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Influence of the casting temperature on dental Co-base alloys properties

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ABSTRACT

Purpose: The goal of the study is to find the relationship between the value of casting temperature on corrosion resistance, hardness and mechanical properties of two Co-Cr-Mo alloys Remanium 2000+ and Wirobond LFC used in dentistry.

Design/methodology/approach: Realized investigations starts from preparing the mould and cast two CoCrMo alloys in 1430, 1440, 1450 and 1460°C. Electrochemical corrosion research were made in water centre which simulated artificial saliva environment, by recording of anodic polarization curves with use the potentiodynamic methods. The compression strength, yield strength and unit shortening was evaluated during the static compression tests on multi-role testing machine MTS. Hardness test were obtained by use the microhardness FM ARS 9000 FUTURE TECH Vickers methods with load 1 kg.

Findings: The manufacturing conditions for the Co-Cr-Mo alloys are one of the possible method which effects in increase or decrease of the safety factor in construction. Realized research of the increasing casting temperature about 10-20°C in regard to conditions offered by producer was found that hardness and corrosion resistance change only in small value, while corrosion current of samples casted from 1460°C increase by one order of magnitude to casting from 1430°C. Increase or decrease casting temperature results in decrease the mechanical properties yield strength and compression strength for both alloys.

Practical implications: Scientific research of the cobalt alloys used on the dentures confirmed that casting temperature as one of the condition during the manufacturing influence on the most important useful properties like corrosion resistance, strength of the prosthetic constructions and machinability of the CoCrMo alloys.

Originality/value: The paper presents an effect of correct selection the casting temperature, on the most important properties of CoCrMo alloys use in dental engineering.

Keywords: Biomaterials; Corrosion; CoCrMo alloys; Prosthodontia; Casting

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PROPERTIES

1. Introduction

The cobalt-base alloys as non precious alloys are next to high noble and noble alloys the third group of metallic materials used in prosthetic dentistry for copings, bridges and frameworks. The first cobalt alloy used in medicine, exactly to stomatology surgery was the Vitallium manufactured in 1929 in the USA. Popularity of the dentures production from cobalt-base alloys gain thanks their very low price in compare with noble alloys connected with great materials properties [1-3].

Materials selection on dentures is usually connected with more than only the price criterion but also, or rather what should be list on the first place, in determine of the corrosion resistance and mechanical properties, because chosen metals must carried out those two criteria no matter the price [4,5]. The corrosion resistance of metal alloys used on dentures was researched and evaluated in according to chemical composition [2], in the electrochemical experiments and by research the quantity of released metallic ions in environment simulating the oral cavity [6,7].

The properties of dentures depend on the quality of used materials (wax, investment material and alloy) on used technology (casting [8], CAD/CAM [9], SLS/SLM [10]) and on the variables of the process.

There were taken many researches concerning on influence different casting conditions on the properties of final dentures. The scientists test surface roughness according in casting techniques - flame, vacuum and electric arc [11,12], relationship between corrosion resistance and presence of the graphite in investment material or in the crucible [13], influence of standard air atmosphere in centrifugal and vacuum machine on structure and properties [14,15].

Among the important parameters of manufacturing process should by listed the casting temperature, which is different for each alloy. For example for casting noble alloys temperature range is from 955 to 1450°C while for no precious alloys temperature range is from 1420 to 1550°C. Metals can be melted by oxy-acetylene blowpipe or by electromagnetic induction. When the metal alloys are insufficiently heated they may don't have enough castability to flow into the casting mould and reproduce all dentures detail. On the second hand when the metal will be heated excessively it may cause in broke the investment materials and damage whole cast [8,16].

The aim of that work is to study how changing the casting temperature influences on corrosion resistance and mechanical properties of the commercial Co-Cr-Mo alloys: Remanium 2000+ and Wirobond LFC used on dentures.

2. Materials and methods

2.1. Materials

Materials used to testing were non precious commercial alloy Remanium 2000+ (Dentaurum) and Wirobond LFC (Bego), base on cobalt used in prosthodontia on crowns, bridgeworks and full cast partial. The composition of cobalt alloys additions and producer recommended properties are presented in Tables 1 and 2.

Materials were delivered as cylinders dimension of 15 mm high and 7.8 mm diameter.

