Comparison of Shear Bond Strength of Recycled Ceramic Brackets with Er,Cr:YSGG and Sandblasting: An In Vitro Study

Vikas Grack Chaudhary¹, Prerna Hoogan Teja², Shruti Mittal¹, Mahak Gagain³, Aashee Verma⁵, Ramanpreet Kour⁶

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Abstract

Aim: This study was performed to compare the shear bond strength (SBS) of recycled ceramic brackets with Er,Cr:YSGG, and Sandblasting.

Materials and methods: A total of 120 noncarious, sound premolars extracted for routine orthodontic treatment were used in this study. These teeth were mounted in polyvinyl cymometha tubes (20 mm × 32 mm) with the use of self-polymerizing acrylic resin. These samples were divided into six groups (Groups A, B, C, D, E, and F). Both monocrystalline and polycrystalline ceramic brackets were used in our study. Groups A and B were the control groups, whereas Groups C, D, E, and F were the study groups. The SBS of all the samples was determined with the help of universal testing machines at a crosshead speed of 0.5 mm/min until bond failure. Bracket base surfaces were observed under a scanning electron microscope. Analysis of variance and Tukey test were used to compare the SBS of all six groups. The adhesive remanent index was calculated under a stereomicroscope at 10x magnification.

Results: Maximum SBS was observed in Group A (control group, bonded with new Monocrystalline ceramic brackets; 8.01 MPa) and minimum in Group E (sandblasted, polycrystalline ceramic brackets; 5.87 MPa).

Conclusion: Both sandblasting and laser treatment were efficient for recycling polycrystalline and monocrystalline ceramics.

Keywords: Er,Cr:YSGG, Sandblasting, Shearbond Strength.

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Introduction

Fixed orthodontic appliances that provide the patient with acceptable esthetics and the orthodontist with optimal technical performance are a highly desired combination.⁷ Manufacturers have made numerous attempts to satisfy this desire. This can be accomplished by metal brackets' size being decreased, invisible or lingual brackets being made, or translucent ceramic brackets being used.⁸ Since their introduction in 1986, numerous varieties of ceramic brackets have been widely popular and an essential component of the clinician's toolkit, being offered by all major orthodontic manufacturers at this time.¹ The majority of ceramic brackets are formed of aluminum oxide and are split into two groups, polycrystalline and monocrystalline, based on the manufacturing process. These brackets are created in mills and molding machines, respectively.³

During orthodontic treatment, failure of the bonding operation occurs frequently; reports range from 3.5 to 23%.⁶ Ceramic brackets are brittle, thus it is unlikely that they will warp during the debonding process because fully debonded brackets do not show any distortion of the bracket base or changes to the slot dimensions.⁴ It is more cost-effective to repair ceramic brackets that have come loose but are still in good shape rather than purchasing new ones. According to Reynolds, the minimum bond strength a bracket needed to withstand occlusal and orthodontic stresses was 5.9–7.8 MPa.⁶

A small number of studies have discussed recycling brackets.⁷ Before rebonding, previous studies recommended a number of methods to clean adhesive residue from ceramic bases. Making debonded chemically held ceramic brackets using a silane coupling agent and burning off the composite residue is one method.

The resulting bond strength was approximately 30% lower than that of the new brackets group, although clinically practical.⁸ Several studies have employed aluminum oxide sandblasting to help roughen the base of debonded ceramic brackets and remove the glue.⁹

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Few studies have taken a look at the impact of processes for recycling on the strength of the shear bond of monocrystalline and polycrystalline ceramic brackets, whereas prior research has mainly looked at the impact of different resin removal techniques on the shear bond strength (SBS) of rebonded brackets. The shear bond capacity of rebonded brackets and structural changes in bracket bases were studied in this study’s evaluation of the effects of various recycling methods.

Materials and Methods
One hundred twenty extracted premolars with healthy and intact buccal enamel, no restorations, attrition, and structural defects, no hypoplastic, caries, or demineralization areas, and teeth that had not undergone any chemical treatment were selected for the study.

Sample Preparation
To expose the crown of the teeth above the cervical region for the purpose of bonding the bracket, each extracted premolar tooth was mounted vertically in a block of polyvinyl cymoetha-acrylate pipe with a diameter of 20 mm × 32 mm.

Brackets
Monocrystalline: Osstem perfect clear two sapphire monoceramic brackets (Hubit Co. Ltd., South Korea)

Polycrystalline bracket: Captain polyceramic brackets (Liberal Traders, New Delhi).

