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Reduce, reuse, recycle - To evaluate the impact of recasting on the useful properties of nickel chromium alloy (an in-vitro study)

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Abstract

Conventional casting of Nickel Chromium alloy for fabrication of metal restoration is a standard procedure but results in a significant amount of metal surplus such as buttons, sprues or defective castings. The surplus produced in dentistry is relatively pure due to the fact that this metal is melted in controlled conditions without necessity to apply any chemical treatment used in industrial castings. Recasting of sprues is frequently practiced in dental laboratories. The resultant change in characteristics and properties of nickel chromium alloy caused by recasting is a topic of interest. Recommendations on the use of re-casted nickel-chromium alloy are in wide disagreement. A total of 120 samples of nickel chromium alloy copings were fabricated by optically scanning a standardized metal die and milling wax patterns. Conventional lost-wax and induction casting technique was employed. The impact of reusing and recasting (two, four and six times) nickel chromium alloy was investigated by evaluating three important parameters: bond strength to porcelain, tensile strength and microstructure.

Keywords: Re-casting, Nickel-chromium alloy, Bond strength to porcelain, Tensile strength, Microstructure.

Introduction

Dental casting alloys have been classified as high noble, noble and predominantly base metal alloys based on their noble metal content (ADA).[1] Base metal alloys such as nickel chromium (Ni-Cr) have been extensively used in dentistry for fabrication of porcelain fused to metal restoration. This can be attributed to their low cost, low density, high strength, high modulus of elasticity, biocompatibility, good bond with porcelain, tarnish and corrosion resistance.[2,3] Conventional casting of Ni-Cr alloy for fabrication of metal restorations is a standard procedure but results in a significant amount of metal surplus such as buttons, sprues or defective castings. The surplus produced in dentistry is relatively pure due to the fact that this metal is melted in controlled conditions without necessity to apply any chemical treatment used in industrial castings.[4] Thus, recasting of sprues is frequently practiced by dental laboratories. The resultant change in characteristics and properties of nickel chromium alloy caused by recasting is a topic of interest.[5] Presence of impurities, porosities, thickness of oxide layer formation, grain structure, intermetallic phases may have a determining effect on the useful properties of the alloy.[6,7,8,9]. Recasting of dental alloys is practiced perhaps for a few reasons such as economic concerns, to reduce the overall cost of the final casting, to avoid exploitation of the natural resources, for environmental protection in terms of energy conservation, decreasing waste volume and minimizing the pollution caused by mining.[10,11] This study was conducted to investigate the impact of recasting (2,4,6 times) nickel chromium alloy on the bond strength to porcelain, tensile strength and microstructure.

Materials and Methods

A standardized stainless-steel die[12] (master die) was optically scanned (Dental wings 7 Series scanner) to fabricate wax patterns for metal copings (Figure 1). A total of 120 wax patterns were milled with the help of Zenotec mini milling machine (Wieland Dental). The stainless-steel die was duplicated (SilagumTM) and poured (Type IV die stone, Ultra rock KalabhaiTM) to form 120 working dies on which the marginal fit of the wax patterns were evaluated subjectively and qualitatively.[13] The wax patterns were invested and casted using Ni-Cr Alloy (Bellabond Plus, Bego) following conventional lost-wax and induction casting technique.

Figure 1: Standardized stainless die.

The metal copings after finishing and sandblasting were seated on the working dies and evaluated for proper fit and thickness (0.5 mm). The leftover buttons, sprues were re-used for subsequent casting procedures in the following manner. (Figure 2)

