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Laboratory evaluation of modern plastic brackets

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SUMMARY The aim of the study was to evaluate some properties of modern orthodontic plastic brackets. Seven bracket brands [Aesthetik-Line (AL), Avalon (AV), Brillant (BR), Elegance (EL), OrthoFlex (OF), Silkon Plus (SL), and Spirit MB (SP)] were included in the study. The properties tested were chemical composition, base morphology, slot roughness, Vickers hardness (VH), and shear bond strength (SBS) with enamel. According to the results, the brackets were composed of polyurethane (AV and OF), polyoxymethylene (BR), and Ca-Al-silicate fibre glass-reinforced polycarbonate (AL, EL, SL, and SP). Metallic slots were composed of austenitic stainless steel (EL and SP) and Ag–Cu alloy (AV). The base morphology exhibited distinct designs, employing parallel retentive canals (AV, EL, and OF) or round-angled square protrusions with major retentive elements (AL, BR, and SP) or a combination of both (SL). The SP metallic slot demonstrated the lowest Sz values. No significant differences were found in VH among the brackets before water immersion (19.6–16.9 VH). After 12 weeks immersion, the brackets showed a significant hardness reduction (16.6–12.9 HV). SBS ranged between 111 and 193 N (8–14 MPa) for all brackets, except from SP (59 N/5 MPa). The predominant failure mode was mixed adhesive and cohesive. Most of the plastic brackets presented a base structure capable of adequate bonding to enamel, regardless of their differences in composition. Slot roughness showed differences among groups. All the brackets demonstrated plasticization after prolonged water storage.

Introduction

Stainless steel is commonly used for manufacturing orthodontic brackets due to the high strength and durability of the alloys employed. However, as the aesthetic appearance of fixed orthodontic appliances has become extremely important over the years, new tooth-coloured materials based on plastics and ceramics have been designed (Brantley and Eliades, 2001).

Plastic brackets, mainly consisted of unfilled polycarbonate (PCB), were introduced in orthodontic therapy in the early 70s and significantly improved aesthetics (Eliades *et al.*, 2004). Nevertheless, they exhibited many problems, such as tie-wing fracture and slot distortion due to lack of strength and stiffness, increased slot roughness, staining, and odour due to oral fluids adsorption (Zinelis *et al.*, 2005) and need of primers for bonding with orthodontic resin adhesives (Feldner *et al.*, 1994). To overcome these problems, efforts were undertaken to improve mechanical strength employing new polymers with increased stiffness (Eliades *et al.*, 2004), incorporation of smooth metallic slots (Zinelis *et al.*, 2005), and polymer reinforcement with glass fibres (Faltermeier *et al.*, 2007). Moreover, the shape of the bracket bases was modified to enhance resin bonding without the need of primers, facilitate bracket debonding upon treatment completion, and minimize enamel damage associated with debonding procedures (Arici and Regan, 1997).

The aim of the present study was to evaluate some properties of modern plastic brackets including composition, morphology, slot roughness, hardness, and bond strength with enamel. The null hypothesis was that no significant differences exist among the brackets types in the properties tested.

Materials and methods

Seven commercially available modern orthodontic plastic brackets were selected for the study (Table 1). All the brackets were for upper central incisors and had Roth 22 slots sizes.

Base morphology and bracket composition

The bonding base of each bracket type was sputter coated with a thin carbon layer and examined by scanning electron microscopy (Quanta 200 SEM; FEI, USA) under high vacuum, 10 KV accelerating voltage, 90 μA beam current, secondary electron detector (ETH) at ×25, ×100, and ×1000 magnifications. For the microstructure and elemental composition, brackets embedded in epoxy resin were cross-sectioned, polished with SiC papers up to 4000 grit size and carbon coated as above. Compositional backscattered electron images (SSD) were recorded (30 KV, 90 μA, ×50) to identify regions with differences in mean atomic number.

The elemental composition (brackets/metallic slots) were determined by energy-dispersive X-ray spectrometry (EDX), with a spectrometer (Sapphire CDU; EDAX Int, USA) attached to the SEM, using a 640 × 640 μm sampling

Table 1 The plastic brackets tested.

Products code/batch	Composition*	Slot type	Manufacturer
Aesthetik-Line (AL) 792-0101	Composite reinforced by fibre fillers	Plastic	Forestadent GmbH, Pforzheim, Germany
Avalon (AV) 4335	Polyurethane	Metallic	Ortho Technology, Tampa, Florida, USA
Brillant (BR) 767-0101	Polyoxymethylene	Plastic	Forestadent GmbH
Elegance (EL) 791-013-03	Fiber glass-reinforced polycarbonate	Metallic	Dentaurum GmbH, Ispringen, Germany
OrthoFlex (OF) 505302	Medical grade polyurethane	Plastic	Ortho Technology
Silkon Plus (SL) 002-2922M	Filler-reinforced polycarbonate	Plastic	American Orthodontics, Sheboygan, Wisconsin, USA
Spirit MB (SP) 495-0111	Filler-reinforced polycarbonate	Metallic	Ormco Corp, Orange, California, USA

*According to manufacturers' instructions.

window (30 KV, 110 μA), 100 seconds acquisition time, and 30–34% detector dead time. The quantitative elemental analysis was performed in a non-standard mode employing carbon background and ZAF corrections by Genesis software (v 5.1; EDAX).

