Calculation Models for Average Stress and Plastic Deformation Zone Size of Bonding Area in Dentine Bonding Systems

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Average stress during shear bond testing, and deformation behaviour during nano-indentation testing were calculated for the bonding area as a bonding site for copolymerization with resin composite in dentine bonding systems. First, average stress was calculated in the bonding area between bovine dentine and composite resin. Secondly, the plastic deformation zone size was calculated using an elastic/plastic deformation zone model after a nano-indentation test. The result clearly showed that average stress depended upon the elasticity of the bonding area, the elasticity value ratio of the composite resin-to-bonding area, and interfacial stress between the dentine and the adhesive resin. In this bonding area, the elasticity/hardness ratio changed depending on the thickness of the bonding area as well as the plastic deformation zone size (b), expressed as a (b/2a)-value (indented triangular length (2a) at nano-indentation test) expanded with increasing the elasticity value.

Key words : Bond strength, Adhesive resin, Bonding agent

INTRODUCTION

In previous studies, bonding between dentine and restorative composite resin was evaluated in terms of adhesive bond strength value^{1–6)}, and variation in bond strength values was explained by the hypothesis that failure was due to cohesive fracture of dentine because the bond between adhesive resin and the dentine exceeded the cohesive strength of the dentine itself. Bond strength varied with dentine depth (superficial, intermediate, and deep dentine)⁶⁾. Nakabayashi *et al.*^{7,8)} reported that the 4-META/MMA-TBB system formed tenacious bonds to enamel or dentine, and a hybrid layer mechanism was proposed as the cause of dentine adhesion. Bond strength increased dramatically when true hybridization occurred because of a resin-impregnated zone⁸⁾. An interdiffusion zone between dentine and composite resin was examined morphologically⁹⁾. After etching and priming with different dentine bonding systems, the bonding site for copolymerization with the resin composite is considered the bonding area. The bonding area has been represented schematically in terms of its morphological aspects in dentine bonding systems^{2,8,9)}. Analytical models are thus needed to calculate average stress and nano-indentation behaviours of the bonding area on the hybrid layer, as we indicated schematically in an earlier report¹⁰⁾. Conditioning with an acidic agent demineralized the dentine surface to a certain depth and left behind a collagen-rich mesh-work¹¹⁾. Bonding monomers altered, as predicted, the collagen-fibre arrangement in a way that facilitated the penetration of an adhesive bonding monomer. Nakabayashi *et*

*al.*⁸⁾ and Van Meerbeek *et al.*⁹⁾ found an adhesive resin layer (bonding area) in the resin-impregnated layer (hybrid layer). The studies on stress distribution in the dentine bonding area showed the following results. Van Noort *et al.*¹²⁾, using finite element stress analysis, found that nonuniform stress acted upon the bonded interface using finite element stress analysis. Wakasa and Yamaki reported that maximum principal stress occurred along the dentine/adhesive resin interface in the bonding area during uniform tensile testing¹³⁾. Interfacial failure might be promoted when critical stress acts in the formation (initiation and propagation) of cracks^{5,14,15)}.

The present study examined shear bond strength and bonding area thickness by shear bond testing and bonding area hardness by nano-indentation testing, and attempted to determine theoretically a) the average strength value along the dentine/bonding interface in the bonding area, and b) the plastic deformation zone size based on elasticity and hardness values of the bonding area, using analytical calculation models. The bonding area was defined as the bonding site of adhesive resin for the copolymerization on the hybrid layer.

