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Research Report

Effects of silkworm fiber position on flexural and compressive properties of silk fiber-reinforced composites

Ariyani Faizah, Dendy Murdiyanto, Yulita Nur Widyawati and **Narawidya Laksmi Dewi**
Department of Biomaterials
Faculty of Dentistry, Universitas Muhammadiyah Surakarta
Surakarta – Indonesia

ABSTRACT

Background: *Fiber-reinforced composites represent a combination of fiber-reinforced composite materials. The availability of fiber within dentistry in Indonesia is limited and, therefore, requires lengthy advance ordering. The increasing use of fiber derived from natural materials, such as silk, is of greater concern due to its considerable mechanical strength, biocompatibility and wider availability. The application of fiber will increase the mechanical strength of fiber-reinforced composites, including both flexural and compression strength. One factor affecting the mechanical strength of fiber is the laying of fiber or fiber position.* ***Purpose:*** *The purpose of this research is to establish the influence of silkworm fiber position on both the flexural and compression strength of silk fiber-reinforced composites.* ***Methods:*** *Flexural strength and compression strength tests using a universal testing machine involved the division of the research population into three treatment groups: compression side, neutral side and tension side.* ***Results:*** *The results of data analysis indicated that the tension side group possessed the highest flexural strength (121.42 MPa), while the compression side group demonstrated the highest compression strength (337.65 MPa). A one-way ANOVA analysis test produced a significant result of p = 0.000 (<0.05) both for silkworm fiber position effect and compression strength of silk fiber reinforced composites.* ***Conclusion:*** *The position of silkworm fiber will affect its flexural strength as well as that of the compression of silk fiber-reinforced composites.*

Keywords: *silk worm fiber; flexural strength; compression strength; fiber position; silk fiber reinforced composite*

Correspondence: Ariyani Faizah, Department of Biomaterials, Faculty of Dentistry, Universitas Muhammadiyah Surakarta, Jl. Kebangkitan Nasional No. 101 Penumping, Laweyan, Kota Surakarta, Jawa Tengah 57141, Indonesia. E-mail: ariyani.faizah@ums.ac.id

INTRODUCTION

Tooth loss can inhibit chewing ability as well as reduce an individual's aesthetic appeal. In cases where large or old teeth are lost, it even reduces performance of the temporomandibular joints (TMJ). Other problems arising from tooth loss are impaired speech function and the psychological aspect related to aesthetics, especially for certain professions that require an attractive dental profile.[1] Treatment to replace a missing tooth usually necessitates use of a fixed denture (GTC).[2] Many materials are used in making GTCs, one of which is fiber-reinforced composite (FRC)[3] which has several advantages including: corrosion-free metal, non-toxic material, minimal preparation and limited maintenance time.[4,5]

FRC is a combination of fiber-reinforced polymer matrix consisting of a polymer monomer which serves to hold the fibers, maintain the pressure between the fibers and, finally, protect the fibers from the external environment. The use of fiber in FRC, thus, has the function of increasing its strength, stiffness and resistance to fracture.[6] Fibers commonly used in dentistry include: glass fiber, aramid fiber, carbon fiber and polyethylene fiber or ultra-high molecular weight polyethylene fiber (UHMWPE). E glass fiber is most commonly used in dentistry[7], having several advantages one of which is attractive aesthetic properties. Nevertheless, the availability of E glass fiber in Indonesia remains extremely limited with lengthy supply time frames.

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In order to overcome limited E glass fiber availability, certain natural fibers have been developed as alternatives to replace dental fiber. One such natural material widely available in Indonesia is silk fiber, with the village of Regaloh in the Pati regency[8] being one of the centers of the silk fiber processing industry. In fact, silk fibers have long been developed by the textile industry, their use being due to strong mechanical properties. Other advantages they offer comprise: strong environmental stability, biocompatibility and flexible shape.[9] Therefore, with such mechanical properties, fibers derived from silkworms are expected to be employed as biomaterials for non-dental fibers.[10]

