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## EFFECT OF RECASTING ON THE USEFUL PROPERTIES CoCrMoW ALLOY

### WPŁYW POWTÓRNEGO PRZETAPIANIA NA WŁAŚCIWOŚCI UŻYTKOWE STOPU CoCrMoW\*

*Recasting of the previously cast metal can change the chemical composition of the newly formed material, which ultimately could affect the properties of a dental alloy. The research used a dental alloy CoCrMoW trade name Remanium 2001. Three groups of dental alloy were prepared by mixing 50% fresh alloy to alloy remnants from previous castings. The specimens in the first casting group used 100% fresh alloy and served as control (R1). The second group consisted of equal amounts of fresh alloy and alloy remnants cast only once (R2). The third group contained 50% fresh alloy and alloy cast twice (R3). Microstructural analysis was performed and the chemical composition, XRD studies, hardness, and tribological test and the metal–ceramic bond strength was investigated according to ISO9693 standard. New material should be used in casting, and if previously casted material is used, it should be mixed with new material. The use of the recasting procedure can lower the costs of CoCrMoW castings and can be safely in dentistry.*

**Keywords:** cobalt alloys, durability of prosthetic devices, recasting.

*Przetapianie uprzednio odlanego metalu może spowodować zmianę składu chemicznego nowopowstałego materiału, co w końcowym efekcie może oddziaływać na właściwości użytkowestopu stomatologicznego. Do badań zastosowano stop stomatologiczny CoCrMoW o nazwie handlowej Remanium 2001. Przygotowano 3 grupy stopu stomatologicznego przez zmieszanie 50% fabrycznie nowego stopu ze stopem po poprzednim przetopieniu. Grupę pierwszą odlano w 100% z nowego fabrycznie stopu jako grupę kontrolną (R1). Grupa druga (R2) została odlana z mieszaniny jednakowych ilości nowego stopu oraz stopu odlanego tylko raz. Grupa trzecia (R3) zawierała 50% świeżego stopu oraz stopu odlanego 2 razy. Wykonano analizę mikrostrukturalną oraz składu chemicznego, badania XRD, pomiary twardości, badania tribologiczne oraz badania przyczepności wg ISO 9693. Wykazano, że w odlewaniu należy używać nowego materiału a w przypadku wykorzystania materiału wcześniej używanego należy go wymieszać z materiałem nowym. Wykorzystanie procedury przetapiania może obniżyć koszty odlewów CoCrMoW oraz może być bezpieczne w stomatologii.*

**Słowa kluczowe:** stopy kobaltu, trwałość aparatów protetycznych, powtórne przetapianie.

## 1. Introduction

The recasting of previously casted alloy is a routine procedure used in dental laboratories in order to reduce the cost of permanent partial dentures.

The prosthetic “scrap” encompasses the residuals generated in frame dentures casting process e.g. originating from the runners, from casting cones and improperly completed melts e.g. with misruns, shrinkage porosities and cracks and is frequently used as a part of charge for recasting [20]. The state of load occurring in oral cavity in course of mastication process is diversified and causes various level of stress concentration in hard tooth tissues and in dental fillings which may result in damages of denture fasteners or in ceramic phase separation from prosthetic apparatuses with permanent porcelain veneers [5, 21].

The addition of 50% recast material to a brand new alloy is allowed by greater part of dental alloys manufacturers. Some manufacturers established the condition that the addition of so called scrap can be recast only once and must wholly originate from the same batch. However the use of additions in the form of repeatedly remelted materials is not allowed by other alloys manufacturers or no information concerning potential use of post-production scrap is not published by them.

In the opinion of Bauer et al. [4] the scrap produced in dentistry is extremely pure due to the fact that this metal is melted in controlled conditions without necessity to apply any chemical process used in industrial conditions. Dental alloys reuse seems promising in case of Ni–Cr [12] and Co–Cr alloys [1] as well as gold based alloys [17].

From references [4, 12, 13] it appears that the properties of recast alloy may differ from the properties of a new alloy purchased from the manufacturer. The differences may be associated with its chemical composition [13], castability [12], as well as with mechanical properties [4]. However the opinions concerning mechanical properties are extremely divided. Some authors [1, 4] think that these properties can increase or decrease [11, 20] but the research carried out by Palaskar et al. [12] demonstrate that there is no statistically significant castability change as a result of alloys recasting. There are experimental studies described in literature [13] and reflecting changed chemical composition of final products under the influence of successive recasting processes and development of new phases determining the changes in alloy properties. The deterioration in the scope of corrosion properties [6] or even cytotoxicity [2] is also possible due to changed chemical composition in case of recasting.

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The process associated with remelted materials use may change the composition of metal oxide surface layer which may be of critical importance for metal ceramic bond [24].

Sufficient bond strength between porcelain and metal structure of applied biomaterial [19, 21] is an important factor determining the durability of metal ceramic apparatuses. The use of recycled alloys is not recommended by Ucar et al. [19] to avoid potential reduction of bond strength between porcelain and metal.

