

Contraction stresses of composite resin filling materials

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The polymerization shrinkage of composite resin filling materials and the tensile stresses developed when the shrinkage is restrained were measured in an *in vitro* experiment. This allows an estimation to be made of the forces exerted upon the enamel walls of cavities filled with the resin in the acid etch technique. The results indicate that the stresses acting on the enamel are low compared to the tensile strength of the enamel.

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Resin filling materials shrink during their polymerization. The shrinkage was measured for several products by *Macchi & Craig* (1969), *Gotfredsen* (1969), and *Lee, Swartz & Smith* (1969). The values obtained for linear contraction ranged from 0.4 to 1.2%.

In the acid etch technique the plastic filling material is pressed into recesses in the enamel structure (*Sharp & Grenoble*, 1971, *Brauer & Termini*, 1972, *Jørgensen & Shimokobe*, 1975). When a resin filling material is fastened to the enamel shortly after mixing, the enamel surrounding the cavity will be pulled in a central direction as the material polymerizes and shrinks (*Bowen* 1967). According to *Jørgensen, Asmussen & Shimokobe* (1975) the tensile forces developed in the filling,

acting mainly in a direction perpendicular to the long axis of the enamel prisms, may cause a fracture of the enamel.

The present paper presents the results of studies that have been performed with the purpose of estimating the magnitude of the tensile stresses which may develop when the polymerization shrinkage in composite filling materials is restrained. In addition the unrestrained linear shrinkage was measured.

MATERIALS AND METHODS

After preliminary studies on the degree of shrinkage of several composite resin filling materials, three products were selected which

exhibited from low to high percentage of contraction. The products are listed in Table I.

Proportioning and mixing were done in accordance with the instructions given by the manufacturers. During the experiments the temperature ranged between 22° and 23°C and the relative humidity between 50 and 60%. The linear contraction and the contraction stresses were determined from 10 specimens of each product.

Linear contraction

Immediately after mixing, the material was placed on a polyethylene foil in a V-shaped 90° groove in a PMMA block. The arms of a strain gauge extensometer (Instron Strain Gage Extensometer, G-51-16 M.) were immersed approximately 2 mm into the material and held in this position by the use of a hard rubber support (Fig. 1). The signal from the extensometer was amplified and continuously recorded on a stripchart recorder. The distance between the extensometer arms was 13.0 mm and the cross-sectional area of the composite resin specimen was approximately 4 mm².

The measurements were started 2 min after commencement of mixing and recorded for 2 h. Calibration of the equipment was frequently performed by the use of an extensometer calibrator.

The data obtained may be dependent on the experimental conditions. However, for the purpose of comparing contraction stresses and linear contraction the method was considered adequate.

Tensile stresses

The freshly mixed material was placed in a cylindrical polyethylene tube which for the purpose of separation had been immersed in a saturated solution of hard wax in toluene and dried. The tube containing the material was then transferred to a universal mechanical testing instrument (Instron Model 1193) and placed vertically between two brass pistons,

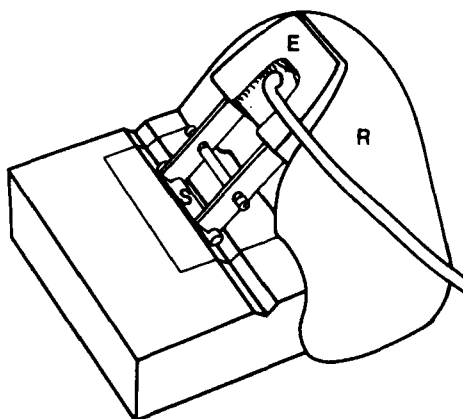


Fig. 1. Extensometer (E) resting on rubber support (R) with arms immersed into specimen (S).

the upper one connected to the load cell of the testing machine and the lower one to the stationary crosshead. The pistons had undercuts in the surface facing the composite resin to secure attachment and grooves in the sides to facilitate escape of resin during mounting of the specimen. This method is similar to the one presented by *Bowen* (1967). The length of the cylindrical specimen between the brass pistons was 5.0 mm and the diameter approximately 4 mm (Fig. 2). The tensile force acting upon the load cell due to contraction of the setting material was continuously recorded. The measurements started 2 min after commencement of mixing and continued for 2 h. Full scale load was 50 N. Standard weights were used for calibration.

