Characterization of restorative short-fiber reinforced dental composites

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The aim was to evaluate and compare certain physical properties including surface-wear of five commercial short fiber-reinforced composites (SFRCs; Alert, NovaPro-Flow, NovaPro-Fill, everX Flow and everX Posterior). The following properties were examined according to ISO: flexural strength, flexural modulus, fracture toughness, water sorption. Degree of conversion was determined by FTIR-spectrometry. A wear test was conducted with 15,000 chewing-cycles using a chewing-simulator. Polymerization shrinkage-stress was measured using tensiometer. SEM was used to evaluate the microstructure of SFRCs. everX Flow exhibited the highest fracture toughness (2.8 MPa m^{1/2}) and the lowest wear depth (20.4 µm) values (p<0.05) among the SFRCs tested. NovaPro Fill (141.5 MPa) and everX Flow (147 MPa) presented the highest flexural strength values (p<0.05). everX Flow showed the highest shrinkage-stress value (5.3 MPa) while other SFRCs had comparable values. The use of SFRCs in dentistry can be advantageous, but special attention should be given to the selection of the materials.

Keywords: Fiber composite, Physical properties, Fracture toughness, Wear

INTRODUCTION

Nowadays, composites are the material of choice for direct restorations on posterior and anterior teeth1. Demands for natural esthetics from patients as well as clinicians are increasing and have led to the popular use of composites on posterior teeth, where considerable mechanical challenges occur under function1,2,3. To withstand these stresses, modification of filler particle size and morphology resulted in improved mechanical properties4. According to Alvanforoush and colleagues, the range of all the reported annual failure rates of composite restorations among long-term clinical studies (15 to 22 years) has improved in the last decade (2006 to 2016) to 1.50 to 2.20%. However, the reasons for failure have shifted from high rates of secondary caries and wear to increasingly significant roles of restoration fractures, tooth fractures and endodontic treatment4. The fracture related material properties, such as crack propagation resistance, deformation under occlusal load, and the marginal degradation of materials have usually been evaluated by the determination of the basic material parameters of fracture toughness and flexural strength4.

Fracture toughness is a mechanical property that describes the resistance of brittle materials to the catastrophic propagation of flaws under an applied load, and thus, it describes damage tolerance of the material5. Fracture toughness values are dependent on the physical properties and chemical composition of the individual component of restorative material. A material which has high fracture toughness has the ability to better resist crack initiation and propagation.

Consequently, the property of fracture toughness and flexural strength become important criterions in a dental materials’ longevity6-7. Fracture toughness of conventional particulate filled composites (PFCs) is still significantly lower than that of dentine8. Furthermore, the microstructure of PFC does not resemble that of dentine. Conventional PFC consists of filler particles embedded in a resin matrix while dentine consists of collagen fibres embedded in a hydroxyl apatite matrix. Therefore, dentine should be rather seen as a natural fibre-reinforced composite9.

The requirement to strengthen composite has led to an ever increasing research effort into reinforcement techniques. Several former approaches dealt with incorporation of ceramic particles (random orientation), whiskers (single or multi-layer) or fibers (continuous or discontinuous fibers in various orientations)10-12. A number of manufacturers have developed short fiber-reinforced composites (SFRCs) which claimed to overcome the weakness of conventional PFC. Many recent studies in the literature have approached to find way to support the remaining tooth structure and improve the durability of the final composite restorations13-16. The attempt has been to use SFRC as dentine-replacing material (bulk base) or post-core foundation under surface layer of enamel-replacing material (PFC), i.e. biomimetic or bilayered composite restorations16. To the author’s knowledge, until now they are a limited number of SFRCs available in the market. These SFRCs perhaps mimic structurally the fibrous structure of dentine and some of them are recommended to use as bulk base or core build-up materials in large cavities of either vital or non-vital posterior teeth14-19.

Earlier formulations of SFRC (Alert, Jeneric/Pentron) was already commercialized in the late 1990s.
as packable composite while the latest type of flowable SFRC (everX Flow, GC, Tokyo, Japan) was launched globally in 2019. Although in-vitro studies have showed good mechanical and physical performance of some SFRCs in comparison with conventional PFCs, the physical properties and wear of these SFRC materials have never been compared. Many of the properties of fiber-reinforced composites are strongly dependent on microstructural parameters such as fiber diameter, fiber length, fiber orientation, fiber loading, and adhesion of fibers to the polymer matrix\(^\text{20}\). In view of the development of newer materials in the market, clinician often has uncertainties regarding the choice of best materials to achieve optimum results. Thus, the aim of this study was to evaluate and compare certain important physical properties and wear of five commercial SFRCs (Alert, NovaPro Flow, NovaPro Fill, everX Flow, and everX Posterior).

