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# Flexural properties of fiber reinforced root canal posts

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## KEYWORDS

Dental materials;  
Root canal posts; Fiber reinforced composites;  
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**Summary Objectives.** Fiber-reinforced composite (FRC) root canal posts have been introduced to be used instead of metal alloys and ceramics. The aim of this study was to investigate the flexural properties of different types of FRC posts and compare those values with a novel FRC material for dental applications.

**Methods.** Seventeen different FRC posts of various brands (Snowpost, Carbopost, Parapost, C-post, Glassix, Carbonite) and diameters, (1.0-2.1 mm) and a continuous unidirectional E-glass FRC polymerized by light activation to a cylindrical form (everStick, diameter 1.5 mm) as a control material were tested. The posts ( $n = 5$ ) were stored at room's humidity or thermocycled ( $12.000 \times$ ,  $5^\circ\text{C}/55^\circ\text{C}$ ) and stored in water for 2 weeks before testing. A three-point bending test (span = 10 mm) was used to measure the flexural strength and modulus of FRC post specimens.

**Results.** Analysis of ANOVA revealed that thermocycling, brand of material and diameter of specimen had a significant effect ( $p < 0.001$ ) on the fracture load and flexural strength. The highest flexural strength was obtained with the control material (everStick,  $1144.9 \pm 99.9$  MPa). There was a linear relationship between fracture load and diameter of posts for both glass fiber and carbon fiber posts. Thermocycling decreased the flexural modulus of the tested specimens by approximately 10%. Strength and fracture load decreased approximately 18% as a result of thermocycling.

**Significance.** Considerable variation can be found in the calculated strength values of the studied post brands. Commercial prefabricated FRC posts showed lower flexural properties than an individually polymerised FRC material.

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## Introduction

Crown restoration of an endodontically treated tooth often requires additional support from the root canal by means of a root canal preparation

and the fabrication of a post and core restoration. Recent reports suggest that the rigidity of the post should be equal or close to that of the root of the tooth to distribute the occlusal forces evenly along the length of the root.<sup>1,2</sup> Prefabricated and cast metal posts are traditionally used. They are, as well as the novel all-ceramic posts, rigid in nature.<sup>3</sup> The rigidity may pose a risk for

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root fracture.<sup>4</sup> Recently, fiber-reinforced composite (FRC) root canal posts have been introduced as an alternative to more conventional materials. The biomechanical properties of FRC posts have been reported to be close to those of dentin.<sup>5</sup> Teeth restored with e.g. carbon/graphite fiber posts are found to resist fracture propagation better than teeth restored with prefabricated titanium posts or cast metal posts.<sup>6</sup> Ongoing clinical trials are also suggesting good results. No post-associated failures during 3 years of follow-up were reported in a study where 236 endodontically treated teeth were restored using carbon/graphite fiber posts.<sup>7</sup> The failure rate using prefabricated metal posts was reported to be 8%.<sup>8</sup>

FRC posts contain a high volume percentage of continuous reinforcing fibers embedded in a polymer matrix, which keeps the fibers together. Matrix polymers are commonly epoxy polymers with high a degree of conversion and a highly cross-linked structure. The first FRC-posts were made of carbon/graphite fibers due to their good mechanical properties. However, they are black in color and thus lack cosmetic qualities. Instead posts made of glass or silica fibers are white or translucent and can be used in situations of higher cosmetic demand. Many studies concerning the mechanical properties of FRC root canal posts have been done. Although the flexural strength of FRC posts has been shown to be relatively high, large variations in the reported flexural modulus of carbon/graphite fiber posts can be found.<sup>4,9,10</sup> The flexural properties are found to decrease after moisture adsorption.<sup>4</sup>

Glass fibers have a lower elastic modulus than carbon/graphite fibers. Glass fiber posts can be made of different types of glasses. Electrical glass (E-glass) is the most commonly used glass type in which the amorphous phase is a mixture of SiO<sub>2</sub>, CaO, B<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub> and some other oxides of alkali metals. S-glass (high-strength glass) is also amorphous but differs in composition. Additionally, glass fiber posts can also be made of quartz-fibers. Quartz is pure silica in crystallized form. It is an inert material with a low coefficient of thermal expansion (CTE).<sup>11</sup>

