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Shear bond strength of feldspathic porcelain in metal ceramic crowns and failure mode after multiple firing cycles (*In-vitro* Study)

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Abstract
Purpose: To investigate the effect of multiple firing cycles on shear bond strength and failure mode of porcelain fused to metal.
Materials and Methods: thirty porcelain fused to metal discs were divided into three groups according to number of firing cycles subjected to; group A; three firing cycles, group B; five firing cycles and group C; seven firing cycles to sinter the porcelain. All the specimens were labeled and stored in distilled water for 48 hours before testing. Shearing test was done by compressive load applied using a chisel shaped metallic rod attached to the upper movable compartment of testing machine traveling at cross-head speed of 1 mm/ min. Fractured specimens were ultrasonically cleaned, carefully checked. All failures mode were analyzed.
Results: The test results showed a statistically significant difference in the mean shear stress averages among the three studied groups (p <0.05) where the first group had 56.90 MPa. The second group is 51.69 MPa, while the third group is 43.54 MPa (Mega Pascal).
Conclusion: Repeated firing cycles up to seven cycles had significant effect on shear bond strength of porcelain fused to metal. Regarding failure mode; all samples had mixed (cohesive adhesive) failure.

Keywords: Shear bond strength, firing cycles, porcelain and metal

1. Introduction

Metal ceramic restorations (MCR) has been considered the golden standard for prosthetic dentistry for the past 40 years [1]. This maybe due to their optimum mechanical properties and fair esthetic qualities, alongside with a clinically satisfactory marginal and internal adaptation [2]. Its bilayered configuration made it to be considered as hybrid restoration, composed of two materials; metal coping and ceramic veneer. In spite of the increase in the use of all-ceramic restorations (ACR), MCR continued to be used due to their low clinical failure (5-year cumulative failure of 4.4%), compared to 6.7% if all ceramic restorations [3]. Moreover MCRs are still indicated where ACR can not function; as in case of increased occlusal load, limited inter-arch space (which limits the thickness of the connectors) [4], increased span length and full-arch Prosthesis. Although manufacturers routinely advertise all-ceramic systems as a viable option for anterior and posterior Fixed Partial Dentures (FPDs). True, there are few clinical studies to support these claims [5]. Karlsson [6] revealed a 93% success rate in a 10-year period, while Palmqvist and Swartz [7] reported a 79% success rate over an 18- 23-year period. In a review of FPDs failures on the past 50 years, Goodacre, *et al*. [8] found that the porcelain fracture was the main factor for failure. The decrease in FPD survival rate after 10 years may be a result of material fatigue and/or a combination of biologic and biomechanical factors [9].
Veneer chipping or fracture is one of the most disagreeable esthetic failure and may be attributed to many factors; increased thickness of veneer, sharp metal angles (10), high occlusal contacts, bending of FPD. To achieve perfected contour, color, and esthetics qualities, multiple firing cycles may be necessary for the construction of MCRs, especially when using the standard layering technique to reach optimum esthetics. The adhesion mechanism between metal and porcelain is believed to be the micro-mechanical bond, compatible coefficient of thermal expansion (CTE) match, van der Waals force, and mainly the suitable oxidation of Metal and inter-diffusion of ions between the metal and porcelain [11], Data presented in literature has shown the bond strength of ceramic to metal substrates to be in the range of 54 -

71 MPa, and a sufficient bond for metal-ceramic has been accepted when the fracture stress is greater than 25 MPa [12]. Residual stresses can likely accumulate during the heating and cooling firing procedures, mainly because of the cooling rate and the CTE mismatch between core and veneer materials. When additional stresses are applied to the restoration, the probability of failure due to fatigue crack propagation might increase, explaining the veneer chipping or fracture. Till now, the effect of multiple firing cycles on the porcelain–metal adhesion remains unclear. The hypothesis of this study is that; the increase in firing cycles might decrease SBS between metal core and veneer.