MATERIALS AND METHODS

The dentine bonding systems used in this study are coded A*, B**, C#, D#, E@ and F@@ for the shear bonding test and the nano-indentation test. The bonding steps of the experimental treatments are listed according to Pashley *et al.*⁶⁾ and Van Meerbeek *et al.*⁹⁾ notation, partly modified for the materials used in this study. a=apply conditioner, b=rinse conditioner, c=air dry, d=apply primer, e=cure primer, f=apply resin, g=thin resin with air, h=visible light cure, i=chemical cure, j=apply low viscosity resin, k=apply composite. The dentine bonding sequences were dcfhk (5 steps) for code A, abcdcfghk (9 steps) for B, abcdcfghijk (11 steps) for C, abcdcfhk (8 steps) for D, abcdefick (9 steps) for E, and abcdfgck (8 steps) for F. Bonding was performed on bovine dentine whose sites were polished with #600 emery paper. The bonding area was limited by the use of double-sided adhesive tape containing a 6 mm diameter hole. A 6×6 mm cylindrical nylon matrix was placed on the treated surface. Visible light-cured resins (A1\$ for code A, B1\$\$ for code B, C1+ for code C, D1++ for code D, and C1 for code E and F) were placed in two 1.5 mm increments by photocuring for 60 s. Between 45 and 60 min after bond, shear bond strength was tested to failure at a crosshead speed of 0.5 mm/min. Ten specimens were prepared for the shear bond strength test (kilograms were divided by the surface area of the bond and then

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- * Imperva Bond, Shofu Inc, Kyoto, Japan
 - ** Light Bond, Tokuyama Co, Tokuyama City, Yamaguchi, Japan
 - # Clearfil Liner Bond, Kuraray Co, Okayama, Japan
 - ## Scotchbond Multipurpose, 3M Co, St. Paul, MN, USA
 - @ Superbond D-liner Plus, Sun Medical Co, Kyoto, Japan
 - @@ Gluma Bonding System, Bayer Dental, Germany
 - \$ Occulsin, ICI Co, UK
 - \$\$ Graft LCII, Shofu Inc, Kyoto, Japan
 - + Clearfil Photo Posterior, Kuraray Co, Okayama, Japan
 - ++ Z-100, 3M Co, St. Paul, MN, USA

converted to MPa)[&] and a nano-indentation test^{&&}. A schematic presentation of the operation of the nano-indenter has been detailed¹⁶⁾. Prior to measurement of nano-indentation behaviour, the indentation position was checked by optical microscopy (X 500 magnification), and the load was precisely indented to the bonding area. The indentation was performed with a nano-indenter with a small load of 6 mN. The thickness of the bonding area was measured using a scanning electron microscope[§].

Calculation models

Fig. 1 shows a schematic diagram on x-y coordinates of a calculation model employing bonding area thickness (d), diameter of bonding area (ℓ) and height of samples including composite resin (D). In Van Noort *et al.*¹²⁾, shear stress direction along the top of the surface of a sample was schematically indicated as a test arrangement, where a two-dimensional plane strain section was assumed. Following to this assumption, the schematic diagram in Fig. 1 was used in this study to average stress along the interface between dentine and adhesive resin. The procedure to calculate average stress is described in Appendix 1 and the stress value is calculated according to the equation (I), where each displacement of bonding area (adhesive resin) and composite resin is denoted by d_u and d_v . In Appendix 1, the applied strain (e) was assumed to be located along x-axis.

Fig. 2 shows schematic diagrams for estimation of plastic deformation zone size (b) and indentation length ($2a$) for the elastic/plastic deformation zone based on nano-indentation testing on the principal axes of the 1- and 2- (indented plane), and 3- directions (indentation direction). The internal stress which occurred after nano-indentation was evaluated on the assumption that indented volumetric change produced uniform *eigenstrain* ϵ_{33}^* only along the indentation direction but the others (ϵ_{11}^* and ϵ_{22}^*) were zero; *eigenstrain* related to internal stress effects was described originally by Mori and Tanaka¹⁷⁾. Fundamentally, it is assumed

Fig. 1 Schematic diagram (coordinate) of shear bond test.

