

Shear bond strength test using different loading conditions – a finite element analysis

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Abstract

Aim: This study evaluated the stress distribution at the bond interface during shear bond strength testing for three loading conditions. **Methods:** A three-dimensional model was created of a specimen for evaluation by the shear bond strength test, using three cylindrical volumes representing the dentin, adhesive system and composite resin. A linear analysis was performed to calculate the stress distribution at the dentin-adhesive interface. Three models simulating different loading conditions were prepared: chisel, orthodontic-looped wire and stainless steel tape. **Results:** Chisel presented severe stress concentrations near the loading site (-10681 to 637 MPa). Wire presented stress concentrations along the radial loading axis (-382 to 216 MPa). Tape presented more uniform stress distribution (-83 to 21 MPa). **Conclusions:** The loading with stainless steel tape allowed more uniform stress distribution at the bond interface, and was a more reliable way to evaluate the bond with regard to the aim of the shear bond strength test.

Keywords: Shear bond strength, stress distribution, loading.

Introduction

In-vitro mechanical tests of dental restorative materials provide dental practitioners with guidance as regards material selection criteria and identifying patterns of optimal clinical use of material. The quality of adhesive material bonding is frequently verified by various laboratory tests, using shear and tensile efforts under certain limitations¹.

In 1997, a study evaluated 50 studies that used laboratory tests to quantify the bond strength at the bond interface, and observed that 80% used the shear bond strength (SBS) test in its several forms². Today, use of the microtensile bond strength (μ TBS) and microshear bond strength (μ SBS)³ tests have increased considerably. However, several recent studies still use the SBS test to evaluate adhesive material bonding⁴⁻¹⁰. In some situations, sectioning of the specimen for μ TBS induces its loss due to failure before the test, and μ SBS cannot be used

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because of the difficulty of making specimens with some materials. In these cases, the SBS test may be used to evaluate adhesive material bond strength. It is important to consider the changes in the test procedures commonly applied in different investigations that have the same aim: to determine the bond strength. For this reason, analyses of the same material inevitably produce different bond strength data^{1,11-14}.

A factor concerns the stress created at the bond interface by the load applied. Sinhoret et al.¹⁵ compared the morphological characteristics of the fractured composite-dentin interface, using an ISO specified test (loading applied with chisel), and non-specified tests (loading applied with stainless steel tape and orthodontic-looped wire). The authors found that the failures were fractures between the adhesive and the dentine when the stainless steel tape was used, suggesting that this loading condition was not subject to the complexity of stress produced by a loading test¹. However, no information was found in the literature on how the stress distribution occurs at the bond interface during the SBS test under these three conditions. The simultaneous interaction of the many variables affecting a restorative system can be studied using simulation in a computerized model. The finite element analysis (FEA) consists of dividing a geometric model into a finite number of elements, each with specific physical properties. The variables of interest are approximated with some mathematical functions. Stress distributions in response to different loading conditions can be simulated with the aid of computers with dedicated software¹⁶.

The aim of this study was to compare the effects of different loading conditions (chisel, orthodontic-looped wire and stainless steel tape systems) used in shear bond tests on stress distribution at the dentin-adhesive interface using FEA. The hypothesis tested was that the loading condition simulating a stainless steel tape creates a more uniform stress distribution at the bond interface.

Materials and methods

A 3-D model was created of a specimen for evaluation by the shear bond strength test, using three cylindrical volumes representing the dentin (6 mm diameter and 1 mm thick), adhesive system (4 mm diameter and 10 μ m thick) and composite resin (4 mm diameter and 6 mm thick). The study model presented the configurations and dimensions presented in Figure 1. The FEA was performed with the FE software program (ANSYS rel 5.2, Ansys Inc., Houston, TX, USA).

The model components were assumed to be isotropic. The elastic constants used in the calculations were obtained from the literature (Table 1)¹⁷⁻¹⁸. The Solid92 element was used, dentin and composite resin (the solid corpus), with 10 nodes and three degrees of freedom per node. The following assumptions were made: there is complete bonding between dentin, adhesive and composite resin; dentin was assumed to contain elastic isotropic material. The volumes were meshed, finally resulting in a 3-D FE model with 15,436 elements and 23,835 nodes.