### MATERIALS AND METHODS

The SFRCs used in the study are listed in Table 1. All composites were manipulated according to the manufacturer’s recommended directions.

**Mechanical tests**

Three-point bending test specimens \((2\times2\times25 \text{ mm}^3)\) were made from each tested composite. Bar-shaped specimens were made in a half-split stainless steel mold between transparent Mylar sheets. Polymerization was done using a hand light-curing unit (Elipar TM S10, 3M ESPE, Seefeld, Germany) for 20 s in five separate overlapping portions from both sides of the metal mold. The wavelength of the light was between 430 and 480 nm and light intensity was 1,600 mW/cm\(^2\).

The specimens from each material \((n=8)\) were stored dry at 37°C temperature for 48 h before testing. Three-point bending test was conducted according to the ISO 4049 (test span: 20 mm, cross-head speed: 1 mm/min, indenter: 2 mm diameter). All specimens were loaded in universal testing machine (Lloyd model LRX, Lloyd Instruments, Fareham, UK) and the load-deflection curves were recorded with PC-computer software (Nexygen 4.0, Lloyd Instruments).

Flexural strength \((\sigma)\) and flexural modulus \((E_f)\) were calculated from the following formula:

\[
\sigma = \frac{3F_m I}{2bh^2}
\]

\[
E_f = \frac{SI^3}{4bh^3}
\]

Where \(F_m\) is the applied load (N) at the highest point of the load-deflection curve, \(I\) is the span length (20 mm), \(b\) is the width of the test specimens and \(h\) is the thickness of the test specimens. \(S\) is the stiffness (N/m) \(S=F/d\) and \(d\) is the deflection corresponding to load \(F\) at a point in the straight-line portion of the trace.

Single-edge-notched-beam specimens \((2\times5\times25 \text{ mm}^3)\) according to adapted ISO 20795-2 standard method (ASTM 2005) were prepared to determine the fracture toughness. Custom-made stainless steel split mold was used, which enabled specimen’s removal without force. Accurately designed slot was fabricated centrally in the mold extending until its mid-height, which enabled central location of the notch and optimization of the crack length \((x)\) to be 0.5. The tested composite was inserted into the mold placed over a Mylar-strip-covered glass slide in one increment. Before polymerization a sharp and centrally located crack was produced by inserting a straight edged steel blade into the prefabricated slot. Polymerization of the composite was carried out for 20 s in five separate overlapping portions. The upper side of the mold was covered with Mylar strip and glass slide...
from both sides of the blade, before being exposed to the polymerization light. Upon the removal from the mold, each specimen was polymerized also on the opposite side. The specimens from each group (n=6) were stored dry at 37°C temperature for 48 h before testing. The specimens were tested in three-point bending mode, in a universal material testing machine at a crosshead speed of 1.0 mm/min.

The fracture toughness was calculated using the Equation: 

\[ K_f = \frac{P L}{B W^{1/2}} \frac{1}{(1-x)^{1/2}} \]  

where: \( f(x) = 3/2x^{1/2}[1.99-x(1-x)(2.15-3.93x+2.7x^2)]/(2(1+2x)(1-x)^{1/2}) \) and \( 0<x<1 \) with \( x=a/W \). Here \( P \) is the maximum load in kilonewtons (kN), \( L \) is the span length (20 cm), \( B \) is the specimen thickness in centimeters (cm), \( W \) is the specimen width (depth) in cm, \( x \) is a geometrical function dependent on \( a/W \) and \( a \) is the crack length in cm.

