height of fall used, H = 0.2 m, was about η = 0.7 (70%). Heating specimens made of studied alloy type CoCrMoTi to discharge lines made with a forced electric furnace bars serving free fall hammer and ensures a maximum temperature of 1600° C warming.

Results and discussions

After the upsetting, the average height of the outlet (h_1) has been made for each temperature all the experimental measured and calculated results being shown in table 2. The results thus obtained were carried out graphs of the variation in deformation resistance - temperature or specific mechanical work - temperature . All the data were obtained considering a return hammer a free fall η = 0.7 (70%) (Heim's method), corresponding to the drop height about H = 0.2 m. It should be also noted that, in the present case, the friction coefficient of the material to deformation and outside working tools was considered as μ = 0.30 (if hot plastic deformation without lubrication). The weight

Table 2

OBTAINED EXPERIMENTAL RESULTS CONCERNING FORMING RESISTANCE OF CoCrMoTi5.5 ALLOY

Temp. °C / Parametrs	Unit	1100	1150	1200	1250
G	N	695,80			
H	m	0,20			
E^*	Nm	97,41			
d_0	mm	10,00			
h_0	mm	15,00			
d_1	mm	10,46	10,66	10,83	10,95
h_1	mm	13,70	13,20	12,80	12,50
V	mm^3	1178			
ε_u	%	8,67	12,00	14,67	16,67
V_d	mm^3	102	141	173	196
σ'_c	MPa	886,1	637,6	519,7	456,1
A	10^4. MPa	955,0	690,9	563,1	497,0
η	%	70			
μ	-	0,30			

* Calculated energy with hammer return η = 0.7

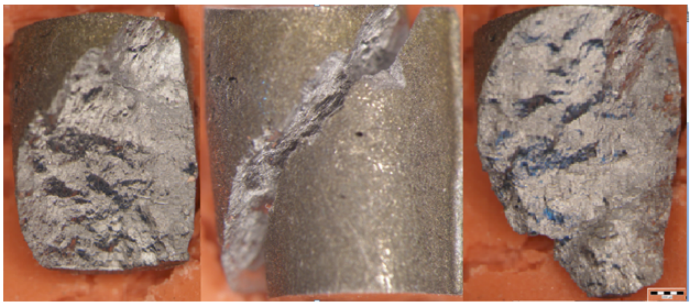

Fig. 4. Macroscopic aspect of fracture for a sample after hot work in aggresive test

of the falling hammer (pile) was G=695.80 N corresponding to a mass of m = 71 kg.

From all the specimens after hot pile driver, there were selected only the specimens with no cracking. This selection of specimens allow a complete macro-structural analysis, which revealed the fracture behaviour of these materials. Macroscopic appearance of a specimen cracked after striking suggestive pile is shown in figure 4, which stands that rupture propagation has a plan to 45° according to the Schmidt's law . At the same time fracture is a specific aspect trasngranular cleavage fracture, as shown in the left-right images of the fracture surfaces. It follows that this alloy, in cast state as taken directly after melting and heating for hot tapping behaves hot fragile breakage.

The experimental results shown in table 2 were processed for plotting the graphs of forming resistance versus temperature (fig. 5) and specific mechanical work versus heating temperature for the analyzed alloy (fig. 6).

After analyzing graphs of variation of the two parameters σ_c and A versus heating temperature one can see that with increasing temperature, resistance to plastic

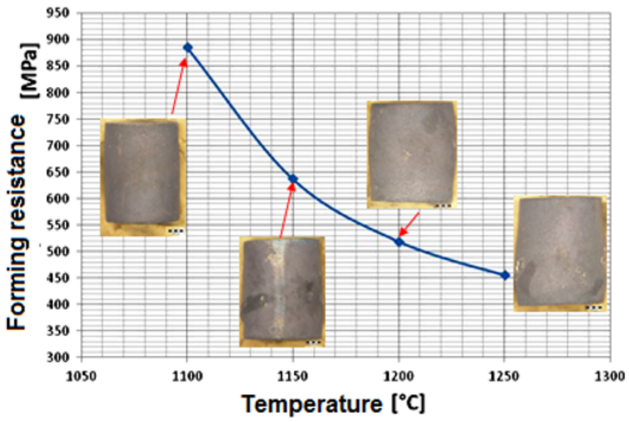

Fig.5. Forming resistance versus heating temperature for CoCrMoTi5.5 alloy, with macroscopic image of the sample after forming

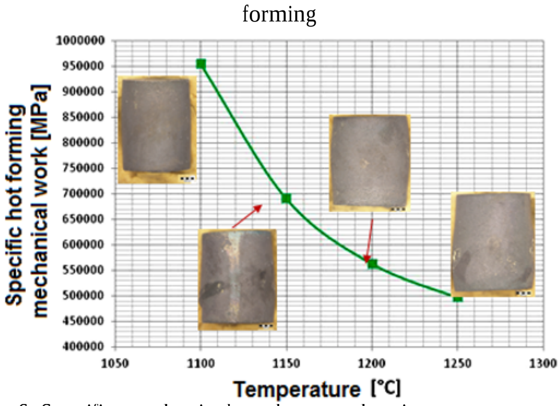

Fig. 6. Specific mechanical work versus heating temperature for CoCrMoTi5.5 alloy, with macroscopic image of the sample after forming

deformation of the alloy studied (CoCrMoTi5.5) decreases in the temperature range investigated. Similarly, specific work done considerable plastic deformation decreases with increasing temperature. In other words, the data obtained it can be concluded that both the yield strength and specific mechanical work of deformation decrease with increasing temperature, as a curve whose slope varies to some of the experimental temperature range.

