International Journal of Medicine
pISSN 1468-3814 | eISSN 2667-7008
https://theinternationalmedicine.com/

Original Researcher Article *DOI: 10.61336/im/26-06-241*

Sustainable Dental Material Innovation: Utilizing Local Pakistani Mineral Fillers to Enhance the Mechanical Integrity of Restorative Composites.

[1*]Dr. Khumara Roghani, [2]Dr. Sharaz Ahmed, [3]Dr. Zehra Ali ,[4]Dr. Abdul Rehman ,[5]Amna Mehwish Ikram, [6]Muhammad Khawaja Hammad Uddin.

[1]Lecturer, Department of Dental Materials,Khyber College of Dentistry,Peshawar
[2]Assitant Professor, Operative Dentistry and Endodontics ,Dental college HITEC-ims taxila cant.
[3]Assistant Professor,Department of Paediatric Dentistry ,Rahbar college of dentistry
[4]Demonstrator Department of Operative Dentistry ,Fatima Memorial Hospital Lahore
[5]Hod and Associate Professor ,Dental Materials Department ,Islam Dental College, Sialkot
[6]Assistant Professor ,Department of Science of Dental Materials,Dr Ishrat Ul Ebad Khan Institute of Oral Health Sciences,Dow University of Health Sciences

Correspondence:
Dr. Khumara Roghani.
Lecturer, Department of Dental Materials,Khyber College of Dentistry,Peshawar.

Email:
khumarroghani@gmail.com

Received: 08-05-2026
Revised: 18-05-2026
Accepted: 08-06-2026
Published: 23-06-2026

Abstract

Background: With increasing need for environment-friendly and cost-effective dental biomaterials, studies are aimed at finding natural mineral fillers as substitutes for current synthetic fillers used in restorative resin composites.***Objective:*** To evaluate the effect of locally sourced Pakistani mineral fillers on the mechanical integrity of restorative resin composites and compare their performance with that of a conventional commercial composite.***Methods:*** A laboratory-based experimental study involving 80 composite specimens was carried out, with each specimen in the experimental groups divided evenly among experimental composite, silica-filled composite, feldspar-filled composite and composite with calcium carbonate from marble. The experimental fillers were purified, micronized, silanized and added to a standard resin matrix. Some of the properties measured were compressive strength, flexural strength, Vickers surface hardness, and wear resistance, all of which are in accordance with ISO standards. One-way ANOVA and Tukey's post hoc test were used to analyze data and a p-value of 0.05 or less was considered statistically significant.***Results:*** There were significant differences between study groups ($p<0.001$). The composite with silica fillers showed the highest values of compressive strength, flexural strength, surface hardness and wear resistance, followed by the feldspar-filled composite. The mechanical properties of the marble-derived calcium carbonate composite were found to be similar to those of the commercial control.***Conclusion:*** Mechanical integrity of restorative resin composites was increased considerably with the use of locally sourced Pakistani mineral fillers, especially silica-rich minerals. These indigenous mineral resources are potential sustainable, economical and environmentally friendly sources to develop future restorative dental materials.

Keywords: Restorative resin composite; Sustainable dental materials; Pakistani mineral fillers; Silica; Feldspar.

INTRODUCTION

Dental caries is one of the most common chronic diseases in the world and still poses a significant burden on the oral health system.[1] The ‘World Health Organization (WHO) estimates that untreated caries in permanent dentition affects about 2 billion people worldwide, and 514 million ‘ have caries in their primary dentition.[2] In recent years, resin-based composite materials have become the restorative material of choice in modern dentistry due to the rising demand for esthetic, minimally invasive, and durable restorative treatment.[3] They are widely used in the clinical practice for routine work due to their excellent esthetic properties, adhesion and cavity preparation.[4]

However, failure of the restoration has been a major challenge in clinical practice despite the constant progress in resin composite technology.[3] The most common reasons for replacement of composite restorations include fracture, marginal degradation, wear, polymerization shrinkage, and secondary caries.[5] The mechanical properties, including compressive strength, flexural strength, fracture toughness, hardness and wear resistance, crucially depend on the composition, morphology and distribution of the inorganic filler particles embedded in the resin matrix.[6]