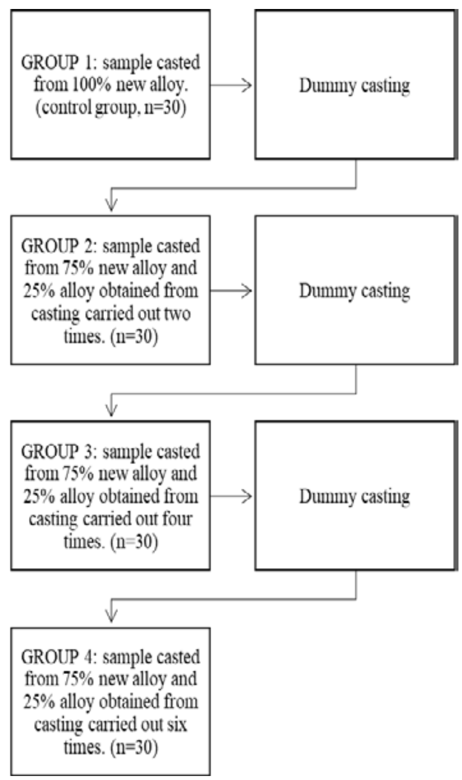

Figure 2: Grouping and Recasting workflow

Recasting Procedure

The amount of alloy required for casting was determined by the density of Ni-Cr alloy, weight of the wax pattern and sprues in grams using wax-grams conversion chart.[14] The total weight of alloy required for casting metal copings (N=30) was 42 grams, hence recasting involved using 34 grams of Ni-Cr alloy (75% fresh alloy) and 8 grams of buttons and sprue Ni-Cr alloy remnants (25%

recast alloy). The 2nd, 4th and 6th round of casting were, dummy castings.[15] A cylindrical shaped dummy was made out of wax suitable for the casting procedure. It was sprued, invested and casted using 25% reused Ni-Cr alloy (buttons / sprues) from previous cycle with 75% fresh Ni-Cr alloy. The casting obtained was sandblasted and sectioned for re-use subsequently for 3rd, 5th and 7th round of casting. A total of 120 Ni-Cr alloy copings were fabricated. 10 copings from each group (1-4) were segregated (10x4) used for testing the three parameter (40 x 3).

The working dies were mounted in acrylic resin using plastic tube mold to serve as a base during testing. These resin-die models were placed on a custom-made jig as per the specimen dimensions to provide adequate support during testing. Ni-Cr copings were seated on working dies for testing purposes. (Figure 3)

Figure 3: Ni-Cr alloy copings seated on working dies mounted in acrylic base.

Bond strength to porcelain test

40 Ni-Cr copings were veneered with porcelain (VitaVMK Master Vita Zahnfabrik). The following steps were followed for veneering- Oxidation, Wash & Opaque firing (0.2–0.3 mm), Dentin (body) porcelain firing (0.5–1.0 mm in gingival third, 1.5–2.0 mm (incisal and occlusal third) and Glaze firing.[16] Measurements were made with a vernier caliper in multiple locations to ensure the porcelain layer was symmetrical. Bond strength to porcelain was tested using universal testing machine (Instron Inc., USA) using the Schwickerath crack initiation test a method described in ISO 9693: 1999. (Figure 4)

Figure 4: Testing bond strength to porcelain.

Tensile strength test

Tensile strength was measured on non-veneered 40 Ni-Cr copings using the universal testing machine (Instron Inc., USA). Each test specimen was placed between the two jaws or heads of the testing machine for the pull-out test at a crosshead speed of 2 mm/minute according to ISO specification 9513.[18,19] (Figure 5)

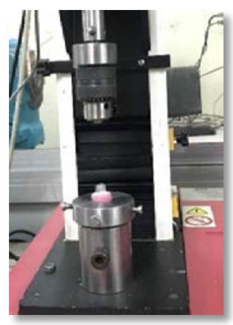

Figure 5:Testing tensile strength.

Microstructural analysis

40 Ni-Cr copings were sectioned and analyzed using a scanning electron microscope (JSM 6380LA, Jeol USA), quantitative image analysis software (ImageJ 1.45s) to calculate total area, pore count, % area of the porosities. (Figure 6)

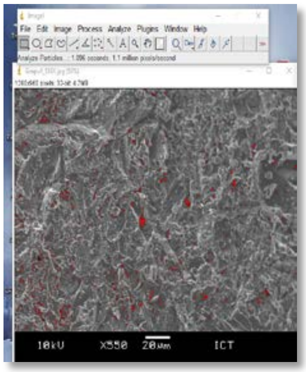

Figure 6: Microstuctural analysis.

