

Effect of Opaque Porcelain Thickness Bond Strength of Porcelain to Ni-Cr Alloys

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Abstract

Objectives: Metal-ceramic restorations are the standard by which all esthetic restorations are measured. Fracture of dental restorations is a multifactorial problem, which is serious and costly. Debonding of porcelain from the metal substructure and the bond strength depend on many factors. The purpose of this study was to determine whether the opaque porcelain thickness has a significant effect on metal ceramic bond strength utilizing the ISO 9663 standard crack initiation test.

Methods: Thirty rectangular Ni-Cr metal bars (25×5×0.3mm) were fabricated according to ISO9663 standards. The metal bars were divided into three groups of 10. Opaque, body and enamel Noritake porcelain were applied on the middle of the bar according to ISO9663 standards up to 1mm porcelain thickness. The opaque porcelain thicknesses were 0.1, 0.2, and 0.3 mm, respectively in the three groups. The 3-point bending test was applied according to the ISO9663 standards and fracture strength (F_{fail}) was measured using a universal testing machine with a crosshead speed of 1.5mm/minute.

Results: Analyses of the data by one-way ANOVA demonstrated no significant differences in bond strength among the three experimental groups ($P=0.26$).

Conclusion: Within the limitations of this study, it is concluded that 0.1mm opaque porcelain provides sufficient bond strength between metal and ceramic in metal-ceramic restorations.

Key Words: Chromium Alloys, Dental Porcelain, Metal Ceramic Alloys

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Introduction:

Metal-ceramic restorations are the standard by which all esthetic restorations are measured and continue to be an optimal choice for an anterior fixed dental prosthesis with limited interarch distance (1). Moreover, they are the restorations of choice for short, inclined and structurally compromised teeth requiring auxiliary retention such as grooves, boxes or pins (2,3).

The metal-ceramic bond is critical for the functional and esthetic success of dental metal-ceramic restorations. Four factors contribute to the strength of metal-ceramic bond:

1. Chemical bond: dictated by the oxide layer formed on the metal substrate that

forms metallic, ionic, and covalent bonds with oxides in the ceramic opaque coating.

2. Mechanical interlocking: the ceramic physically engages the undercuts on the metal substrate surface.

3. Van der Waals forces: attraction based on molecular charges.

4. Compressive forces: which are based on the coefficient of thermal expansion (CTE) (4-7).

Chemical bonding and mechanical interlocking are believed to play the most prominent roles in the bond strength of ceramic to metal (4-7). Van der Waals forces are minor contributors to metal-ceramic bond strength (6). Compressive forces depend on the geometric design of a metal ceramic coping and can draw the veneering ceramic towards the metal upon

cooling after reaching fusion temperature (6).

There are three principal types of porcelain used in the fabrication of metal-ceramic restorations:

- 1- Opaque porcelain
- 2- Body porcelain
- 3- Enamel or incisal porcelain

Opaque porcelain contains a higher concentration of metal oxides than body or enamel porcelain (8,9). The metal oxides scatter and reflect light rather than transmitting it to the metal, thus masking the metal substructure and rendering a more esthetic restoration (1,8). Opaque porcelain also forms the metal-ceramic bond (7, 10-12).

Opaque porcelain is more abrasive than body and enamel porcelains (10). When the restorative space is limited, it is difficult to place metal, opaque and body porcelain in mechanically sound dimensions, and during subsequent clinical adjustment opaque dentin may become exposed, which leads to abrasion of the enamel of the opposing teeth. The abrasive potential is due to the high concentration of metal oxides and different vitrification temperatures, which make the porcelain surface rougher and render the metal ceramic restoration more abrasive against enamel (10, 13). Wear can result in shorter, narrower teeth and may be accompanied by supra eruption or alveolar growth and abrasion and can change the patient's occlusion (13).

The success and predictability of porcelain bond to gold-based alloys has been well documented (14). Precious metal/ceramic alloys have been challenged by manufacturers of numerous nonprecious alloys, who claim superior physical

properties for their products. Sed and Mclean found that all base metal alloy restorations break at the interface but do not break in the porcelain, as is typical for gold alloy restorations (15). Moffa and associates determined that the shear bond strength of two non-precious alloys fused to porcelain was between 13,500 and 13,900 Psi, which was comparable to the bond of a gold-ceramic system (16). McClean demonstrated that nickel and chromium oxide decreased the CTE of Vita porcelain, which might induce stresses and cause failure of non-precious metal-ceramic restorations (17).

