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RESEARCH ARTICLE

The effect of oil palm empty fruit bunch (*Elaeis guineensis Jacq.*) fiber addition at various volume fractions on the compressive strength of flowable composite resin

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ABSTRACT

Oil palm empty fruit bunch (OPEFB) fibers have emerged as a promising natural alternative to synthetic fibers due to their mechanical strength and biocompatibility, although research on their use as a reinforcing in composite resin remains limited. This study aimed to evaluate the effect of OPEFB fiber incorporation on the compressive strength of flowable composite resin. A true experimental design with a post-test-only control group was employed. The OPEFB fibers underwent chemical and double silane treatments and were randomly oriented prior to incorporation. Fifteen cylindrical specimens (6 mm × 12 mm) were allocated into three groups based on fiber volume fraction (0%, 1%, and 1.5%). Compressive strength was tested using a universal testing machine following ASTM D-695 standards. Data were analyzed using one-way ANOVA ($p < 0.05$) followed by a post-hoc Least Significant Difference (LSD) test. The mean compressive strength of flowable composite resins at 0%, 1%, and 1.5% OPEFB fiber volume fractions were 261.99 ± 17.64, 301.20 ± 19.26, 368.52 ± 14.90 MPa. One-way ANOVA test showed that the mean compressive strength in the three groups was significantly different ($p < 0.05$). The post-hoc LSD test showed significant differences ($p < 0.05$) among all groups. This study concluded that the incorporation of OPEFB fiber can enhance the compressive strength of flowable composite resin, with the highest reinforcement observed at the 1.5% OPEFB fiber volume fraction.

Keywords: compressive strength; *Elaeis guineensis Jacq*.; flowable composite resin; oil palm empty fruit bunch

INTRODUCTION

Tooth restoration is a treatment aimed at restoring and repairing the anatomical structure and function of teeth that have been damaged due to dental caries, trauma, or masticatory wear.[1] The selection of an appropriate restorative material plays a crucial role in the success of a restoration.[2,3] With the increasing demand from patients who expect restorations not only to support oral health but also to meet esthetic requirements, manufacturers continue to develop materials to meet these needs, such as glass ionomer cement (GIC) and composite resin.[3]

Excellent aesthetics, tooth-like color, resistance to abrasive forces, adhesion to tooth structures, and ease of handling are the advantages of composite resin, making it increasingly popular for use in both anterior and posterior teeth. The main components of composite resin consist of a matrix, coupling agent, filler, and an activator-initiator system.[1,2] Based on usage characteristics, composite resins are classified into packable composite resin and flowable composite resin. Flowable composite resin is characterized by its high fluidity and excellent marginal adaptation. It can be used for Class I, II, and V restorations and is also effective as a cavity liner. However, its low filler content results in inferior mechanical properties.[4] Since mastication primarily generates compressive forces, especially in posterior teeth, the compressive strength of restorative materials should approximate that of natural tooth structures.[1]

Compressive strength refers to the ability of a material to withstand an applied load before

fracture occurs. It is essential for resisting occlusal forces and maintaining masticatory function.[5] To overcome the limitation of flowable composite resin in terms of compressive strength, fiber reinforcement can be incorporated, forming a fiber-reinforced composite (FRC). FRC has various clinical applications such as splinting, fixed partial dentures, dentin replacement, and post-endodontic restorations. FRC is commonly combined with flowable composite resin as it provides a more stable bond between the tooth structure and the fibers.[6,7] Fibers in FRC distribute stresses more evenly and reduce external loads, thereby enhancing the compressive strength of flowable composite resin.[8] The amount of fiber in FRC is expressed as a volume fraction, as the mechanical properties of FRC depend on the fiber volume used. These properties generally increase with higher fiber volume fractions.[7,8]

Fibers in FRC may be synthetic or natural. Commonly used fibers include synthetic ones such as e-glass and polyethylene fibers due to their strength and esthetic qualities. However, their limited availability and high cost in Indonesia make natural fibers a promising alternative.[9] As environmental sustainability becomes a global priority, natural fibers are increasingly employed as renewable reinforcements, driven by recent findings that confirm their mechanical strength and eco-friendly characteristics. Natural fibers may be derived from plants such as sisal, cotton, kenaf, coir, oil palm empty fruit bunch (OPEFB), and others.[10,11]