Table 1.
Chemical composition of the testing alloys used in studies

Element	Co	Cr	Mo	W	Si	Mn	N
Remanium 2000+	61	25	7	5	1.5	< 1	< 1
Wirobond LFC	33.9	28.5	5	0	1.6	1	Fe: 30

Table 2.
Properties of testing alloys used in studies

Properties	Density	Hardness	$R_{p0.2}$	A_5	E	CTE
	g/cm^3	HV_5	MPa	%	GPa	10^{-6} K^{-1}
Remanium 2000+	8.6	340	700	7	200	14.0
Wirobond LFC	8.2	315	660	11	200	15.9

2.2. Specimens and casting

Stages of preparing the mould to cast test specimens and casting methodology [17]:

- prepare the wax model by cast liquid wax into silicon mould placed in cold water,
- construct the runners with the specimens and place in casting ring (Fig. 1),
- install a paper band, prepare the investment material Moldavest exact (Hera) in vacuum mixer and fill the casting ring,
- put the mold into preheating furnace to burn out the wax and heat before install in casting machine,
- melt the alloy samples by oxy-acetylene blowpipe to four different temperatures: 1430, 1440, 1450 and 1460°C, controlled by infrared thermometer (pyrometer, Fig. 2),
- casting in centrifugal machine and then cooling in air.

All used materials, machines and technologies were typical in dental practice.

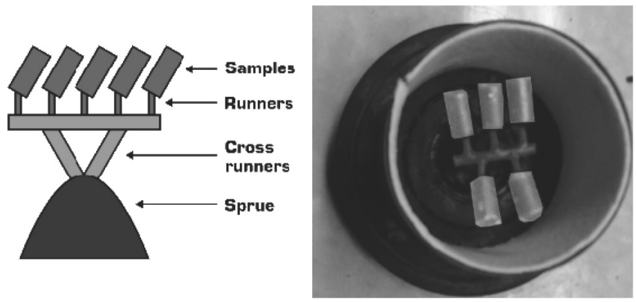


Fig. 1. The prepared model and mould to casting

2.3. Research methodology

The research consider the influence of casting temperature on the corrosion resistance were realized with use the VoltaLab® PGP 201 system for electrochemical tests in room temperature. The test was conduct in the Fusayama solution simulated the human artificial saliva about composition presented in Table 3. For tests was used flat platinum electrode as auxiliary electrode and as references electrode was used calomel (NEK) electrode. Research were carried out through polish standard PN-EN ISO 10271:2004 [17].

Preparing the samples to electrochemical test consist in determine the range of measurement area was between 0.5 and

1.0 cm^2 and calculate it using Equation (1). During electrochemical test the potential scan rate was 1 mV/s.

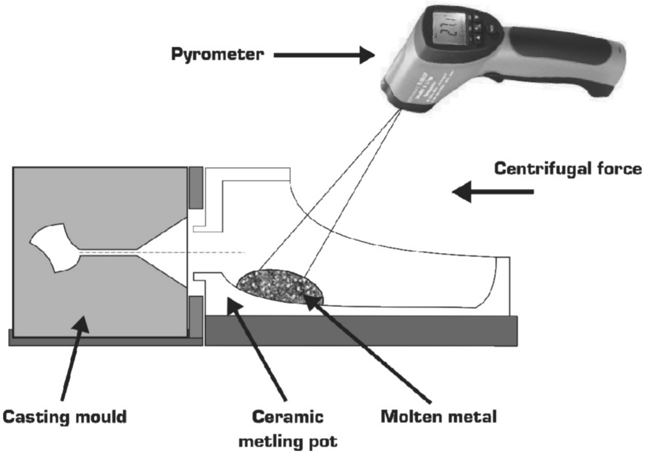
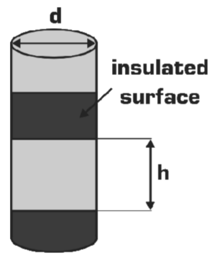


Fig. 2. Centrifugal casting machine with measurement temperature of the melted alloy [9]



$$P = \pi \cdot d \cdot h \quad (1)$$

where:
P - research area [cm^2],
d - sample diameter [cm],
h - height of sample area [cm].

