The importance of low shrinkage and low stress generating composites during curing.
Anton J. de Gee, Cees J. Kleverlaan and Michel Degrange.

Adresses des auteurs
Dr Anton J. de Gee and Dr Cees J. Kleverlaan, ACTA, Department of Dental Materials Science, University of Amsterdam and Free University, Louwesweg 1, 1066 EA Amsterdam, Netherlands.
Dr Michel Degrange, Faculté de Chirurgie Dentaire de Paris V, 1 Rue Maurice Arnoux, 92120 Montrouge, France.

The shrinkage of dental resin composites during light curing is still one of the major drawbacks in adhesive dentistry, as it frequently leads to loss of marginal integrity or enamel fracture.

Shrinkage stress
When a resin composite restoration is adhesively bonded to the cavity walls the curing shrinkage will develop a tensile stress, which is exerted on the cavity walls. The ultimate extent of the shrinkage stress in a cavity determines whether or not bonding to the cavity wall will fail (fig. 1a) or part of the tooth structure will fracture (fig. 1b). Factors that contribute to the shrinkage stress are for example the shape of the cavity,
frequently designated as the C-factor (6), composite formulation (4), conversion (13), and light irradiation (11, 12).

C-factor

The C-factor (6, 8), which is one of the most important factors determining the stress development, denotes the ratio between bonded surface and free non-bonded surface of the filling for a particular cavity configuration. The higher the C-factor, the more constrained the situation becomes and the higher the stress will be. Figure 2 illustrates for a few common preparations how the value of the C-factor can be estimated. In deep class V restorations where the C-factor may reach values as high as C = 5, the contraction stress is the main reason for failure. Various studies on Class V restorations have shown that composites that generate high stresses during curing bear the risk of marginal gap formation (1, 7 and 9). To minimize the risk of gap formation for cavity preparations where the surrounding tooth structure hardly yields or does not yield at all (like in class V cavities) to relief some of the stress, composites which develop a low stress during curing are recommended. For lower C-factors in the range of 1 – 2, as in MOD, MO or DO restorations, the surrounding tooth structure does yield to the stresses and with large preparations the cusps may bend to proportions that can result in post-operative pain (3), enamel cracks or complete enamel fracture (2). As relatively small tensile forces can already bend flexible cusps, composites with high shrinkage values will bend the cusps more than those with a low shrinkage. Therefore composites with low curing shrinkage values are recommended for these cases.
How to make a choice for a composite for a particular cavity configuration?

As stated above composites, which develop a low shrinkage stress during light curing are preferred for rigid cavity configurations, while composites with low curing shrinkage values are favorable for cavity preparations with flexible walls.

Unfortunately shrinkage and shrinkage stress values are not always available. Although manufacturers frequently provide the shrinkage values of their products, comparison with values of other manufacturers is difficult, as different measurement techniques are used. Shrinkage stress values are never reported by manufacturers. A database of shrinkage and shrinkage stress values of a large number of composites, determined by the same methods, would be helpful for the clinician.

Relation between shrinkage and shrinkage stress

Curing shrinkage of a resin composite is usually related to the filler load. When the filler load increases less shrinkage will occur because of the smaller amount of resin available for the polymerization reaction. However, increasing the filler load results in stiffer materials and one may expect that the shrinkage stress will increase in constrained situations such as in class V restorations. In a recent publication (10) where 17 dental resin composites were evaluated for shrinkage and shrinkage stress, 13 composites complied with the expectation that shrinkage and shrinkage stress are related with a high correlation coefficient of $r^2 = 0.88$ (for a 100% correlation $r^2 = 1.00$). Only four composites were an exception and fell off the line of correlation. Based on their shrinkage values, three of them, Filtek Z100, Aelite Flo and Flow-It,
had significantly higher stresses than expected and one, Heliomolar, was significantly lower in stress.

*The aim of this study*

Exceptions as found for Heliomolar (with both a low shrinkage and low shrinkage stress) are interesting for the clinician, as fewer problems are expected with respect to marginal integrity and cusp deflection. Therefore the previously mentioned study (10) was extended to a total of 30 composites in order to reveal possible other composites with both a low shrinkage and shrinkage stress.

*Shrinkage and Shrinkage stress measurements*

The shrinkage was determined with a mercury dilatometer (5) and the shrinkage stress (at C = 2) with a tensilometer (10). Measurements were performed continuously for a period of 30 min. A brief description of the methods is given in fig. 3 and 4.

