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Alternatives to Ceramic Brackets: the Tensile Bond Strengths of Two Aesthetic Brackets Compared *Ex Vivo* with Stainless Steel Foil-mesh Bracket Bases

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Abstract. *The mean tensile/peel bond strengths were evaluated for three types of aesthetic brackets (a ceramic-reinforced bracket and two generations of a ceramic/polycarbonate combination bracket). These were found to be significantly lower than the mean tensile/peel bond strength of a convention foil-mesh stainless steel bracket base. Failure of the ceramic-reinforced polycarbonate brackets occurred predominantly by fracture of the tie wings during testing. With the ceramic/polycarbonate combination brackets, the majority of the specimens failed due to separation of the ceramic and polycarbonate parts of the bracket.*

Index words: Bond Strength, Direct Bonding, Orthodontic Brackets.

Refereed Paper

Introduction

To improve the appearance of fixed orthodontic appliances, and thus increase patient acceptance, several aesthetic materials have been used as an alternative to stainless steel in bracket manufacture.

Plastic brackets, generally made from polycarbonate, were initially well-received, but were subsequently found to suffer from several problems. These included distortion following water absorption, fracture, wear, discolouration and an inability to withstand the torqueing forces generated by rectangular wires (Reynolds, 1975).

Ceramic brackets have the advantages of permanent translucency and greater strength. Unfortunately, they also have the disadvantages of brittleness and excessive bond strength, sometimes leading to bracket fracture during treatment (Scott, 1988) and enamel damage on debonding (Joseph and Russouw, 1990, Redd and Shivapuja, 1991). They have also been found to produce wear of enamel surfaces on opposing teeth (Douglass, 1989).

Attempts have been made to combine the best properties of plastic and ceramic materials in a single bracket. One approach has been the ceramic-filled plastic bracket. Although these brackets are easier to remove from enamel than ceramic brackets, this is due to their significantly lower bond strength (Chaconas *et al.*, 1991).

A different approach has been taken by one manufacturer by combining a ceramic bracket with a polycarbonate laminate as the bracket base (Ceramaflex® brackets, TP Orthodontics, Indiana). The thin polycarbonate bonding pad prevents the inflexible ceramic surface from directly contacting the enamel. It is claimed that the potential for enamel damage due to the excessive bond strength between ceramic materials and enamel is eliminated during debonding since the polycarbonate pad flexes in a similar manner to metal brackets. The shear bond strength of these brackets has been investigated in a previous study (Fox and McCabe, 1992). Although the shear bond strength was found to be similar to a metal bracket, it was concluded from a Weibull analysis of the results that the ceramic bracket/polycarbonate base combination brackets were likely to be more unreliable at low bond strengths. More recently, the manufacturer has introduced a 'second generation' of these brackets. The later brackets have a central window removed from the polycarbonate base so that the ceramic material can bond directly to enamel whilst the remaining polycarbonate pad around the periphery still allows the flexibility during the debonding procedure.

The purpose of this *ex vivo* study was to compare the tensile bond strengths of ceramic filled plastic brackets and the two generations of ceramic/polycarbonate laminated brackets with conventional stainless steel brackets. In addition, the site of bond failure was recorded in order to identify the weakest component of the bracket/base combinations.

Materials and Methods

Brackets and adhesive

Four different types of upper premolar brackets were tested for bond strength in the tensile mode. The brackets were selected in order to allow comparison between a conventional stainless steel foil-mesh bracket base (Dyna-Bond®, Unitek Corporation, Monrovia, California), a ceramic-filled plastic bracket (Silkon®, American

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Orthodontics, Sheboygan, Wisconsin) and the two generations of ceramic bracket/polycarbonate base bracket combinations (Ceramaflex® 1 and Ceramaflex® 2, TP Orthodontics, Indiana). Scanning electron micrographs of the bracket bases are shown in Fig. 1.

The mesh base of the Dyna-Bond® bracket offers mechanical retention for the adhesive, whereas the Silkon® and first generation Ceramaflex® bases rely on a chemical bond. The second generation Ceramaflex® bracket uses both mechanical and chemical bonding.