Fig. 3. Sample prepared to electrochemical test

In order to calculate the corrosion current density (i_{cor}), the Stern-Geary equation was used (2). Because not for all samples was possible to evaluate the Tafel's b_a and b_k coefficients, corrosion current was estimation using approximated Stern-Geary's equation (3), with assumption that $b_a = b_k = 0.12\ V \cdot dec^{-1}$ [17].

$$i_{cor} = \frac{b_a \cdot b_k}{2{,}3(b_a + b_k)R_p} \quad (2)$$

$$i_{cor} = \frac{0{,}026}{R_p} \quad (3)$$

where:
b_a - slope coefficient of the anodic Tafel line,
b_k - slope coefficient of the cathodic Tafel line,
R_p - polarisation resistance [Ωcm^2].

In electrochemical corrosion examination were determined open circuit potential - E_{ocp}, corrosion potential - E_{cor}, corrosion current - i_{cor} and pitting potential - E_b. The electrochemical test was realized in that same conditions what gives possibility to compare it for all samples and even compare results for both alloys.

The influence of casting conditions on the properties of CoCrMo alloys were study in hardness research which was realized by the microhardness FM ARS 9000 FUTURE TECH at the 1 kg load used the Vickers scale and in the statically compression test on multi-role testing machine MTS with research speed 20 μm/s until the specimen was destroyed.

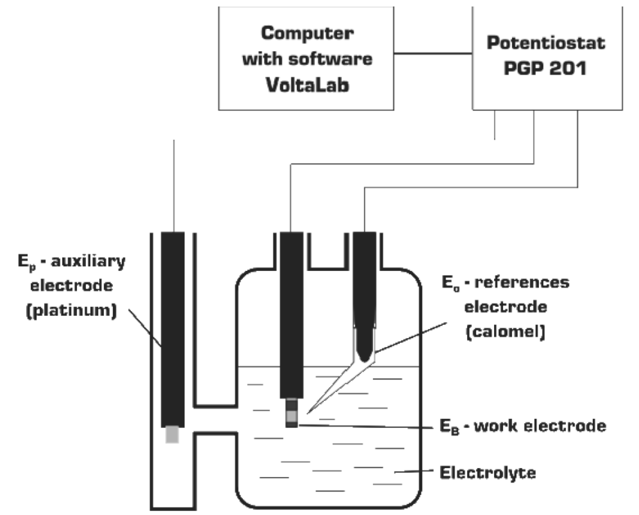


Fig. 4. Scheme of the corrosion resistance set to evaluate pitting resistance

Table 3.
Composition of the artificial saliva by the Fusayama

Element	Content
NaCl	0,4 g/l
KCl	0,4 g/l
$NaH_2PO_4 \cdot 2H_2O$	0,69 g/l
$CaCl_2 \cdot 2H_2O$	0,79 g/l
$Na_2S \cdot 9H_2O$	0,005 g/l
Urea	1,0 g/l
Distilled water	1 l

3. Results and discussion

3.1. Corrosion resistance results

The first step was recording open circuit potential for both alloys after soaking then for 2 hours and then 900 s in corrosion cell (Figs. 5, 6). Obtained results of the free potential were from range -241 to -121 mV for Remanium 2000+ alloy and from range -187 to -106 mV for Wirobond LFC are similar to those get for cobalt-base alloys in diffenrent work [6]. Next on the base of saved anodic curves for Remanium 2000+ (Fig. 7) and Wirobond LFC (Fig. 8) was found how the casting temperature influence on pitting corrosion resistance. Using the Tafel extrapolation of recorded curves was determined the characteristic evidence describing results of electrochemical test of the materials (Tables 4, 5): corrosion potential (E_{cor}), anodic current density (i_{cor}) and breakdown potential (E_b).

