Bond strength of ceramic brackets with various bonding systems

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Ceramic brackets, which are primarily of monocrystalline or polycrystalline sapphire, are esthetically more pleasing than their metal, coated metal and plastic predecessors. They also appear to have some superior bonding characteristics. However, there are some indications of reduced fracture toughness which may lead to uncontrolled bracket wing failure during function. While ceramic bracket bonding has been addressed to some extent, the relationship between bracket bonding behavior and different bonding systems still requires clarification.

Brackets are fabricated of stainless steel, plastic, and in recent years, ceramic. A wide variety of bracket types is available for clinical use. Ongoing research and development continues to improve their properties. The shortcomings of plastic brackets in their present forms include moisture absorption, which progressively weakens the bond strength, discoloration and excessive distortion.[1] While stainless steel attachments have none of the disadvantages of plastic attachments, they are less acceptable esthetically. Ceramic brackets made of monocrystalline sapphire are more esthetically pleasing than either plastic or metal brackets. The material is more transparent than plastic and the color is more stable. Ceramic brackets are also quite strong; they are more difficult to deform than plastic brackets and have a higher tensile strength than stainless steel.[2]

The bonding strength of ceramic brackets has been shown to be significantly higher than that of metal brackets.[3,4] In fact, orthodontists sometimes experience problems during debonding when the bond is too strong to break.[5] This high bond strength results from silanization of the bracket base, mechanical retention, or both. Since these factors may act in combination to produce excessive bond strength, some consideration is being given to fabricating ceramic

Abstract

The purpose of this investigation was to determine the shear and tensile bond strengths of various ceramic and ceramic-filled brackets in combination with commonly used bonding systems. One monocrystalline, two polycrystalline and one ceramic-filled plastic bracket types were tested in combination with one light-cured and two chemically-cured bonding systems. Bonding procedures were performed on properly prepared human teeth. Shear and tensile tests were performed on an Instron test machine. The shear bond strength of the mono- and polycrystalline ceramic brackets was not affected by the bonding system. There was a difference among bonding systems used with the ceramic-filled plastic bracket. Ceramic-filled plastic and polycrystalline ceramic brackets exhibited the greatest resistance to tensile force, while monocrystalline brackets showed the highest propensity for tensile fracture of the wings.

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Key Words

Ceramic brackets • Bonding systems • Shear bond strength • Tensile bond strength

Table 1
Brackets tested

Type	Name	Dimensions (mm) M-D	Dimensions (mm) G-I	Manufacturer
Monocrystal	Starfire	2.99	3.74	"A" Company San Diego, CA
Polycrystal	Transcend	2.55	3.25	Unitek Corp. Monrovia, CA
Polycrystal	Intrigue	2.50	3.30	Lancer Orthodontics Inc. Carlsbad, CA
Ceramic-filled plastic	Silkon	3.15* 2.85**	3.19	American Orthodontics Sheboygan, WI

*Incisal edge
**Gingival edge

Table 2
Bonding systems tested

Cure Type	Name	Manufacturer
Chemical (paste-paste)	Concise	3M Dental Products Division St. Paul, MN
Chemical (paste-liquid)	System 1+	Ormco Corp. Glendora, CA
Light	FluorEver	MacroChem. Corp. Billerica, MA

brackets that are retained only by micromechanical means.

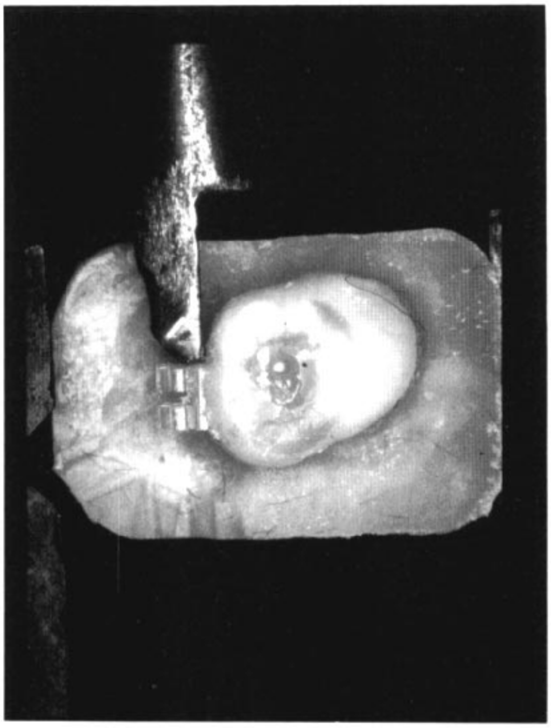
Fractures occasionally occur at the bracket wings during orthodontic treatment and debonding; removal of these brackets may require use of a high-speed diamond bur — a time-consuming procedure. Bond failure may also occur at the resin-enamel interface, jeopardizing the integrity of the enamel surface of the bonded tooth.[6]