Statistical Analysis

Normality of numerical data was checked using Shapiro-Wilk test. Data on bond strength and tensile strength followed a normal curve; hence parametric tests were used for comparisons. Inter-group comparison (>2 groups) was done using one-way ANOVA followed by pair wise comparison using post hoc test. The data for microscopic findings did not follow a normal curve; hence non-parametric tests were used for comparisons. Inter-group comparison (>2 groups) was done using Kruskall Wallis ANOVA followed by pair wise comparison using Mann Whitney U test. For all the statistical tests, $p < 0.05$ was statistically significant keeping α error at 5% and β error at 20%, thus giving a power to the study as 80%.

Results

Bond strength to porcelain

The mean load required for fracture was highest for Group 1; 2.899 ± 0.62 and lowest for Group 4; 1.03 ± 0.29. Whereas, the mean bond strength was highest for Group 1; 7872.6 and lowest for Group 4; 5508.7.

(Table 1)

Table 1: Inter-group comparison of Fracture load, Bond strain and Bond strength:

	Groups	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	F	p value of one way ANOVA
Fracture Load	1	10	2.8990	.6253242	.1961221	1.7000	3.1100		
	2	10	2.2430	.5553988	.1756325	1.1100	2.9500		
	3	10	1.7450	.6411838	.2027601	1.0100	2.9400	9.647	.001**
	4	10	1.0300	.2918142	.0922798	.4600	1.5600		
Bond Strain	1	10	18.527	5.7240313	1.8100976	11.8600	28.1800		
	2	10	17.541	4.9457566	1.4691172	10.4100	25.0000		
	3	10	12.700	4.8682737	1.5394833	6.8200	21.0100	3.953	.016*
	4	10	11.539	4.8083872	1.5205456	5.1400	19.5700		
Bond Strength	1	10	7872.6	2186.04	691.29	5240.30	11083.00		
	2	10	7433.9	2075.76	567.51	4024.16	10893.66		
	3	10	6631.7	2803.08	886.41	4397.00	12849.00	6.640	.001**
	4	10	5508.7	1267.96	400.97	2029.00	6808.00		

Tensile Strength

The mean tensile strength of Ni-Cr alloy copings was highest for Group 1; 673.85 ± 29.65 and lowest for Group 2; 611± 4. The mean yield strength of Ni-Cr alloy copings was highest for Group 1; 476.6 ± 33.5 and lowest for Group 4; 410 ± 48.22. (Table 2)

Table 2- Inter-group comparison of Tensile strength and Yield strength

	Groups	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	F	p value of one way ANOVA
Tensile Strength	1	10	673.85	29.6555	9.3779	628.0	721.0		
	2	10	659.10	61.2489	19.3686	594.0	670.0		
	3	10	620.80	27.8879	8.8189	585.0	678.0	6.674	.001**
	4	10	611.40	46.7480	14.7830	563.0	720.0		
Yield Strength	1	10	476.85	33.5875	10.6213	422.0	546.0		
	2	10	450.05	21.3984	6.7668	427.0	491.5		
	3	10	433.71	24.1357	7.6324	436.0	510.0	1.816	.162^
	4	10	410.60	48.2222	15.2492	425.0	591.0		

Microstructure

The mean pore count for Ni-Cr alloy was highest for

Group 4; 39.80 ± 15 and lowest for Group 1; 10.60 ± 5.6. The mean total area of pores for Ni-Cr alloy was highest for Group 4; 134.49 ± 72 and lowest for Group 1; 32.61 ± 28.8. The mean average size in microns for Ni-Cr alloy was highest for Group 1; 3.688 ± 2.24 and lowest for Group 3; 3.02 ± 1.5. The mean % area porosity for Ni-Cr alloy was highest for Group 4; 0.3450 ± 0.14 and lowest for Group 1; 0.0727 ± 0.07. (Table 3)

