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The Effect of Recasting on Bond Strength between Porcelain and Base-Metal Alloys

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Abstract

Purpose: Long-term success of metal ceramic restorations depends on metal ceramic bond strength. The purpose of this study was to determine whether recasting of base-metal alloys has any effect on metal ceramic bond strength.
Materials and Methods: Super Cast and Verabond base-metal alloys were used to cast 260 wax patterns. The alloy specimens were equally divided into five groups and cast as: group A 0.0%, B 25%, C 50%, D 75%, and E 100% once-cast alloy. Each group was divided into two subgroups: the first group was cast with Super Cast and the second with Verabond. In each subgroup half of the cast alloys were veneered with Vita VMK 68 and the others with Ceramco 3.
Results: Recasting decreased bond strength ($p < 0.006$) when used for 50% once-cast alloy. Group E with 100% new Super Cast alloy veneered with Vita VMK 68 porcelain had the highest bond strength (30.75 ± 9.58 MPa), and group B including 25% new and 75% recast Super Cast alloy veneered with the same porcelain had the lowest bond strength (21.72 ± 5.19 MPa).
Conclusions: By adding over 50% once-cast alloy in base-metal alloys, metal-ceramic bond strength decreases significantly.

In the late 1950s, a break significantly influencing the fabrication of dental restorations occurred in dental technology. This was the successful veneering of a metal substructure with dental porcelain. These restorations have been used successfully for several years.[1] Various types of alloys including noble and non-noble or base metal are used for metal ceramic restorations. A steep rise in the cost of the noble metals and silver in 1973 to 1974 led to a widespread interest in base-metal alloys, also referred to as nonprecious or non-noble.[2] Base-metal alloys contain less than 25% noble metals without gold. Most of these alloys are nickel-chromium (Ni-Cr), nickel-chromium-beryllium (Ni-Cr-Be), and cobalt-chromium (Co-Cr).[2–4] These alloys are harder than noble alloys but usually have lower yield strengths. They also have higher elastic moduli.[4] Therefore, long-span fixed prostheses fabricated from Ni-Cr alloys undergo much less flexure than do similar prostheses fabricated from noble-metal alloys, with less likelihood of fracture of the brittle dental porcelain component. It was hoped that thinner copings and frameworks could result.[3,4] These base metal casting alloys are generally considered more technique sensitive and difficult to cast than the noble metal casting alloys; however, this assessment may reflect some dental laboratories' lack of experience with the Ni-Cr alloys, because excellent results for castability of these alloys have been published. Therefore, the choice of dental laboratory is particularly important when these alloys are selected.[3]

Many Ni-Cr alloy formulations contain up to 2% by weight of Be. The major reason for incorporating this element in the alloy is to lower the melting range and to decrease the viscosity of the molten alloy, thereby improving its castability. Be also provides strengthening and affects the thickness of the oxide layer when the alloy is oxidized for porcelain firing. The latter is an important consideration for base metal casting alloys, which can form much thicker oxide layers than noble metal casting alloys. Fracture through the oxide layer may occur and cause failure of the base metal ceramic restoration.[3]

The popularity of these alloys has dramatically increased over the last few decades due to their mechanical properties and low cost.[5] In dental laboratories, surplus alloy is commonly reused from the initial casting and new alloys added. Hesby et al reported that repeated casting had no effect on the physical properties of base-metal alloys.[6] Nelson et al also reported that recasting Ni-Cr alloys had no effect on physical properties, microstructures, and clinical features of these alloys.[7] Isaac and Bhat examined the effect of base-metal alloy recasting on yield strength and modulus of elasticity. In this study only recast alloys were used. They showed that recasting had detrimental effects on physical properties.[8] Mosleh et al studied the recasting effect on castability of various alloys. They observed that recasting had no effect on castability of base metal and precious alloys; however, a significant decrease was observed in the castability of Ti.[9]

The purpose of this investigation was to determine the effect of recasting on the metal ceramic bond.