Bond strength has been measured in a number of studies using a wide range of etching agents and adhesives with metal and plastic brackets.[7-17] To date, investigations regarding the shear bond strength of ceramic brackets have been limited, with the majority of the data reporting chemically-cured adhesive systems.[3,10,16,18]

The purpose of this investigation was to determine the shear and tensile bond strength of various ceramic and ceramic-filled brackets in combination with a variety of commonly used bonding systems.

Materials and methods

The brackets used in this study, shown in Table 1, were made of monocrystalline alumina (Starfire, "A" Company, San Diego, Calif.), polycrystalline alumina (Transcend, Unitek Corp., Monrovia, Calif.; and Intrigue, Lancer Orthodontics, Inc., Carlsbad, Calif.) and ceramic-filled plastic (Silkon, American Orthodontics, Sheboygan, Wisc.). All the bracket backings were silane coated by the manufacturer; the ceramic-filled plastic bracket also contained retentive holes. The three types of bonding systems used, pre-



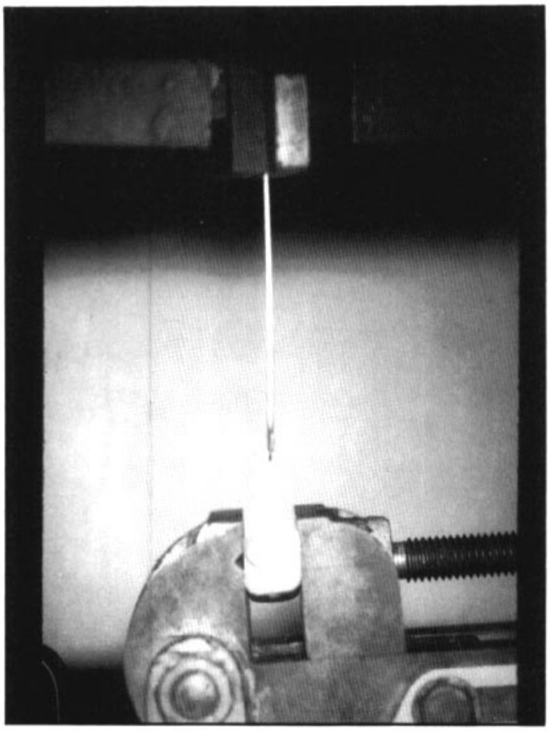


Figure 1
Shear bond strength test set-up.

Figure 2
Tensile bond strength test set-up.

sented in Table 2, were a chemical paste-paste system (Concise, 3M Dental Products Divison, St. Paul, Minn.), a no-mix chemical paste-liquid system (Ormco Corp., Glendora, Calif.) and a visible light cured system (FluorEver, Macro-Chem. Corp., Billerica, Mass.).

The investigation consisted of the following groupings: 4 bracket types x 3 bonding systems x 2 loading modes (shear and tension) = 24 groups. Ten teeth comprised each group for a total of 240 teeth.

Two hundred forty human molar teeth, selected because of their relatively flat facial surfaces and availability, were collected and stored in various antiseptic solutions. The preserving solutions were replaced with 0.9% sterile normal saline at least 1 month before to the tooth's preparation for bonding. Just prior to bonding, each tooth was pumiced with a non-fluoride prophylaxis paste for 20 seconds, rinsed in running water for 10 seconds and dried with an oil-free air source. When dry, the tooth was etched for 1 minute with the solution or gel supplied with the bonding system, rinsed with running water for 30 seconds, and dried with an oil-free air source.

