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Role of Laser Etching on Shear Bond Strength between Recast Nickel-Chromium Alloy and Dental Ceramic: An Experimental Study

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ABSTRACT

Objectives: The purpose of this study was to investigate the effect of laser etching, air bone particle abrasion and acid etching on shear bond strength between re-cast Nickel Chromium alloy and dental ceramics.

Materials and Methods: A master die was made according to ISO 9693; TR (11406). A total of 40 samples were fabricated with 50%w nickel-chromium alloy and 50%w previously casted nickel-chromium alloy. The samples were divided into four groups based on the surface treatment applied. Group 1 served as the untreated control, Group 2 underwent etching with 10% hydrochloric acid (HCl), Group 3 received surface treatment via air-borne particle abrasion, while Group 4 was conditioned using a pulsed Nd:YAG laser. Shear bond strength between ceramic and metal was tested using a universal testing machine and the mode of debonding was evaluated using scanning electron microscope. The obtained values were statistically analyzed using one-way ANOVA and Tukey's HSD Post Hoc test.

Results: The mean values of shear bond strength for Group 1 was 22.69±2.63Mpa, Group 2 was 27.05±2.15Mpa, Group 3 was 34.46±2.46Mpa and Group 4 was 39.54±2.16Mpa. The difference among the groups was significant ($P<0.001$). Hence there was a statistical difference seen in shear bond strength between control and acid etching, air borne particle abrasion and laser etching.

Conclusion: Laser surface conditioning produced more surface roughness compared to acid etching and air bone particle abrasion on re-cast Nickel Chromium alloy which increased the shear bond strength markedly between recast nickel-chromium alloy and dental Ceramic.

Keywords: Acid Etching, Dental; Ceramic; Laser; Nickel; Chromium Alloys; Shear Strength

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INTRODUCTION

The replacement of missing teeth has long been a significant focus in dentistry, with fixed dental prostheses offering high satisfaction to both patients and prosthodontists. These prostheses can transform unhealthy and unattractive teeth into aesthetically pleasing, functional replacements that provide long-term service [1].

Casting remains the traditional method for fabricating dental prostheses, ensuring high accuracy and patient satisfaction with the fit. The technique of lost-wax casting, first introduced by W.H. Taggart in 1907, revolutionized the fabrication of gold dental restorations and continues to be a cornerstone in dental prosthetics [2].

Earlier use of porcelain-fused-to-metal was not very satisfactory where esthetic considerations were paramount. Due to the advent of vacuum firing in the 1950s the porcelain-fused-to-metal restoration had a major impact upon esthetic reconstruction. In many dental laboratories, previously used alloy is combined with new alloy to decrease the cost. But this process alters the metal oxide content at the surface of the dental alloy [3]. It has been noted that the use of newer alloys can enhance the quality of dental castings. Addition of <50% reused alloy to pure alloy is clinically sustainable [4]. There was no significant difference observed in the casting quality between different ratios of new and recast alloys. Hence, the incorporation of new alloy may not be required for casting [5].

The recasting process leads to changes in particle size, purity, and microporosity, which may result in casting defects that can affect mechanical properties due to the release of elements like Cu, Sn, Zn, and Cr. Such alterations can potentially impact the bond strength of the final material [6]. It is recommended that commercial Co-Cr-Mo alloy can be six times reused with 50% new alloy without affecting its castability [7]. Average elastic modulus values were measured for three groups of nickel-chromium (Ni-Cr) metal alloy structures after their first casting, and no significant differences were found between the groups. This indicates that the number of recasting cycles does not have a substantial impact on the elastic modulus. [8]. Significant reduction in bond strength was noticed with the first casting of recast alloy in contrast to addition of second casting of recast alloy [9,10]. Recasting of Ni-Cr alloy showed no significant changes in tensile strength, but there were noticeable alterations in surface roughness [11].

Various surface modification treatments have been recommended to increase the bond strength between ceramics and metal alloys like sandblasting, tin-plating, silica-coating, electro-lytic etching [12,13]. Aluminum-oxide air particle abrasion decreased the mean weight percentage for chromium [14]. Due to the advent of lasers, surface treatment with the Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser is considered as an alternative method. Laser treatment was one of the recommended surface alteration techniques to enhance the bond strength of metals and ceramics [15]. Hence this study aimed to evaluate and compare the effects of acid etching, sandblasting, and laser surface conditioning on the shear bond strength between recast Ni-Cr alloy and ceramic. A hypothesis was formulated that the shear bond strength between the recast Ni-Cr alloy and ceramic after undergoing different kinds of surface treatments would remain consistent across the various methods.

MATERIALS AND METHODS

The samples were fabricated in accordance with ISO 9693; TR (11406) [16], as illustrated in Figure 1. This figure highlights the precise measurements for the base, step, and both the metallic and ceramic structures.

