

Research Article

Investigation of laser irradiation power and beam angle on Ni-Cr metals in improving shear-bond strength of adhesive bridge

Winnie Munte ¹, Haslinda Z Tamin ¹, Indra Nasution ², Putri Welda Utami Ritonga ^{1*}

¹ Department of Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, Indonesia.

² Department of Mechanical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Indonesia.

*Corresponding author: putri.welda@usu.ac.id

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Abstract: Background: Laser irradiation has been widely utilized in the modification of material surfaces by altering their microstructure and topography, however, the effect of irradiation parameters such as power output and beam angle to bonding performance of metallic substrates remain insufficiently understood, especially for Ni-Cr metals. Objectives: This study aimed to evaluate the effects of diode laser power in different beam angles on the surface of Nickel-Chromium (Ni-Cr) metals to improve bonding strength of adhesive bridge. Materials and Methods: Thirty-six cylindrical Ni-Cr metals, with a thickness of 2.0-3.0 mm, and 36 post-extraction maxillary premolars were divided into 6 groups (n=6). A diode laser irradiation was performed on metal samples with beam-angles of 30°, 60°, and 90° and powers of 2.0 watts and 4.0 watts. Teeth were then cemented into metal samples using resin cement. After treatment, shear-bond strength (SB-Strength) testing was carried out using a Universal Testing Machine (UTM). Meanwhile, the samples also were evaluated using Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM). Data were analyzed using a T-test, ANOVA test, and LSD test. Results: A significant SB-strength was found in 30° for 2.0 watt and 90° for 4.0 watt respectively 4.48±1.97 MPa and 5.27±2.50 MPa. Morphological analysis suggested that 30° allows more uniform surface roughness, while 90° allows similar patterns but with higher depth. Conclusion: These results provide practical guidance for clinicians by indicating that perpendicular laser irradiation (90°) at controlled power settings may improve bonding reliability in adhesive bridge procedures involving Ni-Cr frameworks.

Keywords: Laser-material interaction, Irradiation beam, Diode laser, Dental alloys, Resin Cement Adhesion.

Introduction

An adhesive bridge, or fixed partial denture, is indicated in cases where the abutment teeth are healthy, free from caries and restorations, and possess sufficient enamel for adhesive retention ¹. Adhesive restorations employ metallic wing retainers, particularly fabricated from nickel-chromium (Ni-Cr) alloy due to its high corrosion resistance. Despite its advantages, the use of adhesive bridges as definitive restorations remains a concern, primarily because of their limited long-term success rates ^(1,2). Meta-analyses have reported survival rates of 87.7–91.4% after 5 years and approximately 82.9% after 10 years, with debonding identified as the most frequent complication, occurring in up to 19.2% of cases ^(3,4). Multiple factors contribute to the clinical success of adhesive bridge restorations, including preparation design, oral hygiene, mechanical strength, and the restorative materials used. Several studies have identified debonding as the principal cause of adhesive bridge failure ^(5,6). Therefore, to enhance retention, it is essential to employ both physical and mechanical surface treatments such as air and particle abrasion to optimize bonding on both the tooth and metal surfaces within the bridge.

Various surface treatments have been developed to enhance adhesion between dental materials and resin cements. These approaches include mechanical and chemical modifications, such as airborne-particle

abrasion (sandblasting), chemical etching, metal primers, and surface coating techniques. These methods aim to increase surface roughness and improve micromechanical interlocking and chemical bonding between restorations and cements⁽⁷⁾, especially at the metal–resin interface. The success of restoration is largely determined by the integrity of this chemical bond, strongly influenced by the surface modification⁽⁸⁾. Air abrasion devices, employing either air or alumina at high pressures, are widely recommended for surface modification of Ni-Cr alloys⁸; nevertheless, optimal parameters, such as particle size and applied pressure, remain inconsistent across studies. In addition, air abrasion alone may not be sufficient to achieve durable adhesion, often requiring supplementary chemical treatments⁽⁹⁾, such as metal primers, to improve bonding at the metal–resin interface⁽¹⁰⁾.

With advancements in laser technology in dentistry, laser irradiation has emerged as a promising method for creating surface roughness and improving retention between ceramics and resin cement⁽¹¹⁾. The application of lasers as a surface modification to roughen metal surfaces utilizes the thermal energy produced by laser beams (ranging from 200 to 600 μm) to modify the surface properties of the material⁽¹²⁾. Key laser parameters include the wavelength, mode (continuous or pulsed), exposure time, distance, frequency, and irradiation angle. Adjusting these parameters produces varying effects on the modified surface properties⁽¹³⁾. Several studies suggested that some parameters including types of lasers, wavelengths, irradiation angle and power on the surface roughness and shear bond strength (SB-Strength)^(14–16). Moradi and colleagues reported that the increased hardness is attributed to the heat input from the laser, which is determined by both laser energy and the duration of laser-metal interaction⁽¹⁷⁾. Similar findings have been reported for AISI 4130, a chromium–molybdenum low-alloy steel, where reduced interaction time and increased laser pulse enhanced heat transfer, resulting in improved microhardness at a beam density of 84 W/mm^2 and a scanning speed of 4.45 mm/s ⁽¹⁸⁾.

