Al-Azhar Journal of Dentistry

Manuscript 1637

Restorative Dentistry Issue (Removable Prosthodontics, Fixed Prosthodontics, Endodontics, Dental Biomaterials, Operative Dentistry)

Effect of Metal Surface Treatment on Bonding of Porcelain to Recycled Cobalt Chromium and Nickel Chromium

Eman T. Elkallaf

Sahar A . Abdel-Aziz

Zainab R. El-Sharkawy

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Eman T. Elkallaf *, Sahar A. Abdel-Aziz, Zainab R. El-Sharkawy

Crowns and Bridges Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt

Abstract

Purpose: The current study's objective was to assess the shear bond strength between dental ceramic and recycled cobalt and nickel-chromium alloys following various surface treatments. **Materials and methods:** Seventy-two metal−ceramic samples were made and separated into the following categories: group I: nickel-chromium samples $n = 36$ and group II: cobalt-chromium samples $n = 36$. Each group was divided into four subgroups $n = 9$, subgroup 1: cast from 100 fresh alloy, subgroup 2: cast from 50% fresh alloy and 50% fragments from the first subgroup, subgroup 3: cast from 50% fresh alloy and 50 fragments from second subgroup and subgroup 4: cast from 50 fresh alloy and 50 fragments from the third subgroup. Each subgroup was split into three additional divisions ($n = 3$) according to surface treatment, division A: sandblasting, division B: metal conditioner, and division C: laser etching. All samples were veneered with porcelain. The universal testing machine was used to measure the shear bond strength. **Results:** It was discovered that subgroups 1 and 2 had the highest shear bond strength mean values for Ni/Cr and Co/Cr, respectively. Subgroups 3 and 4 were next in line. **Conclusions:** For both tested alloys, as the number of recycling times was increased, the shear bond strength was decreased. All methods of surface treatments had an influence on the bonding of porcelain to recycled cobalt-chromium and nickel-chromium alloys with varying degrees. Sandblasting allowed for the most favorable bond strength among all methods of surface treatments, followed by metal conditioner and ERYAG laser, respectively.

Keywords: Laser etching, Metal conditioner, Sandblasting

1. Introduction

As they combine the metal's strength and durability with the aesthetics of porcelain, metal−ceramic restorations have been extremely successful [1]. High noble and noble metal alloys are favored due to their biocompatibility, appropriate bonding, ease of casting, and mechanical strength. However, due to their lower cost, better mechanical qualities, and lower density, casting alloys made of base metals are frequently chosen [2].

Dental laboratories frequently remelt previously cast metal to reduce the fixed partial denture's unit cost. The metal oxide composition, which is important for the metal−ceramic bond, may change as a result of this process. To assess the strength of the bond between dental ceramic and alloys, the shear test is used [2].

Manufacturers of dental alloy advise against reusing previously melted alloy. Nonetheless, dental labs frequently repurpose surplus [3]. One contentious issue in dental practice is the practice of using melted alloys again in dental labs [4].

Many dental labs have implemented the recycling of dental alloys as a way to minimize environmental hazards and cut costs associated with the materials used. However, in order to prevent the negative consequences that are anticipated from the recasting process, alloy recycling should be done carefully. The quality of the casted part may affect the efficiency of the interface between casted products and the outer esthetic layered materials like porcelain [4].

Received 18 January 2024; accepted 15 February 2024.
Available online 29 October 2024

* Corresponding author at: Youssef Abbasst, Nasr City, Cairo 11765, Egypt.
E-mail address: Emantaha198@gmail.com (E.T. Elkallaf).

https://doi.org/10.58675/2974-4164.1637

Previous research has demonstrated how recasting affects mechanical properties by altering the macrostructure and adding tiny porosity to the recasted alloys' cores, as observed by scanning electron microscopy [5].