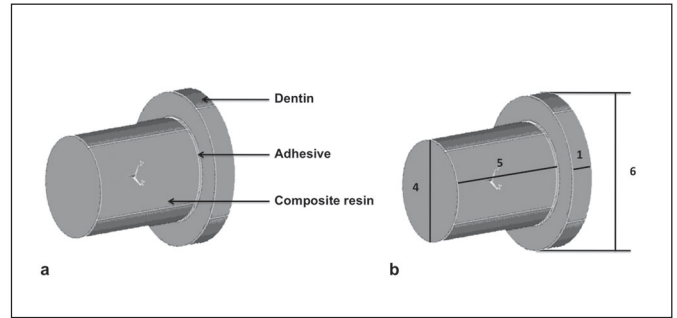


Fig. 1 (a) Components involved in the investigated model; (b) dimensions (mm) of investigated model

Table 1. Mechanical properties considered for FEA

Components	Young's Modulus(E)	Poisson's Ratio(i)	Reference
Dentin	18 GPa	0.31	18
Adhesive system	4 GPa	0.35	17
Composite resin	10 GPa	0.25	17

All of the nodes on the external dentin surface were constrained in all directions. A linear static structural analysis was performed to calculate the stress distribution at the dentin-adhesive interface, under a total load of 200 N. This load produced a mean shearing stress of approximately 16 MPa. Three experimental models simulating different loading conditions were performed (Figure 2):

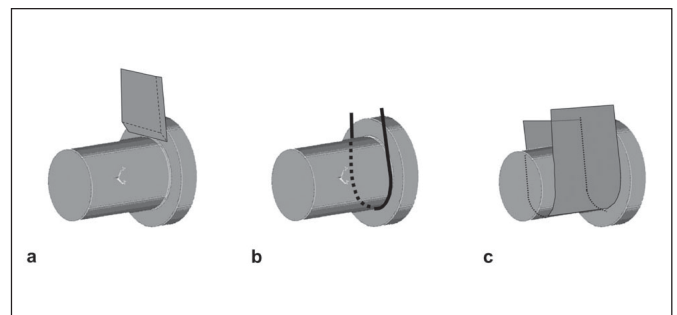


Fig. 2 Schematic illustrations of the different loading conditions: (a) chisel simulation; (b) orthodontic-looped wire simulation; (c) stainless steel tape simulation

- Chisel group – punctual loading at the adhesive-dentin interface, simulating the load applied on the specimen with a chisel;

- Wire group – application of a radial loading 0.5 mm from adhesive-dentin interface, simulating the load applied on the specimen with orthodontic-looped wire;

- Tape group – application of a radial pressure with 5 mm of width, simulating the load applied on the specimen with a stainless steel tape;

Accuracy of the model was checked using convergence tests. Particular attention was given to the refinement of the mesh resulting from the convergence tests at the interfaces. The results were qualitative and quantitatively analyzed with regard to shearing stress distribution at the dentin-adhesive interface.

Results

The stress distribution at the bond interface for the different loading conditions is shown in Figure 3. For the Chisel Group, the bond interface presented high stress levels concentrated next to the point of load application. The shearing stress values ranged from -10681 to 637 MPa. For the Wire Group, the bond interface presented stress concentration along the radial loading axis, but it was

considerably lower than that for the chisel. The shearing stress values ranged from -382 to 216 MPa. For the Tape Group, the bond interface did not present peaks of stress concentration, showing more uniform stress distribution. The shearing stress values ranged from -83 MPa to 21 MPa.

Discussion

The results of the current study showed more homogenous stress distribution at the bond interface during the shear bond strength test using stainless steel tape, supporting the hypothesis of the study. The larger area of contact between the stainless steel tape and the specimen created stress distribution over the entire bond interface. Therefore, the lower stress concentration along the bond interface explains that using tape, sliding occurs between the components of the specimens, characterizing a shear bond strength test.

As regards the loading using the chisel, severe stress concentrations were presented near the loading site, caused by the simulation of the small area of contact between the chisel and the specimen (punctual load). This loading condition creates stresses of complex nature, involving cleavage, traction and compression^{1,19}. Cohesive failures in dentin are commonly found, with portion of the substrate being literally pulled away^{1,20}. The strength values obtained must be ignored when these cohesive failures occur in the dentin, once they do not represent the mean strength measured at the bond interface, and but the cohesive strength of the substrate¹⁹⁻²⁰.

The loading simulating the orthodontic-looped wire also showed stress concentrations, although considerably lower compared with the chisel. A region showing the presence of red color near the radial load observed in Figure 3 indicates the effect of the stress concentrations due to the small area of contact between the wire and specimen. The stresses are not distributed along of whole the interface as when using tape. Sinhoreti et al.¹ considered the failure using wire caused by flexional stress, promoting cohesive fracture of the composite or cohesive fracture of the adhesive. The wire has circular transversal section so the force cannot be applied joint to interface, compatible with the simulation using wire in the current study, in which the radial load was applied 0.5 mm from the bond interface. This fact could increase the flexion pattern at the bond interface²¹⁻²².

