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Carbon fiber post adhesion to resin luting cement in the restoration of endodontically treated teeth

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Carbon fiber posts (CFP) are widely used in the restoration of endodontically treated teeth to enhance the mechanical behavior in spite of metallic posts and to prevent vertical fractures of the tooth under chewing loads. The post is cemented inside the canal lumen using polymer resins with Young's modulus lower than dentine. In this conditions the stress concentration is located at the post-cement interface and in the cement bulk itself, preserving radicular dentine from dangerous stress accumulation. The mechanical resistance of CFP posts cemented in human dentine was evaluated by the means of mechanical pull-out tests assisted by the finite element analysis. The average bond strength and the critical stress values of the CHP-cement interface were 25 MPa and 50 MPa respectively.

Introduction

The restoration of teeth is mainly achieved with post and core when the loss of tooth structure is significant. The post is cemented in the root canal and the core is retained by an apical extension which supports the cast restoration replacing the coronal portion of the tooth [1, 2]. The post and core restoration will continue to increase because of the current trend to retain natural teeth structure into the mature years of life [3].

Carbon fiber posts (CFP) were introduced in dentistry to enhance the biomechanical behavior of endodontically treated teeth by the means of root canal posts [4].

CFP are made of stretched aligned carbon fibers embedded in an epoxy-resin matrix [5, 6]. Follow up of clinical service after three years indicate that this device is a viable alternative to traditional cast metal dowel/core or metal prefabricated posts [1].

The cast (gold alloy) post and core present a higher fracture strength than carbon post and core, however failure of teeth restored with cast posts is characterized by root fracture [7–10]. Even after fatigue testing the adaption of CFP and core to dentine behaves satisfactorily when compared to metallic posts but with a lower fatigue strength [11, 12].

While metallic posts are prone to fatigue failure and corrosion, CFP designs meet the requirements of mechanical strength, retention and corrosion [5, 8–13]. There is a wide literature evidence on the mechanical properties of CFP and several data on adhesive rate retention of cemented CFP in root canals. However, few informations are available on the interface between CFP surface and the resin luting cement and the direct measurement of the bond strength between CFP and cement has never been carried out.

Posts cemented with dentine bonding resin cements suggest less microleakage than non-dentine bonding cements (zinc phosphate and glass ionomer) [14].

In this work the mechanical stability of the post-cement interface and mechanical stresses distribution in the cement layer was analyzed using *in vitro* mechanical pull-out tests of CFP cemented in human tooth specimens assisted by the finite element analysis (FEM).

Materials and methods

A FEM model of a human middle coronal dentine disk substrate was used to simulate a composite post pull-out test. The axialsimmetry conditions led to the development of a bidimensional model using Ansys 5.3 (Swanson Corp.) The ''refine'' technique was used to minimize the percentual energetic error of the model mesh in the layers of primary interest (the interfaces between post and cement and between cement and dentine substrate respectively).

FEM analysis defined the mechanical test set-up and constraints of the experimental system (Fig. 1).

Twenty selected sound middle coronal dentine slices were drilled (diameter $D = 2.4$ mm) and CFP (Composipost RTD, France) (diameter $d = 2.0$ mm) were cemented (C&B Cement, Bisco, USA) in the dentine slices according to the manufacturers' instructions. Coupled teflon molds were used to keep each CFP in axis with the dentine hole while cement hardening, leading to a uniform cement mantle thickness