Bond strength is affected by alloy recasting. This reduction in the bond strength was directly associated with the elemental surface change that happened due to the recasting process [3]. It was reported that reduction of concentration of some elements occurs at the ceramic–metal interface. The concentration of nickel and chromium was decreased during recasting, and it affected the thickness of the interface between castings and porcelain [3].

Testing was done to verify the null hypothesis, which claimed that recycling had no effect on shear bond strength. Therefore, the aim of this work was to assess the shear bond strength between dental ceramic and recycled cobalt-chromium and nickel-chromium alloys that arise from various surface treatments.

2. Materials and methods

2.1. Ethical consideration

The Research Ethical Committee (REC) of Al-Azhar University's Faculty of Dental Medicine for Girls reviewed and approved the current study in accordance with a code (REC-CR-23-09).

2.2. Sample size estimation and statistical power

When comparing two or more groups or subgroups, the t test, ANOVA test, or comparable nonparametric tests will be utilized, respectively. Values varied depending on surface treatment, ranging from 48.16 ± 6.15, 43.3 ± 5.22, to 28.08 ± 4.41, according to a prior study by Kara [6]. For sample size determination, the G power analysis program (version 3.1.9.7) was used.

2.3. Samples grouping

The following categories were applied to 72 metal–ceramic samples: group I consists of 36 samples of MoguCera N nickel-chromium, and group II consists of 36 samples of Nicrallium N4 cobalt-chromium, then divided into four subgroups, totaling nine. Subgroup 1 was formed from 100 fresh alloy, subgroup 2 was formed from 50 fresh alloy and 50 fragments from the first subgroup, subgroup 3 was formed from 50 fresh alloy and 50 fragments from the second subgroup, and subgroup 4 was formed from 50 fresh alloy and 50 fragments from the third subgroup. Depending on the surface treatment, each subgroup was further divided into three divisions ($n = 3$): division A was for sandblasting, division B was for metal conditioning, and division C was for laser etching, as shown in Table 1.

2.4. Metal sample construction

2.4.1. Model construction

An engineering lathe (CNS 350: Arix, Taiwan) was used to design and mill a single stainless-steel die that was shaped like a 4×4 cylinder with a 1×5 base.

2.4.2. Construction of wax pattern

Seventy-two impressions of the one stainless steel die were taken using condensation silicon-based rubber material (Zhermack S. p.A, Italy) in plastic cylinders to produce 72 molds. Melted casting wax (Bego, DentalMart, USA) was poured into the mold space to create wax cylinders. When the wax had fully solidified, the excess was cut off with a sharp carver, and the molds' wax patterns were taken out. Produced wax patterns were divided into 36 wax patterns for the construction of cobalt-chromium samples (Nicrallium BCS dental alloy, France) and 36 wax patterns for the construction of nickel-chromium samples (Scheftner dental alloy GmbH, Germany).

Table 1. Grouping of nickel-chromium and cobalt-chromium samples.

Metal	Surface treatments	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Group I MoguCera N nickel-chromium alloys	Division A	3	3	3	3
	Division B	3	3	3	3
	Division C	3	3	3	3
Total		9	9	9	9
Group II Nicrallium N4 cobalt-chromium alloys	Division A	3	3	3	3
	Division B	3	3	3	3
	Division C	3	3	3	3
Total		9	9	9	9

2.4.3. Spruing of the wax pattern

A 2.5 mm diameter with 6 mm length wax sprue former (Wachsdraht, Bremen, Germany) was attached to one end of each wax pattern. After that, sticky wax was used to assemble the sprued wax patterns in the middle of a rubber crucible former (Whipmix, Us Dental, USA).

2.4.4. Investing

A carbon-free phosphate-bonded investment (Bellavest SH, Germany) was utilized in a ratio of 40 ml of mixing liquid to 160 g of powder and premixed for 15 s by hand with a spatula in a clean bowel until the investment had become wet, followed by mechanical mixing under vacuum using an auto mixer)Motova E. Sommer, Germany) according to the manufacturer's instructions.