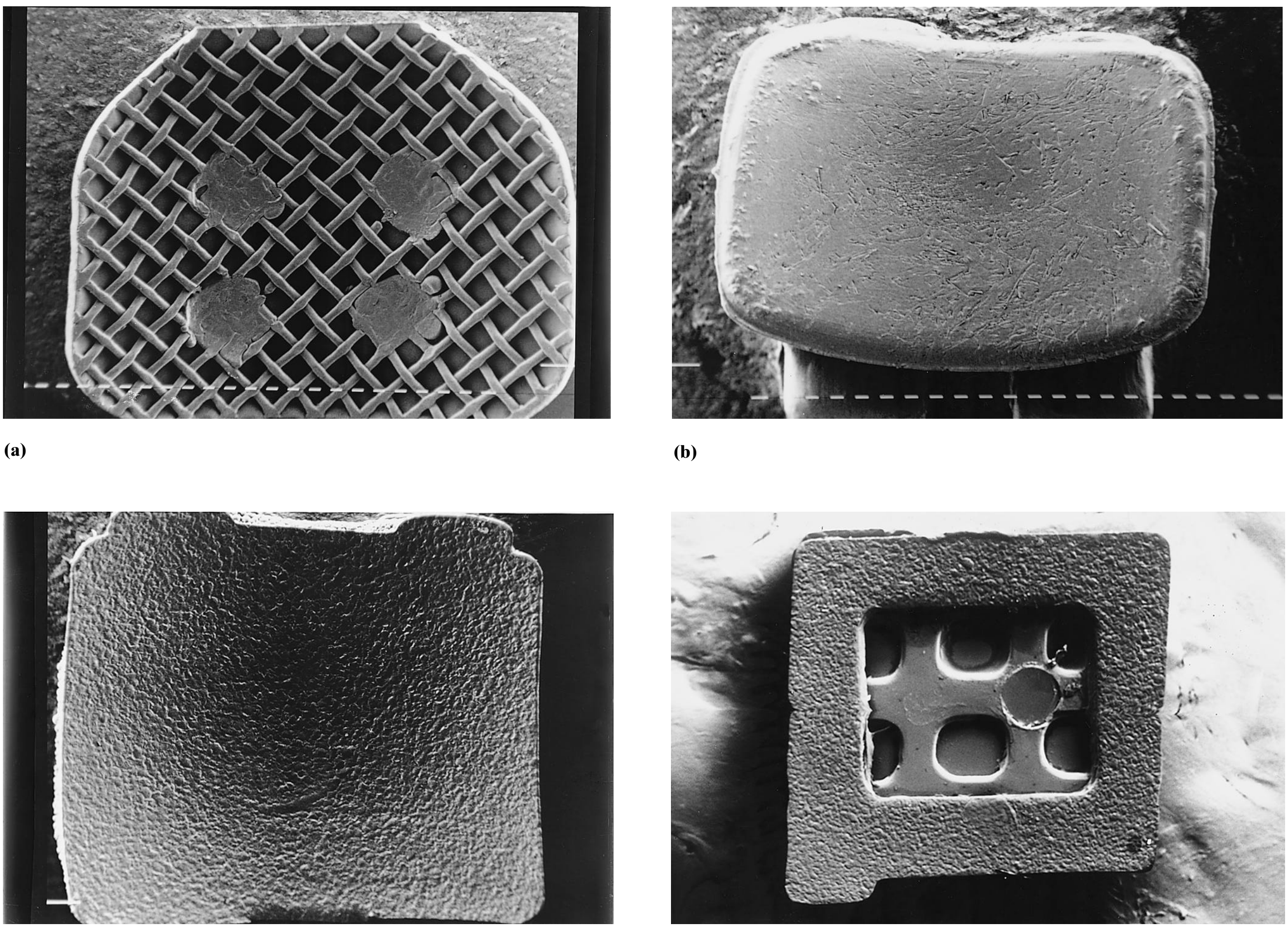
Measurement of the area of the bases was performed by digitizing the base outline on the scanning electron micrographs using a Summagraphics Bit Pad Two data tablet (Summagraphics Corporation, Fairfield, Connecticut) together with the Digit® image analysis package (Taab Laboratories Equipment Ltd, Aldermaston, Berkshire) loaded onto an IBM compatible personal computer.

The adhesive used in the study was a chemically-cured, two-paste, highly-filled system specifically formulated for orthodontic bonding (Concise®, 3M Dental Products, St Paul, Minnesota).

Bonding

The bases were bonded to extracted premolar teeth which had been stored in 70 per cent ethyl alcohol. These teeth were randomly divided into four groups of 20. The buccal surfaces of the crowns were polished using a pumice and water slurry in a rubber cup for 10 seconds. The teeth were then washed with a water spray for 15 seconds and dried. Etching of the enamel surface was performed by the application of a 37 per cent orthophosphoric acid liquid to the buccal surface for 1 minute. Finally, the teeth were rinsed with a water spray for 45 seconds and dried with oil-free compressed air.