Therefore the purpose of the present study was to evaluate the effect of addition of remelted materials on some mechanical properties of CoCrMoW alloy i.e. hardness, tribological wear, metal ceramic bond strength as well as evaluation of microstructure and chemical composition of newly produced castings.

## 2. Material and methods

Remanium 2001 dental alloy (Dentaurum, Germany) with cobalt matrix and nominal Remanium 2001 (w/w) consisting of 63% Co, 23% Cr, 7.3% Mo, 4.3% W, 1.6% Si and Mn<1% and N<1% [27] has been used in tests. This alloy is used for casting of denture elements (among others crowns and bridges) with permanent ceramic veneers. Three groups of identical dental alloy have been prepared in order to simulate standard applications used in dental laboratories. The first group has been casted in 100% from new alloy as a control group (R1). The other groups have been made of 50% new alloy and 50% remnants from the previous group (Table 1). The second group (R2) has been casted as the mixture of equal amounts of the new alloy and the alloy after previous recasting. The alloy used in the third group (R3) has been prepared adding new alloy and 50% remnants from second group (R2).

The process associated with preparation of specimens made of CoCrMoW alloy was carried out in conditions existing in professional prosthetic dental laboratory in accordance with procedures applied for production of metal denture elements. The castings have been produced in investment casting process by means of vacuum – pressure casting machine Nautilus (Bego, Germany) and ceramic crucibles.

Table 1. Different recast alloy groups used in this study

Groups	Procedure
Never cast (R1)	Cast 100% new alloy
Cast once (R2)	Cast from 50% new alloy and 50% remnants from first group
Cast twice (R3)	Cast from 50% new alloy and 50% remnants from second group

The specimens used for testing: hardness, chemical composition analysis and tribological tests have been made as the discs with diameter of Ø 25 mm and thickness of 2 mm. The discs have been subjected to grinding by means of water abrasive papers with grain size of 220, 600 and 1200 correspondingly. After grinding the specimens were mechanically polished by means of diamond particles suspension 3 µm and oxides particles suspension 0.05µm as well as washed in acetone and dried thereafter.

The hardness of tested materials was measured under the load of 98.07N on FV-700 Vickers hardness meter with automatic ARS 900 system manufactured by Future-Tech Corp. Forty (40) hardness measurements have been performed for each group of specimens.

The analysis of chemical composition has been performed by means of Q4 Tasman 130 spark emission spectrometer (Bruker, Germany) in detail Co130 testing channel used to complete five (5) analyses (sparking sequences) for each specimen.

X-ray Diffraction device manufactured by Rigaku Ultima IV and equipped with CuKα has been used for XRD analysis in order to ena-

ble phase identification (mainly carbides identification) for the groups of CoCrMoW alloys under tests.

ICDD database was used for the interpretation of obtained results. The tests were carried out under accelerating voltage of 40 kV and current of 40mA. The scanning range 2θ was included between 35° and 55° at scanning speed of 0.2°min<sup>-1</sup> and step of 0.02°. The scanning range has been selected on the basis data available in literature [10] in a manner enabling the identification of carbides types reinforcing the alloys under tests.

The wear tests were carried out by means of “ball-on-disc” tribotester manufactured by CSM Instruments, at temperature of 37°C in artificial saliva environment (pH=5.3). The composition of artificial saliva has been prepared on the basis of PN-EN ISO 10271:2012 standard [26]. The balls with diameter of 6 mm and hardness of 2000HV (manufactured by CSM Instruments) made of Al<sub>2</sub>O<sub>3</sub> have been used as counterpart (ball). The tests were carried out under the load of 10N with linear speed of 1.88 cm/s on the radius of 3 mm. The total test travel used to record friction coefficient variation was equal to 100 m. The reduction of specimen material volume occurred in the form of wear trace as a result of specimen - counterpart mating was used as the wear measure. Therefore Dektak 150 profile contact tester manufactured by Veeco Instruments has been used to measure the surface area of specimen wear profile along specimen circumference (in 12 locations). Tip radius of measuring needle was equal to 2 µm. The volumetric wear has been determined as the average value of specimen wear surface area multiplied by the circumference of the circle of wear trace produced in the ball-on-disc test.

The specimens for ceramic bond strength tests have been prepared in accordance with requirements included in PN-EN ISO 9693 [25] standard in the form of rectangular plates with dimensions of 25×3×0.5 mm. IPS d.SIGN dental porcelain (Ivoclar Vivadent, Schaan, Liechtenstein) with dimensions of 8×3×1 mm has been applied centrally onto the metal plates. The whole process associated with dental porcelain fusion to metal was carried out in conditions existing in professional prosthetic dental laboratory. Nine (9) specimens from each test group have been used for test. Three point bending test has been carried out by means of Zwick Z100 universal testing machine equipped with 500N measuring head. The distance between the supports was equal to 20 mm and the diameter of specimen supporting rollers was equal to 2 mm. The testing speed (traverse beam feed) was equal to 1.5 mm/min. The loss of bond strength was indicated by the value of force at which a load disturbance (reduction) was observed in deflection curve. Then the bond strength (τ<sub>b</sub>) has been determined using the following formula [25]:

$$\tau_b = k \cdot F_{fail} \quad (1)$$

where: *k* – the factor depending on thickness of base metal and Young module, *F<sub>fail</sub>* – the force causing the loss of metal-ceramic bond strength.