Degree of conversion
Degree of carbon-carbon double bond conversion (DC%) during and after the photoinitiation of polymerization was monitored by Fourier transform infrared spectroscopy (FTIR; Spectrum One, Perkin-Elmer, Beaconsfield, Bucks, UK) with an attenuated total reflectance (ATR) accessory. Composites were analyzed in a mold that was 1.5 mm thick and 4.5 mm in diameter. First, the spectrum of the unpolymerized sample was placed in the mold and measured. Then the sample was irradiated through an upper glass slide for 40 s with a visible light-curing unit (Elipar TM S10, 3M ESPE) producing an average irradiance of 1,600 mW/cm² (Marc Resin Calibrator, BlueLight Analytics, Halifax, Canada). The sample was scanned for its FTIR spectrum after being irradiated. The DC% was calculated from the FTIR spectrum at 1,638 cm⁻¹ of the uncured specimen and normalized against the aromatic C=C peak at 1,608 cm⁻¹ according to the following formula:

\[ DC% = \left[ 1 - \frac{C_{aliphatic}}{C_{aromatic}} \right] \times 100\% \]

where is \( C_{aliphatic} \) is the absorption peak at 1,638 cm⁻¹ of the cured specimen, \( C_{aromatic} \) the absorption peak at 1,608 cm⁻¹ of the cured specimen, \( U_{aliphatic} \) the absorption peak at 1,638 cm⁻¹ of the uncured specimen and \( U_{aromatic} \) is the absorption peak at 1,608 cm⁻¹ of the uncured specimen.

The fraction of remaining double bonds for each spectrum was determined by standard baseline techniques using the comparison of maximum heights of aliphatic and reference peaks for calculations. For each composite, six trials were performed.

Two-body wear
Two specimens of each commercial SFRC were prepared in acrylic resin block for localized wear testing. Longitudinal cavities (20 mm length×10 mm width×3 mm depth) were prepared in and then SFRCs were placed in one increment into the prepared cavities and covered with a Mylar strips and glass slides before light irradiated for 40 s in five separate overlapping portions. The surfaces were then polished flat using a sequence of #1200- to #4000-grit silicon carbide papers. After one day of water storage (37°C), 2-body wear test was conducted using the chewing simulator (CS-4.2, SD Mechatronik, Feldkirchen-Westerham, Germany) which has two chambers simulating the vertical and horizontal movements simultaneously with water. Each of the chambers consists of an upper sample holder that can fasten the loading tip with a screw and a lower plastic sample holder in which the SFRC specimen can be embedded. The specimens were embedded in acrylic resin in the lower sample holder, for use as antagonistic wear materials. The manufacturer’s standard loading balls (Steiitie ball, Ø 6 mm) were embedded in acrylic resins in the upper sample holders, and were then fixed with a fastening screw. A weight of 2 kg, which is comparable to 20 N of chewing force and 15,000 loading cycles with frequency of 1.5 Hz were used.

The wear patterns (n=6) on the surface of each specimen were profiled with 3D optical microscope (Bruker Nano, Berlin, Germany) using Vision64 software. The maximum wear depth values (µm), representing the average of lowest or deepest points of all profile scans were calculated from different points.

Water sorption
Water sorption for each SFRC was measured from seven specimens which were stored in 120 mL of water for 36 days at 37°C. The dry weight (md) of the specimens was measured with a balance (Mettler A30, Mettler Instrument, Highstone, NJ, USA), with an accuracy of 0.1 mg. During water immersion, specimen weight (mw) was measured at 1, 2, 3, 7, 14, 21, 31 and 37 days. Water uptake was calculated as follows:

\[ \text{Water uptake} \% = \frac{(m_w - m_d)}{m_d} \times 100\% \]

Polymerization shrinkage-stress measurement
Glass fiber-reinforced composite (FRC) rods with 4 mm diameter and 4 cm length had one of their flat surfaces ground with 180 grit silicon carbide sand paper. Two FRC rods were attached tightly to a universal testing machine (model LRX, Lloyd Instruments) and SFRC was applied between the FRC rod surfaces. The height of the specimen was set at 1.5 mm. Two light units (Elipar TM S10, 3M ESPE) were used simultaneously for 20 s with the tips in close contact with the composite specimen from both sides. Contraction forces were monitored for 5 min at room temperature (22°C). Shrinkage stress was calculated by dividing the shrinkage force by the cross-section area of the FRC rod. The maximum shrinkage stress value was taken from the plateau at the end of shrinkage stress/time curve. Six specimens were tested for each tested composite.

Microscopic analysis
Scanning electron microscopy (SEM; GeminiSEM 450, Carl Zeiss, Oberkochen, Germany) provided the characterization of the microstructure of the investigated SFRCs. Polished specimens (n=3) from each material were stored in desiccator for one day. Then, they were...
coated with a gold layer using a sputter coater in vacuum evaporator (BAL-TEC SCD 050 Sputter Coater, Balzers, Liechtenstein) before the SEM examination. SEM observations were carried out at an operating voltage of 5 kV and working distance of 3–6 mm.