[&] DCS-500, Shimadzu Co, Kyoto, Japan

^{&&} DUH-200, Shimadzu Co, Kyoto, Japan

[§] EPMA-8705, Shimadzu Co, Kyoto, Japan

Fig. 2 Analytical model for nano-indentation test to calculate the $(b/2a)$ -value as a plastic deformation zone. See Appendix 2 for this calculation.

that there arises volumetric strain (ϵ_{33}^* ; so-called *eigenstrain*) under the presence of stress release after plastic deformation. The indented area measured by nano-indentation testing was converted to a spherical indented surface (radius of $\bar{a}$) under the assumption that the indented area was equal to the area of spherical surface ($\bar{a}=0.420a$ in equation (6) of Appendix 2). The $(b/2a)$ -value to estimate a plastic deformation zone in bonding area is described in equation (7) (Appendix 2).

RESULTS

Shear bond test

Table 1 indicates shear bond strengths and bonding area thicknesses of the dentine bonding systems used, showing widely varied strength values of 4.0 to 21.0 MPa and bonding area thickness of 20 to 120 μm observed by scanning electron microscopy in a manner similar to that described by Wakasa and Yamaki¹³⁾. Based on these observations, bonding area thickness values of 1, 10, and 100 μm were used in this calculation model.

Nano-indentation test

Fig. 3 and 4 show examples of load/indentation depth curves at nano-indentation testing for sample code B and C, which were repeated nine times between 1 and 6 mN after loading to 6 mN. A plastic deformation zone after nano-indentation to a certain load is illustrated, as indicated schematically in Fig. 2. The load after nano-indentation testing to indentation depth, that is, dP/dh , was obtained because of internal stress in the plastic deformation zone after elastic/plastic deformation. From this result, the calculation model was supposed to yield E/H_D (E , elasticity of bonding area; H_D , hardness) and $b/2a$ values to represent the zone size of the plastic deformation.

Analytical results

Fig. 5 shows average stress along the dentine/adhesive resin interface with respect to interfacial stress, with the thickness of the bonding area (1, 10, 100 μm), and the increased values of average stress obtained by $E_R/E=10$ (E_R , elasticity of composite resin; $E=10^3$

Table 1 Shear bond strength and bond area thickness in dentine bonding systems

Code	Shear bond strength (MPa)	Bond area thickness (μm)
A	6.8(3.4)	20(5)
B	6.1(2.6)	115(10)
C	4.5(1.4)	90(7)
D	7.5(4.0)	26(4)
E	21.0(5.2)	40(15)
F	4.0(2.1)	120(25)

Mean (standard deviation)

Fig. 3 Example ; Load/indentation depth curve for code B.

Fig. 4 Example ; Load/indentation depth curve for code C.

MPa) with interfacial stress of 10, 20, 50, and 100 MPa at applied strain=0.01. Fig. 6 shows a change of average stress with increasing elasticity values of the bonding area from 10^2 to 5×10^3 MPa at interfacial stress=10, 20, 50 and 100 MPa, with average stress values increasing with increasing elasticity values of the bonding area. These results show that average stress along the dentine/adhesive resin interface is affected by the elasticity of bonding area.

Fig. 5 Change in average stress values with increased interfacial stress at bonding area thicknesses of 1, 10, and 100 μm .
 Solid line (bold): Bonding area thickness = 100 μm .
 Solid line (thin): Bonding area thickness = 10 μm .
 Dotted line: Bonding area thickness = 1 μm .

Fig. 6 Change in average stress values with increased elasticity value of bonding area at bonding area thickness of 10 and 100 μm . Interfacial stress = 10, 20, 50 and 100 MPa.
 Solid line: Bonding area thickness = 100 μm .
 Dotted line: Bonding area thickness = 10 μm .

Thus, to clarify the effect of elasticity on the average stress value, average stress-to- Ee ratios with respect to elasticity and thickness of bonding area were calculated (Figs. 7, 8),

Fig. 7 Relation of elasticity of bonding area and ratio of average stress/ Ee for bonding area thicknesses of 10 and $100 \mu\text{m}$.
Solid line; Bonding area thickness = $100 \mu\text{m}$.
Dotted line; Bonding area thickness = $10 \mu\text{m}$.