The molecular composition of the brackets was studied by attenuated total internal reflection–Fourier transform infrared spectroscopy (ATR–FTIR). The bases of as received brackets were pressed against a single-reflection diamond element (Ø:2 mm) of an ATR accessory (Golden-Gate MKII; Specac, USA) attached to an FTIR spectrometer (Spectrum GX; Perkin-Elmer, UK) and spectra were recorded under the following conditions: 4000-600 cm^{-1} range, 4 cm^{-1} resolution, and 40 scans acquisition.

Slot roughness

Brackets from each brand (*n*:10) were prepared by cutting the wings down to one-third of the slot depth using a fine diamond disk. The slot floor roughness was evaluated by an optical profiler (Wyko NT 1100; Veeco, USA), operated in vertical shift interference mode, 80 μm scan length, ×46.1 magnification (113 × 148.5 μm sampling area) and 25 l/mm Gaussian filtering. Three-dimensional images and the surface roughness parameters Sa (average roughness), Sq (root mean square roughness), and Sz (average peak to valley high depths of five consecutive sampling measurements) were obtained using the Wyko Vision 32 software (Veeco).

Hardness

Brackets embedded in epoxy resin were ground in a metallographic grinding/polishing machine, until exposure of the wings cross-section. They were then ground up to 4000 grit size and subsequently polished according to the instructions given for polymers and PCBs (Struers A/S, DK). Three groups (A–C, *n*:10 each) were prepared from each bracket type. Specimens of group A were stored in air (control), whereas specimens of groups B and C were immersed in distilled water (37°C) for 1 and 12 weeks, respectively. Hardness measurements (*n*:3 per bracket) were performed by a microhardness tester (HMV2000, Shimadzu, Japan), equipped with a Vickers intender, under 200 g load and 15 seconds contact time.

Shear bond strength with enamel and failure mode analysis

Intact central incisors extracted for periodontal reasons, kept in water at 4°C with addition of 0.5 per cent sodium azide, were used in the study. The crowns were sectioned, embedded in epoxy resin, leaving the labial surfaces free, and horizontally oriented. After epoxy setting, the exposed tooth surfaces were cleaned with a fluoride-free slurry, etched with a 37 per cent phosphoric acid gel (Super-etch gel; SDI, Australia) for 15 seconds, rinsed with water spray for 10 seconds, and thoroughly air dried for 5 seconds. A thin film of a primer (Transbond XT Primer; 3M Unitek, USA) was applied on acid-etched surfaces and a light-cured orthodontic adhesive on bracket bases (Transbond XT; 3M Unitek) without using any plastic primer, according to the manufacturers' instructions. The brackets (*n*:10 per brand) were pressed against the central part of the labial surfaces, excess paste was carefully removed, light cured with a light-emitting diode unit (Radii Plus; SDI, 1200 mW/cm^2 light intensity) for 5 seconds through the bracket and then from apical and incisal edges (10 seconds each), stored in distilled water (2 weeks/37°C), and then debonded in a universal testing machine (Tensometer 10; Monsanto, UK) under a shear load applied at the bracket base–enamel interface, at a crosshead speed of 2 mm/minute. The debonding forces were recorded in Newton and transformed to megapascal after measuring the bracket dimensions with a digital calliper. The failure mode of debonded tooth surfaces was examined under a reflected light video microscope (MS-500C; Moritex, UK) at ×25 magnification and classified according to the modified adhesive remnant index (ARI) scores (David *et al.*, 2002).

Statistical analysis

Two-way analysis of variance (ANOVA) and Tukey test (hardness), one-way ANOVA plus Holm–Sidak test (roughness), and Kruskal–Wallis one-way ANOVA on Ranks plus Tukey test [shear bond strength (SBS)] were used to evaluate statistically significant differences at a 95 per cent confidence level. Statistical analysis was performed by SPSS 17.0 Software (SPSS Inc., Chicago, USA).

Results

Base morphology and bracket composition

At low magnification, the bonding bases demonstrated three types of retentive features (Figure 1): 1. horizontally solid protruding parts separated by parallel retentive canals and free mesial/distal margins [Avalon (AV), Elegance (EL), and OrthoFlex (OF)], 2. evenly distributed round-angled square protrusions/recessions [Aesthetik-Line (AL), Brillant (BR), and Spirit MB (SP)] plus major central retentive elements with free (SP) or sealed margins (BR and AL), and 3. a hybrid design [Silkon Plus (SL)] combining the previous features. At ×100 magnification (Figure 1, inserts), the surface texture appeared smooth for most brackets (AV, OF, SL, and SP). In BR and AL, the round-angled regions were slightly rougher from the rest, whereas in EL, rough protrusions/recessions were identified. At higher magnification (×1000, Figure 2), the retentive elements of AV, BR, OF, SL, and SP demonstrated a typical image of a particle abraded surface, while AL and EL appeared smoother.

