Resin composite formulations with greater fluidity have been introduced to the marketplace in recent years. These “flowable” materials (Fig. 1) have either less filler loading or a greater proportion of diluent monomers in the composite formulation. They are purported to offer higher flow, better adaptation to the internal cavity wall, easier insertion and greater elasticity than previously available products.1 Dentists can now choose from composites with a wide range of viscosities for different clinical applications, from the most fluid resin fissure sealants through flowable, microfill and hybrid composite formulations, to the high-viscosity packable posterior composites. Each category has certain advantages and limitations, the universal hybrid composites providing the best general blend of good material properties and clinical performance for

**Flow, Strength, Stiffness and Radiopacity of Flowable Resin Composites**

(Fluage, résistance, rigidité et radio-opacité des résines composites à faible viscosité)

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• Laura E. Tam, DDS, MSc •
• Dorothy McComb, BDS, MScD, FRCD(C) •

**Sommaire**

**Objectif** : Cette étude avait pour but de caractériser 9 résines composites à faible viscosité de marque déposée, actuellement offertes sur le marché, quant à leur fluage, leur résistance à la flexion, leur rigidité (module d’élasticité) et leur radio-opacité.

**Méthodologie** : Sept résines composites à faible viscosité (Aelite Flo, Filtek Flow, Heliomolar Flow, PermaFlo, Revolution Formula 2, Tetric Flow, Wave) et 2 compomères à faible viscosité (Compoglass Flow, Dyract Flow) ont été évalués. Un composite hybride universel (Filtek Z250) et un compomère de restauration (Dyract AP) ont été utilisés comme témoins. Des essais mécaniques standards sur des spécimens en forme de barre de 25 × 2 × 2 mm ont été effectués après 24 heures et après 1 mois. Les essais de fluage ont été réalisés à l’aide d’un volume fixe de matériau soumis à une charge constante, et la radio-opacité a été mesurée simultanément pour tous les matériaux, sur des spécimens circulaires de 1 mm d’épaisseur.

**Résultats** : Comme prévu, les composites à faible viscosité ont présenté un indice de fluage plus élevé et des propriétés mécaniques moindres que les témoins. Ainsi, le module d’élasticité des composites a été d’au moins 50 % inférieur à celui des matériaux témoins, ce qui indique une grande flexibilité. La résistance à la flexion a été comparable à celle des composites témoins, mais les propriétés de fluage ont varié considérablement. Le matériau Tetric Flow est celui qui a présenté la plus grande radio-opacité, supérieure à celle de l’émail et du composite témoin, tandis que les matériaux Wave et Revolution Formula 2 ont obtenu la plus faible radio-opacité, laquelle s’est révélée inférieure ou égale à celle de la dentine.

**Conclusions** : Les matériaux à faible viscosité offrent un large éventail de propriétés mécaniques et physiques. Cependant, leurs propriétés mécaniques moindres portent à croire que ces matériaux ne devraient pas être utilisés en épaisseur importante aux endroits exposés à une forte charge occlusale. De plus, à l’intérieur des restaurations intracorona-

**Mots clés MeSH** : comparative study; composite resins/chemistry; pliability; stress, mechanical

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Cet article a fait l’objet d’une révision par des pairs.
Flows, Strength, Stiffness and Radiopacity of Flowable Resin Composites