The microstructure of tested materials and their surface after tribological tests has been analysed by means of Phenom G2 pro desk top scanning microscope.

## 3. Tests results and discussion

The microstructure of tested cast alloys is characterized by typical coarse grained dendritic structure (Fig. 1). The microstructure of castings containing remelted material is similar to microstructure of brand new castings. There were no inclusions which could originate from charge contamination in the form of investment material. Furthermore diversified carbides shapes have been revealed in course of SEM analysis. The carbides phases are characterized by dual structure i.e. occurring in the form of blocky precipitations as well as lamellar precipitations (“pearlitic type”). In the opinion of some authors [15],

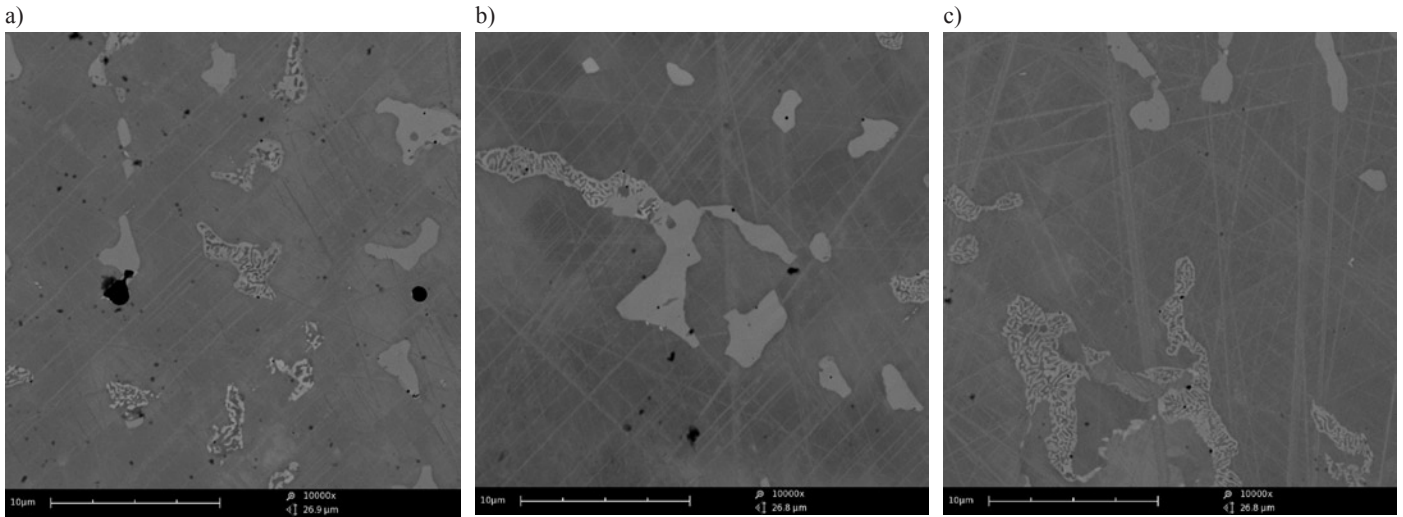


Fig. 1. SEM microstructure of castings: (a) control sample R1, (b) recasting R2, (c) recasting R3

the lamellar structure of carbides is caused by cooling rate variation between 8 and 16 °C/min; 35 °C/min [16] is the maximum cooling rate for the creation of eutectoid phase. Carbides precipitations may have decisive impact on increased reinforcement of an alloy and its reduced plasticity [20].

The average hardness achieved by a brand new alloy and recycled materials reaches a value similar to that declared by the manufacturer of 336HV10 (Fig. 2). There are no significant differences between R1 and R2 groups ( $p=0.942$ ) demonstrated by non-parametric test for independent test by U Mann-Whitney (for  $\alpha=0.05$ ) carried out by means of STATISTICA program. However the difference found between R1 and R3 group ( $p<0.05$ ) as well as between R2 and R3 group ( $p<0.05$ ) was significant.

Hardness results have been additionally analysed by means of Kruskal-Wallis test at assumed significance level  $\alpha=0.05$ . However no significant difference has been found between R1 and R2 groups but the difference found between R1 and R3 group ( $p<0.05$ ) as well as between R2 and R3 group ( $p<0.05$ ) was significant. Detected hardness differences are closely associated with changed chemical composition of remelted materials and particularly with percentage of carbon content contributing to the formation of hard carbides. The changes of chemical composition in tested materials are presented in table 2.