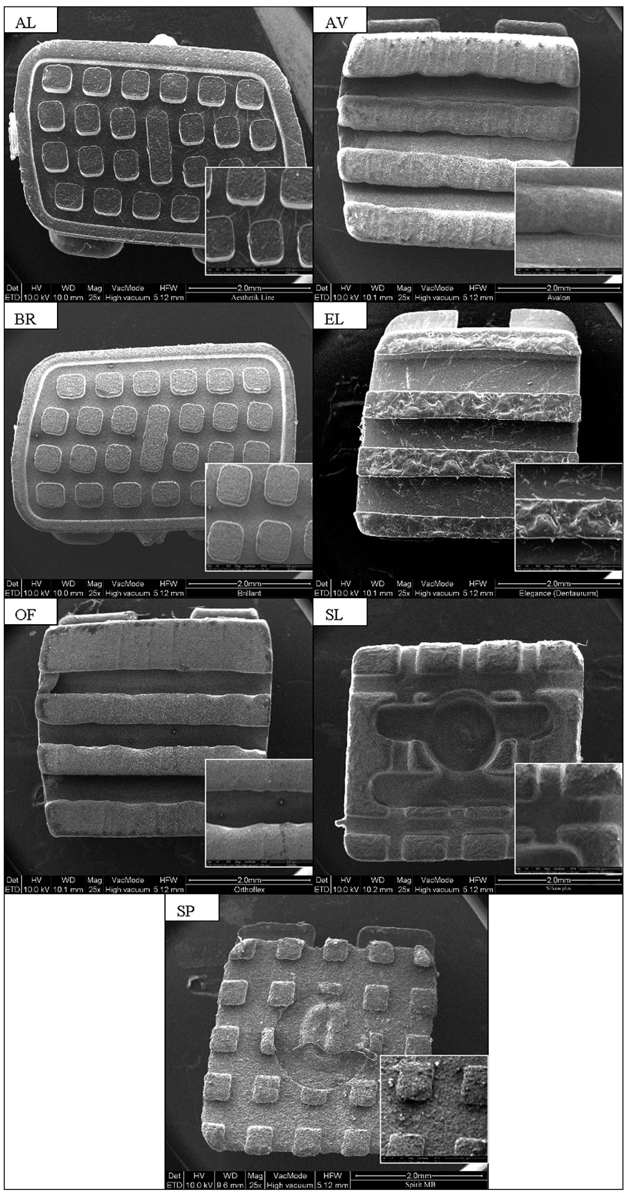

Figure 1 Secondary electron images (ETH) of the bracket bases at ×25 and ×100 (inserts) magnification.

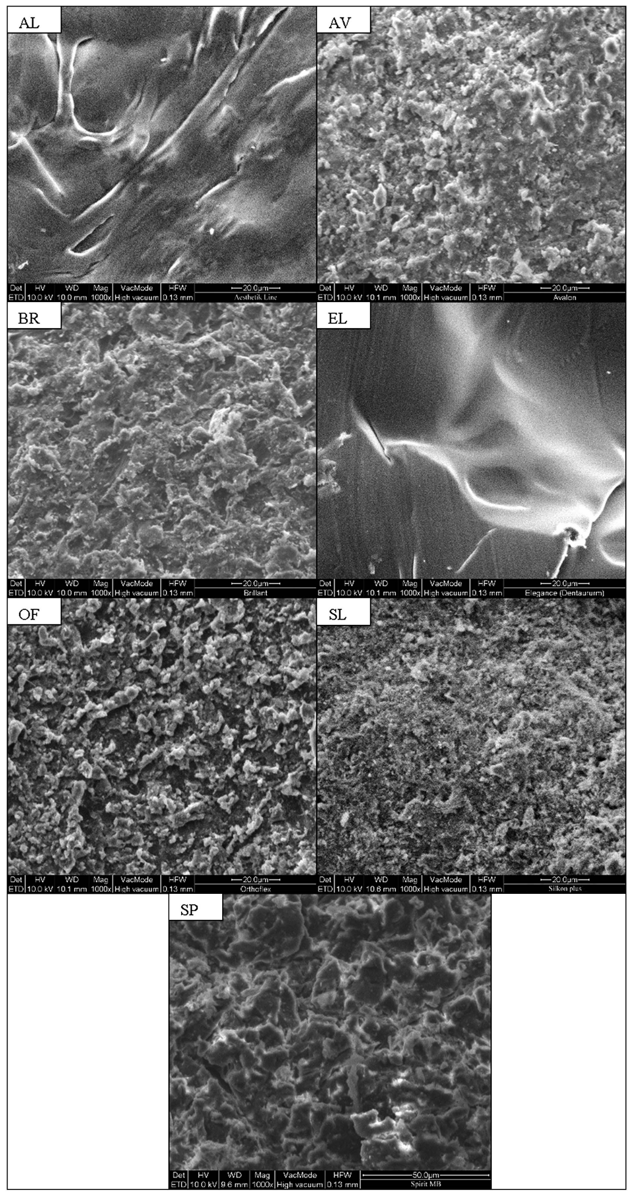

Figure 2 Secondary electron images of bracket base details (×1000 magnification).