The stability of fiber/polymer matrix interface and the effect of possible mismatch of CTEs between fibers and matrix polymers must be considered when the clinical longevity of FRC posts is evaluated. To our knowledge, there remains a lack of studies concerning the stability of FRC posts after thermal cycling. The aim of this study was to investigate the flexural properties and fracture load values of different types of

FRC posts and compare those values with a novel high strength FRC material for dental applications. Furthermore, the influence of thermal cycling in water on the flexural properties was determined.

## Materials and methods

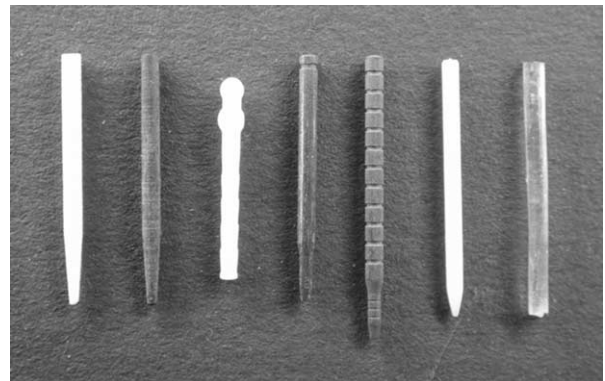
Seventeen different FRC posts of various brands and diameters, and continuous unidirectional glass fiber composite shaped into the form of a post, were tested (Fig. 1). The materials are listed in Table 1. Five posts of each type were tested as dry (stored in room humidity) and five after thermocycling in water (12.000 ×, 5 °C/55 °C, dwelling time of 30 s). Subsequent to thermocycling the posts were stored in water for 2 weeks before mechanical testing.

The three-point bending test according to the ISO 10477 standard (span 10.0 mm, crosshead speed 1.0 mm/min, cross-sectional diameter of loading tip 2 mm) was used to measure the flexural strength and modulus of FRC post specimens. All posts were tested with a material testing machine (model LRX, Lloyd Instruments, Fareham, England) at room temperature (22 ± 1)°C and the load-deflection curves were recorded with PC-software (Nexygen, Lloyd Instruments Ltd, Fareham, England).

Fracture load of post specimens was measured. Flexural strength ( $\delta_f$ ) and flexural modulus ( $E_f$ ) were calculated from the formula:<sup>4</sup>

$$\delta_f = 8F_{\max}l/\pi d^3 \quad (1)$$

$$E_f = 84l^3/(3\pi d^4) \quad (2)$$



**Figure 1** Examples of the studied FRC posts and the control material everStick excluding the post brand Carbonite. From the left: Snowpost, Carbopost, ParaPost FiberWhite, C-Post, C-Post serrated, Glassix and everStick.

