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Effects of sandblasting metal bracket base on the bond strength of a resin-modified glass ionomer cement: an *in vitro* study

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Abstract The introduction of air abrasion (sandblasting) technology to orthodontics may allow reaching optimum bond strength between the metal bracket and resin-modified glass ionomer cement. This study examined the effects of sandblasting metal bracket bases on the *in vitro* tensile bond strength of a resin-modified glass ionomer cement. Two-hundred foil-mesh based brackets were divided into ten groups and combinations of three sizes of aluminum oxide powder (25, 50 and 110 μm) and three sandblasting times (3, 6 and 9 seconds) were tested. One group was not sandblasted and used as control. Analysis of variance showed that bond strength was significantly affected by the sandblasting time ($p < 0.001$) and size of the aluminum oxide powder ($p < 0.001$). Only the group (SO_{25}) sandblasted with 25 μm aluminum oxide powder for 3 seconds yielded higher mean bond strength than that of the control group. The bond strength values were also analyzed using a Weibull analysis, which showed the most favorable size (25 μm) and time combination (3 seconds), and the 5% and 90% probabilities of failures. This study suggests that sandblasting time and particle size have and important effect on the bond between the metal bracket and resin-modified glass ionomer cement.

Introduction

Air abrasive technique (sandblasting) has been used extensively in restorative dentistry to enhance the mechanical adhesion between the metals and adhesive resins [1]. This technique, using a high-speed stream of aluminum oxide particles propelled by compressed air, removes unfavorable oxides, contaminants and increases surface energy and bonding surface area by increasing the surface roughness. It has been also used to improve the bond strength of brackets and bands in orthodontics [2, 3].

For orthodontic bracket bonding, a micro-mechanical interlock must be obtained between the bracket base and the conventional composite resins. Therefore several designs of bracket base (foil-mesh, milled, cast, photo-etched, laser structured etc.) have been devised to gain the maximum bond strength by interlocking. Although, all base designs of metal brackets rely on mechanical retention and have not been satisfactorily chemically bonded to the conventional composite resins, it was reported that glass ionomer cements have ability to bond metal by chemically [4]. However, conventional glass ionomer cements, when used to bond metal brackets to enamel, have shown comparatively inadequate bond strength [5, 6].

Continuing efforts to produce a new adhesive resin which combines the advantageous characteristics of composite resins and glass ionomer cements has led the development of resin-modified glass ionomer cements for orthodontic bonding. The advantages of this hybrid combination include elimination of acid etch technique, increased adhesive properties to metal and enamel, and an ability to absorb and release anticariogenic fluoride ions [7].

Several studies have been conducted to investigate the effect of sandblasting bracket base on the bond strength of

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conventional chemically cured, no-mix or light-cured composite resins [2, 3, 8, 9]. To date, however, there is no data available concerning the bond between sandblasted bracket bases and resin-modified glass-ionomer cements. Therefore, the aim of this investigation was to investigate the effects of sandblasting foil-mesh based metal brackets on the *in vitro* tensile bond strength of a chemically-cured resin-modified glass ionomer bonding cement. The bond failure sites were also investigated.

Materials and methods

Substrates

The resin-modified glass ionomer cement used in this study was a chemically cured system specifically formulated for orthodontic bonding (Fuji Ortho, GC Corporation, Tokyo, Japan). All brackets used were foil-mesh based stainless steel upper central incisor brackets (Midi Diagonal, Leone Sesto, Fiorentino, Italy). Since it was the bond strength between the bracket base and the adhesive which was of most interest in this study, the design of the tensile force application was such as to ensure that fracture took place at that interface as far as possible. Therefore plastic cylinders were used as the substrate instead of extracted human or bovine teeth. Two hundred plastic cylinders were prepared from a slow set resin of the polyester type (Metset Mounting Plastics, Buehler UK Ltd., Coventry, England). A 7 mm radius and 4 mm depth hole was milled in the centre of each cylinder and the base of this cavity was made more retentive by running an inverted cone bur round the base. The resin-modified glass ionomer cement was then mixed and filled in the cavity. The surfaces of cylinders were smoothed with a 400 grit silicon carbide paper to gain a uniformly flat bonding surface.