Table 3: Inter-group comparison of SEM analysis

Groups		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	Chi square value	p value of KW ANOVA
Pore Count	1	10	10.60	5.641	1.784	1	20	19.436	0.001**
	2	10	16.90	12.078	3.819	1	36		
	3	10	13.50	8.114	2.566	2	25		
	4	10	39.80	15.164	4.795	23	67		
	Total	40	20.20	15.675	2.478	1	67		
Total Area Of Pores	1	10	32.61	28.814	9.112	2	105	12.164	0.007**
	2	9	49.60	46.162	15.387	2	143		
	3	10	45.89	37.031	11.710	6	108		
	4	10	134.49	72.388	22.891	7	231		
	Total	39	66.06	62.523	10.012	2	231		
Average Size In Microns	1	10	3.6887	2.2437	.7095	2.0280	9.6000	0.818	0.845^
	2	10	3.1290	.6912	.2185	2.0500	4.1700		
	3	10	3.0239	1.56568	.4951	.3490	4.7700		
	4	10	3.2210	1.20028	.3795	.2500	4.5800		
	Total	40	3.2656	1.49546	.2364	.2500	9.6000		
% Area Porosity	1	10	.0727	.0774124	.02447	.0040	.2700	18.815	0.001**
	2	10	.1011	.1034262	.03270	.0040	.2800		
	3	10	.1490	.0811651	.02566	.0300	.2600		
	4	10	.3450	.1460784	.04619	.1600	.6000		
	Total	40	.1670	.1479761	.02339	.0040	.6000		

100% new Ni-Cr alloy microstructure analysis revealed inter-dendritic phase with a lamellar structure and areas of micro-porosity. Microstructure of castings produced from reused alloys demonstrated irregular dendrites, with increased content of porosities, inclusions and participates.

Discussion

Recycling is predominant in recent literature as an attempt to grabble the issue of conserving natural resources, energy, reducing toxic waste. Metals can be recycled nearly indefinitely, nevertheless many authors are of different opinion regarding the addition of new alloy to reused alloy for subsequent castings. Studies by Harcourt HJ[8], Lewis AJ[6], Bauer J [9] have shown that when base metal alloys are reused, it is necessary to add new alloy to re-casted alloy for maintaining castability and to prevent deterioration in the mechanical properties and biocompatibility of Ni-Cr alloy. There has been much disceptation on the appropriate proportion of re-casted alloy and the fresh alloy as well as the feasible number of recasting without having dramatic adverse changes in the useful properties.

Bearing these factors in mind, the present study was conducted to evaluate the impact of recasting Ni-Cr alloy up to 6 times upon on the bond strength to porcelain, tensile strength and microstructure.

Several tests have been reported in the literature to evaluate the metal-porcelain bond strength such as shear tests, schwickerath crack initiation test (ISO 9693:1999), flexure test (three-point, four-point, biaxial) are among the most commonly used mechanical tests.[20] In the present study, Schwickerath crack test was employed as it is most ideal for test specimen made of a substrate and a thin veneer layer, which is loaded under bending conditions until cracks are initiated at the interface. It is easy to perform, provides an analytical solution for interfacial shear strength calculations.

Beer–Lech K et al[21], evaluated bond strength to porcelain of re-casted Ni-Cr alloy of 100%, 50%, and 0% of the brand-new material. Metal ceramic bond strength of all test samples was greater than 25 MPa. Highest values were recorded for the samples made of 100% of a brand-new material. The findings agree with the results obtained in the present study i.e., bond strength of all test samples was greater than 25 MPa.[1] Metal alloys that are suitable to receive the veneering layer contain certain elements, (such as iron, chrome, tin, indium, etc.) which form thin oxides at the interface during sintering allowing the development of primary chemical bonds with the silica of veneering ceramic. Tucillo et al[22] reported that the thickness of the adherent oxide layer formed at the metal surface might decline due to multiple castings, resulting in decreased bond strength.