Fig. 8 The relation of bonding area thickness and a ratio of average stress/ Ee at E_R (composite resin)/ E (bonding area) = 1 and 10. The value corresponds to value of interfacial stress (10, 20, 50 and 100 MPa).
Solid line: $E_R/E = 1$.
Dotted line: $E_R/E = 10$.

according to equation (I) in Appendix 1. The average stress/ Ee ratio decreased with increasing elasticity values from 10^2 to 10^4 MPa at each value of interfacial stress (Fig. 7). The ratio increased with increasing values of 10^0 , 10^1 , 10^2 and 10^3 μm (thickness of bonding area) for interfacial stress = 10, 20, 50 and 100 MPa at each of E_R/E (1, 10; $E = 10^3$ MPa) (Fig. 8). These results show that the magnitude of average stress might be affected by interfacial stress between the adhesive resin and the dentine within the bonding area. Table 2 indicates the ratio of average stress-to- Ee at each value of interfacial stress (10, 20, 50 and 100 MPa) at strain = 0.01 during the shear bond test, showing an increasing tendency toward interfacial stress. Table 3 indicates dP/dh values at $a=b$ and $a=3b$ for each value of elasticity of bonding area at indentation depth (10^2 to 5×10^4 nm), showing that the dP/dh values increased with indentation depth, that is, associated with plastic deformation. Using the elasticity values of the interdiffusion zone obtained by Meerbeek *et al.*⁹⁾, which ranged from approximately 10^4 to 10^5 MPa, plastic deformation zone sizes were estimated to be $3a$. Figs. 9 and Table 4 show, respectively, the $(b/\bar{a})$ and $(b/2a)$ values with respect to E/H_D (a range of 10^0 to 10^4) and the changes in elasticity value (E) at each $(b/2a)$ value (1, 2 and 3). The values of $(b/\bar{a})$ and $(b/2a)$ were related to increased values of E/H_D , showing that bonding areas of dentine bonding systems could be divided into two groups based on the magnitudes of their elasticity values.

Table 2 The ratio of average stress-to- E (elasticity) e (strain) in the bonding area at interfacial stress values of 10, 20, 50 and 100 MPa for the change of bonding area thicknesses (10 and 100 μm)

Interfacial stress (MPa)	$\langle \sigma_i \rangle / Ee$	
	Bonding area thickness (μm)	
	10	100
10	1.0	1.0
20	1.1	1.3
50	1.5	2.2
100	2.0	3.7

Table 3 dP/dh values at different elasticity values (10^3 , 10^4 and 10^5 MPa) and indentation depths = 10^2 , 10^3 , 10^4 and 5×10^4 nm. At $a = b$ and $a = 3b$, dP/dh values were calculated according to equation (5) in Appendix 2. See Fig. 2 for key.

Depth (nm)	dP/dh (N/m)					
	Elasticity of bonding area (MPa)					
	10^3		10^4		10^5	
	b	3b	b	3b	b	3b
10^2	6×10^2	2×10	6×10^3	2×10^2	6×10^4	2×10^3
10^3	6×10^3	2×10^2	6×10^4	2×10^3	6×10^5	2×10^4
10^4	6×10^4	2×10^3	6×10^5	2×10^4	6×10^6	2×10^5
5×10^4	3×10^5	8×10^4	3×10^6	8×10^5	3×10^7	8×10^6

At $a = b$ and $a = 3b$ for plastic deformation zone size

Fig. 9 The relation of E (elasticity of bonding area)/ H_D (hardness of bonding area) and $b/\bar{a}$ or $b/2a$.
Solid line ; $b/2a$.
Dotted line ; $b/\bar{a}$.

