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Correlation between polymerization shrinkage stress and C-factor depends upon cavity compliance☆

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ARTICLE INFO

Article history:
Received 22 March 2015
Received in revised form
19 August 2015
Accepted 20 November 2015

Keywords:
Dental restorative materials
Photopolymerization
Polymerization shrinkage stress
C-factor
Compliance of constraint

ABSTRACT

Objectives. The literature reports inconsistent results regarding using configuration factor (C-factor) as an indicator to reflect the generation of polymerization shrinkage stress (PS) from dental restorative composites due to the constraint of cavity configuration. The current study aimed at unraveling the complex effects of C-factor on PS based on analytical and experimental approaches together, such that the reported inconsistency can be explained and a significance of C-factor in clinic can be comprehensively provided.

Methods. Analytical models based on linear elasticity were established to predict PS measured in instruments (testing systems) with different compliances, and complex effects of C-factor on PS were derived. The analyses were validated by experiments using a cantilever beam-based instrument and systematic variation of instrumental compliance.

Results. For a general trend, PS decreased with increasing C-factor when measured by instruments with high compliance. However, this trend gradually diminished and eventually reversed (PS became increased with increasing C-factor) by decreasing the system compliance.

Significance. Our study indicates that the correlation between PS and C-factor are highly dependent on the compliance of testing instrument for PS measurement. This suggests that the current concept on the role of C-factor in the stress development and transmission to tooth structures, higher C-factor produces higher PS due to reduced flow capacity of more confined materials, can be misleading. Thus, the compliance of the prepared tooth (cavity) structure should also be considered in the effect of C-factor on PS.

Published by Elsevier Ltd on behalf of Academy of Dental Materials.

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http://dx.doi.org/10.1016/j.dental.2015.11.003
0109-5641/Published by Elsevier Ltd on behalf of Academy of Dental Materials.

1. Introduction

In dental restorations, photo-polymerized composites as restorative materials are confined by the cavity walls, result of which could cause considerable polymerization shrinkage stress (PS) developed at the restorative-tooth interface during and after polymerization that can impart interfacial/cohesive failures and tooth decay from subsequent bacterial biofilm ingrowth [1–3]. Feilzer *et al.* developed the concept of configuration factor (C-factor) for the relationship between the confinement (cavity configuration) and stress development [4]. The C-factor defines the relationship between the free and restrained composite surface area of a dental restoration and is used to correlate with the risk of PS-induced restorative failure in clinic. In order to correlate the measured value of PS to the degree of confinement in experiments, C-factor has been calculated as the ratio of bonded surface area to unbonded area of a sample in the test [4]. However, studies in evaluating polymerization stress have been showing inconsistent results on the correlation of PS and C-factor and thus, using C-factor as an index for the risk analysis has long been controversial. The objective of this study is to systematically investigate complex effects of C-factor on PS development, such that the inconsistent results reported can be explained and a comprehensive significance of C-factor for clinic-relevant environment can be provided.

Inconsistent results of the C-factor effect on PS appear in the studies using testing instruments with different compliances. Most experimental evaluations of the aforementioned PS have been using a force transducer mechanism to record the uniaxial force induced from a disk/cylinder-shape specimen under axial constrains [5]. Although the basic principle of those experiments is the same, differences in the instrumental compliance exist among them. The instruments reported in the literature vary from an ideally rigid one (zero compliance) to a considerably compliant one [6,7]. In order to obtain the zero-compliance, the sample height is maintained constant during the polymerization shrinkage by a servo-controlled feedback unit of the instrument. Using this type of instrument, the higher the C-factor (*i.e.* the higher the ratio of the bonded surfaces) the higher the PS was observed [4,8–11]. This trend was intuitively explained by that, as the C-factor increases (*i.e.* the ratio of free surfaces decreases), the capacity of material deformation (flow) and consequent stress relief decreases. Accordingly, a low C-factor was advised to be maintained in clinic (*e.g.* using incremental filling technique instead of bulk filling) to facilitate the stress relief [4,8]. Quite a few studies (either *in vitro* or *ex vivo*) in the literature [12–16] evaluated effects of C-factor on marginal adaptation of restorations, and the results indeed showed that cavity with lower C-factor was associated with a lower chance of interfacial failure such as microleakage and marginal gap. Thus, C-factor has been acknowledged as a valid variable in experiments to describe the development of PS due to constraints. In instruments with certain compliance (*e.g.* cantilever beam-based instruments) [7,17,18], which provide a more clinically-relevant testing environment as compliant tooth walls, force generated by the force transducer for balancing the polymerization shrinkage is registered as the PS. Using such compliant instruments, some studies indicated the higher the C-factor the lower the PS (opposite to the findings using 'zero compliance' instruments) [7,17,19–22], while the other studies presented no obvious dependency between PS and C-factor [10,23]. Thus, the validity of C-factor as a PS predictor has been questioned.

In this study, combined analytical and experimental approaches were adopted to investigate the complex correlations between C-factor and PS development under various instrumental compliances. The role of sample volume in the C-factor effect on PS development is also discussed since samples can have same C-factor value but different volumes and *vice versa*. Analytically, a simplified model based on the linear elasticity was established to predict PS of restorative materials tested under rigid and compliant systems. Thus, effects of C-factor and sample volume on PS development were derived mathematically. The analytical results were validated by experiments using a NIST-developed cantilever beam-based instrument [24,25]. The effect of instrument compliance on the measurement of polymerization stress was examined by changing the position of restorative composite sample along the length of the cantilever beam, such that the variable instrument compliance can mimic the compliance of the prepared tooth cavity. Our results show that the correlation between PS and C-factor is highly compliance-dependent. For a general trend, PS decreased with increasing C-factor when measured by instruments with high compliance. However, this trend gradually diminished and eventually reversed (PS became increased with increasing C-factor) by decreasing the system compliance. This compliance-dependent effect of C-factor on PS not only explains the numerous inconsistent results reported in the literature; it also provides new insights into the concept of C-factor for clinic-relevant environment and useful guidelines for clinical selection of filling technique in order for a reduced PS.

2. Experiments[2]

In this investigation, a commercial dental composite (TPH Spectra™, Dentsply-Caulk, Milford, DE) was used as the testing material. TPH is a blue light activated, urethane modified Bis-GMA/TEGDMA (50:50 mass ratio) based composite, filled primarily with barium boron aluminum silicate glass particles at 78 wt.% (≈57 vol.%).

The effects of C-factor on polymerization stress (PS) development were examined using a NIST-developed cantilever beam-based instrument (tensometer) [24,25]. The instrument was constructed according to design criteria following first principles of mechanics to provide the accuracy and sensitivity of the PS measurement. The desired compliance of the testing instrument can be easily achieved by varying the sample position along the length of the cantilever beam or by using a beam with different height or different material. In

[2] Certain commercial materials and equipment are identified in this manuscript in order to specify adequately the experimental and analysis procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology (NIST) nor does it imply that they are necessarily the best available for the purpose.