[Insert figures 3 and 4]

*Results and discussion*

Table 1 shows the shrinkage and shrinkage stress values of 30 composites from the present study and those from the previous study (10). The first part of the table (1a) contains 21 composites for which shrinkage and shrinkage stress correlate with $r^2 = 0.81$, while the second part of the table (1b) contains nine exceptions that fell far off the correlation line, either above or below, as shown in fig. 5. Materials far below the correlation line have favorable shrinkage or shrinkage stress properties, compared to the materials on or close to the line and far above the line. Besides Heliomolar from
the previous study (10), five other composites were found with either a low shrinkage or a low shrinkage stress. ELS had exceptional low values for both, while these values were moderately low for Tetric Evo Ceram, Gradia Direct and In Ten-S. From these data the clinician can make a choice for a composite for a particular cavity configuration. Low shrinkage stress developing composite are preferred for rigid cavity configurations, while composites with low curing shrinkage values are favorable for cavity preparations with flexible walls.

**Conclusion**

The majority of the composites (21 composites out of 30) comply with the rule that a low shrinkage is accompanied with a high shrinkage stress and visa-versa. Nine composites were an exception on this rule. Composites that have both a low shrinkage and low shrinkage stress are expected to give the least problems with respect to marginal seal and enamel fracture. The lowest values were found for the composites ELS and Heliomolar.

[Insert table 1a and 1b]

[Insert figure 5]


Questions.

<table>
<thead>
<tr>
<th></th>
<th>Statements</th>
<th>Vrai</th>
<th>Faux</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The higher the C-factor the lower the shrinkage stress.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>For most composites one can state that shrinkage and shrinkage stress are related to each other.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>For flexible cusps the use of a composite with a low shrinkage is most favorable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>For deep class V cavities a composite with a low shrinkage is most favorable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>For composites with a low shrinkage and low shrinkage stress the least problems are expected with regard to marginal seal and cusp deflection.</td>
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</table>
Légendes des illustrations.

Figure 1. Possible consequences of curing shrinkage and curing stress.
(a) Restorations with loss of marginal integrity and (b) Tooth with enamel fractures (arrow).

Figure 2. Five different restorations (top row) and the way to estimate their C-factors (configuration-factor) with the help of cubes (middle row). C-factor = bonded surface/free non-bonded surface. The cylinders (third row) represent resin composites specimens with corresponding C-factors to be measured for shrinkage stress in a tensilometer (fig. 4). The top surfaces of these cylinders are bonded to steel disks and bottom surfaces to a fixed glass plate. The jacket of the cylinders is the free non-bonded surface.

Figure 3. Schematical illustration of the mercury dilatometer for shrinkage measurements. The composite is placed underneath the glass stopper, which is open at the top to allow access for the light guide of the light source. The shrinkage of the specimen results in a drop of the mercury level in the right glass tube, which is followed by the Perspex float carrying the metal core of the LVDT (Linear Variable Displacement Transducer). The signal from the LVDT is continuously sampled by a computer for a period of 30 min. The middle tube with the micrometer is for calibration.

Figure 4. Simplified schematical illustration of the set-up in the tensilometer for shrinkage stress measurements. The composite is placed between a glass plate (fixed
to the lower part of the tensilometer) and parallel to it a steel disk (connected to the load cell). The composite is light-cured from underneath the glass plate and the shrinkage stress development is recorded continuously from the start of light curing up to 30 min. The C-factor of the composite cylinder between the glass and metal is $C = 2$.

Figure 5. Correlation between shrinkage and shrinkage stress. Twenty-one composites (●) showed a high correlation ($r^2 = 0.81$) between shrinkage and shrinkage stress, which demonstrates that for most of the composites low shrinkage is accompanied with high shrinkage stress and visa-versa. Nine composites (♦ and ▲) fell off the correlation line. Materials far below the line (♦) have favorable shrinkage or shrinkage stress properties, compared to the materials on or close to the line (●) and far above the line (▲).
Figures.

Figure 1a.

Figure 1b.

Figure 2.
Figure 3.

Mercury Dilatometer

Light guide of light source
Screw micrometer
Glass stopper
Specimen
Glass tube system filled with mercury
Thermosatuated water bath at 23 °C

Figure 4.

Tensiliometer

load cell
Composite cylinder
Glass plate
Tensiliometer base

Figure 5.

Correlation line for Shrinkage and Shrinkage Stress (30 min values)
Table 1a. Shrinkage and shrinkage stress values at 30 min for 21 composites (out of 30) with a correlation of $r^2 = 0.81$.