In addition, the data of the present study explained the results found by Sinhoreti et al.¹. Among the three loading conditions tested, they found the lowest bond strength values for loading using tape, and interfacial failures between dentin and adhesive, suggesting that tape creates the best condition for establishing the true shear bond strength test. The bond failure occurs due the sliding between the surfaces of composite resin and dentin, as result concentration of tangential force. Moreover, this load produces no fulcrum point or flexion of the composite cylinder, or superficial cleavage, as observed for the load with orthodontic-looped wire and chisel, respectively¹.

Della-Bona et al.²³ suggested that the SBS test is

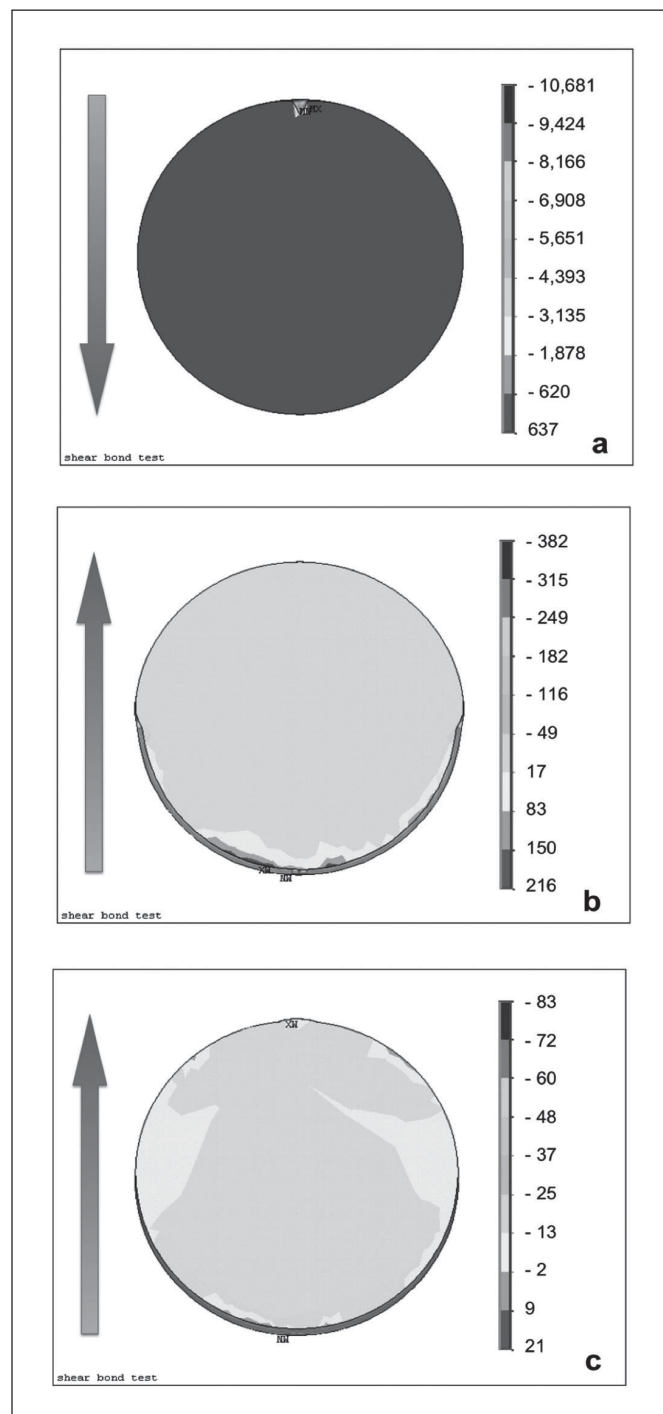


Fig. 3 Shearing stress distribution in the different loading simulations: (a) chisel; (b) orthodontic-looped wire; (c) stainless steel tape. Arrows indicate the direction of load incidence

inadequate as a means of assessing the quality of the adhesive bond of resin composite to ceramic. However, in some situations, sectioning the specimen for the μ TBS induces its loss by failure before of the test. In these cases, the SBS test using the stainless steel tape may decrease the tensile and compressive stresses during the test to evaluate the bond of these friable materials.

Considering the results obtained with 3-D FEA and literature available, it may be concluded the loading with stainless steel tape allows more uniform stress distribution along the bond interface. Therefore, loading using a tape is a more reliable method and must be used to evaluate the bond strength of adhesive materials concerning the aim of the SBS test.