2.4.5. Burning out

The ring with sprues facing down was placed in an electronically controlled burnout furnace (Vita Burnout furnace, Germany). Over the course of 20 min, the temperature was increased to 280 °C. The ring was then inverted to the correct position, that is, facing the sprue upward. Then the temperature was raised up to 970 °C with 5 °C/min and remained at this temperature for 1 h before casting.

2.4.6. Casting

Casting was performed using a high-frequency induction centrifugal casting machine (Dentalfarm Rotojet 2 Casting Machine, Italy). For subgroup (1): 21 g of preweighed fresh alloy was used (100 fresh alloy). For subgroup (2): the sprues and button fragments were separated from subgroup (1) using rotary carborundum separating disc (CNBTR, Tmall, Korea) and micro motor (Marathon, Indiamart, Korea). Then, fragments were treated before recasting by airborne-particle abraded with Al_2O_3 (200-grit) at 0.4 MPa using an airborne particle-abrasive device (Airborne particle abrasive device, Renfert, Germany). Sprues and button fragments were weighed, and 10.5 g fragments were taken to be cast with 10.5 g fresh alloy. For subgroup (3): 10.5 g preweighed fresh alloy +10.5 g fragments from subgroup (2) was used. For subgroup (4): 10.5 g preweighed fresh alloy +10.5 g fragments from subgroup (3) was used.

2.4.7. Divesting and finishing

The casting ring was divested and the metal samples were obtained by the aid of plaster plier. The metal samples were finished using cross-cut tungsten carbide burs and silicon carbide (Carbimet paper discs: Buehler, USA) under water coolant.

2.5. Surface treatments of the metal sample

2.5.1. Division A: sandblasting (n = 3)

For sandblasting, 110 μm aluminum oxide (Al_2O_3) particles were used with an airborne particle abrasive device (Airborne particle abrasive device, Renfert, Germany). A 10 mm space was left between the sample's surface and the blasting tip when it was placed in a metallic holder. Sandblasting was done for 10 s at two bars of pressure [7].

2.5.2. Division B: metal conditioner (n = 3)

Ceram bond (Bredent GmbH, Germany) was applied in a uniform layer thickness onto metal samples by a micro brush. As directed by the manufacturer, firing was completed [8].

2.5.3. Division C: laser etching (n = 3)

The Er:YAG laser (Fotona, Ljubljana, Slovenia) was utilized. A dental handpiece (R14-C) was used with a fiber-optic tip. Two bars of pressure were set for both the water and air. Moving from the bottom to the top, the application tip was kept in slight contact with the metal surface. Applied energy level of 500 mJ; pulse width of 100 μs; frequency of 10 Hz for 45 s [9].

2.6. Porcelain application

The process of building up porcelain was done by layering feldspathic porcelain (VITA Zahnfabrik, Germany).

2.6.1. Wash firing

A thin coat of wash was applied in one direction by brush to cover the entire treated surfaces of metal samples and then was dried. As directed by the manufacturer, firing was completed.

2.6.2. Opaque firing

A small bead of opaque was picked up with a brush and applied in one direction to the first coated surfaces. As directed by the manufacturer, firing was completed.

2.6.3. Body firing

Metal mold construction: To achieve a standardized layer of body porcelain of equal thickness on all the metal samples, a customized two-piece mold was fabricated. The middle portion in the mold had three cylindrical holes with a diameter of 4 mm and thickness of 8 mm, which allowed the porcelain build-up of 4 mm to metal samples of 4 mm thickness.

Every sample was inserted into one of the holes of a specially designed mold. The manufacturer's instructions were followed when mixing the dentin powder and liquid. As directed by the manufacturer, firing was completed.

2.7. Porcelain finishing and glazing

The surface of the samples was finished using a diamond abrasive stone and then polished with a rubber polisher and pumice. Glazing paste (VITA AKZENT Zahnfabrik, Germany) was mixed with glazing liquid and applied in a thin layer to porcelain surfaces using a brush, then fired according to the recommended firing cycle. Finished samples are shown in Fig. 1.