**Table 1 Materials tested**

<table>
<thead>
<tr>
<th>Test material</th>
<th>Manufacturer and location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control materials</strong></td>
<td></td>
</tr>
<tr>
<td>Filtek Z250 (universal</td>
<td>3M ESPE Dental Products</td>
</tr>
<tr>
<td>hybrid composite)</td>
<td>St. Paul, Minnesota</td>
</tr>
<tr>
<td>Dyrract AP (restorative</td>
<td>Dentsply</td>
</tr>
<tr>
<td>compomer)</td>
<td>Konstanz, Germany</td>
</tr>
<tr>
<td><strong>Flowable materials</strong></td>
<td></td>
</tr>
<tr>
<td>Aelite Flo</td>
<td>Bisco Inc., Schaumburg, Illinois</td>
</tr>
<tr>
<td>Compoglass Flow</td>
<td>Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>Dyrract Flow</td>
<td>Dentsply</td>
</tr>
<tr>
<td>Filtek Flow</td>
<td>3M ESPE Dental Products, St. Paul, Minnesota</td>
</tr>
<tr>
<td>Heliomolar Flow</td>
<td>Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>PermaFlo</td>
<td>Ultradent Products Inc., Jordan, Utah</td>
</tr>
<tr>
<td>Revolution Formula 2</td>
<td>Kerr Corporation, Orange, California</td>
</tr>
<tr>
<td>Tetric Flow</td>
<td>Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>Wave</td>
<td>Southern Dental Industries, Cologne, Germany</td>
</tr>
</tbody>
</table>

A prerequisite of all restorative materials is adequate radiopacity to allow the clinician to evaluate restoration integrity at subsequent recall appointments, distinguish caries from restorative material on radiographs, and detect voids, overhangs and open margins. A restorative material with radiopacity slightly greater than, or equal to, enamel is ideal for detection of secondary caries. It is widely recognized that unfilled resin adhesives are radiolucent and that use of thick layers of such materials can present a diagnostic challenge on subsequent radiography. It has been the authors’ personal observation that the radiopacity of some of the flowable composite resin materials used beneath posterior restorations is lower than desirable.

Many dentists have readily accepted flowable composites for a wide variety of uses. Although some in vitro studies have shown that the use of flowable composites reduces restoration microleakage and the occurrence of voids, other research has shown no apparent advantage over universal hybrid composites. Despite limited scientific information, flowable composite materials are being used for a wide range of applications, from liners and pit and fissure sealants, to margin or void repairs and even Class I and V restorations. Newer formulations that have recently been introduced to the market include flowable comomers or polyacid-modified resin composites. Because flowable materials are being used in many clinical applications, dentists need comparative information so that they can select the materials with the most appropriate properties for any particular use.

The purpose of this study was to determine the key properties of flow, flexural strength, modulus of elasticity and radiopacity of 7 currently available flowable composites and 2 flowable compomer materials. One universal composite and one compomer were included in the study as controls.

**Methods and Materials**

The materials used in this study are listed in Table 1.
Flow

Flow measurements for each of the 11 materials were carried out using a method similar to that of Bayne and others, who employed a modification of the American Dental Association flow test for dental cements. A disposable 1-mL B-D syringe (Becton Dickinson & Co., Franklin Lakes, New Jersey) without a needle tip was filled with the test material, and a standard volume (0.5 mL) was extruded onto a glass plate and immediately covered by 3 stacked glass slides (weighing a total of 18 g). After 30 seconds the samples were transferred to a Triad curing unit (Triad 2000, Dentsply, York, Pennsylvania) and cured for 60 seconds. The distance (in millimetres) of the resulting nearly circular disk was measured twice (along perpendicular lines). For each material, the average diameter of 3 disks was used to generate comparative flow results.

Flexural Strength

Flexural strength was determined according to International Organization for Standardization (ISO) standard 4049. Sixteen rectangular bar specimens of each material, measuring 25 × 2 × 2 mm, were prepared by filling a Teflon mould, placing and clamping a glass lid over the mould, and curing for 60 seconds in the Triad light curing unit. After polymerization, 8 specimens of each material were stored in distilled water at 37°C for 24 hours and 8 were stored under the same conditions for 1 month. Before loading, height and width were measured at 3 locations on each specimen; a digital micrometer (Digimatic, Mitutoyo Corp., Tokyo, Japan) with an accuracy of 0.001 mm was used for these measurements. The mean of these 3 measurements was used to calculate flexural strength and modulus of elasticity.

