ORIGINAL RESEARCH

A Comparative Evaluation of Shear Bond Strength of Layered Veneering and Heat-pressed Porcelain to Laser-sintered Cobalt–Chromium Alloy: An *in vitro* Study

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ABSTRACT

Aim: To evaluate and compare the shear bond strength of layered veneering porcelain and heat-pressed porcelain to laser-sintered cobalt–chromium alloy.

Materials and methods: Thirty disks of laser-sintered Co-Cr alloy of dimensions 10 × 4 mm were made and divided into two groups, I and II (n = 15). Metal alloy samples were veneered with porcelain to produce shear bond test samples: group I with conventionally layered porcelain (Ivoclar Vivadent IPS Inline) and group II with pressable porcelain (Ivoclar Vivadent IPS POM). The veneering porcelain, 4 mm in thickness, was either layered or pressed to its corresponding metal alloy samples. Firing of porcelains was carried out in particular furnaces for groups I and II. Shear bond strength testing was conducted in a universal testing machine, and the failure strengths were recorded. Fracture surfaces were characterized visually, under a stereomicroscope. For normality of data, Kolmogorov–Smirnov and Shapiro–Wilk tests were used and Levene's test for equality of variances and t-test for equality of means were also used. Frequencies of shear bond strengths were plotted using histogram and bar diagram.

Results: For group I samples, the mean (standard deviation) shear bond strength was 45.25 MPa and for group II, it was 60.11 MPa. There was a significant difference between groups I and II. Group II had a significantly higher shear bond strength value than group I (p = 0.012). For all shear bond strength testing samples in group I, cohesive, adhesive, and mixed failures were observed, and in group II, mostly adhesive and few mixed were observed.

Conclusion: Shear bond strength of heat-pressed porcelain to laser-sintered Co-Cr alloy was higher than shear bond strength of layered veneering porcelain to laser-sintered Co-Cr alloy.

Keywords: Cobalt–chromium, Computer-aided design/computer-aided manufacturing, Direct metal laser sintering, Porcelain fused to metal.

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INTRODUCTION

Replacement of missing teeth has been a desire of people since thousands of years. Teeth were fabricated from ivory, wood, sea shells, stones, and metals in the past years. With the evolution and introduction of metals in dentistry in 19th century, the gold alloys became popular for restorations. Restorations commonly fabricated for fixed partial dentures may be fabricated in dental laboratory using lost wax technique introduced by Taggart in 1907.[1] Metal alloys have been extensively used as substructures of metal porcelain restorations ranging from single crown to long-span fixed dental prosthesis.[2] Initially gold alloys were selected because of their biocompatibility and ease of use. After the 1960s with gold prices increasing substantially, manufacturers focused on less expensive alternative alloys, such as gold–silver–palladium and palladium–silver alloys with small percentage of indium. But, the main disadvantage with these alloys was lack of adaptability with different ceramic systems.[3] Carr and Brantley[4] demonstrated that liquid palladium can absorb an excessive amount of gas which then can be released during casting and lead to numerous microporosities. So, base metal alloys as an alternative to them, such as nickel–chromium and cobalt–chromium alloys, are being used because of their lower cost.[4] Base metal alloys allow the fabrication of thinner substructure because they have greater rigidity which is related to modulus of elasticity; they are economical. In addition, due to their high hardness grinding of cast base metal alloys, to finish castings is time consuming in dental laboratories.[5] Mackert and Rake[4] demonstrated high bond strength values in a gold–palladium alloy with an intact oxide layer when compared with a nickel–chromium base metal alloy. There is a current trend for replacing the Ni-Cr alloys with Co-Cr alloys, because Ni-Cr alloys contain toxic materials, such as nickel and beryllium which could cause allergy. Co-Cr alloys do not contain such materials and therefore, are more biocompatible and safe for use.[6] Nevertheless, the success of metal porcelain restorations depends primarily on optimal bond strength of porcelain

to metal substructures. There should be chemical and thermal compatibility between the metal and porcelain to allow adhesion of interface during porcelain sintering and also when the restoration is in service.[7] A difference in the coefficient of thermal expansion between the metal and porcelain can result in shear stresses at the interface and lead to an ultimate failure of the metal–ceramic bond. The melting range, however, should be greater for metal alloys to allow firing and glazing of the porcelain.[4]