**Statistical analysis**

The data were statistically analyzed using SPSS software (SPSS ver. 23, IBM, Somers, NY, USA). The results were primarily analyzed by Levene’s test for equality of variances. When the results of the Levene’s test showed homoscedasticity, values were analyzed by one-way analysis of variance (ANOVA) at the p<0.05 significance level followed by a Tukey HSD post hoc test to determine the differences between the groups.

**RESULTS**

Application of Levene’s test yielded results that showed homoscedasticity. The mean values of fracture toughness, flexural strength and modulus and DC% for tested SFRCs with standard deviations (SD) are summarized at Table 2. ANOVA revealed that everX Flow had statistically significantly higher fracture toughness (2.8 MPa m$^{1/2}$) than all other tested SFRCs (p<0.05). While NovaPro Flow showed statistically the lowest fracture toughness value (1.3 MPa m$^{1/2}$) than all other tested SFRCs (p<0.05), everX Flow presented also the highest flexural strength (147 MPa) which was not significantly different (p>0.05) from NovaPro Fill (141 MPa). everX Posterior exhibited the highest flexural modulus (12.6 GPa) and lowest DC% (54.5) among the SFRCs tested (p<0.05). The mean values for wear depth recorded for each material after 15,000 chewing simulation cycles showed in Table 2. Lowest average wear depth was found for everX Flow (20.4 µm) (p<0.05), while no differences found in wear depth between other tested SFRCs (in range: 28–32 µm). Water sorption after 37 days of NovaPro Flow was 0.86 wt%, which was the highest and for Alert was the lowest (0.41 wt%) among all tested SFRCs (Fig. 1). everX Flow showed the highest shrinkage stress value (5.3 MPa, p<0.05) while the other SFRCs had comparable values (p>0.05) (Table 2). SEM analysis showed different fiber diameter of each SFRC (Figs. 2 and 3) and this suggested an explanation for different toughening capability between tested SFRCs.

**Table 2** Mean values (±SD) of fracture toughness (FT), flexural strength (FS), flexural modulus (FM), degree of conversion (DC), wear depth (WD), water sorption (WS), and shrinkage stress (SS)

| Material          | FT (MPa m$^{1/2}$) | FS (MPa) | FM (GPa) | DC (%) | WD (µm) | WS (%) | SS (MPa) |
|-------------------|---------------------|----------|----------|--------|---------|--------|----------|
| Alert             | 1.7±0.4$^b$         | 118±18$^b$ | 9.9±0.9$^c$ | 61.8±0.3$^b$ | 29.7±2.8$^b$ | 0.41   | 3.7±0.2$^a$ |
| NovaPro Flow      | 1.6±0.3$^b$         | 108±12$^a$ | 5.7±0.5$^a$  | 64.9±1.1$^b$ | 28.6±1.6$^b$ | 0.86   | 3.6±0.3$^a$ |
| NovaPro Fill      | 1.3±0.2$^a$         | 141±17$^c$ | 9.1±0.9$^b$  | 61.5±1.5$^b$ | 32±2.2$^b$   | 0.48   | 4.0±0.3$^{ab}$|
| everX Flow        | 2.8±0.4$^{cd}$      | 147±23$^c$ | 9.0±0.7$^b$  | 62.8±0.3$^b$ | 20.4±4.9$^a$ | 0.53   | 5.3±0.6$^c$ |
| everX Posterior   | 2.6±0.4$^c$         | 120±5$^{ab}$ | 12.6±2.8$^c$ | 54.5±1.5$^a$ | 32.5±1.2$^b$ | 0.61   | 3.9±0.2$^{ab}$|

Same superscript letter above the values indicates groups that were statistically similar (p>0.05).

**Fig. 1** Water sorption (%wt gain) of investigated SFRCs during 37 days of storage in water at 37°C.
Fig. 2  SEM photomicrographs of non-fracture polished surface of investigated SFRCs (scale bar=5 µm). (A) everX Flow; (B) NovaPro Flow; (C) Alert; (D) everX Posterior; (E) NovaPro Fill.

Fig. 3  SEM photomicrographs showing a nanofiber bundle in the NovaPro Flow and NovaPro Fill SFRCs.
DISCUSSION

There are limited published studies in the literature comparing SFRCs. Five different commercially available SFRCs were evaluated in this study. All of them were manufactured to be used in high stress-bearing areas and were presented in order to enhance the fracture resistance of posterior composite restorations and core build-ups.