Representative SSD images with the corresponding EDX spectra are given in Figure 3. In AL, EL, SL, and SP, a continuous low atomic number phase incorporating a dispersed high atomic number phase were identified, the latter resembling a fibre-shaped structure, with most fibres arranged parallel to the mesiodistal bracket length. AV, BR, and OF were composed of an unfilled homogeneous phase. U-shaped high atomic number slots were identified in AV, EL, and SP with round angles facing the bracket structure (EL and SP) and evidence of debonding at the slot-wing interface (SP). All the brackets were solid, one piece structures, except from BR, which showed bulk porosity at the neck.

The results of the elemental composition are summarized in Table 2. Fibre-reinforced brackets were mainly composed of an organic matrix with Ca-Al-silicate glass fibres, whereas unfilled materials consisted of an organic matrix with traces of Ca and P contaminants. A stainless steel alloy

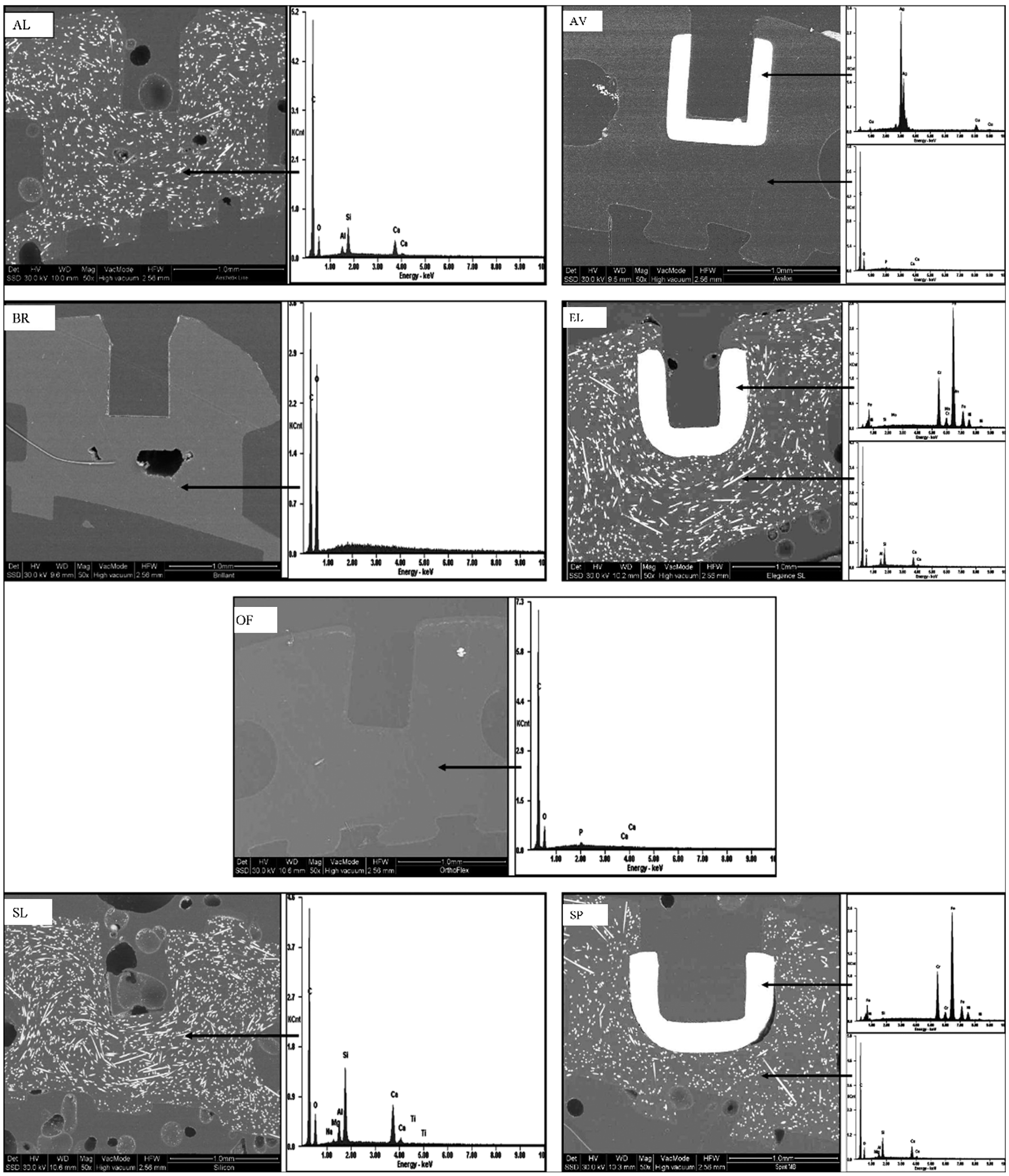

Figure 3 Compositional backscattered electron images (SSD, ×50 magnification) of cross-sectioned bracket specimens and energy-dispersive X-ray spectra of bulk materials and metallic slots.