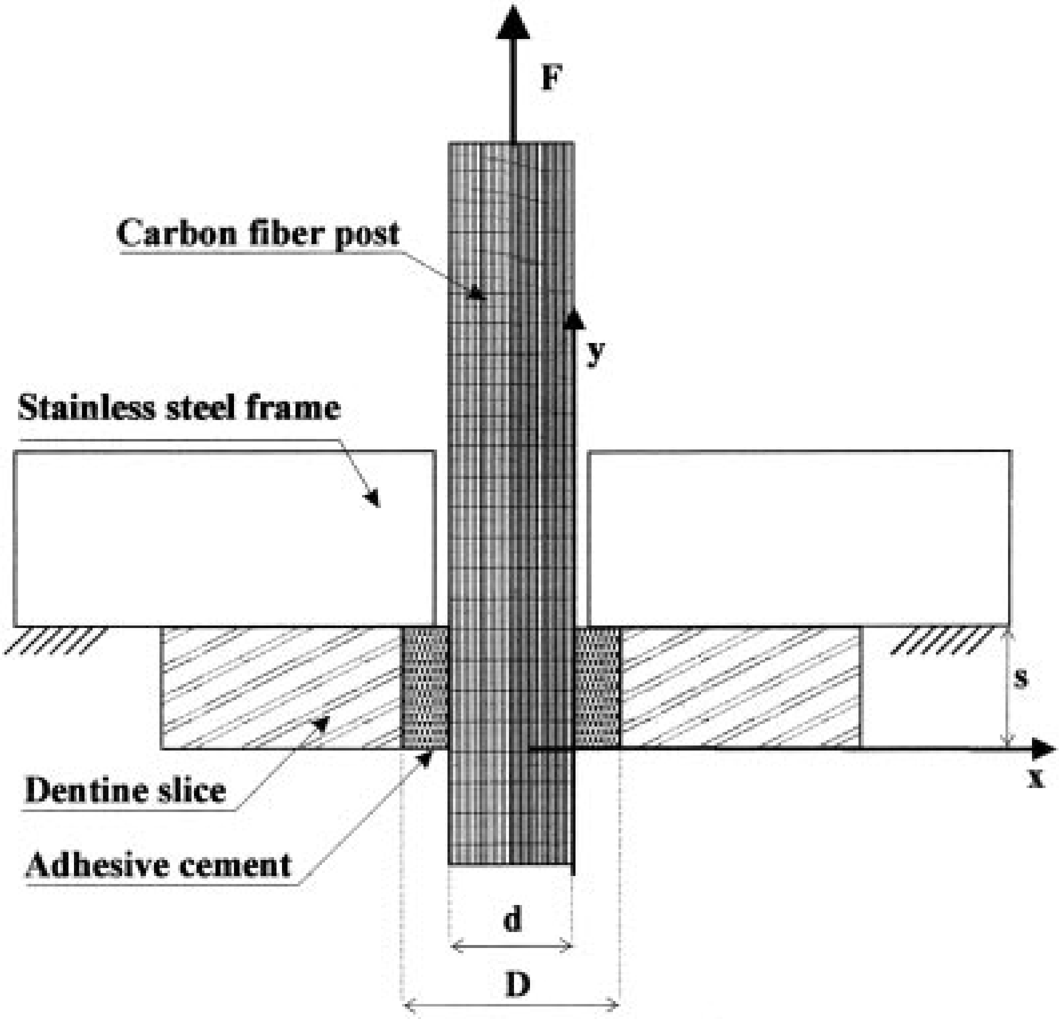

Figure 1 Mechanical pull-out test set-up.

($t_h = 0.2\,\text{mm}$). The FEM designed stainless steel frame constraints the test on an Instron 4204 and the pulling load was monothonically increased at a cross-head speed of 2.0 mm/min in the carbon fibers direction of the post device.

The average shear strength of the CFP-cement interface was computed by dividing the average maximum load (F) by the bonding area cross section:

$$\tau = \frac{F}{\pi \cdot d \cdot s} \tag{1}$$

where s is the dentine slice thickness ($s = 2\,\text{mm}$).

The FEM analysis of the stress distribution related to the maximum load (F) at the cement interfaces was computed according to relation:

$$\sigma = \sqrt{\frac{1}{2} \cdot \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]} \tag{2}$$

where $\sigma_1 \sigma_2$ and σ_3 are the principal stress components and σ_e is the equivalent stress according to Von Mises criteria [15]. Mechanical material properties used for the modeling of a transversely isotropic assumption are shown in Table I.

