

Evaluation of Shear Bond Strength of Porcelain Bonded to Laser Welded Titanium Surface and Determination of Mode of Bond Failure.

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Abstract - The aim of this study was to evaluate the shear bond strength of porcelain to laser welded titanium surface and to determine the mode of bond failure through scanning electron microscopy (SEM) and energy dispersive spectrophotometry (EDS). Forty five cast rectangular titanium specimens with the dimension of 10mm X 8mm X 1mm were tested. Thirty specimens had a perforation of 2mm diameter in the centre. These were randomly divided into Group A and B. The perforations in the Group B specimens were repaired by laser welding using Cp Grade II titanium wire. The remaining 15 specimens were taken as control group. All the test specimens were layered with low fusing porcelain and tested for shear bond strength. The debonded specimens were subjected to SEM and EDS. Data were analysed with 1-way analysis of variance and Student's t-test for comparison among the different groups. One-way analysis of variance (ANOVA) showed no statistically significant difference in shear bond strength values at a 5% level of confidence. The mean shear bond strength values for control group, Group A and B was 8.4 ± 0.5 Mpa, 8.1 ± 0.4 Mpa and 8.3 ± 0.3 Mpa respectively. SEM/EDS analysis of the specimens showed mixed and cohesive type of bond failure. Within the limitations of the study laser welding did not have any effect on the shear bond strength of porcelain bonded to titanium.

KEY WORDS: Bond strength, Titanium, Laser welded, Porcelain

INTRODUCTION

Titanium and its alloys have been widely used in dentistry because of their excellent biocompatibility and corrosion resistance^{1,2}. The major problems encountered in the casting of titanium include its high melting temperature, its high reactivity at elevated temperatures, and its low density leading to internal porosities^{3,4}. The presence of internal void in the crown comes onto the surface when the grinding is done to do the occlusal adjustments. If these voids are left untreated then they may cause mechanical failure of titanium framework and fracture of porcelain layer.

The most common means of joining metals in dentistry is soldering. Conventional soldering method that uses oxygen flame or gas torch is likely to introduce significant concentration of oxygen into titanium surface and cause embrittlement due to diffusion of interstitial oxygen through titanium lattice during melting and solidification process. Hence conventional soldering methods cannot be used for titanium^{4,5}. The other alternative methods are tungsten inert gas welding, laser beam welding, brazing by infrared radiation and plasma welding. Laser welding is the most suitable technique to weld titanium and its alloys because they have high rate of laser beam absorption and lower thermal conductivity. It produces well defined joints and most importantly it involves less tedious procedures than do other dental alloys such as gold⁵⁻⁸.

Laser welding of titanium is used to join the metal framework of implant superstructures, recontouring the metal ridges and cusps, to add contact points after excess grinding. It is also used to block the perforation in titanium coping surface to be veneered with porcelain^{6,7,9}.

The bond strength of porcelain to titanium has been reported high enough for clinical use,^{10,11} and little evidence exists concerning the shear bond strength of porcelain bonded to laser welded titanium. Tore Derand¹² studied the effect of laser welding on the bond strength of porcelain to titanium. The titanium plates were exposed to laser beam and porcelain was applied. A four-point bending test was used to measure the bond strength between the porcelain and titanium plates. He concluded that there was no deterioration of bond strength of fused porcelain to welded titanium.

Though it has been reported that the laser welding does not affect the bonding of porcelain to titanium, there is a need to reassess the above finding with different test specimens and testing methodology. Hence the present study was conducted to evaluate the shear bond strength and mode of bond failure of porcelain bonded to perforated titanium surface and laser welded perforation on the titanium surface. SEM and EDS analysis was done to determine the mode of bond failure.

MATERIALS AND METHODS

Two standardized rectangular shape metal dies of dimensions 10mm X 8mm X 1mm thick was machine cut. One of the metal die had the perforation in the centre with 2mm

*MDS

**MDS, MFPT

diameter. Both the metal pieces had the funnel shaped projection at one side of the rectangle. The diameter of the farther end of the funnel was 3.5mm and 2mm in length. This design helped to hold the specimens during porcelain firing and also served as the sprue former¹³.

The metal dies were duplicated in casting wax using putty elastomer (Aquasil; Dentsply, Konstanz, GmbH Germany) mold. A total of 45 wax patterns were prepared. 30 were prepared from the mold made with perforated die in the centre. They were randomly divided into Group A and B. The remaining 15 specimens were prepared from the mold made with non-perforated die that constituted the control group.