Table 2 Results ofelemental composition (per cent weight) by energy-dispersive X-ray spectrometry.

Bracket	C	O	Na	Mg	Al	Si	P	Ca	Ti
Aesthetik-Line (AL)	70.70	23.96	—	—	0.81	2.67	—	1.85	—
Avalon (AV)	68.51	30.97	—	—	—	—	0.38	0.15	—
Brillant (BR)	38.25	61.75	—	—	—	—	—	—	—
Elegance (EL)	69.15	23.44	—	—	1.41	3.09	—	2.02	—
OrthoFlex (OF)	69.32	30.16	—	—	—	—	0.40	0.15	—
Silkon Plus (SL)	63.62	25.33	0.18	0.34	1.67	5.48	—	3.30	0.10
Spirit MB (SP)	68.52	23.84	—	0.26	1.04	3.77	—	2.58	—
Slot	Si	Mo	Cr	Mn	Fe	Ni	Ag	Cu	
AV	—	—	—	—	—	—	93.56	6.44	—
EL	0.70	0.92	17.95	1.49	71.63	7.32	—	—	—
SP	0.80	—	18.95	1.07	71.15	8.02	—	—	—

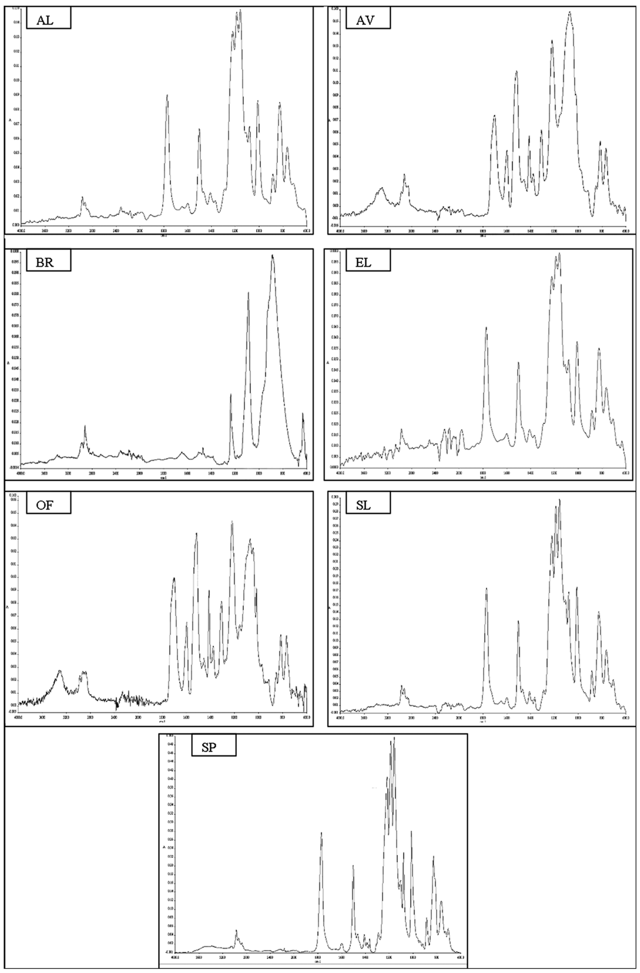

Figure 4 Attenuated total internal reflection–Fourier transform infrared spectra of the brackets.

(8Ni–18Cr) was used in the slots of EL and SP and a Ag–Cu alloy in the slot of AV.

The peak assignments of the FTIR spectra (Figure 4) are listed in Table 3. AL, EL, SL, and SP exhibited the characteristic peaks of aromatic PCBs, AV and OF were typical of polyurethanes (PUs), whereas BR complied with the structure of polyoxymethylene (POM).

Slot roughness

Three-dimensional profilometric images of the slot floors are depicted in Figure 5. The metallic slots (AV, EL, and SP) showed different topographies, including machining tracks (AV) and a rough texture with pits and fissures (EL and SP). The smoothest and more uniform polymeric slot topography was found in AE, SL, followed by BL and OF, the latter exhibiting a rough surface with random protrusions. The results of the roughness parameters are summarized in Table 4. The highest Sa value was found in OF. In Sq, differences were limited between OF–AL and OF–SP, whereas in Sz, four groups with statistically significant differences were encountered (BR–SL ≥ SL–EL–OF > AL–AV > SP).

Hardness

No statistically significant differences were found in VH before water immersion (Table 5). Significantly lower VH values were found in EL and OF after 1 week storage. After 12 weeks storage, OF demonstrated the lowest VH value, the group of BR, EL, and SL intermediate values, and the group of AV, AL, BR, SL, and SP the highest values, all significantly different among groups.

