Modeling mechanic debonding with the help of the Velcro™ fastener.

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Introduction

There seems to be confusion about the forces involved in orthodontic debonding: thus, a search of the American Journal of Orthodontics and Dentofacial Orthopedics (AJODO) online archive between 1986 and June 2007 turned up 190 articles containing the word bond in the title, and only 44 with debonding. The same exercise showed for the Angle Orthodontist (AO) for 1930 to 2007, 92 and 13, respectively, and for the Journal of Clinical Orthodontics (JCO) for 1967 to 2007, 243 and 21, respectively. Aside from showing that bonding is of major interest to practitioners,[1] this endeavor demonstrated that its reverse (debonding) is considered far less important. Searching similarly for the words shear bond and shear-peel, we found in the AJODO 100 titles with shear bond and 6 with "shear-peel". In the AO there were 57 and 2, respectively, while in the JCO, 13 and none, respectively.

Other terms used by some to describe the nature of the forces involved in orthodontic debonding, such as "pivotal or rocking action" for torsion, or "unequal debonding tension force" for peel, were also sporadically found. This may be a reason for the rather chaotic information found in the literature. According to a comprehensive review,[2] the mean bond strengths reported for different combinations of bracket, adhesive and enamel conditioner range from a minimum of 3.9 MPa (found to be adequate for most clinical needs) to a maximum of 29.4 MPa; as early as 1974 Retief[3] reported that enamel fracture can occur with bond strengths as low as 13.5 MPa, a magnitude comparable to the linear tensile strength of enamel.

Recently, Swartz[4] reviewed the many pitfalls found in vitro studies, asking for more meaningful clinical research into orthodontic bonding, while De Castro[5] pleaded for the standardization of in vitro testing methods involving bracket debonding. Despite existing standards[6,7] and adaptations,[8,9] a review of the literature[10] reveals a large variation in these methods, making the comparison of papers difficult and often impossible. Finite-element model calculations of the stress distribution taking place during debonding under tension, shear-peel and torsion show that these methods influence strength measurement and that the typical method of reporting test results cannot reflect such differences.[11]

This multiple choice situation has extended from testing to clinical debonding, only one method actually being used both as a test and on patients.[12, 13] The gap between the two has led to serious consequences, for example, the fact that 3 out of 100 teeth exhibited enamel fracture after debonding Transcend Series 2000 ceramic brackets (3M Unitek).[14] This has prompted the American Association of Orthodontists to warn its members about the dangers involved[15] and to advocate the use of hand instruments pliers, scalers and chisels over other debonding methods (ultrasound, laser, thermal, etc.), despite their being tedious, time-consuming and painful.

In an attempt to make this complex endeavor easier to understand and prevent the use of misnomers, we have tried to model bracket bonding and debonding using the Velcro system.

Basics

While the realed elasticity modules are widely different, the Velcro system™ (Fig.1) resembles orthodontic bonding in that what joins the parts in both cases is simply mechanical interlocking (no chemical interactivity involved). This can be seen by comparing them: in the latter, the resin/composite tags (Fig.2)[16] penetrate the empty enamel prisms left after exposure to 35% phosphoric etching gel for 30 seconds, followed by rinsing and drying (Fig. 3).[16]

Fig.1. Image of Velcro's hooks and loops (eyes)

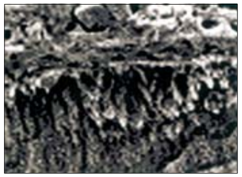


Fig. 2. SEM 3000x. Adhesive tags penetrating the enamel[16]

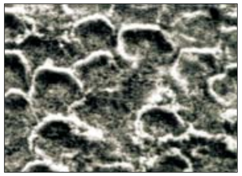


Fig. 3. SEM 3000x. Enamel surface after exposure to acid etch[16]

The Velcro™ system is actually biomimetic. It is claimed that the system's inventor, George de Mestral, was inspired by the cockleburs sticking to his clothes. Upon returning home, he discovered the small hooks that enabled the seed-bearing bur to be transported to new areas. It may be only a question of time before the system is duplicated using hard materials (crystals): mesothelioma is known to be generated by hook-shaped asbestos.

