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The effect of recasting on the Fatigue resistance of Co-Cr alloys

Dr. Husam M. Khalaf, BDS, M.Sc .*
Dr. Shatha S. AL-Ameer, BDS, M.Sc .**
Dr. Ammar A. Alsaady, BDS, M.Sc. Ph.D.***

Abstract

The present study evaluated the effect of recasting cobalt-chromium alloys with the addition of new alloy in different ratios (75% and 50%) on the deflection fatigue resistance using three types of alloys: Wironit (Bego), Remanium (Dentaurum), and Wisil (Wipla). Each alloy was divided into three groups for each test, group I (100% new alloy), group II (75% new alloy +25% recast alloy), and group III (50% new alloy + 50% recast alloy).

Fatigue specimens produced were butterfly-shaped and half round at their cross section with 18mm length, 1mm thickness, and 2mm width. For each alloy group, five samples were prepared.

The results of this study revealed that recasting with adding 75% new alloy did not significantly affect the fatigue resistance of Wironit and Wisil alloys, while significantly affected that of Remanium. Recasting with the addition of 50% new alloy significantly decreased the fatigue resistance of the three types of alloys.

Wironit alloy showed the higher mean values for deflection fatigue resistance compared with Remanium and Wisil alloys.

Key words: Recasting, Fatigue resistance, Cobalt – Chromium alloys

Introduction

The Co-Cr alloys were introduced into dentistry in 1929 and since that time they have come into wide use as an alternative material to gold base alloys for partial denture castings. Co-Cr alloys are much stronger, harder and possess relatively high elastic moduli and low density in addition to low cost. These properties allowed the base metal frameworks to be thinner, lighter and stiffer than it's type IV gold counterpart which gradually discouraged the use of the latter alloy for RPDs construction and is virtually unknown today [(1)].

In our current economy, it is obligatory that the dentists and technicians be conscious about the materials they use. The subsequent demand for semi-precious and non-precious base alloys in dental procedures has resulted in substantial increases in the price of these alloys. With the increased costs of the non-precious metals, it would be economically advisable to re-sue them

*AL-Mustansiria university, College of dentistry, Baghdad, Iraq.
** Baghdad university, College of dentistry, Baghdad, Iraq.
***AL-Mustansiria University, College of dentistry, Baghdad, Iraq.

in combination with new metal alloys to produce restorations with minimum cost for the dental laboratories [(2)].

Although there have been several reports on re-usage of base metal alloys evaluating their mechanical properties such tensile strength, percent, elastic modulus, elongation and hardness [(3-5)], but few studies investigated yield strength which is more important than tensile strength [(6)] and no studies evaluated fatigue resistance of recasted Co-Cr alloy. This study was carried out as a continuation for the previous studies.

Materials and Method

Mold and specimen design for fatigue test:

A silicon mold was designed to reproduce the sample wax patterns which were of half round form with: L=18mm, T=1mm, W=2mm. These dimensions are considered suitable for retentive clasp arms at their rigid third [(7-9)].

The sample design was based on 2 imaginary circles beside each other and a butterfly-shaped specimen was formed between them as shown in figure (1). This design ensured a stress concentration area in the waisted central part of the specimen and it excluded any possibility of fracture in other areas during the bending fatigue test [(10)].

The two ends of the specimen were designed according to the grips or holders of the fatigue machine. The two ends of the sample were of 8mm width and 9mm length to be suitable for the grips of the machine. A 4mm diameter hole was made on one end of the specimen for the fixation of the specimen in the movable holder of the machine.

According to ASTM, E647/1988, the radius of these circles or curvatures was calculated from the following formula:

Where: R = Radius of curvature
L = Length of specimen

$$R = \frac{A^2 + (L/2)^2}{2A}$$

A was calculated from the following formula:
Where: W = Width of the specimen.

$$A = \frac{8}{2} - \frac{W}{2}$$

Preparation and casting of tensile and fatigue specimen:

The silicon mold was used to prepare wax pattern of the specimens. A commercial wax injector was used to transport the melted wax to the lubricated mold. The wax patterns were sprued and invested in phosphate bonded investment material in a casting ring. Five fatigue specimens were invested in each casting ring.

