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Axial shrinkage-stress depends upon both C-factor and composite mass

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ABSTRACT

Objectives. To measure and then mathematically model polymerization stress-dependence upon systematic variations of C-factor (bonded/unbonded area ratio) for the *Bioman* instrument [1], recording stress by *free cantilever-beam deflection*; compliance 1.5 μm/MPa.

Methods. A light-cured resin-composite (RZD103; Ivoclar) with 57% (v/v) 450 nm filler was studied. Facing surfaces: glass slab and steel rod-end, constituting the *Bioman* test chamber, being perpendicular to the measured axial stress-direction, were varied: (a) with rod-diameters (ϕ), from 1 to 10 mm in 1 mm increments (with 0.8 mm gap height); and then (b) with gap heights (h) in 16 steps from 0.05 to 1.50 mm (with $\phi = 10$ mm). For each h and ϕ combination, giving C-factors ranging from 0.6 to 100, shrinkage-stress was recorded for 1 h from start of 40 s irradiation at 600 mW cm^{-2} for photo-polymerization at 23 °C ($n = 3$). Shrinkage-stress (S_σ) was plotted directly as functions of h, ϕ, and C and also *per unit composite mass*, (S_σ g^{-1}). ANOVA and Tukey's statistics were applied.

Results. Series A—diameter variation; with C-factor increasing from 0.6 to 6, gave an exact *exponential* decrease in S_σ from 45 to 8 MPa. Series B—height variation; with C-factor increasing from 3 to 100, gave increasing S_σ from 1 to 8 MPa. Since composite mass played an equally dominant role, plots of stress-variations *per unit composite mass*, (S_σ g^{-1}) separated these effects, confirming progressive off-axial stress-relief with increasing h.

Significance. (i) Values of $h = 0.8$ and $\phi = 10$ mm, recommended [1] for *Bioman* use, were confirmed as appropriate. Every lab instrument for measuring S_σ necessarily embodies specific C-factors and compliance values in the instrument design. (ii) Configuration (C) factor is recognized as an important parameter affecting manifestation of shrinkage-stress within restorative cavities and luting gaps. However, the restorative *mass* must equally be considered when translating *shrinkage-science* into specific clinical recommendations.

1. Introduction

The ratio of bonded to unbonded surfaces has been described as the configuration factor [C-factor], and further it has been suggested that only those restorations with a C-factor less than 1 will withstand shrinkage-stresses produced during the polymerization of resin-composites [2,3]. Contemporary bonding agents may resist the tensile force and maintain integrity (although this can cause cuspal movement and/or sensitivity), but failure of the bond and micro-gap formation remains likely in many situations. A number of studies have assessed the influence of C-factor on marginal gap

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formation/microleakage [4,5] and the shrinkage-stress developed under test conditions [6,7]. Discussion of the effect of C-factor should, however, always be related to a standardized mass of material undergoing shrinkage as was implicitly recognized by Watts et al. [1].

The characterization of polymerization shrinkage behavior and kinetics remains an important aspect in the development of restorative materials. A number of techniques have been employed for the investigation of shrinkage-stress kinetics, including use of Universal Testing Machines and also cantilever beams. The difficulty of comparing data from different studies has been commented on by Sakaguchi et al. [8]: not only are there problems with comparing data from different methods, but also when comparing the same method employed by different research laboratories. More information on the effect of variations in sample preparation will allow for greater insight into the validity of comparisons between studies. Additionally, as uniaxial stress is measured in all the currently employed techniques, variation in C-factor of the specimen will allow for testing of the assumed linear nature of shrinkage-stress vectors in such studies.

The aim of this study was to investigate the effect of variations in specimen size and configuration on shrinkage-stress. The specific objective was to study a model resin-composite using a cantilever beam method (*Bioman* apparatus) with variations in specimen height and diameter in order to:

- compare the maximum shrinkage-stress values,
- correlate the shrinkage-stress values to C-factor.

The null hypothesis was that variations in specimen configuration would have no effect on the shrinkage-stress.

2. Materials and methods

The resin-composite used for the investigation was RZD103, a visible-light-cured experimental formulation (Ivoclar Vivadent, Schaan, Liechtenstein) with 56.7 vol% (76.4 wt%) irregular filler of 450 nm size and monomer matrix comprising a mix of BisGMA, UDMA and TEGDMA.

2.1. Shrinkage-stress measurement

The *Bioman* instrument [1] was used for stress measurements. The lower face of a stainless-steel rod and the upper surface of a glass slab form the surfaces of the specimen 'chamber' (Fig. 1). To systematically investigate effects of different configuration, two series of design-changes were studied, involving changes in: series A: specimen diameter; and series B: specimen height:

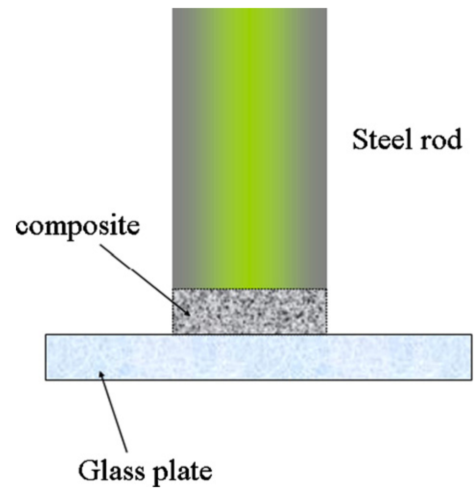

Fig. 1 – Representation of sample chamber and test surfaces.

(A) For the assessment of the effect on shrinkage-stress with variation in specimen diameter [ϕ], the chamber height was set at 0.8 mm (as used for routine testing), and the standard stainless-steel rod was replaced with one of a series of machined rods with varying face diameter. Specimens of diameters varying from 1 mm to 10 mm (in 1 mm increments) were tested (Fig. 2).

(B) For the assessment of the effect on shrinkage-stress with variation in specimen height [h], the standard stainless-steel rod of 10 mm diameter was employed: alteration of the position of this steel rod within the integral clamp allowed the gap between the rod and glass to be adjusted. Specimens of heights varying from 0.05 to 1.5 mm were tested.

For all configurations tested, the surfaces of the test chamber (the glass slab and face of the stainless-steel rod) were lightly grit-blasted with 50 μm alumina powder to promote bonding of the composite specimen. The amount of material required to form a specimen of the correct size without

Fig. 2 – Stainless-steel test rods with varying face diameter: 1–10 mm.