Results

The average recorded maximum load was $F = 340\,\text{N}$ (st. dev. $= 78$). The pull-out load against the displacement increases quasi linearly up to F and then drastically drops when the CFP-cement interface fails (Fig. 2). According to Equation 1 the average bond strength is $\tau = 24.69\,\text{MPa}$ (st. dev. $= 7.08$). However FEM analysis showed that when the system is loaded as described in Fig. 1 the stress distribution along the post surface is not uniform reaching its maximum values near the free surface between the cement and the post. FEM results suggest that the stress state is complex along the

TABLE I Mechanical materials properties used for the FEM of a transversely isotropic assumption

	Dentine	Adhesive	CFB
E_x[GPa]	18	7.0	7.24
E_y[GPa]	18	7.0	118
E_z[GPa]	18	7.0	7.24
ν_{xy}	0.29	0.30	0.269
ν_{yz}	0.29	0.30	0.017
ν_{xz}	0.29	0.30	0.340
G_{xy}[GPa]			2.82
G_{yz}[GPa]			2.82
G_{xz}[GPa]			2.70

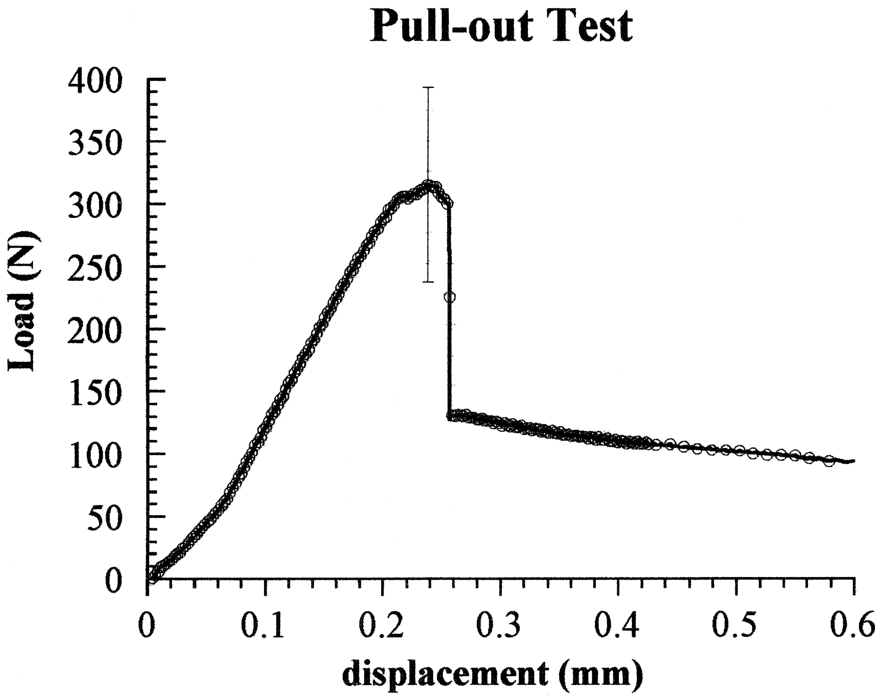

Figure 2 Pulling load against displacement.

cement-CHP interface (Fig. 3). Near the free surface between the cement and the post, all stress component (σ_x, σ_y, σ_z, and τ_{xy}) are important but τ_{xy} is more significant along the same interface if compared to the other stress components. For this reason the von Mises stress was used to control the critic stress value. Fig. 4 compares the equivalent stress distributions at the cement interfaces to the average distribution τ.

Using the actual mean pulling force (F) in the FEM model the critic stress values computed according to Equation 2 was $\sigma_e = 50\,\text{Mpa}$.

Scanning electron microscope observations (SEM) of specimens before and after the test (Figs 5 and 6 respectively) suggest that fracture occurres at the interface between cement and post surface and also partially between carbon fibers and epoxy matrix resin of post.