<table>
<thead>
<tr>
<th>Composite</th>
<th>Manufacturer</th>
<th>Shrinkage (Vol%)</th>
<th>Stress (MPa)</th>
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<tbody>
<tr>
<td>Grandio</td>
<td>VOCO</td>
<td>1.9 (0.2)</td>
<td>20.0 (1.2)</td>
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<tr>
<td>Filtek A110*</td>
<td>3M ESPE</td>
<td>2.2 (0.1)</td>
<td>17.4 (0.8)</td>
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<td>Premise Dentin</td>
<td>Kerr</td>
<td>2.3 (0.1)</td>
<td>13.3 (0.3)</td>
</tr>
<tr>
<td>Clearfil APX</td>
<td>Kuraray</td>
<td>2.3 (0.1)</td>
<td>20.4 (0.9)</td>
</tr>
<tr>
<td>Filtek Z250*</td>
<td>3M ESPE</td>
<td>2.3 (0.0)</td>
<td>13.9 (1.0)</td>
</tr>
<tr>
<td>Quixfil</td>
<td>Dentsply</td>
<td>2.4 (0.1)</td>
<td>15.8 (2.9)</td>
</tr>
<tr>
<td>Filtek Supreme*</td>
<td>3M ESPE</td>
<td>2.5 (0.0)</td>
<td>15.1 (1.3)</td>
</tr>
<tr>
<td>Ceram-X mono</td>
<td>Dentsply</td>
<td>2.8 (0.1)</td>
<td>14.2 (0.6)</td>
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<tr>
<td>Glacier</td>
<td>SDI</td>
<td>2.9 (0.0)</td>
<td>14.3 (1.0)</td>
</tr>
<tr>
<td>Prodigy Condensable*</td>
<td>Kerr</td>
<td>3.1 (0.0)</td>
<td>16.1 (1.1)</td>
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<tr>
<td>Tetric Ceram*</td>
<td>Ivoclar Vivadent</td>
<td>3.2 (0.1)</td>
<td>12.8 (0.7)</td>
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<tr>
<td>Herculite XR*</td>
<td>Kerr</td>
<td>3.2 (0.1)</td>
<td>14.9 (1.0)</td>
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<tr>
<td>Spectrum TPH*</td>
<td>Dentsply</td>
<td>3.2 (0.1)</td>
<td>15.6 (0.7)</td>
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<tr>
<td>Ice</td>
<td>SDI</td>
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<td>15.4 (1.2)</td>
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<td>Charisma</td>
<td>Heraeus Kulzer</td>
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<td>15.3 (0.9)</td>
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<td>Point 4*</td>
<td>Kerr</td>
<td>3.4 (0.0)</td>
<td>11.9 (2.1)</td>
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<tr>
<td>Micro Hybrid Composite</td>
<td>Saremco</td>
<td>3.7 (0.1)</td>
<td>12.5 (0.7)</td>
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<tr>
<td>Heliomolar Flow*</td>
<td>Ivoclar Vivadent</td>
<td>4.2 (0.1)</td>
<td>8.4 (1.0)</td>
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<td>Tetric Flow*</td>
<td>Ivoclar Vivadent</td>
<td>4.4 (0.0)</td>
<td>7.6 (1.3)</td>
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<td>Revolution Formula 2*</td>
<td>Kerr</td>
<td>5.0 (0.1)</td>
<td>6.8 (0.7)</td>
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<tr>
<td>UltraSeal XT Plus*</td>
<td>Ultradent</td>
<td>5.6 (0.1)</td>
<td>3.3 (0.3)</td>
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</tbody>
</table>

* Composite previously measured (10).

Table 1b. Shrinkage and shrinkage stress values at 30 min for 9 composites (out of 30) that fell off the correlation line in figure 5.

<table>
<thead>
<tr>
<th>Composite</th>
<th>Manufacturer</th>
<th>Shrinkage (Vol%)</th>
<th>Stress (MPa)</th>
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<tbody>
<tr>
<td>Heliomolar*</td>
<td>Ivoclar Vivadent</td>
<td>2.0 (0.1)</td>
<td>8.4 (0.8)</td>
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<td>Tetric Evo Ceram</td>
<td>Ivoclar Vivadent</td>
<td>2.0 (0.1)</td>
<td>10.6 (0.2)</td>
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<tr>
<td>ELS</td>
<td>Saremco</td>
<td>2.1 (0.1)</td>
<td>4.2 (0.9)</td>
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<tr>
<td>Gradia Direct</td>
<td>GC</td>
<td>2.4 (0.0)</td>
<td>10.4 (0.9)</td>
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<tr>
<td>Filtek Z100*</td>
<td>3M ESPE</td>
<td>2.6 (0.1)</td>
<td>23.5 (0.4)</td>
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<tr>
<td>In Ten-S</td>
<td>Ivoclar Vivadent</td>
<td>2.7 (0.1)</td>
<td>8.8 (1.0)</td>
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<tr>
<td>ELS Flow</td>
<td>Saremco</td>
<td>3.2 (0.1)</td>
<td>3.0 (0.2)</td>
</tr>
<tr>
<td>Aelite Flo*</td>
<td>Bisco</td>
<td>4.8 (0.1)</td>
<td>16.0 (1.2)</td>
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<td>Flow-it*</td>
<td>Jeneric/Pentron</td>
<td>5.3 (0.1)</td>
<td>15.4 (0.8)</td>
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