It should be emphasized that there is information about elements concentrations under 1% indicated in manufacturer's data. The carbon content for R1 and R2 groups is similar and average hardness values

are identical in the both groups (334HV10). However a change in carbon concentration has been denoted in remelted materials from R3 group which could be the explanation for hardness increase. However, the determining factor in the increase in the hardness of the alloy R3 is a large percentage of the hard carbide  $Cr_3C_2$  (Fig. 3) as compared

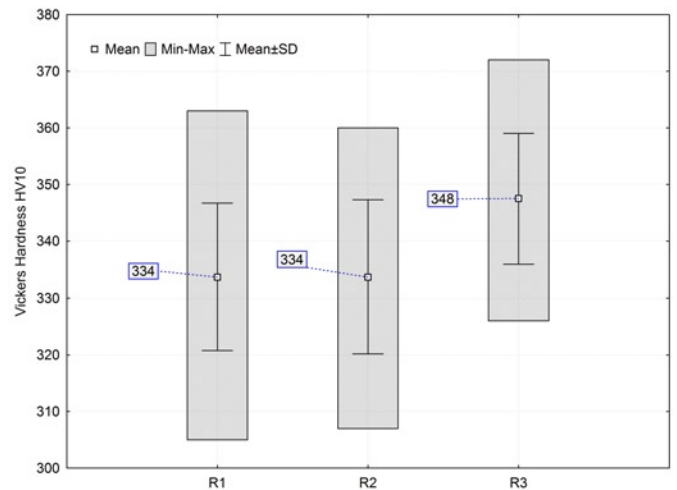


Fig. 2. The comparison of Vickers hardness of tested alloys groups

Table 2. Chemical composition of alloys under test [wt. %]

Groups	C	Si	Mn	P	S	Cr	Mo	Ni
<b>R1</b>	<b>0.059</b>	1.136	0.152	~0.014	<0.0020	22.86	8.426	0.058
Sd.	0.0076	0.013	0.0020	-	-	0.125	0.085	0.0025
<b>R2</b>	<b>0.060</b>	~1.221	0.153	~0.014	0.0029	22.84	~8.570	0.052
Sd.	0.0038	0.028	0.0022	-	0.0011	0.403	0.221	0.0026
<b>R3</b>	<b>0.073</b>	1.199	0.146	~0.014	0.0039	22.05	8.435	0.193
Sd.	0.017	0.047	0.014	-	0.0022	1.230	0.085	0.0029
Groups	W	Fe	Al	Cu	Nb	N	Ti	Co
<b>R1</b>	~4.299	<0.005	<0.005	0.0068	<0.005	0.192	0.0048	62.77
Sd.	0.034	-	-	0.0003	-	0.052	0.0003	0.111
<b>R2</b>	~4.320	<0.005	<0.005	0.0069	<0.005	0.203	0.0051	62.52
Sd.	-	-	0.021	0.0001	-	0.071	0.0002	0.150
<b>R3</b>	~4.315	<0.005	0.140	0.0068	<0.005	0.184	0.0047	63.23
Sd.	0.011	-	0.209	0.0002	-	0.057	0.0003	0.904

to the carbides present in the other study groups. The carbon content within  $0.059 \pm 0.073\%$  indicates that materials under analysis belong to low carbon alloys group.

Figure 3 illustrates XRD pattern for the alloys groups under test indicating only the reflections from carbides without any reflections from matrix. The tests demonstrated the co-existence of carbides i.e. mainly  $Cr_{23}C_6$ ,  $Cr_7C_3$  and  $Cr_3C_2$  in the alloys under test.  $Cr_7C_3$  carbides percentage is the highest in R1 control group;  $Cr_{23}C_6$  carbides prevail in R2 group and  $Cr_3C_2$  in R3 group. Such circumstances are associated with changed chemical composition and carbides transformations occurring in course of alloy recasting processes. Additionally the presence of the following intermetallic phases has been detected in course of tests:  $Cr_{0.7}Mo_{0.3}$  and  $Mo_6Co_7$  – not marked on XRD pattern. However the authors of studies [9, 14] found that  $Cr_7C_3$ ,  $Cr_3C_2$  carbides may be produced in alloys with low chromium content but this opinion has been not confirmed in our tests (about 23% Cr). However Karaali et al. [8] emphasize that carbides i.e. MC,  $M_7C_3$ ,  $M_{23}C_6$  and  $M_6C$  may be produced in cobalt alloys for medical and dental applications but the carbon content occurring in said data is equal to  $0.1 \pm 0.35\%C$  and CoCr alloys for dental applications should be low carbon alloys.

