Biomechanical Behaviour of Fiber Reinforced Composite Dental Bridges

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The major interest of practitioners for FRC dental restorations derives from the biological traits of this technique. The study concerned the biomechanical behaviour of polyethylene fiber reinforced composites. The experimental determination of the maximum pressure force that can be supported by a FRC fixed prosthetic restoration has also been targeted (Construct - Premise Indirect). For this purpose two samples have been used, each been made of a FRC restoration resin bonded to two lateral teeth which are fixed in a plaster block. The 2 samples differ by the fiber width and by the thickness of the veneer composite. The 2 samples have been tested with static short duration loads on a testing machine. It has been observed that both samples had a perfect elastic behaviour for force under 280N (sample 1) and 360N (sample 2). The maximum flexural stresses as a result of the load are 102.77MPa for the first pontic and 92.5MPa for the second one. The persistence of the fiber allows maintaining the bridge under certain conditions and for a certain period of time. If the stress increases the restoration is destructed (the force has to be almost doubled before the important displacement could lead to the fracture of the bridge). In a clinical situation this reversible and cost effective procedure, which is minimally invasive, aesthetically and biologically desirable offers a viable alternative to conventional replacement of lost teeth.

Keywords: FRC, polyethylene fiber, prosthetic restoration

In the past years in the field of dental prosthetics the focus has been on prosthodontics restorations that allow maximum saving of the dental tissue. At the same time adequate mechanical properties that meet the biological criteria as well as the therapeutic restorative criteria have to be ensured. The fiber reinforced composites (FRC) represent a material category with a wide clinical usability [3-7].

Typically, conventional and cantilever bridges require shaping of the teeth surrounding a missing tooth. Crowns are then placed on the shaped teeth and attached to an artificial tooth.

A resin-bonded bridge requires less or no preparation of adjacent teeth, making this procedure truly minimally invasive and keeping the technique reversible. It is often used to replace front teeth, provided that the gums are healthy and the surrounding teeth do not have extensive dental fillings (fig. 1, 2, 3).

Besides numerous in-vivo and in-vitro studies concerning the marginal adaptation and endurance, some experimental research has to be performed in order to determine the mechanical and physical characteristics [8-10].

The scientific literature mentioned recently quite scarce information referring to the mechanical properties of fixed restorations of FRC: flexural strength, elasticity modulus, elasticity strength etc. [11].

The study presented in this paper concerned the biomechanical behaviour of polyethylene fiber reinforced composites. It focused on (1) the determination of the deformation at bridge level, (2) the determination of maximum admissible load (3) the determination of maximum stress at the pontic of the bridges, (4) the determination of shear stress between the composite and fiber, (5) localizing the fracture area, (6) identifying the role of the fiber and (7) possible effects on the abutment teeth.

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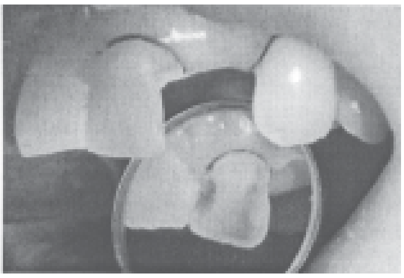

Fig. 1. The minimal preparation of mesial abutment that presented extensive proximal decays

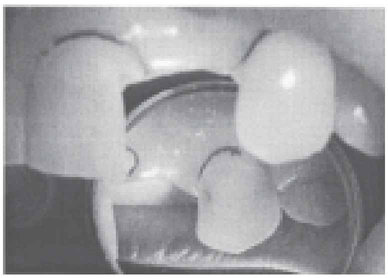

Fig. 2. The minimal preparation of distal abutment that presented small proximal decay

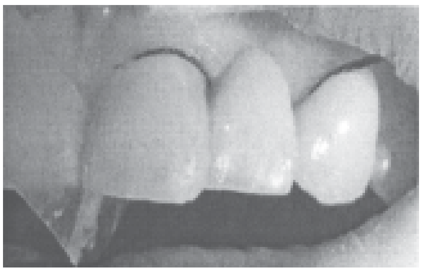

Fig. 3. Final aspect of the restoration

Experimental part

The experimental determination of the maximum pressure force that can be supported by a FRC fixed prosthetic restoration has also been targeted (Construct - Premise Indirect). The Construct system contains braided polyethylene fibers that are gaseous plasma cured and also presilanised with non-filled resin. For this purpose two

