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Effect of alloy type and surface conditioning on roughness and bond strength of metal brackets

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The effect of 5 different surface conditioning methods on bonding of metal brackets to cast dental alloys was examined. The surface conditioning methods were fine (30- μm) or rough (125- μm) diamond bur, sandblasting (50- μm or 110- μm aluminum oxide [Al_2O_3]), and silica coating (30- μm silica). Fifty disc-shaped specimens of 5 different alloys (gold-silver, palladium-silver, nickel-chromium, cobalt-chromium, and titanium) were ground with 1200-grit silicone carbide abrasive and polished before being reused for each conditioning method. Polished surfaces were used as negative controls. After measuring surface roughness (R_z), metal brackets were bonded to the conditioned alloys with a self-curing resin composite. Specimens were thermocycled (5000 times, 5°–55°C, 30 seconds), and shear bond tests were performed. Significantly higher ($P < .001$) surface roughnesses were observed with use of the rough diamond bur ($R_z \sim 33 \mu\text{m}$), 110- μm Al_2O_3 ($R_z \sim 14 \mu\text{m}$), and fine diamond bur ($R_z \sim 10 \mu\text{m}$), compared with the controls ($R_z \sim 1 \mu\text{m}$). Silica coating ($R_z \sim 4 \mu\text{m}$) and 50- μm Al_2O_3 ($R_z \sim 4 \mu\text{m}$) demonstrated no significant difference ($P > .001$) in roughness when compared with the controls. The control group showed no resistance to shear forces (0 MPa). Bond values were greater (19 MPa) when silica coating was used, compared with 50- μm Al_2O_3 (7 MPa) and 110- μm Al_2O_3 (8 MPa) for all alloys tested. However, interaction between alloys and conditioning methods exhibited significant differences ($P < .0001$). (Am J Orthod Dentofacial Orthop 2004;125:42-50)

The need to bond orthodontic brackets onto various types of alloys has increased. Particularly in adult patients, metallic substrates are commonly encountered on the lingual or palatal surfaces of crowns and fixed partial dentures. To enhance the bracket-to-alloy bond strength, pretreatment of the alloy surface is required. There is widespread agreement in the literature that surface roughening is a prerequisite for achieving sufficient bracket-to-alloy bonding.¹⁻⁴

A number of techniques have been reported that mechanically facilitate metal–resin bonding.⁵⁻¹⁰ Of these systems, macromechanical retention with green stones had disadvantages, with unreliable bonding values, gap formation, and microleakage when used

in combination with lightly or highly filled resin composites.^{11,12} Micromechanical bonding systems involve sandblasting and result in improved retention between alloy and resin by cleaning oxides or greasy materials from metal surfaces. This treatment creates a very fine roughness, increasing surface area and thus enhancing mechanical and chemical bonding.¹³ However, bond strengths obtained from sandblasting alone might be insufficient, especially after thermal conditioning.^{14,15}

Advances in silane coupling agents seem to enhance bond strength by promoting a chemical bond between resin composite and alloy.¹⁶ Silane molecules react with methacrylate groups on the monomers in resin composite during free radical polymerization. The system of bonding resin composite to alloy with a silane solution applied after sandblasting produced reliable bonds,^{17,18} but organosilane coupling agents did not bond to alloy surfaces as well as they did to ceramic.^{19,20}

Many authors recommend using an intraoral sandblaster for surface roughening.^{1,4,21} Sandblasting restoration has the potential to remove significant amounts of material and could affect surface texture.²² A recently introduced air abrasion technique based on

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tribochemical silica coating provides ultrafine mechanical retention by sandblasting, as well as chemico-physical bonding between composite resin and alloy with a silane coupling agent. Metal surfaces are abraded with 30- μm grain size aluminum oxide (Al_2O_3) modified with silicic acid, called CoJet-Sand (ESPE, Seefeld, Germany), in an intraoral sandblaster. The blasting pressure embeds silica particles in the alloy surface, rendering the surface chemically more reactive to resin via silane.²³ Studies related to surface conditioning with current methods indicate that silica coating is an important advance in adhesive bonding of resin composites to alloys.³ This coating reduces the influence of alloy composition and oxide formation on the bonding mechanism, thus providing superior bond strengths than those obtained with only electroetching or chemical etching.¹³ Silica coatings are used in many dental applications,²⁴⁻²⁷ including intraoral repair of fractured ceramic surfaces involving metal exposure.²⁷ However, this system has not been investigated for orthodontic use.

The objectives of this in vitro study were to measure and compare surface roughness of a variety of alloys after various surface conditioning methods and to evaluate the shear bond strengths of metal brackets bonded to treated alloy surfaces with 5 different conditioning methods; polished surfaces served as negative controls.

Our hypothesis, based on previous reports,²⁴⁻²⁷ was that silica coating of restorative alloys would significantly enhance bond strength values of orthodontic brackets compared with the use of abrasive treatments alone. Furthermore, treatment with the rough (125- μm) diamond bur or the 110- μm Al_2O_3 were predicted to create the roughest surfaces, especially on noble alloys. The densities of these alloys are twice those of the base alloys and titanium (Ti), and the latter 2 are harder than most noble alloys; therefore, noble alloys were expected to provide the highest bond strength results.

