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Two-dimensional FE Analysis of Principal Stress within Bonding Area as Resin Composite/Dentine Interface

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ABSTRACT

Two-dimensional finite element (FE) analysis examined that the principal stress of bonded specimens to decalcified dentine was estimated by supposing the thickness of bonding area as a resin composite/dentine interface. The distribution of principal stress within the bonding area was sensitive to such an interface site as resin composite/bonding area or bonding area/dentine interface. FE analysis model including bonding area (adhesive resin layer) with various thicknesses exhibited non-uniform stress distribution of principal stress along tensile loading direction.

INTRODUCTION

The role of the collagen-rich layer produced by etching of bovine or human dentine has been evaluated in realation to dentine bonding, and the layer is known as the hybrid layer, or the interdiffusion zone, or the bonding area in dental field[1,2]. It is important to make the layer between resin composite and dentine, which is prepared associated with the penetration of adhesive (bonding) resin after the demineralization of dentine. The resin-dentine bonding was introduced as a primary role of adhesive mechanism[1-7], and the stress level was considered as a measure to estimate the adhesion of bonded dentine[4-9]. The finite element method was proposed for a calculation model which had no bonding area at the resin composite/dentine interface[1]. The result revealed that the maximum value of an interfacial principal stress was near resin composite or dentine sites in the calculation model (no bonding area). Examining the stress direction of the resin composite/dentine interface as the bonding area with various elastic moduli, bond tests were carried out[1,2]. Earlier reports exhibited that the bond strength depended on the thickness and elastic modulus of bonding area and the type of bonding agent[2-9]. The interfacial stress was not uniform along each site when a uniform loading was added to the interface[10]. This study is to examine the effect of thickness of bonding area at the resin composite/dentine interface on the maximum principal stress within the bonding area when loaded by tensile applied stress.

METHODS

1. Two-dimensional FE calculation model

A cylindrical block of resin composite of 3 mm height and 6 mm in diameter was used as a test sample which was bonded to a flat dentine surface. The mean thickness of bonding area was assumed to be 0.025 to 0.2 mm, according to the earlier reports[11-15]. The elastic moduli of the bonding area were estimated to be 0.03 to 12 GPa[14], examining a relation between load change to deflection and elastic modulus value at nano-indentation testing[2,13]. Thus, the elastic modulus assumed in this model was 0.3 GPa for the bonding area. The calculation model by finite element stress analysis was shown in Fig. 1, which included resin composite (R), bonding area (resin composite/dentine interface; E) and dentine (D). In this schematic diagram of test arrangement, the finite element mesh was generated as reported by an earlier report[14]. Upper (A'B'C') and lower interface (ABC) were indicated at the bonding area (B'C' line = 40 μm), and FGH and

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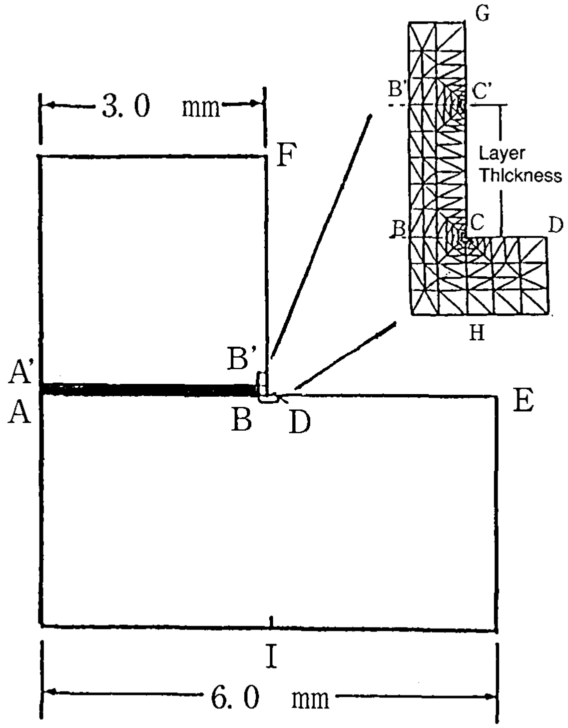

Figure 1 A calculation model (a section of test sample shows a half configuration) at tensile loading direction. The finite element mesh for the stress distribution was generated, and the sections of regions R, E and D mean resin composite, bonding area and dentine (FC distance = 3 mm), respectively. The thickness of bonding area was assumed to be 0.025, 0.05, 0.1, and 0.2 mm. BC and CH distances are 40 and 60 μm. GC' = 60 μm.

