Effect of fiber volume on elastic modulus of post-core fabricated reinforced composite

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ABSTRACT

Background: Post-core restoration is one restoration after endodontic treatment by optimizing the root canal as a retention. Fracture of the root is the most common failure due to the post being less elastic in holding the chewing load, especially the metal post. Fibre-reinforced composites (FRC) post-core indicates to prevent tooth fracture. In addition, the FRC post-core minimizes the reduction of dentine tissue in the root canals, called a minimally invasive dentistry approach. This study examined the effect of the number of fibres on the elastic moduli of fabricated FRC posts using a three-bending point test to determine the elasticity of fabricated FRC posts.
Methods: The study was experimental laboratory research with the post-only control group design using polyethene fibre (Kerr) and flowable composite resin (Kerr), prefabricated post-core (Kerr). The study was divided into four groups, namely prefabricated, fabricated with a volume of 1 fibre, 2 fibres, and 3 fibres, where each group consisted of 6 samples.
Results: There was no significant difference in the magnitude of the force on the specimen ($p>0.05$). The force among the groups was the same, the alteration (deflection) of the specimens among the groups was significantly different ($p<0.05$), except for FRC 3 fibres with prefabricated. The results showed a significant difference among the groups ($p<0.05$) in the value of the elastic modulus.
Conclusion: *The number of fibres of fabricated FRC posts affected on the elastic moduli of FRC post.*

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INTRODUCTION

Root canal treatment is an endodontic treatment to maintain teeth in the oral cavity for a long time. However, root canal treatment causes a weak tooth structure, in which the tooth becomes more brittle and discolored [1,2]. It is the reason many studies are developing restorative materials after endodontic treatment. Dentists should consider selecting the type of restorations after the treatment because they also determine the success of endodontic treatment. The endodontic restoration must revitalize the function of chewing, phonetics, and aesthetics. The restoration design must maintain the remaining tooth structure, minimize dentine loss, retain the remaining tissue well, withstand chewing loads, and protect the remaining tissue structure [3,4].

Post-core restoration is one restoration after endodontic treatment by optimizing the root canal as a retention. Based on the materials, post-cores are divided into metal and non-metal-based materials. Both of these materials have advantages and disadvantages. Although the mechanical properties of metal post-core are better than non-metallic, metal post-core presents poor aesthetics. Vice versa, non-metallics are better aesthetics than metallic but have poor mechanical in strength. To optimize the post-core function in the oral cavity, non-metallic post-cores are developed, made of composites, ceramics and polymers. Recently, non-metallic post-cores have been reinforced with fibres to improve mechanical properties, significantly to withstand chewing loads and prevent fracture [5,6]. Fracture of the root is the most common failure due to the post being less elastic in holding the chewing load, especially the metal post [7].

Fibre-reinforced composites (FRC), a non-metallic post-core, present the main advantages, such as aesthetic and bonding with tooth structure significantly. Besides it, FRC revealed elastic modulus as well as dentin. So FRC post-core indicates to prevent tooth fracture. In addition, the FRC post-core minimizes the reduction of dentine tissue in the root canals, called a minimally invasive dentistry approach. The FRC post-core consists of at least two constituent materials, (1) reinforcing materials, which represent strength and resistance, and (2) matrix (enveloping the reinforcing material), which is the media of application [8,9]. Fibre materials utilize glass, polyethene, or carbon, while sheathing material is a composite resin matrix. The fibres used in FRC are generally 7-10 μm in diameter and are braided, woven or longitudinal in the form of ribbons [10].

FRC post-core made in prefabricated or fabricated. In prefabricated, FRC post-core has different elasticity depending on the manufacturer. Interestingly, each factory produces prefabricated FRC post-core with different matrix and fibre proportions, affecting the FRC properties. Prefabricated FRC post-core are manufactured by the factory from unidirectional E-glass fibres covered with a resin (epoxy resin) matrix. Practitioners use prefabricated FRC posts because the procedure for using them is easier and faster, but prefabricated FRC posts have the disadvantage of not being able to adjust the shape of the root canal [8,11].

Therefore, dentists make fabricated FRC post-core directly in their clinic, which modifies woven polyethene fibre and flowable composite resin into the root canal until it is complete and simultaneously constructs the post-core. Both materials' composition and proportion depending on the root canal's area and width [12]. FRC post-core properties, such as mechanical strength, are determined by the fibre ratio to composite resin and fibre width.