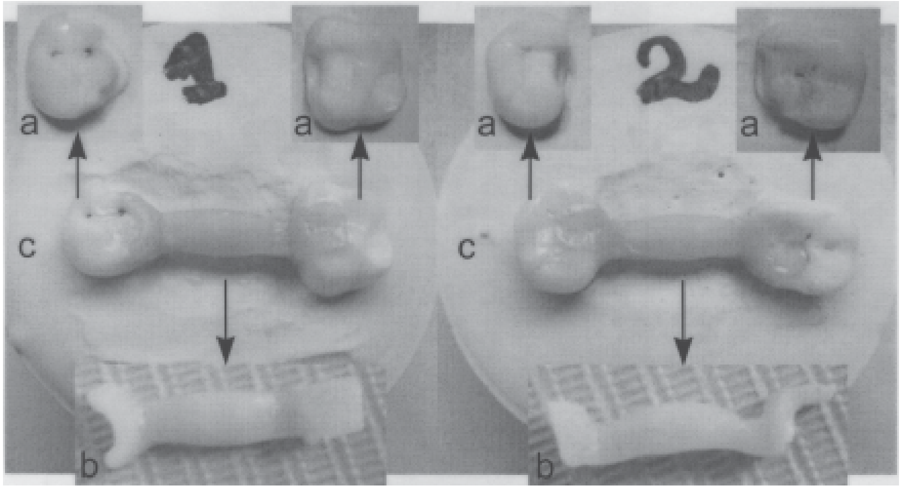

Fig. 4. The investigated samples: a - the dental preparations, b - the FRC fixed restorations, c - final samples having the fixed bridges bonded with dual-cure resin

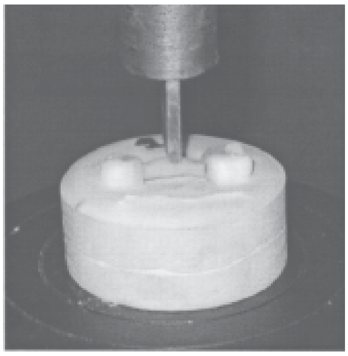

Fig. 5. Sample test

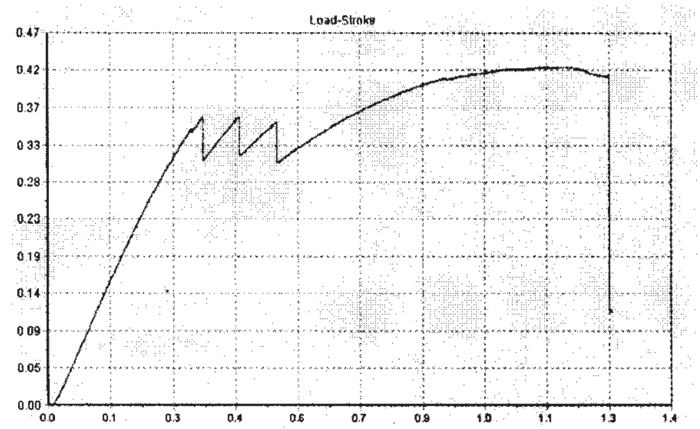

Fig. 6. Variation diagram of the pressure force as a function of displacement (sample 2)