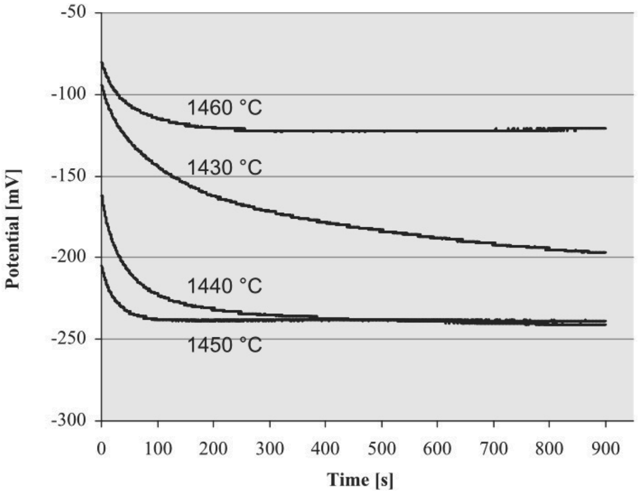


Fig. 5. Open circuit potential curves after 900s tests for Remanium 2000+

The course of the anodic curves and values of the corrosion current for Remanium 2000+ in range from 0.002 to 0.08 μA/cm^2 and for Wirobond LFC from 0.001 to 0.04 μA/cm^2 may suggest that both alloys characterize quite good resistance on the digestion in environment close to those prevailed in oral cavity.

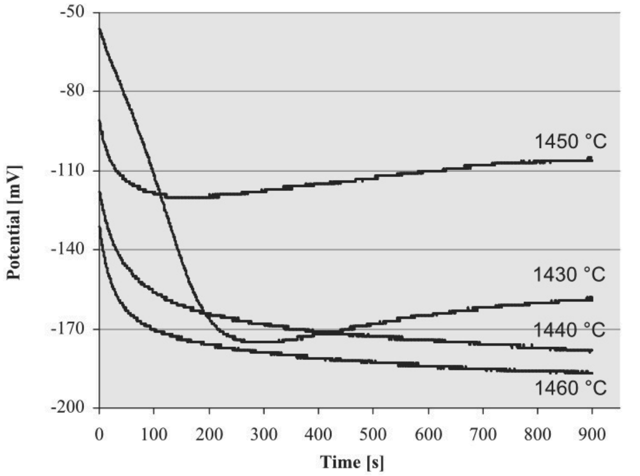


Fig. 6. Open circuit potential curves after 900s tests for Wirobond LFC

When analyzed corrosion current of the Remanium 2000+ samples casting form different temperature it was found that increase the temperature by 20 and 30 °C in regard to values from alloy instruction resulted in increase the corrosion current by an order of magnitude.