**Table 1** The fiber reinforced composite specimens used in this study.

Group	Brand	Fiber type/arrangement	Manufacturer	Diameter (mm)
1	Snowpost (yellow)	Unidirectional Silica-zirconium fiber (60 vol%)	Carbotech, Ganges, France	1.2
2	Snowpost (red)	Unidirectional Silica-zirconium fiber (60 vol%)	Carbotech, Ganges, France	1.4
3	Snowpost (blue)	Unidirectional Silica-zirconium fiber (60 vol%)	Carbotech, Ganges, France	1.6
4	Carbopost 10	Unidirectional carbon fiber (60 vol%)	Carbotech, Ganges, France	1.0
5	Carbopost 12	Unidirectional carbon fiber (60 vol%)	Carbotech, Ganges, France	1.2
6	Carbopost 14	Unidirectional carbon fiber (60 vol%)	Carbotech, Ganges, France	1.4
7	Carbopost 16	Unidirectional carbon fiber (60 vol%)	Carbotech, Ganges, France	1.6
8	ParaPost® FiberWhite	Unidirectional Glass fiber (42% wt%)	Coltène/Whaledent Inc., Mahwah, NY, USA	1.2
9	ParaPost® FiberWhite	Unidirectional Glass fiber (42% wt%)	Coltène/Whaledent Inc., Mahwah, NY, USA	1.35
10	ParaPost® FiberWhite	Unidirectional Glass fiber (42% wt%)	Coltène/Whaledent inc. Mahwah, NY, USA	1.5
11	C-post™	Unidirectional carbon fiber (64 vol%)	Bisco, Inc, IL, USA	1.4
12	C-post™	Unidirectional carbon fiber (64 vol%)	Bisco, Inc, IL, USA	1.8
13	C-post™	Unidirectional carbon fiber (64 vol%)	Bisco, Inc, IL, USA	2.1
14	C-post™ Serrated	Unidirectional carbon fiber (64 vol%)	Bisco, Inc, IL, USA	1.8
15	C-post™ Serrated	Unidirectional carbon fiber (64 vol%)	Bisco, Inc, IL, USA	2.1
16	Glassix	Glass fibre braided plait	Harald Nordin sa Montreux, Switzerland	1.35
17	Carbonite	Carbon fibre braided plait	Harald Nordin sa Montreux, Switzerland	1.35
18	EverStick-post	Unidirectional E-glass (60 vol%)	StickTech, Turku, Finland	1.55

where  $F_{max}$  is the applied load (N) at the highest point of load-deflection curve,  $l$  is the span length (10.0 mm),  $d$  is the diameter of the specimens.  $S = F/D$ , the stiffness (N/m) and  $D$  is the deflection corresponding to load  $F$  at a point in the straight-line portion of the trace. In order to eliminate the influence of the conical end of some of the posts, a short span length was used to get support for the post within the cylindrical part of the post. The parallel-sided cylindrical part of the post was considered to be the specimen.

As a control material for FRC posts, a novel continuous unidirectional glass fibre composite (everStick) was tested under the same testing conditions. The everStick fiber material containing silanized E-glass fibers in light-polymerizable dimethacrylate-polymethylmethacrylate matrix was made into a cylindrical shaped specimen with a diameter of 1.55 mm. The specimens were polymerized in a light curing oven (LicuLite, Dentsply DeTrey GmbH, Dreieich, Germany) for 40 min.

In addition 2 posts of each group were embedded in PMMA and wet-ground with 4000 (FEPA). After that, specimens were sputtered (SCD 050, BAL-TEC AG, Balzers, Liechtenstein) with gold and transverse sections of posts were visually examined with a SEM (JSM-5500, JEOL Ltd, Tokyo, Japan) to determine the differences in posts.

Flexural properties were analysed with three way ANOVA (SPSS, SPSS Inc., Ill, USA) to evaluate the effect of thermocycling, brand of material and

diameter of specimen. To determine statistically significant differences the Tukey post hoc test was used.

## Results

The flexural strength, flexural modulus and maximum fracture load of tested specimens are presented in Figs. 2-4. The analysis of ANOVA revealed that thermocycling, brand of material and diameter of specimen had a significant effect ( $P < 0.001$ ) on the fracture load and flexural strength. The highest flexural strength was obtained with the control material everStick (Fig. 2). In general, thermocycling decreased the flexural modulus of the tested specimens by approximately 10% (Fig. 3). Strength and fracture load decreased by approximately 18% as a result of thermocycling (Figs. 2 and 4). However, the brand SnowPost showed a higher decrease (approx. 40%) in mechanical properties after thermocycling, than the other brands tested (Figs. 2-5). The average reduction percentage in fracture load after thermocycling of the tested post specimens is presented in Fig. 5. The fracture load values correlated to the diameters of the posts (Fig. 6). Visual analysis of SEM-micrographs revealed that a certain amount of porosity exists in all FRC-posts, but porosity in the Snowpost (Fig. 7a) was easily recognized whereas everStick (Fig. 7b) had a tight solid matrix without porosity.