There are various types of lasers utilized in prosthodontics such as dental diode lasers, with wavelengths ranging from 805 to 980 nm, Neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers have been shown to increase both surface roughness and SB-strength at power settings of 3 W and 4 W at 1064nm⁽¹⁹⁾. Under different settings (150 mJ, 1 W, low power for 20 seconds), Er:YAG lasers also appear to enhance SB-strength⁽²⁰⁾. However, at wavelength of 1064 nm, Nd:YAG lasers generate relatively high thermal energy and exhibit strong absorption by metallic surfaces, which may lead to excessive heat accumulation and undesirable surface alterations. Some reports have indicated that Nd:YAG lasers are contraindicated for surface treatment of titanium due to the risk of melting⁽²¹⁾. These thermal effects may compromise surface integrity and negatively affect bonding performance. In contrast, diode lasers offer more controlled energy delivery and are increasingly explored for surface modification; however, their effectiveness in improving metal–resin adhesion remains insufficiently established. In particular, the influence of irradiation parameters, such as power output and beam angle, on the surface characteristics and bonding performance of Ni–Cr alloys has not been fully elucidated. Therefore, this study aimed to investigate the effect of diode laser power (2.0 W and 4.0 W) and beam angles (30°, 60°, and 90°) on the shear bond strength of resin cement to Ni–Cr alloys used in adhesive bridge applications. The null hypothesis was that variations in laser power and beam angle would not significantly affect bond strength.

Materials and Methods

Samples and Materials

Extracted teeth used in this study (after receiving ethical clearance No. 221/KEPK/USU/2025) consisted of maxillary premolars obtained from patients aged 16–20 years (all genders) who underwent orthodontic treatment. The samples were collected from the Dental and Oral Hospital of Universitas Sumatera Utara, Medan, Indonesia, during the period of January–March 2025 (medical records). The inclusion criteria were teeth without hypoplasia, attrition, fractures, caries, or previous prosthetic restoration. Cylindrical nickel-chromium (Ni-Cr) alloy specimens (KeraN), measuring 5 mm in diameter and 3 mm in height, were prepared in accordance with ISO 9917-2:2017 and ANSI/ADA No. 96 specifications.

For the cementation procedure, the resin patterns were fabricated using DuraLay inlay pattern resin. The self-adhesive resin cement employed in this study was dental-grade, LED light-cured cement.

Experimental Design

This research was designed as a laboratory-based experimental study with a factorial experimental design. By following the Federer's representative sampling techniques, in terms of the following equations,

$$(t - 1)(r - 1) > 15 \dots(1)$$

The samples were divided into six groups (each consisting of six samples), totaling 36 specimens as detailed in Table 1.

Table 1: Samples distribution

Groups	Parameters		Number
	Power(watt)	Angle (°)	
A1	2.0	30	6
A2	2.0	60	6
A3	2.0	90	6
B1	4.0	30	6
B2	4.0	60	6
B3	4.0	90	6

Thirty-six extracted from the tooth samples (all genders with ages of 16-20), caries-free upper premolars were selected. The teeth were stored in distilled water containing 0.5% chloramine to inhibit bacterial growth. Each tooth was embedded to one-third of its length into self-cure acrylic resin blocks measuring 20 × 20 × 20 mm. The blocks were positioned using a dental surveyor's (Dentsma) reference table set to zero. An analyzing rod was used to evaluate the convexity of the preparation area. To maximize the flat enamel area on the proximal surface, 1 mm of enamel was removed using carbide burs. The depth of the preparation was verified using a putty index and a periodontal probe. The surfaces were then cleaned and polished with non-fluoridated pumice using a rubber cup at 2,500 rpm for 10 seconds⁽²²⁾.

Materials Preparation

Preparation of Metals Ni-Cr

During the setting process, the crucible former was carefully removed, and the casting ring was positioned sprue-side down in a heating furnace. The temperature was initially set at 49°C for 30 minutes,

then increased to 850°C and maintained for 45 minutes. A nickel–chromium alloy, with a thermal expansion coefficient of $14.1 \times 10^{-6} \text{ K}^{-1}$ and an elastic modulus of 115 GPa, was melted and cast using an electric casting machine.

Following casting, the alloy was allowed to cool and solidify before the investment mold was broken. Residual investment material was removed through sandblasting and ultrasonic cleaning. The sprue was then separated from the metal specimen, and all samples were finished and polished using sandpapers with grit sizes ranging from 150 to 1000. Finally, each specimen was labeled according to its respective group for subsequent diode laser treatment.