Measurements of tensile strength can be done using: three point bending test, pull-out test, indentation test, diametral compression test. Tensile strength testing in the present study was performed using pull out method as it takes into consideration the elastic modulus, thickness and failure load of the substrate.[23] Also, because three- and four-point bending tests demonstrate significant stress concentration effects.[24]

A tensile strength above 300 MPa is necessary to avoid fracture of alloys in fixed restoration.[1]

Prabhu R et al[25] evaluated the effect of recasting Ni-Cr alloy with and without addition of any fresh alloy on its mechanical properties and stated that recasting of Ni-Cr alloy was acceptable with addition of minimum of 50% of new alloy by weight. No light was thrown on the acceptable number of re-castings. Hence, re-using 75% new alloy was adopted in the present study and the findings were consistent with other authors, Nelson et al[26], Issac & Bhat[5] demonstrating a degenerative trend in physical properties as the number of reuse increases.For base-metal alloys, small grain structure, dispersed secondary phases are critical to the strength of the alloys.[2]

Ucar et al [7] in their study stated that some porosity is inevitable in the microstructure of a cast dental alloy which can arise due to the sprue design, inappropriate mold temperature, improper heating of the alloy. Unless the size of the pores is too large and occupying a larger surface area, acting as areas of stress concentration, it is not considered to have a negative contribution on the properties of the alloy. As observed by Cheng H et al[27] in their study, with the increase of recast times, the size of dendritic crystal coarsening, shrinkage cavity, porosity and inclusion gradually increased. A similar observation was documented in the present study; however, no perceived threshold values of porosity have been documented with regards to mechanical properties.

Conclusion

The present study was undertaken to evaluate the impact of recasting Ni-Cr alloy up to 6 times and observe its effect on the bond strength to porcelain, tensile strength and microstructure. Based on the findings: The following conclusions can be drawn:

1) Recasting Ni-Cr did not exceedingly negatively impact its properties thus establishing that reusing Ni-Cr alloy is affirmable in an appropriate proportion with fresh alloy as the components of the alloy lost or altered in the previous casting are plausibly replenished after the addition of fresh alloy.

2) Superior results were produced with 100 % fresh Ni-Cr alloy test group. Recasting Ni-Cr alloy up to 6 times in the proportion of 75% fresh alloy mixed with 25% recasted alloy did not deteriorate the properties of Ni-Cr alloy to a clinically unacceptable level.

References

1. Craig, O’brien and powers. Dental materials, properties and manipulation; 6th edition; mosby,1996 .230-242.
2. Roach M. Base metal alloys used for dental restorations and implants. Dental Clinics of North America. 2007 Jul 1;51(3):603-27.
3. Wataha JC. Alloys for prosthodontic restorations. The Journal of prosthetic dentistry. 2002 Apr 1;87(4):351-63
4. Vaillant-Corroy AS, Corne P, De March P, Fleutot S, Cleymand F. Influence of recasting on the quality of dental alloys: A systematic review. The Journal of prosthetic dentistry. 2015 Aug 31;114(2):205-11.