BCDE edges were respectively written along tensile direction and perpendicular to tensile direction.

2. Effect of thickness on stress distribution

The stress distribution within the bonding area was calculated along the tensile direction. The elastic moduli supposed were 3 GPa for R, 0.3 GPa for E, and 30 GPa for D. The stress distribution was determined at respective interface site during tensile applied loading of 10 MPa. The maximum value of principal stress within the bonding area during tensile loading was calculated in increasing the assumed thickness of bonding area of 0.025, 0.05, 0.1, and 0.2 mm. The fundamental geometry with no bonding area has been already reported as a model to express a two-dimensional plane strain[1,11]. The mesh was generated using the finite element program developed by Nakatsuka, which was calculated for a section of the cylindrical test samples[16]. The small mesh was modelled at the right-angled corner at the interface between the dentine and bonding area and also the resin composite and bonding area. The bonding area has been shown clearly as bonding area as described by Van Meerbeek et al[2], ranging from 1 to 10 GPa as the elastic moduli estimated by nano-indentation testing.

RESULTS

Fig. 2 shows a change of principal stress in the bonding area at tensile bond strength of 10 MPa, which has 0.025 and 0.05 mm as XY distance. The X and Y sites are respectively resin composite and dentine sites. This principal stress as a nominal applied stress was estimated in this model[17]. Fig. 3 shows principal stresses along tensile direction within the bonding area (the thickness of bonding area of 0.1 and 0.2 mm). The maximum

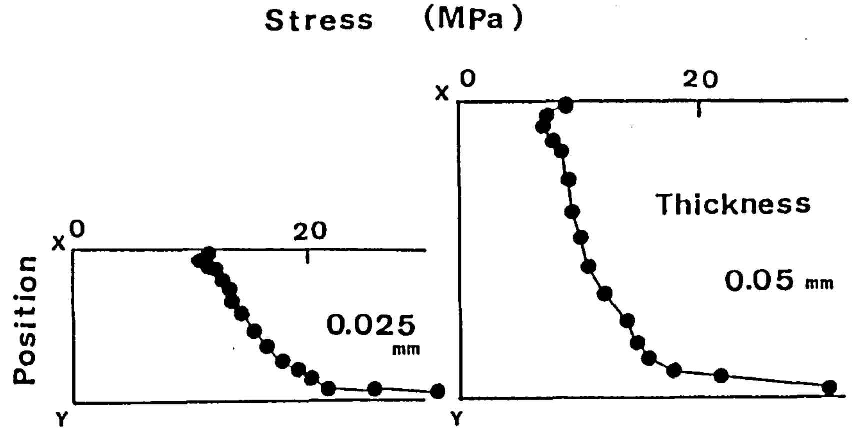

Figure 2 Effect of the thickness of the bonding area (0.025 and 0.05 mm) on the maximum principal at tensile bond strength of 10 MPa. The X Y distance is a thickness of bonding area. The sites of X and Y mean respectively resin composite and dentine site.

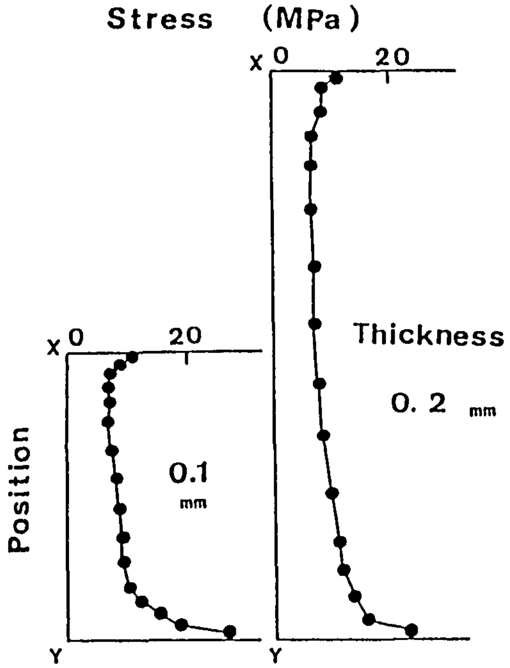

Figure 3 A change of maximum interfacial stress at tensile bond strength of 10 MPa during tensile loading. The thicknesses of bonding area were 0.1 (left side) and 0.2 mm (right side). See Figure 2 for key.