Laser Surface Preparation

The surface treatment technique was carried out by following previous studies with some modifications^(23,24). Firstly, a diode laser with a wavelength in the micrometer range, was applied from a distance of 10 mm for 15 seconds at either 2.0 or 4.0 watts, with varying irradiation angles as specified in Table 1. Following laser irradiation, the Ni-Cr specimens were cleaned ultrasonically in distilled water for 10 minutes and dried with an air spray. Each sample was then treated with a cleaning agent (Zir-Clean) for 15 seconds, rinsed with distilled water, and dried again with an air spray. A metal primer (Z-Prime) was applied to the surface using a microbrush and air-dried for 20 seconds prior to cementation.

Cementation

Each group was cemented to the prepared teeth using automix self-adhesive resin cement. To standardize the cement layer thickness, a 0.5 kg load was applied and maintained for 10 minutes. Excess cement was carefully removed, an oxygen-inhibiting gel was applied to the margins, and the cement was light-cured with an LED device for 20 seconds at a distance of 2 mm from the sample surface. The cemented specimens were stored in an incubator at 37°C for 24 hours to simulate intraoral conditions⁽²⁴⁾.

Experimental Testing

Mechanical Testing

The shear bond strength (SB-Strength) of the adhesive bridge specimens was measured using a universal testing machine (Torse UTM AMU-10, Tokyo, Japan) at a crosshead speed of 1 mm/min. Each specimen, embedded in an acrylic block, was mounted on the machine for testing. The failure loads were recorded and converted into MPa using the following formula:

$$\lambda = \frac{F}{A} \dots (2)$$

As λ denotes the SB-strength, F is the applied force, and A is the adhesive area of the cylindrical specimen^(25,26).

Morphological Analysis

Surface roughness was evaluated using atomic force microscopy (AFM) (Nanosurf easyScan 2 Controller, Ltd., Japan) especially in the irradiated area, and scanning electron microscopy (SEM) (Prisma E SEM, Thermo Fisher Scientific, U.S; accelerating voltage of 15-20 kV) at 500 to 1000x magnification was carried out to assess the morphological features⁽²⁷⁾.

Statistical analysis

Univariate analysis was performed to evaluate the SB-strength of adhesive bridge specimens treated with diode laser irradiation at 2.0 and 4.0 watts and irradiation angles of 30°, 60°, and 90°. An unpaired t-test was used to determine the effect of laser power and beam angle variation on SB-strength. One-way ANOVA was applied to assess the influence of different laser power settings and irradiation angles on the SB-strength of the adhesive bridges.

Results

Effects of Power Variations on SB-strength of Adhesive Bridge

The initial assessment of SB-strength was conducted by evaluating the influence of varying laser power levels across different irradiation angles. The results are presented in Table 2.

Table 2: Average SB-strength Values of Adhesive Bridge Prostheses Based on Laser Power and Irradiation Angles (30°, 60°, and 90°) on Ni-Cr Alloy Surfaces

No. Sample	Shear-bond Strength of Adhesive Bridge in Each Group (MPa)					
	Group A (2.0 Watt)			Group B (4.0 Watt)		
	A1	A2	A3	B1	B2	B3
1	3.99	3.41	1.89	3.14	4.59	9.49**
2	2.76	3.54	3.16**	1.41*	3.07	2.20*
3	4.41	3.49	2.91	4.46**	3.68	6.28
4	8.07**	3.33	2.59	2.11	1.06*	5.59
5	4.97	2.26*	1.52*	1.96	2.27	4.18
6	2.69*	4.98**	2.21	2.24	4.67**	3.91
Average	4.48	3.50	2.38	2.55	3.22	5.27
SD	±1.97	±0.86	±0.62	±1.08	±1.39	2.50

Desc: **The highest; *the smallest

At 2.0 W, the mean SBS decreased with increasing angle, with values of 4.48 ± 1.97 MPa (30°, A1), 3.50 ± 0.86 MPa (60°, A2), and 2.38 ± 0.62 MPa (90°, A3). In contrast, at 4.0 W, SBS increased with irradiation angle, with mean values of 2.55 ± 1.08 MPa (30°, B1), 3.22 ± 1.39 MPa (60°, B2), and 5.27 ± 2.50 MPa (90°, B3), indicating a different interaction pattern at higher laser power.

Normality test was assessed using the Shapiro-Wilk test, yielding the p-values > 0.05 groups at 2.0 watts with irradiation angles of 30° (Group A1), 60° (Group A2), and 90° (Group A3) were 0.215, 0.245, and 0.909, respectively. For the 4.0-watt groups, the p-values at 30° (Group B1), 60° (Group B2), and 90° (Group B3) were 0.342, 0.629, and 0.785, respectively. Normality test was carried out in data for all groups using the Shapiro–Wilk test and indicated no significant deviation from normality (p > 0.05 for all groups). However, given the small sample size (n = 6), these results should be interpreted with caution on the effects of laser power and irradiation angle on the SB-strength of adhesive bridge prostheses on Ni-Cr alloy surfaces.

