BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LXI (LXV), Fasc. 1, 2015
Secţia
CONSTRUCŢII DE MAŞINI

FLEXURAL AND SHEAR STRENGTH OF FIBRE REINFORCED COMPOSITES USED IN PERIODONTOLOGY

BY

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Received: February 9, 2015
Accepted for publication: March 17, 2015

Abstract. Fibre reinforcement is currently a popular approach in dentistry, for various disciplines and applications: restorative dentistry, periodontology, prosthodontics, orthodontics. Both the fibre type and the type of composite have a great influence on the mechanical properties of fibre reinforced composites. The specimens based on different FRC systems were subjected to a three-point bending test in order to evaluate the shear strength and the flexural strength of the most used FRC systems in periodontal therapy.

Key words: fibre reinforced composite; periodontal therapy; three-point bending test; shear strength; flexural strength.

1. Introduction

Fibre reinforced composites (FRC) are more and more widely applied in dentistry, in a variety of disciplines: restorative dentistry, periodontology, prosthodontics, orthodontics (Freilich *et al.*, 2000; Curtis & Timothy, 2008; Zhang & Matinlinna, 2012). Research supports the use of periodontal splinting

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as a recommended therapy to stabilize mobile teeth in order to improve long-term prognosis (Quirynen & Mongardini, 1999; Mosedale, 2007; Akcali *et al*., 2014). Fibre reinforced composite (FRC) is a material combination of fibre and resin polymer matrix. The fibre is the reinforcing phase, providing stability and stiffness, while the resin is the protecting part, ensuring the reinforcement and the possibility to work with the material (Freilich *et al*., 2000; Curtis & Timothy, 2008; Sharafeddin *et al*., 2013).

The properties and the effectiveness of the fibre reinforcement in FRC are based on the fibre type (Glass, Polyethylene, Carbon, Aramid), on the quantity of fibres, on the fibre structure including unidirectional, bidirectional and randomly oriented fibre, fibre position, quantity of fibres, location and volume fraction in construction, fibre-resin matrix adhesion, properties of fibres versus properties of resin matrix, quality of fibre impregnation and water sorption of the matrix (Freilich *et al*., 2000; Curtis & Timothy, 2008; Zhang & Matinlinna, 2012). An important parameter is the interfacial adhesion. Adhesion of particulate filler resin composite has a specific role in the load transfer from the surface of the device to the FRC framework and tooth. This parameter can be evaluated and quantified by the shear strength.

The aim of this study was to assess and compare the shear strength of the fibre and flexural strength of composites for different types of fibre reinforced composite. The considered tested specimens were symmetric sandwich beams with two identical layers (composite) and a continuous core (fibre).

2. Material and Method

2.1. Specimen Preparation

A total of 80 bar-shaped specimens with the following dimensions 2x2x25 mm were fabricated according to ISO Standard 4049/2000 (Ludwick, 2000). The specimens were divided in 16 groups (n = 5), according to the fibre type and width (*Construct* - polyethylene fibre 2 and 3 mm, *Interlig* - braided glass fibre 2 mm, *Splint-It* - unidirectional glass fibre 3 mm) and composite resin (*Filtek Z250, Premise Packable, Premise Flowable, Brilliant Flowable*) used:

- CF2 (Construct 2 mm + Filtek Z250)
- IF2 (Interlig 2 mm + Filtek Z250)
- CF3 (Construct 3 mm + Filtek Z250)
- SF3 (Splint-It 3 mm + Filtek Z250)
- CPP2 (Construct 2 mm + Premise Packable)
- IPP2 (Interlig 2 mm + Premise Packable)
- CPP3 (Construct 3 mm + Premise Packable)
- SPP3 (Splint-It 3 mm + Premise Packable)
- CPF2 (Construct 2 mm + Premise Flowable)
- IPF2 (Interlig 2 mm + Premise Flowable)

- CPF3 (Construct 3 mm + Premise Flowable)
- SPF3 (Splint-It 3 mm + Premise Flowable)
- CBF2 (Construct 2 mm + Brilliant Flowable)
- IBF2 (Interlig 2 mm + Brilliant Flowable)
- CBF3 (Construct 3 mm + Brilliant Flowable)
- SBF3 (Splint-It 3 mm + Brilliant Flowable)

The tested specimens have a sandwich structure which consists of two layer composite resin, having the same thickness (approximate 0.9 mm) and fibre (0.2 mm), a continuous core, made of a solid material, which joints the two layers (Fig. 1). This structure provides a very high level of bending stiffness. The primary function of the core is to transfer shear force between the faces without failure or excessive deformation.