Table 4 The estimated value of elasticity of bonding area of $b/2a$ values of 1, 2, and 3 for dentine bonding systems investigated (code A to F)

Code	Elasticity (MPa)		
	$b/2a$		
	1	2	3
A	7×10^2	5×10^3	1×10^4
B	8×10^2	7×10^3	2×10^4
C	2×10^4	2×10^5	6×10^5
D	9×10^3	5×10^4	2×10^5
E	1×10^3	8×10^3	4×10^4
F	1×10^4	7×10^4	3×10^5

DISCUSSION

This study examined current dentine bonding systems using respective resin composites. Based on shear bond testing and nano-indentation testing, calculation models and equations were proposed to estimate a) average stress along the dentine/adhesive resin interface (Fig. 1); and b) a plastic deformation zone size related to the elasticity-to-hardness ratio (E/H_D) in the bonding area (Fig. 2).

Braem *et al.*¹⁸⁾ reported that low-viscosity resin with about 10^4 MPa was effective in preventing a separation of the dentine/resin interface. As Nakabayashi *et al.*⁸⁾ demonstrat

ed, resin-based adhesives shrink toward the point where they begin curing. 4-META/MMA-TBB system shrinks toward the tissue, and BPO-amines and visible light-cured adhesives tend to shrink away from the dentine surface. Based on these experiments, we studied theoretically the behavior of polymerized adhesives (bonding area) on the hybrid layer.

As suggested by Braem *et al.*¹⁸⁾, interfacial stress at the dentine/resin interface is very important in analysis of fracture processes during shear or tensile bond testing. However, it is difficult to measure the magnitude of interfacial stress. In nano-indentation test, the plastic deformation zone size of the bonding area, as examined, depended upon elasticity of the bonding area (E) as well as the E (elasticity)/ H_d (hardness) ratio for each dentine bonding system. It is thus possible to estimate average stress on the bonding area at bond testing and to clarify the effect of estimated interfacial stress (a range of 10 to 100 MPa), as suggested by Van Noort *et al.*¹²⁾ and Wakasa and Yamaki¹³⁾, on average strength values. The bond strength at each depth of bovine dentine gave varied widely as a function of depth^{1-6,19)}. The macroscopic mode of failure appears to be adhesive in nature which indicates failure at the dentine/composite interface⁶⁾, because the strength values range from 1 to 23 MPa^{20,21)}. Eick *et al.*²¹⁾ proposed a three-level classification scheme based on shear bond strength; 5 to 7 MPa (category I), 8 to 14 MPa (category II) and up to 20 MPa (category III), whereas Triolo Jr *et al.*²²⁾ reported that the bond strength values were 8 MPa or less. McGuckin *et al.*²³⁾ reported that bond strength varied inversely with the dentine's proximity to the pulp. To clarify the nature of the bonding area as observed by repeated experiments¹⁻⁹⁾, the present experiment is of importance in calculating theoretically average stress and elastic/plastic deformation behaviour of the bonding area formed during bonding. Moreover, as described in experimental results showing that bonding area thickness affects bond strength and that elasticity values change according to the nature of the bonding area or interdiffusion zone between dentine and composite resin^{9,10,12,13,16)}, theoretical attempts, based on the stress behaviour during bond and nano-indentation tests, are needed to clarify their estimates.

The plastic deformation zone size of the bonding area changed with increased E/H_d values of dentine bonding systems used (Fig. 9), and the elasticity value of the bonding area depended strongly upon the zone size after elastic/plastic deformation (Table 4). At the bonding areas analyzed by nano-indentation testing, average strengths estimated using these results were lower than values obtained during a bond test (Fig. 5). The change of average stress in the bonding areas with interfacial stress was related to thickness of the bonding area during shear bond test:

1. Average stress was very small for each magnitude of interfacial stress, 10, 20 50 and 100 MPa at each bonding area thickness (1, 10, and 100 μm).
2. Average stress increased with increased elasticity values, 10^2 to 5×10^3 MPa for each interfacial stress = 10, 20, 50 and 100 MPa (thickness of bonding area = 10, 100 μm).

During the dentine bonding test, bonding area showed changes in average stress-to- Ee ratio of various bonding area elasticity values (Figs. 7, 8):

1. For thickness of bonding area (10 and 100 μm), the decreased change of the ratio with increased elasticity values was analyzed.
2. The greater E_R/E ratio (10) showed a smaller average stress/ Ee ratio at each thickness of bonding area, as compared with that at $E_R/E=1$.