The high heating temperature (above 1250°C), the material begins to lose its integrity, which is also necessary in support of explaining the lower plasticity as a result of the melting of the low melting point impurities, impurities at the boundaries between the grains.

Based on these data, the optimal results and that hot plastic deformation to the alloy CoCrMoTi5.5, strictly in terms of resistance to deformation, is 1150÷1250°C; because the deformation resistance of the material values and the specific mechanical work of deformation are optimal. The experimental results are consistent with data obtained by other researchers [1-4,15,18], which demonstrated the possibility of distortion of cobalt base alloys at small degrees of plastic deformation and in a narrow range and high temperatures.

Conclusions

In this paper experiments were conducted in order to determine plastic behaviour of a new experimental alloy type CoCrMoTi5.5 for dental applications. Based on experiments conducted, we determine the optimum range of temperature for hot plastic deformation of CoCrMoTi5.5, strictly in terms of resistance to deformation, respectively 1150 ÷ 1250°C, because the deformation resistance of the material values and the specific mechanical work of deformation are optimal. On the other hand, the alloy in the cast state, after hot free-fall hammer test has a fragile fracture behaviour having the appearance of cleavage transclistalin.

Compared to other alloys or class of cobalt alloys, or from other systems, it can be considered that this alloy has a range of deformable CoCrMoTi located quite high and fracture behavior is brittle character.

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References

1.B. PAUL, R. KAPOOR, J.K. CHAKRAVARTTY, A.C. BIDAYE, I.G. SHARMA, A.K. SURI, Hot working characteristics of cobalt in the temperature, range 600–950°C, Scripta Materialia 60 (2009) 104–107.

2.L. FOUILLAND, M. EL MANSORI, A. MASSAQ, Friction-induced work hardening of cobalt-base hardfacing deposits for hot forging tools, Journal of materials processing technology 2 0 9 (2 0 0 9) 3366–3373.
3.H. KASHANI, A. AMADEH, H.M. GHASEMI, Room and high temperature wear behaviors of nickel and cobalt base weld overlay coatings on hot forging dies, Wear 262 (2007) 800–806
4.YOSHIMITSU OKAZAKI- Effects of Heat Treatment and Hot Forging on Microstructure and Mechanical Properties of Co-Cr-Mo Alloy for Surgical Implants, Materials Transactions, Vol. 49, No. 4 (2008) pp. 817 to 823.
5.GOPINATH MANI, MARC D. FELDMAN, DEVANG PATEL, C. MAULI AGRAWAL, Review Coronary stents: A materials perspective, Biomaterials 28 (2007) 1689–1710.
6.BARRY O BRIEN , WILLIAM CARROLL,The evolution of cardiovascular stent materials and surfaces in response to clinical drivers: A review, Acta Biomaterialia 5 (2009) 945–958
7.BORTUN, C., L. SANDU, Practical guidance for partial removable dentures technologies. Editura Eurobit, Timisoara, 2007, (In Romanian).
8.SUSZ, C., et al., Dental Alloys. Editura Victor Babes Timisoara, 2010, (In Romanian).
9.GHIBAN, A., Studies and researches concerning the mechanical, corrosion and welding behaviour of some cobalt based alloys for dental applications, PhD thesis, University Politehnica Bucharest, 2011: p. 190, (in Romanian).
10.GHIBAN B., GHIBAN A., BORTUN C.M., GHIBAN N., ROSSO M.- Structural characterization of a new cobalt alloy for dental applications, Journal of Optoelectronics and Advanced Materials, vol.15, no.7-8, 2013, p.911-917.
11.GHIBAN N., GHIBAN B., SERBAN N., GHIBAN A.- Heat treatment influence on corrosion behaviour of some metallic biomaterials potentially used in meal-ceramic prosthesis, Key Engineering Materials, vol. 587, 2014, p. 293-296, Trans Tech Publications, Bioceramics, vol. 25.
12.SLOKAR, L., Microstructure and hardness of Co-Cr-Ti alloys for dental castings. Metalurgia International, 2004. **43**: p. 273-277.
13. SLOKAR, L., T. MATKOVIC, AND P. MATKOVIC, Alloying and heat treatment effects on the microstrucure and hardness of biomedical titanium alloys. 2011.
14.C. VALERO VIDAL, A. IGUAL MUNOZ- Effect of thermal treatment and applied potential on the electrochemical behaviour of CoCrMo biomedical alloy, Electrochimica Acta 54 (2009) 1798–1809.
15.YUICHIRO KOIZUMI, SHO SUZUKI, KENTA YAMANAKA, BYOUNG-SOO LEE, KAZUHISA SATO, YUNPING LI, SHINGO KUROSU, HIROAKI MATSUMOTO, AKIHIKO CHIBA- Strain-induced martensitic transformation near twin boundaries in a biomedical Co–Cr–Mo alloy with negative stacking fault energy, Acta Materialia 61 (2013) 1648–1661.
16.CHOU, Y.L., J.W. YEH, H.C. SHIH, The effect of molybdenum on the corrosion behaviour of the high-entropy alloys Co1.5CrFeNi1. 5Ti0.5Mox in aqueous environments. Corrosion Science, 2010. **52**(8): p. 2571-2581.
17.FERNANDES NETO, A.J., et al., Bond strength of three dental porceleins to Ni-Cr and Co-Cr-Ti alloys. Braz.Dent J, 2006. E **17**(1): p. 24-28.
18.GHIBAN, B. AND C.M. BORTUN, Cobalt dental alloys. Structure, processing, optimization. Printech, 2009 (In Romanian)

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