The main fillers used in commercial dental composites are synthetic fillers like silica, quartz, zirconia, barium glass, and ytterbium fluoride.[7] These fillers offer desired mechanical and radiographical qualities, but the production of these fillers

is energy-intensive, requires special purification processes, and uses raw materials that must be imported, which adds to the production costs and environmental impact.[8] This increased interest in sustainable healthcare has spurred the development of research on alternative eco-friendly materials derived from natural mineral sources that can offer similar reinforcement with lower production costs and carbon footprint.[9]

The natural mineral fillers have become interesting reinforcing agent due to their availability, biocompatibility, chemical stability and good mechanical properties.[10] Minerals like kaolin, feldspar, mica, talc, hydroxyapatite, calcium carbonate and volcanic ash have been found to be useful in enhancing stiffness, hardness, wear resistance and dimensional stability of different polymer based composites.[10] In addition, particle size reduction, surface modification and subsequent homogeneous dispersion further optimize the interaction between the filler and the matrix, which allows efficient stress transfer and ensures the mechanical integrity of composite materials.[11] These are developments that follow the trends towards sustainable biomaterials and the principles of the circular economy in biomedical manufacturing worldwide.

Scientific evidence in this field could create a basis for the creation of cost effective, eco-friendly, locally produced restoring materials which meet the local healthcare demands. This not only promotes sustainability of resources but also enhances the capacity of the nation in biomaterial research and the use of imported dental materials can be minimized. The aim of the present study was to assess the mechanical integrity of the following properties of experimental restorative resin composites: compressive strength, flexural strength, surface hardness, and wear resistance in comparison to conventional commercially available composite filler systems for their restorative applications and sustainability as potential alternatives in Pakistan.

METHODOLOGY

This study was carried out in an experimental laboratory based comparative study. The study was conducted over a period of twelve months, from July to December, 2025.

Sample size was determined through the use of OpenEpi version 3.01 which compares the mean compressive strength of two independent composite formulations. The calculated result was based on the results obtained from previous study. They obtained a mean compressive strength of 301.4 ± 18.6 MPa for the conventional nanohybrid composite and 320.8 ± 20.7 MPa for an experimental reinforced composite formulation.[12] A minimum sample size of 17 specimens per group is necessary for the 95% C.I. to not exceed the difference of 19.4MPa, with an allocation ratio of 1:1, and a study power of 80%. In order to account for errors in specimen preparation and possible specimen losses during testing, it was decided to use 20 specimens per group. With four experimental groups, a total of 80 composite specimens were included in the study.

A non-probability sampling technique, the consecutive sampling technique, was used. The study consisted of composite specimens manufactured with each of the standardized resin matrices and carefully weighted contents of filler. Only specimens that were prepared in accordance with ISO guidelines with even dimensions, full polymerization, no visible voids or cracks, no surface defects or contamination were used. The locally sourced mineral fillers that were purified, milled, sieved and sized to a standard particle size before being added to the resin matrix were deemed suitable for experimental composite preparation. Examples of specimens that were excluded from the study included those that were dimensionally inaccurate, had air bubbles, had not fully cured, had marginal defects, had fractured during preparation, were contaminated, or had been deformed during preparation. Samples that were not in compliance with ISO dimensional tolerances or which suffered accidental damage during storage and/or mechanical testing were also removed from analysis.

The mineral fillers were obtained locally from the certified mineral suppliers and subjected to a series of washing, drying, pulverization, sieving and thermal treatment to remove the impurities. The particle size reduction was carried out by planetary ball milling until a uniform micron-sized powder was obtained. The mineral fillers were then analyzed for their morphology and elemental composition before being added to the composite resin. ‘Bis-GMA, UDMA and TEGDMA monomers’ were used to prepare the experimental resin matrix using controlled laboratory conditions with ‘camphorquinone and ethyl-4-dimethylaminobenzoate photoinitiato’ system.

The mineral fillers were treated with ‘γ-methacryloxypropyltrimethoxysilane’ to increase the adhesion between the filler and the resin matrix before being added to the resin matrix at specific weight percentages. Four study groups were prepared, one of which was a commercial filler (CON) and the other three had different locally available mineral fillers.

