Original Article

Effect of fiber position and orientation on flexural strength of fiber-reinforced composite

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Abstract

Background and Aim: One of the most important factors for increasing flexural strength of fiber-reinforced composite (FRC) restorations is the orientation, volume and geometry of reinforcement fibers. The aim of this study was to determine the ef fect of fiber position and orientation on the flexural strength of FRC specimens.

Materials and Methods: In this experimental-laboratory study, five groups (N=8) of test specimens made of one indirect composite were reinforced with pre-impregnated fibers in different positions, orientations or geometry into the rectangle cube speci mens ($3\times3\times25mm^3$). The control group did not contain fiber reinforcement. The test specimens were stored in distilled water for 1 week at 37°C before testing in a three-point loading test with 1mm/min cross head speed. Data were statistically analyzed at 0.05 significance level with Kruskal-Wallis and Mann-Whitney tests.

Results: The mean flexural strength of six experimental groups had significant differ ences (p_1=0.005 and p_2<0.001). The control group showed the lowest initial and final values. The maximum initial flexural strength was seen in the tension group (76.2 MPa) and the maximum final flexural strength was seen in the middle horizontal group (173.9 MPa).

Conclusion: Within the limitations of this study, it may be concluded that the position and orientation of the fibers influenced the flexural strength of the fiber-reinforced composites and the most effective position of the fibers was tension side reinforce ment.

Key Words: Composite resins - Dental materials - Materials failure analysis – Testing Materials

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Introduction

In the last decades there has been much effort towards finding appropriate substitutes for metal-ceramic fixed partial dentures in order to strengthen fixed partial dentures made of fiber reinforced composites (FRC) [1-5]. FRCs include fibers with high strength and modulus of elasticity held by a composite matrix [6-7]. Factors influencing the mechanical properties of FRCs are material properties of the composite and the used fiber, fiber surface characteristics [1], quantity of fibers [8], position, direction [9] and adhesion of the fibers to the composite matrix [1] and water absorption of the composite matrix [7-8].

The positive effect of the fibers' directional orientation on increasing the strength of FRCs has been proved [10-12]. In this situation, the orientation of the fibers has an important role on the amount and quality of the force transfer to the composite matrix. It has been stated that as the volume of fibers increase, the mechanical properties of the composite reaches that of the reinforced fiber. Orientation, quantity and the configuration of the fibers defined as “transverse section design” has been discussed by many researchers. Most of the FRC prostheses are made manually by technicians; therefore, by changing the orientation of the fibers a better mechanical property may be obtained [1]. In this regard, Ellakwa et al. [13] reached the fact that by changing the orientation of the fibers in the samples, the fracture resistance increases and arrangement of the fibers in a disc-shaped sample environment leads to better results. Dyer et al. [1] showed that better flexural strength is achieved by placing the fibers at the tension side distant to the entered force. On the other hand, Lassila et al. [12] believed that only in samples with a lower fiber content in the composite a better flexural strength will be obtained by positioning fibers on the traction side and when there is a high fiber volume the vertical position of the fibers to the force obtained causes higher strength. On the contrary, Valittu [14] stated that change of fiber orientation has no significant influence on the transverse strength of methyl methacrylate samples, but is effective on the mechanical property of composite samples. He did not mention the position of the fibers causing higher strength (or flexural strength?). Dyer [15] noted that the modulus of elasticity increases by placing a layer or more of fibers on the compression side of the FRC, but the toughness of the samples is increased when one layer or more fibers are placed on the tension side.

The objective of this study was to evaluate primary and final flexural strengths of composite samples when fibers are placed in different positions and different orientations.

Materials and Methods

In this experimental-laboratory study, a 3×3×25 mm internal sized plexiglass split mold was designed in order to produce rectangle cube composite specimens and easy to bring these specimens out (Fig. 1). Forty-eight FRC samples were produced in four groups; the control group, the compression and pressure groups, the middle horizontal and middle vertical, and finally the compression - pressure group as demonstrated in Fig. 2.