2.8. Scanning electron microscope examination

Representative samples from both groups were selected for scanning electron microscope examination (SEM) (Prisma E, Thermo Fisher Company). Samples were fixed on aluminum studs with standard diameter using carbon double sticky tape. The SEM examination of each sample was operated at an accelerating voltage of 30 KV. The examination of all groups was done at 1000 × magnification.

2.9. Thermo cycling procedure

Using an automated thermal cycling apparatus (Robota automated thermal cycle; BILGE, Turkey). All samples underwent a thermal aging procedure for 5000 cycles. Each water had dwell times of 25 s and a lag time of 10 s. 5 °C was the low temperature and 55 °C was the maximum temperature to resemble ~5 years of service in the oral cavity [10].

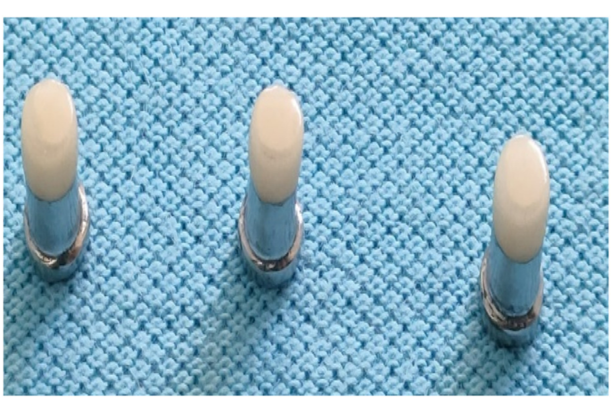

Fig. 1. Finished metal–ceramic samples.

2.10. Shear bond strength

Computer software (Bluehill Lite; Instron Instruments) was used to record the data for each sample that was mounted on computer-controlled testing equipment (Model 3345; Instron Industrial Products, Norwood, USA) with 5 kN a load cell. Tightening screws secured each sample to the testing machines, lower the immovable part through custom made metal housing device with a central cavity into which the metal rod fit (dimensions: 4 × 4 mm). Shear test was done at the ceramic–metal interface using a metallic rod attached to the upper movable part through which a compressive load was applied. The shear was determined as shown $\tau = P/\pi r2$, where r is the radius (mm) of the disc, τ is the shear bond strength (MPa), and P is the load at failure (N) $\pi = 3.14$.

2.11. Evaluation of mode of failure

A digital stereomicroscope (Scope Capture Digital Microscope, China) was used to examine each fractured sample. The types of failure were classified according to the following types [11]:

(1) Cohesive failure: failure entirely within porcelain.
(2) Adhesive failure: failure between metal and porcelain.
(3) Mixed failure: the combination of adhesive and cohesive failure.

3. Results

3.1. Statistical analysis of the results

3.1.1. Scanning electron microscope analysis

All tested samples showed the absence of voids, which was observed through the interface of test pieces composed of fresh alloys, as shown in Fig. 2.

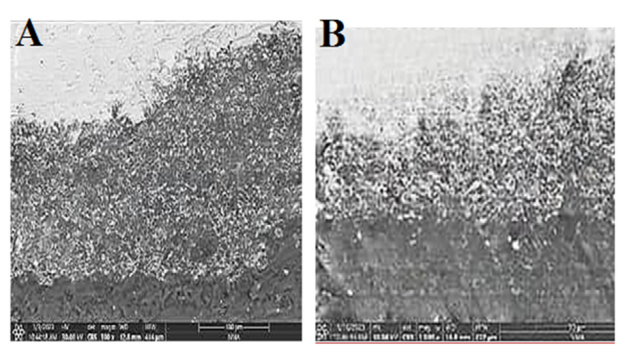

Fig. 2. Interfacial region of fresh alloys: (a) nickel-chromium sample; (b): cobalt-chromium sample.