Sandblasting

Two hundred foil-mesh based metal brackets were divided into ten groups (20 brackets each). The bases of the brackets in the control group were not sandblasted. The brackets in other nine groups were sandblasted with 25 μm, 50 μm or 110 μm aluminum oxide abrasives for 3 seconds, 6 seconds or 9 seconds (Table 1). The line pressure of the sandblasting unit (TopTec 4, Bego, Bremen, Germany) was kept at 58 psi (4 bar) for all sandblasted groups. A special device was made to maintain the 90° angle and 30 mm distance between the tip of the sandblasting hand piece and the surface of the bracket base (Fig. 1). A timer which opens and closes the line pressure according to arranged sandblasting time was also connected the main control of the sandblasting unit. Thus, the sandblasting time was precisely controlled. All sandblasted brackets were cleaned with blast of pressurized air for 3 seconds.

In addition, representative samples of brackets from each group were prepared for examination under the scanning electron microscope (SEM). Figure 2 shows a selection of the sandblasted and unsandblasted (control) bracket bases.

Specimen preparation

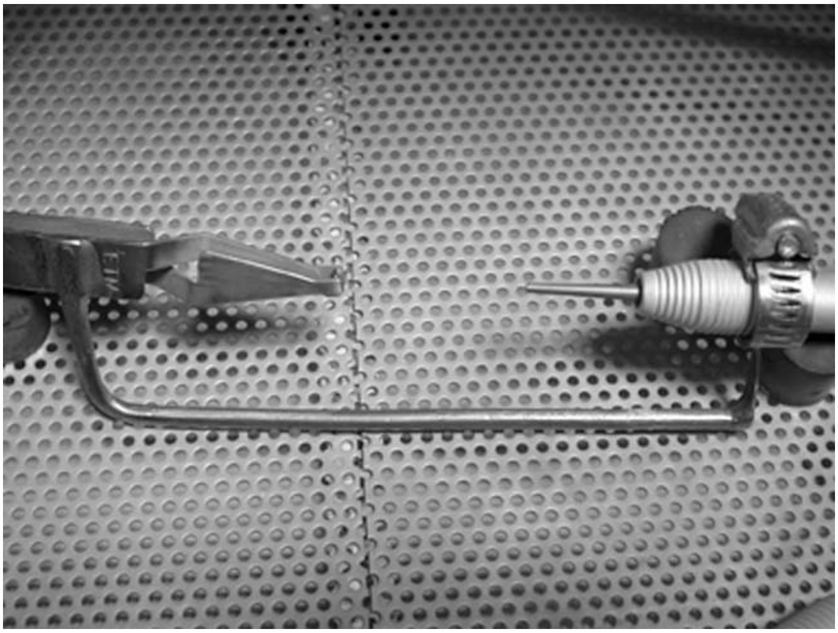
The resin-modified glass ionomer cement was mixed strictly following manufacturer's instruction. Mixed adhesive was applied on the bracket base and the bracket was positioned onto the centre of the cylinder with a light force. The bracket cylinder combinations were immediately placed under constant pressure (200 gr) in a specially designed jig for 10 seconds. A constant pressure was applied because variation in thickness of the adhesive would have inverse effects on the bond strength [10]. The excess adhesive was removed using a small scaler and magnifying glass when the samples were

Table 1 Descriptive statistics, ANOVA and parameters of the weibull analysis of tensile of bond strengths for each group

Group	N	Mean (MPa)	SD (MPa)	Range (MPa)	Tukey's HSD*	Weibull modulus *m*	Correlation coefficient	Characteristics strength σ_0 (MPa)	Bond strength at 5% prob. of failure $\sigma_{.05}$ (MPa)	Bond strength at 90% prob. of failure $\sigma_{.90}$ (MPa)
CO	20	10.2	2.6	4.1–15.1	AB	4.39	0.968	11.2	6.3	14.8
S25$_3$	20	12.5	2.8	8.0–16.6	A	5.30	0.980	13.6	8.6	16.1
S25$_6$	20	9.2	2.6	3.3–13.1	BC	4.32	0.969	10.8	5.7	13.2
S25$_9$	20	7.1	2.9	2.7–12.2	BCE	3.85	0.980	9.9	5.6	12.4
S50$_3$	20	9.8	2.7	5.7–14.9	BC	4.27	0.986	10.1	5.1	12.9
S50$_6$	20	8.4	2.6	4.1–13.9	B	3.60	0.980	9.3	4.1	11.8
S50$_9$	20	6.8	2.5	1.9–10.4	BCE	2.23	0.970	5.4	1.3	7.8
S110$_3$	20	8.9	2.6	4.5–13.4	BC	2.75	0.978	7.9	2.6	11.0
S110$_6$	20	4.8	2.3	0.4– 8.8	EF	3.26	0.968	7.6	3.0	10.8
S110$_9$	20	2.9	1.9	0.4– 6.8	F	1.57	0.988	3.2	0.8	6.9