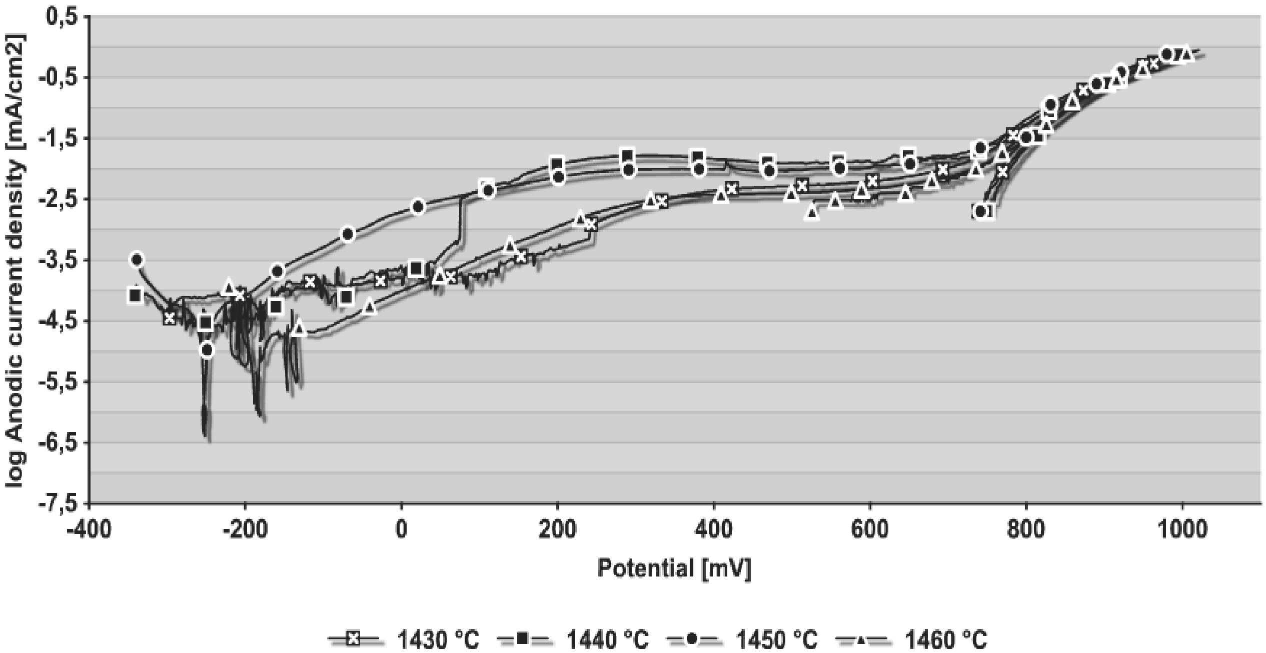


Fig. 7. Potentiodynamic curves of pitting corrosion Remanium 2000+ alloy after four different casting temperature

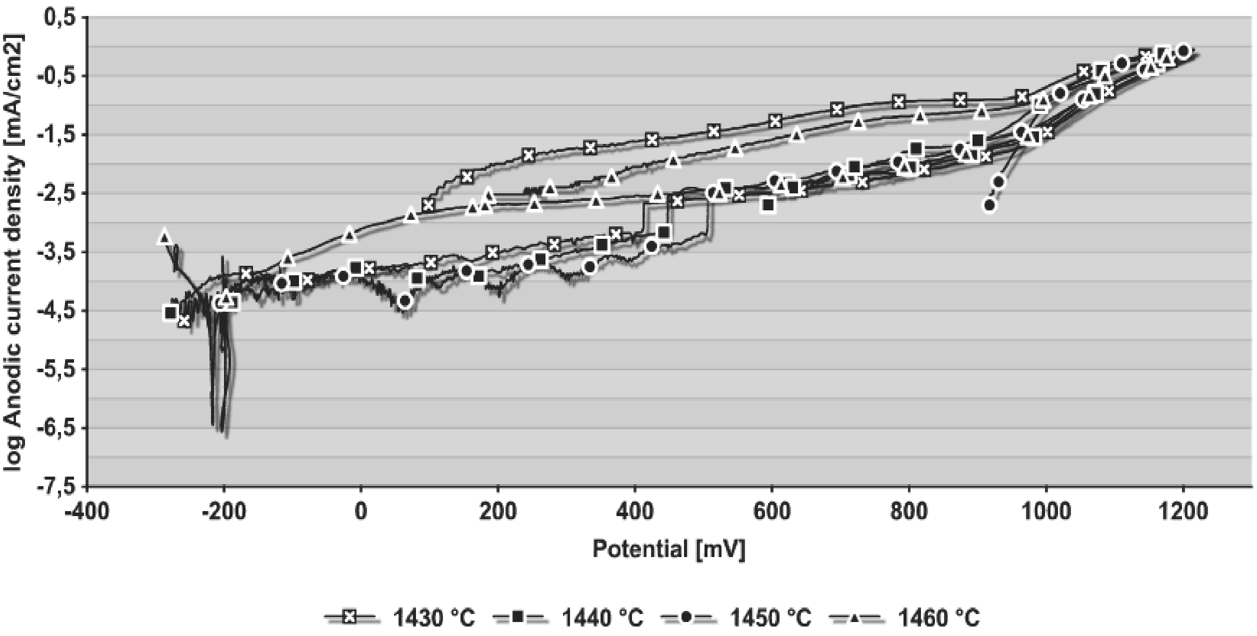


Fig. 8. Potentiodynamic curves of pitting corrosion Wirobond LFC alloy after four different casting temperature

Table 4.
Effect of age hardening on electrochemical parameters of testing the Remanium 2000+ cobalt alloys

Samples	Open circuit potential E_{ocp} [mV]	Corrosion potential E_{cor} [mV]	Corrosion current density i_{cor} [μA/cm^2]	Breakdown potential E_b [mV]
Casting from 1430°C	-197	-202	0,002	838
Casting from 1440°C	-241	-245	0,004	874
Casting from 1450°C	-239	-252	0,08	861
Casting from 1460°C	-121	-184	0,03	887

Table 5.
Effect of age hardening on electrochemical parameters of testing Wirobond LFC cobalt alloys

Samples	Open circuit potential E_{ocp} [mV]	Corrosion potential E_{cor} [mV]	Corrosion current density i_{cor} [μA/cm^2]	Breakdown potential E_b [mV]
Casting from 1430°C	-158	-98	0,001	1108
Casting from 1440°C	-178	-147	0,02	1107
Casting from 1450°C	-106	-198	0,04	1123
Casting from 1460°C	-187	-217	0,1	1076

Similar relationship between changing casting temperature in regard to values from alloy instruction was found for second alloy, add 10°C to default temperature cause in increase of the corrosion current from 0.04 to 0.1 μA/cm^2. For Wirobond LFC alloy was also observed that when decrease the temperature the corrosion current was decrease too. Decreasing the corrosion resistance for researched alloys were also observed by authors in earlier work [17] where were tested influence of the heat treatment.