In efforts to overcome the limitations of lost wax method, computer-aided design/computer-aided manufacturing (CAD/CAM) system has been introduced with various ways to produce dental prosthesis. The newly developed direct metal laser sintering (DMLS) system is an additive metal fabrication technology, based on information received from three-dimensional CAD, in which metal alloy powder is selectively fused with a laser to laminate approximately a 20 to 60 μm thick layer with each shooting to complete a designed metal structure.[5] Advantages of the DMLS system include easy fabrication of complicated shapes, operation of an automatic system and short working time due to elimination of the procedures of fabricating a wax pattern, investing, burnout, and casting works. While the traditional lost wax casting method might waste time in spruing and other procedures, the DMLS system could reduce metal waste by selectively shooting the required amount to form restorations. However, the DMLS system requires a special equipment.[5-8]

Layering is the traditional and principal technique of veneering in which layer is usually overbuilt to compensate for condensation and firing shrinkage. Overall, this technique requires skill and multiple applications and firings.[2] An alternative technique is to press porcelain to the core materials, thereby reproducing the anatomy created in the wax and allowing for the creation of the desired tooth anatomy. Although the pressing technique is not a new technology, a process for pressing porcelain to metal cores using lost wax technique and glass–porcelain ingots has been recently developed.[2] Various tests have been designed and selected by researchers to evaluate metal–ceramic bond strengths. These tests can be classified according to the nature of stresses created, such as shear, tension, combination of shear and tension, flexure, and torsion test designs.[6] Shear strength is the maximum stress that a material can withstand before failure in a shear mode of loading, which can be valuable in the study of interfaces between materials.[2]

A number of studies have been carried out for the shear bond testing of various types of porcelains to different core metal alloys. But the technique of porcelain veneering to laser-sintered base metal alloy substructure has not been studied. So, this study was carried out to evaluate the shear bond strength of pressed and layered porcelains to the corresponding laser-sintered Co-Cr alloys and to decide which method of porcelain veneering will have a better bonding for the longevity of the restoration.

MATERIALS AND METHODS

For preparation of laser-sintered Co-Cr disk samples, a circular sample disk of diameter 10 mm and thickness 4 mm was fabricated with self-cure acrylic resin. The disk was scanned with three-dimensional optical scanner (3M ESPE, USA), and subsequent disks were prepared by rapid prototyping technology with a special machine (EOSINT M 270).[9]

After scanning the disk, computerized 30 images with stereolithographic files were created, which was processed with the dedicated software, DWOS Lava™ and this information was transferred to DMLS software where it was then sliced into layers with chosen thickness of 30 μm. The EOSINT M 270[9] machine processed this information for 6 to 7 hours to form desired shape and number of samples. The samples attached to metal building platform of laser-sintered machine were cut and finished with metal finishing kit. As such, 30 laser-sintered Co-Cr metal disks (Fig. 1) of desired dimensions were prepared.

These 15 samples were airborne-particle abraded with aluminum oxide (100 mm) for 15 seconds at a 10 cm distance, 4 to 6 bar pressure, and at 45° approximate angulation.[10,11] The samples were cleaned with distilled water, kept in a digital ultrasonic cleaner (BEGO). Initial oxidation step was performed on the Co-Cr alloy samples before application of the opaque porcelain. Wash and shade opaque pastes were mixed with modeling liquid on a glass slab with carver, and two thin layers were applied individually on metal samples with brush and subjected to firing in Vacumat 40 Porcelain Furnace (Germany).[11] After this, feldspathic porcelain (Ivoclar Vivadent; IPS Inline) was applied on the metal samples. Each metal sample was placed within the hole of a custom-fabricated

Fig. 1: Samples of laser-sintered Co-Cr disks

Table 1: Different porcelain firing cycles in vacumat 40 T[20]