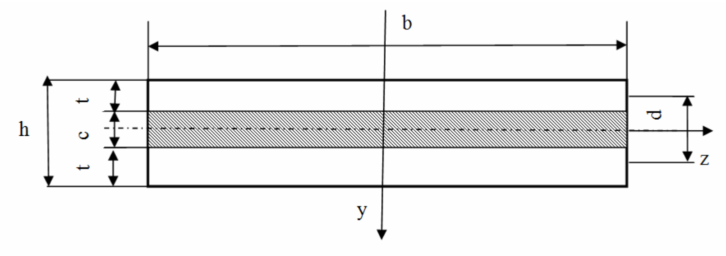

Fig. 1 − Structural sandwich consisting of two face sheets and a continuous core (Bejan *et al.*, 2006).

It is considered that the core material and the two layers are isotropic and the three components have a perfect adhesion between them and work as a coherent unit.

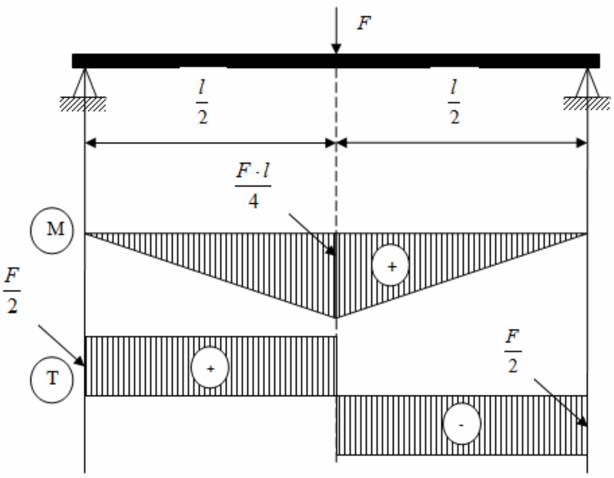

Fig. 2 − Three-point bending loading configuration (Mocanu, 2013).

The specimens were stored at room temperature in distilled water for 24 h before mechanical testing. The specimens made of different FRC systems were subjected to a three-point bending test (Fig. 2). This test may be used to determine the shear strength and flexural strength of the face sheets. Both bending and interlaminar shear stresses are induced in the beam.

For three-point loading, the maximum bending moment in the beam is at midspan and is equal to $M_{\max} = Fl/4$, where F is the central load applied and l is the span length. The transverse shear force, hence the interlaminar shear stress in the beam, is equal to $T = F/2$ and is constant over the entire support span (Fig. 2).

The specimens were tested with static short duration loads on a universal testing machine type WDW-5CE which can be operated in force or strain control as well as crosshead displacement control. An electronic load cell and multiple channel strain-displacement signal conditioning electronics feed into a computerized controller, which processes these data and presents and stores the results in the desired form (stress-strain, stress-displacement, and strain-strain plots). The load was applied at the middle of the test specimens, perpendicular to the long axis, with a rounded-ended striker (Fig. 3). The static testing has been performed at room temperature and normal humidity conditions. Testing was conducted at a crosshead displacement rate of 0.5 mm/min.

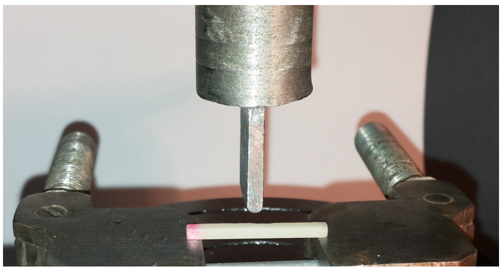

Fig. 3 − FRC specimen in three point bending test.