Grouping of the Samples
All 120 premolar teeth were color coded and randomly separated into six groups of 20 each (Group A, B, C, D, E, and F).

Group A: (Control group) (red) bonded with new monocrystalline ceramic brackets.

Group B: (Control group) (green) bonded with new polycrystalline ceramic brackets.

Group C: (Study group) (yellow) bonded with recycled (with sandblasting) monocrystalline ceramic brackets.

Group D: (Study group) (blue) bonded with recycled (laser treated) monoceramic ceramic brackets.

Group E: (Study group) (black) bonded with recycled (with sandblasting) polycrystalline ceramic brackets.

Group F: (Study group) (white) 20 bonded with recycled (laser treated) polycrystalline ceramic brackets.

Recycling Procedure
According to the procedure outlined by Chung et al.,10 debonded brackets were created. On unetched, slightly moist tooth surfaces, brackets were bonded. Carefully removing any excess bonding adhesive, the brackets were then exposed to a light-emitting diode (LED) source for 20 seconds to light-cure them. Care should be taken to remove the excess composite by using a sharp probe around the bracket before curing.

On unetched, slightly moist tooth surfaces, brackets were bonded. A LED source was used to cure the brackets for 20 seconds after the excess bonding compound had been properly removed. Before curing, care should be taken to carefully remove any extra composite from the bracket using a pointed probe.

Recycling by Sandblasting (Groups C and E)
When cleaning ceramic brackets, 50 µm aluminum oxide abrasive particles were used, with a 10 mm gap between the bracket base and sandblaster, to ensure that there were no visible adhesive traces. The remaining powder from the bracket base was sprayed with air for 15 seconds (Fig. 1A).

Recycling by Er,Cr:YSGG Laser (Groups D and F)
Er,Cr:YSGG (Biolase, Water Laser, Irvine, USA) group was used to treat ceramic brackets. The brackets were irradiated with a laser at a distance of 2 mm at a wavelength of 2780 nm (3.5 W output power, 20 Hz frequency, 140 m tip diameter, 50% air output, and 50% water output). The bracket base was perpendicular to the laser during laser irradiation to remove the adhesive (Fig. 1B).

Rebonding Procedure
The teeth’s buccal surfaces were treated for 15–20 seconds with 37% phosphoric acid, followed by a 10-second water rinse and oil-free air drying. After that, a thin coat of primer was applied to the etched enamel. Both new and recycled ceramic bracket bases received an adequate coating of light cure resin adhesive before being attached on the teeth surfaces. Carefully removing the excess
Resin from bracket bases, an LED curing lamp was used to apply light for 20 seconds.

**Scanning Electron Microscope Evaluation**

One new bracket (monocrystalline = 1, polycrystalline = 1; Fig. 2) and two brackets from each individual of the six groups were evaluated under scanning electron microscope (SEM) at 36x and 100x configuration.

**Testing of SBS**

The universal testing equipment was used to test each specimen in the shear mode at a crosshead speed of 0.5 mm/min until bond failure was observed. The buccal surface of the teeth was set parallel to the force vector for the SBS test. The magnitude of the debonding forces was expressed in newtons, which were then converted to megapascal by multiplying by the surface area of the bracket base (10.45 mm²).

The SEM evaluation and the SBS were tested in the laboratory at the Mechanical Engineering Department, Punjab Engineering College, Sector-12, Chandigarh (Fig. 3).

**Measurement of Residual Index**

All of the samples’ enamel surfaces were examined under a stereomicroscope at a 10x magnification after the SBS was determined, and each tooth’s remaining adhesives were graded using the Modified Adhesive Remnant Index, which was developed by Olsen et al. Scores of 1 and 2 indicated that more than 90% of the composite was still present on the tooth surface. Scores of 3 and 4 indicated that more than 10% but less than 90% of the composite was still present on the tooth surface. Scores of 5 indicated that there was no composite left on the enamel surface.

