A Comparative Assessment of Flexural Bond Strength of Ni–Cr Metal–Ceramic Alloy on Repeated Castings

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ABSTRACT

Aim: The present work is aimed to evaluate and compare the metal–ceramic bond strength and clinical feasibility of three commercially available Ni–Cr alloys with different compositions before and after recasting. The hypothesis of this experiment is to evaluate the effect of the recasting of base metal alloys in the physical and chemical properties of alloys, which in turn affect the metal–ceramic bond strength.

Materials and methods: In the present experiment, we considered 60 Ni–Cr metal samples, which were divided into group I and group II with every 30 samples. Group I consists of 30 samples fabricated with 100% new alloy, and group II consists of 30 samples fabricated with 100% recycled alloy. Groups I and II are further divided into three subgroups IA, IB, IC and IIA, IIB and IIC on the basis of three brands of Ni–Cr alloy as NDN as (A), soft alloy as (B) and superbond as (C) with each of 10 samples. Metal sprues and buttons obtained after casting of group I samples were used as a recast alloy for the fabrication of group II samples.

Results: The flexural bond strength of the fabricated metal–ceramic samples was subjected to three points bending test in a universal testing machine. The obtained values were statistically analyzed using one-way analysis of variance and *post hoc* Tukey analysis. The morphological studies are the stereomicroscopic examination of all the samples revealed alloy–metal oxide disjunction failure.

Conclusion: The mean flexural bond strength for all the groups was above the minimum requirement by American Dental Association (ADA) specification no. 38 and ISO specification 9693. The mean bond strength of group I samples is found to be greater than the group II samples. The soft alloy and superbond have the highest mean bonds when compared among the samples fabricated with 100% new alloy and 100% recycled alloy. Superbond and soft alloy are followed by former and later, and NDN is found to be least for both types. The soft alloy has more reduction in metal–ceramic bond strength in group II (samples fabricated with 100% recycled alloy) when compared to group I.

Keywords: Bond strength and feasibility, Ni–Cr alloys, Recycled alloys.

International Journal of Prosthodontics and Restorative Dentistry (2019); 10.5005/jp-journals-10019-1240

INTRODUCTION

Prosthetic dental reconstructions are always associated with a wide variety of materials such as noble and base metal alloys and ceramics.¹ Metallic restorations are studied for their valuable applications such as decreased tooth reduction, fracture resistance, adaptation, and polishing properties. The physical properties such as hardness, fracture toughness, stress, wear resistance, and the ability to polish the material are considered for a material used in the prosthetic dental reconstruction.^{2,3}

A number of alloys and metals are available for metal–ceramic use in dentistry. Each has its advantages and disadvantages, primarily based on its specific composition.⁴ Continuing research and development are resulting in the production of new technologies and products, giving clinicians even more choices in designing and fabricating metal–ceramic restorations.^{5,6} The restoration process is overviewed with certain minimum results like strength, stability, castability, corrosion/tarnish resistance, burnishability, polishability, and biocompatibility.⁴ Alloys gained importance and provided for a wide range of platforms for research due to the fluctuations in the price of conventional restoration metals like gold, platinum, and palladium.⁷ On the basis of composition, ADA classified the dental casting alloys into three high noble, noble, and predominantly base metal alloys.^{8–10}

For dental restorations, various elements are combined to produce alloys with adequate properties for dental applications because none of the elements by themselves have properties that are suitable.¹¹ The metallic elements that make up dental alloys can be divided into two major groups, the noble metals,

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How to cite this article: Jhansi R, Reddy AV, Prasad KS, *et al.* A Comparative Assessment of Flexural Bond Strength of Ni–Cr Metal–Ceramic Alloy on Repeated Castings. *Int J Prosthodont Restor Dent* 2019;9(3):70–76.