A mandibular central incisor bracket, selected because the bracket's relatively flat base facilitated a more uniform resin film thickness, was then bonded to the enamel, facial surface of each tooth using the appropriate bonding system. Only teeth with an anatomic configuration approximating the bracket base were used; teeth were not ground flat. Bonding procedures were performed according to the manufacturers' instructions. Teeth and brackets bonded with a light-cured bonding system were exposed to a curing light (Visilux 2, 3M Dental Products Division, St. Paul, Minn.), placed approximately 5 mm from the bracket, for 40 seconds. Prior to curing, excess bonding resin was removed using a small scaler.

The bonded teeth were then embedded in a self-curing acrylic resin and stored in 0.9% sterile normal saline at 37° C for 24 hours prior to bond strength testing. Each tooth was oriented, with the testing device as a guide, so its labial surface was parallel to the force during the shear strength test (Figure 1). A steel rod with one flattened end was attached to the movable head of an Instron test machine (Instron Corp., Canton, Mass.). A mesio-distal load was applied to the bracket producing shear at the bracket-tooth interface.

To test tensile bond strength, a triangular testing device made of 0.016 x 0.022 inch stainless steel wire was ligated into the bracket with an 0.010 inch stainless steel ligature wire (Figure 2). A metal hook was secured in the grips in the movable head of the test machine to apply tensile force perpendicular to the bracket-tooth interface. This testing device design distributed the force evenly to the bracket wings through the ligature wires, mimicking the clinical situation where archwires are tied into the bracket slots.

Both shear and tensile bond strengths were measured at a crosshead speed of 0.02 inches

Table 3
Summary of shear bond strengths (MPa)

Bracket-Bonding System Combination	Mean	Standard Deviation
ST + F	19.5	6.3
ST + C	16.7	4.6
ST + SY	15.7	5.1
I + C	14.8	2.9
T + F	13.9	5.7
I + F	13.7	4.4
I + SY	13.5	3.9
T + C	12.4	3.2
T + SY	10.8	3.6
SI + C	8.8	2.5
SI + SY	6.7	1.8
SI + F	5.0	1.2

*Vertical lines connect values which are not significantly different at the 5% level.
Brackets: ST = Starfire, I = Intrigue, T = Transcend, SI = Silkon
Bonding Systems: C = Concise, SY = System 1+, F = FluorEver

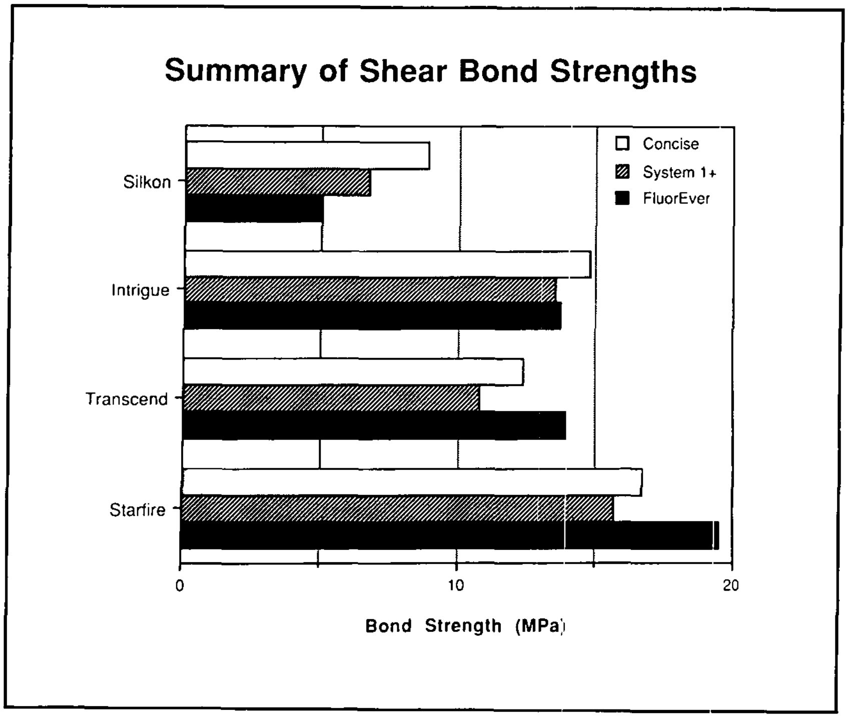


Figure 3
Summary of shear bond strengths for all the combinations of bracket types and bonding systems tested.