Steps of firing (↓)	Program no.	Predrying	min	min	min	Temp. approx		VAC min
Wash opaque firing (powder)	26	600	2.00	4.00	88	950	1.00	4.00
Wash opaque firing (paste)	27	500	6.00	6.00	75	950	1.00	6.00
Opaque firing (powder)	28	600	2.00	4.00	83	930	1.00	4.00
Opaque firing (paste)	29	500	6.00	6.00	72	930	1.00	6.00
Margin porcelain firing	30	600	6.00	6.00	55	930	1.00	6.00
1st dentin firing	34	600	6.00	6.00	55	930	1.00	6.00
2nd dentin firing	32	600	6.00	6.00	55	930	1.00	6.00
3rd dentin firing	33	600	6.00	6.00	53	920	1.00	6.00
Correction firing	34	600	4.00	6.00	50	900	1.00	–
Glaze firing	35	600	0.00	4.00	83	930	1.00	–
Glaze firing with stain 1	36	600	4.00	4.00	83	930	1.00	–
Glaze firing with stain 2	38	600	4.00	4.00	75	900	1.00	–

jig, which allowed the building and condensation of porcelain to a height of 4 mm and diameter 10 mm, resulting in uniform metal–porcelain sample dimensions. After condensation was completed, the metal–porcelain structure was carefully removed and the firing of the porcelain was carried out in the Vacumat 40 Porcelain Furnace. For all layering metal–ceramic samples, the second application of porcelain layers and another porcelain firing cycle was needed to compensate for the contraction generated during the first firing cycle.[2] The details of the initial and final temperatures for porcelain firing cycle are shown in Table 1. Following the same procedure, 15 layered veneering samples were prepared (Fig. 2).

The procedure from first step till shade opaque firing step on laser-sintered Co-Cr disks was the same as it was for layering group I. The modeling wax, Geo Snow-White L transparent (Renfert, Germany),[12] was used to make pattern on Co-Cr disks of dimensions 4 × 10 mm. After complete wax-up, a sprue of 8 mm in length and 4 mm in diameter was attached to built-up wax on the metal disk at 45 to 60° angulation in the direction of flow of porcelain. This assembly was attached to the top of investment ring base at 45° angulation and all sharp angles were rounded with wax;[13] 100 gm of Press VEST Speed IPS investment material powder was mixed in

16 mL liquid and 11 mL distilled water in automated mixer, poured in silicon ring-base assembly, and the ring gauge was positioned. The ring was allowed to set for 30 minutes for setting without any disturbance. For standardization, each sample was invested separately by the same operator following the same procedure. In 20 minutes, it was drawn out from the silicon ring and in the next 10 minutes was allowed to evaporate before placing in the preheating furnace/burnout furnace. This avoided cracks during preheating.[13] The investment ring was placed in the center of burnout furnace for temperature of 850°C and it was kept at the same holding temperature for at least 90 minutes. After complete preheating, the ring was removed at 150°C and transferred quickly to Programat EP 600 Press furnace (Ivoclar Vivadent). The cold IPS InLine POM pellet was placed in the investment ring, Alox press plunger IPS was placed, and pressing was carried out in the press furnace, according to the manufacturer's instructions. After fabrication of all 15 samples in the same way, finishing and polishing of the samples with porcelain finishing and polishing kit were carried out. Glaze paste with modeling liquid mixed on glass slab was applied on each disk with brush and glaze firing was performed. As such, 15 metal–porcelain samples for the heat-pressed group were fabricated (Fig. 3). The details

Fig. 2: Layered-veneering samples—group I

Fig. 3: Heat-pressed samples—group II

Table 2: Different porcelain firing cycles in programat EP 600 press furnace[21]