Fig.1: Plexiglass slot mold

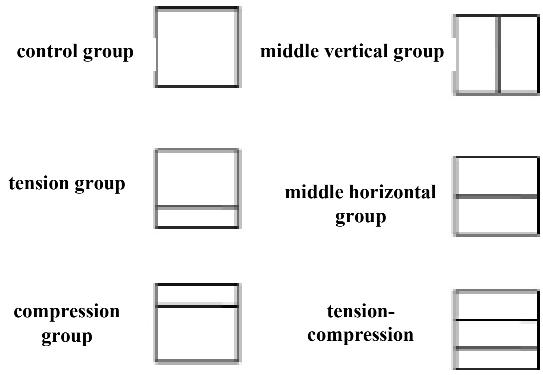

Fig.2: Shematic aspect of cross-section of specimen

1-**The control group**: There was no fiber used to prepare this group. First a 1.5 mm layer of composite (Japan Gradia; GC Corp, Tokyo) was placed at the bottom of the split mold subsequently cured with the radiation intensity of 1200 mW/cm^2 for 48 seconds with the LED light cure machine (Monitex ‘Bluex, GT1200’, Monitex Industrial Co., Taiwan). The radiation was repeated for 40 seconds from the right and left sides. All the light radiations were carried out in free air so attachment of the different layers of composite would be possible in the presence of oxygen inhibition layer [16]. Then another layer of composite was placed on the first layer and the surface was covered by a layer of plexiglass and as mentioned above light radiation was carried out from different directions. Afterwards the mobile pieces of the split mold were separated and the samples were brought out. Eight 3×3×25 mm sized rectangle cube samples were made.

2-**Tension and compression groups**: After obtaining one 1 mm layer of composite (Gradia, Japan) and light radiation from different sides exactly as mentioned in the control group, a 25mm section of preimpregnated reinforced fiber (Fibrex Ribbon, Angelus dental Solutions, Londrina, Brazil) was placed on the first composite layer and cured for 20 minutes. The final layer of composite with 2 mm thickness was placed on the fiber and after covering the surface with a layer of plexiglass similar to the control group, light radiation was carried out three times in different directions. Finally, the samples were emitted. Sixteen samples of this group were randomly divided into two groups which according to the location of the entered force were named as the tension or compression group.

3- **Middle horizontal and middle vertical groups**: First a 1.5 mm thick layer of composite (Gradia, Japan) was compressed precisely in the split mold and consequently light radiated from three different directions. Then a 25 mm long piece of fiber (Fibrex, Ribbon, Brazil) was placed on the composite. Afterwards, the 1.5 mm remainder of the split mold's space was filled by composite and was uniformed by the compression of a layer of plexiglass. Sixteen samples of this group were randomly divided into two groups and based on the location of the force entry were called the middle horizontal and the middle vertical group.

4- **Tension- compression group:** First a 1 mm thick layer of composite (Gradia, Japan) was compressed precisely in the split mold and consequently light radiated from three different directions for 30 seconds. Then a 25 mm long piece of fiber (Fibrex, Ribbon, Brazil) was placed on the first layer and another layer of composite was placed on them and cured for 30 seconds. Again another layer of fiber was put on the other layers and finally, the 1 mm remainder of the split mold's space was filled by composite and was uniformed by the compression of a layer of plexiglass subsequently cured for 30 seconds. Eight samples were made.

The intensity of light radiation with the manual light cure machine was measured by a radiometer (Optilux Radiometer Model 100, Kerr Sybron, Danbury, CA, USA) showing 700Mw/ cm^2. After emitting the samples from the split mold, the flashes were eliminated by paper discs and the dimensions were measured by acaliper (Electronic Digital Caliper, Minova Co., Osaka, Japan) with a 0.01 mm accuracy and the non-standard samples were excluded from the study and replaced by new samples. Finally, the samples were put in the light radiation machine (Labolight; GC Corp, Tokyo, Japan).