All tested samples showed an extensive presence of voids, which was observed through the interface of test pieces composed of recycled alloys as shown in Fig. 3.

3.1.2. Shear bond strength results

Change in the shear bond strength (interdivisions comparison) with the mean ± SD of shear bond strength for all subgroups of Ni/Cr and Co/Cr alloys with different types of surface treatment (laser, metal conditioner, and sandblasting) was shown in Table 2.

3.1.3. Subgroup (1)

Ni/Cr: The mean of shear bond strength was 40.97 ± 11.24 MPa in the laser division, increased to 46.33 ± 8.37 MPa in the metal conditioner, and the highest value 57.42 ± 12.63 MPa was achieved in the sandblasting division.

Co/Cr: The mean of shear bond strength was 38.47 ± 9.36 MPa in the laser division, increased to 42.83 ± 10.82 MPa in the metal conditioner, and the highest value 51.38 ± 13.26 MPa was achieved in the sandblasting division.

The Tukey posthoc test revealed that, for both types of metals (Ni/Cr and Co/Cr), there was a significant difference between sandblasting and the other divisions but not between laser and metal conditioner. The ANOVA test revealed that the overall *P* value was statistically significant.

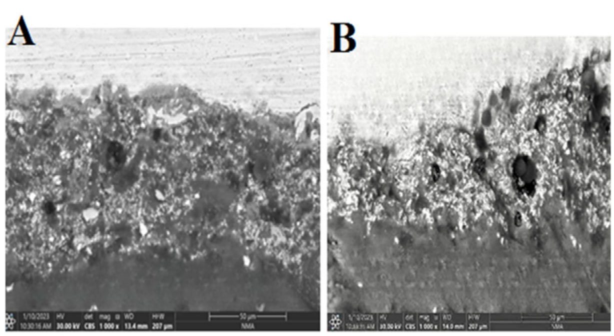

Fig. 3. Voids in the interfacial region of recycled alloys: (a) nickel-chromium sample; (b) cobalt-chromium sample.

3.1.4. Subgroup (2)

Ni/Cr: In the laser division, the mean shear bond strength was 37.22 ± 12.52 MPa; in the metal conditioner, it rose to 43.95 ± 9.36 MPa; and in the sandblasting division, it reached its highest value at 49.63 ± 15.23 MPa.

Co/Cr: The laser division had the lowest mean shear bond strength at 34.20 ± 8.31 MPa, which rose to 38.93 ± 14.92 MPa in the metal conditioner. The sandblasting division achieved the highest value at 46.42 ± 13.82 MPa.

The Tukey posthoc test revealed that, for both types of metals (Ni/Cr and Co/Cr), there was a significant difference between sandblasting and the other divisions but not between laser and metal conditioner. The ANOVA test revealed that the overall *P* value ($P \leq 0.05$) was statistically significant.

3.1.5. Subgroup (3)

Ni/Cr: In the laser division, the mean shear bond strength was 31.21 ± 11.44 MPa; in the metal conditioner, it rose up to 38.93 ± 6.93 MPa; and in the sandblasting division, it reached its highest value at 44.61 ± 14.36 MPa.

There was a statistically significant difference between metal conditioner and laser or between laser and metal conditioner and sandblasting.

Co/Cr: The mean shear bond strength was 30.42 ± 9.15 MPa in the laser division, 33.27 ± 10.24 MPa in the metal conditioner, and 40.93 ± 12.62 MPa in the sandblasting division, where it peaked.

There was a statistically significant difference between metal conditioner and laser and a

Table 2. Mean ± SD of shear bond strength for all subgroups of Ni/Cr and Co/Cr alloys with different types of surface treatment (laser, metal conditioner, and sandblasting).