| Predrying temp. (°C)	(min)	(min)	Rate of temp. increase (°C/min)	Final temp. approx. (°C)	Holding time (min)	Pressure	Stop speed (μm/min)
700	0.00	6.00	50	850–1000	90	Mech	300
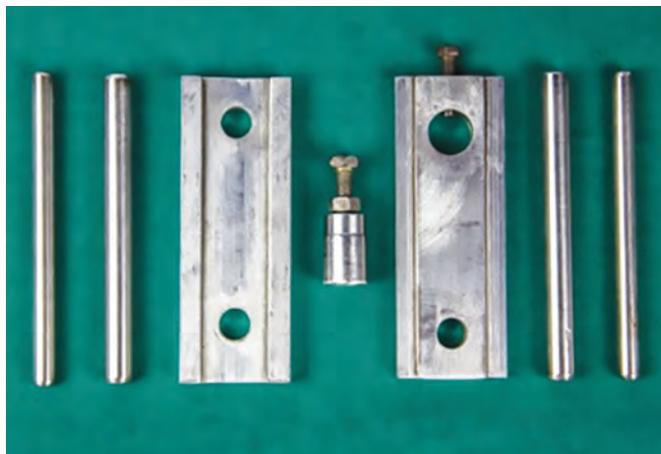
Fig. 4: Specially fabricated stainless steel jig assembly
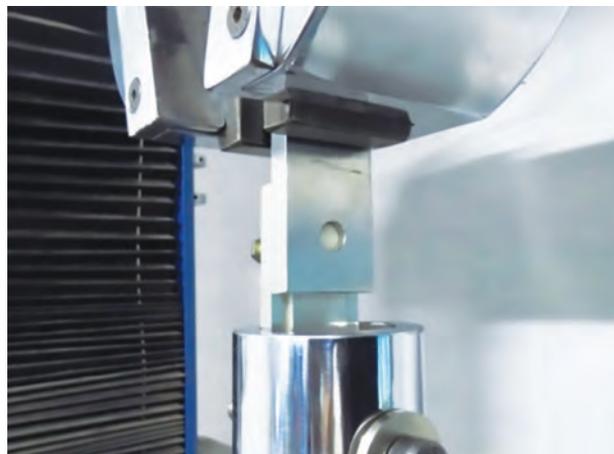
Fig. 5: Jig with test sample *in situ*

of the temperatures for porcelain firing cycle are shown in Table 2.

A specially fabricated stainless steel Jig[6] was fabricated by Shakti Engineering and Fabricators, Turbhe, Navi Mumbai (Fig. 4). It had two stainless steel plates which could slide on each other in opposite direction. Each slider plate had two holes on either side, out of which one was having internal diameter of 10 mm and depth 4 mm. When these holes coincided with each other, sample disk got fit into it in such a way that, one plate would engage its porcelain part and other plate would engage the metal part. At the base of the hole, a screw nut assembly was attached which enabled to move the disk up and down to get the correct interface of metal and porcelain. The other end holes were for holding the Jig on to the Instron machine.

Shear bond testing was done for each sample in both layering and pressed groups by placing them in the Jig assembly (Fig. 5). The disks were placed in such a way that the metal–porcelain interface lay exactly in between the two plates. The rods were then inserted in holes of plates at the other end, and the whole assembly was placed in the Universal Testing Machine (Model No. STS 248, Star Testing System, India) with a crosshead speed of 3 mm/ min with accuracy of machine ±1%. The disks were subjected to shear load at the metal–porcelain interface with increasing load and at crosshead speed of 3 mm/min till the disk debonded completely.[14] The load required to debond each sample was measured to calculate the shear bond strength. The load values obtained in Newtons (N) were converted to MPa by the following formula[15]:

$$\text{Shear bond strength} = \frac{\text{Force (n)}}{\text{Area of interface (mm}^2)}$$
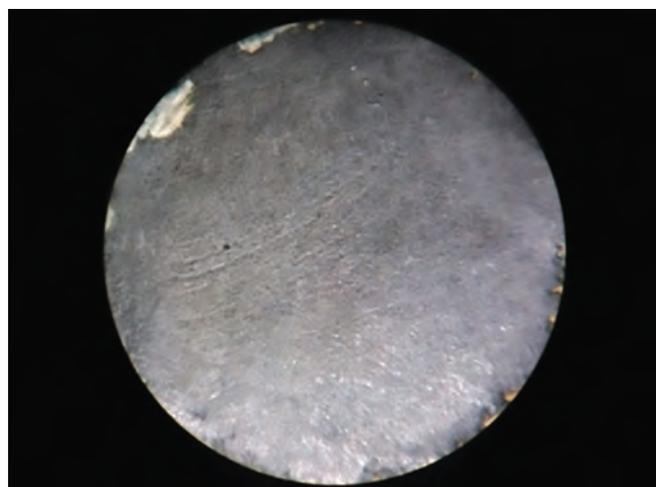
Fig. 6: Stereomicroscopic image of the sample

The samples were examined under a stereomicroscope using ×10 magnification (Fig. 6).