**Statistical Analysis**

The level of significance was established at $p = 0.05$ when data were analyzed using the statistical program SPSS 22.0 (SPSS Inc., Chicago, IL). Analysis of variance (ANOVA) and the Tukey test were used to compare the SBS of six groups.
Shear Bond Strength of Recycled Ceramic Brackets

Table 1: Mean and standard deviation of SBS of six groups (MPa)

<table>
<thead>
<tr>
<th>Group</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.60</td>
<td>9.18</td>
<td>8.01</td>
<td>0.98</td>
</tr>
<tr>
<td>B</td>
<td>3.34</td>
<td>9.00</td>
<td>7.03</td>
<td>1.93</td>
</tr>
<tr>
<td>C</td>
<td>2.39</td>
<td>8.32</td>
<td>7.13</td>
<td>1.61</td>
</tr>
<tr>
<td>D</td>
<td>2.67</td>
<td>8.51</td>
<td>7.12</td>
<td>1.57</td>
</tr>
<tr>
<td>E</td>
<td>3.34</td>
<td>8.42</td>
<td>5.87</td>
<td>1.48</td>
</tr>
<tr>
<td>F</td>
<td>3.34</td>
<td>8.42</td>
<td>6.36</td>
<td>1.62</td>
</tr>
</tbody>
</table>

Table 2: Inter and intragroup comparison of SBS using ANOVA

<table>
<thead>
<tr>
<th>Score</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>All the composite remained on the tooth, as well as the impression of the bracket base</td>
</tr>
<tr>
<td>2.</td>
<td>More than 90% of the composite remained</td>
</tr>
<tr>
<td>3.</td>
<td>More than 10% but less than 90% of the composite remained on the tooth</td>
</tr>
<tr>
<td>4.</td>
<td>Less than 10% of composite on the tooth surface</td>
</tr>
<tr>
<td>5.</td>
<td>No composite remained on the enamel</td>
</tr>
</tbody>
</table>

Table 3: Pairwise comparison of SBS using the Tukey test

<table>
<thead>
<tr>
<th>Group</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>–</td>
<td>0.359</td>
<td>0.488</td>
<td>0.473</td>
<td>0.000</td>
<td>0.015</td>
</tr>
<tr>
<td>B</td>
<td>0.359</td>
<td>–</td>
<td>1.000</td>
<td>1.000</td>
<td>0.185</td>
<td>0.758</td>
</tr>
<tr>
<td>C</td>
<td>0.488</td>
<td>1.000</td>
<td>–</td>
<td>1.000</td>
<td>0.117</td>
<td>0.629</td>
</tr>
<tr>
<td>D</td>
<td>0.473</td>
<td>1.000</td>
<td>1.000</td>
<td>–</td>
<td>0.124</td>
<td>0.644</td>
</tr>
<tr>
<td>E</td>
<td>0.000</td>
<td>0.185</td>
<td>0.117</td>
<td>0.124</td>
<td>–</td>
<td>0.918</td>
</tr>
<tr>
<td>F</td>
<td>0.015</td>
<td>0.758</td>
<td>0.629</td>
<td>0.644</td>
<td>0.918</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 4: Measurement of adhesive remanent index

<table>
<thead>
<tr>
<th>Group</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
</table>

Results

When comparing the SBS of the six groups, Group A (monocrystalline control group) had the highest SBS (8.01, 0.98 MPa), while Group E (polycrystalline, recycled with sandblasting) had the lowest (5.87, 1.48 MPa) (Table 1). There was a statistically significant difference between the six groups (p = 0.001) in the overall ANOVA of the SBS of the six groups (Table 2). But no statistically significant changes in the SBS between the six groups were found in the pairwise comparison using the Tukey test (Table 3).

The adhesive remanent index (ARI) scoring (Table 4) revealed a mixed pattern; the majority of the sample displayed a score of 3, demonstrating that more than 10% but not more than 90% of the composite was still present on the tooth. This suggests that the bracket–adhesive junction was where the fracture was happening. SEM photographs showed the difference between the two types of recycling methods. While the entire surface of sandblasted monocrystalline brackets was very smooth, indicating a loss of mechanical retention, the base of sandblasted polycrystalline brackets was damaged, and only a little amount of adhesive was left on the base (Fig. 4). There was a significant loss of bracket base in laser-treated polycrystalline brackets but no distortion or damage to the overall form of the bracket in monocrystalline brackets (Fig. 5).

Discussion

Metal braces can be recycled using a variety of methods for orthodontic treatment. Selecting a suitable in-office procedure for their reconditioning becomes difficult as the delicate base surface of ceramic brackets is more prone to damage than metal brackets. Sandblasting is frequently used to etch enamel, roughen composite, and remove adhesives from bracket bases. Recently, laser recycling of brackets has been used in a few experiments. As the absorption of Er,Cr:YSGG laser is much more in dental composites than ceramic materials, it is possible to selectively remove adhesive from the bases of debonded ceramic brackets.