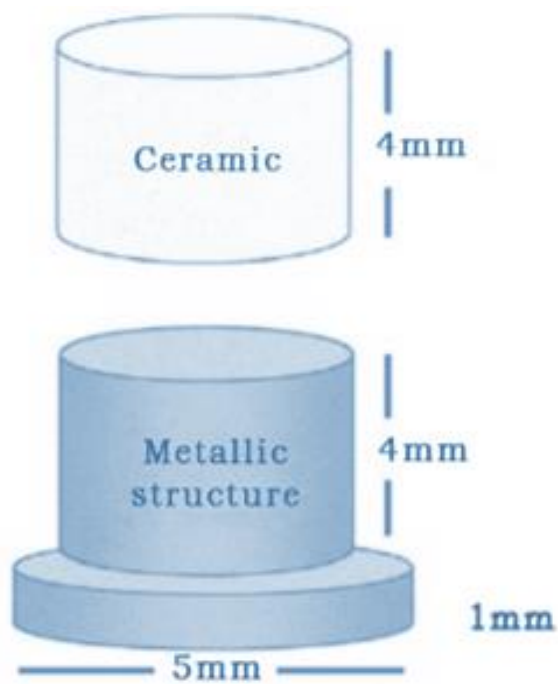

Fig 1. Schematic representation of master die

Initially, cylindrical wax patterns were made using crown wax (BEGO, Germany) which were invested using phosphate bonded investment (Bellasun, BEGO, Germany). The investment was placed in a burnout furnace (Sirio, India) up to 950˚C, then transferred to an induction casting machine (Fornax, Bego, Germany) and casting was done using a mixture of 50% by weight fresh Ni-Cr alloy (Ceralloy NI, Dentalloy, International Private Ltd., India) and 50% by weight previously cast Ni-Cr alloy from buttons produced from earlier castings.

A total of 40 samples were made for this research. The samples were allocated into 4 groups with 10 samples in each group. Group 1 received no treatment, and Groups 2, 3, and 4 were subjected to surface treatment with 10% hydrochloric acid (HCL), air bone particle abrasion and treated laser irradiation, respectively (Figure 2).

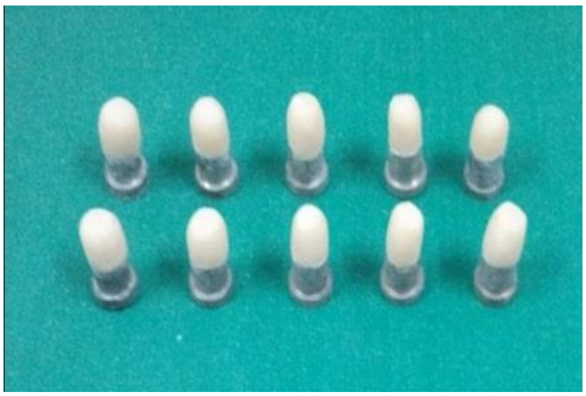

Fig 2. Samples for Shear bond strength test

Surface treatment procedure

The samples were kept at 5mm distance and received surface treatment with 110µm aluminum oxide (Al_2O_3) particles (Aluminox-110, Delta Labs, Chennai, India) for 30 seconds at a pressure of 60 psi, then washed in an ultrasonic bath (Soniclean, Transtek system, Australia) for 10 minutes. Acid treatment was done by placing the samples in a 10%w/v aqueous solution of HCL (Finar reagent, Ahmedabad, India) and boiling them for 30 minutes [12]. For Laser surface conditioning, the samples were treated using Nd: YAG pulsed LASER machine (Q-Switched, Jinan MORN Technology Co.,Ltd, Korea) at a wave length of 1.024 µm [15] and power setting of 2W, with 50 Hz frequency at a depth of 20µ in 2mm space interval with an angle of 90^{o} to the metal surface in horizontal manner.

Ceramic application procedures

The samples were rinsed using an ultrasonic cleaner (Sonic Clean, Transkit System, Australia), then placed in a ceramic furnace (Ivoclar, Programat P100) to remove surface impurities such as gases and oils. The furnace was gradually heated to oxidize the metal surface, with a rise in temperature of 140˚C per minute to reach the final temperature of 980˚C.

After oxidation, two layers of B1 shade opaquer (IPS d.Sign System, Ivoclar, Liechtenstein) were applied to the Ni-Cr samples, with a total thickness of approximately 0.7mm. The samples were then fired in a ceramic furnace and a body ceramic (IPS d.Sign System, Ivoclar, Liechtenstein) was layered over the opaquer, forming a final height of 4mm (Figure 3).