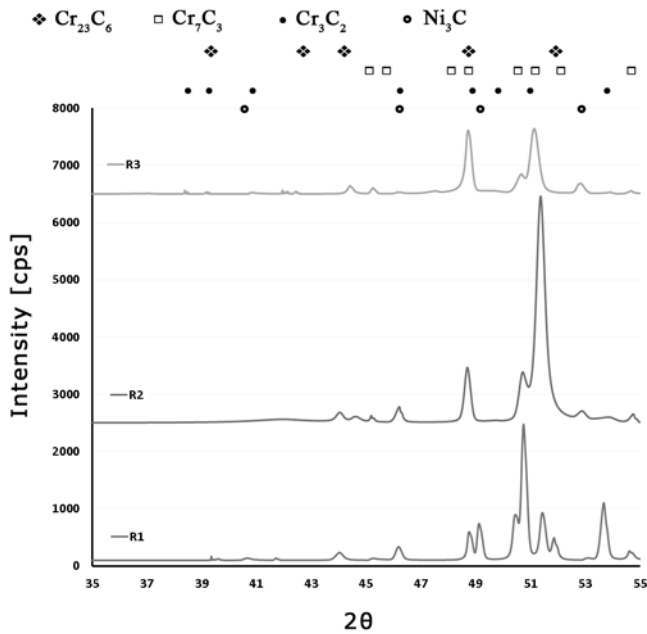


Fig. 3. XRD patterns of the as-cast R1, R2, R3 alloys

The results of tribological tests in artificial saliva demonstrated average friction coefficient on the level  $\mu = 0.32 \pm 0.341$  – similar for all materials groups under test (table 3).

Table 3. Summary of friction coefficients determined for tested materials mating with counterpart made of  $Al_2O_3$

Groups	Average $\mu$	Standard deviation
Never cast (R1)	0.320	0.021
Cast once (R2)	0.329	0.043
Cast twice (R3)	0.341	0.019

Figure 4 illustrates the changes of friction coefficient for mating surfaces CoCrMoW (specimen) –  $Al_2O_3$  (counterpart) along the distance of 100 m. The top points of roughness profile are sheared off first, therefore the initial values of friction coefficients are higher. As a result of running – in of friction surface, the contact area between mating surfaces increases and the friction coefficient is reduced and stabi-

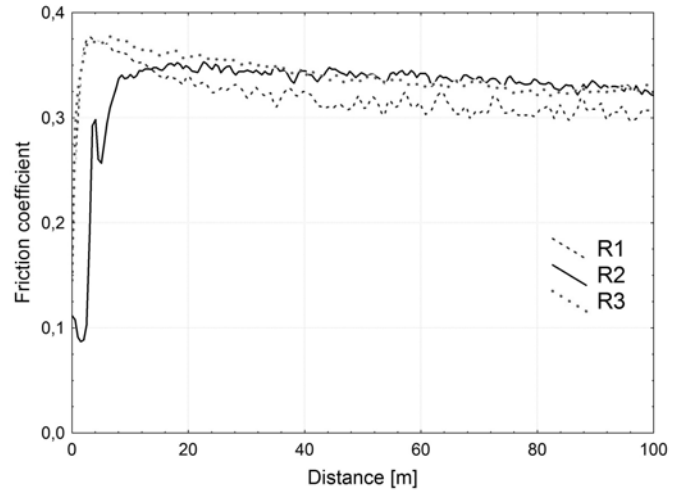


Fig. 4. The curve illustrating changes of friction coefficient vs. distance at the load of 10N

lized. The stabilization of friction coefficients is practically observed in all cases under test after the distance of 20 m. The higher carbon content in an alloy and consequently increased hardness causes increased friction coefficient observed for R3 alloy.

Hard carbides precipitations constitute a natural barrier for the counterpart material. The analysis of wear profiles (Fig. 5) and surface of paths – SEM pictures (Fig. 6) indicate to abrasive wear mechanism. The microcutting in the form of continuous cracks along wear traces and abrasion wear abrasion wear of relatively soft matrix are prevailing factor in this case. The wear process is intensified as a result of an additional impact of hard carbide phase loosely rolling between mating surfaces of specimen and counterpart with wearing surfaces. Such behaviour causes increased abrasive wear effect in alloys being tested. The scratches are caused by rolling carbides on the specimen mating surface or plastic deformation of matrix fragments leaving specific traces in the form chases. The chases are clearly visible on wear trace profile (Fig. 5). The authors of studies [3, 23] also confirm in their tests that the abrasive wear is the prevailing factor causing the destruction of the top layer of CoCrMo casting alloys.

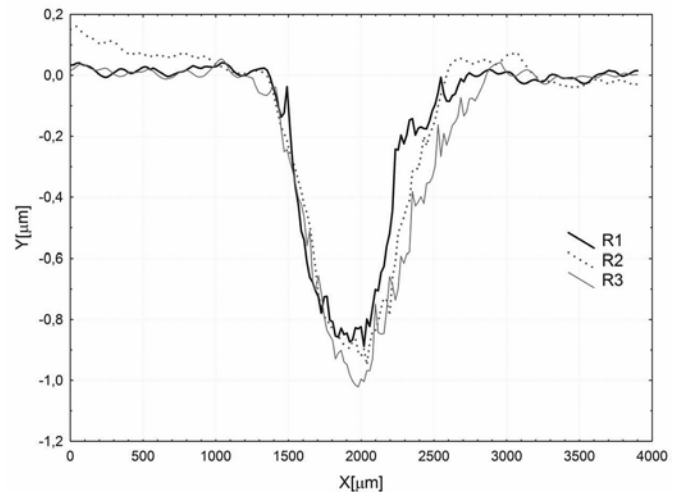


Fig. 5. Typical wear traces profiles

Figure 7 illustrates the results for volumetric wear for tested materials. When comparing the tested materials, it is possible to observe higher wear resistance of R1 control material by about 14% in relation to R2 alloy. However in case of addition of two times remelted