However, several studies showed no significant change in characteristic FRC post-core by fibre volume addition [8,11,13]. The value of the FRC elastic modulus based on the volumetric fraction of the fibre varies and still needs to be clarified.

This study examined the effect of the number of fibres on the elastic moduli of fabricated FRC posts using a three-bending point test to determine the elasticity of fabricated FRC posts. As a comparison, we will use commercial prefabricated fibre post-core, often used today.

RESEARCH METHODS

The study was experimental laboratory research with the post-only control group design using polyethene fibre (Kerr) and flowable composite resin (Kerr), prefabricated post-core (Kerr). The study was divided into four groups, namely prefabricated, fabricated with a volume of 1 fibre, 2 fibres, and 3 fibres, where each group consisted of 6 samples.

Three pieces of glass plate were prepared with dimensions 2 mm, 50 mm, and 25 mm (figure 1) the distance of each glass on the top layer of 2 mm and then glued with paper tape. Sheets of polyethene fibre are placed between the cracks of the top layer of glass and coated with flowable composite resin. Each spread is pressured, so the resin enters the gap between the fibres. Add fibre sheets until they reach a thickness of 2 mm. After that, irradiation was carried out for 20 seconds; the composite fibres were removed from the glass plate (figure 2). The same thing was done in groups 2 and 3. All good specimens were soaked in water for 24 hours at 37°C [14,15].

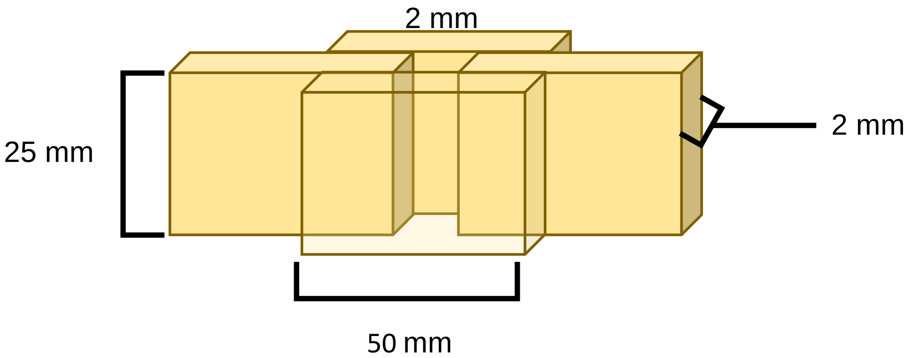

Figure 1. Preparation of fabricated post specimens by glass plates (mould space)

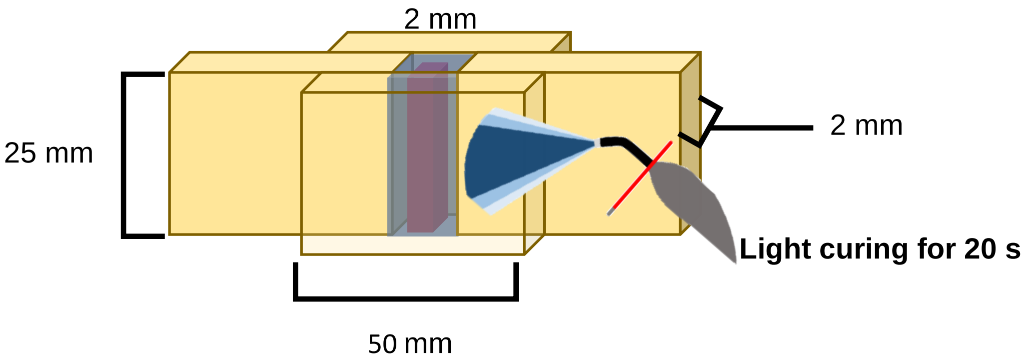

Figure 2. Processing Post-Core Fabricated FRC in mould space

(Red box represented fibres; blue box represented composite; light brown represented glass plate)

Three-point bending test by adjusting it according to the ISO10477 standard, namely the range of 15.0 mm; crosshead speed 1.0mm/min; cross-sectional diameter of the loading tip of 5 mm. This setting was used to measure the fracture strength of the specimen at room temperature using a universal testing machine (Autograph; AG-I 20kN, Shimadzu, Kyoto Japan). Loading was continued until the tooth specimen or sample showed a rupture or crack of approximately 85% of the loading point [16].