stress value was observed near dentine site. It is evident that a non-uniform stress distributes in the bonding area, in spite of the uniform mode of tensile load. This result agreed with an earlier report of Van Noort et al that non-uniform interfacial stress occurred in the calculation model with no bonding area at the resin composite/dentine interface[1,11]. Fig. 4 shows the maximum value of principal stress values at dentine sites within the

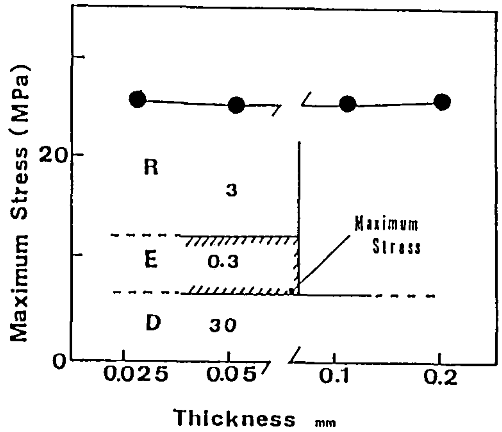

Figure 4 Maximum principal stress at the most sensitive dentine sites in the bonding area of 0.025, 0.05, 0.1 and 0.2 mm. See Figure 1 for key.

bonding area with the thicknesses of 0.025, 0.05, 0.1, and 0.2 mm. The average stress within the bonding area was 26 MPa as the maximum value at the most sensitive dentine sites. The interfacial stress value (the maximum) at the lower interface (bonding area/dentine interface) was constant when different thicknesses of bonding area at the resin composite/dentine interface were supposed in this study.

DISCUSSION

The adhesive mechanism of various etched-dentine adhesive systems is remarkably similar, although different types of conditioners, primers and adhesive resins are used. Formation of hybrid layer between dentine and resin composite, which was first described by Nakabayashi et al[15], was thought to be the adhesive mechanism of most dental adhesive systems. A primer is applied after the conditioner is rinsed off. The primer wets and penetrates the collagen-mesh network, to increase the wettability of the dentinal surface. An adhesive resin is applied to it and penetrates the primed dentine. The resin copolymerized with primer to form an intermingled layer of collagen and adhesive resin, which was the copolymerized region on the hybrid layer at the resin composite/dentine interface[13]. The factors which affected the magnitude of bond strength were test geometry, loading configuration and stiffness of bonding area[13,18]. The bonding area as the resin composite/dentine interface was important in considering an adhesive mechanism[1,11,17], because fracture phenomenon within the bonding area was theoretically determined. Thus, the following results have been examined as the quality of the bonding area at the resin composite/dentine interface. The elastic moduli among resin composite, adhesive resin and dentine were different[17]. The stress distribution within the bonding area along tensile direction was not uniform at tensile bond strength of 10 MPa during uniform tensile loading (Figs 2, 3), showing that the maximum principal stress values occurred at the edge of dentine site. In general, the bonding resins in commercial dentine bonding systems had the wide varied elastic moduli (a range of 0.1 to 20 GPa) as estimated by nanoindentation testing[2,13,17]. It was also reported that the effect of Poisson ratio of bonding area on the magnitude of stress distriburtion was considered[17], because the value measured was 0.25 to 0.35 for unfilled resin systems[3,20,21]. A Poisson ratio of bonding area was assumed to be 0.30 in this study. The other studies also assumed to be 0.30 as the Poisson ratio for an adhesive resin or a unfilled base resin matrix in the bonding systems[1,2,14,16-19]. Our calculation results clarified the variation of stress distribution along tensile direction and then the magnitude of maximum value at dentine site was the same for each thickness of bonding area in the calculation model. Test model including bonding area was effectively applied to calculate the stress distribution and the maximum principal stress using finite element stress analysis when applied by tensile bond test of the resin composite/dentine interface. From these results, this study suggests that the fracture sites during tensile loading will be dentine sites at the resin composite/dentine interface. Namely, earlier reports said that the fracture surfaces observed by scanning electron microscopy were the sites of adhesive failure and cohesive failure parallel to the dentinal tubules[10,13,15]. This suggests that the fracture occurs on the subsurface of the dentine including the tubular walls. This study concluded that the principal stresses of cylindrical test samples were estimated by FE model, supposing the thicknesses of bonding area as a resin composite/dentine interface. The results showed that the distribution of principal stresses within the bonding area was sensitive to such a site as resin composite/bonding area or bonding area/dentine interface. FE analysis model including bonding area with various thicknesses was applied effectively to represent non-uniform stress distribution of principal stress along tensile loading direction.

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