Low Power

Based on the results of the Shapiro-Wilk test, the significance values (p) for all tested groups of Ni-Cr metal samples ranged from 0.215, 0.245 to 0.909, indicating that the data were normally distributed (p>0.05) (Appendix). One-way ANOVA analysis yielded a significance value of p = 0.0001 (p < 0.05), demonstrating a significant effect of 2.0-watt laser power with irradiation angles of 30°, 60°, and 90° on

the SB-strength of adhesive dental bridge prostheses on Ni-Cr alloy. Given the p-value of 0.0001, a Post Hoc test was subsequently performed to identify which groups contributed to the observed effect. The Post Hoc test results revealed that the groups treated with 2.0-watt laser power at irradiation angles of 30° and 90° showed a p-value of 0.0001 ($p < 0.05$), indicating that these group pairs had a significant influence (Table 3).

Table 3: One-way ANOVA Test Results: Effect of 2.0-Watt Laser Power and Irradiation Angles (30°, 60°, and 90°) on SB-strength of Adhesive Bridge Prostheses on Ni-Cr Alloy

Groups	(n)	Shear-bond Strength (MPa)	P Value
		Average ± SD	
A1	6	4.48±1.97	0.042*
A2	6	3.50±0.86	
A3	6	2.38±0.62	
Significant differences among groups			P Value
Group A1 – A2			0.412
Group A1 – A3			0.034*
Group A2 -- A3			0.320

Desc: * Significant

High Power

One-way ANOVA analysis also resulted in a significant value of $p = 0.0001$ ($p < 0.05$), indicating a significant effect of 4.0-watt laser power with irradiation angles of 30°, 60°, and 90° on the SB-strength of adhesive dental bridge prostheses on Ni-Cr. Post hoc analysis using the Least Significant Difference (LSD) test indicated that the B3 group exhibited significantly higher shear bond strength compared to B1 ($p = 0.044$). However, no statistically significant differences were observed between B1 and B2 ($p = 0.793$) or between B2 and B3 ($p = 0.145$). (Table 4).

Table 4: Post-hoc LSD on The Effect of 4.0-Watt Laser Power and Irradiation Angles (30°, 60°, and 90°) on SB-strength of Adhesive Bridge Prostheses on Ni-Cr Alloy

Groups	(n)	Shear-bond Strength (MPa)	P value
		Average±SD	
B1	6	2.55±1.08	0.045*
B2	6	3.22±1.39	
B3	6	5.27±2.50	
Post-hoc LSD			P Value
Groups B1 – B2			0.793
Groups B1 – B3			0.044*
Groups B2 -- B3			0.145

Desc: * Significant

Analysis of Morphological and Surface Roughness

When the SB-strength tests have been evaluated, each sample was further evaluated using scanning electron microscopy (SEM) and atomic force microscopy (AFM) to observe surface changes on the Ni-Cr alloy following diode laser surface treatment. Figures 1 and 2 present the SEM and AFM results for each group, respectively.

SEM analysis demonstrated that diode laser irradiation at 2.0 W influenced the surface morphology of Ni-Cr alloys depending on the beam angle. At a 30° irradiation angle, the surface exhibited pronounced irregularities characterized by increased roughness, the presence of shallow grooves, and the formation

of localized micro porosities (Figures 1-A1a and 1-A1d). In contrast, samples irradiated at 60° showed comparatively smoother surfaces with fewer irregular features and only minimal shapes of micro porosities (Figures 1-A2b and 1-A2e). At 90°, the surface appeared smoother, with almost no surface disruption and no clearly defined micro porosity, indicating a lower degree of surface modification (Figures 1-A3c and -A3f).