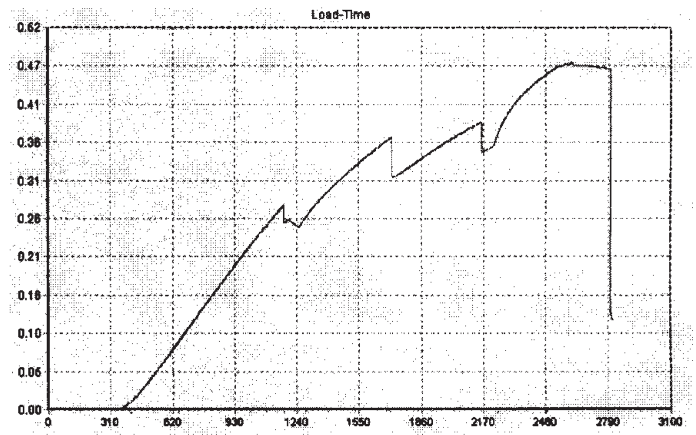

Fig. 7. Variation diagram of the pressure force as a function of time (sample 2)

samples have been used, each been made of a FRC restoration resin bonded to two lateral teeth which are fixed in a plaster block.

Each restoration was composed of 3 elements (fig. 4):

- wo retainers shaped as a class II inlay and mesial onlay (total surface area is 4x8 mm with a depth of 1 mm)

- one pontic of 15mm.

The 2 samples differ by the fiber width and by the thickness of the veneer composite (for sample no 1 - a 1 mm wide fiber was used and for sample no 2 - a 2 mm wide fiber was used).

The 2 samples have been tested with static short duration loads on a testing machine type WDW-5CE using a maximum force of 25kN. Flexural testing of the samples was performed using load speed of 0.02mm/min, for avoiding the impact shock.

The static testing has been performed in normal temperature and humidity conditions.

A custom made pressure stamp allowed a concentrated force located in the middle of the occlusal face of the pontic (the contact surface between the pontic and the pressure stamp was $0.44mm^2$) (fig. 5).

Results and discussions

During the tests the pontic load was constantly visualized and recorded. In the end of the trials the diagrams that show the variation of the load in kN as a function of displacement in mm (fig. 6) and time in sec (fig. 7) were obtained.

The displacement patterns of the samples and their behavior during testing (crack initiation and propagation, destruction by fracture etc.) have been monitored by analyzing the acquired data. In the first sample, cracks were initiated on the mucosal face of the pontic on the opposite side of the applied force where the tensile stress was located. A second crack appeared at junction of the pontic with the inlay. These cracks propagated inside the veneer composite and on the interface between the fiber and the composite. The sample was destroyed by a terminal force of 470N. In the second sample, the first crack appeared also at the mucosal face of the pontic where the tensile stress was located. In the next stage, cracks appeared at the junction of the pontic with the onlay and then at junction with the inlay. The maximum force before destruction was 423 N.

It has been observed that both samples had a perfect elastic behaviour for force under 280N (sample 1) and 360N (sample 2). Establishing the elasticity limit is very important because it shows the level of stress above which permanent deformation appears in the dental restoration. From a clinical point of view at this level breakage of the reinforced material begins even though it is not visually detectable. It has been noticed that the thickening of reinforcement fiber allowed cracks to appear in case of higher forces, 360N vs 280N.

The schematic representation of the loading of the 2 pontics is shown in figure 8.

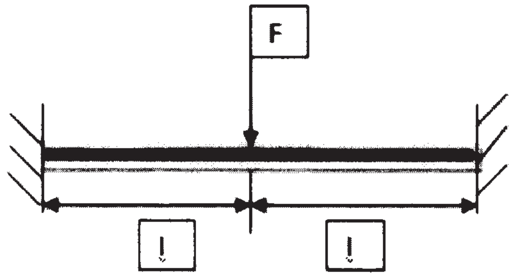

Fig. 8. Schematic representation of the loading of the 2 pontics

The study of the undetermined static system which underwent the flexural stress, equivalent of the studied scenario lead to the determination of the flexural momentum and of the shear force which stressed the 2 pontics.

The maximum normal stress which operates in the pontic mass can be calculated with the Navier formula [12]:

$$\sigma_{max} = \frac{M_{i_{max}}}{W_z}$$

where:

M_{imax} - maximum flexural momentum of the pontic;

W_z - strength modulus of the transversal section;

For the study scenario, the maximum flexural momentum was recorded at the level of the force and equals to $\frac{F \times l}{4}$. The strength modulus of the transversal sections of the bridges can be determined with $bh^2 / 6$.