Ni/Cr	Laser	Metal conditioner	Sandblasting	*P* value**
Subgroup 1	40.97 ± 11.24^{B}	46.33 ± 8.37^{B}	57.42 ± 12.63^{A}	0.000^{S}
Subgroup 2	37.22 ± 12.52^{B}	43.95 ± 9.36^{B}	49.63 ± 15.23^{A}	0.004^{S}
Subgroup 3	31.21 ± 11.44^{B}	38.93 ± 6.93^{AB}	44.61 ± 14.36^{A}	0.000^{S}
Subgroup 4	25.83 ± 7.04^{C}	25.93 ± 9.05^{B}	33.28 ± 7.91^{A}	0.001^{S}
Co/Cr	**Laser**	**Metal conditioner**	**Sandblasting**	***P* value**
Subgroup 1	38.47 ± 9.36^{B}	42.83 ± 10.82^{B}	51.38 ± 13.26^{A}	0.000S
Subgroup 2	34.20 ± 8.31^{B}	38.93 ± 14.92^{B}	46.42 ± 13.82^{A}	0.007S
Subgroup 3	30.42 ± 9.15^{B}	33.27 ± 10.24^{B}	40.93 ± 12.62^{A}	0.003S
Subgroup 4	25.13 ± 6.43^{C}	25.38 ± 4.28^{B}	29.30 ± 4.18^{A}	0.000S

S, significant ($P \leq 0.05$); NS, nonsignificant ($P > 0.05$). **Overall *P* value of interdivisions comparison.

A and B capital letters for interdivisions comparison and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

nonsignificant difference between sandblasting and the other divisions.

3.1.6. Subgroup (4)

Ni/Cr: In the laser division, the mean shear bond strength was 25.83 ± 7.04 MPa; in the metal conditioner, it raised up to 25.93 ± 9.05 MPa; and in the sandblasting division, it reached its highest value at 33.28 ± 7.91 MPa.

Co/Cr: In the laser division, the mean shear bond strength was 25.13 ± 6.43 MPa; in the metal conditioner, it raised up to 25.38 ± 4.28 MPa; and in the sandblasting division, it reached its highest value at 29.30 ± 4.18 MPa. There was a significant difference between the divisions for both kinds of metals (Ni/Cr and Co/Cr), according to the Tukey posthoc test.

Change in the shear bond strength (intersubgroups comparison) with the mean ± SD of shear bond strength for all subgroups of Ni/Cr and Co/Cr alloys with different types of surface treatment (laser, metal conditioner, and sandblasting) was shown in Table 3.

3.1.7. Ni/Cr

Laser: subgroup (1) achieved the highest mean shear bond strength (40.97 ± 11.24 MPa), while subgroup (4) achieved the lowest mean (25.93 ± 9.05 MPa).

Metal conditioner: Subgroup (1) had the highest mean shear bond strength (46.33 ± 8.37 MPa), while subgroup (4) had the lowest mean (25.83 ± 7.04 MPa).

In terms of mean shear bond strength, subgroup (1) (57.42 ± 12.63 MPa) had the highest result, while subgroup (4) (33.28 ± 7.91 MPa) had the lowest. This was through sandblasting.

There was no statistically significant difference between subgroups 2 and 3 or between subgroups 1 and 2 concerning the three divisions. But subgroups 1 and 4 as well as subgroups 1 and 3 differed noticeably from one another.

3.1.8. Co/Cr

Laser: The mean shear bond strength (38.47 ± 9.36 MPa) was highest in subgroup (1) and lowest in subgroup (4) (25.13 ± 6.43 MPa). Subgroup (1) exhibited the highest shear bond strength (42.83 ± 10.82 MPa) among the metal conditioners, while subgroup (4) displayed the lowest mean (25.38 ± 4.28 MPa(. Subgroup (1) attained the maximum mean shear bond strength (51.38 ± 13.26 MPa) during sandblasting, while subgroup (4) achieved the lowest (29.30 ± 4.18 MPa).

There was no statistically significant difference between subgroups 1, 2, and 3 for three divisions. However, there were notable differences between subgroups 1 and 4.