SBS with enamel and failure mode analysis

The highest debonding force was recorded in AV and the lowest in SP (Table 6). The ranking of statistically significant differences was AV > EL and OF > AL > SL > SP. For debonding pressures, the ranking of statistically significant differences was modified (AV–EL ≥ EL–OF > AL–SL ≥ SL–BR > SP). The failure mode analysis showed that in AL, AV, BR, OF, and SP, more than 60% of the specimens left the tooth surface were covered up to 50 per cent with adhesive resin remnants (Table 7). AV (43 per cent) and SL (68 per cent) showed debonding with 100 per cent of the tooth surface cover with resin remnants, including failures at the adhesive–bracket interface (30 per cent for AV and 80 per cent for SL).

Discussion

According to the results, the testing hypothesis was not verified since significant differences were found in the properties tested among the bracket types.

The FTIR analysis showed that three types of polymers were used in the bracket manufacturing process: aromatic PCBs, PUs, and POM. All the PCB brackets tested were filled with Ca-Al-silicate glass fibres, oriented parallel to the slot length to withstand the complex force patterns applied by the activated wires. Unfilled PU (AV and OF)

Table 3 Fourier transform infrared spectroscopy peak assignments.

Product	Characteristic in peaks (/cm) and group assignments	Structure
Avalon (AV) and OrthoFlex (OF)	3300 (NH), 2970–2870 (CH), 1704, 1698 (C=O, H-bonded), 1597 (ring NH), 1522 (HNCO), 1411–1308 (CH), 1219 (C=O), 1069 (C—O—C)	Polyurethane (PU)
Brillant (BR)	2923 (CH), 1097 (asymmetric C—O—C), 903 (symmetcic C—O—C)	Polyoxymethylene (POM)
Aesthetik-Line (AL), Silkon Plus (SL), and Spirit MB (SP)	2980–2840 (CH), 1769 (C—O—CO—O—C), 1597 (C=O), 1504 (ring C—C), 1400–1300 (CH), 1217, 1187, 1160 (triplet C—O), 1081 (C—C—C), 1015 (O—C—O)	Aromatic polycarbonate (PCB)

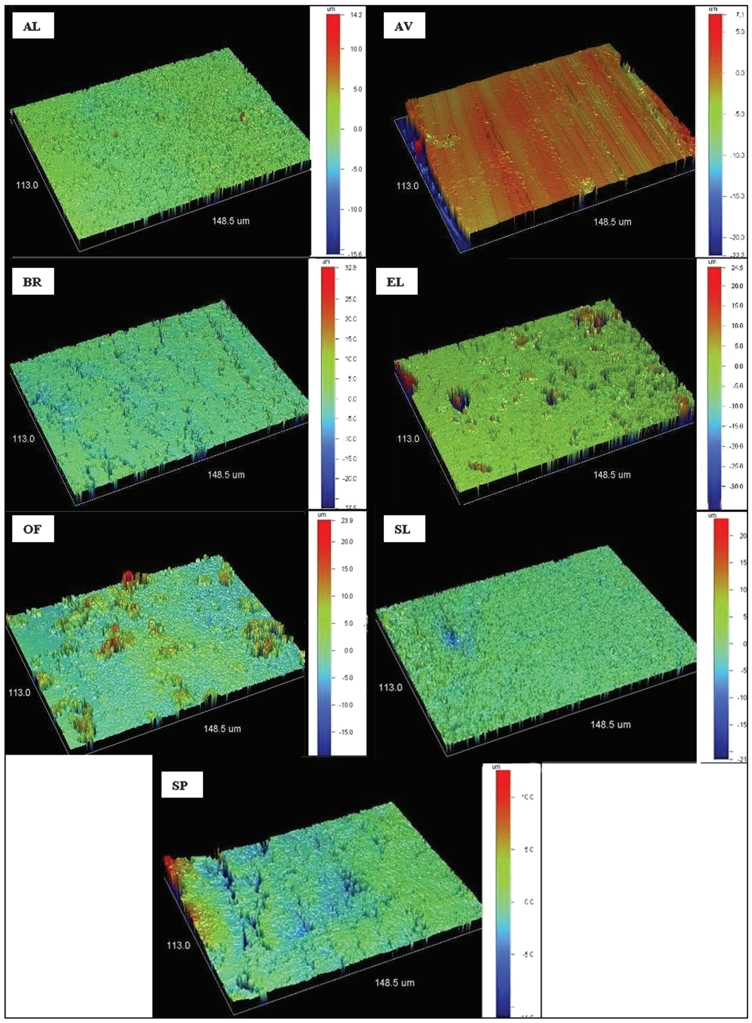

Figure 5 Three-dimensional profilometric images of the slot floor of the brackets (×41.6 magnification).

and POM (BR) brackets were introduced as alternatives to PCB, possibly to address the biocompatibility issues raised due to bisphenol-A release from PCB (Suzuki *et al.*, 2000). Medical grade PUs are free of plasticizers, with good mechanical properties and biocompatibility. The presence of H-bonded C=O groups imply that the PU brackets tested are in the most stable form, with limited capacity to undergo H-bonding with the environment (Eliades *et al.*, 2005). The traces of Ca and P found are assigned to extrusion agents (i.e. Ca stearate) used during PU manufacturing. POM (known also as polyacetals) possess low friction, high wear resistance, high stiffness, and good physical properties. However, biocompatibility concerns have been expressed for POM, as well, due to formaldehyde release upon water storage (Kusy and Whitly, 2005). The metallic slots, provided in EL and SP, were made of austenitic stainless

Table 4 Results of slot surface roughness (means and standard deviations)*.