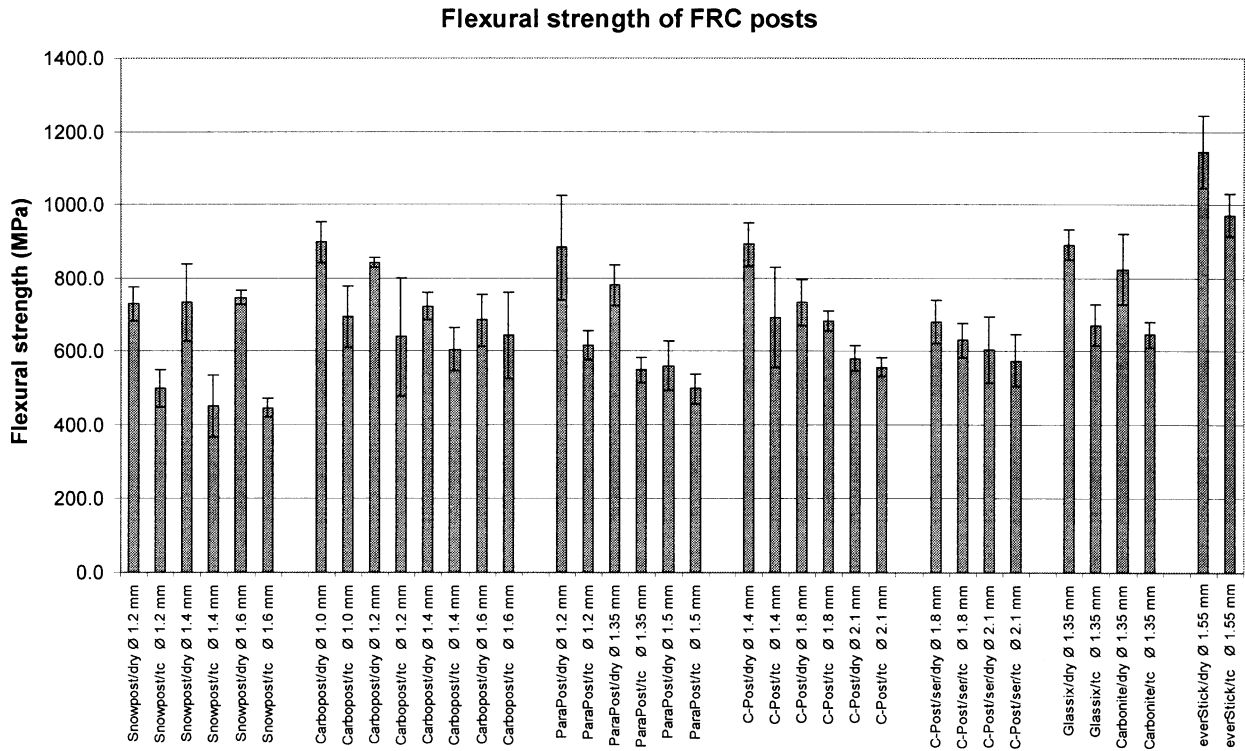


Figure 2 Flexural strength of the studied FRC post specimens. The bars represent the mean value in MPa (SD) of five specimens.

