ORIGINAL ARTICLE
ISSN 2645-4351
https://doi.org/10.22037/jds.v43i1.45561

Comparison of Physical and Mechanical Properties of Iranian and Foreign Composites

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Submitted: 27 May 2024
Revised: 14 September 2024
Accepted: 10 September 2024
Published: Winter 2025

How to cite:
Valian A, Golbari N, Nikaein M. Comparison of Physical and Mechanical Properties of Iranian and Foreign Composites. J Dent Sch 2025;43(1):23-28.

Abstract

Objectives: Although dental composites offer clinical ease of use and a reasonable level of aesthetics, they still suffer from issues, such as low resistance to abrasion and fracture, post-polymerization shrinkage, and low stress tolerance, which restrict their applications. Given the current social conditions in the country and to support knowledge-based companies in the production of domestic composites, the present study aimed to investigate certain physical and mechanical properties of Iranian composites in comparison with foreign composites. **Methods:** Two types of commercially available foreign resin-based composites, Filtek Z250 (3M) and Den fil (Vericom), and the Iranian composite Trivers (Trimed) were investigated in terms of their mechanical and optical properties. For data analysis, ANOVA and post hoc tests at a 5% significance level were performed. **Results:** Z250 composite exhibited superiority in most mechanical properties, while Trimed composite exhibited lower mechanical properties, although these differences were not statistically significant for compressive strength(p=0.435). **Conclusion:** Based on the results of this study, Trimed composite showed promise for clinical application, although further laboratory and clinical investigations are required to improve the production quality of domestic composites.

Keywords: Physical Properties; Mechanical Properties; Composite

Introduction

Existing dental composite materials offer clinical ease of use and a satisfactory level of aesthetics. However, they continue to be limited by drawbacks, such as low resistance to abrasion and fracture, post-polymerization shrinkage, and low stress tolerance, which restrict their applications.[1] Dental composites typically consist of four components, including an organic resin matrix, inorganic reinforcing particles, a bonding agent, and an initiator/activator system. The reinforcing particles are primarily composed of minerals, such as silica, quartz, or silica glass compounds, or combinations thereof, which are sought after for their appropriate abrasion resistance, compressive strength, and biocompatibility.

A large number of studies have been conducted to improve the mechanical and physical properties of composites. As a result of these studies, numerous methods have been introduced to enhance the mechanical properties of composites, such as increasing filler content, modifying the polymerization and filler type, improving the type of polymers used in the matrix, creating a better bond between the filler and matrix, and optimizing the filler arrangement.[2] However, despite significant advancements in this field, the toughness, strength, and durability of this material for applications in high-stress points still require further investigations.

Among the laboratory tests conducted to determine the mechanical strength of fabricated composites are flexural and compressive strength, discoloration, and microhardness, which were evaluated in the present study. Composites are clinically influenced by high levels of flexural stress in the anterior and posterior regions. If they lack sufficient flexural strength, they may deform under chewing forces, ultimately leading to marginal seal degradation between the composite and the tooth.

Discoloration of composite restorations is one of the most common reasons for their replacement. Concerns remain regarding the color stability of these materials when used in the oral environment for a long run. Another important test is microhardness, defined as a material's resistance to penetration by a device under specific force and time. Microhardness can be predictive of the clinical success of resin composites.[3]

Given the current socio-economic conditions of the country and in an attempt to support knowledge-based companies in the field of domestic composite production, the present study aimed to investigate certain physical and mechanical properties of Iranian composites in comparison with foreign counterparts.

Methods

The current research was an in vitro study aimed at evaluating certain physical and mechanical properties of an Iranian composite compared to foreign composites. Two commercially available foreign resin composites, Filtek Z250 (3M, USA) and Denfil (Vericom, Korea), and the

Iranian composite Trivers (Trimed), were investigated. For all tested composites, shade A2 was used. Detailed information on each material is presented in Table 1.

Table 1 - Characteristics of the investigated composites

Composite resin	Type of composite	Filler type (by weight percentage, type, and size)	Resin matrix	manufacture
Filtek Z250	Microhybrid	zirconia/silica (3 microns or less) surface-modified silica particles (20 micron) 82%	BIS-GMA, UDMA, BIS-EMA, PEGDMA and TEGDMA	3M Dental Products, St. Paul, MN, USA
Denfil	Microhybrid	80% by volume inorganic fillers, fumed Silica microfillers (0.04 µm) and Barium Aluminosilicate particle fillers (≤ 1µm)	BIS-GMA, TEGDMA	Vericom, Korea
Triverse	Nanohybrid	Glass ceramic Barium Aluminosilicate,BRsilicalte(79%)	BIS-GMA, TEGDMA	Trimedi Tehran,Iran