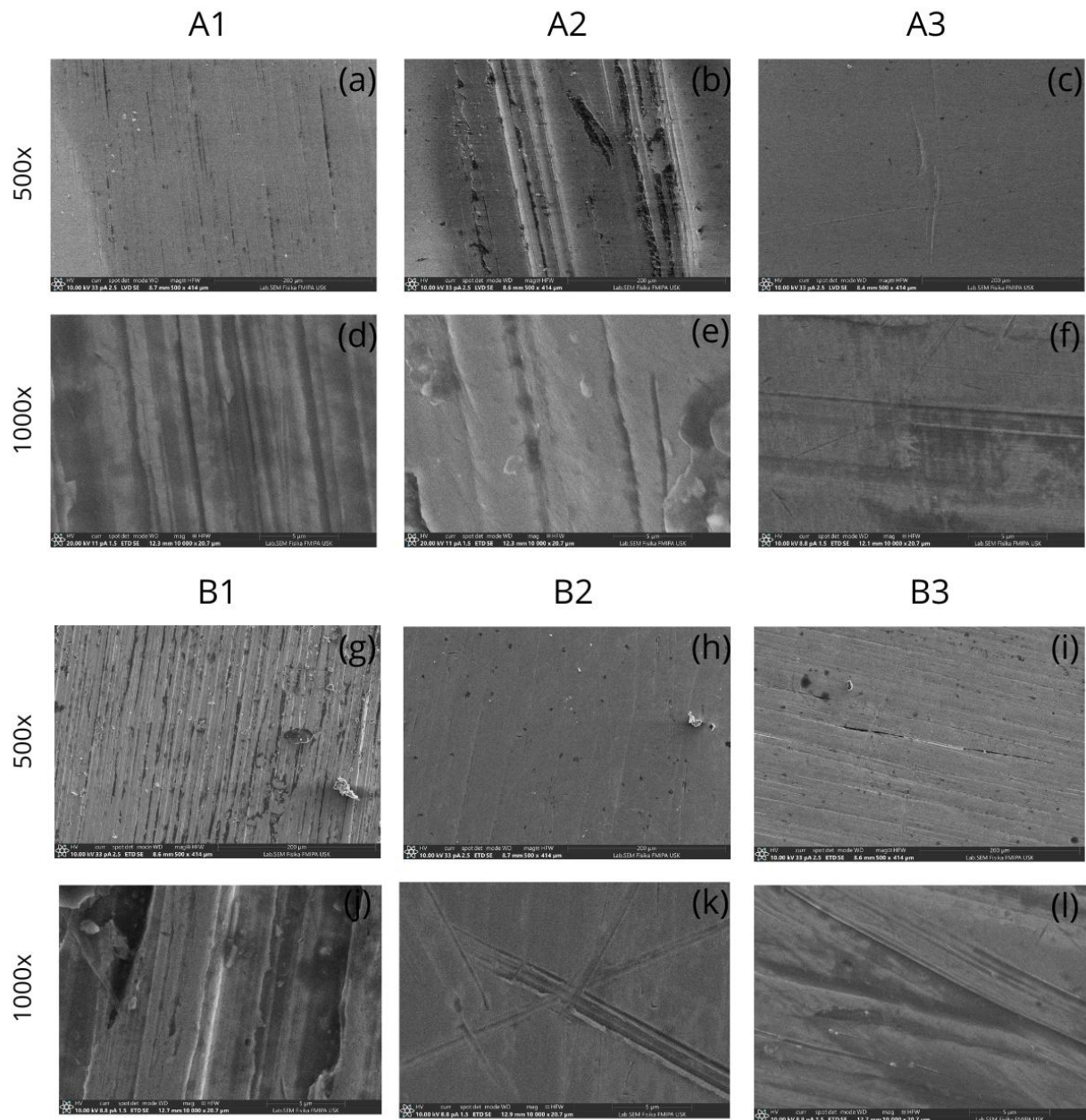


Figure 1: SEM micrographs at 500× and 1000× magnification of Group A1 (a and d), A2 (b and e), A3 (c and f), Group B1 (g and j), B2 (h and k), and B3 (i and l).

The surface roughness in Figure 2 displayed that lower degree at 30° had more irregularities indicated in Figure 2-A1 and -B1. Similar results were observed in A2 and B2 with 60°, while the 90° appeared to be smoother with no fissure-like shapes compared to the other groups. Based on Table 5, At 2 W, the lowest roughness was observed at 30°, with Ra values of 4.7–5.7 nm, accompanied by relatively low peak-to-valley parameters (Ry = 25 nm, Rp = 14 nm, Rv = -11 nm). When we increased to 60°, a substantial increase in roughness (Ra = 33–40 nm), indicating more pronounced surface irregularities. At 90°, roughness decreased compared to 60° (Ra = 19–22 nm; Ry = 79 nm), suggesting a partial reduction in surface

disruption at perpendicular direction. A similar trend was observed at 4 W, although overall roughness values were higher. At 30°, Ra increased to 10–12 nm (Ry = 43 nm), indicating enhanced surface modification compared to 2 W. The highest roughness was again recorded at 60° (Ra = 39–45 nm; Ry ≈ 150 nm), with increased peak (Rp = 79 nm) and valley depths (Rv = -67 nm), reflecting significant surface deformation. These findings demonstrate that irradiation at 60° produces the greatest surface roughness, while 30° results in the smoothest surface, and increasing laser power amplifies the overall surface modification.