Each specimen was subjected to a 3-point bend test on an Instron uniaxial servo-mechanical testing machine (model 4301, Instron Corporation, Canton, Massachusetts) at a crosshead speed of 1 mm/minute, with loading until failure. Testing was conducted with each specimen immersed in a 37°C water bath to simulate clinical conditions. The maximum load recorded at the time of failure was captured electronically. Flexural strength (F, in megapascals) was calculated using the following formula:

\[ F = \frac{3PL}{2WH^2} \]

where \( P \) is the maximum measured load at failure (in newtons), \( L \) is the distance between the supports (fixed at 20 mm), \( W \) is the mean width of the specimen measured before testing (in millimetres), and \( H \) is the mean height of the specimen between the tension and compression surfaces (also in millimetres).

Modulus of Elasticity

The elastic modulus (E, in gigapascals) was determined from the slope of the load deflection curve generated during the 3-point bend test according to the following formula:

\[ E = \frac{\delta FY}{L^3/4WH^3} \]

where \( \delta F \) is the change in force (\( \delta F \)) per unit change in deflection (\( \delta Y \)) of the centre of the specimen, \( L \) is the distance between the supports on the tension surface (20 mm), \( W \) is the width of the specimen (in millimetres) and \( H \) is the thickness of the specimen between the tension and compression surfaces (also in millimetres). The slope, in newtons per millimetre, was measured in the initial straight-line portion of the load deflection graph.

Radiopacity

For each material, a split-ring metal mould and clamps were used to produce 5 disk specimens measuring 6.0 mm in diameter and 1.0 mm in thickness, in accordance with ISO 4049. The specimens were photo-polymerized as before and ground through 400-grit sandpaper to create a flat surface. Specimens were measured after finishing to verify the critical tolerance of 1.0 ± 0.01 mm. Five longitudinal sections of human permanent molar teeth were also prepared to the same thickness using an Accutom saw (Struers Co., Copenhagen, Denmark). One specimen of each material, one tooth section and a standard proprietary aluminum step wedge were positioned side by side on occlusal radiographic film (Ekta Speed Plus, EO-42P, Kodak Canada Inc., Toronto, Ontario). The wedge’s maximum thickness was 13.5 mm and the step size was 1 mm. The step wedge served as an internal standard for each radiographic exposure and allowed calculation of the radiopacity of each material in terms of aluminum thickness. Films were exposed for 0.37 milliseconds with a dental radiography unit (Belmont-Takara Phot-X 2001 CP, Belmont Takara Co., Frankfurt, Germany) at 70 kV and 10 mA; the object-to-film distance was 400 mm. The films were processed in a standard automatic processor (Dent-X, Elmsford, New York).

The optical density of the radiographic images was measured with a transmission densitometer (Macbeth TD-504, Macbeth Corp., Newsburgh, New York) (mean of at least 4 readings per specimen). Following the method of El-Mowafy and Benmergui the optical density data for the aluminum steps were entered into a computer, and the best possible exponential fit was used for curves of aluminum optical density. Aluminum equivalency for each sample of test material and each dentin and enamel section was extrapolated directly from the graph and used to calculate mean aluminum thickness equivalency.

Statistical Analysis

One-way analysis of variance (ANOVA) and Duncan’s multiple-range statistical tests (\( p < 0.05 \)) were conducted on all physical and mechanical test results.

Results

Flow

The flow of behaviour of all of the flowable composites was distinct from that of the universal hybrid composite and compomer restorative materials (Fig. 2). The proprietary flowable materials demonstrated a wide range of flow behaviour, with the most fluid (PermaFlo) providing almost twice the flow of the least fluid (Aelite Flo) under the same conditions.
Flexural Strength

The control composite had the highest mean value for flexural strength at 24 hours (117.4 MPa) and 1 month (95.6 MPa) (Tables 2a and 2b, Fig. 3). Flexural strength values for the flowable composites varied from 66.9–102 MPa at 24 hours and from 61.1–88.7 MPa at 1 month. For most materials, flexural strength was significantly lower at 1 month than at 24 hours. There was a significant interaction between material and time ($F = 6.667$, $p < 0.05$).