The use of GTC in the oral cavity will, furthermore, generate a variety of pressures during the mastication process, namely: compressive strength, tensile strength and shear strength. Such clinical conditions should be taken into account when making GTC, especially that produced from FRC. Moreover, FRC used in the manufacture of GTC should possess strong mechanical properties with the aim of avoiding marginal degradation and restoration cracking.[11] The mechanical properties of the fibers are generally influenced by composite filler resin particles, fiber volume and fiber position.[12]

Many factors influence the mechanical strength of fibers including: their composition, volume, orientation and position. Fiber position refers to the laying position of fiber[12], differences in which can affect the amount of pressure distributed from the matrix to the fiber. For example, fiber placed on the compression side, neutral side and tension side will distribute pressure across all FRC layers.[13] Therefore, research into fiber position placed in the FRC component, needs to be conducted since fiber position is one of the factors that will support the mechanical strength of FRC following its application within the mouth. Hence, this research aimed to reveal the effects of certain silkworm fiber positions on the flexural and compressive strength of silk fiber-reinforced composites.

MATERIALS AND METHODS

The materials used in this research comprised packable composite resin (Filtek Z250 XT, 3M ESPE, USA), silkworm fiber (Pati, Central Java) and silane coupling agent (Monobond N, Vivadent Ivoclar, Liechtenstein). Preparation was conducted by first storing silkworm fibers in a desiccator for 24 hours in order to minimize their internal water concentration. These fibers were cut with scissors to a length of 25 mm suitable for a flexural strength test and also to a length of 3 mm for a compressive strength test. Having been weighed, 3 mg of the cut fibers were subjected to a flexural strength test, while 0.7 mg, equivalent to a layer of dental fiber, underwent a compressive strength test. Finally, the fibers used as samples for the flexural strength test were molded into 2 mm × 2 mm × 25 mm beams, while those used for the compressive strength test were formed into a cylinder 3 mm in height and 6 mm in diameter.[14] The molds used for this purpose were constructed from metal.

In the next stage, the samples were divided into three groups, namely: Group I (compression side), Group II (neutral side) and Group III (tension side), each consisting of nine samples. Thus, the research required a total of 27 specimens for each test. In Group I with the compression side position, up to three quarters of each mold was filled with the composite, i.e. about 1.5 mm from the top of the mold for the flexural strength samples and 4 mm for the compressive strength samples. The height of the composite filling used was marked using a small ruler, specifically designed to indicate the one-third, half-way and three-quarter points of the total height of the mold.

Each of the silkworm fibers was subsequently placed on a glass plate, with one drop of silane coupling agent being applied via micropipette. The fibers were allowed to stand for one minute and then dried for another minute with an electric fan. The silanized fiber was then placed with tweezers on the top of the composite. The composite resin was injected again over the fibers until they were fully immersed and flattened with a plastic implement. Polymerization was then carried out using a light curing unit. All samples were divided into four parts to enable each to undergo perfect polymerization due to its ability to adapt to the size of the light cure unit tip. Each part of the FRC was irradiated for 40 seconds, while the unlit part was covered with aluminum foil until all parts were irradiated. The sample was removed from the mold with any excess polymer being removed by disk polishing before the position of the fiber was indicated by means of a marker. The same procedure was conducted with both the tension side and neutral side groups, but the fibers were placed in one-third of each mold with the laying position on the tension side group. Meanwhile, the fibers were placed in the middle of each mold on the neutral side.

Prior to testing, each of the prepared samples was soaked in 20 ml of distilled water contained in a conical tube which was placed in an incubator at 37° C for 24 hours after which time the sample was removed and dried with absorbent paper. Then, flexural strength and compression strength tests were conducted by means of a universal testing machine at the Materials Laboratory, Mechanical Engineering Faculty, Universitas Gajah Mada (UGM). Both the flexure strength test and three-point bending test were performed using a Universal Testing Machine. The samples were placed on a support board at 20 mm intervals (1). Each sample was then subjected to 1 mm/min loading (P) at its center until a fracture occurred. Thereafter, a generated value (P) emerged on screen as the maximum load acceptable by the sample. The magnitude of flexural strength was then expressed in MPa with the data being

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analyzed using the following formula:

$$\sigma = \frac{(3P.1)}{2bd^2}$$

Note:
σ : flexural strength (MPa.)
P : maximum load that can be supported by the sample before the object fractures (Newton)
l : distance between support board and pedestal (mm).
b : sample width (mm).
d : thickness of the tested sample (mm).