Wax burnout was carried out by putting the investment muffle in furnace for two hours until reaching 1000°C and in the second hour, the muffle position was upside down to eliminate any carbon residue. The casting of Co-Cr alloy was carried out by the use of centrifugal induction melting machine, at casting temperature of each alloy according to the manufacturer's instruction. After casting, the muffle was allowed to cool down slowly to room temperature then casting was divested and sandblasted to remove any remnants of the investment, roughness and irregularities. The final dimensions of specimens were accomplished through finishing and polishing procedures using dental vernia.

The remaining buttons and sprues related to group I were used as recasted alloy. These were sectioned into small pieces by a cutting disc mounted on a laboratory hand piece because these can be melted more readily than large masses and to facilitate weighing of the cast alloy to be mixed with certain amounts of fresh alloy, while the buttons and sprues related to the second and third groups were neglected.

Group II & III were casted by mixing the new and recasted alloy at different ratio by weight with the aid of sensitive electronic balance as follows:

For fatigue test specimen, each casting ring consumed:

Group I : 44 gm new alloy

Group II : 33 gm new alloy + 11 gm cast alloy

Group III : 22 gm new alloy + 22 gm cast alloy

Fatigue resistance testing procedure:

The fatigue testing procedure was under taken by the use of bending fatigue machine (HSM20, HI TECH scientific) . The basic mechanism of the machine is to drive the free end of a cantilever up and down by a reciprocating mechanism. The procedure speed of the testing machine is a million cycles in about three hours. The action of the machine is to apply alternating (positive and negative) deflection or fluctuating bending (one way only) to determine fatigue performance.

In a dental appliance, stress reversal is unlikely to occur and the structure will be stressed in one direction and allowed to return to zero in each cycle [8,10,11]. In the present study, the one way deflection cycles was used. The specimen was stressed in upward movement against its half round cross section as what happened in RPD clasp during insertion and removal when the clasp arm contact the greatest curvature of the abutment tooth and deflected outward [7].The tip deflection planned for most Co-Cr clasps is in the order at 0.25 mm [8,11].Each specimen was marked in the center of its length; a deflection of 0.25 mm was measured at its movable end by a dial gauge with an extended spindle whose tip was applied to the upper surface of the specimen as in. The deflection of the central point of the specimen was measured by the same dial gauge which was 0.125 mm simulating the clinical situation when the clasp tip is deflected to 0.25 mm during insertion and removal. The first rigid third however is subjected to little amount of deflection at which the clasp fatigue occurs mostly [7,12].

After setting up the specimen in the testing machine, it was fatigued until fracturing. The no. of loading cycles which caused the fatigue fracture was recorded automatically.

Results

The means of the number of loading cycles required to cause fatigue fracture of all specimen groups with 0.25 mm deflection are illustrated in table (1). The highest mean value for number of loading cycles required to cause fatigue fracture was registered for group I of Wironit alloy, while the lowest mean value was registered for group III of Wisil alloys. One way ANOVA test revealed a significant difference between the means of the number of loading cycles of the three groups of Wironit and Wisil alloys table (2), while there was a highly significant difference between the groups of Remanium alloy.

Student t-test table (4) for Wironit alloy revealed a non-significant difference between the means of the number of loading cycles of group I and II, while a significant difference was found in the comparison between group I with III and group II with III. Student t-test table (4) for Remanium alloy revealed a significant difference in the comparison between group I with II, group I with III and group II with III. Student t-test table (4) for Wisil alloy showed a non-significant difference between the means of the number of loading cycles of group I and II while a significant difference in the comparison between group I with II and group II with III.

One way ANOVA test was used to compare all alloy groups of the same percentage. Table (3) revealed a highly significant difference for groups I between the three alloys, also the same for group II and group III.

Student t-test Table (5) revealed a significant difference between each type of alloy with the other for group I, group II and also for group III specimens.

Discussion

Most restorative materials must withstand force during either fabrication or mastication [6]. With the increased cost of the non precious metals, it is advisable to recast them in combination with new metal [2]. Three brands of Co-Cr alloys were used and recasted with the addition of new alloy in different percentages to show its effect on the yield strength, E, hardness, and fatigue resistance. Comparison between alloy types also has been studied.