The stress relaxation of the load measuring system was checked by applying an initial force of 25 N. During 2 h the force varied within 1.5% which was deemed insignificant in the present experiment.

The compliance of the instrument (bars, joints, load cell) was studied by mounting an extensometer over a turn-buckle fastened to the load cell and the stationary crosshead. When the turn-buckle was rotated, the compliance of the system could be measured for varying loads. The relationship between load and deflection was linear. For loads of a magnitude which was observed in the present

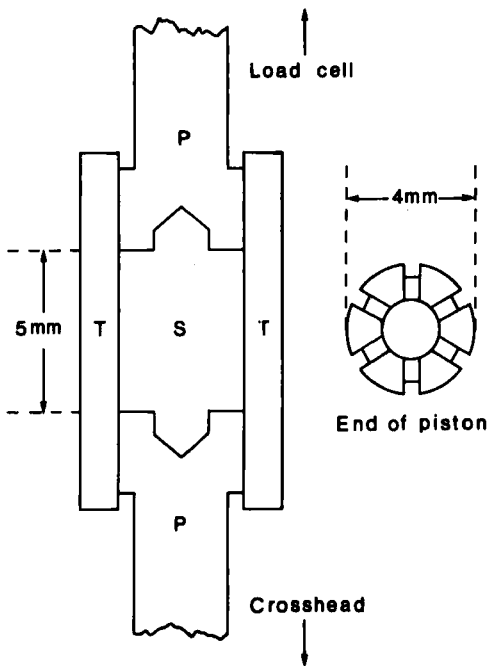


Fig. 2. Specimen (S) confined between pistons (P) within a polyethylene tube (T).

experiment (24 N) the compliance was 11–12 μm .

In order to test the degree of adherence of the material to the brass pistons an extensometer was connected across the joint, and the load was applied. The strain observed was calculated to originate from the material itself. Consequently, the joint was judged to be stable.

RESULTS AND DISCUSSION

The contraction percentages recorded in the course of 2 h are presented graphically in Fig. 3 as mean graphs for each product. Actual percentage values together with standard deviation values at certain times are given in Table II. It is noticed that a considerable part of the 2 h contraction values was obtained after 15 min.

The results of the measurements of contraction stresses are given as mean graphs in Fig. 4. Figures are presented in Table III.

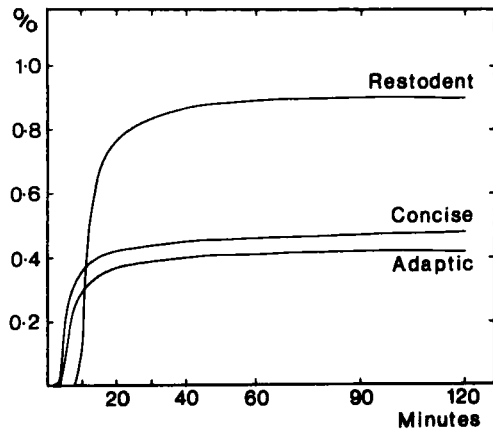


Fig. 3. Linear polymerization contraction.