Analysis of changing the corrosion potential for Remanium 2000+ alloy confirmed that increase the casting temperature exacerbate the resistance of material in working environment, because the potential decrease by 43 and 50 mV consequently for samples casted from 1440 and 1450°C in comparison to default value of temperature while on the base of analysis realized for second alloy it was found that add 10°C to default 1450°C causes decrease the corrosion potential about of 19 mV. Whereas decrease the casting temperature of Wirobond LFC alloy about 10 and 20°C result in increase the corrosion potential even by 100 mV to -98 mV.

When analysis the pitting potential there was observed that higher temperature conditions cause increase the potential in range from 23 to 49 mV. The same effect was found in decrease to casting temperature of the Wirobond LFC alloy. Change the corrosion current and potential suggested better corrosion resistance in tested environment but pits initiation potential was smaller comparison to obtained in default value of temperature. The difference of breakdown potential was very small (16 mV) and statistically not significant.

While comparing results of electrochemical testing of the two researched alloys it was found that because of the higher values of corrosion potential and breakdown potential and the corrosion current at very closely values the Wirobond LFC alloy characterize better corrosion resistance in tested environment simulated the conditions prevailing in oral cavity. Resistance on corrosion depends in a large parts from material structure and alloy chemical composition as shown in works [2,7] alloys about higher chromium content characterized better corrosion resistance.

3.2. Mechanical properties

Results of the hardness tests for alloys casted from different temperature in compared to Remanium 2000+ default 1430°C and to Wirobond LFC default temperature 1450°C suggest that in researched range casting temperature influence for both alloys on hardness. For Remanium 2000+ alloy increase casting temperature about 10 or 20°C resulted in increase hardness but the differences was very small, from the range of 5 to 28 HV so statistically not significant, while add 30°C to default temperature cause decrease hardness by 48 HV (Fig. 9). For Wirobond LFC alloy increase casting temperature about 10°C resulted in change hardness from 340 to 374 HV_1, while after cast from temperature smaller than default the hardness increased over 200 HV_1 (Fig. 10).

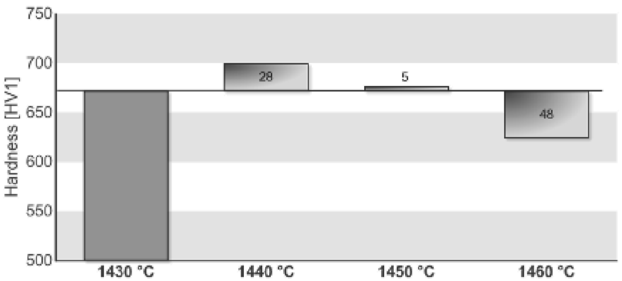


Fig. 9. Influence of casting temperature on hardness of the Remanium 2000+alloy

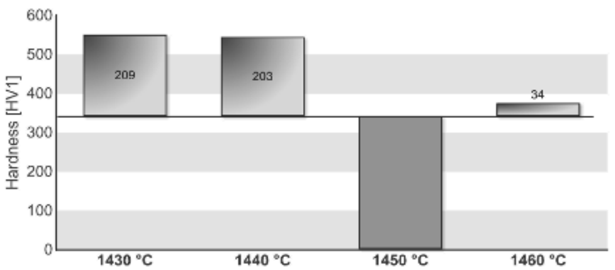


Fig. 10. Influence of casting temperature on hardness of the Wirobond LFC alloy

Next stage of research the influence of casting temperature on the materials properties was the static compression tests in which during the experiments for each samples were recorded curves showed relationship between strain and stress of Remanium 2000+ alloy (Fig. 11) and of Wirobond LFC alloy (Fig. 12). Study the curves course enabled to established three characteristic values: yield strength $R_{c0,2}$, compression strength R_c and shortening A_c.

