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RESEARCH ARTICLE

Impregnation of various fiber tapes toward mechanical properties of dental fiber-reinforced composites

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ABSTRACT

Synthetic dental fiber tape for fiber reinforcement (FRC) restoration is relatively costly and its availability is still limited in Indonesia, so natural dental fibers have been used as an alternative material. The aim of this study was to assess the effect of impregnation of various fiber tape toward the flexural strength and hardness of FRC. The materials used were natural *Bombyx mori* silk fibers (Indonesia), dental polyethylene tape (Construct Kerr, USA), dental Quartz tape (Quartz Splint UD, France), dental E-glass tape (Everstick TM, GC, Japan), silane coupling agent (Ultradent, Jordan), and composite resin (Denfil-Flow, USA). Five groups of samples consisted of FRC with various fiber tapes were prepared: unidirectional-silk, braided-silk, quartz, polyethylene, and E-glass. The five groups of FRC were tested to determine the flexural strength and hardness. The results were analyzed by one-way ANOVA, followed by LSD test. The results showed that the highest flexural strength was in the quartz group (496.84 ± 109.14 MPa), while the lowest was in the braided-silk group (139.39 ± 4.30 MPa). The highest hardness property was in the unidirectional-silk group (141.29 ± 25.17 VHN), while the lowest was in the braided-silk group (139.39 ± 4.30 VHN). The ANOVA showed that various fiber tapes significantly influenced the flexural strength and hardness of FRC ($p < 0.05$). The LSD showed that the unidirectional-silk, braided-silk, and polyethylene groups demonstrated no significant difference. The LSD for hardness showed that the unidirectional-silk group had a significant difference with the other groups ($p < 0.05$). It can be concluded that various fiber tapes influenced the flexural strength and hardness of FRC. Natural silk fibers showed comparable flexural strength and hardness with the other fiber tapes.

Keywords: fiber tape; FRC; flexural strength; hardness

INTRODUCTION

The National Institute of Health Research and Development, Indonesian Ministry of Health reported that the percentage of Indonesian citizens who experienced cavities was 45.3%; that of missing/extracted teeth was 19%, and that of loose teeth was 10.4%. Various actions taken for treatment need were reported, namely dental fillings (4.3%), dentures and dental implants (1.6%), ortho and periodontal treatment (0.7%).[1] Dental care is still very little compared to the dental problems that arise. This is partly because the materials used for dental treatment are still imported, so the price is high, resulting in expensive dental treatment costs.

Recently, the need for reinforcement materials for fillings, splinting, preparing fixed dentures, dental bridges, implants, endodontic posts, space maintainers, and orthodontic retainers has increased rapidly due to an increase in consumer demand for dental restorations. The supply of polyethylene fiber, quartz, and E-glass synthetic reinforcing materials is insufficient due to restrictions on the import of goods from the government. Based on this condition, it is necessary to look for alternative and innovative materials to strengthen dental restorations which are strong, aesthetic, made from local source, renewable, and economical.

Research and use of natural fibers are growing rapidly nowadays because natural fibers have many advantages compared to artificial ones. Some of the advantages of natural fiber are:

it is lighter, easy to obtain, relatively affordable, and, most importantly, environmentally friendly. The use of natural fibers today has penetrated various fields of human life; just like artificial fibers, natural fibers can also be used as a modification of artificial fibers.

Research has shown that the use of silk fibers derived from the cocoons of *Bombyx mori* silkworm in dental restorations showed beneficial physical, mechanical, and biological properties.[2,3,4,5,6] Based on these reports, the use of dental restoration reinforcement made of silk fiber (silk-thread) can be further developed and will be very beneficial for the community. The composition of the fibers is known to have a significant effect on the mechanical properties.[7] The fiber arrangement can be prepared in unidirectional and multidirectional type like woven or braided. Fibers with a multidirectional arrangement are easy to control and adapt well to the contours and arches of the teeth, whereas fibers with a unidirectional arrangement have the advantage of easy wetting due to their thread-like shape.[8]

Restorations of FRC in the oral cavity must have good mechanical properties because they must be able to withstand masticatory loads. Flexural strength and hardness are mechanical properties that can be used as predictors in assessing the ability of restorative materials to withstand masticatory loads.[9] The aim of this study was to assess the effect of various fiber tapes impregnated with resin on the flexural strength and hardness of FRC.