The patterns were sprayed with a surface tension-reducing agent (True Blue, Renfert Co, Germany) and allowed to air dry. A layer of moistened ceramic-based liner (Keravlies; Dentaaurum, GmbH Germany) was placed lining the investing ring. 550gm of Titec investment material (Titec; Orotig, Verona, Italy) was mixed with 75ml of titec fluid using a vacuum mixer, and the invested ring was kept in a pressure pot at 2lbs of pressure. Wax burnout was carried out as per the manufacturer's specifications. Cp Grade II titanium was cast in a semiautomatic pressure-type casting machine with 1 chamber (Titec 201F; Orotig) under the argon pressure of 4 lbs.

The Group B specimens with perforations were subjected to laser welding using pure titanium wire (Bego, Remtitan, Germany). The welding parameters were adjusted according to the manufacturer's instructions (Fig 1). Finishing and polishing was done using titanium finishing and polishing kit¹⁴ to reproduce the surface texture similar to that of the control group. The specimens were sandblasted and cleaned ultrasonically. Low fusing porcelain (Titan Ceramics, Vita Zahnfabrik, Bad Sackingen, Germany) was applied and fired according to manufacturer's instructions. Inlay wax of 2mm thickness was built on the test specimen and was duplicated using putty elastomer. This putty index was used as a jig to build the 2mm ceramic layer on the samples. Porcelain was built on the specimens with 2mm diameter holes by keeping them on the glass plate. First the hole was filled and the porcelain got struck in it and the surface was done using the jig.

The shear bond strength between porcelain and titanium was evaluated in Instron universal testing machine. A metallic fixture was fabricated for holding the specimens in universal testing machine. The fixture had rectangular upper and lower member with dimensions of 6cm × 5cm and 7cm × 5cm respectively. The upper member had a square shaped gap in the centre (2cm × 2cm). Here, another metallic part, which held the specimen, was inserted. This was split into two sections with the gap similar to the shape of test specimen with funnel shaped sprue. After placing the specimen, these two sections were held tightly with the help of the screws and tightened with allen keys. The upper and lower members of the fixture were joined together with two screws and tightened with allen keys.

The Instron machine had two cross heads, upper and the lower. The crossheads are mounted on a hydraulic framework connected to a digital recording unit, which record the load applied to porcelain. Shear bond strength was tested at a crosshead speed of 0.5mm/min and load was applied by placing sharp edge of chisel at the interface

between titanium and porcelain. It was gradually increased till the porcelain fractured from the metal surface. The chisel was fixed to the upper jaw of the testing unit, positioned parallel to porcelain-titanium interface. The fracture loads were recorded in Kilogram forces (Kgf), which were converted to Mega Pascal (MPa).

Data obtained from the test specimens were subjected to statistical analysis using 1-way analysis of variance (ANOVA). Pair-wise comparison of the 3 groups was undertaken using Student's t-test. The level of confidence was set at 5%.

These tests were performed by statistical package software (SPSS for windows version 10: SPSS). Debonded specimens were prepared for SEM and EDS analysis to determine the mode of bond failure. Bond failure was analysed in terms of adhesive, mixed or cohesive failure.

RESULTS

The bond strength values for control group, Group A and B were found to be 8.4 ± 0.5 Mpa, 8.1 ± 0.4 Mpa and 8.3 ± 0.3 Mpa respectively (Table 1). One-way ANOVA was undertaken for all the groups. The test showed no statistically significant difference at the 5% level of confidence with an F value of 2.19 ($p < 0.05$), and as shown in Table 2. Further, the Student's t-test was performed to discover any statistical significance among paired groups, and the results obtained are presented in Table 3. The results displayed no statistically significant difference in the shear bond strength values between groups.

The SEM photomicrographs of the debonded specimen of control group, Group A and B are shown in Fig 2, 3, & 4 respectively. The photomicrograph of Group B specimen before application of porcelain is shown in Fig 5. The photomicrographs showed the mixed and cohesive type of bond failure. These micrographs were further substantiated with the EDS analysis by showing the chemical composition of the debonded specimens. Control group showed higher concentration of silica 35%. Small traces of Al, Na, and Ca were also seen. Group A and B showed both high and low levels of silica.