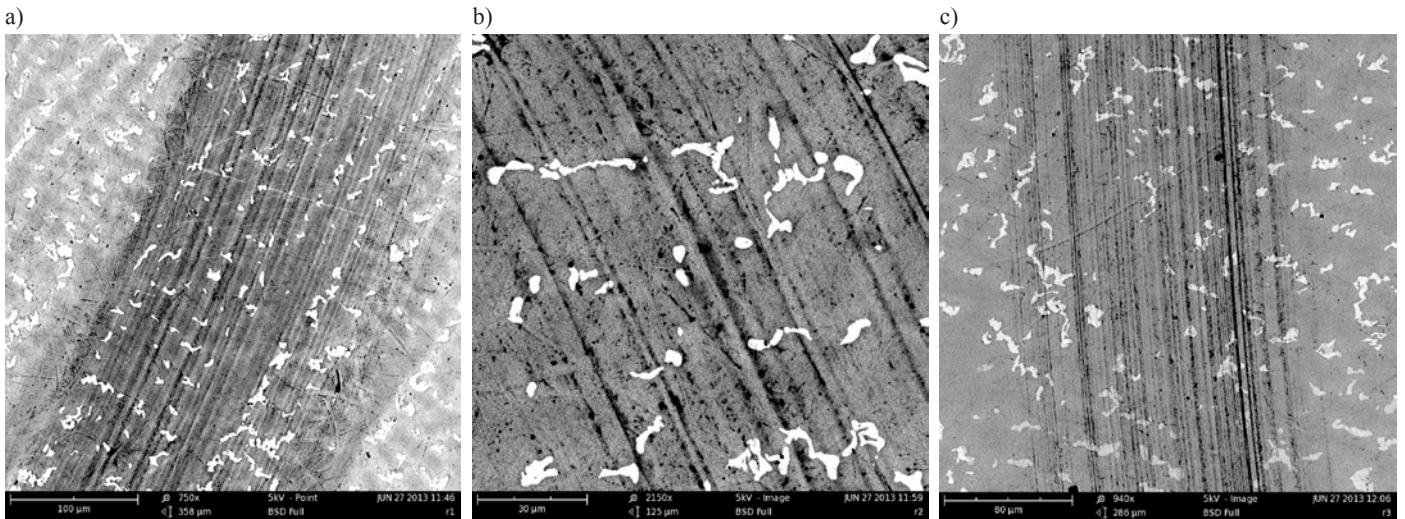


Fig. 6. SEM microstructure of wear trace: (a) R1, (b) R2 and (c) R3.

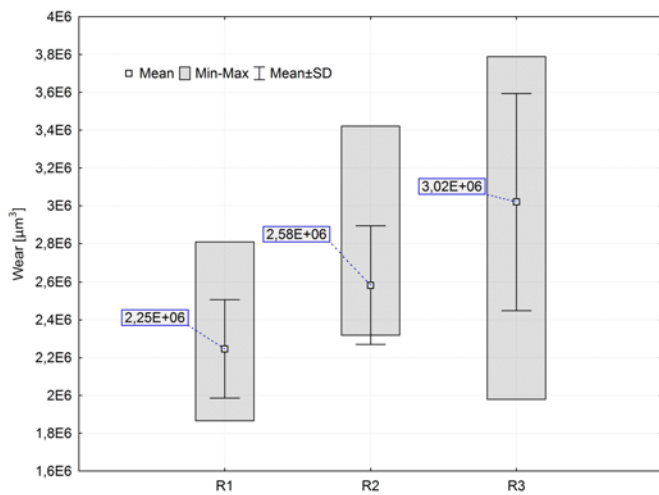


Fig. 7. Diagram illustrating volumetric wear for tested materials obtained for the distance of 100m

material to the fresh alloy (R3 specimen) its wear resistance will be reduced by about 34% in relation to R1 control specimen.

As described in literature [23], abrasive wear of cobalt alloys is determined by hard carbide particles or hard protrusion which are depressed by the counterpart and moved in relation to mating surfaces thereafter. From data available in literature [22] it appears that wear intensity in high carbon CoCrMo alloys is significantly lower than in low carbon alloys due to the fact that low carbon CoCrMo alloys are characterized by low volume percentage of carbides. The value of friction coefficient is affected by the environment (liquid medium) contacting and interacting with an active surface. For instance 0.36%NaCl environment increases the friction coefficient in high carbon cobalt casting alloys and its reduction in case of low carbon alloys [23]. However this trend is completely reversed in different medium (e.g. in 50% bovine serum or Dulbecco's Modified Eagle's Medium).