RESULTS

The findings of test samples were calculated and tabulated as in Tables 3 and 4. The lowest values were found for samples A9 and A11 and were 20.70 and 19.95 respectively.

The p-value for the Levene's test is greater than that of 0.05, which confirms that the variances are homogeneous for the two groups and it confirms the assumption of equality of variance for the independent t-test. Since the p-value for the t-test is less than 0.05, it indicates that we should reject the null hypothesis and conclude that the mean shear bond strength of the heat-pressed porcelain is significantly higher than that of the layered veneering porcelain.

Table 3: Shear bond strength of samples of group A in newton

Group: layer veneered samples		
Sample no	Max load (N)	Shear bond strength (MPa)
I1	3420.2	43.52
I2	4860.8	61.86
I3	5635.0	71.71
I4	2420.6	30.80
I5	3047.8	38.79
I6	3822.0	48.64
I7	3214.4	40.91
I8	5703.6	72.59
I9	1626.8	20.70
I10	3704.4	47.14
I11	1568.0	19.95
I12	3567.20	45.40
I13	4772.6	60.74
I14	2616.6	33.20
I15	3381.0	43.03
Average		45.26

Table 4: Shear bond strength of samples of group B in newton

Group: heat-pressed samples		
Sample no	Max load (N)	Shear bond strength (MPa)
II1	4096.4	52.13
II2	4321.8	55.00
II3	5919.2	75.33
II4	7291.2	92.79
II5	8045.8	102.40
II6	3547.6	45.15
II7	3194.8	40.66
II8	3165.4	40.28
II9	5096.0	64.85
II10	4165.0	53.01
II11	4557.0.	57.99
II12	4831.5	61.49
II13	4478.6	57.00
II14	4400.2	56.00
II15	3743.6	47.64
Average		60.11

Table 5: Adhesive remnant index scores

Group I		Group II	
Sample no	ARI score	Sample no	ARI score
I1	1	II1	0
I2	1	II2	0
I3	0	II3	0
I4	0	II4	0
I5	1	II5	0
I6	2	II6	0
I7	3	II7	0
I8	0	II8	0
I9	1	II9	0
I10	0	II10	0
I11	3	II11	0
I12	0	II12	0
I13	1	II13	0
I14	0	II14	0
I15	0	II15	0

Graph 1: Histogram showing frequency of shear bond strength for group I

The 12 samples of group II had adhesive failure, which means there was low adhesion in between laser-sintered alloy and heat-pressed porcelain, but high cohesion within the porcelain. However, for group I, there were equal numbers of adhesive and cohesive failures, which means layered veneering porcelain has high adhesion with laser-sintered alloy, but low cohesiveness within the porcelain when compared with group II (Table 5).

Frequencies of shear bond strength are shown using histograms in Graphs 1 and 2 for groups I and II respectively. Graph 3 shows difference in shear bond strengths between the two groups.

DISCUSSION

The success of a metal–ceramic restoration depends primarily on the strong adhesion between the porcelain and alloy.[16] Optimum bonding with accurate technique produces excellent results, thereby improving the clinical outcome and longevity of the restorations.[17] The bond strength is clinically relevant and can affect the longevity of a restoration.[18] According to International Standards Organization, the bond between metal alloy and veneering porcelain should be minimum 25 MPa.[2] The present study was conducted to evaluate the shear bond strengths of layered and pressed veneering porcelain to the laser-sintered Co-Cr alloy and to evaluate which technique has a better shear bond strength.