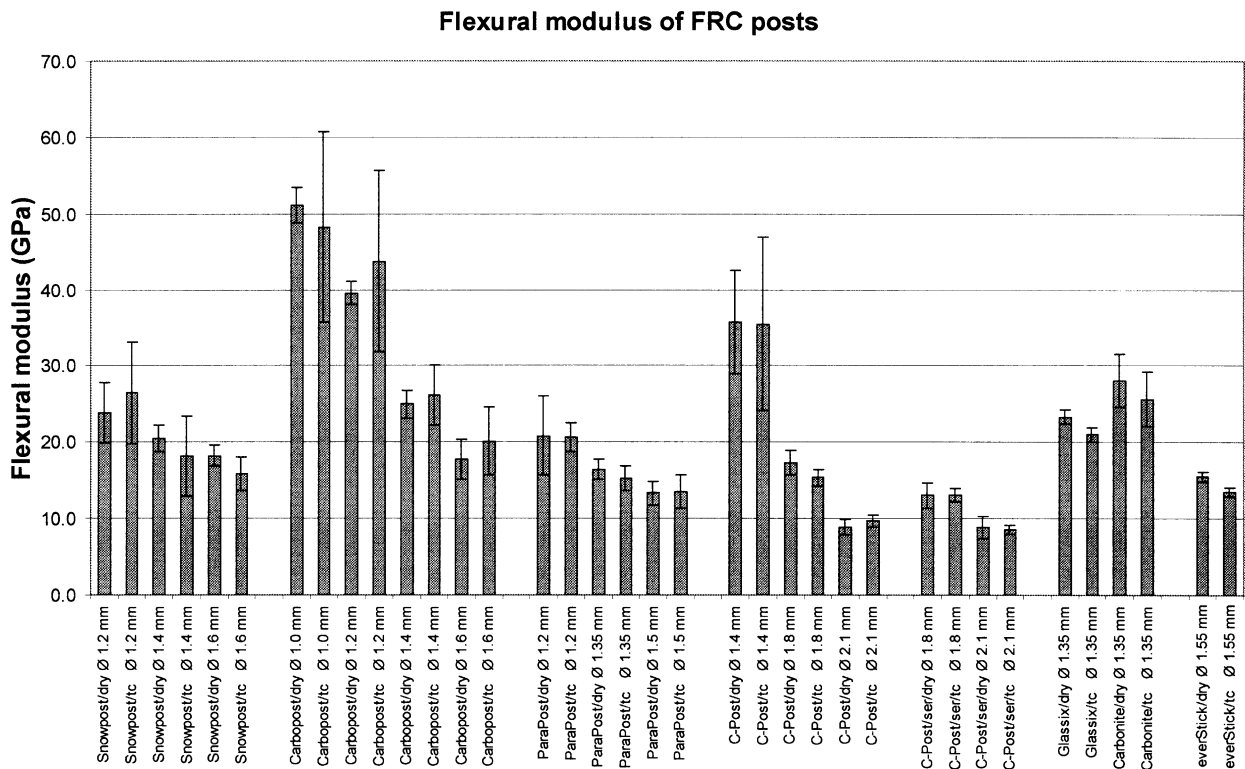


Figure 3 Flexural modulus of the studied FRC post specimens. The bars represent the mean value in GPa (SD) of five specimens.

