Journal of Dental Research
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J DENT RES 1987 66: 1636
DOI: 10.1177/00220345870660110601

Setting Stress in Composite Resin in Relation to Configuration of the Restoration

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The setting stress in composite resins was studied as a function of restoration shape. The shape is described by the configuration factor, C, the ratio of the restoration's bonded to unbonded (free) surfaces. In an experimental set-up, the shape of the restoration was simulated by cylindrical forms of various dimensions. The shrinkage stress was measured continuously. It was shown that in most of the clinically relevant cavity configurations, the stress-relieving flow is not sufficient to preserve adhesion to dentin by dentin-bonding agents.

J Dent Res 66(11):1636–1639, November, 1987

Introduction.

In adhesive restorations made from composite resins, the maturing bond strength to dentin, by dentin adhesives, is in competition with the developing shrinkage stress of the setting material (Davidson *et al.*, 1984). Only in restorations where flow can relieve a great part of this stress will the bond be prevented from disruption (Davidson and de Gee, 1984). Since the degree of flow will be determined by material being supplied from the free, unbonded, outer surfaces of the restoration (Davidson, 1986), the preservation of the bond depends, among other things, on the three-dimensional configuration of the restoration. In the present investigation, the role of the configuration on the setting stress in a composite resin restoration was studied in order for the extent of success of dentin-bonding agents to be established.

Materials and methods.

The experimental set-up consisted of two opposing, identical, parallel steel disks (diameter d = 5, 10, or 15 mm), of which one was connected to a load-cell and the other (at a distance h) to the cross-head of a tensometer (Zwick, 1463/0 Eisinger, West Germany) (Fig. 1). Composite material was inserted between the two disks and shaped to a cylinder according to the circumference of the disks. In order to be bound to the disks, their surfaces were silane-coated (Kulzer & Co. GmbH, Silicoater, West Germany). This set-up provided for continuous recording of the shrinkage stress of simulated restorations with known configuration factors (C), being the ratios of bonded surface (the disks' planes) to unbonded (free) surface (the cylinder jacket). For one disk diameter (d) and various disk-to-disk distances (h), five examples are drawn in Fig. 2. For each C-value, a rectangular, schematical restoration is also drawn for which the respective C-values can be calculated easily. For different d-values and h-values, C-values were calculated according to the relation:

$$C = \frac{\text{total disk surfaces}}{\text{cylinder jacket surface}} = \frac{2\pi(\frac{1}{2}\,d)^2}{2\,\pi\,\frac{1}{2}\,d\,h} = \frac{d}{2h}$$

Received for publication June 1, 1987
Accepted for publication July 31, 1987

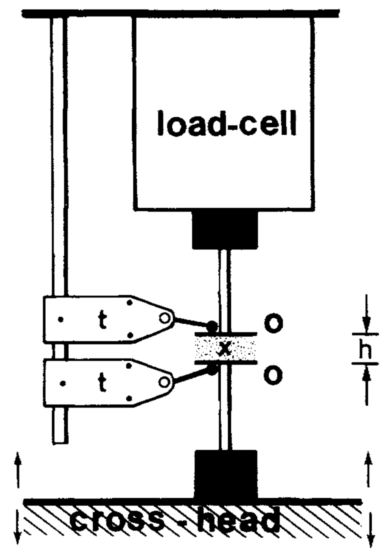

Fig. 1 — Schematic representation of the tensometer arrangement: The sample (x) was inserted between the two parallel steel disks (o) with diameter (d), placed at a mutual distance (h). During the curing process, any yielding of the load-cell to the contraction force was registered by the two displacement transducers (t), which immediately drove the cross-head to re-establish h.

In this expression, C is independent of the sample volume — *e.g.*, a C-value of 5 can be achieved by choosing d = 5.0 and h = 0.5, d = 10.0 and h = 1.0, or d = 15 and h = 1.5 mm. The corresponding volumes are 9.8, 78.5, or 264.9 mm^3, respectively.

The recording of the shrinkage stress was carried out under conditions by which the disks were prevented from being pulled to one another by the shrinkage stress (h was kept constant). Thus, any axial sample contraction, due to yielding of the load-cell to the shrinkage force, was immediately counteracted by a displacement of the cross-head of the tensometer to re-establish the original disk-to-disk distance (± 0.2 μm). This process was controlled by the two displacement transducers (t in Fig. 1), which drove the cross-head as soon as a contraction was registered. In this way, the shrinkage stress was determined for:

(1) various configuration factors C, and
(2) various sample volumes at fixed configuration factors C.