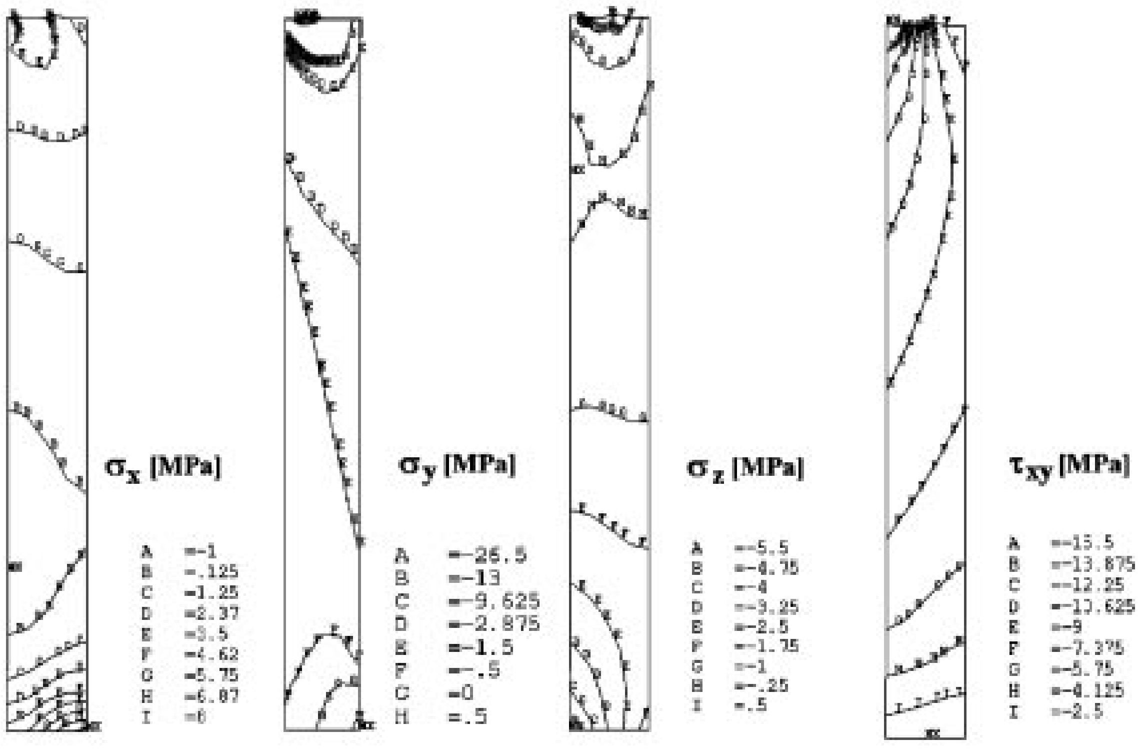

Figure 3 Stress components σ_x, σ_y, σ_z, and τ_{xy} in the cement.