MATERIALS AND METHODS

This was laboratory experimental research. The research was held at the Integrated Research Laboratory and the Vocational School Engineering Materials Laboratory, Faculty of Dentistry, Universitas Gadjah Mada, Indonesia. Information on the research materials used is shown in Table 1. Thirty FRC specimens were divided into 5 groups (n = 6). The distribution of the specimen groups is shown in Table 2. The research was declared feasible to be carried out in accordance

Table 1. Product information of current research

Materials	Manufacture	Description
Natural Silk	Local silk, Central Java, Indonesia	Natural organic silk fiber from *Bombyx mori* cocoon in the form of threads silanated with resin; prepared in unidirectional and braided tapes.
Construct	Kerr, USA	Synthetic organic fiber of UHMWPE silanated with resin without filler; prepared in braided tape.
Quartz Splint	Quartz Splint, France	Synthetic inorganic fiber of quartz fibers prewetted with resin; prepared in unidirectional tape.
everStick TM	Stick Tech Ltd, Finland	Synthetic inorganic fiber of E-glass fiber impregnated with bis-GMA and PMMA; prepared in unidirectional tape.
Denfil Flow	Vericom, Korea	Light-cured radiopaque flowable composite resin.
Silane	Ultradent Products, USA	Coupling agent used to prepare the surface for bonding resin.

Table 2. Description of FRC groups based on type of fibers tape

Group	Specimen number	Description
1	6	Resin impregnation on unidirectional-silk tape
2	6	Resin impregnation on braided-silk tape
3	6	Resin impregnation on braided-polyethylene tape
4	6	Resin impregnation on unidirectional-quartz tape
5	6	Resin impregnation on unidirectional-E-glass tape

with an ethical permit obtained from the Ethics Committee of the Faculty of Dentistry, Universitas Gadjah Mada, Indonesia by number 169/KE/FKG-UGM/EC/2022.

Unidirectional silk ribbons (group 1) were prepared by weighing 0.155 g of silk fiber then dipped in silane solution for 1 minute and dried. The fibers were arranged in a brass mold with a width of 2 mm and a length of 80 mm, then impregnated with flowable composite resin. Braided silk ribbons (group 2) were made by weighing 0.155 g of silk fiber, then the fibers were divided into 3 equal portions and braided. The braided fibers were laid out in a brass mold and impregnated with flowable composite resin. Group 3, 4, 5 of restoration tapes were ready-to-use silane-based restoration tapes purchased commercially.

Preparation of flexural strength test specimens was as follows. A fiber tape with a width of 2 mm and a length of 25 mm was prepared. A brass mold with a size of 2x2x25 mm was prepared and filled with flowable resin up to 0.5 mm. The fiber tape was placed on top of it, then filled with flowable resin again up to 2 mm. The flowable composite had to be impregnated until all the fiber surfaces were covered and the mold was completely full. The FRC surface was covered using a glass slide, then cured using an LED light curing unit (LED Woodpecker, China) perpendicular to the study specimen for 20 seconds. After the irradiation was complete, the specimen was removed from the mold. The specimens were immersed in distilled water for 24 hours in an incubator (MIR 162, Sanyo, Japan) at 37 °C.[10] The specimens were then ready to be tested for mechanical strength.

Flexural strength test (three-point bending test) using the Universal Testing Machine (Tokyo Testing Machine, Japan) was performed based on ISO 4049:2019. This test was carried out by placing the specimen on a support board with a distance of 20 mm (L), then the specimen was given a load right in the middle at a constant speed (1 mm/min) until it fractured. The number (P) appearing on the monitor screen showed the maximum pressure that can be accepted by the specimen. Next, the flexural strength was calculated in MPa units.[10]

The hardness test for the specimen using Vickers Hardness Testing Machine (Matsuzawa, Kanagawa, Japan) was evaluated based on ISO 6507-2. This test was carried out by placing the specimen on a support board with an angle of 136°, with a load of 294.2 N for 10 to 15 seconds. The length of the diagonal was measured with a microscope or measuring instrument capable of determining the length of the indentation on the diagonal. The measurement results can be seen using the Vickers hardness number. Vickers hardness number is a number given from the pressure application and surface area that has been measured based on the indentation of a pyramid-shaped indenter. This number can be calculated from the size of the indentation (F) and the average diagonal (d2) of the indentation.[10]

RESULTS

The mean and standard deviation of the flexural strength from the dental fiber-reinforced composite in this research are shown in Table 3. The flexural strengths varied from 139.39 ± 4.30 MPa (braided-silk) to 496.84 ± 109.14 MPa (unidirectional-quartz).

Table 3. Mean and standard deviation of FRC flexural strength (MPa) with various fibers tape

Group	Flexural Strength (MPa) Mean ± sd
Unidirectional-silk	141.29 ± 25.17 [a]
Braided-silk	139.39 ± 4.30 [a]
Braided-polyethylene	152.63 ± 15.21 [a]
Unidirectional-quartz	496.84 ±109.14 [b]
Unidirectional-E-Glass	328.64 ± 56.39 [b]

Table 4. Mean and standard deviation of FRC surface hardness (VHN) with various fibers tape

Group	Hardness (VHN)
Unidirectional-silk	109.67 ± 25.85[a]
Braided-silk	76.17 ± 16.40[b]
Braided-polyethylene	86.00 ± 12.20[b]
Unidirectional-quartz	80.50 ± 11.95[b]
Unidirectional-E-Glass	89.50 ± 10.35[b]

The statistical analysis using ANOVA proved that the type of fibers significantly influenced the flexural strength of dental FRC ($p < 0.05$). The LSD post hoc analysis showed that the unidirectional-silk and braided-silk groups had a significant difference ($p < 0.05$) with the other groups (braided-quartz and unidirectional-E-glass).