In the present study, the new flowable micrometer scale SFRC (everX Flow) exhibited significantly higher fracture toughness (2.8 MPa m$^{1/2}$) and flexural strength (147 MPa) values than all other tested SFRCs. This is in accordance with Lassila et al., and Garoushi et al., studies, which showed superior fracture toughness and flexural properties of experimental micrometer scale short fiber-reinforced flowable composite. To our knowledge there are no other dental composites with fracture toughness values above 2.6 MPa m$^{1/2}$. According to the study of Ilie et al., hybrid PFCs exhibit the highest fracture toughness among direct restorative materials, with an average value of 1.84 MPa m$^{1/2}$. The millimetre scale SFRC (everX Posterior) showed relatively high fracture toughness (2.6 MPa m$^{1/2}$) and this also in agreement with several studies, which reported superior fracture toughness values among commercial hybrid and bulk fill composites.

Short fibers enhanced the ability of the material to resist the crack propagation, as well as to reduce the stress intensity at the crack tip from which a crack propagates in an unstable manner. As a consequence, an increased fracture toughness can be expected. A recent systematic review by Heintze et al., showed that fracture toughness being mostly correlated with clinical fracture toughness being mostly correlated with clinical fracture resistance parameters (fracture toughness and flexural properties values among direct restorative materials, with an average value of 1.84 MPa m$^{1/2}$). The micrometer scale SFRC (everX Posterior) showed relatively high fracture toughness (2.6 MPa m$^{1/2}$) and this also in agreement with several studies, which reported superior fracture toughness values of everX Posterior in comparison with many commercial hybrid and bulk fill composites.

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Furthermore, several in vitro studies have revealed a strong correlation between fracture toughness of a material and fracture behavior of the corresponding dental restoration. In particular for biomimetic or bilayered restorations made of a dentine-replacing SFRC core and an enamel-replacing PFC veneer a more nature-like fracture behavior and fewer catastrophic failures were observed if the SFRC had a more dentine-like fracture toughness.

On the other hand, nanometer scale SFRCs (NovaPro Flow and NovaPro Fill) and low aspect ratio micrometer scale SFRC (Alert) had significant lower fracture toughness than everX Flow and everX Posterior (Table 2). In order for a fiber to act as an effective reinforcement for polymers, stress transfer from the polymer matrix to the fibers is essential. This is achieved by having a fiber length equal to or greater than the critical fiber length and the given fiber aspect ratio in range of 30–94. Aspect ratio, critical fiber length, fiber loading and fiber orientation are the main factors that could improve or impair the mechanical properties of fiber reinforced composites. Aspect ratio is the fiber length to fiber diameter ratio (l/d). It affects the tensile strength and the reinforcing efficiency of the fiber reinforced material. It should be noted that adhesion of the fibers to the polymer matrix also influences to the critical fiber length (l) that is the minimal length of high aspect ratio fiber fillers which can effectively reinforce the resin composite. Sufficient adhesion between fiber and matrix provides good load transfer between the two components, which ensures that the load is transferred to the stronger fiber and this is how the fiber actually works as reinforcement. However, if the adhesion is not strong and if any voids appear between the fiber and the polymer matrix, these voids may act as initial fracture sites in the matrix and facilitate the breakdown of the material.

The micrometer scale SFRC (everX Flow) had an aspect ratio of more than 30 because the diameter of microglass fibers used was 6 µm and the length in range of 200–300 µm. everX Posterior had fiber (0.17 µm) length distribution between 0.3 and 1.5 mm, which is in the range of the reported critical fiber length and desired aspect ratio. This is therefore not surprising that short fiber fillers inclusion with resin matrix revealed improvements in fracture toughness.

Alert has fiber length in micrometer scale (20–60 µm) and diameter of 7 µm (Fig. 2), while NovaPro composites have fiber diameter in nanometer scale (50–200 nm) and length in range between 100 and 150 µm, which is well below the critical fiber length and desired aspect ratio. This explained the difference in fracture toughness values between the commercial SFRCs. These differences were seen by SEM analysis (Figs. 2 and 3), which prove that materials with different microstructure characteristic and fiber aspect ratio (length and diameter) could differ with regards to physical properties and wear.