3.2. Mode of failure analysis of the fractured specimens

Adhesive, cohesive, or mixed failure types among all the surface-treated subgroups were noted and represented in Table 4.

4. Discussion

Metal–ceramic restorations are widely accepted by patients and dentists alike, and they have

Table 4. Failure mode analysis in nickel and cobalt-chromium samples.

	Adhesive	Cohesive	Mixed
Subgroup 1			
Ni–Cr	11.1	77.7	11.1
Co–Cr	11.1	66.6	22.2
Subgroup 2			
Ni–Cr	11.1	55.5	33.3
Co–Cr	22.2	66.6	11.1
Subgroup 3			
Ni–Cr	33.3	22.2	44.4
Co–Cr	33.3	22.2	44.4
Subgroup 4			
Ni–Cr	44.4	22.2	33.3
Co–Cr	55.5	11.1	33.3

Table 3. Mean ± SD of shear bond strength for all subgroups of Ni/Cr and Co/Cr alloys with different types of surface treatment (laser, metal conditioner, and sandblasting).

Ni/Cr	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4	*P* value[a]
Laser	40.97 ± 11.24^{A}	37.22 ± 12.52^{AB}	31.21 ± 11.44^{B}	25.93 ± 9.05^{C}	0.000^{S}
Metal conditioner	46.33 ± 8.37^{A}	43.95 ± 9.36^{AB}	38.93 ± 6.93^{B}	25.83 ± 7.04^{C}	0.000^{S}
Sandblasting	57.42 ± 12.63^{A}	49.63 ± 15.23^{AB}	44.61 ± 14.36^{B}	33.28 ± 7.91^{C}	0.000^{S}
Co/Cr	**Subgroup 1**	**Subgroup 2**	**Subgroup 3**	**Subgroup 4**	***P* value[a]**
Laser	38.47 ± 9.36^{A}	34.20 ± 8.31^{A}	30.42 ± 9.15^{A}	25.13 ± 6.43^{B}	0.018^{S}
Metal conditioner	42.83 ± 10.82^{A}	38.93 ± 14.92^{A}	33.27 ± 10.24^{A}	25.38 ± 4.28^{B}	0.001^{S}
Sandblasting	51.38 ± 13.26^{A}	46.42 ± 13.82^{A}	40.93 ± 12.62^{A}	29.30 ± 4.18^{B}	0.000^{S}

S, significant ($P \leq 0.05$); NS, nonsignificant ($P > 0.05$).

A, B, C capital letters for intersubgroups comparison and the means with different superscripts are statistically significantly different at $P \leq 0.05$.

[a] Overall *P* value of intersubgroups comparison.

significant applications in current dental treatment procedures [12].

With the added benefits of being less expensive and having a lower specific gravity, the majority of the properties of base metal alloys satisfy the requirements of gold alloys. Cobalt and nickel-chromium alloys, which are becoming common in restorative dentistry, are among them [13,14].

The Ni−Cr alloy type was chosen due to its excellent qualities and biocompatibility, which boost the durability of dental restorations. Its low cost, strong corrosion resistance, and high modulus of elasticity characterize it [15]. Because of its better mechanical and financial qualities, lower density, higher modulus of elasticity, strong corrosion resistance, and high bonding strength with ceramic, the cobalt-chromium alloy type was chosen [16].

A stainless steel die was made in order to standardize Ni−Cr and Co−Cr samples that were used in this study as previously performed in another study [3].

A two-piece mold that was specifically designed was made to be able to provide a uniformly thick layer of body porcelain on each of the metal samples. Five cylindrical holes in the middle of the mold, each measuring 4 mm in diameter and 8 mm in length, permitted the 4 mm porcelain build-up to 4 mm metal samples [3].

Strong metal−porcelain adhesion is essential for prosthesis longevity and clinical efficacy [17].