2.2. Flexural Strength

The axial bending stresses are compressive on the surface of the beam where the load is applied and tensile on the opposite surface, varying linearly through the beam thickness (Navier relation) (Bejan *et al.*, 2006). The flexural strength in the face sheets varying linearly through the composite thickness is calculated with formulae (Mocanu, 2013):

$$\sigma_c = \frac{M \cdot E_c}{D} \cdot y, \ for \begin{cases} -h/2 \le y \le -c/2 \\ c/2 \le y \le h/2 \end{cases} \tag{1}$$

The maximum bending stress, in the face sheets, at midspan is given by:

$$\sigma_{c\max} = \frac{M_{\max} \cdot E_c}{D} \cdot \frac{h}{2} = \frac{F_r \cdot l}{D} \cdot \frac{E_c h}{8} \quad (2)$$

where: h – the beam height, D – the bending stiffness per unit width calculated with the formulae (3), F_r – the fracture force.

The bending stiffness per unit width is the product of face elastic modulus and moment of inertia (Bejan *et al.*, 2006). So:

$$D = 2 \cdot E_c \cdot I_c = 2 \cdot E_c \left[\frac{bt^3}{12} + bt \cdot \left(\frac{d}{2} \right)^2 \right] = \frac{bt}{2} E_c \cdot \left[\frac{t^2}{3} + (c+t)^2 \right] \quad (3)$$

where: t – the face sheets thickness, c – the core thickness, b – the beam width, d – the distance between the centres of gravity of the face sheets: $d = c + t$ (Fig. 1), E_c – face elastic modulus, I_c – moment of inertia of face sheets (calculated of Steiner formulae) (Mocanu, 2013).

2.3. The Shear Strength

The shear strength on the height of a sandwich structure is calculated with Juravski relation:

$$\tau = \frac{T}{D \cdot b} \cdot (S \cdot E_f) \quad (4)$$

where: T – the transverse shear force ($T = F/2$), E_f – elastic modulus of the core (fibre), $S \cdot E_f$ – the product of moment static and core elastic modulus.

In the core, for $-c/2 \le y \le c/2$ it can be written:

$$S \cdot E_f = \frac{b}{2} \cdot \left(\frac{c}{2} - y \right) \cdot \left(\frac{c}{2} + y \right) \cdot E_f \quad (5)$$

D – the stiffness per unit width is:

$$D = E_f \cdot I_f = E_f \cdot \frac{bc^3}{12} \quad (6)$$

Substitution of (5) and (6) into eq. (4) gives:

$$\tau = \frac{F}{2} \cdot \frac{1}{E_f \cdot \frac{bc^3}{12}} \left[\frac{1}{2} \cdot \left(\frac{c^2}{4} - y^2 \right) \cdot E_f \right] = \frac{3F}{bc^3} \cdot \left(\frac{c^2}{4} - y^2 \right) \tag{7}$$

In the neutral plane where the bending stress passes through zero the interlaminar shear stress is maximum, varying parabolically from zero on each surface of the beam (Mocanu, 2013). For a beam of rectangular cross section the shear stress is maximum on the beam axis (for $y = 0$) and is given by (Adams & Lewis, 1997):

$$\tau_{f\max} = 0.75 \frac{F_r}{bc} \tag{8}$$

3. Results

The specimens were tested until fracture failure. The maximum loads, equivalent to the fracture force, were registered by the computer software and are presented in Table 1. The bending stiffness was calculated using formula (3).

Table 1

Maximum Load and Bending Stiffness of Specimens

Groups (n = 5)	Maximum load [N]		Bending stiffness [N·mm^2]
	Average	Std. Dev.	
CF2	14.80	0.66	15051.6
IF2	17.03	1.31	
CF3	52.20	1.41	22577.4
SF3	21.04	1.48	
CPP2	14.42	0.99	13586.4
IPP2	17.01	0.85	
CPP3	39.20	1.63	20379.6
CPP3	23.04	1.03	
CPF2	22.40	1.26	10323
IPF2	28.60	0.93	
CPF3	40.03	1.27	15484.5
SPF3	36.60	1.72	
CBF2	13.61	0.73	6926.4
IBF2	18.76	0.96	
CBF3	30.78	1.23	10389.6
SBF3	30.62	1.43	

One-way ANOVA was performed was applied to maximum loads, having first verified that the data met the requirements of normal distribution and homogeneity of group variances (Table 2). In all the analyses, the level of significance was set at p = 0.05 and calculations were done by the SPSS 18.0 software (SPSS; Chicago, IL, USA).