The alloy used in this study for fabrication of substructures for both groups was Co-Cr alloy, which was sintered with laser sintering machine (EOSINT M270, EOS Germany). This is a CAD-CAM-based procedure, having advantages of reduced laboratory time, ease of fabricating and retrieval as compared with the conventional lost wax
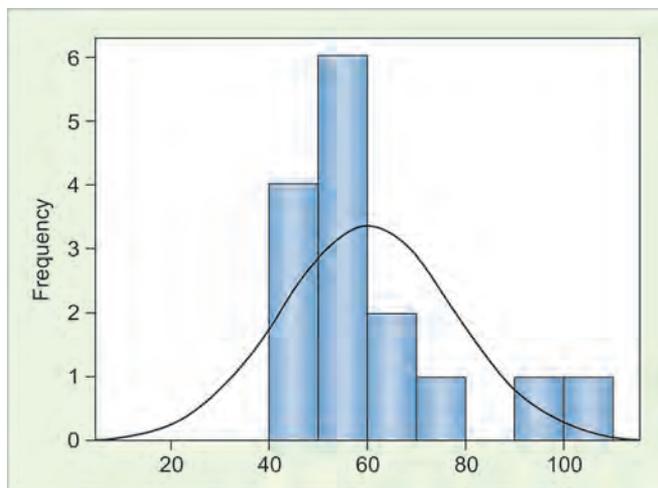
Graph 2: Histogram showing frequency of shear bond strength for group I
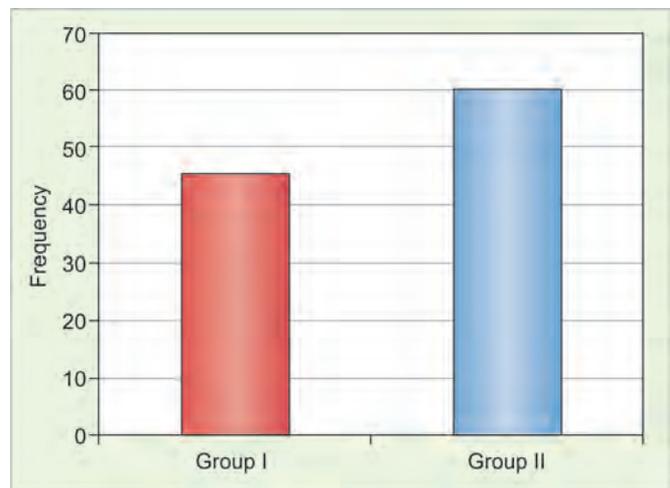
Graph 3: Comparison of shear bond strength of groups I and II

technique.[19] The CAD-CAM technology was developed as an alternative to the conventional casting method with the aim of producing dental restorations in a standardized, reproducible, and efficient way and also as a new method to process dental material.[20,21] The advantages of CAD/CAM techniques are simplicity, reduced costs, and reduced manufacturing time.[22]

For heat-pressed group II, the desired shape of the samples was achieved with a single pressing procedure.[3,23] However, the layered veneering group I samples required two to three applications with firings, and subsequently, adjustments were needed to acquire the definitive shape for shear testing. Thus, the metal–ceramic samples in groups I and II had similar procedures performed in terms of the process of opaque application. However, application of veneering ceramics was done either via layering or pressing.

Kulunk et al[24] used several air-abrasion particles to determine the effects of the particle size and types on the metal–ceramic bond strength, and reported that 110 µm Al_2O_3 particles showed the highest bond strength. Therefore, the metal samples in this study were all sandblasted with 100 µm Al_2O_3 particles with 4 to 6 bar air pressure to increase surface roughness.[24] For technicality of each material in both groups I and II, manufacturer's recommendations were followed. Finally, glaze firing was performed to enhance the surface quality. A variety of factors, such as material composition and properties, firing temperatures, cooling rates, operator's skill, porosities, and fabrication process, may affect the quality and strength of the bond between the core and the veneering materials.[25]

Laboratory observations confirmed that the press-on-metal technique requires much less time than the conventional layering technique for preparing dental porcelain. However, the press-on-metal technique has some limitations and processing restrictions. Different methodologies to evaluate shear bond strengths might be considered. Additional studies may evaluate the mechanical properties of the different veneering ceramics, such as flexural strengths and fracture toughness, and the effect of application methods.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions may be drawn:

- Layered veneering porcelain to laser-sintered Co-Cr alloys had low shear bond strength.
- Heat-pressed porcelain to laser-sintered Co-Cr alloys had high shear bond strength.
- Shear bond strength of heat-pressed porcelain to laser-sintered Co-Cr alloy was higher than the shear bond strength of layered veneering porcelain to laser-sintered Co-Cr alloy.

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