The results of this study for Co-Cr clasp that is subjected to cyclic bending with 0.25mm deflection agree with the findings of Harcourt [12], Earnshaw [13], Morris et al. [14] and Brockhust [15] but disagree with Bates [11].

A significant difference was found between the groups of Wironit alloy and between the groups of Wisil alloy while a highly significant difference was found between the groups of Remanium alloy. For each alloy type, group I recorded a higher mean value than other groups.

Recasting might lead to the production of casting porosities and increase the number of inclusions [3,16,17] and these microporosities and impurities reduce the cross-sectional area of the specimen and induce a stress concentration area initiating crack propagation and fatigue fracture and this agrees with Craig & Powers [6], Harcourt [12], Lewis[18] . Adding recasted alloy might increase the microporosity as the percentage of recasted alloy increased. Group III (50% recasted alloy) decreased the fatigue resistance more than group II (25% recasted alloy).

Carbon content might demonstrate a marked increase in percentage with repeated melting procedure [19-21] and almost all elements in Co-Cr alloys react with carbon to form carbide and any procedure that result in increasing the carbide content of the alloy will reduce fatigue resistance and this agrees with Craig & Powers [6].Adding 50% recasted alloy increased the carbon content, consequently the carbides formed in the tested specimens more than when adding 25% recasted alloy which may explain the less loading cycles required to fracture group III than group II samples.

Ductility is one of the mechanical properties that effects fatigue resistance. A high degree of elongation indicates a good ductility. The increased ductility will improve the resistance to fatigue [6,22].Small amount of microporosity in the test specimen may decrease the elongation considerably and this is in accordance with Craig & Powers [6].The carbides may also increase and manganese may decrease during remelting [3,19-21] the result is decreased ductility and this agrees with Earnshaw [22].

The recasting process causes increase in the grain size [17]. Biffar & Appel cited by Vallittu & Kokkonen [8] examined the grain count in a clasp cross section which has been reported to be as low as two or three. They stated that the coarse grain structure of the clasp suggests poor fatigue strength. Since 50% of the specimen of group III is recasted, which showed larger grain size, one might expect fewer grain count in group III specimens than in group II specimens which explain the lower fatigue strength. But this disagrees with Vallittu & Miettinen [9] who stated that the larger grains of the Co-Cr alloy clasp lengthened the fatigue life of the clasp.

There was a highly significant difference between the corresponding groups of the three alloys. Differences in the fatigue resistance of various commercial Co-Cr alloys of a relatively close composition were found by Vallittu & Kokkonen [8] and Henriques et al [24]. This was related to the difference in the minor alloying elements [6,18, 22,24].

The other reason is the yield strength, Wironit alloy revealed the highest mean value of yield strengths, and in turn, it revealed the highest mean value of loading cycles to cause fatigue fracture. This agrees with Brockhurst [15].

It has been estimated that the greater stress necessitated by removing restorations from the mouth or placing them in position probably amounts to 1500-3600 per year and if no wearing of the retentive undercuts of the tooth is seen, metal fatigue may fracture the Co-Cr clasp after approximately 7 years of use [6,9]. In comparison with this study, the mean values of loading cycles for fatigue fracture of all specimen groups (new & recasted) would seem to give a mean life more than seven years, which seemed to be greatly different from clinical observations. The difference may be attributed to that the clasps clinically are subjected to conditions other than insertion and removal of the dentures such as alternate stress applications occurring during mastication [6,8], mishandling of the clasps by the patient and the mechanical adjustment by the technician and the dentist in addition to the stress concentration areas like voids and sharp angles [11] and finally the reducing effect of saliva on fatigue resistance of Co-Cr clasps [25].

Conclusions

1. Recasting with the addition of 75% new alloy did not significantly affect the fatigue resistance of Wironit and Wisil alloy while significantly affect the fatigue resistance of Remanium alloy.
2. Recasting with the addition of 50% new alloy significantly decreased the fatigue resistance of the three types of alloys.
3. Wironit alloy showed the higher mean values for fatigue resistance compared with Remanium and Wisil.