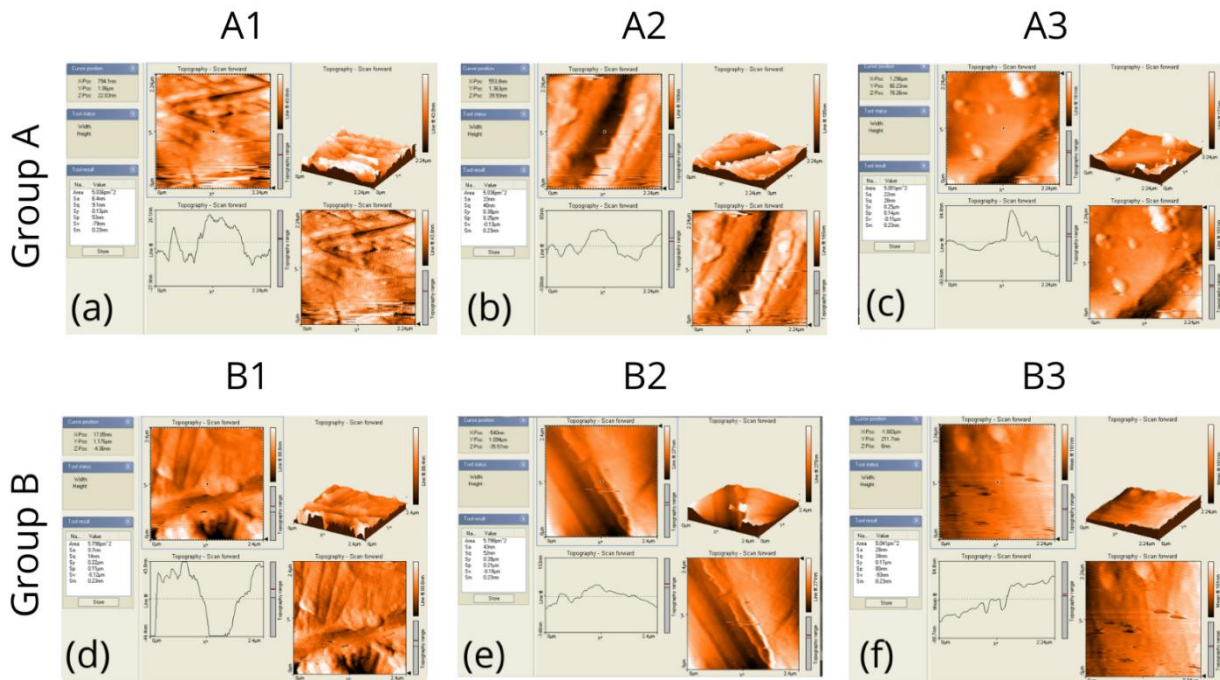


Figure 2: Surface roughness of laser power on Group A of 2.0 watt with (a, b, and c; 30°, 60°, 90° respectively) and Group B of 4.0 watt with (d, e, and f; 30°, 60°, 90° respectively)

Effects of Irradiation Angles in SB-strength

Based on the results of the Shapiro-Wilk test, the significance values (p) for all groups of metal coping samples tested ranged from 0.215 to 0.342, indicating that the data were normally distributed ($p > 0.05$). The Independent t-test yielded a significance value of $p = 0.0001$ ($p < 0.05$), demonstrating that there was no significant effect of irradiation angle at 30° with 2.0-watt and 4.0-watt diode laser power on the SB-strength of adhesive dental bridge prostheses on Ni-Cr alloy.

Similarly, the Shapiro-Wilk test for all groups of metal coping samples tested at a 60° irradiation angle produced significance values (p) between 0.245 and 0.629, confirming normal data distribution ($p > 0.05$). The Independent T-test resulted in a significant value of $p = 0.0001$ ($p < 0.05$), indicating no significant effect of a 60° irradiation angle with 2.0-watt and 4.0-watt diode laser power on the SB-strength of adhesive dental bridge prostheses using Ni-Cr alloy.

For the 90° irradiation angle, the Shapiro-Wilk test showed significance values (p) ranging from 0.785 to 0.949, demonstrating normal data distribution ($p > 0.05$). The Independent t-test also resulted in a significant value of $p = 0.0001$ ($p < 0.05$), indicating that there was no significant effect of a 90° irradiation angle with 2.0-watt and 4.0-watt diode laser power on the SB-strength of adhesive dental bridge prostheses on Ni-Cr alloy.

Discussion

Diode lasers predominantly involve heat transfer, which can modify Ni-Cr alloy surfaces. The heat generated induces re-solidification at the surface, which can influence roughness and, consequently, metal-resin adhesion. In this study, both 2.0 W and 4.0 W laser powers showed statistically significant differences among irradiation angles ($p < 0.05$). Post hoc analysis indicated significant differences between A1-A3 ($p = 0.034$) and B1-B3 ($p = 0.044$), suggesting that beam angle plays a critical role in determining bond strength. This finding indicates a statistically significant effect among the groups subjected to 4.0-watt power at irradiation angles of 30°, 60°, and 90°, as evidenced by p-values less than 0.05. A report by Sutrisman and Tamin in 2024, found a greater retention and durability at a 4.0-watt and 3 cm of focal⁽²⁸⁾.