Key: CO indicates unsandblasted control group; S, sandblasted; 25, 25 μm particle size of aluminium oxide; 50, 50 μm particle size of aluminium oxide; 110, 110 μm particle size of aluminium oxide; 3, 3 seconds sandblasting; 6, 6 seconds sandblasting; 9, 9 seconds sandblasting.
*Groups showed with different letters were significantly different at $p = 0.05$ lavel according to Turkey's HSD test.

Fig. 1 Device used to control the distance between the surface of the bracket base and the tip of the sandblasting hand piece.



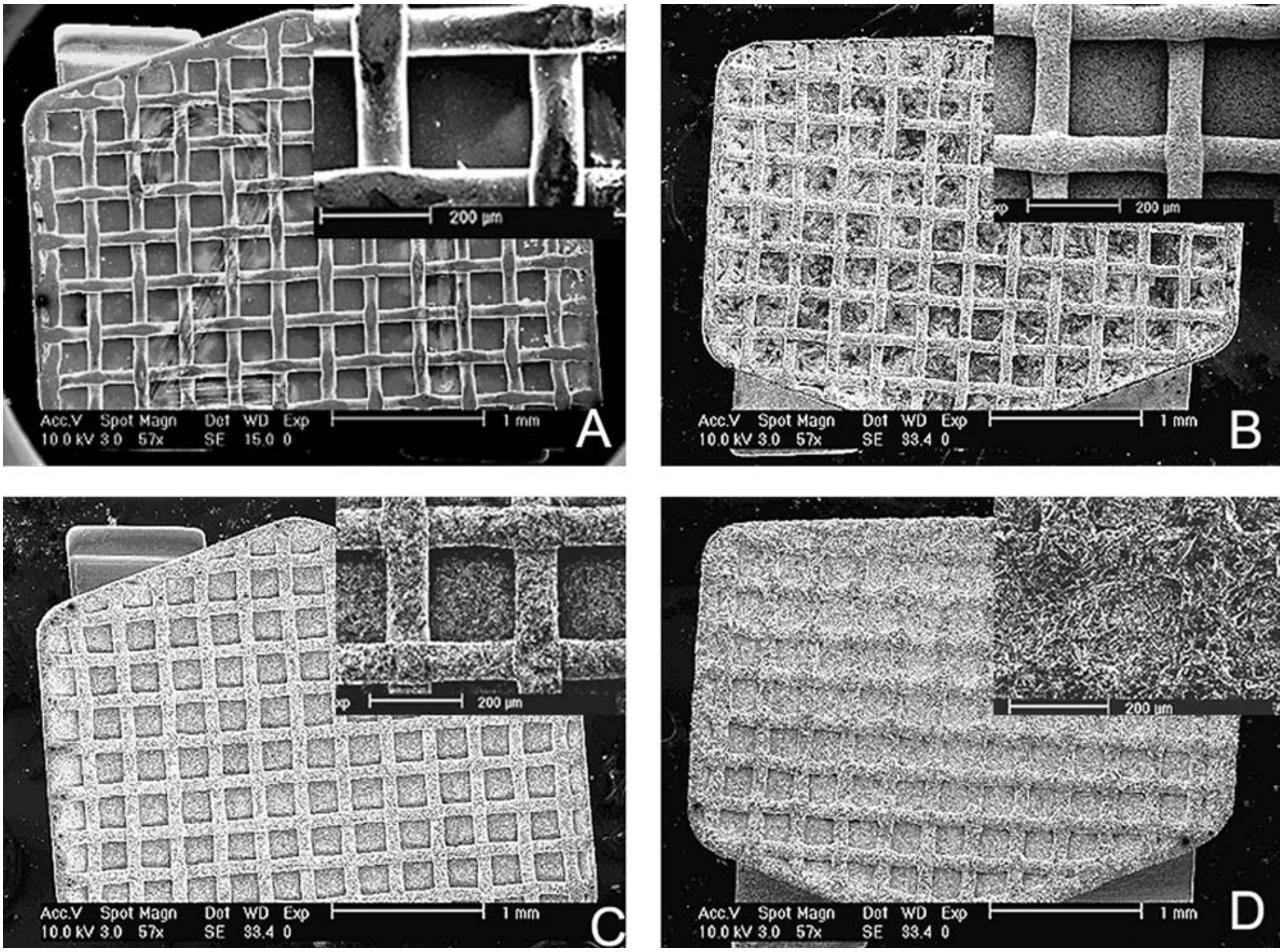


Fig. 2 Scanning electron micrographs of foil-mesh based metal brackets. (A) unsandblasted, (B) sandblasted with 25 μm diameter aluminum oxide powder for 3 seconds, (C) sandblasted with 50 μm diameter aluminum oxide powder for 6 seconds, and (D) sandblasted with 110 μm diameter aluminum oxide powder for 9 seconds.

under this constant pressure jig. Two brackets were bonded with each mix of the resin-modified glass ionomer cement. The bracket bonded specimens were then left undisturbed for 5 minutes at room temperature before being stored in water at 37°C for 24 hours.

Testing

In this study, tensile test was carried out using a Lloyd LRX testing machine (Lloyd Instruments Plc, Fareham, Hampshire, England). For tensile testing, a custom cast nickel-chromium bracket holder that adapted closely under the bracket tie wings was constructed [11]. The peak force levels, automatically recorded on the testing machine, were converted to stress per unit area (MPa) by dividing the force (Newtons) by the mean unit area of the base of the bracket (9.63 mm^2). A crosshead speed of 1 mm per min was used.

In addition to the tensile bond strength, the other variable evaluated for all groups was the bond failure site. Bond failure sites were classified as cohesive (within the adhesive resin) or bracket-adhesive interface.

Statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA) and any significant differences revealed by this procedure were further investigated using the Tukey's honest significant difference (HSD) multiple-range test with a 95% confidence limit ($p < 0.05$).

The results of tensile bond strengths were also evaluated as a function relating the probability of failure to applied stress by means of Weibull analysis. This analysis offers a means of predicting the dependability of a material or composition. Simple calculations allow the prediction of failure probability at any selected level of stress or vice versa [12, 13]. The Weibull cumulative distribution function presents the data in a format of probability of failure P_f versus applied stress σ:

$$P_f = 1 - \exp\left[-\left(\frac{\sigma - \sigma_u}{\sigma_0}\right)^m\right]$$

where σ is the applied stress, σ_u the threshold stress (i.e., the stress below which the probability of failure is zero), σ_0 a normalizing parameter (often selected as the characteristic stress, at which the probability of failure is 0.632), and m the Weibull modulus that has practical implication. A high value of m indicates a close grouping of fracture stress values, whilst a low value indicates a wide distribution with a long tail at low stress levels. It is customary to assume that $\sigma_0 = 0$, an assumption which has been confirmed by others [13, 14].

In order to analyze the failure sites, contingency tables were designed and subjected to the chi-square (χ^2) test.

Results

The mean tensile bond strengths and standard deviations for each group are shown in Table 1. It can be seen that the group sandblasted with 25 μm diameter aluminum oxide for 3 seconds (S25$_3$) has the highest mean bond strength value, followed by the control group (CO). The lowest value was given by the group sandblasted with 110 μm diameter aluminum oxide for 9 seconds (S110$_9$). A factorial ANOVA was performed to investigate the effects of the particle size of the aluminum oxide (25, 50 and 110 μm in diameter) and the sandblasting time (3, 6 and 9 seconds) on the tensile bond strength (MPa). The results revealed that the bond strength is significantly affected by the particle size ($p < 0.001$) and the sandblasting time ($p < 0.001$).

Using the bond strength (MPa) as the dependent variable, an analysis of variance (ANOVA) showed a significant difference ($F = 23.02$, $p = 0.000$) between the groups at the 95% confidence level. The grouping of these differences by Tukey's HSD multiple-range indicated that S25$_3$ demonstrated higher mean tensile bond strength than the other groups apart from CO (Table 1).

Table 1 also lists the results of the Weibull analysis of bond strengths for each group. The predictability of a group can be seen on examination of the *m* value (Weibull modulus). Higher *m* values indicate a more predictable system and, therefore, possibly, a more clinically reliable system. For example, S25$_3$ has an *m* value of 5.30, while S110$_9$ has an *m* value of 1.27. This difference implies more clinical predictability with S25$_3$ than with S110$_9$ under tensile force. It, also, can be observed from the Table 1 that the *m* values progressively decreased for all particle sizes of aluminum oxide powder (25, 50 and 110 μm), when the sandblasting time was increased from 3 to 9 seconds.