Table 2
One-Way ANOVA Results for Maximum Load

	Source of Variation	SS	Df	MS	F	P-value
Maximum load [N]	Between Groups	9464.86	15	630.99	424.17	<0.001
	Within Groups	95.21	64	1.49		
	Total	9560.06	79			

It was observed that the first fracture line appeared along the axis of the force, on the compressive surface of the specimen. The crack progressed toward the junction area between the fibre and the composite veneer and subsequently the crack propagated along the fibre. In the final stage, catastrophic failure appeared at the tension side. It is important to correlate the flexural strength of the composite sheets to the flexural strength of the entire FRC specimen. In order to calculate the flexural strength of the composite, we used formulae (2), where the values of the maximum load supported by each specimen and of the bending stiffness are given in Table 1.

An important aspect is the interfacial adhesion between composite sheets and the fibre reinforcement. Interlaminar shear stress occurs in this area and influences the integrity of the FRC specimen, by delamination.

The maximum shear strength at the composite - fibre interface was calculated with formulae (8). The values of flexural and shear strength are presented in Table 3, and the statistical analysis is presented in Table 4.

For all FRC, it was observed that the shear strength was approximately 50% lower than the flexural strength of the composite. This aspect implies that the destruction of the specimens was due to composite fracture, and that the interlaminar shear stress represents a secondary mechanism of failure.

The fibre width influences the resistance of the specimens. Considering the different widths of polyethylene fibres, one can notice that the flexural strength and the shear strength were higher in specimens with 3 mm than in groups with 2 mm fibre, for all types of composite used:

– $\sigma_{\mathrm{CF3}} > \sigma_{\mathrm{CF2}}$ with 135%

– $\sigma_{\mathrm{CPP3}} > \sigma_{\mathrm{CPP2}}$ with 81%

– $\sigma_{\mathrm{CPF3}} > \sigma_{\mathrm{CPF2}}$ with 19%

– $\sigma_{\mathrm{CBF3}} > \sigma_{\mathrm{CBF2}}$ with 50%.

Table 3

Flexural and Shear Strength of Specimens

Groups (n = 5)	Flexural strength [MPa]				Shear strength [MPa]			
	Sum	Average	Std. Dev.	Variance	Sum	Average	Std. Dev.	Variance
CF2	277.8	55.56	2.48	6.15	138.75	27.75	1.24	1.53
IF2	320.2	64.04	4.93	24.29	159.6	31.92	2.46	6.03
CF3	653.15	130.63	3.53	12.47	326.25	65.25	1.76	3.11
SF3	263.26	52.65	3.72	13.81	131.5	26.3	1.86	3.45
CPP2	271.09	54.218	3.73	13.91	135.15	27.03	1.86	3.46
IPP2	319.25	63.85	3.18	10.13	159.45	31.89	1.59	2.53
CPP3	490.51	98.10	4.09	16.73	245.01	49.002	2.04	4.17
CPP3	288.8	57.76	2.58	6.68	143.96	28.792	1.29	1.66
CPF2	421.14	84.23	4.73	22.41	209.94	41.988	2.36	5.57
IPF2	536.8	107.36	3.51	12.29	268.09	53.618	1.75	3.06
CPF3	501.83	100.37	3.19	10.20	250.14	50.028	1.59	2.53
SPF3	458.8	91.76	4.30	18.51	228.7	45.74	2.14	4.60
CBF2	255.92	51.18	2.75	7.57	127.55	25.51	1.37	1.88
IBF2	351.74	70.348	3.58	12.78	175.84	35.168	1.79	3.19
CBF3	385.11	77.02	3.07	9.42	192.34	38.468	1.53	2.35
SBF3	382.73	76.55	3.59	12.87	191.33	38.266	1.79	3.22

Table 4

One-Way ANOVA Results for Flexural and Shear Strength

	Source of Variation	SS	df	MS	F	P-value	F crit
Flexural strength [MPa]	Between Groups	40203.4	15	2680.23	203.98	5.4E-48	1.83
	Within Groups	840.96	64	13.14			
	Total	41044.35	79				
Shear strength [MPa]	Between Groups	10030.09	15	668.67	204.34	5.11E-48	1.83
	Within Groups	209.43	64	3.272			
	Total	10239.52	79				

Regarding the influences of the fibre type on the flexural strength, there were noticed the following:

− in the groups with 3 mm fibres and Filtek Z250, the flexural strength of the composite was 2.5 higher for Construct than for Splint-It.