The higher SBS observed in Group B3 (4.0 W, 90°) may be attributed to more uniform energy distribution and enhanced surface modification, however, variability in Groups A1 and B3, including relatively high values (e.g., 8.07 MPa and 9.49 MPa), indicates the presence of potential outliers that may have influenced group means. These variations are likely related to localized differences in laser-material interaction, as Ni-Cr alloys may undergo non-uniform thermal effects, resulting in heterogeneous surface morphology. At 2.0-watt power and a 30° angle, only slight, irregular micro porosity was produced, whereas at 60° and 90° angles (Figure 1: A1, A2, and A3). Both suggested that limited micro porosity was observed at lower power (2.0 W), while higher power (4.0 W) produced more pronounced surface features that may enhance micromechanical interlocking. Micro porosity was indistinct, resulting in lower SB-strength values for these latter angles. Our assumption is due to distributed higher-energy of laser over a broader surface area, therefore; generating substantial energy led to the loss of Ni-Cr ions and the formation of micro porosity, which subsequently influenced the bond strength of metal-coping.

Lasers can achieve the irregular microporous by delivering photon-induced thermal energy that generates concave surface morphologies indicated in Figure 2, thereby facilitating cement infiltration. In prosthodontic applications, the energy and velocity of the laser influence the mechanical properties of the metal. Uneven heat distribution can lead to localized vaporization of the irradiated material, keyhole effects, and variations during the laser irradiation process⁽²⁹⁾. When a laser interacts with a metal surface, it induces localized heating to the austenitization temperature, resulting in heat accumulation and subsequent martensitic transformation, which manifests as geometric changes in the hardened region³¹ as seen in Figure 1. The SB-strength at irradiation angles of 60° and 90° was notably lower compared to that at 30°, possibly due to the effect of the diode laser wavelength (800–1064 nm), which can enhance the depth of laser penetration into the metal, thereby causing the direction of cement displacement to be more easily lifted and reducing SB-strength^(30,31).

Further confirmation obtained as a significant effect among the groups treated with 4.0-watt power at irradiation angles of 30°, 60°, and 90°, reflected by p-values less than 0.05. This outcome is attributable to the diode laser's shorter wavelength, which results in lower absorption and, at a 90° irradiation angle, allows the 4.0-watt heat input to play a more pronounced role in improving adhesion. At a 90° irradiation angle, increasing the diode laser power to 4.0-watt leads to greater penetration depth into the Ni-Cr metal. As the irradiation angle increases, the penetration depth of the laser also increases while the width of laser irradiation narrows, and compared to higher heat input at smaller angles, the energy generated is substantial, causing significant loss of Ni-Cr ions, which affects the bond strength of the metal coping^(32,33). The greater the laser energy delivered to the metal surface, the more the cement adhesion decreases, as excessive ablation from high laser energy weakens the metal's adhesive properties^(32,33).

A smaller laser convergence angle results in a larger irradiated surface area compared to 60° and 90° angles. This condition enhances adhesion and yields higher SB-strength values as the smaller convergence angle alters the direction of cement displacement from a tendency to lift off to a more parallel sliding movement along the Ni-Cr metal surface⁽³⁴⁾. Increase in SB-strength at 30° irradiation angle with 2.0-watt laser power in this study was attributed to mechanical interlocking between the resin cement, Ni-Cr alloy, and tooth structure, which can improve the retention of adhesive dental bridge prostheses. As suggested by Dewi et al. in 2019, laser energy absorption on material surfaces is influenced by specific conditions, such as irradiation angle and surface roughness⁽³⁵⁾. The heat-affected zone on the material surface was measured and compared, demonstrating that different laser powers at irradiation angles of 10°, 20°, and 30° tend to produce consistent results. However, changes in the irradiation angle impact on the size of the laser beam, thereby increasing the total laser energy delivered. When the laser beam angle shifts from perpendicular to oblique, a smaller irradiation angle results in a greater laser-irradiated area on the material surface⁽³⁶⁾. Discrepancies in our study outcomes may be due to variations in laser power, scanning speed, and material type.

The group irradiated at a 60° angle with 2.0-watt power did not show a significant difference, with a significant value of $p = 0.0001$ ($p < 0.05$), indicating no significant difference between groups irradiated at 60° with 2.0-watt and 4.0-watt power. Dundar (2021) reported that a 60° angle produces greater surface roughness compared to 45° and 90° angles when roughening titanium surfaces using a Yb:Fiber laser at a constant power setting⁽³⁷⁾. Regarding the effect of increased laser power, raising the laser power from 2 to 2.5 W can enhance the surface roughness and the SB-strength of resin cement to zirconia⁽²⁰⁾. When lasers are applied at varying angles, the SB-strength of resin cement to Y-TZP ceramic materials increases⁽³⁸⁾. Variations in findings across studies may be explained by differences in irradiation angle and the corresponding increase in laser energy.