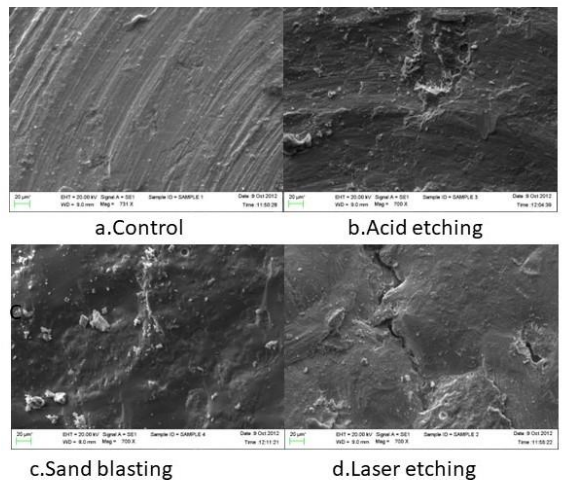

Fig 3. Scanning Electron Microscope Image of various surface treatment

Evaluation of shear bond strength

The shear bond strength between Ni-Cr and ceramic was evaluated using a universal testing machine (Instron 3382, Shimadzu, Tokyo, Japan) at a cross-head speed of 1.0mm/min. A vertical load was applied at 0.5mm at the junction of the metal ceramic until they are fractured (Figure 4).

Fig 4 Shear bond strength test

Shear bond strength (MPa) was calculated by dividing the load at which failure occurred by the surface area. Fractured surfaces were evaluated under a scanning electron microscope (SEM, Zeiss Evo MA15) to assess mode of failure (Figure 5).

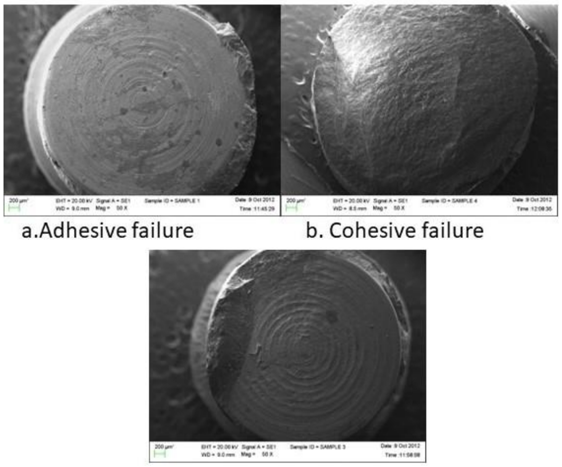

Fig 5. Scanning electron microscope images of different types of failure

Statistical analysis

Priori power analysis (G Power software, version 3.1), determined that a sample size of ten per group would achieve 100% power at a significance level of 0.001. SPSS version 22.0 (IBM, Chicago, USA) was used for analysis. Mean shear bond strength was examined with one-way ANOVA, followed by Tukey's HSD post-hoc test for group comparisons.

RESULTS

Table 1 shows the mean shear bond strength values between recast Ni-Cr alloy and dental ceramic after different surface treatments.

Table 1. Shear bond strength (MPa) values across all study groups

Group	Mean	SD	Min	Max
1	22.69	2.63	19.34	26.87
2	27.05	2.15	23.57	30.11
3	34.46	2.46	30.64	38.52
4	39.54	2.16	35.16	42.76
Total	30.93	6.97	19.34	42.76

SD: standard deviation; Min: minimum; Max: maximum

ANOVA was used for group comparisons. We found a statistically significant difference (P<0.001) in shear bond strength among the groups (Table 2)

Table 2. One-way ANOVA findings comparing shear bond strength between and within groups

	Sum of Square	Mean Square	F	P
Between Groups	1695.89	565.28		
Within Groups	01.12	5.58	101.18	<0.001
Total	1896.98	5.58		

Multiple group comparison was done using Tukey's HSD test and Post Hoc analysis, which showed significant difference (P<0.001) between groups (Table 3).

Table 3. Mean difference and Tukey's HSD findings between the groups

Groups (I)	(J)	Mean difference (I-J)	Standard error	P
	2	-4.35	1.05	0.001
1	3	-11.76	1.05	<0.001
	4	-16.85	1.05	<0.001
	1	4.35	1.05	0.001
2	3	-7.4	1.05	<0.001
	4	-12.49	1.05	<0.001
	1	11.76	1.05	<0.001
3	2	7.4	1.05	<0.001
	4	-5.08	1.05	<0.001
	1	16.85	1.05	<0.001
4	2	12.49	1.05	<0.001
	3	5.08	1.05	<0.001

SE: standard error

Mode of failure of samples between ceramic bonded to recast nickel-chromium alloys showed adhesive, cohesive, and/or mixed failure types, as demonstrated in Table 4.