DISCUSSION

In fixed Prosthodontics soldering may affect the longevity of the metal ceramic bond¹⁶. Galindo¹⁷ studied the bond strength of palladium-gallium alloy specimens that had been intentionally perforated, soldered and then veneered with porcelain. The results showed no statistically significant differences in the metal ceramic bond strength of the soldered and non soldered specimens. Kang¹⁸ carried out a similar study but demonstrated that solder material might negatively affect porcelain-metal crowns.

Several methods have been suggested to test the shear bond strength between porcelain and metal. A 3-point flexure test¹⁰, 4-point flexure test¹², and biaxial bending¹⁹ have been used. All of these tests have inherent limitations that prevent from obtaining true metal-porcelain bond strength values. Shear bond strength values are also dependent on the geometry of the test apparatus, the applied load and the nature of the material^{10, 19, 20}.

EVALUATION OF SHEAR BOND STRENGTH OF PORCELAIN BONDED TO LASER WELDED TITANIUM SURFACE AND DETERMINATION OF MODE OF BOND FAILURE.

Table 1. Mean and Standard deviation of shear bond strength (MPa) in three different test Groups

Groups	No: of samples	Mean	SD	SE(Mean)	Minimum	Maximum
Control group	15	8.448	0.5337	0.1378	7.390	9.190
Group A	15	8.119	0.3891	0.1005	7.330	8.690
Group B	15	8.277	0.3463	0.08941	7.360	8.890

Table 2. One –way ANOVA of shear bond strength

Source	DF	SS	MS	F-value	P-value	Significance
Between groups	2	0.8106	0.4053	2.19	0.1250	NS*
Within groups	42	7.787	0.1854			
Total	44	8.597				

* Not Significant at 5% level of significance

Table 3. Statistical comparison (Student's t-test) of the shear bond strength between the groups.

Comparison between	Mean	SD	t-value	p-value	Significance
Control Group and Group A	8.448 8.119	0.5337 0.3891	1.93	0.0642	NS*
Control Group and Group B	8.448 8.277	0.5337 0.3463	1.04	0.3077	NS*
Group A and Group B	8.119 8.277	0.3891 0.3463	1.17	0.2500	NS*



Figure 1. The control group, specimen with perforation and laser welded specimen

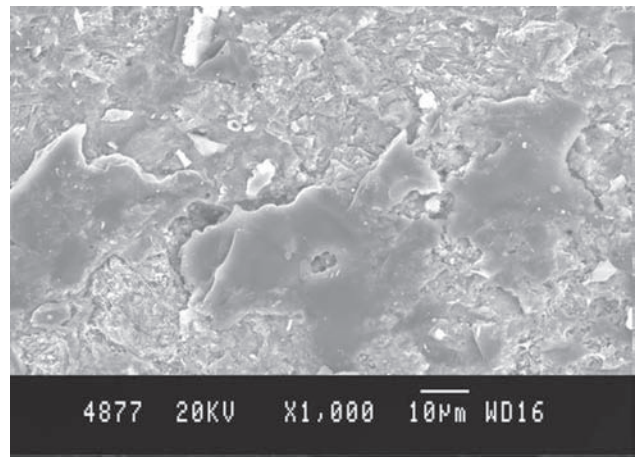


Figure 3. SEM photomicrograph of Group A specimen with areas of metal and porcelain (Mixed type of Failure)

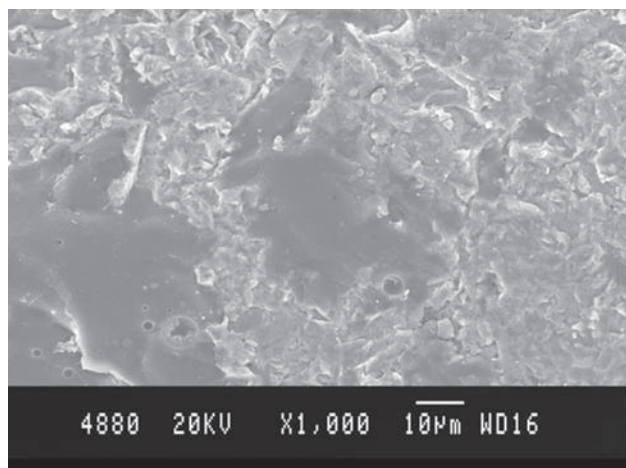


Figure 4. SEM photomicrograph of Group B specimen showing mixed type of failure.