OPEFB fiber is an agricultural waste product from palm oil (*Elaeis guineensis Jacq*.) processing that is largely underutilized, commonly used only as compost or land filler, which can contribute to environmental pollution.[12,13] Indonesia is the world's largest palm oil producer, with the Central Bureau of Statistics reporting a production of 46.2 million tons in 2022. Approximately 22% of this yield consists of OPEFB waste.[14] OPEFB fibers have high cellulose content, giving them good mechanical properties.[13,15] Moreover, OPEFB fibers demonstrate superior performance compared to other natural fibers such as jute, hemp, linen, kenaf, and sisal.[16]

Previous studies on natural fibers as reinforcement materials for composite resins have been conducted by several researchers. Hadianto et al demonstrated that sisal fiber enhanced the flexural strength of composite resin at a 1% volume fraction, although the strength decreased at higher fractions due to inadequate fiber wetting by the coupling agent.[17] Similarly, Wan Theng et al reported that kenaf fibers at 1% and 2% did not improve the flexural or compressive strength of composite resin, owing to insufficient fiber surface characteristics to establish strong bonding with the resin matrix.[18] Research by Fransiska et al on silk fibers indicated an optimal flexural strength at a 5% volume fraction, which declined as the fraction increased because of weak interfacial adhesion.[9] Abdullah et al further reported that OPEFB fibers exhibit favorable mechanical properties and a rough, porous surface that promotes strong adhesion when used to reinforce polymer composites.[15]

However, studies on the reinforcement of flowable composite resin using OPEFB fiber in dentistry remain limited. Therefore, this study aims to determine the effects of adding OPEFB fibers at 0%, 1%, and 1.5% volume fractions on the compressive strength of flowable composite resin.

MATERIALS AND METHODS

This was a laboratory-based experimental study. The experiment was conducted at the Central Laboratory, Andalas University, the Materials Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Andalas University, and the Metallurgy Laboratory, Faculty of Engineering, Andalas University. Plant identification was confirmed by the Herbarium of Andalas University (ANDA). Ethical clearance for this study was obtained from the Ethics and Advocacy Committee, Faculty of Medicine, Andalas University (No.11/UN.16/KKEP-FK/2025).

A total of 15 fiber-reinforced composite (FRC) samples were prepared, divided into three groups with fiber volume fractions of 0%, 1%, and 1.5% (n = 3). The volume fraction was calculated by

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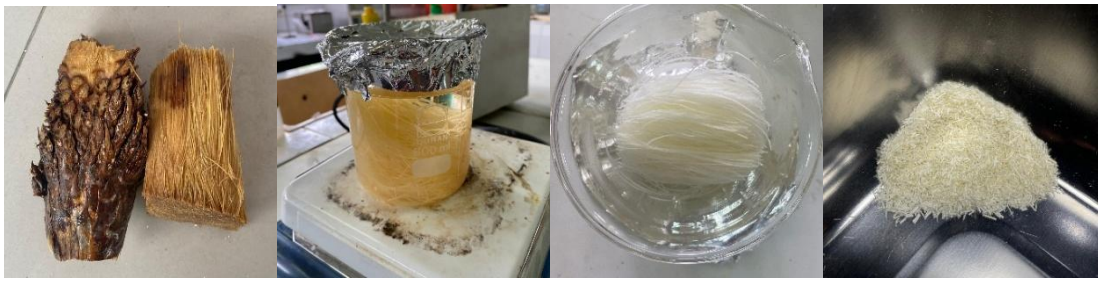

Figure 1. Stages of chemical treatment of oil palm empty fruit bunch (OPEFB) fiber: (A) raw OPEFB; (B) alkalization using a 10% NaOH solution with a fiber-to-NaOH ratio of 1:20 (w/v); (C) bleaching using a 3.22% $NaClO_2$ solution with a fiber-to-$NaClO_2$ ratio of 1:25 (w/v); and (D) chopped fiber