The samples were placed in 37 degrees distilled water for 48 hours and one hour after bringing them out from this environment, they were left in the room in order to reach room temperature. The three-point loading test was performed on 20 mm-distance-pedestals and 20 Newton force and 1 mm/min speed according to the standard specification ISO: 1077 and using the Universal Tesing Machine (Dartec Series, England). The machine's force was entered upon the middle of the samples which had been targeted before. Dartec machine increases the force upon the tested samples till the sample shows resistance. Once the samples fracture, the entered force declines immediately and in case there is no resistance, the force stops. Observing the behavior of the samples in the machine and specifically some of the samples reinforced with fibers, two numbers were recorded for each sample by the computer attached to the machine. The first number was recorded when the first fracture happened in the sample, which was the tension part undergoing fracture, called the initial fracture force and the second number recorded was the sample's final fracture and termination of the resistance against the entered force applied by the machine called the final fracture force. This is similar to what other studies have performed [1,15] and the reason is that these composite samples fracture in two stages; once when the covering composite fractures and second when the reinforced fibers fracture. Subsequently, $S=3FL/2bd^2$ is used to calculate the initial flexure strength (MPa) and the final flexural strength (Mpa). In this equation, F stands for force, L stands for length, b stands for width and d stands for sample thickness. Finally, the median flexural strength was calculated for the samples and compared between the groups. SPSS ver. 11.5 for Windows (SPPSS Inc. Illinois, USA) was used for statistical analysis. Because of variance non-homogenecity, Kruskal-Wallis and Mann-Whitney tests were used to analyze the data. Significant difference was set at 0.05.

Results

Table 1 demonstrates the median flexural strength for evaluated samples. Kruskal-Wallis test showed that there was a significant difference between the median initial flexural strength of the samples in different groups (p=0.005). To complete the analysis after the Kruskal-Wallis test, the Mann-Whitney test was used to compare the median initial flexural strength pairwise among groups (Table 2). Table 3 demonstrates median and mean final flexural strength for the evaluated samples. Kruskal-Wallis test showed that there was a significant difference between the median final flexural strength in the tested specimens (p=0.001). To complete the analysis, after the Kruskal-Wallis test, the Mann-Whitney test was used to compare the median final flexural strength pairwise among the groups (Table 4). It has to be mentioned that in some of the evaluated groups such as the fiber reinforced group on the pressure side and the group without fiber, only one figure was recorded by the machine because the sample was fractured in one stage and the initial and final flexural strength were the same.

Table 1: Mean and Median Initial Flexural Strength of the Tested Specimens (MPa)

Group	Number	Minimum	Maximum	Median	Mean	Standard Deviation
Control	8	63.88	91.66	74.30	76.21	9.74
Tension	8	68.05	158.33	112.50	116.32	26.98
Compression	8	66.66	101.39	86.80	85.59	10.80
Middle Horizontal	8	81.94	119.44	92.36	94.96	13.46
Middle Vertical	8	80.55	101.39	94.44	92.36	6.96
Tension and Pressure	8	65.27	212.50	97.22	111.8	47.02
Total	48	63.88	212.50	92.36	96.12	26.47

Table 2: Pairwise Comparison of Initial Flexural Strength (MPa) Among Groups Analyzed

	Control	Tension	Pressure	Middle Horizontal	Middle Vertical	Tension and Pressure
Control	-	0.006	0.08	0.01	0.004	0.03
Tension	-	-	0.012	0.052	0.015	0.34
Compression	-	-	-	0.26	0.16	0.27
Middle Horizontal	-	-	-	-	0.71	0.87
Middle Vertical	--	-	-	-	-	0.52

Table 3: Final Flexural Strength of Samples (MPa)

Group	Number	Minimum	Maximum	Median	Mean	Standard Deviation
Control	8	63.88	91.66	74.30	76.21	9.74
Tension	8	111.11	201.39	163.19	160.59	30.76
Compression	8	66.66	101.39	86.80	85.59	10.80
Middle Horizontal	8	143.05	208.33	168.05	173.95	22.49
Middle Vertical	8	87.50	133.33	108.33	108.16	13.37
Tension and Pressure	8	113.33	248.61	169.44	167.70	45.86
Total	48	63.88	248.61	113.88	128.70	47.17

Table 4: Final Flexural Strength of Samples (MPa)