per minute. After failure, the teeth and brackets were examined using an optical microscope at maximum magnification of 300X. The bond strength test results were analyzed using one-way and two-way ANOVA statistical tests at a 0.05 confidence level.

Results

The first considerations to be presented are related to the shear bond strength tests, showing the interaction between the different bonding systems and bracket types. The mean shear bond strength and standard deviation for each combination tested are summarized in Table 3 and Figure 3.

The highest bond strength resulted when monocrystalline brackets were bonded with any of the bonding systems tested, and when one brand of polycrystalline bracket (Intrigue) was bonded with a chemical paste-paste system. There were no differences among these combinations at the 5% level. The bonding strengths of the other polycrystalline bracket tested (Transcend) with a light-cured bonding system and the polycrystalline Intrigue bracket with all bonding systems (with the exception of Concise as mentioned above) were statistically similar, and were lower than the bonding strength of the group described above. The lowest shear bond strength overall was obtained with the ceramic-filled plastic bracket. This bracket's highest shear bond strength resulted with the paste-paste system; its lowest strength was found with the light-cured system. This difference was statistically significant.

During testing in the shear mode, the location of the failure varied with the different bracket-bonding system combinations. The locations and frequency of failure are summarized in Table 4. Observed failures were: adhesive at the junction between bracket base and bonding system; at the bonding system-enamel interface; or cohesive failure of the bonding system. Quite often, these failures occurred in combination.

During tensile bond strength testing, a large proportion of the wings of the brackets fractured prior to any bond failure. Consequently, the data is separated into two groups: bond failure and wing fracture. Table 5 presents the data for brackets which experienced tensile bond failure. In contrast, the data in Table 6 is for those brackets which experienced wing fracture. The values presented in this latter table represent the stress at the bracket base at the time of wing fracture.

Table 5 shows that bond failure (separation of the bracket from the tooth surface) occurred primarily with the polycrystalline Transcend

Table 4
Location and frequency of failure locations during shear testing

Bracket-Bonding System Combination	Tooth-Bonding System	Bracket Base-Bonding System	No Preferential Site
ST + C	5	5	0
ST + SY	4	4	2
ST + F*	4	1	3
T + C	0	10	0
T + SY	5	5	0
T + F	9	1	0
I + C	3	6	1
I + SY	3	7	0
I + F	7	2	1
SI + C#	4	5	0
SI + SY	5	5	0
SI + F	5	3	2

*Two teeth experienced enamel fracture
#One bracket fractured at the base
Brackets: ST = Starfire, T = Transcend, I = Intrigue, SI = Silkon
Bonding Systems: C = Concise, SY = System 1+, F = FluorEver

Table 5
Summary of tensile bond strengths (MPa)

Bracket-Bonding System Combination	Bond Failure Mean	S.D.	N
T + F	14.91	2.18	9
T + SY	14.53	1.97	7
T + C	13.17	2.91	3
SI + C	10.91	2.10	6
I + F	10.78	0	1
I + C	10.78	0	1
ST + F	9.94	0	1
ST + SY	8.06	0.56	3
SI + F	7.12	1.62	10
SI + SY	6.97	2.87	10
ST + C	5.76	0.19	3

Brackets: ST = Starfire, I = Intrigue,
T = Transcend, SI = Silkon
Bonding Systems: C = Concise,
SY = System 1+, F = FluorEver

Table 6
Summary of bracket base stresses at wing failure (MPa)

Bracket-Bonding System Combination	Wing Fracture Mean	S.D.	N
T + SY	16.20	1.51	3
T + F	16.01	0	1
T + C	15.67	2.87	7
SI + C	13.96	0.79	4
I + F	12.77	2.06	9
I + C	11.16	2.09	9
I + SY	10.26	0.77	10
ST + SY	7.07	1.12	7
ST + F	6.94	2.50	9
ST + C	5.82	1.34	7