It is our opinion that the system can be used to foster better understanding of the effect of the various forces applied to the tooth/bracket system. Indeed, descriptions of enamel fracture under different debonding loads using such modern means as finite-element modeling (FEM), scanning electronic microscopy (SEM) and image software analysis fail to present a simple and intuitively easy method of viewing the phenomena involved.

Materials and Method

The force needed to detach a model to which a standard-size "hook" fastener was glued was provided by a scale-type device, already described.[17-19] The only modification was the replacement of water with stainless steel balls as the weight. To enable the balls to flow evenly, a sand-timer-like arrangement was used: as soon as the model became detached, the direction of the ball flow was manually changed and the flow interrupted.

The model selected didn't have as its goal the duplication of a direct-bonding bracket, but rather to evidence the forces involved in its detachment. Several prisms, 65 mm in length, were cut from a hardwood road having a square section of 1" x 1". After adjusting the prisms' bases to fit the size of the Velcro squares, we provided the model with detachable eyes or levers. The latter were used to delineate the different levels at which the force was applied (Fig. 4). The geometry of the typical edgewise bracket can be approximated by the prism formed by the model's base and the level corresponding to position 1; higher levels were provided only to reveal detachment trends.

The "hook" part of a Velcro fastener was firmly attached to the model's base with Krazy Glue™. Purchased as die-cut squares having a standard size of 22 mm x 22 mm, the fastener had a weak adhesive as backing, which was removed. Interestingly, its interlocking ability has remained the same even after being subjected to denatured ethylic alcohol or butyl acetate, or napped with a fine steel brush. Tens of delaminating and debonding tests against its counterpart showed good resistance to fatigue. The "loop" counterpart, obtained from Home Depot as Industrial Velcro bands 2" wide, was bonded as is to a pad (actually, a wood board 18 x 13 x 2 cm). The latter, which we will call the "support," was fastened to the lab bench vertically or horizontally, as shown in Figures 5 and 6, respectively.

The tests were performed by pressing the Velcro hook-covered base of the model into the desired position against its looped counterpart, rigidly attached to the support. A metal hook connected to the scale by a wire was made to be attached at any eye of or lever of the model. After making sure that all the desired angles were observed, we started to add weight to the other end of the wire. When the model became detached, weight was either added or subtracted about 20 times while we changed the model's position on the support about every 5 minutes. When in each case the force exceeded the strength of the model's attachment to the support, the corresponding weight was noted as the ultimate force and recorded on the charts.

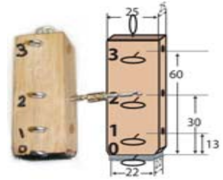
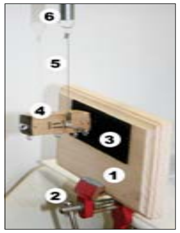


Fig. 4. Image of the model and its geometry

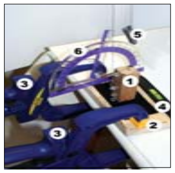


(1) for measuring shear, peeling and torsion. Fastened with help of vice (2), board supports "loop/eye" tape (3), on which lies model (4), which in turn is hooked to measuring scale through a wire 5 provided with a deadening spring 6.

Fig. 5. Vertical arrangement of piece of board, or pad.

Results

This simple test has been adapted to many more situations than those presented here. Fig. 7 shows the value of the ultimate forces parallel with the support at which the model remains still attached. When the angle of pull varied between ± 10°, the force needed for debonding increased. Figure 8 shows the values of the ultimate forces perpendicular to the support at which the model remains attached.