Equal amounts of Concise® enamel bond sealant resins A and B were mixed thoroughly and applied to the etched surface in a thin coat with the sponge applicator provided in the kit. After the application of the sealant, brackets were bonded to the teeth with the bonding paste mixture using the procedure recommended by the bracket manufacturer. Concise® plastic bracket primer was applied to the Ceramaflex® bracket bases for 45 seconds prior to bonding. Before polymerization of the adhesive occurred,



(a) (b) (c) (d)

FIG. 1 Scanning electron micrographs of the bracket bases. (a) Dyna-Bond® bracket base (scale bar = 100 μm). (b) Silkon® bracket base (scale bar = 100 μm). (c) First generation Ceramaflex® bracket base (scale bar = 100 = 100 μm). (d) Second generation Ceramaflex® bracket base showing the cut out window in the polycarbonate base (scale bar = 1000 μm).

any excess was removed from the tooth surface using a dental probe with the aid of a magnifying glass.

The apical two-thirds of the root was removed from each tooth to allow accurate horizontal placement of the teeth into plastic mounting cups with the labial surface facing upwards for the application of the tensile testing assembly. The bonded teeth were mounted horizontally in a cylinder of slow-setting resin (Metset, Buehler, Coventry, England) with the bracket slot parallel to the surface and were then stored in distilled water at 37°C for 24 hours prior to testing.

Bond testing

The tensile/peel bond test was performed using a Lloyd M5K testing machine (Lloyd Instruments plc., Fareham, Hampshire, England). The tensile load was applied to the bracket samples via a 0·020″ × 0·025″ stainless steel wire assembly consisting of two 40 × 10 mm rectangles of wire which were soldered at one end as described previously (Regan and van Noort, 1989). With the labial surface of the specimen positioned at right angles to the direction of the applied force and the tie wings directly below the testing assembly, a tensile/peel force was applied at a crosshead speed of 2 mm/minute and the maximum tensile/peel force to debond the bracket was recorded in Newtons.

Following testing, each bracket base and the debonded tooth surface were inspected under an optical microscope at a magnification of ×20 to determine the predominant site of failure. This was classified as either adhesive failure or bracket component failure. The classification of adhesive failure included failure at the base/adhesive interface, the enamel/adhesive interface or fracture within the adhesive itself. The bracket components failed either by fracture of the tie wings or separation of the ceramic and polycarbonate parts of the Ceramaflex® brackets.

Analysis of results

The differences in bond strength were analysed statistically using an analysis of variance (ANOVA) and any significant differences revealed by this procedure were further investigated using the Scheffe test with a 95 per cent confidence limit ($P<0·05$).

Results

The mean forces required to debond the brackets in the tensile/peel mode, together with their ranges and standard deviations are given in Table 1. The highest mean bond strength was obtained with the foil-mesh based metal bracket (Dyna-Bond®), and the lowest with the ceramic-reinforced polycarbonate bracket (Silkon®). Using the bond strength (in Newtons) as the dependent variable, an analysis of variance (ANOVA) showed a significant difference between groups at the $P<0·0001$ level of significance.

The grouping of these differences by the Scheffe Multiple Range test at the 95 per cent confidence level ($P<0·05$) revealed that there was no significant difference in the mean tensile/peel bond strength between the first and second generation Ceramaflex® brackets and the Silkon® brackets. However, the mean tensile/peel bond strength of the foil-mesh Dyna-Bond® brackets was significantly higher than the other three types of bracket.

Table 1 *Mean, range and standard deviation (in Newtons) of the tensile bond strength for each bracket base*

Bracket type	Mean	Range	S.D.
DB	133·3	60·2–192·4	34·1
S	54·1	31·3–98·1	16·8
C1	56·5	16·2–97·1	21·8
C2	66·4	23·5–101·5	19·5

Key: DB, Dyna-Bond® brackets; S, Silkon® brackets; C1, first generation Ceramaflex® brackets; C2, second generation Ceramaflex® brackets.

Table 2 *Number of bracket failures at each failure site when subjected to tensile bond testing*

Bracket type	Enamel/adhesive/base	Tie wing	Delamination
DB	20	0	0
S	7	13	0
C1	6	1	13
C2	10	0	10

Key: DB, Dyna-Bond® brackets; S, Silkon® brackets; C1, first generation Ceramaflex® brackets; C2, second generation Ceramaflex® brackets.

Table 2 shows the predominant site of the bond failure for each group. All the Dyna-Bond® brackets showed failure at the adhesive interface. This type of failure occurred in 35 per cent of Silkon® brackets with the remaining 65 per cent of failures due to fracture of the tie wings. Adhesive failure occurred in 30 per cent of the first generation Ceramaflex® brackets with 65 per cent of the failures due to separation (delamination) of the ceramic bracket and polycarbonate base. One bracket failed due to a fractured tie wing. The debonding of the second generation Ceramaflex® brackets showed equal numbers failing at the adhesive interface and due to delamination of the polycarbonate base and ceramic bracket. Statistical analysis did not reveal any significant relationship between the bond strength and the site of failure.