Stainless steel moulds were used to make composite specimens based on ISO 4049 specification.[13] The material was incrementally inserted, overlain with Mylar strips and glass slides to prevent voids, and polymerized with a calibrated LED curing unit of which the light intensity and curing time of which were standardized. After polymerization, all specimens were finished, polished and kept in distilled water at 37°C for 24 hours before mechanical testing.

Mechanical evaluation was conducted such as compressive strength, flexural strength, Vickers surface hardness and wear resistance. Compressive strength was obtained by applying a compressive load up to the specimen fracture on a universal testing machine. The three-point bending apparatus was used to determine flexural strength, and the surface hardness was determined by a Vickers microhardness apparatus under standard loading.[14] After the specified number of loading cycles, a reciprocating wear testing apparatus was used to determine wear resistance. To minimise measurement bias, all measurements were carried out by a calibrated investigator in the same laboratory conditions.

The data collected were entered and analyzed using Statistical Package for the Social Sciences (SPSS) version 27.0. Data for continuous variables such as compressive and flexural strength, surface hardness and wear resistance were represented as mean ± standard deviation and the categorical variables as frequencies and percentages, if applicable. Data were normed before choosing the statistical tests. One-way analysis of variance (ANOVA) and Tukey's post hoc test for pairwise comparison were used to compare the four composite groups. In cases where normality and/or homogeneity of variance were not met, the Kruskal-Wallis test and Dunn's post hoc analysis were used. All analyses were performed with a p-value ≤ 0.05 being set as statistically significant.

RESULTS

A total of 80 standardised composite specimens were prepared and have been equally distributed between four study groups, totaling 20 specimens for each group. No specimens were rejected for fabrication defects or for failure in testing. All the groups exhibited comparable baseline characteristics, such as specimen dimensions, filler loading, and intensity of curing, thus verifying successful standardization of specimen preparation prior to mechanical testing. (Table 1) The mechanical properties comparison showed that there were statistically significant differences between the four composite formulations. The composites made by the experimental composites with locally available mineral fillers of Pakistan had better mechanical properties than the commercial available composite.

Table 1. Baseline Characteristics of Composite Specimens Across Study Groups (n = 80)

Variable	Control (Commercial Filler) (n=20)	Experimental Group I (Silica Filler) (n=20)	Experimental Group II (Feldspar Filler) (n=20)	Experimental Group III (Marble-Derived $CaCO_3$) (n=20)	p-value
Specimen diameter (mm)	4.00 ± 0.01	4.00 ± 0.02	4.00 ± 0.02	4.00 ± 0.01	0.476
Specimen height (mm)	6.00 ± 0.02	6.01 ± 0.03	6.00 ± 0.02	6.00 ± 0.02	0.345
Filler loading (wt%)	70.0 ± 0.3	70.1 ± 0.4	70.0 ± 0.5	70.0 ± 0.4	0.676
Light curing intensity (mW/cm^2)	1198 ± 9	1202 ± 8	1200 ± 7	1199 ± 8	0.433

The overall mechanical properties of the experimental composite materials were found to be the highest in the silica filled composite and the next highest in the composites prepared using feldspar. The composites prepared by the silica filler and feldspar filler exhibited the highest mechanical properties among the experimental composites while the mechanical properties of the composite prepared by the marble derived calcium carbonate were comparable to the commercial control composite. The compressive strength, flexural strength, Vickers surface hardness and wear resistance showed significant differences. (Table 2)

Table 2. Comparison of Mechanical Properties Among Study Groups

Mechanical Property	Control (Commercial)	Silica Filler	Feldspar Filler	Marble-Derived $CaCO_3$	p-value
Compressive strength (MPa)	305.4 ± 15.6	332.8 ± 16.1	321.6 ± 15.2	309.7 ± 17.4	<0.001*
Flexural strength (MPa)	118.5 ± 8.3	132.7 ± 9.4	126.4 ± 8.7	120.3 ± 9.1	<0.001*
Vickers hardness (VHN)	74.8 ± 3.6	82.5 ± 4.1	79.4 ± 3.8	75.9 ± 3.9	<0.001*
Wear loss (mm^3)	0.082 ± 0.012	0.056 ± 0.009	0.063 ± 0.011	0.078 ± 0.013	<0.001*