Fracture of dental restorations is a multifactorial problem, which is serious and costly (18-20). Debonding of porcelain from metal substructure and the bond strength depend on many factors (18-20) including the alloy to be used, the thickness of oxide layer of the metal, alloy preparation before porcelain application (cleaning, oxidation and sandblasting procedures), porcelain thickness, the type of porcelain used, the number of firing cycles of the porcelain, the compatibility of the CTE of the porcelain and alloy and the firing temperatures (18-20). Among all these factors, we only evaluated the effect of opaque porcelain thickness on bond strength.

Caputo *et al.* (21) evaluated the effect of oxide layer thickness and concluded that this factor did not affect the bond strength of base metal alloys. Huang *et al.* (22) evaluated the effect of nickel and chromium percentages in base metal alloys and concluded that alloys with more aluminum and beryllium content yielded higher bond strength values. O'Connor *et al.* (23) indicated that beryllium percentage was an important factor affecting bond strength in

base metal alloys. Bezzon *et al.* (24) stated that 0.9% beryllium provided maximum bond strength. De Vasconcellous *et al.* (25) concluded that increasing the firing temperature of opaque porcelain increased the bond strength.

Several mechanical tests have been described in the dental literature for determining the debonding strength/crack initiation strength at the metal-porcelain interface, including 3-point and 4-point flexural strength tests and shear tests (10, 26, 27). However, it was the Schwickerath test, first proposed by Lenz *et al.*, (26) that promulgated ISO 9693: 1999(E) (28) for determining the debonding strength/crack initiation strength of metal-ceramic materials used in dental restorations.

Metal-ceramic restorations pass ISO 9693 when at least four out of six specimens have a debonding strength exceeding 25 MPa (28). Due to the abundance of various testing methodologies, which has limited the ability of investigators to compare the results of different metal-ceramic bond strength studies, the International Organization for Standardization standardized metal-ceramic bond strength testing through the Schwickerath crack-initiation test, a three-point bending test (ISO/FDIS 9693: 1999) (28).

There are no clear references about the optimal thickness of opaque porcelain in the range of 0.1 to 0.3 mm. It is obvious that if we have a thinner layer of opaque porcelain, we will have more space for body and enamel porcelain, and more esthetic results can be achieved especially in cases with limited interarch space.

Two questions remain to be answered:

1-Does a thinner porcelain layer mask the color of the metal?

2-Does a thinner porcelain layer provide a sufficient bond between Ni-Cr metal alloy and Noritake porcelain?

The purpose of this study was to determine whether the opaque porcelain thickness has a significant effect on metal-ceramic bond strength based on the ISO 9663 standard crack initiation test.

Methods

ISO 9693:1999(E) for metal-ceramic dental restorative systems specifies procedures for characterizing the debonding strength of metal-ceramic dental restorations (28). Figure 1 shows the dimensions of specimens used in this study according to the ISO9663 standards. In this *in vitro* experimental study, according to the similar studies (23-28), 30 rectangular non-precious metal bars were cast. To fabricate the cast metal bars, wax patterns were made using 22-gauge casting wax sheets (Azarteb, Tehran Iran) that were cut into 22.5mm × 3.5mm × 0.6mm flat strips. The patterns were sprued (Figure 2) and invested with phosphate bonded investment material (Degovast, Degussa, Zurich, Germany) mixed under vacuum for one minute. After one hour setting time, the specimens were placed at room temperature burnout oven (KFP, Tehran, Iran) and gradually heated to 900°C.

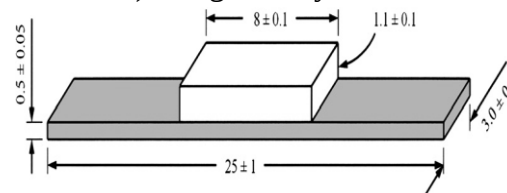


Figure 1 – The schematic view of the metal bar and porcelain dimensions according to the ISO9663; 1999 (E) standards



Figure 2 – The wax model of metal bars before casting

After burnout for 90 minutes, the specimens were cast with a natural gas and oxygen blowpipe in a centrifugal casting machine (KFP, Tehran, Iran). All specimens were cast with Sankin dental alloy (Dentsply, Sankin, Tokyo, Japan), which is a base metal Ni-Cr alloy for metal ceramic fixed partial denture. The composition of the alloy is presented in Table 1. Castings were allowed to cool at room temperature. After investment and cleaning with 50µm aluminum oxide particles under 60 Psi pressure (Bego, Bremen, Germany), the specimens were divided into three groups of 10. All metal bars were adjusted to 25mm × 3mm × 0.5mm dimensions using aluminum oxide barrel stones (Shofu Dental Corp., San Marino, CA, USA) and a laboratory handpiece (NSK, Fukuoka-Ken, Japan). Dimensions were verified with a Boley gauge (Dentaurum, Berlin Germany). All metal bars were ultrasonically cleaned in distilled water for 10 minutes. Porcelain areas were marked lightly with #11 surgical scalpel (Ehsanteb, Tehran, Iran). Two lines perpendicular to the long axis of each bar were drawn with 8.5mm distance from each other and 4.25mm distance from the center of the bar.

