RESEARCH PAPER

Mechanical Performance Evaluation of Ramie Fibre–Reinforced Dental Composite: Compressive Strength, Flexural Strength and Microhardness

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Abstract

Background: Fiber-reinforced dental composites are designed to improve stress distribution and resistance to fracture. The present thesis investigated ramie fibre as a natural reinforcing phase in a dental composite. Aim: To compare compressive strength, flexural strength and surface microhardness of a 1% ramie fibre-reinforced dental composite with the commercially available short-fibre-reinforced composite everX Flow. Methods: Ramie fibres were surface modified by alkaline treatment and silanization and reduced in size by ball milling. Following pilot evaluation, 1% fibre concentration was selected. Thirty specimens of the experimental composite and 30 everX Flow specimens were evaluated. Compressive strength was measured using cylindrical specimens in a universal testing machine; flexural strength was measured by three-point bending; and microhardness was assessed by the Vickers test. Results: Compressive strength was 2206.77±291.43 MPa for 1% ramie and 2209.64±276.17 MPa for everX Flow, with no significant difference (t=0.039, df=58, p=0.969). Flexural strength was 145.98±17.86 MPa and 153.69±18.43 MPa, respectively, with no significant difference (t=1.646, df=58, p=0.105). The thesis narrative reports microhardness of 31.94±6 VHN for ramie and 30.52±6 VHN for everX Flow, whereas Table 7 reports 31.94±4.13 and 30.52±8.55 VHN; the independent-samples t-test was t=−0.819, df=58, p=0.416. Conclusion: Under the tested in vitro conditions, 1% ramie fibre reinforcement did not significantly compromise compressive strength, flexural strength or microhardness compared with everX Flow.

Keywords: ramie fibre; fibre-reinforced composite; compressive strength; flexural strength; microhardness; Vickers hardness; dental composite

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1. Introduction

Endodontically treated teeth may have reduced structural integrity because of the cumulative loss of tooth structure resulting from caries, trauma, previous restorations, access cavity preparation, and subsequent endodontic procedures. The removal of dentinal tissue, particularly from the marginal ridges and other structurally important regions, can reduce the tooth's ability to withstand functional loading and may increase susceptibility to deformation, crack initiation and fracture. In addition, endodontically treated teeth are frequently restored in conditions in which the remaining tooth structure must withstand complex and repetitive occlusal forces. Consequently, the restorative material plays an important role not only in replacing the lost tooth structure but also in contributing to the overall mechanical behaviour of the restored tooth. An ideal restorative material for such applications should therefore provide adequate strength and resistance to mechanical stresses while permitting a minimally invasive and conservative restorative approach. [1,2]

Adhesive restorative techniques have become an integral component of contemporary restorative dentistry because they permit preservation of sound dental tissues and facilitate bonding between the restorative material and tooth substrate. Resin-based composites are widely used in adhesive dentistry because of their favourable esthetics, handling characteristics, versatility and ability to bond to tooth structure through contemporary adhesive systems. However, conventional flowable resin-based materials generally contain a relatively high proportion of resin matrix and may demonstrate lower mechanical properties than highly filled restorative composites. Their use in situations where the restorative material is expected to make a substantial contribution to the reinforcement of structurally compromised teeth may therefore require additional strategies to improve their mechanical performance. One such approach is the incorporation of reinforcing fibres into the resin matrix. Fiber reinforcement can improve load transfer within the composite and may influence crack initiation and propagation by mechanisms including stress transfer, crack deflection, crack bridging and energy dissipation. [3,4]

Among the different approaches to fibre reinforcement, short-fibre-reinforced composites have attracted considerable interest because they combine the handling characteristics of resin composites with the reinforcing potential of dispersed fibres. Unlike continuous fibre systems, short fibres are distributed throughout the resin matrix and can provide reinforcement in multiple orientations. When subjected to an external load, the fibres can contribute to the distribution and transfer of stresses within the composite, potentially reducing the concentration of stresses within the resin matrix. The randomly or semi-randomly dispersed fibre architecture may also provide a more isotropic reinforcing effect compared with reinforcement that is restricted predominantly to a single fibre direction. These characteristics make short-fibre-reinforced composites particularly relevant for restorative applications in which resistance to different modes of mechanical loading is required. EverX Flow was used as the commercial control in the present thesis, providing a clinically relevant short-fibre-reinforced composite against which the experimental material could be evaluated. [5,6,7]

In recent years, increasing attention has also been directed toward the development of naturally derived reinforcing fibres as alternatives or complements to conventional synthetic reinforcement systems. Natural fibres possess several potentially favourable characteristics, including renewability, relatively low density and the possibility of obtaining useful mechanical reinforcement when appropriate fibre–matrix adhesion is achieved. However, the incorporation of natural fibres into polymeric restorative materials presents specific challenges. The hydrophilic nature of many natural fibres can result in limited compatibility with hydrophobic resin matrices, while surface impurities, moisture and the chemical composition of the fibre can influence interfacial bonding. Appropriate fibre surface modification and dimensional reduction are therefore important considerations when developing natural-fibre-reinforced resin composites.