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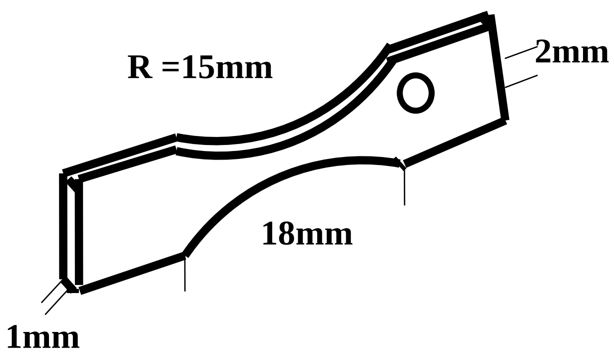

Figure (1): Design & dimensions of the fatigue specimen.

Table (1): Mean no. of loading cycles and SD for fatigue fracture of all groups

		Mean	SD	SE	Min	Max	C.V%
Wironit	Group I	185862	27516	12305	150726	216248	14.8
	Group II	146199	30301	13551	108602	192844	20.73
	Group III	104687	20816	9309	84314	132372	19.88
Remanium	Group I	109487	28670	12822	71370	138706	26.19
	Group II	62551	12895	5767	40224	72663	20.62
	Group III	41608	5336	2386	34986	47030	12.82
Wisil	Group I	49316	8141	3641	40004	60024	16.51
	Group II	41841	7316	3272	32660	50640	17.49
	Group III	26498	10591	4736	15138	40254	39.97

Table(2):One way ANOVA test for the mean No.of loading cycles for fatigue fracture of Wironit® (wir), Remanium (rem) and Wisil® (wis) groups

S.O.V	SS			Df			MS			F-test			P-value		
	Wir	rem	wis	wir	rem	wis	wir	rem	wis	wir	rem	wis	wir	rem	wis
between	1.648	1.208	1.353	2	2	2	8.238	6.041	6767	11.72	17.83	8.75	0.002 S	0.000 HS	0.005 S
within	8.434	4.067	92786	12	12	12	70285	3389	7732						
total	2.491	1.615	2.281	14	14	14									

Table(3): One way ANOVA test for the mean No.of loading cycles for fatigue fracture of Group I (G.I) ,Group II (G.II) , Group III (G.III) of the three alloys

S.O.V	SS			Df			MS			F-test			P-value		
	G. I	G. II	G.III	G.I	G.II	G.III	G.I	G.II	G.III	G.I	G.II	G.III	G. I	G.II	G.III
between	4.683	3.053	1.720	2	2	2	2.342	1.526	8.601	42.69	40.24	44.95	0.000 HS	0.000 HS	0.000 HS
within	6.581	4.552	2.296	12	12	12	54845	37930	19131						
total	5.341	3.508	1.950	14	14	14									

Table (4): Student t-test between the means no. of loading cycles for fatigue fracture of groups of same alloy

		t-test	*p-value*	*Sig*
Wironit	GroupI & GroupII	2.17	0.067	NS
	GroupI & GroupIII	5.26	0.0013	S
	GroupII & GroupIII	2.53	0.039	S
Remanium	GroupI & GroupII	3.34	0.021	S
	GroupI & GroupIII	5.20	0.0065	S
	GroupII & GroupIII	3.36	0.020	S
Wisil	GroupI & GroupII	1.53	0.17	NS
	GroupI & GroupIII	3.82	0.0067	S
	GroupII & GroupIII	2.67	0.032	S

*P<0.05 Significant **P>0.05 Non significant

Table (5): Student t-test between the means no. of loading cycles for fatigue fracture of all alloy groups

		t-test	p-value	Sig
GroupI	Wironit & Remanium	4.30	0.0037	S
	Wironit & Wisil	10.64	0.0004	S
	Remanium & Wisil	4.51	0.011	S
Group II	Wironit & Remanium	5.68	0.0024	S
	Wironit & Wisil	7.49	0.0017	S
	Remanium & Wisil	3.12	0.020	S
GroupIII	Wironit & Remanium	6.56	0.0028	S
	Wironit & Wisil	7.49	0.0007	S
	Remanium & Wisil	2.85	0.036	S

*P<0.05 Significant