Materials and methods

In this study, Ni-Cr-Be alloys were used to study the effects of base-metal recasting on metal ceramic bond strength. Specimens of each alloy were equally divided into five groups (A, B, C, D, E) and were cast as follows: group A with 0.0%, B with 25%, C with 50%, D with 75%, and E with 100% once-cast alloy. In this study 260 wax patterns were used in accordance with DIN draft 13,927 (0.5 mm thick, 3 mm wide, 25 mm long) for casting 130 specimens with Super Cast (Thermabond Alloy, Mfg. Los Angeles, CA) and 130 specimens with Vera Bond alloy (Aalba Dent Inc., Cordelia, CA).[10]

Table 1 shows the nominal compositions of these alloys. Wax patterns were sprued and invested with Bellavest T materials (Bego, Bremen, Germany). Following the manufacturer's instructions, castings were made by centrifugal induction and a casting machine (Fig 1). In each subgroup, half of the specimens were veneered with Vita VMK 68 porcelain system (Vita VMK-GF, Vita ZahnFabrik, Bad Sackingen, Germany) and the other half with Ceramco 3 (Dentsply Intl, York, PA). The groups are presented in Table 2. A uniform thickness of 1 mm porcelain with 3 mm width was applied along an 8 mm length in the central portion of each metal specimen, and porcelain dimensions were controlled.[10]

Table 1 Composition (%) of the base-metal alloys used in this study

	Ti	Co	Be	Al	Mo	Cr	Ni
Super Cast	–	–	1.6	–	5	14	75
Verabond	0.35	0.45	1.95	2.9	5	12	77.95

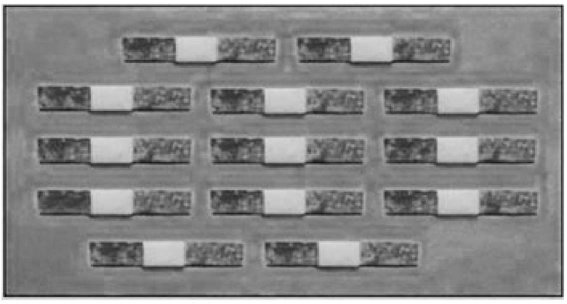

Figure 1 Prepared base metal specimens.

A universal testing machine (Zwick/Z250, Zwick Gmbh Co., Ulm, Germany) performed a three-point bending test to measure metal ceramic bond strength. The load resulting in bond failure was recorded in Newtons (N), and bending strength (MPa) was calculated according to the following formula:

$$\sum = \frac{3PI}{2bd^2},$$

where P equals maximum force (N), I equals distance between the supports (mm), b equals width of the specimen (mm), d equals thickness of specimen (mm), and $\sum$ equals bond strength (MPa).[1,5,10-12] Data were statistically analyzed using three-way ANOVA, Tukey HSD, and *t*-test with significance level set at 0.05.

Results

Table 3 shows specimen bond strength values. Three-way ANOVA (Table 4) showed no significant difference in metal ceramic bond strength between Super Cast and Verabond base-metal alloys ($p = 0.239$); however, the percentage of recast base-metal alloys ($p = 0.006$) showed there was a significant difference in metal ceramic bond strength. The Tukey test results indicated a statistical relationship between different groups in this study (Table 5).

An adequate bond occurred when the fracture stress was above 25 MPa,[4] so the bond strengths in all groups were compared to 25 MPa by a *t*-test. VC2, VD1, and VE groups showed significantly lower bond strength than 25 MPa. The bond strengths of groups A1 and C1 were significantly higher than D1, but the bond strengths of groups A2, B2, C2, D2, and E2 were not significantly different.

Discussion

Base-metal alloys are used extensively in dentistry. Cast Ni-Cr and Co-Cr alloys are used in ceramic metal restorations. Ni-Cr alloys containing Be are still popular.[4] The attractiveness of these materials stems from their corrosion resistance, high strength and modulus of elasticity, low density, and low cost.[1,4] These alloys are harder than noble alloys but usually have lower yield strengths.[1,4] The physical properties of these alloys are controlled by the presence of minor alloying elements such as carbon, molybdenum, beryllium, tungsten, manganese, nitrogen, tantalum, gallium, and aluminum.[4] Many Ni-Cr alloy formulations contain up to 2% by weight of Fryllium. The major reason for incorporating this element in the alloy is to lower the melting range and to decrease the viscosity of the molten alloy, thereby improving its castability.[3] Some Ni-Cr alloys, especially those containing Be, have mold-filling abilities superior to all other groups. This mold-filling permits easier casting of thin sections and produces sharp margins on castings.[13] These base metal casting alloys are generally considered more technique sensitive and difficult to cast than noble casting alloys.[3] Allergic responses to the constituents of base metal alloys, especially Ni, are observed occasionally. High hardness complicates occlusal adjustment and polishing.[1]

Table 2 Specimen preparation, group A with 0.0%, B with 25%, C with 50%, D with 75%, and E with 100% once-cast metal alloy by weight. Number (1) represents the metal alloys veneered with Vita VMK 68 and (2) with Ceramco 3. (S) represents Super Cast and (V) Verabond.

