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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 [Al₂O₃]), 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 (Rz), 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 (Rz = 33 μm), 110-μm Al₂O₃ (Rz = 14 μm), and fine diamond bur (Rz = 10 μm), compared with the controls (Rz = 1 μm). Silica coating (Rz = 4 μm) and 50-μm Al₂O₃ (Rz = 4 μm) 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 Al₂O₃ (7 MPa) and 110-μm Al₂O₃ (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
Tribochemical silica coating provides ultrafine mechanical retention by sandblasting, as well as chemophysical bonding between composite resin and alloy with a silane coupling agent. Metal surfaces are abraded with 30-μm grain size aluminum oxide (Al₂O₃) 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. Studies related to surface conditioning with current methods indicate that silica coating is an important advance in adhesive bonding of resin composites to alloys. 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. Silica coatings are used in many dental applications, including intraoral repair of fractured ceramic surfaces involving metal exposure. 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, 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 Al₂O₃ 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 Al₂O₃) (Korox, Bego, Bremen, Germany), and silica coating (CoJet). Tables I and II summarize the characteristics of surface-conditioning methods and alloys 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, RONVIG A/S, Daugaard, 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 ($R_s$) 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 pressure measurements. Each 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, Dentaurum, 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 mm$^2$, 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. 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$_2$O$_3$ and 30-μm silica, or between fine diamond bur and 110-μm Al$_2$O$_3$. The lowest surface roughness values were obtained with polished control specimens ($R_s \sim 1$ μm), followed by 50-μm Al$_2$O$_3$ ($R_s \sim 4$ μm) and 30-μm silica ($R_s \sim 4$ μm). The roughest surfaces were produced by the 125-μm diamond bur ($R_s \sim 33$ μm). 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 ($R_s \sim 12$ μm).

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$_2$O$_3$ (8 MPa) or 110-μm Al$_2$O$_3$ (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$_2$O$_3$ 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
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 Al₂O₃ 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 Al₂O₃ 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. 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.

Bond strength values after sandblasting with both grit sizes were in accordance with those in some previous reports, although some studies have reported lower values. 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. The stressed polymer might also contribute to additional water uptake at
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-\(\mu m\) Al\(_2\)O\(_3\), 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.
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. Roulet 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 concluded that, in humid conditions, this moisture might lead to stress corrosion and growth of subcritical cracks.

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.
CONCLUSIONS

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

1. Diamond burs and 110-μm Al₂O₃ created higher surface roughnesses than 50-μm Al₂O₃ 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 Al₂O₃ treatment.
REFERENCES