5. Issac L, Bhat S. Effect of re-using nickel-chromium alloy on its ultimate tensile strength, yield strength and modulus of elasticity. Indian journal of dental research: official publication of Indian Society for Dental Research. 1998;9(1):13- 7.
6. Lewis AJ. The effects of remelting on the mechanical properties of a nickel base partial denture casting alloy. Australian dental journal. 1975 Apr;20(2):89-93
7. Ucar Y, Aksahin Z, Kurtoglu C. Metal ceramic bond after multiple castings of base metal alloy. Journal of Prosthetic Dentistry. 2009 Sep 1;102(3):165-71
8. Harcourt H.J.: The remelting of cobalt -chromium alloys. Brit Dent. J. 1962, 112: 198-204
9. Bauer J, Cella S, Pinto MM, Costa JF, Reis A, Loguercio AD. The use of recycled metal in dentistry: Evaluation of mechanical properties of alloy waste recasting. Resources, Conservation and Recycling. 2010 Oct 1;54(12):1312-6.
10. Ayres RU. Metals recycling: economic and environmental implications. Resources, conservation and recycling. 1997 Nov 1;21(3):145-73
11. Thopegowda NB, Shenoy K, Shankarnarayana RK, Kukkila J, Vaddya SB, Gingipalli K. Recycling of materials used in dentistry with reference to its economic and environmental aspects. Int J Health Rehabil Sci. 2013;2(3):140- 5.
12. Gonzalo E, Suárez MJ, Serrano B, Lozano JF. A comparison of the marginal vertical discrepancies of zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. The Journal of prosthetic dentistry. 2009 Dec 1;102(6):378-84.
13. Tjan AH, Li T, Logan GI, Baum L. Marginal accuracy of complete crowns made from alternative casting alloys. Journal of Prosthetic Dentistry. 1991 Aug 1;66(2):157-64
14. Hera Insert Conversion Table Wax to Alloy Weight EN, Kulzer
15. Denzine AF, Kolakowski TA, Matlock WM, Wallace JF. Influence of Grain Refinement on the Structure and Properties of Cast Nickel-Base Superalloy Turbine Components. United Stated Army Aviation System Command Report; 1977 May, 77-27.
16. Rathi S, Verma A. Material selection for single-tooth crown restorations. InApplications of nanocomposite materials in dentistry 2019 Jan 1 (pp. 225-235). Woodhead Publishing.
17. Kosyfaki P, Swain MV. Adhesion determination of dental porcelain to zirconia using the Schwickerath test: strength vs. fracture energy approach. Acta biomaterialia. 2014 Nov 1;10(11):4861-9
18. Mayta-Tovalino FR, Ccahuana-Vasquez VZ, Rosas-Díaz JC. Removal force of cast copings to abutments with three luting agents. Journal of Dental Implants. 2015 Jan 1;5(1):25.
19. ISO 9513:2012, Metallic materials -- Calibration of extensometer systems used in uniaxial testing.
20. Diniz AC, Nascimento RM, Souza JC, Henriques BB, Carreiro AF. Fracture and shear bond strength analyses of different dental veneering ceramics to zirconia. Materials Science and Engineering: C. 2014 May 1;38:79-84.
21. Beer–Lech K, Pałka K, Skic A, Surowska B, Gołacki K. Effect of Recasted Material Addition on the Quality of Metal-Ceramic Bond: A Macro-, Micro-, and Nanostudy. Advances in Materials Science and Engineering. 2018.
22. Tuccillo JJ, Lichtenberger H, Nielsen JP. Composition stability of gold base dental alloys for different melting techniques. Journal of dental research. 1974 Sep;53(5):1127-31.

23. Berenbaum R, Brodie I. Measurement of the tensile strength of brittle materials. British Journal of Applied Physics. 1959 Jun 1;10(6):281.
24. Anusavice KJ, Dehoff PH, Fairhurst CW. Materials science: comparative evaluation of ceramic-metal bond tests using finite element stress analysis. Journal of dental research. 1980 Mar;59(3):608-13.
25. Prabhu R, Geetha Prabhu KR, Ilango T. Dental prosthesis: an evaluation on mechanical properties of recast base metal alloys. Journal of Clinical and diagnostic research. 2011;5(8):1682-5
26. Nelson DR, Palik JF, Morris HF, Comella MC. Recasting a nickel-chromium alloy. Journal of Prosthetic Dentistry. 1986 Jan 1;55(1):122-7.
27. Cheng H, Zhao W, Chen R, WU W, LI X, Zheng M. Effects of recasting on the composition and microstructure of Ni-Cr ceramic alloy. Chinese Journal of Tissue Engineering Research. 2009:7511-6.