The characteristic strength (σ_0) in Weibull analysis is similar to the mean derived from the analysis of variance which assumes a normal distribution. Examining the characteristic strengths, it was observed that the ranking of the characteristic strengths of all groups was the same as those of their mean bond strengths. Values of tensile forces required for 5 and 90% probabilities of failures ($\sigma_{.05}$, $\sigma_{.90}$) revealed that, at lower force levels the groups sandblasted for 9 seconds were more likely to fail than the groups sandblasted for 3 and 6 seconds. S110$_9$ showed the lowest values for the 5 and 90% probabilities of failures ($\sigma_{.05} = 0.8$ and $\sigma_{.90} = 6.9$ MPa) under tensile forces. S25$_3$ reached the highest values ($\sigma_{.05} = 8.6$ and $\sigma_{.90} = 16.1$ MPa), followed by the CO ($\sigma_{.05} = 6.3$ and $\sigma_{.90} = 14.8$ MPa) (Table 1).

Table 2 shows the distribution of the failure sites expressed as frequency of occurrence. Under tensile forces, CO, S25$_9$, S110$_6$ and S110$_9$ groups showed predominantly bracket-adhesive interface type of failures, whereas the other groups

Table 2 Frequent and percentage occurrence (%) of the failure sites for each group tested

Group	N	B/A	COH
CO	20	13(65)	7(35)
$S25_3$	20	9(45)	11(55)
$S25_6$	20	9(45)	11(55)
$S25_9$	20	12(60)	8(40)
$S50_3$	20	9(30)	14(70)
$S50_6$	20	7(35)	13(65)
$S50_9$	20	10(50)	10(50)
$S110_3$	20	8(40)	12(60)
$S110_6$	20	11(55)	9(45)
$S110_9$	20	15(75)	5(25)

Key: CO indicates unsandblasted control group; S, sandblasted groups; 25, 25 μm particle size of aluminium oxide; 50, 50 μm particle size of aluminium oxide; 110, 110 μm particle size of aluminium oxide; 3, 3 seconds sandblast; 6, 6 seconds sandblast; 9, 9 seconds sandblast; B-A (bracket- adhesive type of failure), more than 50% of the bonded bracket base surface is free of resin-modified glass ionomer cement; COH (cohesive failure), more than 50% of failure occurs within the resin-modified glass ionomer cement.

namely, $S25_3$, $S25_6$, $S50_3$, $S50_6$ and $S110_3$, predominantly had cohesive type of failures.

Chi-square analysis of the failure sites did not show any statistically significant difference ($p = 0.122$) between the groups. That is to say there was not a significant association between the sandblasting combinations and failure site.

Discussion

Although in the present study technique inconsistencies were minimized by using the same type of bracket for all groups, ensuring a standardized sandblasting and bonding method, and by developing easily reproducible tensile testing method, some unavoidable factors might still affect the outcome of test. Firstly, tensile testing 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 *in vitro* bond strength studies a number of complex jigs have been designed to provide this. However, peel and shear forces can still occur, despite these alignment jigs because of the geometric complexity of orthodontic brackets. Therefore, some investigators have referred to the bond strength as tensile-peel or shear-peel [15, 16]. Secondly, non uniformity in the stress field distributions also can be introduced by the inherent curvature (particularly in canine and premolar brackets) and surface roughness of bracket bases [17]. Although uneven stress concentration is a problem in bond strength testing of adhesives in restorative dentistry, it was considered by the authors that this could be accepted for orthodontic *in vitro* bond strength studies because the aim was to predict the clinical picture. Nevertheless, the standard deviations in the tensile bond strengths obtained in this study were in the range which would normally occur in this type of test [2, 3, 9].

Several studies have reported that sandblasting bracket bases greatly increases their retentive surface which produces a significant reduction in the probability of failure relative to the unsandblasted samples [2, 3, 18]. In a previous study, it was reported that sandblasting the mesh-base of the stainless steel bracket for 3 seconds increased the bond strength of the conventional glass-ionomer cements to a level that may be clinically acceptable [2]. In the present study, similar results are gained only for $S25_3$ group. However, in previous studies, the adhesive thickness was not controlled during bonding and brackets were directly bonded to extracted human premolars. As it was stated previously, the bond between the bracket base and the resin-modified glass-ionomer cement was of most interest in this study. Therefore, no tooth substrates were used and the adhesive thickness was controlled by application of a constant pressure during bonding.