Ramie fibre was selected as a natural reinforcement in the present thesis because of its potential as a cellulose-rich reinforcing material. To improve its suitability for incorporation into the resin matrix, the thesis developed a surface-treated ramie formulation involving alkaline treatment, silanization and ball milling. Alkaline treatment can modify the fibre surface by removing or reducing non-cellulosic components and exposing a greater proportion of the cellulose-rich structure. Subsequent silanization is intended to improve chemical interaction between the treated fibre surface and the resin matrix, thereby promoting interfacial adhesion and facilitating more effective stress transfer. Ball milling further reduces the fibre dimensions and assists in obtaining a form suitable for incorporation into the composite matrix. Following the evaluation of different formulations, 1% fibre was selected for the final experimental composite. [13,14,15,16,18]

The mechanical characterization of a restorative composite requires assessment of more than one property because different mechanical tests reproduce different aspects of the stresses encountered during clinical function. Compressive strength provides information regarding the ability of a material to withstand predominantly axial compressive loading and is particularly relevant because posterior restorative materials are subjected to substantial compressive forces during mastication. Flexural strength evaluates the behaviour of the material when subjected to bending and provides an indication of its ability to resist fracture under combined tensile and compressive stresses. Surface microhardness, in contrast, provides information regarding the resistance of the material surface to localized indentation and may offer insight into the degree of surface mechanical integrity and polymerized matrix characteristics.

The present focused manuscript therefore considers only three mechanical outcomes: compressive strength, flexural strength and surface microhardness. These properties provide complementary information regarding resistance to axial loading, bending-related fracture and localized surface indentation, respectively. Evaluation of these parameters allows a focused comparison of the experimental 1% surface-treated ramie-fibre-reinforced composite with the selected commercial short-fibre-reinforced control and conventional restorative material, while maintaining the scope of the investigation specifically within the mechanical performance of the developed restorative composite.

2. Aim and Objectives

Aim: To evaluate and compare the compressive strength, flexural strength and microhardness of a 1% ramie fibre-reinforced dental composite with everX Flow.

1. To fabricate the 1% ramie fibre-reinforced dental composite.
2. To compare compressive strength between 1% ramie and everX Flow.
3. To compare flexural strength between 1% ramie and everX Flow.
4. To compare surface microhardness between 1% ramie and everX Flow.
5. To determine the statistical significance of differences between the two materials.

3. Materials and Methods

3.1 Study design and groups

The source thesis describes an in vitro experimental comparison of a 1% ramie fibre-reinforced dental composite with everX Flow. Each principal mechanical test used 30 specimens per group.

Group	Material	n
Control	everX Flow	30
Experimental	1% Ramie Fibre Reinforced Composite	30
Total		60

3.2 Fibre processing and composite formulation

Ramie fibres underwent alkaline treatment, washing, drying, ball milling and silanization before incorporation. The optimized formulation contained 1 wt% treated ramie fibre. The thesis describes a Bis-GMA/TEGDMA resin matrix with approximately 70 wt% inorganic fillers such as silica or barium glass. Controlled mechanical mixing was used to promote homogeneous fibre distribution and reduce agglomeration. [17,19]

3.3 Compressive strength

Cylindrical specimens measuring 4 mm in diameter and 6 mm in height were fabricated. Specimens were light cured, stored in distilled water at 37°C for 24 hours, and tested vertically in a universal testing machine at a crosshead speed of 1 mm/min until fracture. Maximum failure load was recorded and compressive strength was expressed in MPa. The thesis describes the method as following ISO 9917 and ADA Specification No. 27. [23]

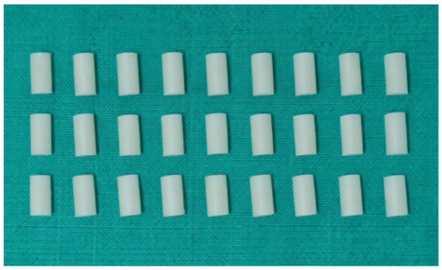


Figure 1. Thirty everX Flow specimens prepared for compressive strength testing (4 mm × 6 mm).

