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Evaluation of sources of uncertainties in microtensile bond strength of dental adhesive system for different specimen geometries

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ABSTRACT

Objective. The aim of this research is to use finite element analysis (FEA) to quantify the effect of the sample shape and the imperfections induced during the manufacturing process of samples on the bond strength and modes of failure of dental adhesive systems through microtensile test. Using the FEA prediction for individual parameters effect, estimation of expected variation and spread of the microtensile bond strength results for different sample geometries is made.

Methods. The estimated stress distributions for three different sample shapes, hourglass, stick and dumbbell predicted by FEA are used to predict the strength for different fracture modes. Parameters such as the adhesive thickness, uneven interface of the adhesive and composite and dentin, misalignment of axis of loading, the existence of flaws such as induced cracks during shaping the samples or bubbles created during application of the adhesive are considered. Microtensile experiments are performed simultaneously to measure bond strength and modes of failure. These are compared with the FEA results.

Results. The relative bonding strength and its standard deviation for the specimens with different geometries measured through the microtensile tests confirm the findings of the FEA. The hourglass shape samples show lower tensile bond strength and standard deviation compared to the stick and dumbbell shape samples. ANOVA analysis confirms no significant difference between dumbbell and stick geometry results, and major differences of these two geometries compared to hourglass shape measured values. Induced flaws in the adhesive and misalignment of the angle of application of load have significant effect on the microtensile bond strength. Using adhesive with higher modulus the differences between the bond strength of the three sample geometries increase.

Significance. The result of the research clarifies the importance of the sample geometry chosen in measuring the bond strength. It quantifies the effect of the imperfections on the bond strength for each of the sample geometries through a systematic and all embracing study. The results explain the reasons of the large spread of the microtensile test results reported by various researchers working in different labs and the need for standardization of the test method and sample shape used in evaluation of the dentin–adhesive bonding system.

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1. Introduction

To date no standard test has been approved for measuring the bond strength of dentin and composite using dental adhesive system. Different test methods and parameters used have resulted in discrepancy of the data reported by different researchers on the same adhesive system. The factors affecting the bond strength have been addressed by few researchers before. Pashley et al. [1] have listed these factors in a review paper under the broad categories of substrate variables, etching variables, priming variables, bonding variables, storage variables and testing variables. Most of this review has focused on the issues relating to the differences induced by the material properties or the process used in sample preparation. The substrate and adhesive variables induce inherent differences in the material properties. Data reported on the dentin and bovine strength can be up to 50% different depending on the source and part of the dentin or bovine used. The same sort of data spread is reported for demineralized dentin, with some data on the strength being almost one-third of the other test data. The process used in the preparation of the sample as well such as etching and priming have effect on the interface properties and therefore on the bond strength.

Van noort et al. [2] have analyzed the effect of the test method in the bond strength results. They have made a comparison between the microtensile test and shear test in measuring bond strength. Applying FEA they have concluded that the shear test results in unfavorable stresses in the specimen. Consequently, they have recommended the tensile test as a preferred test method for measuring bond strength.

While the advantages of the microtensile test were proved, many researchers applied the method to measure the bond strength of dental adhesive [3–6]. Nakabayahsi et al. [3] apply the method to detect defects in the specimen. They study the effect of defects in the failure characteristics of the miniaturized samples.

Capel Cordoso et al. [4] use the microtensile bond strength to compare the bond strength of three adhesive systems with the cohesive strength of dentin and composite. In all three systems they find the adhesive bond strength to be much lower than the strength of composite or dentin. Yoshiyama et al. [5] apply the microtensile test to measure the bond strength to different regions of dentin. They have reported higher bond strength on the coronal and apical dentin compared to the bond strength to the cervical root dentin.

The effect of specimen size and geometry in the results of the bond strength is studied partly by other researchers [7–9]. Phrukkanon et al. [7] have investigated specimens with round and rectangular cross sections. For four different adhesive systems they have reported higher bond strength for the circular cross section compared to the rectangular cross section. The second parameter they have considered is the cross sectional area of the samples. For three different cross sections, lower bond strength is estimated for larger cross sections. The results have been explained using FEA to estimate the stress distribution. They have attributed this result to higher stress values for the samples with larger cross section. Other researchers have used Griffith theory to explain the same results. They have reasoned that smaller samples

will have smaller flaw size and therefore higher strength. In Phrukkanon's research they have increased the surface area without changing any other part of the sample. If they scale up all parts of the sample with the surface area the FE results would not indicate any changes for different surface areas. Whereas experimental tests still indicate smaller strength for the samples with larger cross sectional area. This shows a second parameter having role in reducing the bond strength for the larger size specimens which is recommended by Griffith's theory.

Although the researchers have highlighted the parameters affecting the result of the bond strength in the previous studies, there is little indication of quantifying each effect and systematic study.

At the same time most of the previous researches on the factors affecting the result of the bond strength have identified only one or two parameters, ignoring the other parameters. In the current research we have considered broad range of factors affecting the bond strength and modes of failure. Using finite element analysis we have investigated the effect of each parameter on the general stress distribution in different regions of adhesive, at the interface of the adhesive and composite and at the interface of adhesive and dentin. We have quantified the effect of each variable on the bond strength and modes of failure for the most commonly used geometries of stick, dumbbell and hourglass. The advantage of using finite element analysis in this respect is that it makes separation of the parameters and its effect possible. This possibility does not exist with the experimental test while interaction of the variables is normally unavoidable. The final FEA predictions of bond strength, its variations and modes of failure are derived from bringing together the results of analysis for all the identified individual parameters. Microtensile bond strength experiments are performed in order to validate the FEA estimation of the mode of failure, bond strength and its standard deviation for the mentioned geometries. The experimental measurements of these parameters and the ranking of different geometries in bond strength approve the collective predictions of FEA. This confirms the reliability of the FEA in its estimation of other individual effects as well.

2. Methodology

2.1. Finite element analysis

The main approach used in this research is finite element analysis which is validated by experiments. All the variables affecting the bond strength measured during microtensile test are identified. The first variable considered is the effect of the geometry of the specimen on the bond strength. Three most commonly used geometries in the experimental tests have been considered. This includes stick, dumbbell and hourglass geometries. Another set of parameters considered is induced as a result of the inaccuracies and errors during making the samples or performing the tests. In this category, variables such as adhesive thickness, uneven spread of adhesive, and misalignment of the axis of the applied load are examined for all three specimen geometries. Finally, the effect of the presence of flaw at the edge of adhesive and at the middle sections

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