The results of yield strength for tested specimens from Remanium 2000+ suggest that increase the casting temperature about 10 to 30°C compared to temperature from the alloy instruction results in decrease the yield strength and the higher difference was found after casting from 1460°C because tested samples showed $R_{c0,2}$ about 64 MPa smaller than casting from 1430°C (Fig. 13). The same relation was observed for Wirobond LFC alloy for which change the casting temperature relate to default values 1450°C quoted by producer caused the yield strength was decrease from range 57 to 153 MPa after casting in temperature lower about 10°C (Fig. 14).

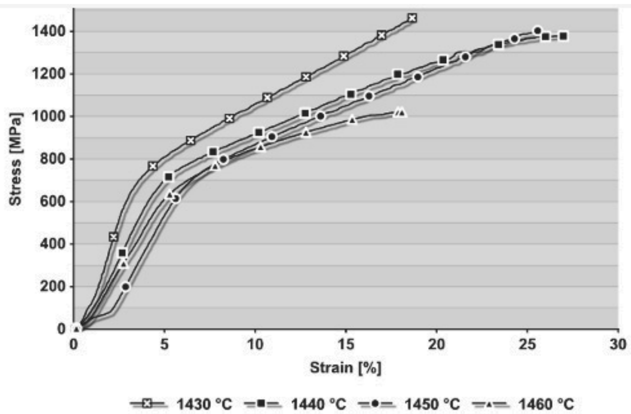


Fig. 11. Compression strength curves after different casting of the Remanium 2000+ alloy

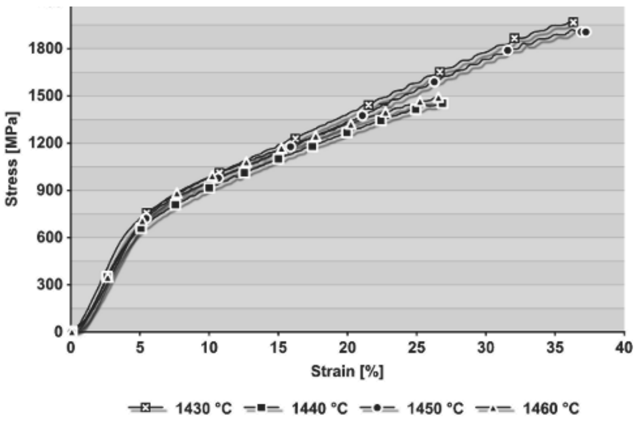


Fig. 12. Compression strength curves after different casting of the Wirobond LFC alloy

Research of the compression strength like in the yield strength confirmed that casting temperature influences on properties of the dentures, in this case on materials used to produce the dentures. Increase the casting temperature for Remanium 2000+ alloy resulted in decrease the compression strength statistically not significant after increase about 10 and 20°C but after cast from

1460°C the strength was lower about 441 MPa in comparison with default temperature (Fig. 15). The results of compression strength received from static compression tests confirmed the influence of casting temperature for second of the researched alloy Wirobond LFC. Change the casting temperature by increase or decrease about 10°C in regard to default values given in the alloy instruction resulted in decrease the strength by approximately 450 MPa for both series of specimens (Fig. 16).

Obtain in static compression tests results for research the mechanical properties suggest that increased the casting temperature in manufacturing dentures from CoCrMo alloys results in decrease the yield and compression strength. Reduction of the mechanical properties as was noted in work [19] is connected with that in higher temperature of process the grains size growing and the structure becomes more coarse grain structure what in effect decrease the strength.

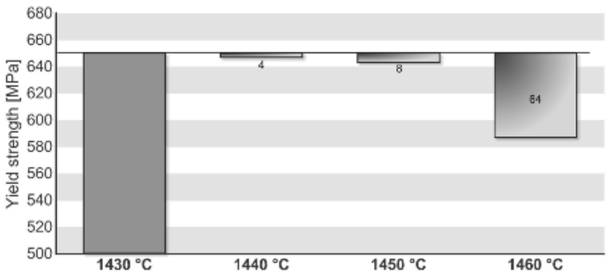


Fig. 13. Influence of casting temperature on yield strength of the Remanium 2000+ alloy