Source of support: Nil

Conflict of interest: None

and the base metals.¹² Nickel-based and cobalt-based are the two main categories of base-metal metal–ceramic alloy systems that exist. Base metal alloys are considered for their excellent physical properties as they exhibit the highest modulus of any alloy type used for cast restorations.¹¹

The base-metal alloys have been reported to have better castability than noble-metal alloys for metal–ceramic usage.¹³ The good physical and mechanical properties such as hardness and elastic modulus of Ni–Cr alloys made it useful as a thinner cross-sectional material, which provides more space for porcelain veneering for good resistance.¹⁴ Nickel plays a predominant role in the alloy for providing the ceramic–metal adherence.¹⁵ Chromium is used as the second largest constituent in the alloy because of its

corrosion resistance.¹⁶ It is also responsible for the formation of a superficial layer of extremely adherent oxide to the metal. Apart from the host material such as Ni and Cr, other elements such as molybdenum, beryllium, aluminum, titanium, silicon, and iron are present in a negligible amount for their various supporting physical and mechanical properties.¹⁷ The diffusion measurements have shown that principally Mo and F were found in the interaction zone. Molybdenum plays an important role in oxide formation and grain refinement and also promotes the formation of eutectic phases with nickel.¹⁸ Even though the usage of beryllium used for its casting and enhanced porcelain bonding in nickel-chromium-beryllium alloys, it is not recommended for health concerns associated with beryllium.¹⁹ Aluminum increases the metal-ceramic by suppressing the formation of thick chromium oxide and also enhances the tensile and yield strengths of the alloys. Silicon reduces the oxidation of the alloy and significantly improves the adherence of oxide.²⁰

Ni-Cr alloys have an adequate hardness in between 400 MPa and 1,000 MPa with an elevated modulus of elasticity and a linear coefficient of thermal expansion similar to ceramics. These alloys provide adequate resistance to corrosion and available at a low cost.²¹ These alloys are widely used in single crowns, partially fixed prostheses, and infrastructure for partial fixed prosthesis. The patient's hypersensitivity to nickel is the major disadvantage to the usage of these Ni-Cr alloys.²²

Dental ceramics present favorable properties like compressive strength and wear resistance, thermal conductivity, and optical similarity to dental tissues. They also offer advantageous properties such as radiopacity, marginal integrity, color stability, and biocompatibility.²³ In the present experiment, we used the feldspathic ceramic. Feldspathic were pioneer ceramics fabricated, by high fusion, they are composed of quartz, feldspar, and kaolin.¹⁸ They provide excellent esthetic properties, with adequate opacity and translucency obtained by alterations of the mixture components. They are currently widely used in extremely thin laminates during smile esthetic recovery, with this application, the underlying tooth reinforces the laminate.¹⁸

The present experiment aims to evaluate and compare the metal-ceramic bond strength of three commercially available Ni-Cr alloys with different compositions namely NDN as (A), soft alloy as (B), and superbond as (C) with each of 10 samples on repeated castings.

MATERIALS AND METHODS

Materials

Casting wax sheets, sprue wax, Begosol—mixing liquid (1,000 mL) and Dental Bellasun C and B high heat casting investment (phosphate) of 160 g were purchased from BEGO, Germany, and Ceramic Modeling fluid, VITA VMK Master, A2, Opaque and Dentine were purchased from VITA, Germany. Three commercial grades of 100% pure thirty Ni-Cr alloys of NDN type from Premier Dent International, India and beryllium free superbond and soft type, non-precious dental casting ceramic alloy were purchased from American Dent All Inc. (ADA-i). All the materials and chemicals/chemical reagents used in the present experiment are of analytical grade, which are above 99% purity and are used without any further purification.

Preparation of Samples

Sixty wax patterns each of the dimensions of 25 × 3 × 0.5 mm were cut from the BEGO pattern wax sheets, as per ISO specification 9693.²⁴

All the sixty metal samples were fabricated using the conventional lost-wax casting technique,²⁴ and the prepared wax patterns were spread using the sprue wax, as shown in Figure 1A. The sprue wax patterns were attached to the crucible former, and a casting ring is positioned, which is invested with phosphate bonded investment using standard W/P ratio as per manufacturers' recommendation as shown in Figure 1B. To burnout the wax the crucible former is placed in a burnout furnace at the temperature between 750°C and 1030°C for 1 hour, and the required mold was obtained. It was then placed into an induction-casting machine for the fabrication of Ni-Cr alloy specimens.²⁵