The Table summarizes the experiments carried out in this study for the chemically initiated composites Silar (batch A:5T7 and B:5T7A, 3M Co., St. Paul, MN) and P10 (batch A:5Y1 and B:5R1, 3M Co., St. Paul, MN). They were mixed according to the manufacturer's instructions. Each experiment was conducted at room temperature (23° C) and repeated at least three times. For each experiment, curves for the stress as a function of time were plotted. Subsequently for each C-value, one curve was constructed which represented the mean of such a set of curves.

TABLE

SURVEY OF CONFIGURATION FACTORS C (RATIO OF BONDED TO UNBONDED SURFACE) AND THEIR CORRESPONDING VOLUMES V (IN mm^3), FOR DIFFERENT DISK DIAMETERS d AND DISK-TO-DISK DISTANCES h (IN mm)

	h:	0.1	0.2	0.3	0.5	1.0	1.5	2.0	2.4	2.5	5.0	7.5
d=5	C:	25★	12.5	8	5★	2.5	1.7	1.3	1.0	1★	0.5	--
	V:	2.0	4.0	6.0	10	20	29	39	48	49	99	--
d=10	C:	50	25★●	17	10★●	5★●	3.3	2.5●	2.1★	2●	1★●	0.7★
	V:	8.0	16	24	40	79	118	158	190	196	393	589
d=15	C:	--	--	25★	15	7.5	5★	3.7	3.1	3	1.5	1★
	V:	--	--	53	88	177	265	353	425	442	883	1325

★ and ● denote the C-values which were used in the actual experiments with Silar and P10, respectively.

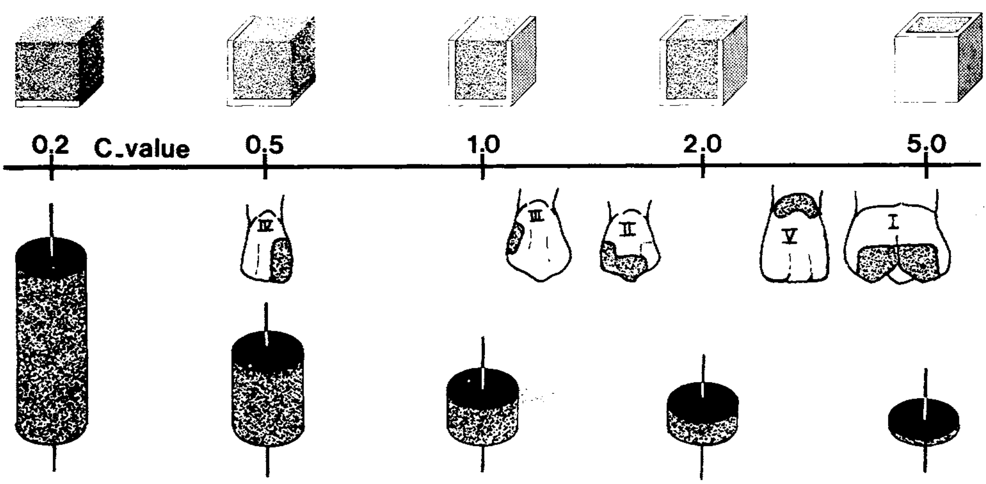

Fig. 2 – An outline of the relation between different schematic, rectangular restorations, the corresponding C-values, standard Class I, II, III, IV, and V restorations, and cylindrical experimental samples in proportion to the respective C-values.