Among the investigated SFRCs, NovaPro Flow showed lowest values of flexural strength and modulus, which seems to be a result of lower fiber load level. The most important and extensively investigated variable for mechanical performance in dental composites is filler loading. Filler loading can be expressed in weight fraction or volume fraction of which the latter is the most relevant one with respect to mechanical properties. Previous studies found a positive correlation between filler loading and flexural performance. Kim et al., reported that the threshold of filler loading for the highest toughness values in composites was 55% by volume. In this study, the SFRC with a lower filler loading (everX Flow) showed better fracture toughness and flexural strength values than other SFRCs which have high volume filler loading (Table 1). In other words, this study demonstrated the absence of a direct relationship between volumetric content of inorganic particles and fracture resistance parameters (fracture toughness and flexural strength). The difference in fracture toughness and flexural properties values among the tested SFRCs may be due to other factors than filler loading. Stress transfer from the polymer matrix to filler particles is one of the important factors affecting fracture
toughness and flexural strength values. There may be differences in the adhesion between filler particles and matrix among these resin composites. Besides the filler system, monomer structures of the resin matrix also influence the mechanical properties. According to Chen and his colleagues, the impregnation of the hydroxyapatite nanofibers into dimethacrylate dental resins may lead to two-sided effects, reinforcement due to a uniform distribution of hydroxyapatite nanofibers, but undermining if the nanofibers accumulate during processing to form bundles[36]. Vidotti and others showed that as the hydroxyapatite nanoparticle mass fraction increased a small portion of the hydroxyapatite nanofibers started to form bundles, creating mechanical weak points that led to lower mechanical properties[37]. A weakening effect due to bundling of nanofiber may have occurred in this study as well. A nanofiber bundle in the NovaPro SFRCs is shown in a SEM image (Fig. 3).

Among all tested SFRCs, everX Flow displayed the highest shrinkage stress values (Table 2). The magnitude of polymerization shrinkage stress has been determined to be dependent on the extent of the reaction, volumetric shrinkage, the stiffness of the material and its ability to flow[37,38]. Higher DC% and cross-linking density of everX Flow may result in a high stiffness, which ultimately causes high shrinkage stress. Ferracane and Hilton stated in their review article that most of the potential clinical manifestations (microleakage and cusps deflection) of shrinkage stress can be negated by the presence of excellent adhesion to the tooth structure, thus providing a resistant seal[39]. Hence, further in vitro studies should be evaluated the microleakage and cusps deflection of these SFRCs.

The wear of composite is a complex process involving fatigue, as well as erosive, adhesive, and abrasive components[40]. The two-body wear test has been developed to simulate in vivo wear and many authors have used, though a high variation in the results have been seen even with the same material and testing technique[41]. In our study, the lowest wear depth values were found for everX Flow (20.4 µm, Table 2). Thus, microfiber filler loading were not worsening the wear of the SFRC. It should be taken into account that micro and millimeter scales SFRCs (except for Alert) are instructed to be used as bulk base or core foundation and should not be used as final fillings. They require an additional surface layer of conventional hybrid composite for receiving appearance of natural tooth and good polished surface. However, sometimes because of manipulating fault, this procedure is unavoidable in clinical conditions[41,42].

When the composites are exposed to or stored in water, two different mechanisms occur. First there will be uptake of water producing an increased weight (sorption) and leaching or dissolution of components from the material into the mouth (solubility)43. In the present study, NovaPro Flow after 37 days showed water uptake percentage of 0.86 wt%, which was the highest among all tested SFRCs (Fig. 1). This can be attributed to the the lower filler content of NovaPro Flow. This findings are in agreement with a study by Ilie and Hickel, which showed that although the incorporation of nanofillers in the resin matrix improved the esthetics to some extent, the larger surface area to volume ratio of the fillers in the nanofilled materials tended to increase the water uptake44. The amount of the absorbed water is also affected by hydrophilicity of the polymer matrix and by the chemical stability of the filler particles in an aqueous solution45.

**CONCLUSION**

Within the limits of this in vitro study, it can be concluded that commercial SFRCs have different properties, which should be taken into account when optimum reinforcing results are to be achieved. The new SFRC (everX Flow) has superior fracture toughness and good wear resistance but higher polymerization shrinkage stress.

**ACKNOWLEDGMENTS**

This study belongs to the research activity of BioCity Turku Biomaterials Research Program (www.biomaterials.utu.fi) and it was supported by Stick Tech Ltd. —Member of the GC Group.

**CONFLICTS OF INTEREST**

Author SG has received consultancy fees from StickTech/ GC. Author PV consults for Stick Tech —Member of the GC Group in R&D and training. Author LL declares to have no conflict of interest. Author FK declares to have no conflict of interest.

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