To examine the stress behaviour of the bonding area during shear bond testing, the average stress in bonding area was calculated when applied to dentine/resin interface as the composite according to our calculation model (Appendix 1). Average stress values changed with elasticity of the bonding area (E), thickness of the bonding area (d) and interfacial stress related to applied stress. Average stress in the bonding area increased with the increased elasticity values 10^2 to 5×10^3 MPa as compared with $100 \mu\text{m}$ thickness than in that with $10 \mu\text{m}$, and thus the nature of adhesive resin of bonding area as a polymerized site is important in evaluating bond strength. We may predict fracture sites along the dentine/adhesive resin and adhesive resin/composite resin interfaces, if it is possible to determine fracture strength when average stress in the bonding area reaches to a certain level of yield stress. These models are effective in calculating the magnitudes of average stress and the plastic deformation zone in relation to fracture mechanisms in the bonding area.

CONCLUSION

In the dentine bonding systems investigated, average stress and nano-indentation behaviour in the bonding area were analyzed in relation to bond strength to bovine dentine. It was found that average stress increased with interfacial stress for each of bonding area thickness (1, 10, and $100 \mu\text{m}$). In calculation models, elasticity, interfacial (dentine/adhesive resin) stress, and bonding area thickness were important in the estimation of average stress. This study also compared theoretical values of elastic/plastic indentation zones through nano-indentation analysis of bonding areas with respect to changes in elasticity.

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APPENDIX 1

The equilibrium of stress along the x-axis can be expressed as

$$d(\sigma_i)/dx = c(d_u - d_v) \quad (\text{A})$$

where c is an unknown constant value, and $d_u - d_v$ the displacement caused by interfacial stress σ_0 between dentine and adhesive resin in the bonding area.

In the bonding area the stress, σ_i can be estimated as $E(d(d_u)/dx)$, and the stress in equation (A) can be expressed as

$$\sigma_i = Ee + C_1 \cosh(Ax) + C_2 \sinh(x) \quad (\text{B})$$

where $A^2 = c/E$, C_1 , C_2 = stress-dependent factors.

The boundary conditions for determining unknown integration values in equation (B) are

assumed to be in the following equations,

$$\sigma_l = \sigma_0 \text{ at } x = l \quad (C)$$

$$d(\sigma_l)/dx = 0 \text{ at } x = 0 \quad (D)$$

The stress in the bonding area can be estimated as

$$\sigma_l = Ee[1 + (B-1)\cosh(Ax)/\cosh(Al)] \quad (E)$$

where $B = \sigma_0/Ee$.

The displacement along the x-axis can be calculated as

$$\gamma = \tau/\mu = (\tau_0/\mu)(d/x) \quad (F)$$

At an arbitrary point r, $(d_v - d_u)$ displacement can be given as

$$d_v - d_u = \frac{\tau_0 l}{\mu} \int_a^D \frac{1}{r} dr = \frac{\tau_0 l}{\mu} \ln(D/d) \quad (G)$$

Thus, A can be solved as

$$A = (2/Dd)^{\frac{1}{2}} (\mu/E)^{\frac{1}{2}} (1/\ln(D/d))^{\frac{1}{2}} \quad (H)$$

Then, the average stress in the bonding area can be determined as

$$\langle \sigma_l \rangle = \frac{1}{l} \int_0^l \sigma_l dx = Ee[1 + (B-1)\tanh(Al)/Al] \quad (I)$$

APPENDIX 2

After a nano-indentation test, internal stress occurred as indicated in Fig. 3, and the value of σ_{33}^* can be estimated when ε_{11}^* and $\varepsilon_{22}^* = 0$ and only ε_{33}^* occurs, according to the concept introduced by Mori and Tanaka¹⁷⁾, as

$$\sigma_{33}^* = -\{8E/15(1-\nu^2)\}\varepsilon_{33}^* \quad (1)$$

where E = elasticity of bonding area and ν = poisson ratio.