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References

1. Sinhoreti MA, Consani S, De Goes MF, Sobrinho LC, Knowles JC. Influence of loading types on the shear strength of the dentin-resin interface bonding. *J Mater Sci Mater Med*. 2001; 12: 39-44.
2. Al-Salehi SK, Burke FJ. Methods used in dentin bonding tests: an analysis of 50 investigations on bond strength. *Quintessence Int*. 1997; 28: 717-23.
3. Placido E, Meira JB, Lima RG, Muench A, de Souza RM, Ballester RY. Shear versus micro-shear bond strength test: a finite element stress analysis. *Dent Mater*. 2007; 23: 1086-92.
4. Kanehira M, Finger WJ, Ishihata H, Hoffmann M, Manabe A, Shimauchi H, et al. Rationale behind the design and comparative evaluation of an all-in-one self-etch model adhesive. *J Dent*. 2009; 37: 432-9.
5. Czarnecka B, Deregowska-Nosowicz P, Limanowska-Shaw H, Nicholson JW. Shear bond strengths of glass-ionomer cements to sound and to prepared carious dentine. *J Mater Sci Mater Med*. 2007; 18: 845-9.
6. Ercan E, Erdemir A, Zobra YO, Eldeniz AU, Dalli M, Ince B, et al. Effect of different cavity disinfectants on shear bond strength of composite resin to dentin. *J Adhes Dent*. 2009; 11: 343-6.
7. Dos Santos PA, Garcia PP, Palma-Dibb RG. Shear bond strength of adhesive systems to enamel and dentin. Thermocycling influence. *J Mater Sci Mater Med*. 2005; 16: 727-32.
8. Aida M, Odaki M, Fujita K, Kitagawa T, Teshima I, Suzuki K, et al. Degradation-stage effect of self-etching primer on dentin bond durability. *J Dent Res*. 2009; 88: 443-8.
9. Phark JH, Duarte S, Jr., Kahn H, Blatz MB, Sadan A. Influence of contamination and cleaning on bond strength to modified zirconia. *Dent Mater*. 2009; 25: 1541-50.
10. Erickson RL, Barkmeier WW, Kimmes NS. Bond strength of self-etch adhesives to pre-etched enamel. *Dent Mater*. 2009; 25: 1187-94.
11. Pecora N, Yaman P, Dennison J, Herrero A. Comparison of shear bond strength relative to two testing devices. *J Prosthet Dent*. 2002; 88: 511-5.
12. Van Noort R, Cardew GE, Howard IC, Noroozi S. The effect of local interfacial geometry on the measurement of the tensile bond strength to dentin. *J Dent Res*. 1991; 70: 889-93.
13. Katona TR, Long RW. Effect of loading mode on bond strength of orthodontic brackets bonded with 2 systems. *Am J Orthod Dentofacial Orthop*. 2006; 129: 60-4.
14. Oilo G, Olsson S. Tensile bond strength of dentin adhesives: a comparison of materials and methods. *Dent Mater*. 1990; 6: 138-44.
15. ISO/TR-11405. Guidance on testing of adhesion to tooth structure. International Standardization Organization. 1994.
16. Spazzin AO, Galafassi D, de Meira-Junior AD, Braz R, Garbin CA. Influence of post and resin cement on stress distribution of maxillary central incisors restored with direct resin composite. *Oper Dent*. 2009; 34: 223-9.
17. DeHoff PH, Anusavice KJ, Wang Z. Three-dimensional finite element analysis of the shear bond test. *Dent Mater*. 1995; 11: 126-31.
18. Kamposiora P, Papavasiliou G, Bayne SC, Felton DA. Finite element analysis estimates of cement microfracture under complete veneer crowns. *J Prosthet Dent*. 1994; 71: 435-41.
19. Sudsangiam S, van Noort R. Do dentin bond strength tests serve a useful purpose? *J Adhes Dent*. 1999; 1: 57-67.
20. Tantbirojn D, Cheng YS, Versluis A, Hodges JS, Douglas WH. Nominal shear or fracture mechanics in the assessment of composite-dentin adhesion? *J Dent Res*. 2000; 79: 41-8.
21. Van Noort R, Noroozi S, Howard IC, Cardew G. A critique of bond strength measurements. *J Dent*. 1989; 17: 61-7.
22. Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? *J Dent Res*. 1997; 76: 1298-307.
23. Della Bona A, van Noort R. Shear vs. tensile bond strength of resin composite bonded to ceramic. *J Dent Res*. 1995; 74: 1591-6.