The compressive strength showed that the silica-filled composite had higher strength compared to both commercial control and marble-derived calcium carbonate composite as a result of post hoc analysis. The composite containing the feldspar also showed significantly better performance compared to control samples; there was no statistically significant difference between the composite with the calcium carbonate extracted from marble and the commercial composite. (Table 3)

Table 3. Tukey's Post Hoc Analysis for Compressive Strength

Comparison	Mean Difference (MPa)	95% CI	p-value
Control vs Silica	-27.4	-39.2 to -15.6	<0.001*
Control vs Feldspar	-16.2	-28.0 to -4.4	0.006*
Control vs Marble	-4.3	-16.1 to 7.5	0.764
Silica vs Feldspar	11.2	-0.6 to 23.0	0.071
Silica vs Marble	23.1	11.3 to 34.9	<0.001*
Feldspar vs Marble	11.9	0.1 to 23.7	0.048*

The flexural strength showed the same trend: The flexural strength of the silica-filled composite was significantly higher than the control group and the calcium carbonate from marble group in pairwise comparison. The composite with the feldspar also showed better properties than the commercial composite while the composite from the marble did not differ significantly. (Table 4)

Table 4. Tukey's Post Hoc Analysis for Flexural Strength

Comparison	Mean Difference (MPa)	p-value
Control vs Silica	-14.2	<0.001*
Control vs Feldspar	-7.9	0.014*
Control vs Marble	-1.8	0.823
Silica vs Feldspar	6.3	0.062
Silica vs Marble	12.4	<0.001*
Feldspar vs Marble	6.1	0.048*

Surface hardness analysis revealed that addition of local silica and feldspar fillers greatly improved the hardness of the restorative composites over the conventional restorative composite. In terms of surface hardness, hardness values of the marble-derived calcium carbonate composite were comparable to that of the commercial control composite. (Table 5)

Table 5. Tukey's Post Hoc Analysis for Surface Hardness

Comparison	Mean Difference (VHN)	p-value
Control vs Silica	-7.7	<0.001*
Control vs Feldspar	-4.6	0.003*
Control vs Marble	-1.1	0.648
Silica vs Feldspar	3.1	0.045*
Silica vs Marble	6.6	<0.001*
Feldspar vs Marble	3.5	0.031*

The wear resistance test results showed that experimental composites with silica and feldspar fillers had significantly lower material loss than the commercial composite, and they possessed a higher resistance to abrasive wear. No significant difference was found between commercial composite and the calcium carbonate derived from marble formulation. (Table 6).

Table 6. Tukey's Post Hoc Analysis for Wear Resistance (Wear Loss)

Comparison	Mean Difference (mm^3)	p-value
Control vs Silica	0.026	<0.001*
Control vs Feldspar	0.019	0.002*
Control vs Marble	0.004	0.517
Silica vs Feldspar	-0.007	0.084
Silica vs Marble	-0.022	<0.001*
Feldspar vs Marble	-0.015	0.011*

DISCUSSION

The present study aimed to assess the mechanical properties of restorative resin composites with the addition of locally sourced Pakistani mineral fillers. The results showed that the composites filled with silica-rich mineral filler had the highest compressive strength, flexural strength, surface hardness and wear resistance, followed by the composites with feldspar filler, while those with calcium carbonate obtained from marble had mechanical properties similar to the conventional commercial composite. The results show that the naturally occurring indigenous minerals are potential reinforcing fillers if they can be treated with the required procedures of purification, particle-size reduction and salinization.