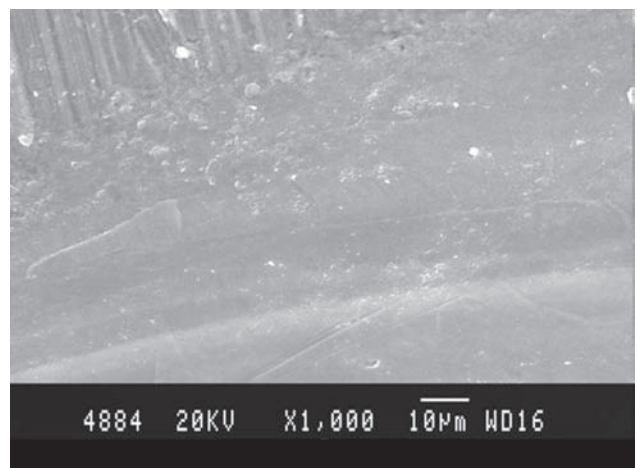


Figure 5. SEM photomicrograph of Group B specimen before application of porcelain. Well fused surface of parent metal and laser welded titanium.

In the present study a rectangular test specimen with a perforation of 2mm diameter in the centre was chosen to check the shear bond strength. The shear bond strength was evaluated using a universal testing machine with a push type of shear test. The findings of the present and other studies^{12, 21} showed statistically insignificant difference with the laser welding having less effect on the bond strength of porcelain to titanium. The magnitude of bond strength values obtained (8.2 ± 0.3 MPa) was less compared to the bond strength values reported by Tore Derand¹² (54.3 ± 18.5 MPa) and Zhu JF²¹ (46.8 ± 0.7 MPa). Lesser shear bond strength values in the study may be due to the failure of producing the uniform shear stress. If the test produces stress concentration at the interface of the porcelain termination sites then the values will be lower than the true bond strength²⁰. However, the bond strength values were found to be consistent among all the three groups indicating that laser welding (Group B) and the presence of perforation (Group A) did not affect the bond strength.

O'Brien^{22, 23} formulated the non specific cohesive plateau theory to describe the metal ceramic bonding. According to this theory the interfacial bond strength increases from minimum level where purely adhesive failure between metal ceramic occurs to maximum level corresponding to purely cohesive failure through ceramic, indicating optimum bond strength. Mixed adhesive-cohesive failure modes indicate intermediate levels of bond strength. SEM photomicrographs of the debonded specimens showed similar physical appearance with a predominance for mixed and cohesive type of failure. The surface of all the groups showed similar topography with predominantly mixed type of failure that exposed metal and porcelain surfaces adhering to titanium. The mixed failure showed areas of adhesive failure between the metal and metal oxide with a dark grey layer and the cohesive failure is within the porcelain.

EDS analysis of the control group displayed titanium and elements of Al, Si, K and Ca. A high percentage of Si (35%) was registered suggesting cohesive type of failure. Group B specimens showed both adhesive and cohesive type of bond failure. In case of adhesive type, silica levels will be low. It is reported that the lesser concentration of silica detected in EDS spectrum may be attributed to the fact that Si in the investment is not stable when in contact with liquid titanium because it reacts with titanium to form titanium silicide and titanium oxide²⁴.

The EDS analysis of laser welded titanium surface was similar to that of the titanium surface before and after sandblasting thus indicating similar chemical composition (Ti 95%) of the parent metal and laser welded titanium. This similarity in the chemical composition supports the results of the bond strength value of the control group (8.4 ± 0.5 MPa), Group A (8.1 ± 0.4 MPa) and Group B (8.3 ± 0.3 MPa). The Group A specimens had better bond strength values, may be inferred that the porcelain might have clogged into the 2mm perforation resulting in mechanical interlocking. This mechanical bonding might have resulted in similar bond strength values as compared to control group and Group B.

CONCLUSION

Within the limitations of the study it is concluded that laser welding of titanium may not affect the long term prognosis of titanium ceramic bond. Thus it is recommended that the procedure of laser welding can be done to repair perforations or voids in the crown prior to porcelain application.

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EVALUATION OF SHEAR BOND STRENGTH OF PORCELAIN BONDED TO LASER WELDED TITANIUM SURFACE AND DETERMINATION OF MODE OF BOND FAILURE.

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