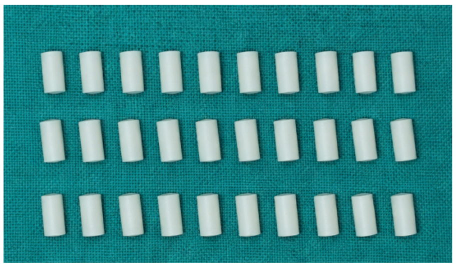


Figure 2. Thirty 1% ramie fibre-reinforced dental composite specimens prepared for compressive strength testing (4 mm × 6 mm).

3.4 Flexural strength

Rectangular specimens measuring 25 mm × 2 mm × 2 mm were fabricated and light cured. Specimens were stored in distilled water at 37°C for 24 hours. Three-point bending was performed using a 20-mm support span and a crosshead speed of 0.75 mm/min until fracture. Flexural strength was calculated in MPa using the ISO 4049 formula. [24]

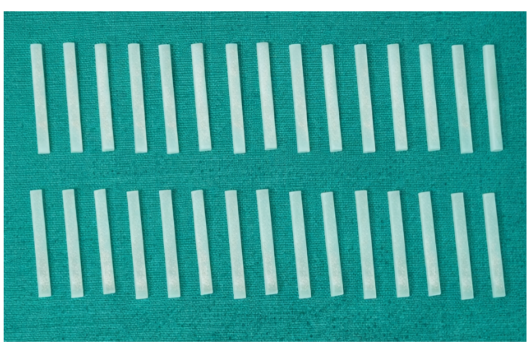


Figure 3. Thirty everX Flow specimens prepared for flexural strength testing (25 mm × 2 mm × 2 mm).

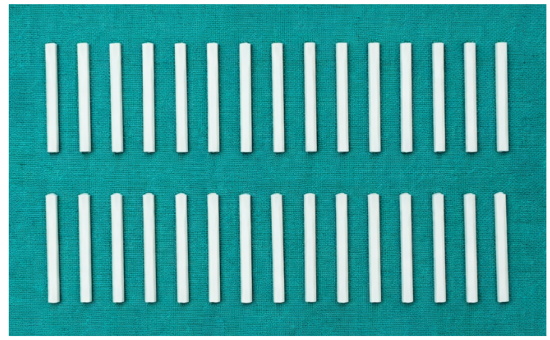


Figure 4. Thirty 1% ramie fibre-reinforced composite specimens prepared for flexural strength testing (25 mm × 2 mm × 2 mm).

3.5 Surface microhardness

Surface hardness was assessed using a Vickers microhardness tester. The dedicated hardness-method section describes disc specimens measuring 6 mm in diameter and 2 mm in thickness; the general specimen-preparation section reports 10 mm × 2 mm. The thesis therefore contains an internal dimensional discrepancy, which is retained here. Specimens were polished before testing. Three indentations were made at different locations and averaged, with values expressed as Vickers Hardness Number (VHN). The method describes a standardized load commonly of 200 g and a dwell time of 15 seconds. [9,10]

Figure 5. Vickers hardness tester MHV 1000Z used for microhardness testing.

3.6 Statistical analysis

The thesis reports use of IBM SPSS Statistics Version 25.0. Normality was assessed using the Shapiro–Wilk test. Independent-samples t-tests were used to compare the two groups. Statistical significance was set at $p<0.05$. [23,24]

4. Results

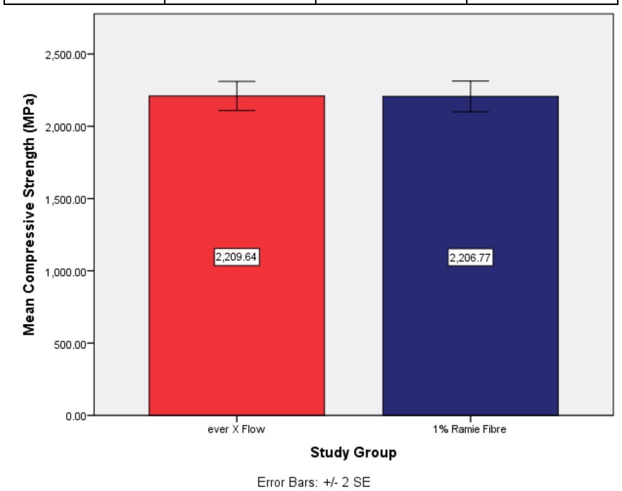
4.1 Compressive strength

The mean compressive strength of everX Flow was 2209.64±276.17 MPa, whereas the 1% ramie fibre-reinforced composite demonstrated 2206.77±291.43 MPa.