Table 1- The composition of Dentsply Sankin Nickel chromium dental alloy

The element	Percentage in alloy
Ni	72.8%
Cr	4.9%
Cu	12.3%
Other	10%

A ceramic furnace was calibrated according to the manufacturer's recommendations. Each bar underwent cleaning with distilled water, oxidation, and air-borne particle abrasion using 50µm aluminum oxide particles at 60Psi pressure. In the first group, the thickness of applied opaque porcelain was designed to be 0.1mm. The second group was designed to have 0.2mm and the third group 0.3mm opaque porcelain thickness. The opaque porcelain (Noritake, Tokyo, Kuraray Co., Japan) was added to each bar according to the manufacturer's instructions. All adjustments were made with sandpaper (Abzar, Tehran, Iran) and verified with a Boley gauge (Dentaurum, Berlin, Germany) with 0.1mm accuracy and a wrench caliper (Mitutoyo, Kawasaki Japan) with 0.05mm accuracy. After adjusting and verifying the opaque porcelain thickness, the body and enamel (incisal) porcelains were applied (Figure 3). The final thickness of porcelain was 1mm. The dimensions were adjusted according to the dimensions prescribed by ISO 9663 standards. Again, verifications were done with a Boley gauge and wrench.



Figure 3 – Metal bar after porcelain application

Metal ceramic debonding strengths were determined according to ISO 9663 standards by 3-point bending test (28). The ceramic specimens were placed symmetrically on the opposite side of the load application and equidistant between the two specimen supports laying 20.0 mm from each other (Figure 4). The force was applied via a symmetrically aligned bending piston at a

crosshead speed of 1.5 mm/minute in a universal testing machine (Zwick Roell, Ulm, Germany) (Figure 5). Fracture load (F_{fail}) was recorded in Newtons and debonding/crack initiation strengths (D/CIS) were calculated via the formula $\tau_b = K \times F_{fail}$ where τ_b was the debonding strength/crack initiation reported in Megapascals (MPa). K is a constant, which is a function of the thickness of the metal specimens and their elastic modulus. It is determined from a table in ISO 9663; 1999(E) and is reported in MPa/N. F_{fail} is the load at failure which is determined by a universal testing machine and is reported in Newtons.



Figure 4 – The specimen's holder in universal testing machine with pillars 20.0mm from each other



Figure 5 – Specimens in universal testing machine (Zwick machine) with a crosshead speed of 1.5mm/min

The τ_b among the three groups was analyzed using one-way ANOVA. The data were

tested with Shapiro-Wilk test for normal distribution of the data. Homogeneity of variance was tested with Levene's test.

Result

The mean τ_b values measured in MPa along with the standard deviation values are shown in Table 2 and Figure 6. The mean bond strength was higher in group 2 (27.07 ± 1.26 Mpa) than the two other groups; the two other groups had no significant difference in this regard. However, the standard deviation was higher for group 3 (26.72 ± 1.16) in comparison with group 1 (26.72 ± 0.7). All bond strength values were higher than the minimum clinically acceptable value according to the ISO 9616. The data were tested with Shapiro-Wilk test for normal distribution. Homogeneity of variance was tested with the Levene's test. As all data had normal distribution and were homogenous, ANOVA was used for determining the possible significant differences among the groups. Analyses of the raw data with one-way ANOVA demonstrated no significant differences among the three experimental groups ($P=0.26$).

The thickness of opaque layer did not significantly affect the debonding strength of the Noritake porcelain applied on the Sankin Ni-Cr dental alloy.