2. Materials and Methods

The research sample consisted of 30 cylindrical disks with a diameter of 8 mm and a thickness of 3 mm, which were made of metal alloy Nickel-chromium (Kera NH), applied to the top surface of each metal disc a layer of feldspar porcelain (IPS Classic, Ivoclar vivadent) 8 mm in diameter (analogous to the metallic disc diameter) 2 mm thick and in A3 color (making up 65% of the clinical color choices among Color groups] [13], the research sample was divided into three main equal groups N = 10 according to the number of firing cycles: group A; three firing cycles, group B; five firing cycles and group C; seven firing cycles.

2.1 Preparation of cast specimens

A metal die was prepared according to the sample dimensions (cylindrical disc, 8mm in diameter; and 3mm in thickness and its silicone index (Polyvinyl siloxane, Dentsply) was used to standardize the waxed parts for formation of the metallic aspect of the specimen. Thirty wax molds were made using inlay wax (Bego, Germany) and invested in a phosphate bonded investment material (Bellasun, Bego). Casting was done using centrifugal casting machine (OKAY PLUS, Galoni, Italy), through the lost wax casting technique, to obtain thirty correspondent metallic portion of the specimens (Figure 1). Metal surface treatment was performed by oxidation, sandblasting with aluminum oxide (250μ) under 2-bar pressure for 10 seconds (Shera, Leuforde, Germany) (Figure 2), and then oxidation again.

The specimens were cleaned with tap water, isopropyl alcohol and then allowed to dry for 10 minutes.

2.2 Veneering procedure

Two thin layers of opaque porcelain powder (Ips Classic-Ivoclar Vivadent) in a paste/liquid mix were applied on the metal specimens using a brush and fired according to the manufacturer's instructions (Vita Vacumat 40) (Figure 3).

Dentin porcelain was condensed to a height of 2mm in a slightly oversized silicone putty index to compensate for the contraction generated during the first firing cycle and submitted to dentin firing to achieve the final dimensions of the samples. The specimens were randomly divided into three subgroups and subjected to repeatedfirings as per manufacturers' instructions (Figure 4)

Fig 1: metal discs after

Fig 2: metal discs after grit-blasting the specimens with aluminum oxide (250μ).

Fig 3: metal discs after placement of opaque layer.

Fig 4: samples are ready for Shear bond strength testing

2.3 Shear bond strength test

Shearing test was done by compressive load applied using a chisel shaped metallic rod attached to the upper movable compartment of testing machine traveling at cross-head speed of *1* mm/min. The load required for debonding was recorded in Newton (N).

2.4 Shear bond strength calculation

The load at failure was divided by bonding area to express the bond strength in MPa: (τ = P/ πr2) where; τ =shear bond strength (MPa, P =load at failure (N) π =3.14 and r =radius of veneer disc (mm).

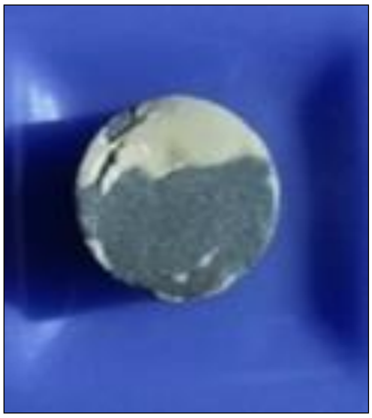

Fig 5: Fractured sample

3. Results

The mean and standard deviation values between groups, are summarized in Table (1). The highest mean value was observed in group A (56.9 MPa) and the lowest mean value was observed for group C (43.54 MPa). Statistical analysis revealed significant difference between groups ($P < 0.05$). Statistical analysis among groups showed significant differences as well. (Table 2). Regarding mode of failure; 100% of the samples showed mixed failure mode