Independent-samples t-test analysis showed no statistically significant difference (t=0.039, df=58, p=0.969), indicating comparable compressive performance. Shapiro–Wilk testing confirmed normal distribution for everX Flow (p=0.687) and 1% ramie fibre composite (p=0.913). [5,6,21,22]

Group	N	Mean (MPa)	SD	Shapiro–Wilk p
everX Flow	30	2209.64±276.17	276.17	0.687
1% Ramie Fibre	30	2206.77±291.43	291.43	0.913

Test	t-value	df	Sig. (2-tailed)
Independent samples t-test	0.039	58	0.969



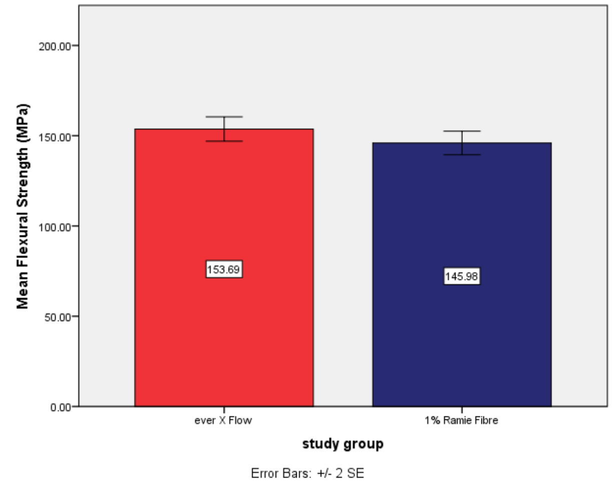
Graph 1. Graphical representation of mean comparison of compressive strength (MPa) between everX Flow and 1% ramie fibre-reinforced composite.

4.2 Flexural strength

The mean flexural strength of everX Flow was 153.69 MPa, while the 1% ramie fibre-reinforced composite demonstrated 145.98 MPa. Each group consisted of 30 specimens. The ramie group showed a slightly lower mean value, but the difference was not statistically significant (t=1.646, df=58, p=0.105). [4,5,6,7]

Group	N	Mean (MPa)	SD	Shapiro–Wilk p
everX Flow	30	153.69±18.43	18.43	0.351
1% Ramie Fibre	30	145.98±17.86	17.86	0.715

Test	t-value	df	Sig. (2-tailed)
Independent samples t-test	1.646	58	0.105



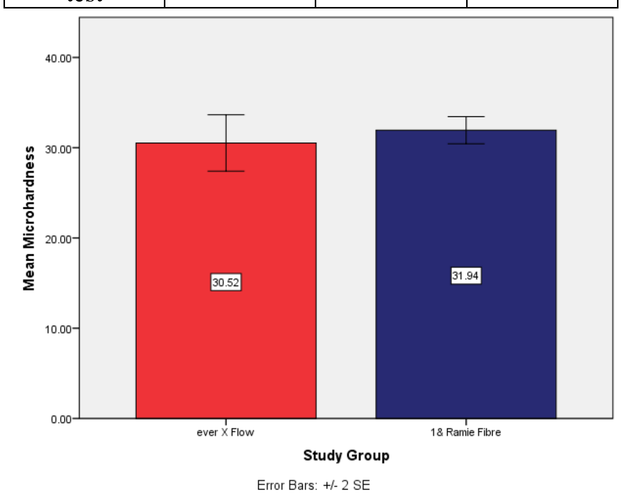
Graph 2. Graphical representation of mean comparison of flexural strength (MPa) between everX Flow and 1% ramie fibre-reinforced composite.