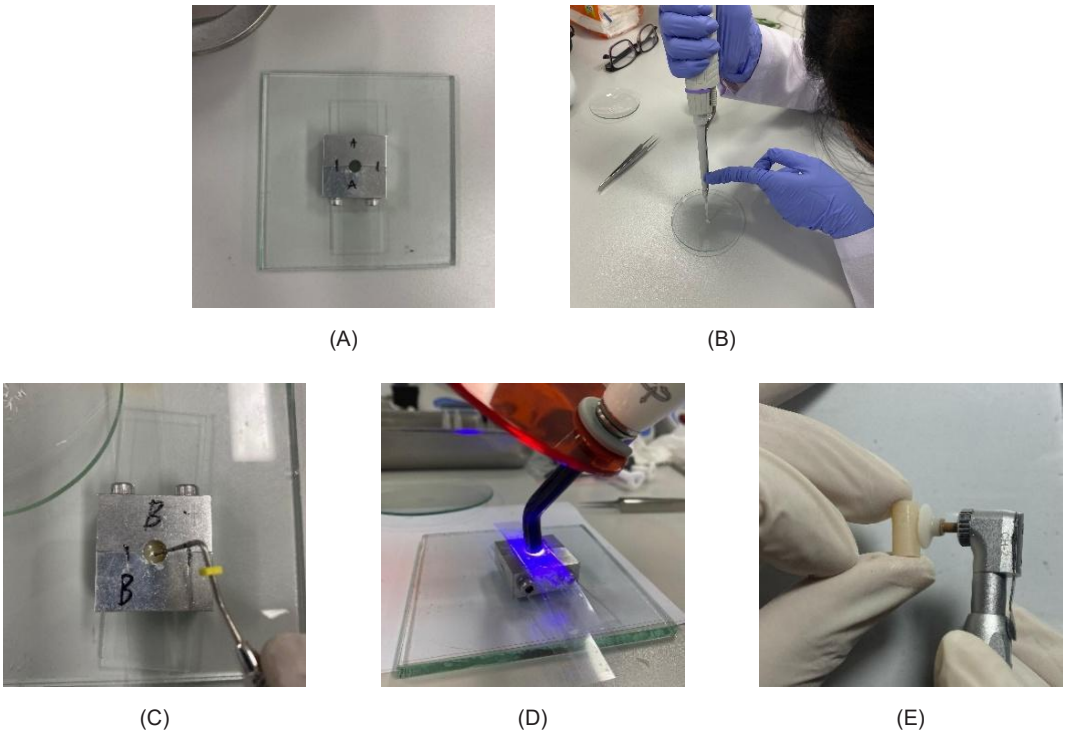

Figure 2. Stages of FRC specimen preparation (A) Cylindrical mold (B) Silane application and sample mixing (C) Injection into the mold (D) Curing process (E) Specimen polishing

converting the volume percentage into weight using the formula:[19]

$$V_f\,(\%) = (W_f / r_f) / (W_f / r_f + W_r / r_r) \times 100\% \quad (1)$$

Description:

- V_f (%) = OPEFB fiber volume (%)
- W_f = OPEB fiber weight (g)
- r_f = OPEFB fiber density (g/cm^3)
- W_r = Weight of resin matrix without fiber (g)
- r_r = Resin matrix density (g/cm^3)

The collected OPEFB fibers (PT. Agrindo Indah Persada, Merangin, Jambi) were chemically treated using the method described by Susi et al. (2023). OPEFB fibers were washed, manually separated, soaked in 2% soap solution for 5 hours, rinsed, and then dried in an oven at 60 °C for 48 hours. Bleaching was carried out using 3.22% $NaClO_2$ solution (1:25 w/v) at 75 °C ± 5 °C with pH adjusted to 4–4.5 using acetic acid for 1 hour and repeated twice. The fibers were rinsed with distilled water until a neutral pH was achieved and subsequently

Figure 3. Stages of compressive strength testing using a universal testing machine

alkalized with 10% NaOH solution (1 : 20 w/v) at room temperature for 2 hours, followed by rinsing to neutral pH.[12] After oven drying at 60 °C for 24 hours, the fibers were cut to approximately 1 mm and weighed to determine the amount according to the designated fiber volume fractions of 0%, 1%, and 1.5%. Weighing was performed using a digital analytical balance with 0.0001 g accuracy (ABS 220, Kern, Germany).