Meanwhile, a Universal Testing Machine was used to measure compressive strength by placing each sample on the metal plate in the center of the machine and activating an engine moving at a speed of 1 mm/min which suppressed the sample until a fracture occured. The value of compression strength (MPa) could then be obtained using the following formula:[15]

$$CS = F / A$$

Note:
CS : Compressive Strength (MPa)
F : Compression load (N)
A : Sample base area l (mm^2)

Data on the flexural and compressive strengths were analyzed with a one-way ANOVA statistic test.

RESULTS

The results of the flexural strength test on the silk fiber reinforced composites of several silkworm fiber positions can be seen in Table 1. Its contents indicate that certain increases in the mean flexural strength value of silkworm fiber reinforced composites occurred, namely: 121.42 MPa in the tension side group, 95.25 MPa in the neutral side group and 65.84 Mpa in the compression group. The highest flexural strength was found in the tension side group (121.42 ± 1.07 MPa), while the lowest was in Group I, the compression side group (65.84 ± 0.86). The data was then subjected to a Saphiro-Wilk normality test in order to determine whether the data on the flexural strength was normally distributed. The results for each group indicated that all data relating to flexural strength was normally distributed ($p>0.05$).

In the next stage, the data on the flexural strength

Table 1. Mean and standard deviation of the flexural strength of the silk fiber reinforced composites (MPa)

Groups	n	$\bar{x}$	SD
I	9	65.84	±0.86
II	9	95.25	±1.03
III	9	121.42	±1.07

Table 2. Results of the LSD test on the flexural strength

Positions	Compression side	Neutral side	Tension side
Compression side		0.000	0.000
Neutral side			0.000
Tension side			

Table 3. Mean and standard deviation values of the fiber positions on the compressive strength of silkworm fiber reinforced composites (MPa)

Groups	n	$\bar{x}$	SD
I	9	337.65	±1.05
II	9	275.78	±0.86
III	9	259.02	±0.77

was subjected to homogeneity analysis using a Levene's test whose results showed that all data on the flexural strength was homogeneous ($p>0.05$). Thereafter, a one-way ANOVA test was conducted to analyze the effects of silkworm fiber positions on the flexural strength of silk fiber reinforced composites. The results of the one-way ANOVA test indicated that the silkworm fiber positions had significant effects on the flexural strength of silkworm fiber reinforced composites ($p<0.05$). A 95% confidence level LSD test was then carried out to determine the significance of flexural strength differences between the fiber silkworm position groups.

Based on the contents of Table 2 above, there was a significant difference ($p<0.05$) between the compression side group and both the neutral side and tension side groups. A significant difference also existed between the neutral side group in relation to the compression side and tension side groups. Similarly, there was a significant difference between the tension side group and the compression side and neutral side groups ($p<0.05$). The results of the compression strength test on the fiber silkworm positions can be seen in Table 3.

Table 3 showed the highest mean compressive strength value of silkworm fiber reinforced composites to be found in Group I, namely; the compression side group (337.65 ± 1.05 MPa). The data on the compressive strength was then tested further to analyze their normality using a Saphiro Wilk test. The results of the normality test indicated that the data of all three groups relating to compressive strength were normally distributed ($p>0.05$).

The data on the compressive strength was assessed for homogeneity using a Levene's test the results of which showed that the data on compressive strength was homogeneous with a significance value of 0.455 ($p>0.05$). A one-way ANOVA test was then conducted to analyze the effects of silkworm fiber positions on the compressive strength of silk fiber reinforced composites. Its results indicated that the silkworm fiber positions had significant effects on the compressive strength of silkworm fiber

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Table 4. Results of the LSD analysis of the compressive strength

	Compression side	Neutral side	Tension side
Compression side		0.000	0.000
Neutral side			0.000
Tension side			

reinforced composites (p<0.05). The Least Significant Difference test (LSD) with a 95% confidence level was then performed to determine the significance of compressive strength differences between the fiber silkworm position groups, the results of which are illustrated in Table 4.