After the casting was completed, it was taken out of the induction-casting machine and allowed to cool. The castings were retrieved, by divesting and subjected to sandblasting using, 100 µm aluminum oxide (Al₂O₃). After sandblasting the sprues were cut with carborundum disc and the samples were finished with the finishing burs as shown in Figure 2.²⁴

Preparation of Metal Samples for Porcelain Application

The surfaces designated for veneering of the samples were sandblasted with 5 µm aluminum oxide (Al₂O₃) particles to create

Figs 1A and B: (A) Sprued wax patterns; (B) Casting ring placed on sprued wax patterns

Figs 2A to F: (A to C) Group IA, IB and IC—100% new alloys; (D to F) Group IIA, IIB and IIC—100% recycled alloys

a rough surface and cleaned in an ultrasonic cleaner. All the metal samples were degassed, which resulted in the formation of adherent oxide layer for better bonding with ceramic, and removes any presence of hydrides or impurities over the metal surface that interferes with metal-ceramic bond.²³

Porcelain Build-up

The castings were veneered by using the opaque and body ceramic (VITA VMK Master). The ceramic buildup was done as per the ISO 9693 specification²⁶ with dimensions of 8 mm in length, 3 mm in width, and 1 mm thick at the center of the metal strip.²⁵ To retain a uniform thickness of ceramic for the entire specimen's the ceramic application is finished in four layers of which one layer of opaque and three layers of dentin. After the application of each layer, conventional brush technique was pursued condensation of porcelain, and then the samples were placed in the ceramic firing machine (VITA Vaccumat 40T) and subjected to firing.²⁴

The obtained 60 metal samples, which were divided into group I and group II with every 30 samples. Group I consists of 30 samples fabricated with 100% new alloy, and group II consists of 30 samples fabricated with 100% recycled alloy. Groups I and II are further divided into three subgroups IA, IB, IC, and IIA, IIB, and IIC on the basis of three brands of Ni-Cr alloy as NDN as (A), soft alloy as (B) and superbond as (C) with each of 10 samples. Metal sprues and buttons obtained after casting of group I samples were used as a recast alloy for the fabrication of group II samples (Fig. 3).

Characterization

The bond strength of the fabricated metal-ceramic samples was calculated by subjecting the samples to the three-point bending test in a Dak System Inc., universal testing machine—series 7,200 as per the ISO 9693 standards.²⁷ Samples were supported by fixtures that were placed at a 20 mm distance and the ceramic part facing downwards and being deformed in a universal testing machine at a crosshead speed of 0.25 mm/minute. The minimum load at which the bond failure occurred was recorded in Newtons, and bond strength was calculated using the formula, performed on x in a universal testing machine as per the ISO 9693 52 and DIN draft 13,92,753 testing procedures. Samples were supported by fixtures

that were placed at a 20 mm distance and the ceramic part facing downwards and being deformed in a universal testing machine at a crosshead speed of 0.25 mm/minute. The statistical analysis was performed on ANOVA—short for “analysis of variance”—is a statistical technique for testing if 3(+) population means are all equal.²⁸

Flexural Bond Strength

The fabricated metal-ceramic samples were subjected to the three-point bending test in a universal testing machine as per the ISO 9693 and DIN draft 13,927 testing procedures. Samples were supported by fixtures that were placed at a 20 mm distance and the ceramic part facing downwards and being deformed in a universal testing machine at a crosshead speed of 0.25 mm/minute. The minimum load at which the bond failure occurred was recorded in Newtons and bond strength was calculated using the formula,²⁹

$$\Sigma = 3PI/2bd^2$$

where P equals maximum force (N), l equal distance between supports (mm), b equals the width of the specimen (mm), d equals the thickness of specimen (mm), and the results obtained were subjected to statistical analysis.