4.3 Microhardness

The Results narrative reports mean microhardness values of 30.52±6 VHN for EVER X FLOW and 31.94±6 VHN for 1% Ramie Fibre. Table 7 reports 30.52±8.55 VHN and 31.94±4.13 VHN, respectively. The 1% ramie group therefore showed a slightly higher mean microhardness in both descriptions. The independent-samples t-test showed no statistically significant difference (t=−0.819, df=58, p=0.416). [9,10]

Group	N	Mean and SD (VHN)	Source table p value
EVER X FLOW	30	30.52±8.55	0.351
1% RAMIE FIBRE	30	31.94±4.13	0.972

Test	t-value	df	Sig. (2-tailed)
Independent samples t-test	−0.819	58	0.416



Graph 3. Graphical representation of mean comparison of microhardness (VHN) between everX Flow and 1% ramie fibre-reinforced composite.

5. Discussion

Discussion

The principal finding of this focused analysis is that incorporation of 1% surface-treated ramie fibre produced a composite whose compressive strength was essentially equivalent to that of everX Flow. The mean values differed by only 2.87 MPa, and the statistical comparison was clearly non-significant ($p=0.969$). This finding is important because compressive strength represents the ability of a restorative material to withstand predominantly axial loading without catastrophic deformation or fracture. In the clinical environment, restorative materials are repeatedly exposed to compressive forces generated during mastication, particularly in posterior teeth where occlusal loading can be substantial. The absence of a statistically significant difference indicates that, within the experimental conditions and fibre concentration investigated, incorporation of surface-treated ramie fibre did not adversely influence the material's resistance to compressive loading. Therefore, the addition of 1% ramie fibre appears to have preserved the bulk mechanical integrity of the composite rather than producing a dilution effect or creating sufficient internal defects to reduce compressive performance. [3,5,6]

The magnitude of the difference between the two materials further supports this interpretation. A difference of only 2.87 MPa, combined with a very high p-value, suggests that the observed variation was small relative to the variability within the tested groups. It is important, however, to distinguish statistical comparability from proof of identical material behaviour. A non-significant result demonstrates that the present study did not detect a statistically significant difference under the specified experimental conditions; it does not establish that the two materials are mechanically identical under every loading condition. Nevertheless, the close mean values provide evidence that the experimental material retained a level of compressive performance comparable with the established commercial short-fibre-reinforced control.

The comparable compressive performance can be considered in relation to the processing of the ramie fibre. Alkaline treatment and silanization were intended to improve fibre–resin interaction, while ball milling was used to reduce fibre dimensions and facilitate dispersion. These processing steps are particularly relevant because the reinforcing effect of a fibre-containing composite depends not only on the intrinsic properties of the fibre but also on the quality of the interface between the reinforcing phase and the surrounding polymer matrix. Poorly bonded or inadequately dispersed fibres may act as stress-concentration sites and may facilitate crack initiation rather than reinforcement. Conversely, a well-integrated reinforcing phase can participate in stress transfer from the polymer matrix and may limit localized failure by distributing applied stresses over a larger region of the composite. The observed compressive result is therefore consistent with successful incorporation of the fibre without a measurable loss of bulk strength. [15,17,19,21]

The surface treatment of ramie fibre may have contributed to this behaviour by improving compatibility between the natural fibre and the resin matrix. Natural cellulose-based fibres possess a chemically complex surface and may demonstrate limited interaction with hydrophobic polymeric matrices in their untreated state. Alkaline treatment can alter the surface morphology and composition of the fibre, potentially increasing surface roughness and exposing reactive groups. Silanization may subsequently facilitate chemical coupling between the fibre surface and resin matrix. Together, these modifications may improve interfacial adhesion and reduce the likelihood of premature fibre debonding under load. Ball milling may additionally have assisted in producing smaller fibre particles capable of being more uniformly distributed within the resin. The combined effect of these processing procedures may therefore explain why the addition of a relatively low fibre concentration did not compromise compressive strength. [15,17,19,21]

The relatively low fibre concentration should also be considered when interpreting the compressive findings. Only 1% ramie fibre was incorporated into the final experimental formulation. At such a concentration, the fibres may provide localized reinforcement while allowing the resin matrix to remain the dominant continuous phase. This may be advantageous from the perspective of maintaining handling characteristics and reducing the probability of excessive fibre agglomeration. At higher concentrations, natural fibres may potentially become more difficult to disperse uniformly and may introduce voids or interfacial defects if adequate wetting and coupling are not achieved. The present findings therefore suggest that the selected 1% concentration was compatible with preservation of compressive performance, although they should not be extrapolated directly to higher fibre concentrations without further experimental verification.