Gwinnett observed that there was no statistically significant difference between the SBS of metal and ceramic and ceramic-filled plastic brackets affixed to human incisor teeth with a strongly filled composite resin. 11 He discovered that ceramic brackets combined esthetics with a bond strength that was equivalent to and as dependable as their metal counterparts, indicating that they might provide a practical alternative to their metal counterparts.

Maskeroni et al. 13 also found, in agreement with our findings, that bond failures in the phosphoric acid etch group occurred at the bracket or resin contact with most of the resin remaining on the tooth surface. Adhesive remanent index scores of 3 were present over the bulk of the value. 6 Lew et al. 14 found that the bond strength of recycled ceramic brackets was clinically adequate and was comparable to our Group C (sandblasted, monocrystalline ceramic bracket), Group D (laser-treated monocrystalline ceramic brackets), Group F (laser-treated polycrystalline ceramic brackets), and Group E (sandblasted, polycrystalline ceramic brackets).

In contrast to rebonded ceramic brackets, fresh brackets exhibited the highest mean bond strength, according to research done by Chung et al. 15 In contrast to our findings, which showed a statistically significant difference (p = 0.001) between new and recycled (rebonded) ceramic brackets, their study found that the bond strength of sandblasted rebonded brackets with sealant applied to the bases was not significantly different from that of new brackets. Even though recycling orthodontic brackets might be less expensive, there is a concern with the cost of Er,Cr:YSGG laser systems. The results of a prior study by Ishida et al. 16 suggested that the Er,Cr:YSGG laser might be used to encourage the usage of recycled orthodontic brackets. In a work by Yassaei et al., 16 the SBS of the recycled bracket by Er:YAG was reported to be 13.40 MPa, which was roughly twice the value of our result. In the 3.5-W laser group, 5.9% of the adhesive was still on the base, compared with 3.1% in the 4-W laser group. This information demonstrates that the bases of debonded ceramic brackets were completely free of adhesive residue after using the Er,Cr:YSGG laser. 6 While the fracture resistance of the monocrystalline ceramic brackets is often lower than that of the polycrystalline brackets, they exhibit greater strength. Additionally, because polycrystalline units do not allow for significant transmissibility, which increases energy loss, monocrystalline brackets take less laser energy to...
debond than polycrystalline brackets. Another study by Zain and Al-Khatieeb\(^7\) found that the CO\(_2\) laser group had the lowest mean SBS, whereas Er,Cr:YSGG laser group, Sandblasted group, and new brackets had the highest mean SBS.

In our study, SEM images demonstrated that the laser recycling method was effective in removing the adhesive with no damage to the base of the bracket in the case of monocrystalline brackets (Group D), whereas there was significant damage to the bracket base in the case of polycrystalline brackets treated with laser (Group F). The general structure of the retentive pattern was altered when recycled with sandblasting (Groups C and E), and the entire surface was extremely smooth. Although it has been demonstrated that sandblasting works equally as well as the Er,Cr:YSGG laser for roughening composite and removing glue from the bases of metallic orthodontic brackets,\(^7\) previous studies have shown that it is not suitable for reconditioning ceramic brackets.\(^{10,17}\) The entire base surface is affected by the sandblasting procedure, which can destroy a considerable portion of the fine undercut on the bonding pads of the ceramic brackets. The Er,Cr:YSGG laser, in contrast, spares the rest of the base, only affecting the areas where the adhesive is still intact. Rebonding ceramic or undamaged metal brackets is less expensive. The time required to clean and prepare the base of brackets for rebonding, as well as the cost of additional materials or equipment for these techniques, on the other hand, should be taken into consideration by clinicians. The increased danger of cross-infection is one concern leveled toward the use of recycled items. Any recycled equipment, however, has limitations because the recycling process thoroughly cleans and decontaminates the appliances.

**Summary and Conclusion**

The findings of this investigation led to the following conclusions:

- For recycling polycrystalline and monocrystalline ceramic brackets, both sandblasting and the Er,Cr:YSGG laser were effective.
- The average SBS of ceramic brackets that had been sandblasted and laser-treated fell within the ideal range (5.9–6.8 MPa).
- The overall ANOVA of the SBS of the six groups revealed a statistically significant difference between the six groups ($p = 0.001$).
- The ARI score displayed a heterogeneous pattern; the fracture was occurring at the bracket-adhesive contact and the majority of the sample showed a score of 3.
Scanning electron microscope images showed that the Er, Cr:YSGG laser recycling approach was successful in removing the adhesives without causing any damage to the bracket’s base, in contrast to the sandblasting method, which caused smoothing and deformation of the mechanical retentive pattern of the bracket’s base.

References