A cylindrical metal mold with dimensions of 6 mm diameter and 12 mm height, following ASTM D-695 (ASTM, 2023), was marked at every 2 mm for light-curing guidance and placed on a glass plate. The OPEFB fibers were treated with silane (Ultradent Products Inc., USA) in a ratio of 2.0 µl silane per 1.0 mg fiber, applied twice for a total of 60 seconds. The fibers were randomly oriented and manually mixed with flowable composite resin (Filtek Z350 XT Flowable, 3M ESPE, USA) using a figure-eight motion, then inserted into the mold using a layer-by-layer technique (every 2 mm) followed by light curing.[9] The FRC surface was covered with a celluloid strip and cured with a light-curing unit perpendicularly at the marked levels. Curing was repeated at the bottom of the specimen in the same manner. After curing, the specimens were removed from the mold and excess resin was finished using Enhance burs.

The specimens were stored in an incubator at 37 °C for 24 hours before compressive strength testing was performed using a universal testing machine (UTM AMU-10, Torsee, Japan) according to ASTM D-695:2023. The data obtained were then calculated using the following formula:

$$CS = 4P / \pi D^2 \quad (2)$$

Description:

CS = Compressive strength
P = Axial load (N)
πD^2 = Surface area (mm^2)

Subsequently, parametric statistical analysis was carried out using one-way analysis of variance (ANOVA) to evaluate the effect of OPEFB fiber volume fraction on the compressive strength of fiber-reinforced composite, with a significance level of $p < 0.05$. Post-hoc LSD testing was then performed to determine the magnitude of the mean differences between groups.

Table 1. Compressive strength of flowable composite resin with OPEFB fiber reinforcement

Groups	n	Mean ± SD (MPa)	Min (MPa)	Max (MPa)
0% OPEFB Fiber	5	262.00 ± 17.65	235.97	282.82
1% OPEFB Fiber	5	301.21 ± 19.26	284.56	326.20
1.5% OPEFB Fiber	5	368.53 ± 14.90	350.49	386.93

Table 2. One-Way ANOVA results for compressive strength of flowable composite resin with OPEFB fiber reinforcement

Groups	n	Mean ± SD (MPa)	p
0% OPEFB Fiber	5	262.00 ± 17.65	
1% OPEFB Fiber	5	301.21 ± 19.26	< 0.001
1.5% OPEFB Fiber	5	368.53 ± 14.90	

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Table 3. Post-Hoc LSD test results for compressive strength of flowable composite resin with OPEFB fiber reinforcement

Groups	0% OPEFB Fiber	1% OPEFB Fiber	1.5% OPEFB Fiber
0% OPEFB Fiber		0.004*	< 0.001*
1% OPEFB Fiber			< 0.001*
1.5% OPEFB Fiber			

RESULTS

The mean compressive strength values of flowable composite resin reinforced with OPEFB fibers at various volume fractions are presented in the following Table:

Based on Table 1, the mean compressive strength of flowable composite resin reinforced with 1% OPEFB fiber was 301.21 ± 19.26 MPa. The highest mean compressive strength was observed in the 1.5% OPEFB fiber group at 368.53 ± 14.90 MPa, while the lowest mean was found in the control group without fiber reinforcement (0%) (262.00 ± 17.65 MPa).

Normality testing in each group using the Shapiro-Wilk test showed p values greater than 0.05, indicating that the data were normally distributed. Homogeneity testing with Levene's test also demonstrated homogeneity ($p > 0.05$). Therefore, a parametric analysis using one-way ANOVA was appropriate, as the assumptions of normality and homogeneity were satisfied.

The results of the one-way ANOVA presented in Table 2 show $p < 0.001$, indicating a statistically significant difference in compressive strength among the three groups. Following the significant ANOVA result, a post-hoc Least Significant Difference (LSD) test was conducted to determine the specific differences between groups. Based on Table 3, significant differences were observed in compressive strength when the 1.5% OPEFB fiber group was compared with both the 0% and 1% OPEFB fiber groups ($p < 0.05$).