The values of friction coefficients obtained by the authors of the present article is similar to the data available in literature [23] obtained from tests performed for high carbon alloys ( $\mu=0.19\div0.25$ ) and for low carbon alloys ( $\mu=0.27\div0.28$ ) in various liquid media (but other than artificial saliva).

However the authors of the present article were unable to make any references in wider form because the scientific studies in the scope of tribological measurements for recast CoCrMo alloys in artificial saliva environment still remain to be realized. So called wear factor

K considering the force and sliding distance applied in course of test is specified as a comparative wear measure by the authors engaged in the scope tribological wear research [18, 23]:

$$K = \frac{\text{Wear volume}}{\text{Applied force} \times \text{sliding distance}} [\text{mm}^3 \text{N}^{-1} \text{m}^{-1}] \quad (2)$$

The table No 4 presented below contains the values of wear factors for all tested groups. Iijima et al. [7] emphasize the fact that the wear factor is an important feature characterizing the tribological properties of materials used for the production of prosthetic apparatuses. Furthermore they indicate to a serious problem occurring in the greater part of research studies in the scope of prosthetic dentistry i.e. the fact that the tribological properties are neglected by the scientists concentrating on the examination of strength and corrosion properties.

Significant differences between R1 and R2, R2 and R3 as well as R1 and R3 groups ( $p<0.05$ ) have been demonstrated in course of statistical analysis of wear volume carried out in the form of U Mann-Table 4. Summary of determined wear factors

Groups	Wear factor K [ $\text{mm}^3 \text{N}^{-1} \text{m}^{-1}$ ]	Standard deviation
Never cast (R1)	$2.25 \times 10^{-6}$	$0.26 \times 10^{-6}$
Cast once (R2)	$2.58 \times 10^{-6}$	$0.31 \times 10^{-6}$
Cast twice (R3)	$3.02 \times 10^{-6}$	$0.57 \times 10^{-6}$