Model (1) is attached to support (2), which is fastened by clamps (3). For position accuracy, level (4), plumbline (5) and protractor (6) were provided

Fig. 6. Horizontal arrangement of pad (2) for measuring tension and peeling.

In Figure 9 are represented values of the ultimate debonding forces applied at level 0, i.e., that of the support. With the exception of tension, the value of which remained constant, the higher the level of force application, the easier it was to debond. Figure 10 shows the variation in ultimate debonding forces at the model's different levels.

Discussion

According to the American Society for Testing and Materials (ASTM) and the British Standards Institute,[20] shear is the mode of application of a force to a joint that acts in the plane of the bond. In other words, it is the state at which the stress is tangential to a face of the material, or applied parallel to the cross-sectional area tested. In contrast, peel is the mode of application of a force to a joint in which one or both of the adherents are flexible and in which the stress is concentrated at a boundary. In other words, stress consists in pulling away from the surface at a predetermined angle. Acting usually at right angles to the lap joint, it reaches a maximum at its ends.

The interface is stressed in tension and shear, and the force is concentrated along the zone of contact of the substrate to the a dhesive. The contact zone can degenerate into a very small area, and the local tensile stress that develops becomes almost infinitely high, even when the peeling load is relatively small. Figures 8 to 11 confirm that the two terms in the syntagm shear-peel are so different that they cannot be put together except for indicating an attempt to approximate pure shear, knowing that.a force-specimen misalignment is quite common,[21]

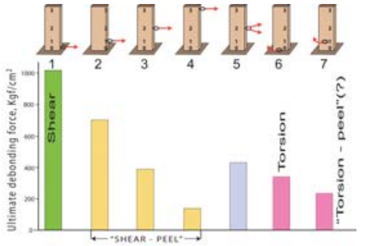


Fig. 7. Debonding forces applied on the model (above) and their impact on the related ultimate bond strength (below)
Forces parallel with the support

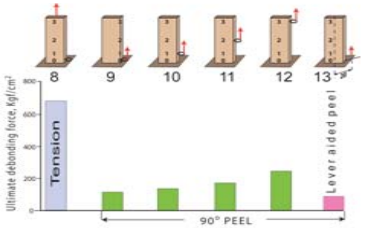


Fig. 8. Debonding forces applied on the model (above) and their impact on the related ultimate bond strength.
Forces perpendicular on the support

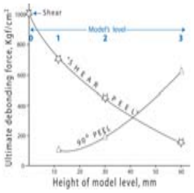


Fig. 9. The ultimate bonding force needed to debond the model at the level 0 (its interface with the support)

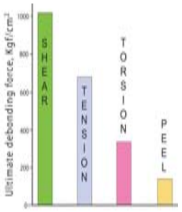


Fig. 10 Ultimate bonding force needed to debond the model at different levels.

As can be observed, peeling is the most destructive (in our case, efficient) type of loading/debonding, followed by torsion and tension. Other information that can be easily translated to bracket debonding is, as far as tension is concerned, the fact that the higher the level at which force is applied, the more difficult to detach the sample. And the longer the lever (power arms, hooks), the easier the debonding.

Conclusion

The model used didn't show significant fatigue of the rigid-converted Velcro™ fastening system. Although the elas-ticity modulus of the examined systems differs significantly, the information provided by the model is valuable.

Just as there is neither black nor white—just shades of grey—it is very likely that almost all tests and clinical debondings are variations of peeling. Pure shear is a fata morgana, while "shear-peel" is a pierced umbrella for both tests and office treatment, and therefore misnomers; the attempt to achieve it, however, helps the tester assess the bond's resistance to the highest possible stress. the bond strength exhibited by a bracket under a variety of forces. The lowest effective debonding force is achieved at the adhesive/enamel interface either by peeling at 90° or by cleavage. Tension and torsion are not efficient enough, unless substantially combined with peel. The more distant the point of force application from the bracket's center, the easier the debonding.

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