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Strain development in bulk-filled cavities of different depths characterized using a non-destructive acoustic emission approach

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ABSTRACT

Objectives. (1) To evaluate the effect of cavity depth and composite type on the interfacial debonding in bulk-filled cavities. (2) To correlate the theoretical shrinkage stress and the level of interfacial debonding determined by acoustic emission (AE).

Methods. 80 sound molars were divided in two groups to receive a Class-I cavity (3.5 × 3.5 mm) with 2.5- or 4.0-mm depth. The cavities were restored with either a conventional paste-like (Filtek Z100, 3M ESPE), a conventional flowable (G-ænial Universal Flo, GC), a bulk-fill paste-like (Tetric EvoCeram Bulk Fill, Ivoclar Vivadent) or a bulk-fill flowable (SDR, Dentsply) composite ($n = 10$). AE signals were recorded from the start of curing for 20 min. The cumulative number of AE events was correlated with the theoretical maximum shrinkage stress induced by each composite. Two samples from each group were scanned using micro-computed tomography (μCT) and qualitatively evaluated.

Results. Both composite type and cavity depth had a significant influence on the number of AE. The conventional paste-like composite generated significantly more AE than the other composites. The AE number increased sigmoidally in function of time, with a more rapid increase after a few seconds for the conventional composites than for the bulk-fill composites. A strong linear correlation was found between the predicted shrinkage stress values and the total number of AE events for both cavities depth. Representative μCT images showed larger de-bonding areas for 4.0-mm cavities and for conventional composites.

Significance. Premature interfacial or cohesive cracks can already develop during placement/curing of the composite. This might compromise the restoration integrity and in turn affect its survival in the long term. The amount AE events increased linearly with the theoretical maximum shrinkage stress of the composites.

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1. Introduction

Acoustic emission is commonly defined as transient elastic waves within a material, caused by the release of localized stress energy [1,2]. It is a non-destructive, highly sensitive technique, permitting the detection of dynamic processes in a material, such as the initiation and growth of extremely small flaws. In composite restorations, matrix cracking, filler de-bonding or adhesive failure may all contribute to acoustic emissions [3]. Only active features (e.g. crack growth) are recorded; thus, developing and stagnant defects can be distinguished in function of time. Lately, this technique has been employed for examination of interfacial de-bonding of composite restorations that occurs when polymerization strain cannot be relieved due to unconstrained deformation of the material [4–8].

Marginal integrity is considered to be an important factor in the clinical success of a composite restoration [9]. Apart from the adhesive approach, marginal integrity is also influenced by the characteristics of the composite, such as shrinkage stress [10], surface adaptability [11] and mechanical properties [12]. A direct relationship exists between degree of conversion and volumetric shrinkage [13,14]. Therefore, it is often hypothesized that a reduced final degree of conversion will lead to lower shrinkage and contraction stress [14]. Also, so called ‘soft-start’ polymerization has often been proposed to slow down the reaction rate and thus to extend the time for viscous flow, which allows deformation without constraint. In theory, these elements also occur when the depth of cure is exceeded; the deeper levels of the composite will reach a lower final degree of conversion and the attenuation decreases the intensity of the curing light considerably, thus inducing a slower onset of polymerization. However, this is not a desirable approach to reduce shrinkage stress, since mechanical properties are not optimized at decreased conversion levels [15,16] and uncured monomers may cause adverse effects to the pulp tissue [17–19].

Bulk-fill composites aim to resolve these problems with an improved depth of cure, while the shrinkage stress is decreased. The flowable ‘base’ bulk-fill composites, which require capping with a conventional composite in a clinical situation, are generally less viscous, which facilitates adaptation [20]. On the other hand, the paste-like ‘full-body’ bulk-fill composites are sufficiently wear-resistant without the need of a composite capping layer and thus are being indicated for genuine bulk-filling [21].

Volumetric shrinkage and the elastic modulus are the most important properties influencing shrinkage stress of composites. The ‘full-body’ bulk-fill composites exhibit higher filler loading and less volumetric shrinkage than the ‘base’ versions [22–24], but have higher elastic modulus [25,26]. Several studies have assessed the effects of shrinkage stress; however, the results are inconsistent, which may be attributed to differences in the stress-measuring methods employed [27]. These usually are custom-made devices and do not use tooth cavities and thus also do not involve cavity/tooth compliances. In order to overcome these limitations, a mathematical model that combines the effect of material properties, specimen geometry and external constraints was recently proposed to assess the shrinkage stress kinetics in dental composites [28]. Based on this analytical approach and with the addition of an equi-triaxial stress component to simulate a clinical situation, Yang et al. [29] reported a strong linear correlation ($R^2 = 0.9955$) between the theoretical maximum shrinkage stress and the number of acoustic events in 2.0-mm deep Class-I composite restorations. To the best authors’ knowledge, acoustic emission induced by bulk-fill composites was not yet investigated in deeper cavities, such as 4.0-mm deep, which are truly eligible for bulk-filling. Hence, the equation by Yang et al. [29] was not yet validated for deeper cavities and bulk-fill composites. The hypotheses advanced in this study were that (1) the type of composite and (2) the cavity depth have no significant influence on the number of acoustic events (AE) during polymerization in bulk. Correlations were also made between the total number of AE and predicted shrinkage stress values based on an analytical model.

2. Materials & methods

2.1. *Specimen preparation and restorative procedure*

Eighty sound, human molars were gathered as approved by the Commission for Medical Ethics of KU Leuven (file number S57622), cleaned and stored in a 0.5% chloramine solution and randomly divided in eight experimental groups (n = 10) according to the composite type and cavity depth (Table 1). Next, the occlusal surface of the teeth from the four groups, in which a 4.0-mm deep cavity would be prepared, was build up with a flowable composite (G-ænial Flo, GC, Tokyo, Japan) after etching and bonding (G-ænial Bond, GC). Hence, a flat reference surface at the level of the cusps was obtained, which allowed determining the cavity depth objectively. In the remaining four groups, 1.5 mm was trimmed from the cups (IsoMet 1000 Precision Saw, Buehler, Lake Bluff, IL, USA) to obtain a flat reference surface at a lower level. Hence, the bottoms of the 4.0-mm deep and 2.5-mm deep cavities, respectively, were located at similar dentin levels (Fig. 1).

Square Class-I cavities (3.5 × 3.5 mm) were prepared using a medium-grit diamond bur (REF 835KR 314 010, ISO 806 314 156524 010, Komet, Lemgo, Germany) on a high-speed turbine, mounted in the MicroSpecimen Former (The University of Iowa, Iowa City, IA, USA). After preparation of the cavity, the tooth was cut 6 mm below the occlusal cavity surface (IsoMet 1000 Precision Saw), retaining the coronal part, and rinsed thoroughly with distilled water. A one-step self-etch adhesive (G-ænial Bond, GC) was applied conforming to the manufacturer’s instructions and cured for 10 s using a LED device (Bluephase 20i, Ivoclar Vivadent, Schaan, Liechtenstein) with an output of 1,200 mW/cm^2 (“high” mode), verified by the Bluephase radiometer (Ivoclar Vivadent) prior to each use.

2.2. *AE test*

Subsequently, the sample was attached to a 20.5-mm diameter, 375-kHz resonant, multi-purpose AE sensor (VS375-M, Vallen Systeme, Icking, Germany) with silicone grease (High vacuum grease, Dow Corning, Midland, Michigan, USA). A two-channel AE system (Vallen AMSY-5, Vallen Systeme) was used