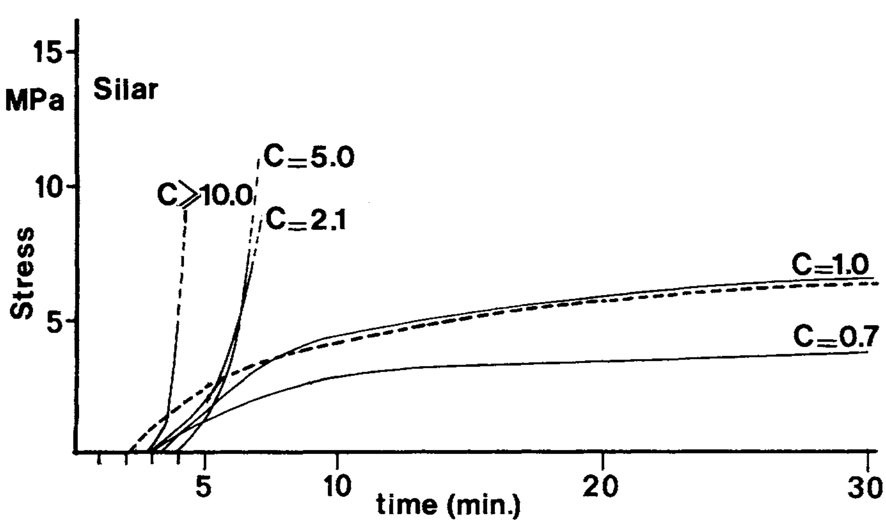

Fig. 3 – Stress development in Silar as a function of polymerization time for various configuration factors (C) (disk diameter = 10 mm). The dotted sections of the curves for C > 10.0, C = 5.0 and 2.1 represent the range in which cohesive failure occurred. The dotted line represents the bond strength of Scotchbond, in combination with Silar, to dentin (Davidson *et al.*, 1984).

Results.

The influence of the configuration factor C on the developing shrinkage stress in an adhesive (chemically initiated) composite resin restoration of Silar and P10 is shown in Figs. 3 and 4, respectively. Whenever possible, the shrinkage stress was followed over a period of 30 min. In most cases, however, the measurements ended earlier by spontaneous failure of the

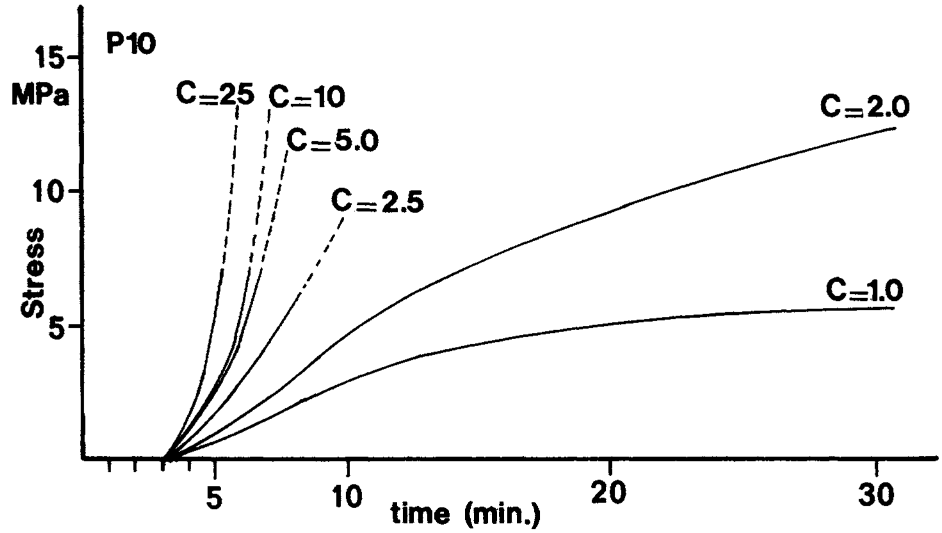

Fig. 4 — Stress development in P10 as a function of polymerization time for various configuration factors (C) (disk diameter = 10 mm). The dotted sections of the curves for C = 2.5, 5.0, 10, and 25 represent the range in which cohesive failure occurred.

material. All failures were cohesive, indicating that the adhesive bond to the silane-coated disks was in all cases the strongest. The stress-values of spontaneous failures registered for a particular C-value were generally spread over a wide range. This was due to the fact that the correcting speed of the motor-driven cross-head was not always able to match the speed of the fast-developing shrinkage. The dotted sections of the curves in Figs. 3 and 4 cover the range in which spontaneous fractures occurred. Fig. 5 shows the stress development for C = 1 and 5 at various volumes for Silar. The experiment for C = 1 with d = 15 mm and h = 7.5 mm could not be carried out properly, since the volume of 1325 mm^3 was too large to handle. Also, the results for C = 25 are not included. In these cases, cohesive failure occurred very early at practically zero value.