After sandblasting, only the group ($S25_3$) sandblasted with 25 μm diameter aluminum oxide for 3 seconds showed a 12 per cent higher mean tensile bond strength when compared with the control group (CO). This improvement in the tensile bond strength offered by sandblasting could be explained by the increasing the surface area and thinning the oxide layer on the stainless steel bracket base. Therefore, these increases in the tensile force values required to debond the brackets bonded with resin-modified glass ionomer cement could be attributed to both the enhanced chemical and mechanical bond potentials provided by the sandblasting. However, the other sandblasted groups had lower mean bond strength values than that of the control group. An explanation of this phenomenon comes from the scanning electron micrographs of the sandblasted bracket bases which shows distortion and loss of the meshwork of the bracket bases (Fig. 2 C and D). This distortion and wearing-away of the meshwork due to either the sandblasting with the larger diameter aluminum oxide powders or sandblasting for longer time periods (6 or 9 seconds) could have caused a reduction of the mechanical retention between the resin-modified glass ionomer cement and the bracket base.

Several factors, such as pressure used during sandblasting, distance of application (distance between bracket base and tip of sandblasting unit), particle size of the aluminum oxide powder used and sandblasting time, have considerable effects on the outcome and should be strictly controlled during this procedure. However, there has been no standardization in sandblasting techniques in the dental literature. Therefore there are problems in drawing meaningful conclusions from comparing the different studies, due to the areas of inconsistency in this method.

The results of this study revealed that using either large size aluminum oxide powder (110 μm) or long sandblasting time (6 or 9 seconds) could have an inverse effect on the tensile bond strength because of the distortion of the meshwork base of the bracket. It can be stated that the sandblasting time should considerably be reduced when the aluminum oxide powder larger than 25 μm was used for sandblasting (Table 1). It should also be pointed out that there was a shift from the cohesive to the bracket-adhesive type of bond failures when the powder size and sandblasting time was increased (Table 2). Therefore, it may be tentatively suggested that the adhesion between the metal bracket base and the resin-modified glass ionomer cement has more mechanical than chemical nature.

Weibull analysis is not routinely used in orthodontic bond strength studies. However, several authors used it to relate the results of *in vitro* studies to clinical performance [19, 20]. In the present study a wide range of *m* values (Weibull modulus) were obtained. The small *m* values indicate that the data could be fitted well to a normal distribution. It was stated that an *m* value of 3.4 corresponds precisely with normally distributed data and only data having a Weibull modulus value of 3 or more can be fitted to a Gaussian distribution [21]. Hence, using Weibull analysis is valid in here (Table 1). It has, also, been confirmed that a substantial number of test samples required to determine an accurate value for the Weibull modulus. For brittle materials, such as ceramics, over 60 samples are required to obtain 90% confidence in the *m* value [22].

In this study, the sandblasted group $S25_3$ and CO reached the highest values for the 5 and 90% probabilities of failures under tensile forces, respectively. However, the sandblasted groups $S110_9$ and $S50_9$ showed the lowest values for the 5 and 90% probabilities of failures and low values of Weibull modulus. Therefore, it is reasonable to state that a high number of bond failures have to be expected in orthodontic treatment when the foil-mesh based metal brackets were sandblasted with 50 or 110 μm of aluminum oxide powders for 9 seconds.

Conclusions

On the basis of the data that were collected and statistically analyzed in this study, the following conclusions may be drawn.

1. Sandblasting of foil-mesh based metallic bracket with 25 μm aluminum oxide powder at 58 psi for 3 seconds increased the mean tensile bond strength of resin-modified glass ionomer cement by 12 per cent.
2. Sandblasting metal bracket bases longer than 3 seconds and using 50 or 110 μm diameter aluminum oxide powders reduced mean tensile bond strength because of the distortion observed in the meshwork.
3. Sandblasting time, distance and size of the aluminum oxide powder have considerably important effects on the bond strength. When this technique is used in order to increase the adhesion between the metal bracket base and the resin-modified glass ionomer cement, these factors should properly be controlled.

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