MATERIAL AND METHODS

A total of 50 disc-shaped specimens (5 mm thick, 8 mm in diameter) of 5 different alloys (10 specimens per alloy group) were invested and cast. The specimens were then used consecutively for testing 5 different surface conditioning methods: fine (30- μm , item number: 8837.314.014, Brasseler, Lemgo, Germany) or rough (125- μm , item number: 6837.314.014, Brasseler) diamond bur, sandblasting (50- μm or 110- μm Al_2O_3) (Korox, Bego, Bremen, Germany), and silica coating (CoJet). Tables I and II summarize the characteristics of surface-conditioning methods and alloys

Table I. Compositions and manufacturers of alloys used

Alloy	Brand name	Manufacturer
Au-Ag	Degulor M	Degussa, Hanau, Germany
Pd-Ag	Ored 93	Orba, Pforzheim, Germany
Ni-Cr	Wirloy	Bego, Bremen, Germany
Co-Cr	Remanium	Dentaurum, Pforzheim, Germany
Ti	Rematitan	Dentaurum

Table II. Alloy surface-conditioning methods used

Test method	Abrasive and size	Manufacturer
Control group	1200 grit silicon carbide abrasive + silicone polishing burs (prepolish, polish, superpolish)	Struers, Struers A/S, Denmark Shofu, Ratingen, Germany
Fine diamond bur	30 μm	Brasseler, Lemgo, Germany
Rough diamond bur	125 μm	Brasseler
Sandblasting	50- μm Al_2O_3	Bego, Bremen, Germany
Sandblasting	110- μm Al_2O_3	Bego
Silica coating	30- μm silica	ESPE, Seefeld, Germany

tested. A pilot study was carried out to ensure that specimens could be reused. All alloy surfaces were first abraded with 1200-grit silicone carbide abrasive (Buehler, Lake Bluff, Ill) and polished with silicone polishing burs (prepolish: H403, polish: 0404, superpolish: 404B, Shofu, Ratingen, Germany) before being reused for each conditioning method. Polished surfaces were used as negative controls. Abraded and polished specimens were cleaned for 10 minutes in an ultrasonic bath (Branson, Ultrasonic Cleaner, Shelton, Conn) containing ethylacetate and then air-dried with oil-free air.

The cylindrical diamond burs, connected to a holding jig, with their shafts parallel to the surface of the specimen, were rotated at 40,000 rpm under water spray and applied at a force of approximately 1 N, as set by the apparatus. Sandblasting was performed vertically at approximately 10 mm with 2.5 bar pressure with an intraoral sandblasting device (Dento-Prep, RØNVIG A/S, Dagaard, Denmark).

For the silica coating process, the sandblasting device was used again but filled with CoJet-Sand. In accordance with the manufacturer's instructions, the

abrasive was applied vertically to the metal surfaces at 10 mm with 2.5 bar pressure for 13 seconds. Silane (ESPE-Sil, ESPE) was applied to conditioned specimens in this group and allowed to air-dry (5 minutes).

After each surface conditioning, the mean surface roughness depths (R_z)²⁸ of 10 specimens from the 5 main conditioning groups and the control group were measured (Perthometer S8P 4.51, Feinprüf GmbH, Göttingen, Germany). These samples were not used for the shear bond test because the roughness measurement destroyed the surface. The mean roughness value was calculated from 5 single roughness measurements. Each value represented the distance between the lowest and the highest point of the profile.

A total of 50 maxillary central-incisor metal brackets (item number: 705-018-50, Ultratrimm, Dentaureum, Pforzheim, Germany) were bonded to each conditioned alloy surface with a self-curing resin composite (Concise, 3M, St Paul, Minn). The average surface area for the bracket base was 12 mm², according to the manufacturer. Alloy surfaces were cleaned and air-dried; resin-composite was mixed according to the manufacturer's instructions and then applied to the bracket base. The bracket was placed on the alloy surface with bracket pliers and a positioning and loading device that applied a force of approximately 5 N. Before setting, excess resin was removed from the bracket periphery, and completed test specimens were stored in 0.9% sodium chloride solution at 37°C for 1 week. Specimens were then subjected to 5000 thermocycles between 5°C and 55°C, with a transfer time of 30 seconds and a dwell time of 30 seconds, in accordance with ISO standard 10477.²⁹ After thermocycling, bracket shear bond strengths were determined with a universal testing device (Zwick 1120, Ulm, Germany). For this test, the discs were mounted in a jig with the brackets positioned vertically. The shear force at a cross-head speed of 1 mm/minute was transmitted to the bracket by means of a square plate of the same size as the bracket. The force required to shear the bracket was recorded and converted into units of stress (MPa) with the known bracket area.

The results were statistically analyzed (SAS for Windows 8.02/2001, Cary, NC). The means of each group were analyzed by 2-way analysis of variance (ANOVA), with shear bond strength as the dependent variable, and the surface conditioning methods and the alloy types as the independent factors. *P* values less than .05 were considered statistically significant in all tests. Multiple comparisons were made with the Tukey test. Furthermore, because the interaction between alloy type and surface treatment

was significant ($P < .0001$), ANOVA for repeated measures and Bonferroni post hoc tests were used to determine the effect of individual surface conditioning across different alloys.