Table 4. Failure modes of ceramic bonded to recast nickel-chromium alloys

Mode of Failure	Groups (%)			
	1	2	3	4
Adhesive Failure	70	40	10	30
Cohesive Failure	10	40	50	60
Mixed Failure	20	20	40	10

DISCUSSION

Metal ceramic prosthesis was used with good clinical performance, esthetics and durability for many years in dentistry [17]. Ni-Cr alloy is the frequently used metal alloy with excellent mechanical properties and marginal integrity without any adverse reactions The success of metal-ceramic restorations largely depends on the bond strength between metal and ceramic. The most common mechanical failure is the ceramic's debonding from the metal [18]. The reuse of casting alloy significantly reduces the bond strength due to changes in its mechanical properties. To overcome this problem, various surface treatments were applied to restore the bond strength to acceptable levels.

Many factors are considered to insure successful metal-ceramic bonding like coefficients of thermal expansion and contraction of metal and ceramic [19], geometric design of the metal substructure [20], metallurgical composition of the alloy, porcelain application technique, rate of cooling, the firing cycles (rate, temperature and atmosphere), application of bonding agents, surface pretreatment procedures of the metal coping [21] and repeated casting [22]. Fracture of the ceramic may occur due to the flexion of a metal ceramic framework during function. The junction of the metal and opaque porcelain determines the bond strength. Repeated firings of the metal-ceramic restoration would theoretically lead to a decrease in metal-ceramic thermal compatibility and a subsequent decrease in bond strength due to oxide formation at the metal and ceramic junction. This over-production of oxides at the interface might be responsible for the lower bond strength [23].

Sprue and the button portion are the wastage of casting, so remelting of previously cast metal can be done to reduce the amount of metal that is wasted. This process may change the composition of metal at the surface, that may condemn the metal and ceramic bond. Some use a new metal while others prefer adding up to 50% buttons or sprues from the previously made castings [24]. During casting, some trace metals like Cu, Cr, Sn, and Zinc may be oxidized or lost [24]. To enhance the bond strength between the metal and ceramic, many surface treatments like pre oxidation, application of bonding agents, airborne particle abrasion, degasification can be done.

To overcome these potentially bond-weakening, aluminum oxide abrasives have been used to increase surface area, eliminate alloy tags, uncover surface voids and to achieve micro retentive surface topography which may enhance the wettability of ceramic alloy by molten porcelain [25] Parchańska-Kowalik et al [26] reported that hydrochloric acid treatment is an effective method to enhance bond strength with low-fusing porcelain compared to airborne particle abrasion. Al Hussaini et al [12] stated that airborne-particle abrasion showed higher bond strength than acid-etching. The possibility of surface contamination with alumina particles may affect the mechanical bond between ceramic and titanium. Laser-etching method eradicates the issue of surface contamination with alumina and could be a viable option to consider [12]. Laser surface conditioning produces more surface roughness compared to acid-etching and sandblasting methods. Hence, laser treatment may be a possible method to enhance the bond strength between metal and ceramic [12,27].

The mean shear bond strength between recast nickel-chromium alloy and ceramic for Groups 1, 2, 3, and 4 were 22.69±2.63 Mpa, 27.05± 2.15 Mpa, 34.46±2.46 Mpa, and 39.54±2.16 Mpa, respectively. According to ISO standards 9693, the shear bond strength should be higher than 25 MPa. In this study, the bond strength of ceramic to recast Ni-Cr alloy without any surface treatment was found to be less than 25 Mpa. The samples that were acid etched showed only minimal better bond strength, though in acceptable levels. The samples that were subjected to air borne particle abrasion showed significant increase in bond strength and the laser etched samples showed the best results compared to the other three groups.

Statistical analysis showed the significance value ($P<0.001$), hence there was a statistically significant difference in bond strength between the control and the other surface treatmentThe shear bond strength between metal to ceramic was greater in laser-etched surfaces (Group 4) than in sandblasted (Group 3), acid etched (Group 2) and control (Group 1) groups.

Analysis of the fracture surface with SEM revealed adhesive failure between the metal and ceramic and cohesive failure within the ceramic. The oxide layer of the ceramic surface was detached which is the evidence for better bonding between the metal and ceramic. Clinically, the metal-ceramic failure would be cohesive. The maximum 70% adhesive failure occurred in the controls (Group 1). Laser surface conditioning showed more surface roughness in recast Ni-Cr alloy compared to sandblasting.

CONCLUSION

The authors concluded that remelting previously used Ni-Cr alloy significantly reduced the shear bond strength with dental ceramics. However, laser surface conditioning resulted in greater surface roughness on the recast alloy compared to acid etching and airborne particle abrasion, both of which led to considerable improvements in shear bond strength between the recast Ni-Cr alloy and dental ceramics. Implementing laser surface conditioning as a standard procedure can greatly enhance the bond strength of recast alloys, ultimately influencing the success of metal-ceramic restorations.

CONFLICT OF INTEREST STATEMENT

None declared.

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