Based on the LSD test results as depicted in Table 4, there were significant differences in the compressive strength of silkworm fiber reinforced composites between the compression side group, the neutral side group and the tension side group.

DISCUSSION

Differences in flexural strength are influenced by several factors, namely; fiber volume, position, type and orientation, as well as the impregnation of resin composite. These factors can determine the mechanical strength of fiber-reinforced composites since fiber is a component that acts as a pressure distributor.[16] The fiber type used in this study was that produced by silkworms due to the mechanical strength resulting from its fibroin content.

Since fiber is a potential component in the distribution of pressure, high mechanical strength is also influenced by fiber position. Flexural force is a mechanical force constituting a combination of compressive strength, tensile strength and shear strength. Increased flexural strength will occur if the fiber is placed on a weak denture area located on the tension side. The tension side position will then induce maximum tensile pressure in the fiber affecting the elongation of denture dimensions.[13] Thus, the maximum tensile pressure was detected in the tension side group within which the pressure will be distributed evenly within the FRC.[12]

On the other hand, the neutral and compression side groups did not demonstrate high flexural strength value. The placement of fibers on the middle or neutral side alone generated sufficient flexural strength and minimum tensile strength, but maximum shear strength. These observations suggest that the neutral side position exerts limited influence on flexural strength.[16] Meanwhile, the placement of fibers on the compression side is ineffective since pressure present there is not directly distributed to the FRC but, initially, to the composite.[17] Consequently, the position of the fibers in three-quarters of the mold base received only limited tensile strength with the result that flexural strength decreased. Conversely, fibers on the compression side will gain in compressive strength.[18]

Based on the results of the compressive strength test contained in Table 3, the compression side group generated the highest compressive strength compared to that of the tension side and neutral side groups. The results of the ANOVA test analysis then indicated that the different fiber positions significantly affected the compressive strength of silk with a significance value of 0.000 (p<0.05). The results of the Post Hoc test analysis combined with those of an LSD test showed that there were significant differences in the compressive strength of silk fiber reinforced composites between the groups (p<0.05) (Table 4).

Therefore, it can be said that the placement of fibers in a position corresponding to the pressure received by FRC can distribute the pressure efficiently and effectively resulting in increased mechanical strength, including compressive strength. It means that the position of the fiber on the compression side will distribute the pressure more appropriately in a manner producing higher compressive strength. In other words, the position of fiber on the compression side is more dominant in increasing the compressive strength of composite resin. The compression side position approaching the surface of the composite will experience a compression load. Therefore, the laying of fiber on the compression side will distribute the pressure and increase its resistance to the applied pressure. Meanwhile, the neutral side position will experience maximum shear strength and maximum tensile strength which prevents the effective distribution of compression pressure.[17]

Fiber-reinforced composite is now selected as a fixed denture material. Fixed dentures or GTC must possess sufficient mechanical strength to withstand mastication loads.[13] The mastication loads exerted on GTC include: compressive strength, shear strength and tensile strength. Compressive strength is received by the GTC at its top, shear strength at the center and tensile pressure at the bottom. This situation needs to be taken into consideration when FRC is employed as a material in the manufacture of GTC in order to produce the necessary mechanical strength to withstand the load experienced during the process of mastication.

As a result, fiber serving as a component that can distribute the pressure must be placed in an appropriate position to facilitate the effective and timely distribution of the pressure exerted on the GTC. The research findings showed that in order to achieve high flexural strength, fiber should be positioned on the tension side, while achieving good compressive strength required the placing of fiber on the compression side. Finally, it can be concluded that silkworm fiber positioned on the tension side will possess the greatest flexural strength of all silk fiber reinforced composites, while silkworm fiber placed on the compression side will demonstrate the highest compressive strength. This indicates that in order to obtain the desired mechanical strength results in the manufacture of GTC by using FRC, fiber placement should be conducted through a combination of tension side and compression side positions. The combination of fiber placement will then allow

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appropriate pressure distribution according to the pressure placed on the GTC during the mastication process.

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