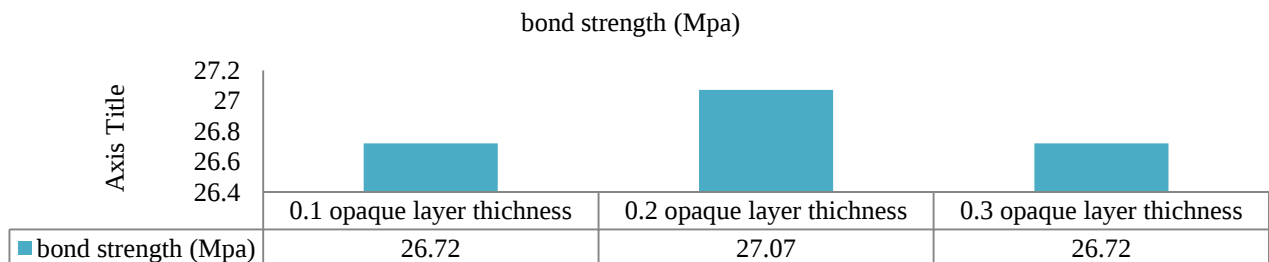


Figure 6- the result of the bond strength according to the opaque porcelain thickness

Table 2- Results

Group	Opaque thickness	N	Mean τ_b (MPa)	Standard deviation	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
G1	0.1mm	10	26.72	0.70	26.22	27.22
G2	0.2mm	10	27.07	1.26	26.17	27.97
G3	0.3mm	10	26.72	1.16	25.88	27.56

Discussion

The purpose of this study was to determine the effect of opaque porcelain thickness on bond strength of porcelain to Ni-Cr alloys and compare the metal-ceramic bond with 0.1, 0.2 and 0.3mm opaque porcelain layer thicknesses. Our results showed that the thickness of opaque porcelain layer had no significant effect on the metal-ceramic bond strength. All measured bond strength values exceeded 25MPa, and therefore passed the ISO9663; 1999(E) standards (28). The ISO qualification requires at least four experimental specimens having a 25MPa bond strength (18).

It is unclear from the ISO9663 and previous research that what load point corresponding to the initial debonding of a metal ceramic system should be used (29). Such debonding strengths can be determined. Wood *et al.* (29) reported that maximum recorded load did not correspond to the initial metal ceramic debonding but rather to the delamination of the metal and ceramic.

In the dental literature, there is no distinct discussion about the opaque layer thickness. The opaque layer provides the bond between metal and ceramic and masks the metal color. In some literature, it is recommended to use 0.2mm or 0.3mm thick opaque layer (1,2,4,5). We evaluated the effect of opaque porcelain thicknesses on the bond strength to assess the possibility to use thinner layers of

porcelain especially in cases where limited vertical space is an issue.

Wood *et al.* (29) reported that debonding/crack initiation strength generally improved by the use of an opaque layer. They measured the bond strength with and without opaque porcelain and concluded that opaque porcelain increased the bond strength. They did not manage the limitation of vertical space in cases with limited interocclusal space and short clinical crowns. Thus, it is reasonable to use 0.1mm of opaque dentin in order to obtain stronger bond and manage the limitation of vertical space.

Jorn *et al.* (30) reported that porcelain fractures occurred within the opaque layer and did not correlate with the porcelain application technique. Thus, it is reasonable to reduce the thickness of opaque porcelain. Barghi and Lorenzana (31) stated that a minimum of 0.3mm of opaque layer is essential to mask the color of the metal. They evaluated different alloys and porcelain. We did not evaluate the color, although in all samples the metal color was masked well visually. Therefore, the differences may be attributed to the alloy type and porcelain type. In situations of limited space, it is recommended to use alloys with a lighter color that can be masked with a thinner layer of opaque porcelain. Barghi and Lorenzana (31) demonstrated that 0.2mm opaque layer was sufficient for Ceramco porcelain, but 0.3mm

opaque thickness was necessarily required for Vita porcelain.

Crispin *et al.* (32) evaluated the correlation of different alloys with the required thickness of opaque to mask the metallic color of the alloy and stated that in some alloys such as Ag-Pd a greater thickness of opaque was required to gain esthetic results. Since most other studies in the literature were done before the ISO standards were developed, it is difficult to relate the findings to other investigations.

We only evaluated the bond strength of one type of ceramic to one type of alloy. As our results supported the use of 0.1mm opaque porcelain thickness, it is recommended to test other alloys and ceramics. Also, it is

recommended to evaluate the masking capacity of 0.1mm opaque dentin in different alloys as well as the mode of failure.

Conclusion

Within the limitations of this study, it is concluded that 0.1mm opaque porcelain thickness provides sufficient bond strength between Sankin Ni-Cr metal alloy and Noritake ceramic in metal-ceramic restorations.

Conflict of Interest: “None Declared”

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