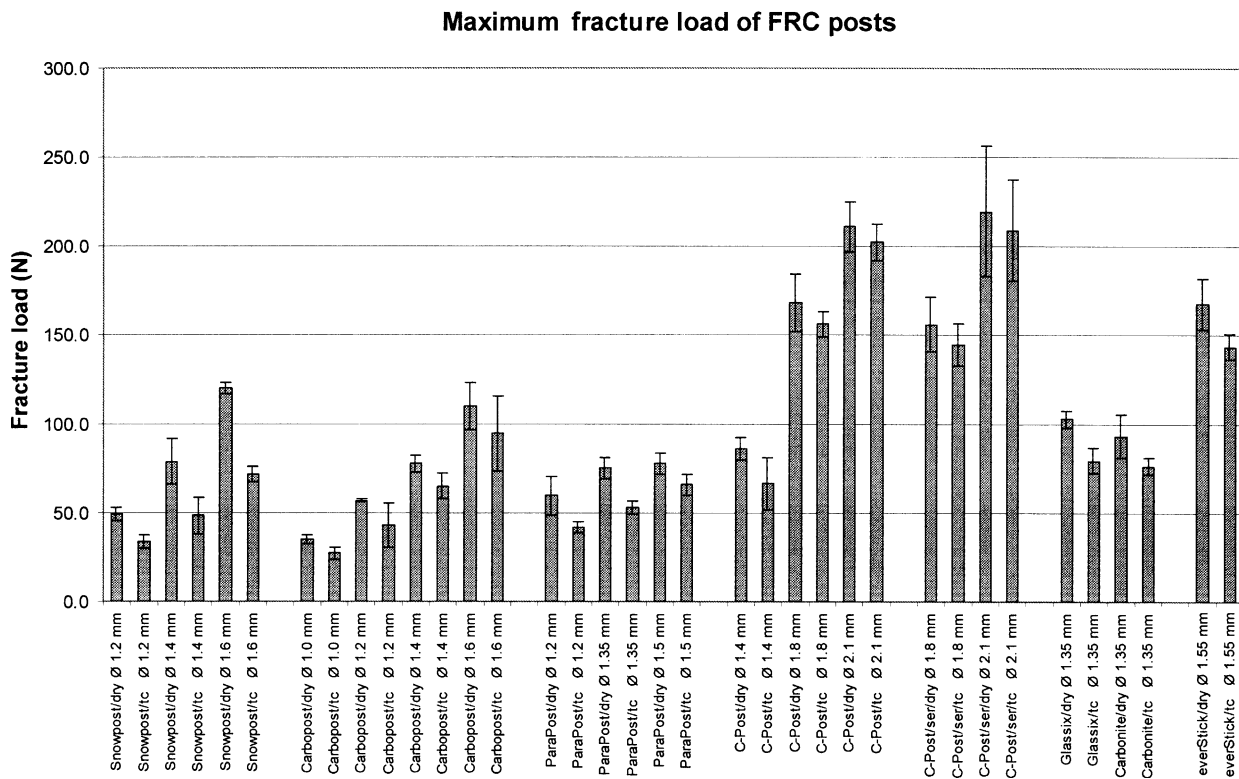


Figure 4 Maximum fracture load of the studied FRC post specimens. The bars represent the mean value in N (SD) of five specimens.

**Discussion**

Many studies concerning the mechanical properties of FRC posts have recently been published. <sup>4,9-10,12,13</sup> Lack of standardization of the testing conditions and methods has resulted in large variations in the mechanical properties reported.

In the present study, thick posts showed lower flexural strength values (MPa) than thin posts although the fracture load values (N) behaved oppositely (Figs. 2 and 4). The results show that when a three-point bending test is used to measure flexural properties of FRC-posts, the results are related to the ratio of span length and diameter

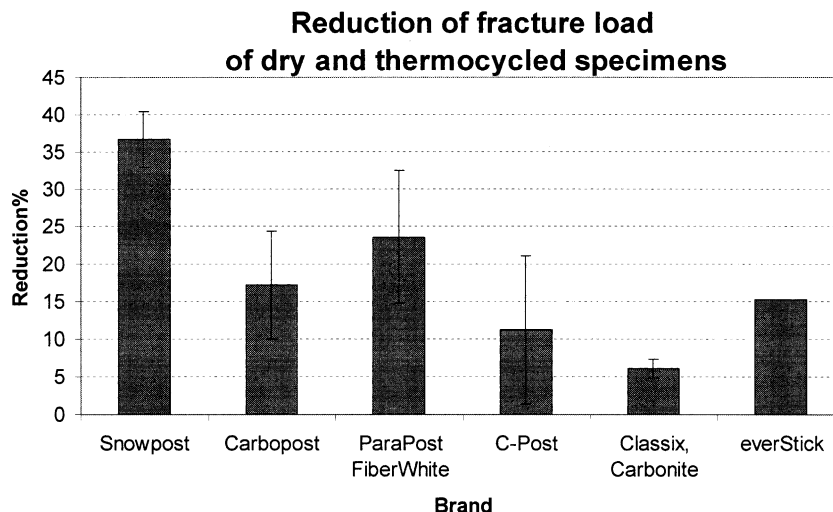
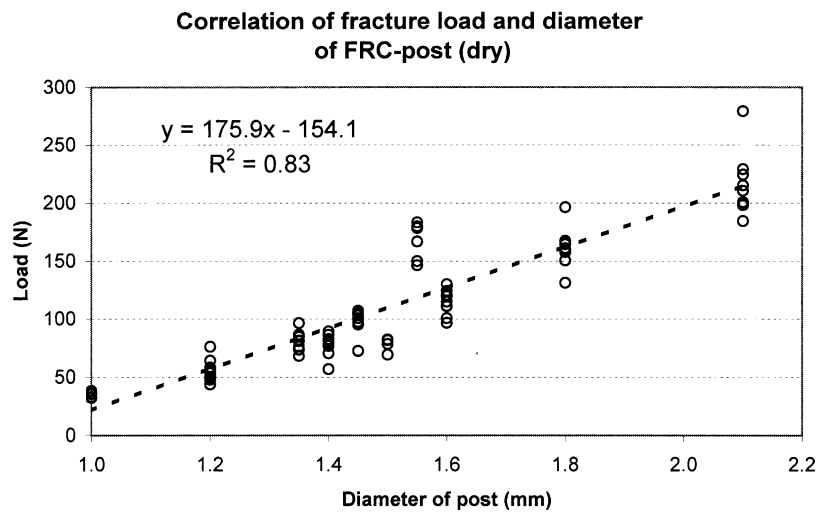