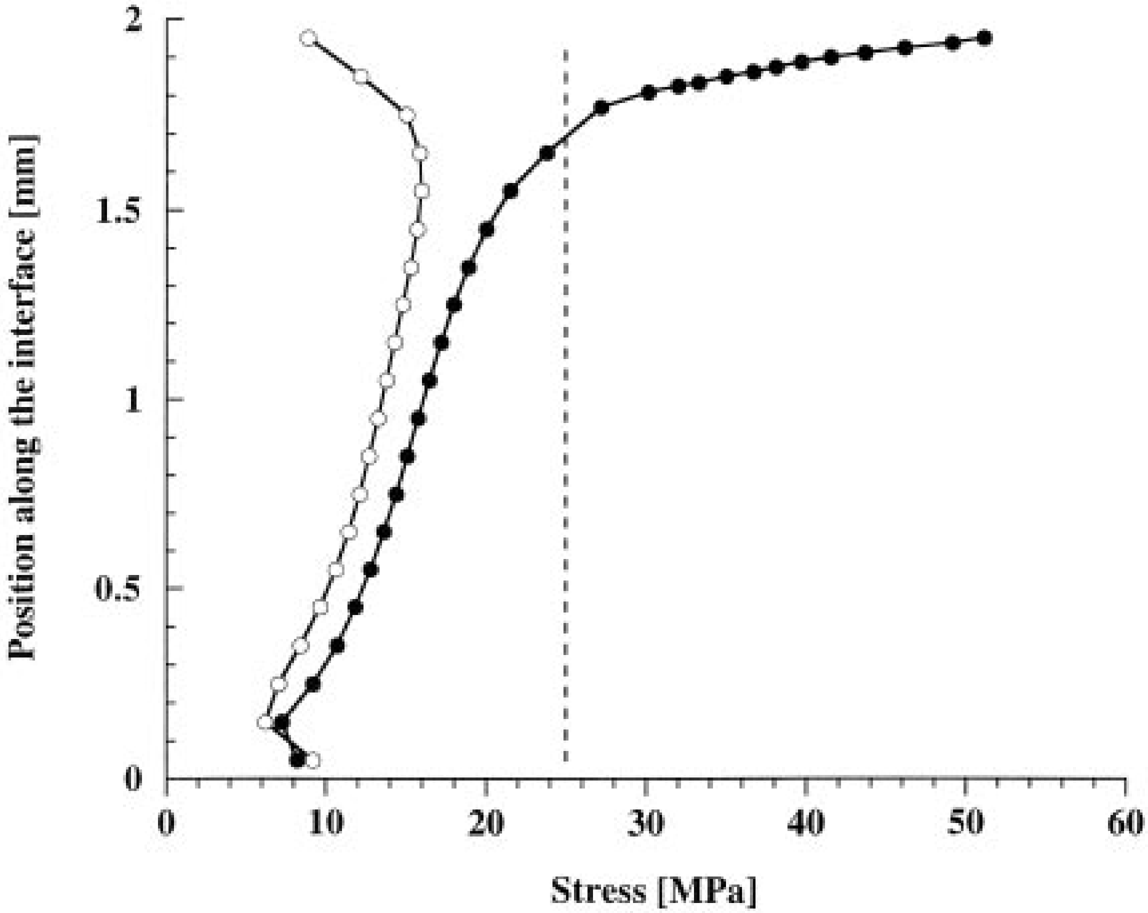

Figure 4 Stress distribution at the cement interfaces: —●— equivalent stress distribution at the CFP-cement interface; —○— equivalent stress distribution at the cement-dentine interface; ----- average shear stress distribution.

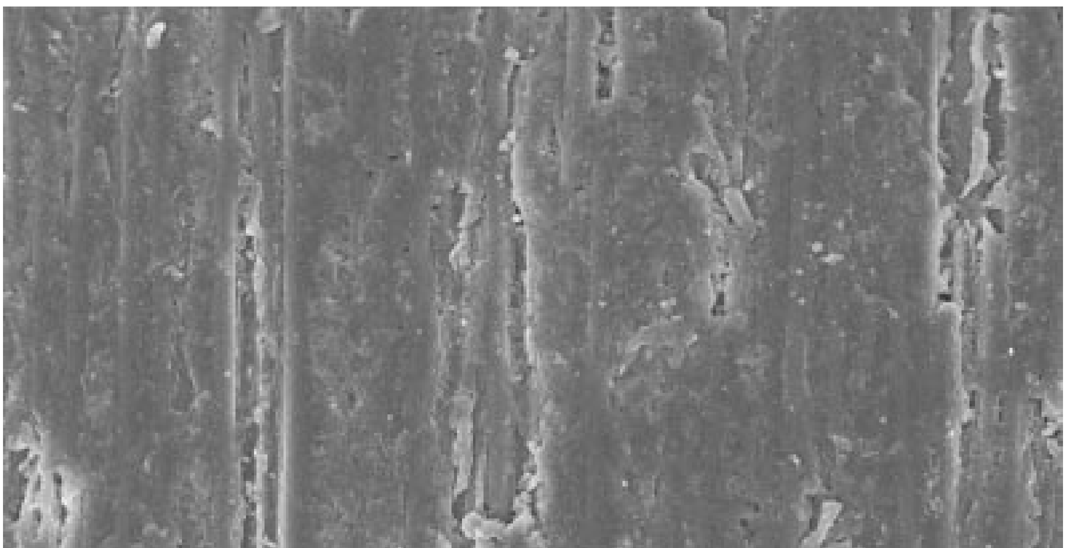

Figure 5 SEM of the CFP surface (×500) before the pull-out test.