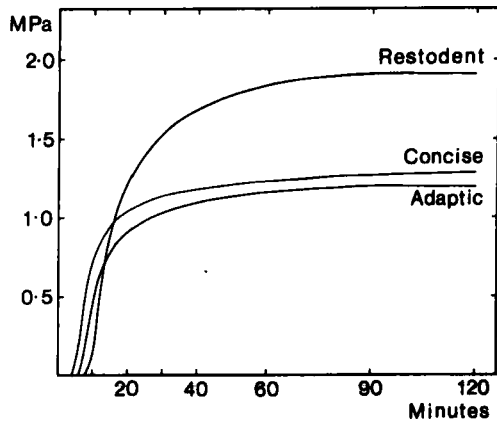


Fig. 4. Stresses in the resin caused by restrained polymerization shrinkage.

Table I. Products examined

Product	Manufacturer	Batch No.
Adaptic [®]	Johnson & Johnson	0314D48
Concise [®]	Minnesota Mining & Mfg. Co.	42917
Restodent [®]	Lee Pharmaceuticals	1E0162 (liquid) 1E0163 (powder)

By comparing the linear contraction (Fig. 3) and the contraction stresses (Fig. 4) it is seen that the curves follow the same general pattern.

The data obtained indicate that the more a composite resin shrinks on polymerization, the greater are the tensile forces developed when the contraction is restrained. The results also give the magnitude of the stresses that a 5 mm long body of composite resin may produce when bound between the load cell and the stationary crosshead of the mechanical testing instrument. The main point of interest is then whether this experimental set-up allows any estimate to be made concerning the stresses induced in the enamel margins of a cavity filled after etching of the enamel. It is obvious that the stresses will depend on the resilience of the structure to which the contracting material is attached. The tooth as well as the load measuring device

yields to some extent when acted on by a force.

Jørgensen, Matono & Shimokobe (1976) measured deformation of cavities in axially loaded teeth and found a relationship of 0.1–1.0 $\mu\text{m}/\text{kg}$, depending on the type of cavity. This would correspond to 0.25–2.5 μm for the forces encountered in the present experiment. Similar measurements carried out by the present authors indicate that the deformation may well exceed these figures in cases of large class 3 cavities in incisors subjected to an axial load.

The value for the compliance of the testing machine corresponds to the deformation of large class 3 cavities in certain cases. Indications are, however, that the equipment yields somewhat more than the tooth structure surrounding a composite filling would do. This discrepancy implies that the tensile stresses acting on the enamel is to some

Table II. *Linear contraction, %*

Minutes	Adaptic		Concise		Restodent	
	Mean (n = 10)	Stand. dev.	Mean (n = 10)	Stand. dev.	Mean (n = 10)	Stand. dev.
4	0.00	0.00	0.02	0.04	0.00	0.00
6	0.12	0.08	0.24	0.07	0.00	0.00
8	0.25	0.04	0.32	0.05	0.00	0.00
10	0.29	0.04	0.36	0.05	0.11	0.09
20	0.36	0.03	0.41	0.04	0.77	0.04
120	0.42	0.03	0.48	0.04	0.90	0.05

Table III. *Contraction stresses, MPa*

Minutes	Adaptic		Concise		Restodent	
	Mean (n = 10)	Stand. dev.	Mean (n = 10)	Stand. dev.	Mean (n = 10)	Stand. dev.
4	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.18	0.10	0.00	0.00
8	0.16	0.08	0.50	0.13	0.01	0.01
10	0.45	0.13	0.70	0.11	0.13	0.12
20	0.90	0.08	1.04	0.10	1.22	0.09
120	1.21	0.15	1.30	0.11	1.92	0.14

extent underestimated in the present study. However, the difference between the measured stresses and the tensile strength of sound enamel appears to be quite large. Reliable information on the tensile strength of enamel loaded in known relation to the prism orientation does not seem to have been published. One of the present authors (N.R.G.) has, however, made a series of measurements of the tensile strength of enamel using the diametral compression test (unpublished results). The values obtained when loading the enamel perpendicularly to the long axes of the prisms range from 20 to 40 MPa which is far above the stresses that are likely to develop in the enamel margin as a result of the contraction of a composite resin filling attached to it.

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