Statistical Analysis

The results obtained were tabulated and subjected to statistical analysis for assessment and comparison of flexural bond strength within the groups and in between the groups. Data were analyzed using IBM SPSS 23 version. Hypothesis testing uses statics to choose between hypothesis regarding whether data is statistically significant or occurred by chance alone. Descriptive for scale data, one-way ANOVAs with *post hoc* Tukey test. One-way ANOVA test is considered to be an effective analysis method to test the difference between the mean of two groups on a single variable. For each group of respondents, the N , the mean, the standard deviation, the standard error of the mean, confidence interval for the mean, the minimum value, and the maximum value are tabulated. ANOVA contains information about the ANOVA test comparing means both between and within groups and includes the sum of squares (a measure of variance), df (degrees of freedom), mean square, the F value, and the sig. value. However, the results of the ANOVA alone do not indicate which groups differ significantly. Thus, the multiple comparisons output which displays the results of the *post hoc* LSD test is necessary.

RESULTS

The maximum bond strength in each subgroup of group I samples is IA—40.342, IB—48.481, and IC—47.781, and the minimum bond strength recorded is IA—36.762, IB—45.182, and IC—42.212. Similarly, the maximum bond strength each subgroup of group II samples is IIA—37.556, IIB—38.712, and IIC—40.663, and the minimum bond strength recorded is IIA—32.773, IIB—33.218, and IIC—36.242. The detailed analyses of results were specified in discussion with the help of Figure 4.

The obtained values are tabulated, as shown in Table 1. The results showed a statistically significant difference between the flexural bond strength values of the three commercially available Ni-Cr alloys, which could be because of the differences in the elemental composition of Ni-Cr alloys resulting in the difference in

Figs 3A to F: (A to C) Metal-ceramic samples of group IA, IB and IC of 100% new alloys; (D to F) Group IIA, IIB and IIC of 100% recycled alloys

the oxide layer formed at the metal-ceramic interface. The results also show that recasting had a negative impact on metal-ceramic bond strength, which is in accordance with various studies.

In Figure 5A, the mean flexural strengths of group I (NDN, superbond, and soft) are shown on the upper X-axis with black color line and group II (NDN, superbond, and soft) are shown on lower X-axis with red color line. Figure 5B shows the minimum and maximum mean flexural bond strength from each subgroup.

One of the key tools for performing morphological studies on fractured parts are binocular stereomicroscope.^{30–33} From Figure 6 (A—soft alloy and B—superbond), it is clearly shown that stereomicroscopic examination of the group I (100% pure Ni-Cr alloy). From Figure 6 (C—superbond and D—soft alloy) group II (100% recycled Ni-Cr alloy) samples, were considered because superbond has the highest mean bond strength followed by soft alloy, and least for NDN, which revealed alloy-metal oxide disjunction failure.

DISCUSSION

In general, failure analysis includes examination of a fractured component in order to investigate the circumstances surrounding a failure event with the expectation of eventually elucidating the cause of failure. The failures may be the result of design deficiency, material deficiency, i.e., fabrication process, or the stress-induced conditions.³⁴

The flexural bond strength of group I, which consists of 30 samples which in turn divided into three subgroups as IA, IB and IC on the basis of three brands NDN, superbond and soft Ni-Cr alloy and group II, which consists of 30 samples (100% recycled) which in turn divided into three subgroups as IIA, IIB, and IIC on

the basis of three brands NDN, superbond, and soft Ni-Cr alloy are as shown in Figure 4. Figure 4 shows the flexural bond strength on the Y-axis and sample number on the X-axis of a total of 60 samples divided into group I (30 samples) and group II (30 samples), and each group is divided into a subgroup with 10 samples. Group I (100% pure alloys) with subgroups as IA (NDN), IB (soft alloy), and IC (superbond) represented with black, red, and green lines. Similarly, group II (100% recycled alloys) with IIA (NDN), IIB (soft alloy), and IIC (superbond) are represented with blue, sky-blue, and pink lines. All the bond strengths of sixty samples are recorded in between 32 MPa and 49 MPa.