The results for the 90° irradiation angle, shows the highest mean value at the highest power (5.27 ± 2.50 MPa). The Independent T-test for both groups demonstrated a significant level of $p = 0.0001$ ($p < 0.05$), indicating a statistically significant difference between the groups at a 90° irradiation. The diode laser, characterized by a shorter wavelength, results in lower absorption of the penetrating laser energy. At a 90° irradiation angle, the application of a 4.0-watt heat input plays a more substantial role in enhancing adhesion. The increase in diode laser power to 4.0-watts at the 90° angle leads to greater penetration depth (narrow area) into the Ni-Cr metal⁽³⁶⁾. In comparison to higher heat input at smaller irradiation angles, the energy generated during surface degradation of Ni-Cr metal is considerable, resulting in significant loss of Ni-Cr ions, which in turn affects the adhesive strength of resin cement to the metal in adhesive bridge prostheses^(32,33). Based on our null hypothesis was partially rejected as our findings showed that diode laser parameters showed a statistically significant effect on shear bond strength, although not all group comparisons demonstrated significant differences.

The limitations of this study include the evaluation of only the SB-strength between the resin cement and the Ni-Cr metal surface of adhesive bridge prostheses, without assessing the cement's adhesion to the tooth substrate. In addition, a metal primer was applied to enhance chemical bonding between the resin cement and Ni-Cr alloy, consistent with common clinical practice. However, the combined use of metal primer and diode laser irradiation may act as a confounding factor, as it is difficult to distinguish the individual contribution of laser-induced surface modification from the chemical bonding effect of the primer. Another limitation is the inability to control the cement thickness in accordance with ANSI/ADA No. 96 and ISO 9917:2003 and 4049:2000 specifications, which stipulate a maximum resin cement

thickness of 50 μm ⁽³⁹⁾. Furthermore, the manual casting process of Ni–Cr specimens may introduce internal porosity and surface inconsistencies, contributing to variability in SBS values, as reflected by the relatively high standard deviations and the presence of potential outliers. Future studies should consider incorporating CAD/CAM-fabricated metal specimens and evaluating the combined effects of laser treatment and metal primers to better simulate clinical applications and improve bonding performance.

Conclusion

There is an effect that that diode laser irradiation significantly influences the SB-Strength of adhesive bridge prostheses on Ni–Cr alloy, with a statistically significant effect observed at 2.0 W across irradiation angles of 30°, 60°, and 90° ($p = 0.042$). At 4.0 W, a similar significant effect was observed ($p = 0.045$), with the highest SBS recorded at a 90° irradiation angle. SEM observations highlight visible morphological changes at lower angles; AFM data indicate that intermediate irradiation angles (60°) produce the highest surface roughness. Importantly, the highest SBS was achieved at 90°, implying that optimal bonding performance is not solely dependent on maximum roughness but also on the uniformity and nature of surface modification induced by laser irradiation.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contributions

Conceptualization, W.M., H.Z.T., and P.W.U.R; methodology, W.M. and H.Z.T.; validation, W.M.; Formal Analysis, W.M. and I.N.; investigation, W.M.; data curation I.N.; writing—original draft preparation, W.M. and P.W.U.R; writing—review and editing, W.M.; supervision, H.Z.T. and P.W.U.R. All authors have read and agreed to the published version of the manuscript.

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التحقيق في تأثير قدرة التشعيع الليزري وزاوية الحزمة على معادن النيكل-كروم بهدف تحسين قوة الترابط القسوي للجسر اللاصق. ويني مونتي هاسليندا تامين، إندرا ناسوتيون، بوتري ويلدا، أوتامي ريتونغا

المستخلص

استخدم التشعيع الليزري على نطاق واسع لتعديل أسطح المواد عبر تغيير البنية المجهرية والطبوغرافية السطحية، إلا أن تأثير قدرة الليزر وزاوية الحزمة على قوة ترابط معادن النيكل-الكروم ما يزال غير واضح بشكل كافٍ. هدفت هذه الدراسة إلى تقييم تأثير الليزر الثنائي بزوايا مختلفة على تحسين قوة الترابط للجسر اللاصق. شملت الدراسة 36 نموذجًا معدنيًا من النيكل-الكروم و36 ضاحكًا علويًا مستخلصًا، قُسمت إلى ست مجموعات وفق زوايا التشعيع (30°، 60°، 90°) وقدرتي الليزر (2 واط و4 واط). بعد تثبيت الأسنان بالإسمنت الراتنجي، أُجري اختبار قوة الترابط القسوي، إضافة إلى فحوصات المجهر الإلكتروني الماسح ومجهر القوة الذرية. أظهرت النتائج أعلى قوة ترابط عند زاوية 90° بقدر 4 واط، تليها زاوية 30° بقدر 2 واط. كما بينت التحاليل المورفولوجية زيادة الخشونة السطحية وتحسن انتظامها، مما يشير إلى فعالية التشعيع الليزري العمودي في تعزيز موثوقية الترابط السريري للجسر اللاصق.