RESULTS

Figures 1 and 2 display the mean roughness and shear bond strength values associated with surface conditioning techniques and alloy materials. The 2-way ANOVA revealed significant differences ($P < .05$) between groups, depending on the combinations of surface conditioning techniques, surface roughness, and the interaction with alloy materials.

Among conditioning groups, no significant difference in surface roughness ($P > .05$) was observed between 50- μm Al_2O_3 and 30- μm silica, or between fine diamond bur and 110- μm Al_2O_3 . The lowest surface roughness values were obtained with polished control specimens ($R_z \sim 1 \mu\text{m}$), followed by 50- μm Al_2O_3 ($R_z \sim 4 \mu\text{m}$) and 30- μm silica ($R_z \sim 4 \mu\text{m}$). The roughest surfaces were produced by the 125- μm diamond bur ($R_z \sim 33 \mu\text{m}$). Gold-silver (Au-Ag) alloy was affected the most after conditioning techniques, exhibiting a mean roughness value of 14 μm , and Ti alloy was affected the least ($R_z \sim 12 \mu\text{m}$).

Significantly greater ($P < .001$) shear bond strengths with respect to the 30- μm silica (19 MPa) and the rough diamond bur (15 MPa) were observed compared with the controls (0 MPa). All brackets bonded to the polished surfaces failed during thermocycling.

Pooled values among alloys indicated that shear bond strengths were not significantly different ($P > .05$) among fine diamond (8 MPa), 50- μm Al_2O_3 (8 MPa) or 110- μm Al_2O_3 (8 MPa) conditioning treatments. The effect of individual conditioning treatments exhibited significant differences ($P < .05$) within and across the different alloy materials. Among all alloys tested, nickel-chromium (Ni-Cr; 12 MPa), Ti (12 MPa), and cobalt-chromium (Co-Cr; 11 MPa) alloys showed the highest bond strengths after all conditioning methods (not statistically significantly different from each other: $P > .05$); Au-Ag had the least favorable mean bond strength (7 MPa).

Although ANOVA for repeated measures showed a negative correlation between surface roughness and shear bond strength for 110- μm Al_2O_3 treatment (Figs 3-7), a positive correlation was found between surface roughness and bond strength for Au-Ag, Ni-Cr, and palladium-silver (Pa-Ag) (Figs 8-12).

DISCUSSION

The silica coating followed by silanization enhanced the bond strength between the metal brackets

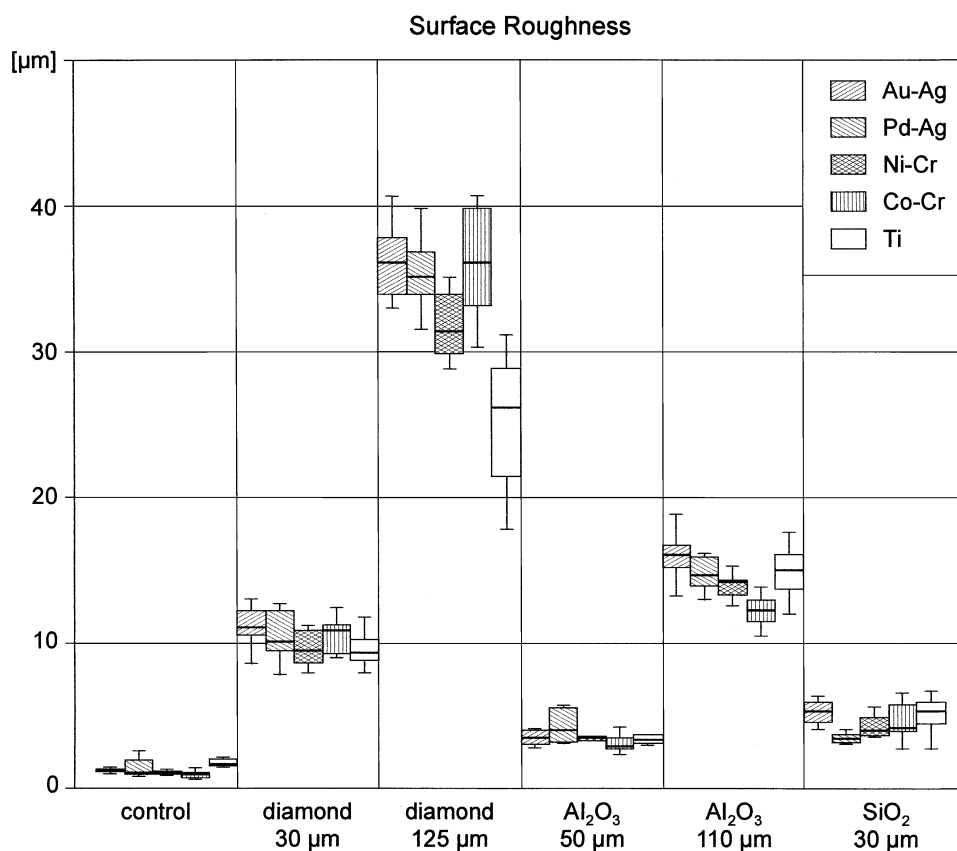


Fig 1. Surface roughnesses (μm) (R_Z) of tested alloys ($n = 10$) for each conditioning method. Results are presented as box plots. Horizontal line inside each box plot shows mean value; horizontal lines of box give 25% and 75% quartiles; lines outside box, minimum and maximum values.

and the restorative alloys and created low surface roughness values that proved our hypothesis.