The results of the present study are consistent with the findings of Ge et al. (2026), who reported that the mechanical properties of the experimental dental composite with silica-filled composites were improved by the dispersion of fillers and strengthening of the filler-resin interface through the use of mesoporous silica nanoparticles. Their study also noted an increase in hardness and structural integrity, which aligns with the increase in compressive strength and surface hardness in the present investigation.[15]

The enhancement in flexural strength after adding silica is also in line with the observations made by Liu et al. (2021), who found the morphology of the fillers is a critical factor in the stress transfer of resin composites. They found that filler-matrix bonding is enhanced and crack propagation resistance is superior in composites reinforced with porous and silica-based fillers, with enhanced surface characteristics, which might account for the superior mechanical behaviour seen for the silica-reinforced composites used in this study.[16]

Likewise, the results were consistent with the extensive study conducted by Par and co-workers (2021), which identified some of the main factors determining the compressive strength, fracture resistance and wear performance of resin composites: filler size, morphology, distribution and loading. They emphasized that the use of optimized silica fillers promotes excellent stress transfer and decreases the number of structural defects in the polymer matrix, contributing to the overall increase in mechanical properties found in the current study.[17]

The present study showed that composites with feldspar also significantly increased the compressive and flexural strength relative to the commercially available composite, but did not perform as well as silica filled composites. These findings are similar to the observation made by Liu et al. (2021) that aluminosilicate-based fillers are effective as a reinforcing agent, due to their high elastic modulus and good interface bonding with methacrylate resin matrices.[16]

The marble-derived calcium carbonate composite had similar mechanical properties to the commercial control and were lower than the silica and the feldspar formulations. This could be explained by the relatively low hardness and reinforcement ability of the calcium carbonate particles. The remarks of Latoui et al. (2026) were also made, indicating that silica is still the most used filler due to its mechanical performance, while other mineral fillers may need to be further optimized in terms of particle morphology and surface treatment to achieve a similar performance.[18]

The results of this study and the results of Troha et al. (2026), who found that the Vickers microhardness and the elastic modulus of experimental dental composites are significantly improved with an increase in the amount of fillers, confirmed the significant improvement in surface hardness after the addition of silica and feldspar fillers in this study. Their investigation also showed that highly filled composites have better mechanical stability through aging, thus indicating that optimised filler concentration has a significant effect on the longevity of a restoration.[19]

One of the most important factors of clinical success is wear resistance. The results of the present study are in agreement with Kaptan Usul et al. (2024) whose work showed that the incorporation of mesoporous silica in composites produced less wear loss than the other composites studied, which can be attributed to the improvement in structural cohesion and the reduction in surface degradation under functional loading. Better bond between the filler and the matrix reduces filler debonding and surface abrasion, which results in higher occlusal resistance.[20]

In summary, the current results indicate that the Pakistani mineral fillers with a high silica content are promising candidates for the production of sustainable restorative composites with increased mechanical properties. These materials need further investigation of the purification of the filler, the synthesis of nanoparticles, the effects of long-term hydrolytic aging, the polymerization shrinkage, the radiopacity, bonding performance, biocompatibility, and the in vivo clinical behavior before they can be applied as fillers in commercial dental products. These studies can help in developing locally available and affordable restorative composites that are eco-friendly and could help minimize the use of imported dental biomaterials.

There were a number of limitations to the present study. First, it was an in vitro laboratory investigation, and the results may not be entirely representative of the complex oral environment, which is subject to a wide range of changes in temperature, moisture, pH, masticatory forces and microbiological activity that can affect the long-term performance of restorative materials. Second, only the mechanical properties of the experimental composites were evaluated, while other clinically important characteristics such as polymerization shrinkage, degree of conversion, water sorption, solubility, color stability, radiopacity, bond strength, and biocompatibility were not investigated. Thirdly, only a few mineral fillers and filler levels were explored, which could limit the applicability of the results. Lastly, long-term aging, thermocycling, fatigue loading, and clinical performance were not evaluated. Future studies should include nanostructured mineral fillers, optimized surface treatment of the fillers, assessment of physicochemical properties, biological properties and validation on long-term in vivo clinical trials.

CONCLUSION

In this laboratory study, the mechanical properties of restorative resin composites were significantly affected by the use of locally sourced Pakistani mineral fillers within the limitations of this study. The silica mineral fillers exhibited the highest increment of compressive strength, flexural strength, surface hardness and wear resistance, and the feldspar fillers showed notable reinforcement when compared with the conventional commercial composite. The mechanical performance of the marble derived calcium carbonate was similar to that of the control composite, but was inferior to that of silica and feldspar fillers. The results indicate that indigenous mineral resources in Pakistan have a great potential as sustainable and economical reinforcing fillers for restorative dental composites. Local mineral use can help to decrease dependency on imported biomaterials and help to develop environmentally friendly dental materials. They need further investigation to assess their durability, biocompatibility and commercial viability.