Modulus of Elasticity

The modulus of elasticity at 24 hours and 1 month were highest for the control composite and the control compomer (Tables 3a and 3b, Fig. 4). The moduli for the flowable materials were approximately one-third to one-half that of the control composite. For all materials there was a significant interaction between material and time ($F = 73.775$, $p < 0.05$).

Radiopacity

Tetric Flow had the highest radiopacity (Fig. 5), above that of both enamel and the control composite. Both Wave and Revolution Formula 2 showed lowest radiopacity, below or equivalent to that of the dentin. All materials met the ISO minimum standard of radiopacity, equal to or greater than that of the same thickness of aluminum.

Discussion

Mechanical and radiopacity tests performed according to ISO test methods for resin-based restorative materials provided basic comparative information for the test materials. The ISO has set 80 MPa as the minimum flexural strength for polymer-based filling and restorative materials claimed suitable for restorations involving outer occlusal surfaces. All of the flowable materials tested exceeded or came very close to fulfilling this requirement. Although Bayne and others used biaxial flexural strength tests, comparison of their results with those for the newer materials tested here showed a general trend toward an increase in flexural strength, to a level more comparable to that of the control composite. However, despite achievement of minimum ISO flexural strength requirements,
it is still recommended that flowable materials be restricted to
minimal or adjunctive clinical situations.

The properties of resin composites depend primarily on the
material composition. A correlation exists between filler
content and mechanical properties, particularly for modulus
of elasticity: the higher the filler content, the higher the
modulus and the greater the resistance to deformation.
Conversely, the lower the filler content, the greater the poly-
merization shrinkage and the lower the ability to resist defor-
mation. The best compromise for most restorations appears to
be a fine hybrid resin composite with a flexural modulus of
approximately 10 GPa. In this study the flowable materials as
a group consistently exhibited markedly lower stiffness than
the hybrid composite and compomer restorative materials.
This suggests that flowable materials (elastic modulus at
24 hours ranging from 2.8 to 6.0 GPa) are not sufficiently
rigid to withstand significant occlusal forces when used in
bulk. In addition, the literature is equivocal regarding the
effectiveness of low-modulus flowable composites in reducing
microleakage. However, use of flowable composites did
not increase microleakage in any study, and there were
favourable effects on reducing microleakage in some stud-
ies.1,9,18 It has been suggested that these favourable effects are
due to the improved cavity adaptation and stress-absorbing
ability outweighing the effects of increased polymerization
shrinkage.18 Thicker layers appear to be more effective.9,10 The
causes of and preventive measures for microleakage are multi-
factorial and complex; these factors will confound the results
of in vitro leakage studies of resin composites, in which leak-
age tends to be the rule rather than the exception. Using only
a composition-based approach to relieve shrinkage stress may
be too simplistic. Ensuring optimal dentin bonding and using
incremental layers of composite in appropriate configurations
are key factors in minimizing the deleterious effects of poly-
merization shrinkage.

Radiopacity is an essential property for all restorative mate-
rials, and ISO standards stipulate that minimum radiopacity
be equal to or greater than that of an equivalent thickness of
aluminum (1 mm in this study). Although the radiopacity of
dentin and enamel specimens varies, pure aluminum provides