The highest surface roughness was caused by sandblasting with 110- μm Al_2O_3 and the rough diamond bur, as was expected. However, this finding invalidated the other hypothesis, that roughness might contribute to higher bond strength values. In contrast to what was expected, high surface roughness obtained after rough diamond bur or 110- μm Al_2O_3 did not always result in high bond strengths.

High surface roughness could be a disadvantage, even though the bond strengths were acceptable when compared with the accepted standard of 6 to 8 MPa for metal brackets to enamel.³⁰ Interestingly, significant increase in bond strength was noted after silica coating, although surface roughness was less than those of other surface treatment methods. This result indicates that comparable bond strengths could also be achieved without creating high surface roughness with silica

coating and silanization. Clinicians cannot always identify the type of alloy used for a restoration. Because low surface roughness and high bond strengths were obtained, chair-side silica coating should be recommended for bonding brackets to all metallic restorations. This finding agrees with the research hypothesis and previous reports.^{13,24-27}

Bond strength values after sandblasting with both grit sizes were in accordance with those in some previous reports,^{1,4} although some studies have reported lower values.^{31,32} However, bond strengths obtained from both grit sizes were not significantly different for all alloys tested.

One reason for the difference in bond strengths with the same materials and methods could be storage conditions. Thermocycling is a commonly accepted means of stressing the resin composite to achieve a degree of artificial aging.^{13,21,26,29} The stressed polymer might also contribute to additional water uptake at

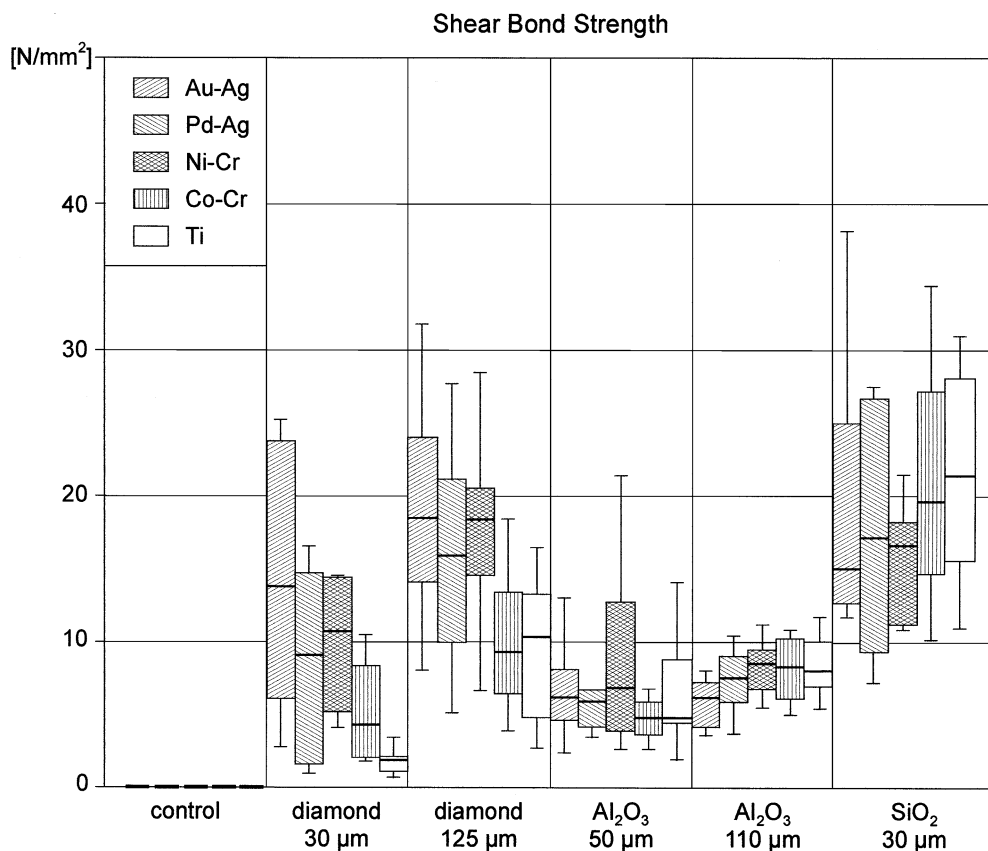


Fig 2. Shear bond strengths (MPa) of metal brackets bonded to conditioned alloy discs. N = 10 specimens per experimental group.

the bonded interface and result in weakening because of the plasticizing effect of water over an extended time. Usually bond strength values decrease^{1,18,33,34} after thermocycling, although in some cases, no differences were found.^{7,35} This finding makes it difficult to directly compare the results of this study with those of others. Whether thermocycling might have an effect on the bond strength remains a matter of discussion.