Table 1: The mean and standard deviation values between groups

	Mean	Standard Deviation
Group A	56.90	4.16
Group B	51.69	1.91
Group C	43.54	2.30

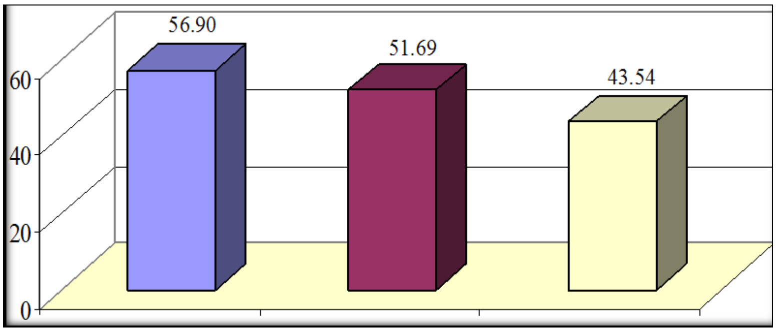

Chart 1: Mean values among groups.

Table 2: P value among groups

(I)	(J)	difference between two mediums	significance level	significance of differences
Group A	Group B	5.21	0.000	There are significant differences
	Group C	13.35	0.000	There are significant differences
Group B	Group C	8.14	0.000	There are significant differences

4. Discussion

The MCR is a combination of both ceramic and metal materials, combines the esthetic of porcelain and the strength and precise fit of the metal [14]. So, how these two dissimilar materials bond together to function as a useful composite in dentistry? According to Wagner, there are three main factors that determine the success of the ceramic-metal bond: residual stresses, interfacial chemistry, and interfacial morphology [15]. These three factors are interdependent and are difficult to evaluate individually [16].

Every material has a coefficient of thermal expansion. The coefficient of thermal expansion (CTE) is defined as the fractional increase in length per unit rise in temperature. It is generally considered the alloy should have a higher CTE than the ceramic (termed positive coefficient mismatch) to produce axial compressive stress in the porcelain after cooling to room temperature. Since dental ceramics are much stronger under compression than tension, this residual compressive stress can effectively increase the bond strength [17].

This thermal compatibility of the metal-ceramic pair could play a significant role in bond strength because it constitutes the main physical requirement to avoid stress at the interface [18]. The CTEs of the metal and ceramics must be compatible in order to avoid stress [19]. The recommended mean difference between alloy and ceramics CTEs (from room temperature to 600oC) is from 0.5 to 1.0 10^{-6} $°C^{-1}$ [20].

The success of a metal-ceramic restoration depends primarily on strong adhesion between the porcelain and alloy. Many methods have been proposed to quantify such adhesion, but none is completely exempt from errors, due to the complexity of the ceramic/metal bonding [21].

Several authors in the literature suggested the use of shear bond strength test [22, 23], and considered it as one of the most reliable methods to evaluate the bond strength because it concentrates the applied tension on the interface between two materials. Bonding between porcelain and metal is possible by means of three mechanisms: Van der Waals' forces, mechanical retentions and chemical bonding according [24]. Several studies demonstrated that preparation of the alloy surface resulted in an increase in bond strength between metal and porcelain surfaces. In this study mechanical retention, it was used through sandblasting with $Al2O3$ (250µm) as a metal surface treatment. Multiple firing procedures are essential to achieve better contour, color, and esthetics although there is no scientific data on the precise number of firing cycles to achieve a perfect ceramic restoration [25]. In the present study, there was statistically significant difference between firing cycles for bond strength values. The result came in accordance with Mackert, *et al*., who observed shear bond strength statistical difference after repeated firing [26]. Other studies [22, 27, 28]. Using the shear test with different methods and other types of alloys, reported results varying from 15 MPa to 60 MPa. The variation of the results in the studies is high, due mainly to the inexistence of a universal methodology for evaluation of bond strength of the porcelain fused to metal substrate. As a relief, literature have described that shear bond strength mean greater than 10MPa indicate clinically satisfactory results [22, 28]. The results of this study ranged from 43, 54-56,90 MPa; within the safety borders.

Results of this study showed 100% mixed failure mode presenting unfavorable failure mode. As this failure mode clinically needs opaque composite and may be difficult to be optimally repair.

5. Conclusion

Within the limitation of the study, it could be concluded that; the bond strength of metal ceramic restorations is affected by repeated firing cycles, as it decreases with the increase in the number of firing cycles and its exposure to heat.

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