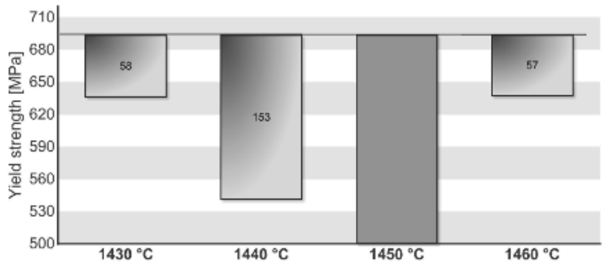


Fig. 14. Influence of casting temperature on yield strength of the Wirobond LFC alloy

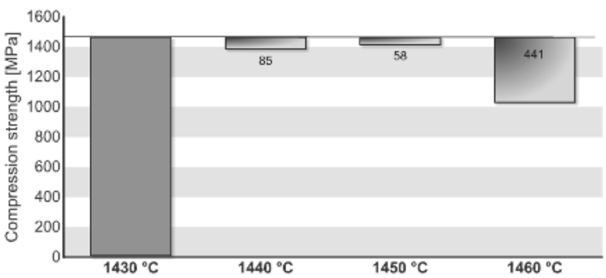


Fig. 15. Influence of casting temperature on compression strength of the Remanium 2000+ alloy

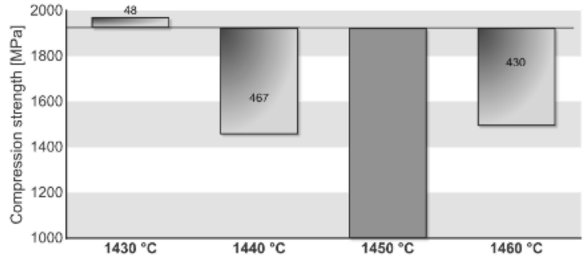


Fig. 16. Influence of casting temperature on compression strength of the Wirobond LFC alloy

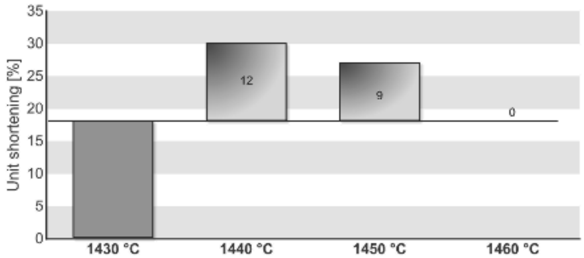


Fig. 17. Influence of casting temperature on shortening of the Remanium 2000+ alloy

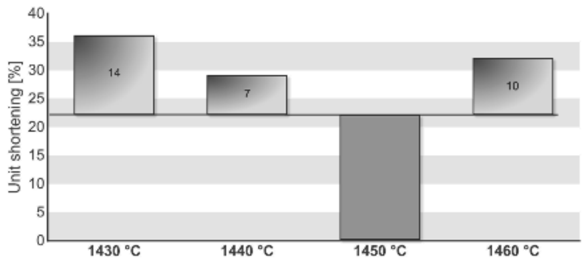


Fig. 18. Influence of casting temperature on shortening of the Wirobond LFC alloy

However increase the casting temperature for both Remanium 2000+ and Wirobond LFC alloys results in decrease the brittleness [19] and alloys by increase the shortening about 9-12% (Figs. 17, 18) become much more plasticity.

4. Conclusions

The CoCrMo alloys usually are use to producing the crowns, bridges and removable partial dentures because of their very good properties and very accractive price, one hundres times less than high nobel alloys. The producer of each alloys always join to them a instruction for use which comprises information about the manufacturing conditions and related properties of the casts. In practice establishe the temperature from which alloys is castng is very difficult and how showed in realized work the temperature of liquid alloys influence on functional properties of the casts and finaly on the dentures.

On the base of realized study and research it was found that increasing the casting temperature of CoCrMo alloys even by

30°C results in changing the corrosion resistance, because corrosion current increase ten times and the corrosion potential decrease average 20%. Also mechanical properties were changing when increase the casting temperature, both yield strength and compression strength decrease compare to values obtain for default temperature given with alloy instruction, yield strength were smaller about 10% and the compression strength about 25%, while the plastic properties shown as shortening was increase about 10%.

Acknowledgements

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