Although satisfactory bond results are obtained after sandblasting with 110-µm Al₂O₃, the material loss from these procedures is clinically important. Restorations generally remain in the mouth after the brackets are debonded, and damage to the alloy due to extreme roughening of the surfaces during the pretreatment should be avoided. Longer application time might result in more material loss from the alloy surface, creating more roughness than desired, with no increase in bond strength; prolonged polishing procedures would also be required. Therefore, the duration of air abrasion remains to be investigated.

Bond strengths are influenced by several factors,

including the type of resin composite used. A commonly used chemically cured resin composite with large fillers was chosen for this investigation. Further investigations with the use of other bracket adhesive agents should be done.

In an attempt to standardize the film thickness of the bonding resin, brackets were bonded with a force of 5 N. This experimental method is not typical clinically, and application forces can vary from clinician to clinician, thereby affecting the thickness of the bonding resin.

Conventional surface-roughness measurement techniques often require surface contact with the object being measured; this could potentially damage the surface. Evaluation of roughness through surface contact involves the use of a stylus that is drawn over the sample to detect and record variations in surface irregularity. A primary limitation of the present technique is that the stylus must be drawn perpendicular to the surface. Noncontact methods should be considered in future studies.

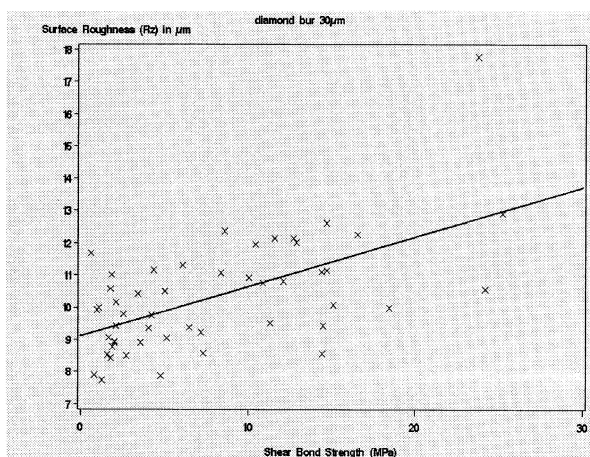


Fig 3. Scatter plots for fine diamond bur (30 μm). Pearson correlation coefficient between surface roughness and shear bond strength = 0.60, $P < .0001$ ($n = 60$).

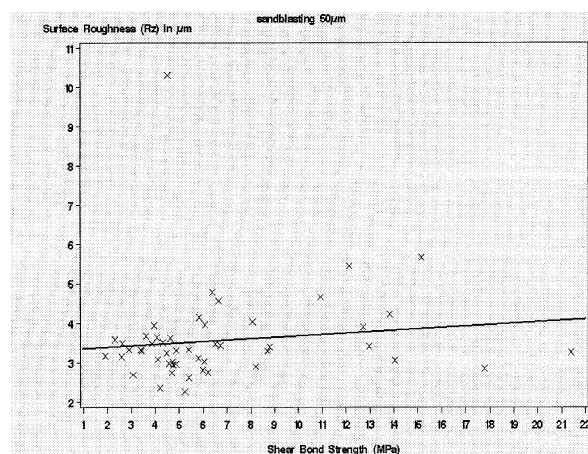


Fig 5. Scatter plots for sandblasting with 50- μm Al_2O_3 . Pearson correlation coefficient between surface roughness and shear bond strength = 0.13, $P < .3056$ ($n = 60$).

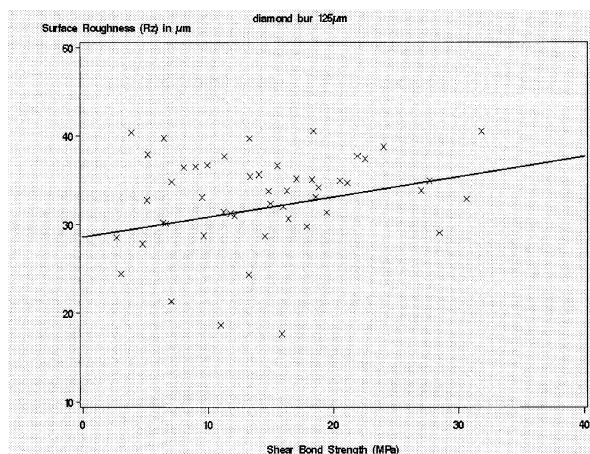


Fig 4. Scatter plots for rough diamond bur (125 μm). Pearson correlation coefficient between surface roughness and shear bond strength = 0.28, $P = .0299$ ($n = 60$).