For measuring the effect of cyclic loading on the specimen, a three-point loading test was carried out with a range setting of 15.0 mm; cross-sectional diameter of the tip of the 5 mm loading applied to a frequency of 1 Hz and constant deflection. Constant deflection using a fatigue testing machine (Servopulser; EHF-FV05-10LA, Shimadzu, Kyoto, Japan) was 0.1, 0.2, and 0.3 mm. the loading will be indicated by a sinusoidal pattern with a maximum amplitude of 0.1, 0.2 and 0.3 mm and consumed for 1000 revolutions. After that, each specimen was carefully observed and statiscally tested to see if the three-point bending test failed.

RESULTS

Table 1. Descriptive of Elastic Modulus of Fabricated and Prefabricated FRC

Groups	Force (N*mm)	Diameter (mm)	Deflection (mm)	Length (mm)	Span lenght (mm)	ME (MPa)
1 fiber	123.33	2.02	0.97	50	20	27.56
2 fibers	124.17	2	1.40	50	20	19.11
3 fibers	117.50	2.07	2.07	50	20	12.19
Prefabricated	111.67	1.98	2.07	50	20	11.75

ME, modulus elasticity

FRC is a combination of a polymer matrix material with a coupling agent and fibre, which aims to strengthen the properties and functions of a material. The results showed that the fibre volume affected the magnitude of the force on the specimen, the deflection and the elastic modulus of the fabricated and prefabricated FRC. The maximum force on the specimen, until specimens were fractured, was affected by fibre volume—the lower the fibre volume, the higher force and the elastic modulus. Conversely, the amount of deflection increases with increasing fibre volume. One fibre volume of FRC represented the lowest deflection value (0.97 mm) and the highest elastic modulus (27.56 MPa) among the other groups. Although the deflection value of prefabricated FRC and three fibres volume of FRC presented the same deflection value and was the lowest among the other groups (2.07), the elastic modulus value of prefabricated FRC (11.75 MPa) was lower than that of three FRC fibres (12.19 MPa) (table 1).

Table 2. Descriptive analysis of modulus elasticity of fabricated fiber reinforced composite

Variables	groups	N	Mean	SD	SE	Min	Max	P value
Force (N*mm)	1 fiber	6	123.33	4.08	1.67	22.12	34.50	0.064
	2 fibers	6	124.17	3.76	1.54	14.99	22.12	

	3 fibers	6	117.50	10.84	4.42	9.23	13.97	
	Prefabricated	6	111.67	11.69	4.77	8.49	16.24	
Deflection (mm)	1 fiber	6	0.97	0.14	0.06	.80	1.20	0.000
	2 fibers	6	1.40	0.18	0.07	1.20	1.70	
	3 fibers	6	2.07	0.16	0.07	1.90	2.30	
	Prefabricated	6	2.07	0.27	0.11	1.70	2.50	
Modulus elasticity (MPa)	1 fiber	6	27.56	4.26	1.74	22.12	34.50	0.000
	2 fibers	6	19.11	2.65	1.08	14.99	22.12	
	3 fibers	6	12.19	1.92	0.78	9.23	13.97	
	Prefabricated	6	11.75	2.71	1.11	8.49	16.24	

Data described the Analysis of Varian (Anova) ($p<0.05$)

N, number of samples within group; *, significant difference; SD, standard deviation; SE, standard error; Min, minimum value; Max, maximum value

Table 3. Scheffe Post Hoc test on Modulus elasticity

Groups	Mean differences	P value
1 fiber – 2 fibers	8.455*	0.001*
1 fiber – 3 fibers	15.369*	0.000*
1 fiber – prefabricated	15.086*	0.000*
2 fibers – 3 fibers	6.914*	0.008*
2 fibers – prefabricated	7.351*	0.004*
3 fibers – prefabricated	0.437	0.996

Data described the multi comparison analysis by scheffe post hoc test

*, significant difference

The elastic modulus is the stiffness of a material affected by the deflection and the force on it. Table 2 revealed the maximum force on the specimen, the deflection and the modulus of elasticity. The highest fibre volume needed the lowest force. Although there was no significant difference in the magnitude of the force on the specimen ($p>0.05$), the force on the fibre with two fibres volume was more significant than the other groups (124.17 N*mm). Even though the force among the groups was the same, the alteration (deflection) of the specimens among the groups was significantly different ($p<0.05$), except for FRC 3 fibres with prefabricated. The results also indicated that the more fibre volume, the greater the deflection value (table 2).