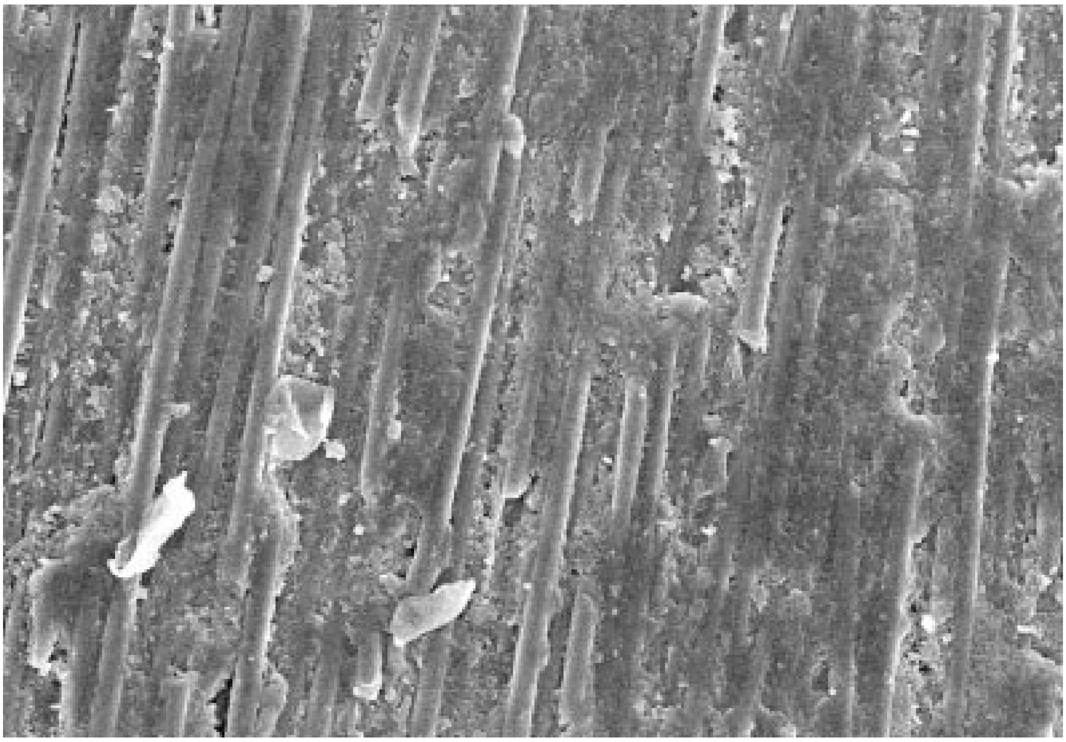

Figure 6 SEM of the CFP surface (×500) after the pull-out test.

Discussions

A post does not equally distribute the load along the root length. The contribution of cylindric posts $(d = 1.0\,\text{mm})$ to fracture resistence of a restored tooth is negligible because the post occupies the canal region which is a neutral area with regard to lateral loadings acting on the coronal portion [16, 17]. Thus the main requirements of the post are strength, retention and passivity. As the post diameter approachs higher dimensions, under cheewing loads, the post acts as a mechanical bypass concetrating the stress at the tip, increasing the fracture risk of the surrounding dentinal walls weikened by the root canal preparation [4–7, 11, 16]. Root fracture of implanted metal posts and cast gold posts are related to the mechanical stiffnesses which are higher than the surrounding tissue and higher than CFP leading to stress concentration at the tip.

According to the pull-out test analysis the stress distribution at the cement interfaces (Fig. 4) approaches the minimum values in the middle of the bonded length (s). The maximum value of the stress at the CFP-cement interface is reached at the upper or lower leading edge of the bonded length if the applyed stresses pull-out or push-out the cemented post respectively. FEM of cemented hip prostheses show a similar stress distribution in the stem-cement interface [18–20]. Bone cement or other interlayers act as mechanical buffers, withstanding the mechanical stresses due to the mismatch between metal and bone properties [18]. Composite hip prostheses (which are mainly carbon fibers reinforced polymer) were designed in order to uniformly distribute the load-transfer stresses at the cement interfaces and preserve bone from stress-shielding effects [21].

Conclusions

The authors conclude that the FEM assisted pulling test asseses correct informations about the actual bond strength values between carbon fiber post and resin luting cement. The loading condition in this apparatus are comparable to clinical situations underlining that the debonding of this interface is driven into the luting cement due to the difference between the relative rigidity of the cement and the post which is higher than that between cement and dentinal substrate. The high stress deviation $(\sigma_e = 50\,\text{MPa})$ from the average value $(\tau = 25\,\text{MPa})$ suggest that the load transfer pattern and retention properties may be improved through a CFP design.

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