Discussion.

Standard preparations (according to G.V. Black) are cut to a certain depth which is related to its length and width. Therefore, a rough estimation can be made for the C-values in the clinical situation. The simulated restorations and the various C-values, drawn in Fig. 2, show that for the clinical situation, the ratio of bonded to unbonded (free) surface, attains a maximum value at C = 5. Clinical examples are Class I and Class V restorations.

A majority of the clinical restorations have C-values of approximately 1 to 2. Class II and Class III restorations (as a whole or built up in sections) may account for these ratios. Values of C ≤ 1 refer to Class IV restorations and composite layers, applied to flat or shallowly curved surfaces.

Figs. 3 and 4 each show two distinct situations — namely, those in which the shrinkage stress develops slowly, leaving the samples intact, and those in which the stress development is so fast that it leads to "spontaneous" failure (all failures were cohesive, since the adhesion to the silane-coated disk surfaces was relatively high). The former situation always occurred, for both Silar and P10, when the configuration factor C ≤ 1. Apparently the stress relaxation by flow, supplied by the unbonded (free) surface, is sufficient to maintain the coherence of the sample and its bond. The remaining shrinkage stress slowly attains values which are lower than or just reach into the range of reported bond strengths of dentin-bonding agents (Eliades *et al.*, 1985; Komatsu and Finger, 1986; Odén and Øilo, 1986). This indicates that adhesion to dentin with the current adhesives will also survive in clinical cases when C ≤ 1.

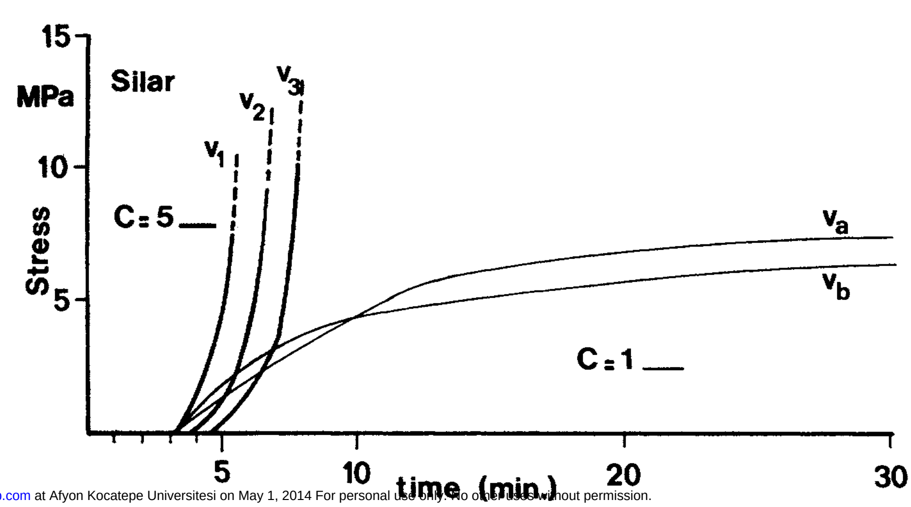

Fig. 5 — Stress development in Silar as a function of polymerization time for the configuration factors, C = 1 and 5, at various volumes ($V_1 = 265$, $V_2 = 79$, $V_3 = 10$, $V_a = 49$, and $V_b = 393$ mm^3).

When $1 < C < 2$, inconsistent results were obtained; for both Silar and P10, some samples broke spontaneously and others did not. An example of a measurement without failure at $C = 2$ is shown in Fig. 4. Yet, in the clinical situation, the adhesive bond might fail, since the shrinkage stress surpasses the bond strength with dentin. The latter consideration, added to the inconsistent experimental results, indicates that the current dentin adhesives will be the unreliable factor in restorations with $1 < C < 2$.