The results showed a significant difference among the groups ($p<0.05$) in the value of the elastic modulus. The elastic modulus of FRC 1 fibre was the highest compared to the other groups (27.56 MPa), and the prefabricated FRC group had the lowest elastic modulus value (11.75 MPa). The post hoc Scheffe test results showed significant differences between treatment groups, except between the FRC 3 prefabricated fibre group ($p=0.996$) (table 3).

This recent study made FRC posts by embedding fibres parallelly to the longitudinal axis in a composite resin matrix. After that, the FRC post is subjected to elastic modulus testing by three-point bending. The posts were pressed between three points (2 points as support; 1 point as a point of compression or stress). The three-point bending test is a simulation test with a bridge-like design to determine the elastic modulus of material or elasticity. The result of this elastic modulus is significantly influenced by force applied to the specimen to cause a deformation (deflection) [17–19].

The results indicated that the volume of fibres affects the value of the deflection and elastic modulus of FRC posts. The greater the fibre volume, the lower the elastic modulus; in other words, the greater the fibre volume, the more elastic the FRC material. More fibre volume might reduce the force's power and distribute the specimen's load. Meanwhile, the low fibre volume could not distribute the load that hits it. One factor affecting FRC's mechanical strength is fibre volume/ density. Low concentrations can cause uneven fibre distribution, so some parts of the FRC are not supported by [14,20,21].

In addition, the position of the fibre, which is longitudinal and perpendicular to the point of the test equipment, affects the resistance of the FRC to compressive forces. The orientation of the fibre direction affects the strength of FRC, namely the direction of the fibre and its layout in the matrix. The smaller the fibre orientation angle, the greater the fracture resistance of the FRC. The characteristics of the FRC post, such as the ratio between the fibre and the composite resin, the width of the fibre, and the strength of the connection between the composite resin and the fibre, influence the FRC post's mechanical properties [22,23].

DISCUSSION

The number of fibres in the FRC fabricated post group with three fibres is more than the other fabricated FRC post groups. Fibre and composite composition would affect the density of FRC. FRC's density will affect the FRC posts' resistance in bearing the load. The static and dynamic properties of the FRC post depended on the density of the FRC post, which might be related to the fibre and composite composition. In addition, it was also influenced by the nature of the fibre interface [24,25].

The number of fibres will affect the elasticity of a material. A previous study stated that the fibre in this material increases the restorative material's elasticity. FRC is a combination of fibre material with a resin matrix. The purpose of combining resin matrix material with fibre as a post material is to strengthen the physical and mechanical properties of the post material so that it can be inert in the root canal and withstand the chewing load that hits it. Fibre has an important role in distributing pressure on FRC materials. The elasticity and ability to withstand loads depend on the amount of fibre and the type of woven fibre. The design of the woven fibre affects the effectiveness of load delivery along the woven fibre, which is delivered to the resin matrix [26–29].

This study uses the three-point bending test. This test will affect the post's biomechanical properties, especially the FRC post's flexural properties. The three-point bending test caused shear stress, and this will affect the validity of the flexural properties calculation. In the anisotropic test, it is better to use a ratio between the length of the span and the diameter of the test material, namely 40:1, to reduce shear stress (avoid failure). However, this study uses a ratio of 7.5:1. This is done considering that the load imposed on the test specimen is only one-way or isotropic [30–32].

The composite functions as a binder between fibres, a binder between FRC, root canals and a resin-based luting cement material. Composite resin is frequently used because of its high mechanical properties, good bonding ability with teeth, and adhesive properties. Composite resin is often used as a core build-up because it has hardness and fracture hardness similar to the natural tooth structure and can be prepared immediately after the curing process. According to a study by Burke, prepared amalgam core build-up placed according to the protocol showed higher fracture resistance compared to composite materials and glass ionomer cement. A material with a high modulus of elasticity has a low impact resistance. A sudden collision can come from trauma due to a sudden blow. The elastic modulus is an important parameter for determining the stress response of post and core materials where a material with a high elastic modulus absorbs more stress. A material must have a modulus of elasticity close to that of dentin. If a load is applied to a post and core system with a higher modulus of elasticity than dentin, the post and core system will not be able to follow the elastic deformation but will cause stress which can lead to root fracture.

CONCLUSION

The number of fibres of fabricated FRC posts affected on the elastic moduli of FRC post. The more fibres number, the more elastic the FRC, so the FRC more durable toward direct loading. However, this study needed further studies, especially effect the number of fibres to other mechanical test, such as impact strength.

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