Discussion

These results show that all three aesthetic brackets produced a significantly lower tensile/peel bond strength than a conventional stainless steel bracket with a foil-mesh base. Although there were some differences in mean bond strength between the three aesthetic brackets these were not statistically significant.

When tested in the tensile/peel mode as described in this paper, a high proportion of the aesthetic brackets debonded due to a structural failure of the bracket itself. In the case of the Silkon® bracket this was due to breakage of the tie wings. A high proportion of the Ceramaflex® brackets suffered a separation of the polycarbonate base and the ceramic component of the bracket.

Comparing bond strength results with other investigations is notoriously difficult due to the variety of materials, differences in experimental methods and the units used to measure the results (Fox *et al.*, 1994).

Tensile testing ideally requires a system which will align the specimen and substrate so that the forces act at right angles to the surface of the specimen. For *ex vivo* bond strength studies a number of complex jigs have been designed (Eden *et al.*, 1970; Ferguson *et al.*, 1984; Merrill *et al.*, 1994). However, peel and shear forces can still occur, despite these alignment jigs due to the geometric complexity of the orthodontic brackets (Katona and Moore, 1994; Katona and Chen, 1994). Further non-uniform stresses are produced by the 'fillet effect' due to changes in geometry at the edge of interfaces (Van Noort *et al.*, 1989).

The Dyna-Bond® bases performed similarly to stainless steel brackets used in other studies (Regan *et al.*, 1993). Ceramic-reinforced Silkon® brackets were included in a comparative study by Chaconas *et al.* (1991). Although a higher mean bond strength was obtained than the present study, the brackets were tested in the shear mode. This would be expected to produce a greater bond strength than testing in the tensile mode. The few previous studies involving Ceramaflex® brackets have involved shear testing of the first generation brackets. Fox and McCabe (1992) found that the shear bond strength of Ceramaflex brackets was similar in magnitude to a metal bracket, although, following a Weibull analysis of the results, they concluded that they may be less reliable in clinical use. Franklin and Garcia-Godoy (1993) reported that the mean shear bond strength of the Ceramaflex® brackets was significantly less than conventional ceramic brackets. Although the mean shear bond strength of the Ceramaflex® brackets was less than stainless steel brackets, this was not found to be statistically significant. It was also noted that all the Ceramaflex® brackets failed at the interface between the bracket and polycarbonate components leaving the polycarbonate base on the tooth following debonding. Bordeaux *et al.* (1994) also found the Ceramaflex® brackets to have a lower shear bond strength than both ceramic and stainless steel brackets. In their study, 90 per cent of the debonded Ceramaflex® brackets left the plastic wafer on the tooth surface with the adhesive and they felt that these brackets were at the minimum bond strength for successful clinical use.

In the present study, these results were confirmed except that lower mean bond strengths than previously published studies were obtained for the aesthetic brackets. This could be explained by the tensile mode of testing employed. The reason for adopting this method of debonding was to identify the lowest bond strength which could produce failure in the clinical situation. Shear tests tend to simulate the direction of the force applied to debond the brackets at the end of treatment or resistance to occlusal forces whereas a tensile test may indicate possible failure due to archwire ligation.

The load at failure is commonly normalised by dividing it by the area of the bracket base. The smallest bracket base area was the Silkon® (10·51 mm^2). The area of the Dyna-Bond® base (15·85^2 mm) was similar to the first generation Ceramaflex base (15·82 mm^2). The second generation Ceramaflex base had a total area of 18·08 mm^2 which included the ceramic 'window' with an area of 6·48^2 mm. However, an average stress value may not shed much light on the failure events in the joint because of non-uniform stress fields within the adhesive layer (Van Noort *et al.*, 1989; Rees and Jacobsen, 1990). Since a high proportion of brackets in this study failed due to component failure rather than at the base/adhesive interface, the bond strengths are presented in Newtons rather than MegaPascals. With an internal structural failure of the bracket, the bracket base area is not so relevant.

Extrapolation of the results of this investigation to the clinical situation should be done with caution. Whilst they suggest that a higher proportion of the two types of aesthetic brackets may be expected to fail during treatment when compared with stainless steel bases, in the absence of long-term clinical trials it is impossible to know if this is of practical relevance.

Conclusions

1. Both ceramic-reinforced and ceramic/polycarbonate combination bracket bases give a significantly lower mean tensile/peel bond strength than a conventional foil-mesh base when tested *ex vivo*.
2. Failure of the ceramic-reinforced Silkon® brackets occurred mainly by fracture of the bracket tie wings.
3. Failure of Ceramaflex® brackets occurred largely by separation of the ceramic and polycarbonate components of the brackets.
4. Clinical trials would be required before the relevance of these findings to orthodontic practice could be fully evaluated.

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