At C-values greater than 2, all samples, both Silar and P10, failed cohesively. For the clinical situation, it may be expected that the early-maturing dentin-bond composite interface will be the first to fail under the fast-developing shrinkage stress (Figs. 3 and 4). An explanation for the reported lower contraction stress values in the literature (Bowen, 1967; Bowen *et al.*, 1983; Hegdahl and Gjerdet, 1977) can be sought in incomplete bonding or premature partial separation of the bond. Adhesion achieved with mechanical bonding (Bowen, 1967; Hegdahl and Gjerdet, 1977) or bonding to roughened aluminum with Clearfil Bonding Agent (Bowen *et al.*, 1983) may not be as high as that which could be obtained by bonding to the silane-coated disks in our study. A partial separation of the bond will contribute to the flow capacity of the restoration, since the C-value will decrease, and therefore results in a lower contraction stress. Moreover, Hegdahl and Gjerdet (1977) made no corrections for the compliance of the testing machine, which they estimated to be comparable with that of large Class III cavities (C 1).

In general, an increasing rate of shrinkage stress development with an increasing C-value leads to a decreasing flow capacity. Values of C larger than 5 do not commonly occur for clinical restorations. High C-values ($C > 25$) may be of interest in predicting the preservation of adhesion of inlays cemented with composite resins. Although failure is inevitable in the experimental set-up, the result of cementation may be different, if the shrinkage stress in the very thin cement layer can be relieved by sufficient strain of the cavity walls and/or inlay (Kemp-Scholte *et al.*, 1987). In the present experimental set-up, strain was continuously cancelled out, making stress relief impossible.

In another study on this subject (Hansen and Asmussen, 1985), a surface-to-volume ratio was taken to describe the configuration of the restoration. The experiments with increasing volumes at two distinct C-values, shown in Fig. 5, illustrate that in general the shrinkage stress is dependent on the $\frac{d}{2h}$ ratio and independent of the volume of a restoration. Therefore, it was not appropriate to include the volume as a variable in our description of the configuration. In the clinical situation, however, enlarging the volume beyond a certain value, within the dimensions of a tooth, might lead to loss of tooth structure walls (Fig. 2, first row from right to left). In such cases, one crosses the boundary of a certain class and also decreases the corresponding C-value to a more stress-relieving situation. In our experiment, only the moment at which the shrinkage stress starts to develop is influenced by the volume. This shift to the left on the time axis, at increasing volumes, can be sought in the increasing temperature, since the transfer to the environment of the exothermic heat of polymerization is more limited for larger volumes.

A study into the stress development of light-curing composite resins is in progress.

REFERENCES

BOWEN, R.L. (1967): Adhesive Bonding of Various Materials to Hard Tooth Tissues, *J Am Dent Assoc* 74:439–445.

BOWEN, R.L.; NEMOTO, K.; and RAPSON, J.E. (1983): Adhesive Bonding of Various Materials to Hard Tooth Tissues: Forces Developing in Composite Materials During Hardening, *J Am Dent Assoc* 106:475–477.

DAVIDSON, C.L. (1986): Resisting the Curing Contraction with Adhesive Composites, *J Prosthet Dent* 55:446–447.

DAVIDSON, C.L. and DE GEE, A.J. (1984): Relaxation of Polymerization Contraction Stresses by Flow in Dental Composites, *J Dent Res* 63:146–148.

DAVIDSON, C.L.; DE GEE, A.J.; and FEILZER, A.J. (1984): The Competition between the Composite-Dentin Bond Strength and the Polymerization Contraction Stress, *J Dent Res* 63:1396–1399.

ELIADES, G.C.; CAPUTO, A.A.; and VOUGIOUKLAKIS, G. (1985): Composition, Wetting Properties and Bond Strength with Dentin of 6 New Dentin Adhesives, *Dent Mater* 1:170–176.

HANSEN, E.K. and ASMUSSEN, E. (1985): Cavity Preparation for Restorative Resins used with Dentin Adhesives, *Scand J Dent Res* 93:474–479.

HEGDAHL, T. and GJERDET, N.R. (1977): Contraction Stresses of Composite Resin Filling Materials, *Acta Odontol Scand* 35:191–195.

KEMP-SCHOLTE, C.M.; DAVIDSON, C.L.; FEILZER, A.J.; and DE GEE, A.J. (1987): Marginal Sealing in Relation to Curing Contraction, *J Dent Res* 66:269, Abst. No. 1300.

KOMATSU, M. and FINGER, W. (1986): Dentin Bonding Agents: Correlation of Early Bond Strength with Margin Gaps, *Dent Mater* 2:257–262.

ODÉN, A. and ØILO, G. (1986): Tensile Bond Strength of Dentin Adhesives, *Dent Mater* 2:207–213.