Brackets: ST = Starfire, I = Intrigue,
T = Transcend, SI = Silkon
Bonding Systems: C = Concise,
SY = System 1+, F = FluorEver

and ceramic-filled plastic brackets. The values for Transcend with any bonding system, as well as the values for ceramic-filled plastic with the paste-paste bonding system, were the highest. Bond strength values for ceramic-filled plastic brackets bonded with paste-liquid and light-cured bonding systems were similar and significantly lower than those for combinations detailed above.

Most wing failures occurred with the polycrystalline Intrigue brackets — almost 100% at mean base stress of 11.4 MPa. Monocrystalline brackets also experienced a very large number of wing failures. With this bracket type, the lowest base stress resulted, a mean of 6.6 MPa. The polycrystalline Transcend brackets that underwent wing fractures did so at the highest base stress, a mean of 16.0 MPa. The least amount of wing failure was noted with the ceramic-filled plastic brackets, especially those bonded with the paste-paste bonding system.

Discussion

The experimental design of this investigation included a 1-minute contact of the etching medium and the enamel surface. Some investigators have suggested that etch times as short as 15 second may be used with no significant difference in surface morphology or bond strength.[19] Consequently, the conclusions of this study would be valid for any etching regimen between 15 and 60 seconds.

The data with respect to the various combinations of esthetic brackets and bonding systems is summarized in Figure 3. The monocrystalline ceramic bracket exhibited the greatest shear bond strength values with all three bonding systems. The high bond strength was especially evident when the light-cured bonding system was used. This effect may be explained by the light transmission characteristics of the various brackets tested. Monocrystalline brackets are extremely transparent, allowing the curing light to readily penetrate the bracket to cure the light-sensitive bonding system. Consequently, a more complete cure is achieved, leading to the higher observed bond strength. Polycrystalline brackets are less transparent, and had lower bond strengths. The ceramic-filled plastic brackets are the least transparent of all, and also had the lowest bond strengths. Because light does not penetrate these brackets as readily, the cure may be less complete and the bond strength lower.

All the brackets tested in this study were treated with silane prior to bonding. The ceramic-filled plastic brackets, in spite of the inclusion of a macromechanical feature in their base design, produced the lowest shear bond strength, suggesting that silanization of this bracket is not effective. On the other hand, the very high bond strength of the silane-treated ceramic brackets could be ameliorated by eliminating the silane and modifying the base to enhance micromechanical attachment to the tooth surface. In this way, it may be possible to achieve a combination of sufficient bond strength and safe debonding after active treatment. This approach has been adopted by one manufacturer, Unitek, leading to the second generation of Transcend brackets which rely exclusively on micromechanical retention.

Achieving the highest shear bond strength may not be the most significant clinical factor, since all the bracket-bonding combinations investigated in this study may have sufficient shear bond strength to withstand the functional and therapeutic forces to which they are subjected in the mouth. In fact, the high shear bond strength exhibited by the monocrystalline bracket and light-cured bonding system may very well represent a clinical problem during debonding.

The weakest shear bond strength in this study was shown by the ceramic-filled plastic bracket. However, the strength may very well be sufficient to withstand any intra-oral forces during orthodontic treatment, while remaining the easiest of the four to remove and hence the least likely to cause damage to the tooth structure.

Tensile bond strength is important not only during active treatment when ligating an archwire to the bracket wings, but it may also also have bearing with respect to debonding. The plastic-filled ceramic bracket withstood the greatest amount of tensile force before it fractured, and the single crystal bracket the least.

Conclusions

This investigation has shown that shear bond strength of ceramic brackets is not significantly affected by the bonding system. The shear bond strength of ceramic-filled plastic brackets does vary with the bonding system, with the highest readings produced in combination with a chemical paste-paste bonding system. Ceramic-filled plastic and the Transcend polycrystalline bracket exhibited the greatest resistance to tensile force, while monocrystalline brackets showed the highest propensity for tensile fracture.

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