Statistical analysis using one-way ANOVA and *post hoc* Tukey analysis showed a statistically significant difference ($p < 0.001$) in metal-ceramic bond strength values for the samples within the groups and in between the groups. Group I samples had more mean bond strength values than group II samples. Among group I samples, soft alloy has the highest mean bond strength followed by superbond and least for NDN. Among group II samples, superbond has the highest mean bond strength followed by soft alloy, and least for NDN. When compared between the groups, the soft alloy (Ni-Cr alloy) fused to ceramic has more reduction in metal-ceramic bond strength after 100% reuse of alloy.

The adherence between the ceramic and metal has been attributed to Van der Waals forces, mechanical bonding, chemical bonding by bonding oxides, and contracting forces by mismatch of coefficient of thermal expansion. The mechanical bond depends on surface roughness, dovetails, projections, and anchor points. The chemical bond is dictated by the oxide layer formed on the metal substrate that forms ionic, covalent, or metallic bonds with oxides in the ceramic opaque layer. Compressive bonding forces result from differences in the thermal expansion of the ceramic and metal substrate.

Failure analysis is of great relevance in material analysis for the dental industry today. The systematic documentation of the damage, as well as tests and investigation, is given prior importance. The flexural test impact on the specimens was studied by using the stereomicroscope, which is useful for the mapping and interpretation of the fracture surface. The present morphological study is intended to have an understanding of the failure process in Ni-Cr 100% pure and recycled alloys for dental restoration applications.²⁹ To have an enhanced spatial relationship and gross detection of crack features, the stereomicroscope analysis at low magnification with oblique lighting. These figures were considered because, among group I samples, soft alloy has the highest mean bond strength followed by superbond and least for NDN.

After bracket failure, the enamel surface was examined under optical magnification ($\times 10$), and the amount of adhesive remaining on the tooth was recorded using the adhesive remnant index (ARI).

Fig. 4: Flexural bond strength of group I (30 samples) and group II (30 samples) (NDN, superbond and soft Ni-Cr alloys)

Table 1: Mean measurements of flexural bond strength in various materials of group I and II

Material	Number of samples	Minimum	Maximum	Mean	Std. deviation	F value	p value
IA	10	36.762	40.342	38.99340	1.075438	68.94	<0.001 highly significant
IB	10	44.983	48.481	46.53800	1.266216		
IC	10	42.182	47.781	44.61250	1.981676		
IIA	10	32.733	37.556	35.95	1.45	9.41	<0.001 highly significant
IIB	10	33.218	38.712	35.40	1.83		
IIC	10	36.242	40.663	38.69	1.27

Figs 5A and B: (A) Mean flexural bond strength of group I and II (NDN, superbond and soft Ni-Cr alloys); (B) Maximum and minimum flexural bond strength from each group

Figs 6A to D: Stereomicroscopic images of: (A and B) Group I; (C and D) Group II

The criteria for ARI scoring were as follows: score 0—no adhesive left on the metal surface, score 1—less than half of adhesive left on the metal surface, score 2—more than half of adhesive left on the

metal surface, and score 3—all adhesive left on the metal surface.³⁵ The ARI of all the sixty samples, i.e., group I and II (NDN, superbond, and soft) Ni-Cr alloys are shown in Figure 7.

Fig. 7: Adhesive remnant index group I and II (NDN, superbond and soft Ni-Cr alloys)

CONCLUSION

The following conclusions were drawn from the results obtained and analyzed results.

- The mean flexural bond strength for all the groups was above the minimum requirement by ADA specification no. 38 and ISO specification 9693.
- Group I samples had more mean bond strength values than group II samples.
- Among samples fabricated with 100% new alloy, soft alloy has the highest mean bond strength followed by superbond, and least for NDN.
- Among samples fabricated with 100% recycled alloy, superbond has highest mean bond strength followed by soft alloy and least for NDN.
- The soft alloy has more reduction in metal-ceramic bond strength in group II (samples fabricated with 100% recycled alloy) when compared to group I.

ACKNOWLEDGMENTS

The authors are thankful to Dr Rohini Kumar, Scientist, Indian Institute of Chemical Technology (IICT), for providing the Universal Testing Machine and DIN testing apparatus. The St. Joseph Dental College is acknowledged for providing all the necessary equipment and environment for conducting the experiment.

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