Flexural strength was numerically lower for the 1% ramie composite than for everX Flow, with means of 145.98±17.86 MPa and 153.69±18.43 MPa, respectively. Nevertheless, the difference was not statistically significant ($p=0.105$). The approximately 7.71 MPa numerical difference indicates a tendency toward higher flexural performance for the commercial control, but the statistical analysis does not provide sufficient evidence to conclude that the ramie-reinforced composite has inferior flexural strength under the conditions tested. The relatively large standard deviations observed in both groups are also relevant because they indicate appreciable specimen-to-specimen variation, which can reduce the ability of statistical testing to identify relatively small differences between group means.

Flexural loading produces a more complex stress state than axial compression and is sensitive to several material and specimen-related factors, including fibre orientation, fibre–matrix adhesion, fibre length and distribution, specimen geometry, matrix composition and the mechanical properties of the reinforcing phase. During a flexural test, different regions of the specimen are subjected to tensile and compressive stresses simultaneously. The reinforcing fibres must therefore interact effectively with the surrounding matrix to transfer and redistribute these stresses. Fibre orientation becomes particularly important because reinforcement is generally more effective along the direction in which the fibres can carry load. In a short-fibre system with dispersed fibres, the three-dimensional distribution may provide multidirectional reinforcement, but the random orientation also means that not every fibre will be optimally aligned with the applied load. [4,5,6,7,21]

The numerical difference in flexural strength may reflect the higher intrinsic stiffness and strength of the glass-fibre reinforcement used in the commercial control. Glass fibres possess well-established reinforcing characteristics and are widely used in fibre-reinforced dental composites because of their favourable mechanical properties and ability to transfer stress within the resin matrix. The ramie fibres, despite their potential reinforcing capability, have different intrinsic material characteristics and may therefore produce a different response under bending. In addition, the mechanical performance of natural fibres can be influenced by fibre processing, dimensions, surface treatment, moisture content and fibre–matrix interactions. Consequently, the absence of a statistically significant difference should be interpreted alongside the numerical trend rather than ignoring it completely. The present statistical result does not demonstrate a significant disadvantage for the ramie formulation, but the numerical difference indicates that further optimization may be warranted if flexural performance is to be maximized. [4,5,6,7,21]

Another possible explanation for the difference in flexural values is the interaction between fibre concentration and the reinforcing efficiency of the composite. The use of only 1% ramie fibre may have been sufficient to maintain mechanical performance but may not have provided the same degree of reinforcement achieved by the fibre system in everX Flow. Increasing fibre content does not necessarily result in a proportional increase in strength, because reinforcement depends on adequate wetting, dispersion, fibre aspect ratio, orientation and interfacial bonding. Nevertheless, the present results indicate that the selected concentration was sufficient to avoid a statistically significant reduction in flexural strength. Future investigations could therefore evaluate whether alternative fibre concentrations, milling conditions, fibre dimensions or surface-treatment protocols can improve flexural performance without negatively affecting other properties.

The microhardness results similarly showed no significant difference. The ramie composite had a slightly higher mean value than everX Flow, while the independent-samples t-test yielded $p=0.416$. Preservation of microhardness suggests that addition of 1% ramie fibre did not produce a measurable deterioration in the cured surface's resistance to localized indentation. This finding is relevant because surface hardness is influenced by the composition and degree of polymerization of the resin matrix as well as by the presence and distribution of reinforcing phases. The slightly higher mean value observed for the experimental composite suggests that the incorporation of ramie fibre at the selected concentration did not weaken the surface sufficiently to reduce indentation resistance. However, because the difference was statistically non-significant, the result should be interpreted as preservation of microhardness rather than evidence that ramie fibre significantly increases surface hardness. [9,10]

The microhardness finding may also indicate that the addition of 1% fibre did not substantially disrupt surface polymerization or create an excessive concentration of poorly integrated particles near the tested surface. In fibre-reinforced composites, the local surface response can potentially be affected by fibre exposure, fibre distribution, matrix composition and the quality of curing. The absence of a significant reduction suggests that the experimental formulation retained satisfactory surface mechanical integrity under the conditions of the microhardness test. Nevertheless, microhardness should be interpreted specifically as a surface property. Although higher hardness can be relevant to resistance to indentation and surface deformation, it should not be equated directly with clinical wear resistance. The present thesis did not directly evaluate standardized abrasion or wear behavior within this focused mechanical assessment. This distinction is particularly important when considering the clinical implications of the findings. A material exhibiting satisfactory microhardness may still demonstrate different behaviour under cyclic mastication, toothbrushing abrasion, opposing-material contact or prolonged exposure to the oral environment. Similarly, surface hardness alone cannot provide information regarding fatigue resistance, fracture toughness or the ability of a restorative material to maintain structural integrity under repeated loading. Consequently, the microhardness results provide useful information regarding localized surface mechanical behaviour but should not be interpreted as a direct surrogate for long-term clinical wear performance.