	Control	Tension	Pressure	Middle Horizontal	Middle Vertical	Tension and Pressure
Control	-	0.001	0.08	0.001	0.001	0.001
Tension	-	-	0.001	0.49	0.003	0.71
Compression	-	-	-	0.001	0.005	0.001
Middle Horizontal	-	-	-	-	0.001	0.79
Middle Vertical	--	-	-	-	-	0.003

Discussion

In this laboratory evaluation, the flexural strength of rod-shaped composites in some groups with different fiber orientations were compared with each other and also with a group without fiber. In this evaluation, similar to some other studies it was showed that fiber reinforcement leads to significant increase in the flexural strength [13-15,19]. In a review of article by van Heuman [17], it has been stated that reinforced fibers may only increase flexural strength of FRCs in certain circumstances and the orientation of the reinforced fibers is more important than the type of fibers used. Vallittu [14] believed that although change in fiber orientation does not have a significant effect on the transverse strength of methyl methacrylate, it does effect the mechanical properties of composite samples.

The mean range of final flexural strength was 76.2-173.9 MPa. The control group (the group without fiber) had the least final flexural strength and among the groups with fiber, the middle hor izontal group had the highest final flexural strength. Based on the Mann-Whitney test, no significant difference was observed between the latter group and the reinforced fiber group on the tension side and the reinforced with two layer fiber group on the tension and compression side. The least final flexural strength was also related to the compression side with reinforced fibers. For clinical use, the initial flexural strength is a more accurate and more important index in comparison to the final flexural strength, because fiber reinforced composite prosthesis will be useless after the first fracture in the oral cavity [1]. Some studies have mentioned that placing fibers in locations other than the tension side of the sample does not lead to a remarkable increase in the resistance against initial fracture. Our study was in congruence with these mentioned studies regarding this matter [1,9,18]. On the other hand, Dyer et al. noted that by placing the fibers on the pressure side, elasticity coefficient of FRC increases and placing the fibers on the tension side increases the toughness.

Lassila et al. [12] believed that only in samples with a lower fiber content in the composite a better flexural strength will be obtained by positioning fibers on the traction side and when there is a high fiber volume the vertical position of the fibers to the force obtained causes a higher strength. In some studies, it has been demonstrated that flexural strength of composite prosthesis increases with the decrease in fiber volume [1,13]; therefore, it has been suggested to place polyethylene fibers on the tension side far from the force entry [12]. In bar-shaped samples, similar to what was used in this study, the volume of fibers compared to the volume of composite was small so the results could be compared to these studies. Of course, it should be emphasized that placing the fibers completely on the tension side may lead to increase in the dentations on the surface of the prosthesis, subsequently causing plaque formation [15]. The fibers used in this evaluation were impregnated fibers. Pfiefer believes that non-impregnated fibers are more effective in increasing the flexural strength of reinforced composites [19]. Ellakwa et al. [9] state that the difference between preimpregnated and non-impregnated fibers is only seen when the samples are bar-shaped and in more complex samples such as composite bridges which are made as normal teeth, there are no differences between these two types of fibers. In this study, the mean flexural strength of the evaluated samples are higher than the present study. One of the reasons may be difference in fiber quality between these two studies. In the present study, E-glass fibers were utilized, but Ellakwa et al. [9] used polyethylene fibers.

In comparison of mean final flexural strength between the middle vertical and middle horizontal reinforced fiber groups, the results showed that when the fibers are horizontal (perpendicular to the direction of force entrance) the outcome is much more efficient than when the fibers are vertical (parallel to the direction of force entrance). The mentioned fact has been confirmed by other studies too [1,19,20].

Based on the limitations of this study, such as using rod-shaped samples, we suggest this study to be performed on real teeth extracted from the oral cavity or samples very much similar to clinical circumstances. We also suggest the results to be compared by thermocycling and dynamic loading.

Conclusion

According to the laboratory condition of this study, the direction and orientation of the fibers effect the flexural strength of fiber reinforced composites and placement of the fibers on the tension side of the samples increases the flexural strength of the samples.

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