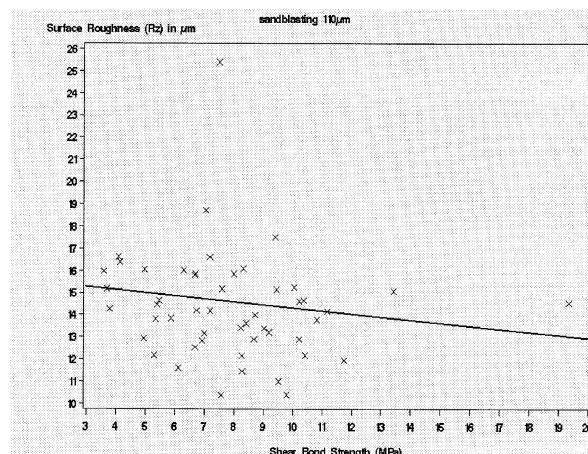


Fig 6. Scatter plots for sandblasting with 110- μm Al_2O_3 . Pearson correlation coefficient between surface roughness and shear bond strength = -0.14 , $P = .2947$ ($n = 60$).

Clinicians should consider using a rubber dam when applying a silica coating system intraorally. Manufacturers call for use of a rubber dam for 2 reasons: to avoid the mess created by sand in the mouth, and to avoid a humid environment. Roulet³⁶ reported that silanized interfaces seem to be unstable in humid conditions, and the silane bond was found to deteriorate under atmospheric moisture. Because adhesive resins absorb water, the bond between silane and the composite resin was expected to deteriorate with hydrolysis over time. It was con-

cluded that, in humid conditions, this moisture might lead to stress corrosion and growth of subcritical cracks.²⁴

The type of alloy materials to which brackets are bonded is especially important. In this study, despite well-controlled in vitro conditions, the intragroup variation was high. This result might be due to differences in alloy composition and the interaction of silanes on different metal oxides, as well as differences in particle deposition on and into such alloys.

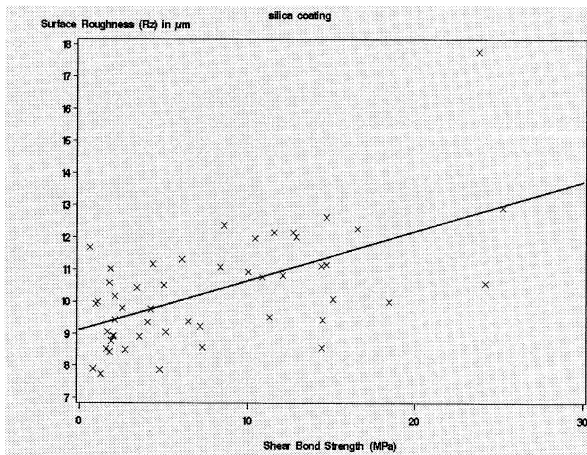


Fig 7. Scatter plots for silica coating with 30- μm silica. Pearson correlation coefficient between surface roughness and shear bond strength = 0.32, $P = .0135$ ($n = 60$).

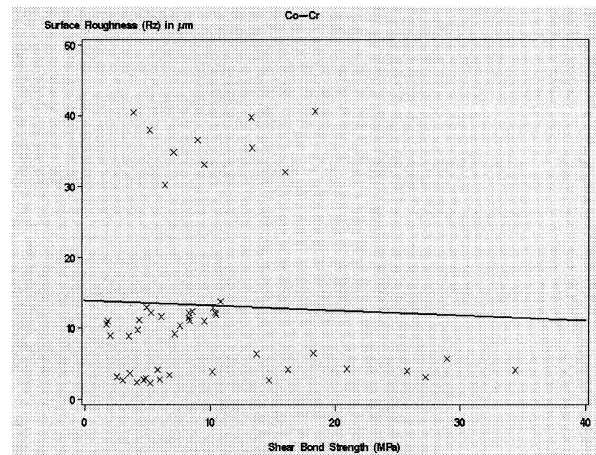


Fig 9. Scatter plots for Co-Cr. Pearson correlation coefficient between surface roughness and shear bond strength = -0.04 , $P = .7673$ ($n = 50$).

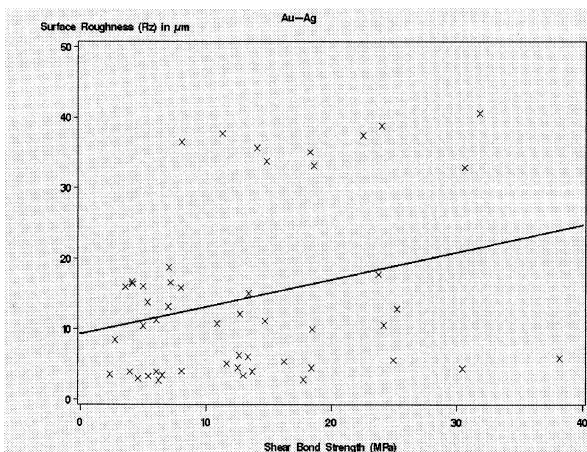


Fig 8. Scatter plots for Au-Ag. Pearson correlation coefficient between surface roughness and shear bond strength = 0.28, $P = .0299$ ($n = 50$).