For the calculation model of Fig. 2, load and internal strain can be calculated as

$$P = -2\pi(\bar{a})^2 \sigma_{33}^* \quad (2)$$

$$\varepsilon_{33}^* = \delta V / V \quad (3)$$

where $\delta V = \frac{1}{3} \left(\frac{\sqrt{3}}{4} d^2 \right) h$, $V = \frac{1}{2} \left(\frac{4}{3} \pi b^3 \right)$.

A substitution of equations (1) and (3) into (2) leads to the formula to predict load

$$P = K \frac{E}{1-\nu^2} \left(\frac{1}{b} \right)^3 h^5 \quad (4)$$

where K is a constant value.

The change of load to indentation depth (h) can be calculated as

$$\frac{dP}{dh} = K' \frac{E}{1-\nu^2} \left(\frac{1}{b} \right)^3 h^4 \quad (5)$$

where K' is a constant value.

During a nano-indentation test, H_D can be calculated as

$$H_D = 0.37081P/h^2$$

where $h = 0.269a$

(6)

$$\bar{a} = 0.420a.$$

A substitution of (4) into (6) leads to the formula to predict plastic deformation zone size, $b/2a$

$$\frac{b}{2a} = K'' \left(\frac{1}{1-\nu^2} \right)^{\frac{1}{3}} \left(\frac{E}{H_D} \right)^{\frac{1}{3}} \quad (7)$$

where K'' is a constant value.

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3-メタクリロキシプロピールシリルトリイソシアナートと3-メルカプトプロピールトリメトキシシランの混合シラン処理剤を陶歯、貴金属合金および非貴金属合金の接着プライマーとして用いた。サーマルサイクル試験1,000回後、陶歯、銀合金およびステンレススチールに

対する接着強さは良好であった。このときの陶歯の破断面の状態は初期の状態と同じであり、2本が陶歯、残りはレジン凝集破壊であった。しかし、コバルトクロム合金には効果は認められなかった。

歯科用アマルガムの初期圧縮強さと合金相の生成

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歯科用アマルガムの初期強さ特性を合金相の生成と関連づけて調べるために、5種のアマルガムについて1時間後、6時間後、24時間後、および7日後の圧縮強さを測定し、同一時間後に各アマルガムのX線回折を行った。試験したアマルガムは、いずれも24時間後には7日後の圧縮強さの約90%、または、それ以上に達した。しかし、1時間後から24時間後までの初期圧縮強さの増加はアマルガムの種類によって異なっていた。試験した5

種のうち、2種のアマルガムは6時間後に7日後の圧縮強さの約90%に達した。7日後の圧縮強さに対する初期圧縮強さの比と γ_1 相の回折強度比(7日後の回折強度に対する1時間後、6時間後ならびに24時間後の回折強度の比)との間には有意な相関が認められ、初期圧縮強さの増加は主として γ_1 相の生成に依存することが示された。

象牙質接着システムにおける接着領域の平均応力および塑性域の計算モデル

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本研究では、象牙質接着システムにおいてコンポジットレジンと重合する接着場所としての接着領域 (bonding area) での剪断接着試験による平均応力および nano-indentation 試験で求めた変形挙動を評価することとした。はじめに、接着領域内平均応力は象牙質・接着レジン界面に沿って計算する。第2には、塑性変形域の大きさを nano-indentation 試験ののち、弾性・塑性変形を呈する領域をモデル化して計算した。その結果、平

均応力を接着領域の弾性率(E)、(コンポジットレジンの弾性率、 E_R/E) 比および象牙質・接着レジン界面応力によって表わすことができた。さらに、この接着領域では B/H_D (接着領域の硬さ) 比がその接着領域の厚さに依存することや塑性域の大きさを示す $(b/2a)$ 比 (b ; 塑性域の大きさ, $2a$; nano-indentation 試験での圧痕長さ) が接着領域の弾性率の増加とともに大きくなることを明確に示した。