DISCUSSION

This study was conducted to evaluate the compressive strength of flowable composite resin reinforced with OPEFB fibers at various volume fractions. Compressive strength is defined as the capacity of flowable composite resin to withstand stress until fracture or deformation occurs.[5] The compressive strength of flowable composite resin generally ranges from 210 to 300 MPa.[1] In this study, the highest mean compressive strength was observed in the 1.5% OPEFB fiber group, while the lowest was found in the 0% OPEFB fiber group. This indicates that the addition of OPEFB fibers to flowable composite resin increases its compressive strength compared to the non-reinforced group.

Fibers within the composite resin distribute stresses more evenly and reduce external loads, thereby enhancing compressive strength.[8] OPEFB fibers contain cellulose ranging between 42.7%–65%.[16] Cellulose, a semicrystalline polysaccharide derived from plant-based natural fibers, consists of fibrils that form hydrogen bonds, providing strength, rigidity, and biocompatibility to OPEFB fibers.[14] This finding is consistent with studies by Cevanti et al and Nugroho et al, which reported that cellulose-based plant fibers can enhance the compressive strength of composite resin. This effect occurs because cellulose contains hydroxyl groups that can bond with the resin matrix.[20,21]

Cellulose is insoluble in water, alcohol, or ether, and does not undergo melting even when heated to 260–270 °C.[22] OPEFB cellulose fibers have a rough and porous surface, which facilitates bonding with the resin matrix.[15,23] In this study, cellulose isolation from OPEFB fibers was performed using alkalization and bleaching, following the method developed by Susi et al. This process is essential to remove amorphous layers that hinder fiber–resin bonding.[12] This finding aligns with Widyasrini and Sunarintyas, who reported that alkalization disrupts amorphous surface layers, creating a rougher surface that enhances fiber–resin adhesion.[24]

Another factor influencing compressive strength is the application of silane as a coupling agent. Silane acts through hydrolysis and condensation processes.[6] During hydrolysis, silanol (Si–OH) or alkoxysilane groups are formed, which then undergo condensation from monoalkoxysilane to dialkoxysilane and eventually trialkoxysilane.[25] Drying promotes condensation, indicated by the physical transformation from liquid to more solid form. Trialkoxysilane groups are responsible for adhesion between the fibers and the resin composite.[26,27] In this study, silane was applied twice with two drying steps. This agrees with Faizah and Pratiwi, who stated that repeated silane application allows successive hydrolysis of the outer and intermediate layers, leading to optimal mechanical properties when applied twice.[28]

Fiber orientation also contributes to the compressive strength of flowable composite resin. This study used short randomly oriented chopped fibers of approximately 1 mm in length. Randomly oriented fibers exhibit isotropic properties, providing reinforcement in multiple directions.[29,30] This is consistent with Fonseca et al, who reported that randomly distributed short fibers increase the compressive strength and fracture toughness of composite resins.[31]

The increase in compressive strength is also influenced by fiber volume fraction. Based on the post-hoc LSD test (Table 3), significant differences were observed between groups with fiber fractions of 0%, 1%, and 1.5%. Volume fraction refers to the quantity of fibers incorporated into the composite resin to enhance its mechanical properties.[6] This is consistent with studies by Fransiska et al and Lassila et al, which demonstrated that fiber volume fraction affects the mechanical properties of composite resin. This effect occurs due to differences in thickness between the composite resin matrix and the additional reinforcing fibers.[9,32]

This study has several limitations, particularly in material characterization. Because the research focused solely on evaluating the compressive strength of the flowable composite resin, FTIR and XRD analyses were not performed, limiting the understanding of fiber crystallinity that may influence fiber–matrix interactions. SEM analysis was also not conducted, preventing direct observation of surface morphology and failure patterns. Therefore, future studies should incorporate these characterization techniques, expand mechanical testing, and optimize the alkaline treatment of OPEFB fibers to support their potential as reinforcement materials for composite resins in dentistry.

CONCLUSION

The present study demonstrated that the incorporation of OPEFB fibers significantly increased the compressive strength of flowable composite resin. The highest compressive strength was observed in the 1.5% fiber volume group, followed by the 1% group, while the lowest was in the control group without fiber reinforcement. These findings indicate that higher fiber volume fractions lead to improved mechanical performance, highlighting the potential of OPEFB fibers as a natural alternative reinforcement material in dental composite resins.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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