Product	Sa (μm)	Sq (μm)	Sz (μm)
Aesthetik-Line (AL)	0.68 (0.13)[b]	0.95 (0.17)[c]	20.02 (1.77)[c]
Avalon (AV)	0.69 (0.38)[b]	1.19 (0.53)[b,c]	24.02 (1.40)[c]
Brillant (BR)	0.92 (0.10)[b]	1.52 (0.21)[b]	35.38 (6.60)[a]
Elegance (EL)	0.68 (0.13)[b]	1.59 (0.63)[b]	30.11 (5.08)[b]
OrthoFlex (OF)	1.72 (0.28)[a]	2.44 (0.45)[a]	31.71 (4.96)[a,b]
Silkon Plus (SL)	0.82 (0.13)[b]	1.25 (0.21)[b,c]	32.95 (6.20)[a,b]
Spirit MB (SP)	0.80 (0.22)[b]	1.01 (0.24)[c]	13.96 (2.92)[d]

*Same superscripts letters per column imply mean values with no statistically significant difference ($P > 0.05$).

Table 5 Results of Vickers hardness measurements (means and standard deviations)*.

Product	Group A (air)	Group B (1 w H_2O/37°C)	Group C (12 w H_2O/37°C)
Aesthetik-Line (AL)	18.13 (0.81)[a,1]	17.26 (0.70)[b,1]	16.63 (0.67)[c,1]
Avalon (AV)	18.43 (1.72)[a,1]	17.33 (0.69)[b,1,2]	15.77 (0.87)[c,2]
Brillant (BR)	18.86 (1.57)[a,1]	16.80 (1.43)[b,2]	16.37 (0.40)[b,c,2]
Elegance (EL)	16.88 (4.26)[a,1]	16.00 (1.65)[a,b,1]	14.95 (0.30)[b,2]
OrthoFlex (OF)	19.55 (2.43)[a,1]	14.43 (1.58)[a,2]	12.85 (1.30)[a,3]
Silkon Plus (SL)	18.35 (1.23)[a,1]	17.95 (0.53)[b,1]	15.95 (1.16)[b,c,2]
Spirit MB (SP)	18.16 (1.42)[a,1]	17.53 (0.61)[b,1,2]	16.10 (0.57)[c,2]

*Same superscript letters imply mean values with no statistically significant differences within each group and same superscript numbers among groups per bracket type ($P > 0.05$).

Table 6 Results of shear bond strength with enamel (means and standard deviations)*.

Product	Bond strength (*N*)	Bracket area (mm^2)	Bond strength (MPa)
Aesthetik-Line (AL)	148.46 (4.3)[d]	14.7	10.10 (0.5)[c]
Avalon (AV)	193.38 (3.2)[f]	13.6	14.22 (2.1)[e]
Brillant (BR)	110.83 (1.1)[b]	14.4	7.70 (0.6)[b]
Elegance (EL)	165.11 (3.8)[e]	12.2	13.53 (0.3)[d,e]
OrthoFlex (OF)	166.13 (2.1)[e]	14.8	11.23 (1.2)[c,d]
Silkon Plus (SL)	125.56 (2.4)[c]	12.7	9.89 (1.4)[b,c]
Spirit MB (SP)	59.30 (1.0)[a]	12.1	4.90 (0.9)[a]

*Same superscripts letters imply mean values with no statistically significant differences ($P > 0.05$).

steel, commonly used in orthodontic appliances, to effectively transfer torque on teeth. The Ag–Cu alloy introduced in AV was selected to reduce friction. Nevertheless, the intra-oral corrosion stability of this alloy (i.e. Cu release) may raise some concerns. Metallic slot debonding from the PCB matrix, found in SP, may influence the force transfer characteristics to the tooth structure. The latter are also affected by the slot design. Slots with round angles may induce a more even stress distribution pattern in the plastic wings, reducing thus stress concentration at weak structural points, like the bracket neck.

Table 7 Results of adhesive remnant index (ARI) score index and percentage score incidence*.