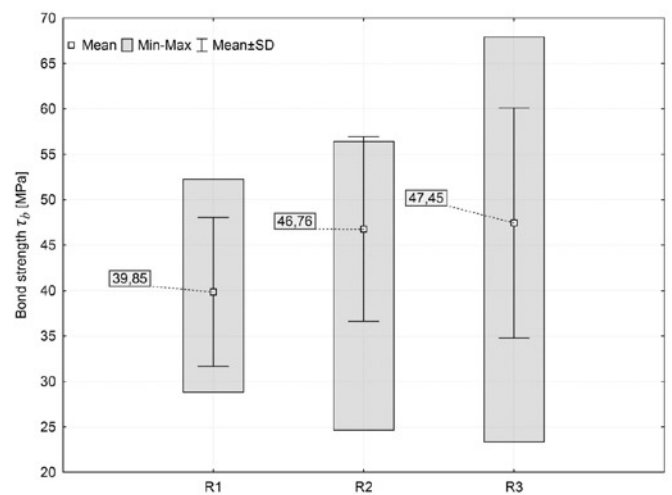


Fig. 8. The mean bond strength of metal-ceramic systems for different groups

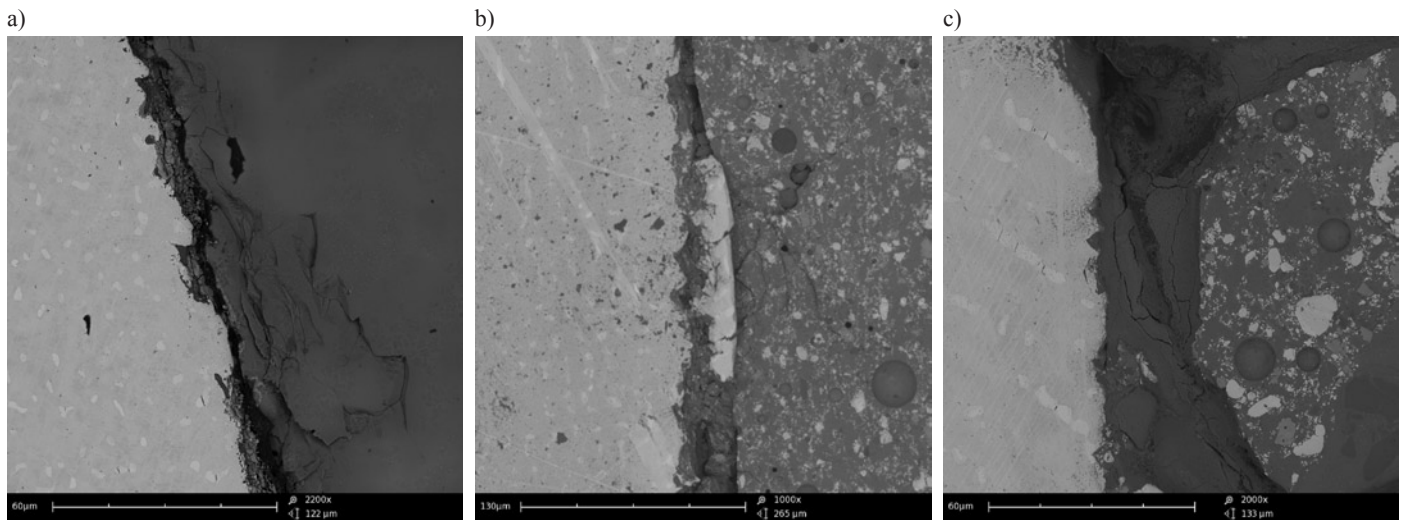


Fig. 9. SEM microphotograph of the cross-section of the metal-ceramic systems after debonding: (a) R1, (b) R2, (c) R3

Whitney test (for  $\alpha=0.05$ ). However the significant differences only between R1 and R3 groups ( $p<0.05$ ) have been demonstrated by means of Kruskal-Wallis analysis. The differences demonstrated as a result of comparison between R1 and R2 groups were insignificant but  $p$  was close to  $\alpha$  ( $p=0.06$ ). The power of U Mann-Whitney test is the highest among non-parametric tests. In case of of Kruskal-Wallis test more prudence is necessary when drawing any substantive conclusions from performed tests due to greater probability of type I and II errors.

Figure 8 illustrates the variations of bond strength for metal-ceramic systems carried out in accordance of ISO 9693 procedures. This standard assumes the minimum strength on the level of  $\tau_b = 25$  MPa in three point bending test. The mean strength values for metal-ceramic bond demonstrate that this minimum value has been achieved and even significantly exceeded in certain cases. Only in R2 and R3 specimens group with the addition of remelted alloy, one case of case has been recorded in each group when a specimen under test achieved the value  $\tau_b < 25$  MPa. The production of prosthetic apparatuses with permanent porcelain coat is a difficult process due to different nature of chemical bonds occurring in the both materials. This process in large part depends on manual skills of dental technician who should uniformly apply the dental porcelain onto metal substrate in a manner ensuring complete wetting of metal substrate and the thickness of individual ceramic layers being applied should be not excessive in order to avoid the weakening of metal-ceramic bond structure by pores occurring in course of porcelain firing process. Therefore the failure to achieve the minimum value of 25Ma for said two specimens could probably caused by excessive porosity in ceramic structure created in application phase but not by the addition of recast material.

In summary, no deterioration has been observed in metal-ceramic bond strength for alloys containing recast materials be even an insignificant growth. Comparing the results obtained for R2 group and for R1 control group, it can be observed that dental porcelain bond strength is 17% higher in R2 group. In case of comparison between R1 and R3 group the bond strength is increased in R3 alloy. However no statistically significant changes have been indicated by means of U Mann-Whitney test at significance level  $\alpha=0.05$  in all combinations of specimens under test ( $p>0.05$ ). Such statistical result may be affected by a large dispersion in min-max values and insufficient size of sample ( $n=9$ ); although the quantity of specimens used for tests was

higher than that required in ISO 9693 standard (min. 6 pcs). However there is a significant difference between R1 and R3 group ( $p<0.01$ ) at significance level  $\alpha=0.1$ .

Figure 9 presents SEM microphotographs of the cross-section of the metal-ceramic systems after debonding for dental porcelain on metal substrate. The adhesive-cohesive fractures have been obtained in almost all tested groups of alloys on the metal substrate end. The cohesive fracture has been obtained in several cases (Fig. 9c) for R3 test group, with the fracture occurring within ceramic or metal oxides transition layer.

Ucar et al. [19] suggest that porcelain veneers on recast metals may result in changed composition of surface metal oxide and consequently in a critical impact on metal-ceramic bond strength. Their three point bending tests for NiCrMo demonstrated that use of recast base metal alloy with fresh alloy reduces the metal alloy-ceramic material bond strength but they did not achieve any statistically significant difference in metal-ceramic bond strength for alloys containing recast material.

#### 4. Summary and conclusions

The alloys produced by the authors with the addition of recast materials meet the quality requirements applicable to prosthetic dental elements in the scope of their quality and durability and can be used in prosthetic dental laboratories. After applying remelting materials, in spite of small increase in hardness wear increased, preferably while affected the adhesion of dental porcelain. Hence, one can predict that such a material is certainly better suited to veneering than abrasion working elements.

On the basis of its own research found that the production of durable prosthetic castings is possible provided that relevant procedure is adhered to, i.e. at least 50% of brand new must be used and remaining part of alloy may be casted once or twice. In the present study, the alloys with 50% addition of recast materials have been tested up to the second generation level only. Therefore the authors suggest the recasting of alloy addition to the level of determined number of generations as well as the testing of effect of increased number of recasting processes on the alloy properties. The recasting procedure may reduce the costs of CoCrMoW castings and may be safely used in dentistry.

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