	A	B	C	D	E
Super Cast (S) and Vita VMK68 (1)	AS1 N = 13	BS1 N = 13	CS1 N = 13	DS1 N = 13	ES1 N = 13
Super Cast (S) and Ceramco 3 (2)	AS2 N = 13	BS2 N = 13	CS2 N = 13	DS2 N = 13	ES2 N = 13
Verabond (V) and Vita VMK68 (1)	AV1 N = 13	BV1 N = 13	CV1 N = 13	DV1 N = 13	EV1 N = 13
Verabond (V) and Ceramco 3 (2)	AV2 N = 13	BV2 N = 13	CV2 N = 13	DV2 N = 13	EV2N = 13
Total	52	52	52	52	52

As an economic measure, excess gold alloys (buttons and sprues) have routinely been recast in combination with new metals to produce new castings. Although recasting of base-metal alloys is common, consistent results have been reported when adding new metal to previously used metal in the recasting of Co-Cr alloys. The results of this study showed that recasting the base-metal alloys had a negative effect on metal ceramic bond strength and that adding more than 50% recast alloy resulted in a significant decrease in bond strength. The formation of a strong bond between the opaque porcelain layer and the cast alloy is essential for the longevity of the metal ceramic restoration.[3] The bond between metal and ceramic is a result of chemisorption by diffusion between the surface oxides on the alloy and in the ceramic. These oxides are formed during wetting of the alloy by the ceramic and firing of the ceramic. Many factors control the ceramic-metal adhesion: the formation of strong chemical bonding, mechanical interlocking between two materials and residual stresses. In addition, the ceramic must wet and fuse to the surface to form a uniform interface with no voids.[4] Ucar and Zafar noted the importance of adherence of oxides on the formation of a strong bond between metal and porcelain.[14]

According to several studies, the main factor in decreasing the metal ceramic bond strength in base-metal alloys is the increased thickness of the oxide layer.[7,8,14–16] To control the oxide layer of Ni-Cr alloys, manufacturers add a few elements such as Al, Be, and Y to avoid Ni and Cr oxide layer growth.[4]

Table 3 Mean bond strength values (MPa) of specimens based on type of base metal alloys, type of porcelain, and percentage of recast base metal alloys

Alloy/recasting/ porcelain	Mean	N	Standard deviation	Minimum	Maximum
SA1	30.75	13	9.58	19.50	46.93
SB1	26.86	13	2.61	23.82	30.89
SC1	25.53	13	4.30	19.06	31.99
SD1	21.72	13	5.19	15.95	33.17
SE1	24.78	13	4.17	19.90	33.17
SA2	23.12	13	3.47	18.69	31.32
SB2	24.23	13	2.62	20.74	29.85
SC2	26.93	13	4.28	21.37	37.92
SD2	29.42	13	5.02	21.21	41.04
SE2	23.01	13	4.47	18.46	33.60
VA1	26.38	13	4.20	20.44	31.56
VB1	24.08	13	2.51	21.04	28.27
VC1	27.33	13	3.47	24.12	35.95
VD1	23.13	13	2.79	19.06	27.64
VE1	25.03	13	3.05	20.44	31.26
VA2	28.19	13	5.88	22.75	39.66
VB2	25.34	13	3.55	19.60	33.40
VC2	22.52	13	2.67	17.79	26.97
VD2	24.32	13	2.85	20.07	28.68
VE2	23.79	13	1.42	21.51	26.33
Total	25.32	260	4.70	15.95	46.93

Table 4 Three-way ANOVA results for ultimate bond strength

Source	Type III sum of squares	df	Mean square	F	*p*
Alloy	25.253	1	25.253	1.395	0.239
Recast	266.389	4	66.597	3.678	0.006
Ceramic	14.429	1	14.429	0.797	0.373
Alloy*recast	55.142	4	13.786	0.761	0.551
Alloy*ceramic	0.825	1	.825	0.046	0.831
Recast*ceramic	425.664	4	106.416	5.878	0.000
Alloy*recast*ceramic	602.069	4	150.517	8.314	0.000
Error	4345.213	240	18.105		
Total	1,72,532.529	260			
Corrected total	5734.985	259			

Table 5 Tukey test results. Only the groups with significant relationship with each other are presented

Comparison between groups	Mean difference	Significance
SA1,SA2	7.62	0.001
SA1,SB2	6.51	0.017
SA1,SD1	9.03	<0.001
SA1,SE2	7.73	0.001
SA1,VB1	6.67	0.012
SA1,VC2	8.22	<0.001
SA1,VD1	7.61	<0.001
SA1,VD2	6.43	0.021
SA1,VE2	6.95	0.007
SA2,SD2	−6.29	0.027
SD1,SD2	−7.7	0.001
SD1,VA2	−6.47	0.019
SD2,SE2	6.4	0.022
SD2,VC2	6.9	0.007
SD2,VD1	6.28	0.028