The most popular technique for increasing the metal's surface roughness is sandblasting, which also produces undercuts and micropores for the porcelain's mechanical adhesion. It was reported that sandblasting with 110 m Al_2O_3 led to substantial changes in the surface texture with increased surface irregularities of both alloys [18].

The idea behind the Er: YAG laser was that it could eliminate the particles through a process known as ablation that produces micro-porosities and enhanced micromechanical retention. This process involves micro-explosion and vaporization. The laser unit's settings for this study were 500 mJ pulse energy, 10 Hz frequency for 45 s, and 100 μs pulse width, which was in line with findings from another study [19].

According to certain authors, the most appropriate method for ascertaining the bond between two materials is the shear test, because it is simple, easy to perform, and produces rapid results [20,21].

This study's findings were corroborated by another [22], which found that the sandblasting method yielded the highest bond strength and laser irradiation less than the sandblasting method due to the surface density of grooves and porosities generated by laser etching was lower in comparison with the sandblasting method.

Additionally, a different study found that the sandblasting subgroup had the highest shear bond strength (SBS) mean value, and the laser-etching subgroup had the lowest mean value. Co−Cr alloys' surface irregularities increased, and their surface texture underwent significant changes after being sandblasted with 110 μg Al_2O_3 [6].

Regarding metal bonding agent application, improved SBS results in the present study matched those of the other study. Compared to Co−Cr specimens without bonding agents, specimens with bonding agents showed a noticeably stronger bond [23].

The reuse of previously melted and cast alloys is a routine procedure used in dental laboratories to further reduce the cost of dental restorations. This procedure is widely used in everyday practice [24].

The results of the present study were in agreement with another study by Meenakshi et al. [25], which found that the metal−ceramic bond strength decreased significantly with multiple recastings.

Another study found that there was a significant decrease in the bond strength value when the content of recast metal increased, thus making the metal−ceramic bond weaker [26]. The reduction in the bond strength in this study can be attributed to the presence of interfacial voids, which was supported by a scanning electron microscope and congruent with another study [27].

Cohesive failure mode within the porcelain is the most desirable failure mode, indicating that the metal−porcelain bond was stronger than that within porcelain and that more destructive force was needed to separate the metal and porcelain [7]. This failure mode was in agreement with the high SBS values of subgroups (1, 2) of both alloys. Mixed failure indicated that the bond strength in some areas was not strong enough, and this was consistent with the SBS values of subgroup (2). Adhesive failure is not an ideal situation because this indicates a lower bond between the metal and ceramic than that within the ceramic interior, and fewer destructive forces were needed to separate them. This failure mode was in agreement with the SBS values of subgroups (4) of both alloys [28].

The current study was not free of restrictions; this study limits the evaluation of some other properties, such as compressive strength and color stability.

4.1. Conclusions

(1) All surface treatment methods had varying degrees of impact on porcelain's ability to bond with recycled nickel and cobalt-chromium alloys. Out of all the surface treatment techniques, sandblasting produced the strongest bond, which was then followed by metal conditioner and ERYAG laser, in that order.
(2) Shear bond strength decreased for both tested alloys as the number of recycling times increased, though the lowest one still surpassed the acceptable limit of bond strength as advised by ISO standards.

4.2. Recommendation

To learn more about the connection between metal surface treatments and porcelain bond strength, more research and larger sample-size clinical studies are required to guide the development of more durable bonds and ensure their long-term survival in the oral cavity.

Ethical information

The Research Ethical Committee (REC) of AL-Azhar University's Faculty of Dental Medicine for Girls reviewed and approved the current study in accordance with a code. REC-CR-23-09.

Funding

The Authors declare they didn't receive any external funding.

Conflicts of interest

There are no conflicts of interest.

Acknowledgements

First and foremost. With deep appreciation, I would like to thank Fathea Elsayed Abdel-Rahman Hasan, assistant lecturer in crowns and bridges at the Faculty of Dental Medicine for Girls, Al-Azhar University, for her continuous guidance during the writing of this thesis.

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