Figure 5 Reduction in fracture load of FRC post specimens after thermocycling. The bars represent the mean reduction percentage (SD) of each post brand tested.





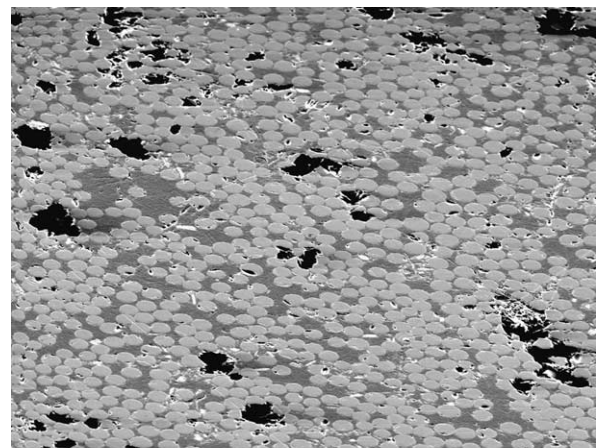
**Figure 6** Linear regression curve of the effect of post diameter on fracture load of FRC post specimens (dry storage).

( $L/D$ -ratio) of the test set-up. Although this phenomenon has been described in several papers,<sup>14,15</sup> it has not been interpreted by the researchers. Recommendation for high strength engineering composites, especially for anisotropic FRCs is that a high  $L/D$ -ratio (40:1 or 60:1) should be used in order to eliminate shear effect during bending test and to produce a failure to the outer surface of the specimen.<sup>15-17</sup> A lower  $L/D$ -ratio produces more shear deformation in the FRC specimen.<sup>18</sup> Engineering material standard of ASTM D 2344 for short beam test uses  $L/D$  ratio of 4 to determine the interlaminar shear strength of a material.  $L/D$  ratios of the specimens used in this study varied from 4.7 to 8.3, suggesting that the ratios remain at a lower level than recommended by standards.

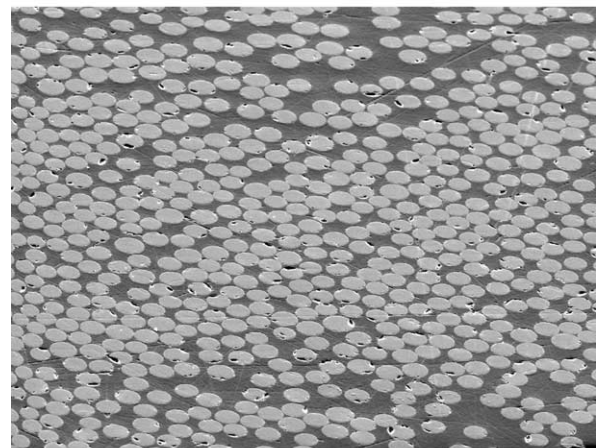
As seen in Fig. 6, all FRC post specimens showed a linearly increasing resistance against loading force along with an increase in diameter. Both carbon/graphite and glass fiber reinforced posts behaved similarly. However, if interfacial bonding between fiber and matrix is not adequate, no better mechanical properties are acquired.