− in the groups with 3 mm fibres and Premise Packable, the flexural strength of the composite was 1.7 higher for Construct than for Splint-It.

− in the groups with 2 mm fibres and Brilliant flow, the flexural strength of the composite was with 37% higher for Interlig than for Construct.

Comparing only the groups with glass fibres, it should be pointed out that for IF2, IPP2 and IPF2 groups (Interlig samples) the values of flexural strength and of shear strength were higher compared with SF3, SPP3 and SPF3 groups (Splint-It samples) (12-23%), even if the width of Splint-It (3 mm) is higher than the width of Interlig (2 mm).

It is reported that an increase in fibre volume results in improvement of mechanical properties (Alander *et al*., 2005; Behr *et al*., 2005). However an increase in load bearing capacity is not exclusively caused by higher fibre volume, but also by the strength of the resin matrix, the bonding between fibres and matrix and deterioration by water sorption of fibres and matrix (Abdulmajeed *et al*., 2011; Chen *et al*., 2011).

From the clinical point of view, the fact that the fracture of the composite appears first and then the crack progresses along the fibre, offers a window of opportunity to the clinician allowing him to repair the restoration intra-orally, before the fibre gets impregnated with saliva.

4. Conclusions

Both the type of the fibre and the type of the composite have a great influence on the shear and flexural strength of FRC specimens.

For all specimens, the flexural strength was significant higher than the shear strength (50%), which implies that the destruction of the specimen is primarily due to composite fracture and secondarily to the delamination at the interface between the composite and the fibre.

The fibre width influences the resistance of the specimens. Comparing specimens with different widths, it was noticed that the flexural strength and the shear strength were higher in specimens with 3 mm than in groups with 2 mm fibre, for all types of composites used; the most important difference was registered between groups CF2-CF3 (135%).

The specimens which exerted the best ratio between high flexural strength and high shear strength have the best indications to be used in periodontal therapy for dental splinting.

The potential of these restorations that replace metal, with all disadvantages that they carry, allow minimal preparation with exceptional aesthetic results at very affordable costs in a short time. This is very motivating and appealing to many specialists and patients. Nevertheless the high variability of materials and techniques combined with the execution sensitivity and overall the reported survival rate can be discouraging for some practitioners.

Based on the critical evaluation of the available FRC systems, recommendations for individualized clinical FRC selection can be made, which is of great importance for successful outcomes of periodontal splints.

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REZISTENȚA DE RUPERE LA ÎNCOVOIERE ŞI FORFECARE A COMPOZITELOR RANFORSATE CU FIBRE UTILIZATE ÎN PARODONTOLOGIE

(Rezumat)

Compozitele ranforsate cu fibre sunt utilizate cu succes în stomatologie, în diverse ramuri: terapie restaurativă, parodontologie, protetică şi ortodonție. Tipul de fibră şi tipul de compozit au o influență decisivă asupra proprietăților mecanice ale compozitelor ranforsate cu fibre. Probe realizate din diferite tipuri de compozite ranforsate cu fibre utilizate în parodontologie au fost supuse unei solicitări de încovoiere în trei puncte, pentru a determina rezistența de rupere la încovoiere şi forfecare a acestora. Pentru toate probele, rezistența de rupere la încovoiere a fost semnificativ mai mare decât rezistența de rupere la forfecare, ceea ce implică faptul ca principalul mecanism de deteriorare a compozitelor ranforsate este fracturarea compozitului, iar secundar intervine delaminarea, la interfața de adeziune dintre compozit şi fibră. Probele care au prezentat cel mai bun raport între o rezistență crescută de rupere la încovoiere şi o rezistență crescută de rupere la forfecare prezintă cele mai bune indicații de utilizare în terapia parodontală de imobilizare.