The mean surface hardness from the dental fiber-reinforced composite evaluated is shown in Table 4. The surface hardness varied from 76.17 ± 16.40 VHN (braided-silk) to 109.67 ± 25 VHN (unidirectional-silk). The statistical analysis using ANOVA proved that the type of fibers significantly influenced the surface hardness of dental FRC ($p < 0.05$). The LSD post hoc analysis showed that the surface hardness of the braided-silk group had a significant difference with that of the other groups ($p < 0.05$).

DISCUSSION

Composite resin restorations must have good mechanical properties because they must be able to withstand masticatory loads. Flexural strength is a mechanical property that can be used as a predictor to assess whether a material can withstand masticatory loads in the mouth.[9] Flexural strength is the ability of a material to withstand before fracture. The result showed that the highest flexural strength was shown by the unidirectional quartz fiber ribbon reinforcement. There are some possible causes of this finding. First, quartz fiber contains silica components like glass fiber which provides high strength. Compared to glass fiber, quartz silica fiber contains crystalline silica, while glass fiber contains amorphous silica.[11] Crystalline silica fiber was proven to have higher resistance to bending and fatigue than amorphous one. Second, the preparation of quartz fiber ribbon splint was in a unidirectional form. The unidirectional arrangement has the advantage of easy resin wetting because of its threadlike shape.[8] According to a previous study,[12] the difference in flexural strength can be affected by the impregnation or wetting of resin on fiber. Impregnation of fiber with resin is required to allow resin to be in contact with the surface of fiber. The absence of close contact can cause voids and porosity, resulting in more water absorption and a decrease in flexural strength after FRC immersion in water.

Fiber impregnation in this study used bis-GMA resin. The increase in flexural strength was also due to the bond between the silane coupling agent and bis-GMA. The silanol silane groups can bind to the hydroxyl groups of hydrolyzed monomers such as bis-GMA to form silyl ethers derived from bis-GMA. The presence of cracks and voids causes water absorption which will reduce mechanical strength and hydrolytic degradation of polysiloxane from FRC. In addition, the void due to the absence of fiber impregnation with resin can serve as a place for oxygen to be confined. Oxygen can inhibit the polymerization of the resin, thus reducing the strength of FRC.[13]

The result showed that silk fibers (unidirectional and braided) and polyethylene fiber did not have significant differences in terms of flexural strength. This might be because the three fibers were in the same group, namely organic fiber. When compared with glass fiber and polyethylene fiber, the inorganic fiber group showed higher flexural strength. Nonetheless, all the FRC sample groups in Table 3 could be said to produce mean flexural strength that met the ISO standards for dentistry, namely ≥ 50 Mpa.[14] Based on this, the five types of fiber tapes can be recommended for use as reinforcement for dental restorations.

Hardness is an indicator to determine the mechanical properties of a material against resistance, wear, and abrasion. Hardness is also associated with the stiffness and strength of a material. Hardness will affect the durability of restorative materials for the long term in the oral cavity.[15] Table 4 shows the highest hardness was found in FRC with the addition of unidirectional-silk tape (109.67 ± 25.85 VHN). This is possible because the tape used has a unidirectional woven arrangement so it is easy to wet and impregnate with resin, thus improving the mechanical properties of FRC, including hardness. Silk contains β-crystallites. It turns out that a better alignment of β-crystallites forms peptide chains which will correlatively lead to stronger silk fibers. Silk fibres have an excellent ability to absorb energy at high loading speed rates, superior to that of cotton and nylon. Silk fiber is stronger than an steel wire of equal thickness and, more importantly, does not show the phenomenon of yielding before breaking.[16] It is reported that silk is reactive to light, less chemically resistant, and absorbs water. However, it is abrasion resistant and biodegradable and has good elasticity. On the other hand, glass is unaffected by light, does not absorb water, does not naturally degrade, and is chemically inert.

This study was limited to the production of braided silk ribbon by dividing the measured fibers into 3 equal portions then braided manually by hand. The result of the braided ribbon was thicker than the commercial ones. This might cause less convenience to the patient, especially in relation to appearance although the strength was high. It is suggested for future research to examine the effect of the mechanical strength of more than 3 braided silk groups on patient convenience.

CONCLUSION

Based on the data analyzed, it can be stated that various fiber tapes influenced the flexural strength and hardness of dental FRC. Natural silk fibers, in the form of both unidirectional and braided tapes, showed comparable flexural strength and hardness with the other commercial fiber tapes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest with the data contained in the manuscript.

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