From a clinical perspective this suggests that thick posts contribute more favourably to the fracture resistance of the root-post-core-crown system than thin posts, presuming that excess preparation and subsequent weakening of the remaining root dentin is at the same time avoided.

Differences in the mechanical stability after thermocycling were found between the post specimens tested. Snowpost specimens showed approximately 40% reduction in flexural strength after thermocycling, whereas flexural strength of the other post brands tested and the control material



(a)



(b)

**Figure 7** (a, b) SEM-micrographs taken from transversal section of FRC-root canal post representing (a). Snowpost (blue) and (b) everStick. Original magnification  $300\times$ .

everStick decreased by approximately 18% as a result of thermocycling. On the other hand, a study by Torbjörner et al. reported a 65% decrease in the mechanical properties of the carbon/graphite fiber post Compositest<sup>®</sup> after thermocycling.<sup>4</sup> However they compared posts with different diameters with each other and the results are thus affected by the influence of the *L/D* ratio.

When specimens are exposed to thermocycling the differences between coefficients of thermal expansion (CTE) of the individual materials may affect the long term stability of the FRC-post-tooth combination. Large variations in CTE exist between reinforcing fibers and the matrix polymer used in FRC posts (polymer matrix:  $40\text{--}80 \times 10^{-6}/^{\circ}\text{C}$ , E-glass:  $8 \times 10^{-6}/^{\circ}\text{C}$ , quartz:  $0.2 \times 10^{-6}/^{\circ}\text{C}$ , carbon/graphite-fiber:  $0.4 \times 10^{-6}/^{\circ}\text{C}$ ).<sup>11</sup> It should be emphasized that the thermomechanical behavior of anisotropic/orthotropic/isotropic dental FRCs is not fully understood at the moment. The reduction in flexural properties of SnowPost specimens after thermocycling could be related to the discrepancy in the CTE between the materials of SnowPost composite. The difference in CTE between silica-zirconium fibers and the polymer matrix is bigger than that of E-glass, S-glass and carbon/graphite fibers and matrix polymer. Also the porosity, which is seen in the SEM-micrographs of SnowPost might be one explanation for the reduction of mechanical properties after thermocycling.

The present study has to be considered as a short-term water exposure study. Our results are in accordance with several other studies showing that a decrease in mechanical properties is taking place during 30 days of water storage and is caused by plasticization of the polymer matrix by water.<sup>19–21</sup> In long-term water exposures, hydrolyzation of the silane coupling agent which is used to promote adhesion between the fibers and the polymer matrix, might play a major role.<sup>22–24</sup>

Interestingly, it was found that the control material everStick, E-glass FRC polymerized by light activation to a cylindrical form, presented the highest flexural strength values. This unexpected finding could be explained by the optimization of the polymer matrix and fiber properties to function as a composite material. More precisely, the difference in the polymer matrix of everStick compared to the matrices of other tested FRCs is based on the existence of PMMA chains in the cross-linked polymer matrix. PMMA chains with a molecular weight of 220 KD plasticize the cross-linked bisGMA based matrix of the everStick FRC, and thus reduce stress formation in the fiber-matrix interface during deflection. This may be assumed to

contribute to the higher strength of everStick FRC material.<sup>25</sup>

Clinically, it is well established that the longevity of root-post-core-crown systems used to restore an endodontically treated tooth is affected by many factors e.g. the design, length and thickness of the post, the ferrule effect, cementation and the quantity of remaining tooth substance.<sup>26,27</sup> Many *in vitro* studies<sup>5,28</sup> have shown that FRC-posts might possess some benefits over metal posts due to their modulus of elasticity being closer to that of dentin. This phenomenon of 'modulus compensation of stress induced root fractures' could have an impact on the post-core-crown restorations in the future. However, it should be noted that the modulus of the material is only one parameter influencing stress formation. Among others, the diameter of the post, as demonstrated by the present study, should be taken into account.

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