When the three outcomes are considered together, the experimental material demonstrated a consistent pattern of mechanical comparability. Compressive strength was virtually identical to the control, flexural strength was modestly lower but statistically comparable, and microhardness was modestly higher but statistically comparable. The fact that none of the three evaluated outcomes demonstrated a statistically significant disadvantage for the 1% ramie formulation provides an internally consistent indication that incorporation of the surface-treated natural fibre did not substantially compromise the mechanical properties investigated. Thus, the results support the source thesis conclusion that 1% surface-treated ramie fibre can be incorporated into the composite without significantly compromising the evaluated mechanical properties. [5,6,13,14]

The overall pattern is also relevant from a materials-development perspective. The experimental composite did not outperform everX Flow across all parameters, nor was such superiority demonstrated statistically. Rather, the principal outcome was preservation of mechanical performance despite replacement or incorporation of a natural reinforcing phase. This is an important distinction because the potential value of natural-fibre reinforcement does not necessarily depend on producing a material that is mechanically superior to established commercial fibre-reinforced composites. Demonstrating that a natural fibre can be incorporated while maintaining clinically relevant mechanical characteristics provides an important foundation for subsequent formulation optimization and more extensive mechanical and biological evaluation.

The mechanical findings are also compatible with the proposed reinforcing mechanisms described in the thesis, including stress transfer, crack deflection and fibre bridging. When an applied load is transmitted from the resin matrix to well-bonded fibres, the fibres can carry a portion of the applied stress and thereby reduce the stress concentration within the matrix. If a crack develops, fibres crossing or interacting with the crack path may alter its trajectory, reduce its rate of propagation or require additional energy for crack advancement. Fibre bridging can provide an additional mechanism by which the fibres resist separation of the crack surfaces. Although these mechanisms cannot be established solely from the mechanical data, they provide a theoretical framework for understanding how a relatively low concentration of appropriately treated fibres may contribute to maintaining the mechanical integrity of the composite. [7,8,15,17]

SEM observations in the source thesis showed ramie fibres embedded within the resin matrix with limited evidence of fibre pull-out and relatively continuous interfaces. These morphological observations provide a plausible structural basis for the mechanical performance. Limited fibre pull-out may indicate that the fibre–matrix interface was sufficiently developed to permit effective transfer of applied stresses rather than allowing extensive interfacial separation. Similarly, relatively continuous interfaces suggest satisfactory integration of the treated fibre into the surrounding resin. Such observations are particularly relevant for natural-fibre-reinforced composites because interfacial defects can otherwise function as sites for stress concentration and crack initiation. However, SEM findings should be regarded as supportive morphological evidence rather than direct proof of a particular strengthening mechanism. [7,8,15,17]

The relationship between morphology and mechanical properties also highlights the importance of the surface-treatment sequence used in the present formulation. The combination of alkaline treatment, silanization and ball milling was not simply a means of incorporating ramie fibre into the composite; it was intended to modify the fibre so that it could function more effectively within the resin matrix. The mechanical results, together with the SEM observations, suggest that the processing strategy produced a fibre phase that could be incorporated without generating sufficient interfacial defects to cause significant deterioration in the tested properties. Further microscopic and spectroscopic investigations would nevertheless be useful to characterize the fibre–matrix interface more comprehensively and to determine the contribution of each individual treatment step.

Importantly, the present results establish material performance under standardized laboratory conditions rather than clinical fracture resistance of restored teeth. This distinction should be emphasized when translating the findings into clinical relevance. A restorative composite may demonstrate favourable intrinsic mechanical properties in standardized specimens while behaving differently when placed in an actual tooth. Clinical tooth structure has complex geometry, variable thickness, anatomical stress concentrations and a heterogeneous substrate. The performance of a restoration is also influenced by cavity design, adhesive procedures, polymerization conditions, occlusal loading, parafunctional activity and the remaining amount of sound tooth structure. Therefore, compressive strength, flexural strength and microhardness cannot independently predict the survival of a restored endodontically treated tooth.