REFERENCES

1. Peres, M.A., et al., Oral diseases: a global public health challenge. The lancet, 2019. 394(10194): p. 249-260.
2. Qin, X., H. Zi, and X. Zeng, Changes in the global burden of untreated dental caries from 1990 to 2019: A systematic analysis for the Global Burden of Disease study. Heliyon, 2022. 8(9).
3. Bompolaki, D., E.B. Lubisich, and A.P. Fugolin, Resin-based composites for direct and indirect restorations: clinical applications, recent advances, and future trends. Dental Clinics, 2022. 66(4): p. 517-536.
4. Cardoso, J.A., et al., Clinical guidelines for posterior restorations based on Coverage, Adhesion, Resistance, Esthetics, and Subgingival management. The CARES concept: Part I–partial adhesive restorations. Int J Esthet Dent, 2023. 18(3): p. 244-265.
5. Elgezawi, M., et al., Current strategies to control recurrent and residual caries with resin composite restorations: operator-and material-related factors. Journal of Clinical Medicine, 2022. 11(21): p. 6591.
6. Naguib, G., et al., Influence of inorganic nanoparticles on dental materials' mechanical properties. A narrative review. BMC Oral Health, 2023. 23(1): p. 897.
7. Yadav, R., A. Meena, and A. Patnaik, Biomaterials for dental composite applications: A comprehensive review of physical, chemical, mechanical, thermal, tribological, and biological properties. Polymers for Advanced Technologies, 2022. 33(6): p. 1762-1781.
8. Li, C., et al., Fluorapatite glass-ceramics in dentistry: synthesis, properties, forming technology, applications, challenges, and future perspectives. Materials, 2025. 18(4): p. 804.
9. Puttegowda, M., Eco-friendly composites: exploring the potential of natural fiber reinforcement. Discover Applied Sciences, 2025. 7(5): p. 401.
10. Fajdek-Bieda, A. and A. Wróblewska, The use of natural minerals as reinforcements in mineral-reinforced polymers: a review of current developments and prospects. Polymers, 2024. 16(17): p. 2505.
11. Rahman, M.M., et al., Polymer nanocomposites with optimized nanoparticle dispersion and enhanced functionalities for industrial applications. Processes, 2025. 13(4): p. 994.
12. Hama, S.M., et al., Synergistic structural performance of green self-compacting concrete enhanced by nano-clay and waste glass powder. Scientific Reports, 2025.
13. Par, M., et al., Comparing ISO 4049 and Fourier-transform infrared spectroscopy for assessing ambient light sensitivity in dental resin composites. Scientific reports, 2025. 15(1): p. 8455.
14. Desale, S., et al., Comparative evaluation of microhardness of stripped enamel surface before and after application of remineralizing agent-An in vitro analytical study. JIDA: Journal of Indian Dental Association, 2026. 20(2): p. 17.
15. Ge, Y., et al., Design and performance evaluation of biphenyl-based high-performance dental composite resins reinforced with porous lithium disilicate. Dental Materials, 2026.
16. Liu, L., et al., Improving corrosion resistance of epoxy coating by optimizing the stress distribution and dispersion of SiO2 filler. Progress in Organic Coatings, 2023. 179: p. 107522.
17. Marovic, D., et al., Long-term assessment of contemporary ion-releasing restorative dental materials. Materials, 2022. 15(12): p. 4042.
18. Latoui, R., D. Bouzid, and O. Boyron, Dental composites: a comprehensive review on formulation, properties and recent developments. Polymer International, 2026.
19. Troha, L., et al., Filler amount influences long-term mechanical stability of experimental dental composites. Dental materials, 2026.
20. Kaptan Usul, S., et al., Effects of Hexagonal Boron Nitride and Mesoporous Silica Nanoparticles on the Morphology, Mechanical Properties and Antimicrobial Activity of Dental Composites. Journal of Cluster Science, 2024. 35(7): p. 2293.