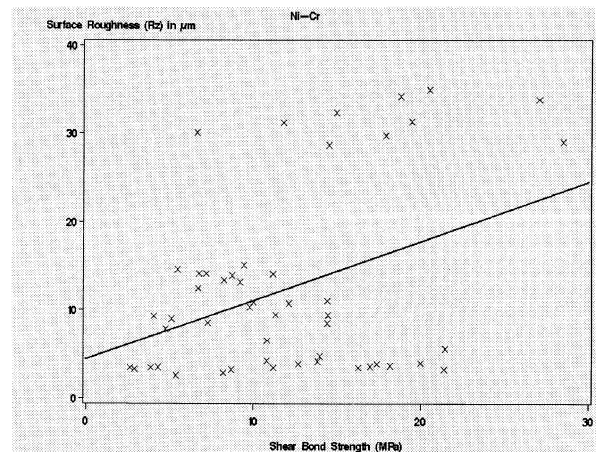


Fig 10. Scatter plots for Ni-Cr. Pearson correlation coefficient between surface roughness and shear bond strength = 0.40 $P = .0044$ ($n = 50$).

CONCLUSIONS

Within the limitations of the present study, the following conclusions can be made:

1. Diamond burs and 110- μm Al_2O_3 created higher surface roughnesses than 50- μm Al_2O_3 or 30- μm silica.
2. The highest shear bond strengths with the lowest surface roughness were obtained in the silica-coated and silanized groups for all types of alloys. The bond values of these groups were well above the accepted standard (6-8 MPa) for metal brackets to enamel.

3. The roughness and the bond strength values of the metal brackets varied with the type of alloys used and the conditioning systems applied. The roughness changed the most in Au-Ag alloy, and the Ni-Cr, Ti, and Co-Cr alloys showed the highest bond strengths, regardless of the conditioning methods.
4. Positive correlations were observed between surface roughness and bond strength for Au-Ag, Ni-Cr, and Pd-Ag, but negative correlations were seen between shear bond strength and surface roughness for 110- μm Al_2O_3 treatment.

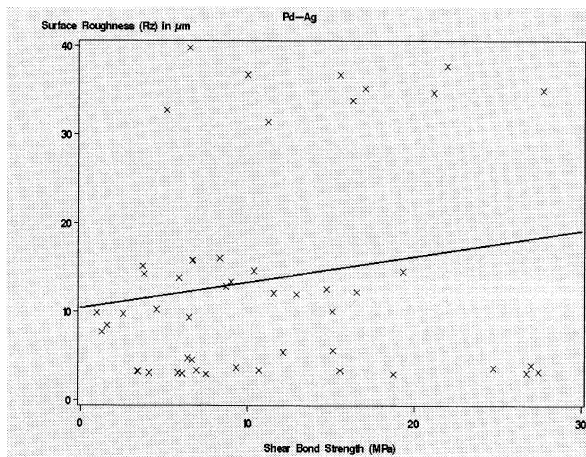


Fig 11. Scatter plots for Pd-Ag. Pearson correlation coefficient between surface roughness and shear bond strength = 0.18, $P = .2011$ ($n = 50$).

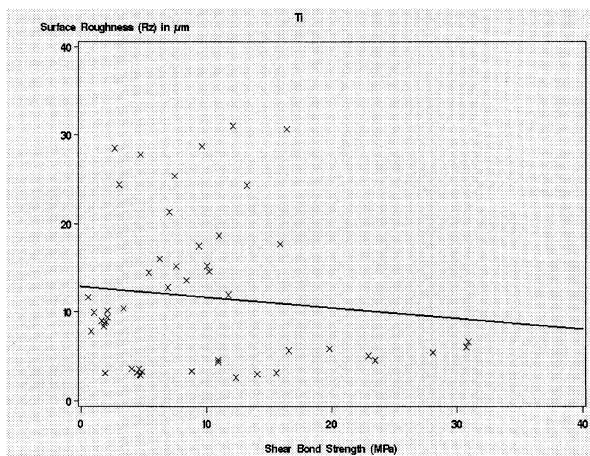


Fig 12. Scatter plots for Ti. Pearson correlation coefficient between surface roughness and shear bond strength = -0.11 , $P = .2782$ ($n = 50$).