The studied pontic has a length of 2l = 15mm, width b = 4.2mm and a height of h = 3.5mm. The maximum flexural stresses as a result of the load are 102.77MPa for the first pontic and 92,5MPa for the second one.

It has been observed that with both samples the destruction was preceded by the longitudinal extension of the fracture along the pontic leading to the disjunction between the composite and the fiber (fig. 9, 10).

The shear stress that appears at the interface between the composite and the fiber can be determined using Juravski's formula: [1]

$$\tau(y) = \frac{T \quad S_z(y)}{b(y) \quad I_z}$$

where:

T - the shear force (in the studied scenario equals F / 2)

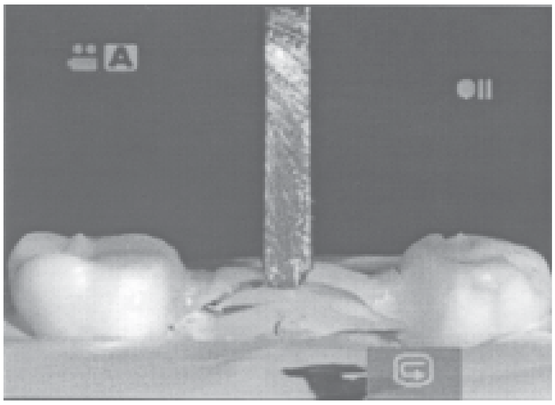

Fig. 9. The test failure of sample 1

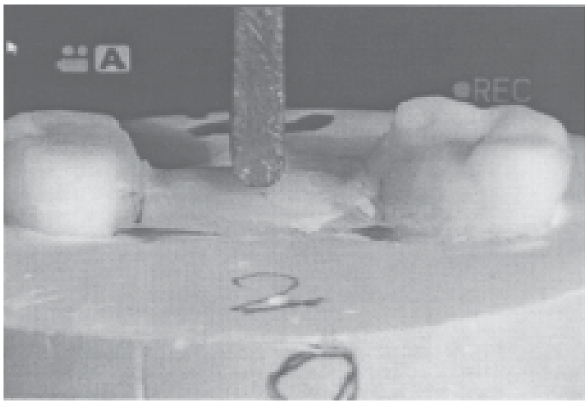

Fig. 10. The test failure of sample 2

$S_z(y)$ - the static momentum of the surface above or below the fiber where the shear stress is determined

b(y) - the fiber width where the shear stress is calculated

I_z - the inertial momentum where the transversal section (for the studied pontic, the inertial momentum is determined using formula $bh^3 / 12$).

The shear stress resulted from the flexural load amount to 19.57MPa for the first pontic and to 17.61MPa for the second pontic.

The clinical observations and research in the field of resin bonded bridges [1-13] show the fracture pattern of some non-reinforced composite bridges where the fracture line is transversal on the pontic and its appearance and propagation are sudden denoting its brittle character of the composite at macroscopic level.

In the case of the tested samples, the time of bridge destruction was delayed respective to the time of the first crack which confirms the importance of the reinforcement fiber for supporting the restoration for the biomechanical point of view [14-21]. This allows keeping the bridge in place even after the initiation of the crack which is a very important clinical (esthetical and psychological aspect) [11]. At this moment the restoration structure permits intraoral repair and the normal function of the bridge [22].

Between the 2 moments, the initiation of the crack and the breakage of the pontic, one can observe the appearance of cracks between the pontic and the retainers.

Again the persistence of the fiber allows maintaining the bridge under certain conditions and for a certain period of time. If the stress increases the restoration is destructed (the force has to be almost doubled before the important displacement could lead to the fracture of the bridge).

Conclusions

Although, the experimental results show a good agreement with the clinical observations, due to the limitations of the experiment, no detailed investigation is performed in order to analyze the failure mechanism of the bridge. The composite resin reinforced with high modulus polymer fibers increase significantly the structural strength and stiffness of the bridge and therefore improve its clinical performance.

In a clinical situation this reversible and cost effective procedure, which is minimally invasive, aesthetically and biologically desirable offers a viable alternative to conventional replacement of lost teeth.

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