The process of remelting these alloys can decrease the Be, Al, and Y contents.[4,14] According to Juliano's study on recasting effects on bond strength, the quantity of $AlNi_3$ decreases on the surface of the alloy. There is a possibility that along with the decreased quantity of Al on the surface, the quantity of Be decreases due to recasting base-metal alloys.[17] The decreased surface of Be and Al in the recast alloys increases the thickness of the oxide layer and consequently decreases the strength of metal ceramic bond; so it seems that when the quantity of recast alloy is more than 50%, it has a negative effect on metal ceramic bond strength. Many tests have been used to determine the bond strength between ceramics and metals; however, the ideal test currently does not exist. One of the established bond strength tests is the planar shear test. Other commonly used tests are the flexural tests. The flexural tests require layers of ceramics to be bonded to a strip or plate of metal. The coated metal plate is flexed in a controlled manner until the ceramic fractures. In the three-point flexure test, ceramic is fired to one side of a rectangular strip of metal. The ceramic-metal strip is supported by two knife edges, and the specimen is loaded in the center with the ceramic surface down until failure occurs.[4] An adequate bond occurs when the fracture stress is above 25 MPa; however, with many metal ceramic systems, values of 40 to 60 MPa are common.[4] The American Dental Association Council on Dental Materials, Instruments and Equipment has recommended the three-point bending test for evaluating metal ceramic bond strength.[18] This test has the following advantages: simple and reproducible manufacturing of specimens, quantitative determination of the bond strength, testing of all possible metal/ceramic combinations, and use of a commercially available testing machine. In addition, both ISO 9693 and DIN draft 13,927 recommended the three-point bending test for evaluation of metal ceramic bond strength.[10,19] DIN draft 13,927 is to be used for alloys with a similar modulus of elasticity, such as in this study; however, for alloys with a different modulus of elasticity, other standards, in which the effect of modulus of elasticity on flexural strength is considered, such as ISO 9693, should be used. Of course, specimen dimensions in both standards are almost the same.[18] Ucar et al evaluated the effect of multiple castings on bonding of a single selected base metal and a dental ceramic; the results from two different tests used in this study for bond load evaluation were in agreement that a decrease in bond was observed as the number of recastings increased.[14]

Studies on the effect of recasting metal-based alloys on physical properties have also shown different results. Isaac and Bhat's study showed that recasting negatively affects the physical properties of base-metal alloys (modulus of elasticity),[8] whereas the results of studies by Nelson et al[6] and Hesby et al[7] showed that recasting the base-metal alloys had no effects on the physical properties.

According to Issac and Bhat's study, one possible cause of decreased strength of the metal ceramic bond can be decreased modulus of alloy elasticity. Since ceramic is fragile, it cannot match the deformation of the alloy, so it breaks at the weakest point, being the metal ceramic bond[8]; however, as long as strain or change in interatomic distance is less than 1%, the modulus of elasticity remains essentially constant. Extreme compression or extreme tension, respectively, raise or lower the modulus of elasticity.[20] Besides the change in elemental composition, the thermal expansion coefficient (CTE) of the dental alloy used is also altered after multiple castings. A match between CTE of the alloy and the dental ceramic is necessary for the longevity of the metal ceramic restoration. The change in CTE might also affect the bond between the dental alloy and the ceramic.[14] Additional research is needed to evaluate the changes in CTE and modulus of elasticity after recasting base-metal alloys.

The ceramic bond strengths in Vita and Ceramco were similar in this study, and similar to other studies.[21] In addition, the bond strengths of Super Cast and Verabond alloys were also similar in this study.

As both of these alloys included Ni-Cr-Be, and their compositions are alike, similar bond strengths could be expected. Although there has been no similar study comparing these two alloys, Huang et al showed that the trademark of Ni-Cr-Be alloys had no effect on the metal ceramic bond.[15] Most studies on the effect of recasting base-metal alloys and the rate of corrosion and cell toxicity have shown that using 50% recast alloy increases corrosion of the alloy and cell toxicity.[22-24] Moreover, the time and cost required to clean the button and sprue and remove the investment for reusing challenge the choice of recasting base-metal alloys.

Conclusions

Considering the limitations of this study the following conclusions were drawn:

1. Adding more than 50% of recast alloy significantly decreased the bond strength of the metal ceramic.
2. There was no significant difference in the bond strength of Super Cast and Verabond alloy with ceramic.
3. There was no significant difference in the bond strength of metal ceramic veneered with Vita porcelain and Ceramco.

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