Furthermore, the three evaluated properties do not encompass all dimensions of restorative durability. Long-term fatigue, thermocycling, hydrothermal aging, water sorption, wear and clinical survival would require separate investigations. Fatigue testing would be particularly relevant because dental restorations are subjected to repeated rather than single loading events during normal function. Thermocycling and water exposure may additionally influence the resin matrix and fibre–matrix interface over time. Water sorption may be especially relevant for natural-fibre-containing systems because cellulose-based fibres can interact with moisture. Accordingly, the favourable results observed in the present investigation should be considered an initial assessment of mechanical compatibility rather than evidence of long-term clinical durability.

The absence of significant differences in the present study should also be interpreted within the context of the experimental design and sample variability. Statistical non-significance does not necessarily establish equivalence in the formal statistical sense unless an appropriately designed equivalence or non-inferiority analysis has been performed. The current findings demonstrate that statistically significant differences were not detected between the groups for the evaluated outcomes. This distinction is important when formulating conclusions and prevents overstatement of the results. The most appropriate interpretation is therefore that the 1% surface-treated ramie composite showed mechanical performance statistically comparable to the control within the limits of the present experimental conditions.

From a sustainability perspective, the ability of a low concentration of ramie fibre to maintain mechanical performance comparable to a commercial short-fibre composite supports further investigation of natural-fibre reinforcement. Natural fibres represent an area of interest because they may provide an alternative reinforcing resource and may contribute to the development of more resource-conscious composite formulations. However, sustainability should not be inferred solely from the use of a natural material. The environmental impact of fibre cultivation, processing, chemical surface modification, milling, composite manufacture, clinical service life and eventual disposal must be considered when evaluating the overall sustainability of such materials. The present study therefore provides a mechanical foundation for further investigation rather than a complete assessment of environmental performance. [11,12,13,14,16,18]

Overall, the findings suggest that incorporation of 1% surface-treated ramie fibre into the experimental resin composite was mechanically feasible. The experimental material maintained compressive strength at a level essentially comparable to everX Flow, demonstrated a numerically lower but statistically comparable flexural strength, and showed a numerically higher but statistically comparable surface microhardness. Taken together, these findings indicate that the selected natural-fibre formulation did not significantly compromise any of the three mechanical properties evaluated. The results therefore provide preliminary support for continued development of surface-treated ramie fibre as a reinforcing phase in resin-based dental composites. Further studies should build upon these findings by investigating fibre concentration, fibre dimensions, surface-treatment optimization, fatigue behaviour, fracture toughness, wear, aging, water sorption, thermal cycling, biocompatibility and ultimately the fracture resistance and clinical performance of teeth restored with the experimental material.

6. Integrated Comparison

Property	everX Flow	1% Ramie Fibre	t	df	p-value	Interpretation
Compressive strength	2209.64±276.17 MPa	2206.77±291.43 MPa	0.039	58	0.969	No significant difference
Flexural strength	153.69±18.43 MPa	145.98±17.86 MPa	1.646	58	0.105	No significant difference
Microhardness*	30.52±8.55 VHN	31.94±4.13 VHN	−0.819	58	0.416	No significant difference

*Tabulated thesis values are presented. The Results narrative separately reports 30.52±6 VHN and 31.94±6 VHN.

7. Limitations

• The investigation was performed in vitro and cannot establish clinical survival.
• Long-term fatigue, thermocycling, hydrothermal aging and standardized wear were not directly evaluated.
• Fracture toughness and failure of restored teeth were not directly tested.
• The thesis contains an internal discrepancy in the reported microhardness specimen diameter.
• The thesis contains different narrative and tabulated SD values for microhardness; these have been preserved rather than recalculated.

8. Conclusion

Within the limitations of the in vitro study, the 1% ramie fibre-reinforced dental composite demonstrated mechanical performance comparable to everX Flow for all three evaluated properties. Compressive strength was 2206.77±291.43 MPa versus 2209.64±276.17 MPa, with p=0.969. Flexural strength was 145.98±17.86 MPa versus 153.69±18.43 MPa, with p=0.105. Microhardness showed a slightly higher mean for the ramie composite, but the difference was not statistically significant (t=−0.819, df=58, p=0.416). The findings indicate that 1% surface-treated ramie fibre did not significantly compromise compressive strength, flexural strength or surface microhardness under the tested laboratory conditions.

9. Data Preservation Note

All values, sample sizes, statistical results and graphs in this focused manuscript were taken from the uploaded thesis without recalculation or silent correction. Where the thesis itself contains different narrative and tabulated microhardness values, both are identified explicitly.

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