REFERENCES

- Zachrisson BU, Büyükyılmaz T. Recent advances in bonding to gold, amalgam and porcelain. *J Clin Orthod* 1993;27:661-75.
- Gillis I, Redlich M. The effect of different porcelain conditioning techniques on shear bond strength of stainless steel brackets. *Am J Orthod Dentofacial Orthop* 1998;114:387-92.
- Özcan M, Pfeiffer P, Nergiz I. A brief history and current status of metal-ceramic surface conditioning concepts for resin bonding in dentistry. *Quintessence Int* 1998;29:713-24.
- Jost-Brinkmann PG, Bohme A. Shear bond strengths attained in vitro with light-cured glass ionomers vs composite adhesives in bonding ceramic brackets to metal or porcelain. *J Adhes Dent* 1999;1:243-53.
- Livaditis GJ, Thompson VP. Etched castings: an improved retentive mechanism for resin-bonded retainers. *J Prosthet Dent* 1982;47:52-8.
- Livaditis GJ. A chemical etching system for creating micromechanical retention in resin-bonded retainers. *J Prosthet Dent* 1986;56:181-8.
- Smith GA, McInnes-Ledoux P, Ledoux WR, Weinberg R. Orthodontic bonding to porcelain—bond strength and refinishing. *Am J Orthod Dentofacial Orthop* 1988;94:245-52.
- Tanaka T, Atsuta M, Nakabayashi N, Masuhara E. Surface treatment of gold alloys for adhesion. *J Prosthet Dent* 1988;60:271-9.
- van der Veen JH, Jongbloed WL, Dijk F. SEM study of six retention systems for resin to six differently treated metal surfaces. *Dent Mater* 1988;4:272-7.
- Alberts HF. Metal-resin bonding. *Adept Report* 1991;2:29-36.
- Eames WB, Rogers LB, Feller PR, Price WR. Bonding agents for repairing porcelain and gold. *Am J Orthod Dentofacial Orthop* 1977;2:118-21.
- Andreasen GF, Stieg MA. Bonding and debonding brackets to porcelain and gold. *Am J Orthod Dentofacial Orthop* 1988;93:341-5.
- Peutzfeldt A, Asmussen E. Silicoating. Evaluation of a new method of bonding composite resin to metal. *Scand J Dent Res* 1988;96:171-6.
- Creugers NHJ, Welle PR, Vrijhoef MMA. Four bonding systems for resin-retained cast metal prostheses. *Dent Mater* 1988;4:85-8.
- Laufer BZ, Nicholis JIJ, Townsend D. SiO_x coating: a composite to metal bonding mechanism. *J Prosthet Dent* 1988;3:320-7.
- Plueddemann EP. Nature of adhesion through silane coupling agents. New York: Plenum Press; 1982. p. 111.
- Diaz-Arnold AM, Wistrom DW, Aquilino SA, Swift EJ. Bond strengths of porcelain repair adhesive systems. *Am J Dent* 1993;6:291-4.
- Thurmond JW, Barkmeier WW, Wilwerding TM. Effect of porcelain surface treatments on bond strengths of composite resin bonded to porcelain. *J Prosthet Dent* 1994;72:355-9.
- Newman SM, Dressler KB, Grenadier MR. Direct bonding of orthodontic brackets to esthetic restorative materials using a silane. *Am J Orthod Dentofacial Orthop* 1984;86:503-6.
- Wood DJ, Bubb NL, Millar BJ, Dunne SM. Preliminary investigation of a novel retentive system for hydrofluoric acid etch-resistant dental ceramics. *J Prosthet Dent* 1997;78:275-80.
- Zachrisson Y, Zachrisson BU, Büyükyılmaz T. Surface preparation for orthodontic bonding to porcelain. *Am J Orthod Dentofacial Orthop* 1996;109:420-30.
- Kern M, Thompson VP. Sandblasting and silica coating of a glass infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. *J Prosthet Dent* 1994;71:453-61.
- Hansson O. Strength of bond with Cospan Opaque to three silicoated alloys and titanium. *Scand J Dent Res* 1990;98:248-56.
- Özcan M. The use of chairside silica coating for different dental applications. *J Prosthet Dent* 2002;87:469-72.
- Özcan M, Akkaya A. New approach to bonding all-ceramic adhesive fixed partial dentures: a clinical report. *J Prosthet Dent* 2002;88:252-4.
- Özcan M. Fracture strength of ceramic-fused-to-metal crowns repaired with two intraoral air-abrasion techniques and some aspects of silane treatment—a laboratory and clinical study (dissertation). Cologne, Germany: Medical and Dental School of Cologne; 1999.
- Özcan M, Niedermeier W. Clinical study on the reasons and location of the failures of metal-ceramic restorations and survival of repairs. *Int J Prosthodont* 2002;15:299-302.

28. International Organization for Standardization. Determination of roughness parameters Ra, Rz, Rmax by means of stylus instruments: terms, measuring conditions. DIN 4768. Geneva: International Organization for Standardization; 1990.
29. International Organization for Standardization. Dentistry-polymer-based crown and bridge materials. Amendment ISO 10477. Geneva: International Organization for Standardization; 1996.
30. Reynolds IR, von Fraunhofer JA. Direct bonding in orthodontic attachments to teeth: the relation of adhesive bond strength to gauze mesh size. *Br J Orthod* 1975;3:91-5.
31. Jost-Brinkmann PG, Drost C, Can S. In-vitro study of the adhesive strengths of brackets on metals, ceramic and composite. Part 1: bonding to precious metals and amalgam. *J Orofac Orthop* 1996;57:76-87.
32. Jost-Brinkmann PG, Can S, Drost C. In-vitro study of the adhesive strengths of brackets on metals, ceramic and composite. Part 2: bonding to porcelain and composite resin. *J Orofac Orthop* 1996;57:132-41.
33. Sorensen JA, Engelman MJ, Torres TJ, Avera SP. Shear bond strength of composite resin to porcelain. *Int J Prosthet Dent* 1991;4:17-23.
34. Burke BM, Rock WP. Factors affecting the shear bond strength of orthodontic brackets to porcelain. *Br J Orthod* 1999;26:285-90.
35. Komori A, Ishikawa H. Evaluation of a resin-reinforced glass ionomer cement for use as an orthodontic bonding agent. *Angle Orthod* 1997;67:189-96.
36. Roulet JF. Degradation of dental polymers. Basel: Karger; 1987. p. 60.