Product	Score 1	Score 2 (%)	Score 3 (%)	Score 4 (%)	Score 5 (%)	Score 6 (%)
Aesthetik-Line (AL)	0	5 (50)	1 (10)	1 (10)	2 (20)	1 (10)
Avalon (AV)	0	4 (40)	5 (50)	1 (10)	0	0
Brillant (BR)	0	5 (50)	4 (40)	1 (10)	0	0
Elegance (EL)	0	3 (30)	4 (40)	3 (30)	0	0
OrthoFlex (OF)	0	4 (40)	4 (40)	2 (20)	0	0
Silkon Plus (SL)	0	2 (20)	0	1 (10)	2 (20)	5 (50)
Spirit MB (SP)	0	4 (40)	4 (40)	2 (20)	0	0

*Score 1: no adhesive left on tooth; Score 2: less than 25% adhesive left; Score 3: 25–50 per cent adhesive left; Score 4: 50–75 per cent adhesive left; Score 5: more than 75 per cent adhesive left; and Score 6: 100 per cent adhesive left, with adhesive failure at the bracket–adhesive interface.

It has long been considered that slot roughness may significantly affect sliding mechanics (Drescher *et al.*, 1989). Several investigations have been performed on the effect of archwire and slot raw materials, sizes, ligation type, and presence of wet or dry conditions (Thorstenson and Kusy, 2003; Chimenti *et al.*, 2005). It has been postulated that plastic brackets induce higher friction than metallic ones (Tselepis *et al.*, 1994). In the present study, only amplitude roughness parameters were evaluated. Sa failed to demonstrate reduced roughness in metallic slots, despite that a plastic slot gave the highest values. The same applied for Sq; metallic slots were classified in both the groups demonstrating statistically significant differences. In Sz, that is more sensitive to changes in peak/valley heights, the brackets were classified in four statistically homogeneous groups, with the lowest values obtained from a metallic slot. Apparently, the definition of each parameter modified the statistical outcome. Further work should be done on this subject employing more parameters, like the hybrid and functional, for the full characterization of slot roughness.

Bonding of resin orthodontic adhesives to plastic brackets is typically mechanical and is achieved by creating macroretentive elements in the base (Brantley and Eliades, 2001). Methacrylate priming of plastic bases had been advocated to increase interfacial strength. According to the manufacturers' instructions, none of the new brackets tested required this step. The base of most brackets demonstrated a rough micromorphology to increase bonding area and thus micromechanical interlocking. The brackets with sub-millimetre rectangular retentive elements (AL, BR, SP, and SL) exhibited a major central retentive indentation, to increase torque resistance, a feature missing from the bases with solid horizontal protrusions (AV, EL, and OF) since the latter offer intrinsic torque resistance.

Hardness testing was performed on bracket wings because this structure is considered as the most sensitive.

The results before water storage showed no statistically significant differences in VH, in accordance with previous studies (Zinelis *et al.*, 2005). However, polymers like PCB, PU, and POM contain hydrophilic groups (i.e. CH─O, C═O, C─O─C, COO, NH, and NCO) that absorb water and undergo plasticization, affecting the mechanical properties (Srivastava, 1999). Variations in the polymer molecular weight and filler content may explain the differences found in the extent of water plasticization among the materials tested. It is anticipated that bracket loading, temperature, and pH fluctuations along with exposure to oral fluids may further reduce hardness and fatigue limits of the polymer structures (Kusy and Whitly, 2005). However, the extent of plasticization that may critically affect force transfer characteristics is not known. To address this issue, randomized controlled clinical studies are required.

The results of the SBS test, although with considerable methodological limitations (Eliades and Brantley, 2000), are within the range reported for metallic brackets (Cossa *et al.*, 2006), excluding SP. The low values of SP are probably attributed to the reduced size and number of retentive base protrusions. Despite that intra-oral ageing may reduce the strength and modify the failure mode, the results obtained from most brackets are promising, taking into account that no base primer was used. The debonding values were given both in load (Newton) and in pressure units (Megapascal) since calculation of the bonding area based only on bracket length/width, leads to a significant error. The ranking of the debonding values in Newton and Megapascal was almost the same, implying a standard effect of the bonding bases. The failure mode analysis manifested ARI scores of 2 and 3 (enamel covered up to 50 per cent with adhesive resin) in most products, which complies with the failure mode of metallic brackets (Liu *et al.*, 2004). Considering that the clinical debonding procedure of plastic brackets involves bending distortion of the wings, just like in the metallic brackets (Brantley and Eliades, 2001), it can be concluded that the plastic brackets tested are safe regarding enamel integrity.

Conclusions

Under the limitations of present study, the following conclusions can be drawn:

- The brackets tested were composed of unfilled PUs, unfilled POM, and Ca-Al-silicate fibre glass-reinforced PCBs.
- The bonding base morphology demonstrated that distinct designs comprising of parallel solid protrusions and retentive canals or evenly distributed round-angled square protrusions/recessions with major retentive elements or combinations of both.
- Differences were found in slot roughness. A metallic slot demonstrated the lowest Sz values.
- No statistically significant differences were found in hardness before water immersion among the brackets tested. However, after prolonged water storage, the same brackets demonstrated a significant reduction in hardness.
- The bond strength values with enamel and the failure mode of most brackets tested were comparable with the values reported for metallic brackets, although no base primers were used.

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