Table 3a Modulus of elasticity at 24 hoursa

<table>
<thead>
<tr>
<th>Test material</th>
<th>Mean modulus of elasticity ± SD (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtek Z250</td>
<td>11.6 ± 1.4</td>
</tr>
<tr>
<td>Dyrect AP</td>
<td>9.1 ± 1.0</td>
</tr>
<tr>
<td>PermaFlo</td>
<td>6.0 ± 0.7</td>
</tr>
<tr>
<td>Tetric Flow</td>
<td>5.8 ± 1.1</td>
</tr>
<tr>
<td>Filtek Flow</td>
<td>5.1 ± 1.5</td>
</tr>
<tr>
<td>Dyrect Flow</td>
<td>5.1 ± 0.8</td>
</tr>
<tr>
<td>Compoglass Flow</td>
<td>4.4 ± 0.6</td>
</tr>
<tr>
<td>Revolution Formula 2</td>
<td>4.2 ± 0.5</td>
</tr>
<tr>
<td>Aelite Flo</td>
<td>4.2 ± 0.4</td>
</tr>
<tr>
<td>Heliomolar Flow</td>
<td>3.9 ± 0.4</td>
</tr>
<tr>
<td>Wave</td>
<td>2.8 ± 0.7</td>
</tr>
</tbody>
</table>

SD = standard deviation.
aVertical lines indicate values that are not significantly different from one
another (p < 0.05).

Table 3b Modulus of elasticity at 1 montha

<table>
<thead>
<tr>
<th>Test material</th>
<th>Mean modulus of elasticity ± SD (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtek Z250</td>
<td>10.8 ± 0.8</td>
</tr>
<tr>
<td>Dyrect AP</td>
<td>9.8 ± 0.9</td>
</tr>
<tr>
<td>PermaFlo</td>
<td>5.5 ± 0.6</td>
</tr>
<tr>
<td>Revolution Formula 2</td>
<td>5.0 ± 0.6</td>
</tr>
<tr>
<td>Filtek Flow</td>
<td>4.8 ± 0.9</td>
</tr>
<tr>
<td>Tetric Flow</td>
<td>4.6 ± 0.6</td>
</tr>
<tr>
<td>Aelite Flo</td>
<td>4.2 ± 0.6</td>
</tr>
<tr>
<td>Dyrect Flow</td>
<td>4.2 ± 0.7</td>
</tr>
<tr>
<td>Wave</td>
<td>4.1 ± 0.9</td>
</tr>
<tr>
<td>Compoglass Flow</td>
<td>3.8 ± 0.6</td>
</tr>
<tr>
<td>Heliomolar Flow</td>
<td>3.2 ± 0.3</td>
</tr>
</tbody>
</table>

SD = standard deviation.
aVertical lines indicate values that are not significantly different from one
another (p < 0.05).
Flow, Strength, Stiffness and Radiopacity of Flowable Resin Composites

a constant value. All of the flowable materials tested in this study would pass the ISO minimum standards; however, the radiopacity of 2 of the products, Revolution Formula 2 and Wave, was comparable to or less than that of the dentin samples. The highest radiopacity was exhibited by Tetric Flow, which had radiopacity higher than that of both enamel and the control composite. Studies have emphasized the desirability of high radiopacity in flowable composites that may be used beneath posterior composite restorations.19,20

Flowable composites may offer significant advantages when used as intermediate layers, according to the concept of radiopaque filled adhesives. They can also be used to improve adaptation to the cavity surface in areas that are difficult to access, especially when high-viscosity posterior composite materials are used subsequently. The proprietary materials tested here offer a wide range of properties reflecting the fact that optimal physical, mechanical and handling properties have not been defined for this group of materials. The optimal material would provide controlled fluidity combined with optimal radiopacity and high strength. The diversity among the various proprietary flowable composite materials indicates that the clinician should consider the anticipated clinical use and select the material with the most appropriate properties. Further studies are required to ascertain the potential clinical benefits and limitations of this class of flowable materials.

Conclusions

The flowable composite and compomer materials tested had greater fluidity and lower rigidity than the universal composite or compomer materials. Although disparate in terms of relative flow and radiopacity, the flowable materials had similar strength parameters, with approximately 50% of the rigidity of regular composites and approximately 80% of the flexural strength. Their lower mechanical properties suggest that these materials should not be used in bulk in areas that experience high occlusal loading. For intracoronal restorations, clinicians are advised to use materials with high radiopacity. Use of materials with radiopacity close to or less than dentin may result in future diagnostic challenges.

The clinical applications and performance of these materials require further study.

References


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