Compressive Strength Test

Ten cylindrical specimens(n=10) were fabricated in a metal mold with dimensions of 4 mm in diameter and 6 mm in height for each composite group. The composites were packed within the mold in a layered manner, and each layer was light-cured for 20 seconds using an Optilux halogen-based light-curing unit (SDS, USA) at an intensity of 600-650 mW/cm². After complete polymerization, the specimens were stored in distilled water at 37°C for 48 hours, then subjected to a compressive strength test at a speed of 0.5 mm/min using a Zwick 020, Z –Roell/Zwick Testing Machine (Mechanical GmbH & CO.KG, Germany). A one-way analysis of variance (ANOVA) using SPSS software version 20 was employed for statistical analysis of the results at a significance level of 0.05.

Three-Point Flexural Strength Test

For this test, steel molds measuring 2×2×25 mm were prepared, and composite specimens (n=10) were placed inside these molds. Each side of the specimen was irradiated for 30 seconds (60 seconds in total) using an Optilux halogen-based light-curing unit (SDS, USA) with an intensity of 600-650 mW/cm² (the unit's intensity was periodically checked using a radiometer). Each side of the specimens was cured in three 20-second stages with overlapping stages, and then the specimens were removed from the mold and stored in water at 37°C for 24 hours. The three-point flexural strength was measured using a Universal Testing Machine. In this test, the span between the supports was 20 mm, with crosshead speed of 0.75 mm/min, and the maximum load was 50 N. The load was applied until the specimen failed, and the flexural strength data were recorded. A one-way ANOVA of the subgroups and post hoc pairwise comparisons were performed to analyze the data at a significance level of 0.05.

Surface Microhardness (Vickers) Analysis

Disc-shaped specimens (5 specimens from each group) were prepared using a Plexiglas mold with 10mm diameter and 2mm thickness following being approved by the ISO 4049 standard. The mold was placed over a glass slab and filled to the brim with the material to prevent air bubbles. Both sides of the mold were covered with transparent matrix tape to prevent the material from coming into contact with oxygen during polymerization. Another glass slab was placed over the mold and gently pressed to remove excess material and eliminate porosity. The specimen was then light-cured using an Optilux halogen-based light-curing unit (SDS, USA) at an intensity of 600-650 mW/cm². Each specimen was carefully removed from the mold and examined for any visible structural defects. After that, the edges of the specimen were sanded with sandpaper. A 136° diamond pyramidal indenter with a fixed force (300 gf) was used to make indentations on the specimens for three times over 10 seconds. The lengths of the diagonals of the diamond-shaped indentations were then calculated using a microscope connected to the device and the corresponding software. A one-way ANOVA of subgroups and post hoc pairwise tests were performed at $p<0.05$.

L*A*B Measurement

To prepare the specimens (5 specimens from each group), a 10 mm diameter, 2 mm thick Plexiglas annular mold was used. The mold was placed over a clear glass slab and filled with the composite. A cover slip was then placed over the mold to remove any excess composite. The specimen was then light-cured for 20 seconds using an Optilux halogen-based light-curing unit (SDS, USA) at an intensity of 600-650 mW/cm². The prepared specimens were then polished using soft, medium, and coarse aluminum oxide polishing discs (Sof-Lex Pop on Orange series-3M ESPE/St. Paul, MN, USA) to remove the resin-rich layer and create a smooth, polished specimen surface. For this purpose, each polishing disc was moved rotationally and intermittently over the specimens for 31 seconds to prevent excessive heating of the specimens, which could culminate in changes at their surface. The specimens were then immersed in distilled water for 24 hours. After this period, the specimens' L*A*B Comission Internatinal L'Eclairage (CIE) parameters were measured against a white and black background using a reflectance spectrophotometer (Scanning SpectroCam, USA, Ihara) and the L*A*B CIE system. The unit's valve size was 1.5×2 mm, and the measurement geometry was 45°/1°. Daylight D65 and a standard viewing angle of 11° were selected.

Color Stability Analysis

Two tea bags (yellow label tea Lipton, London) were placed in 250 mL of boiling distilled water for three minutes. The specimens were then immersed in the tea solution for 72 hours. The tea solution was prepared fresh daily, and the specimens were rinsed with distilled water for 30 seconds after each immersion and gently cleaned with a soft toothbrush to remove any debris adhering to the specimens due to immersion. After four days, the specimens were transferred to a spectrophotometer for color measurement after the re-staining stage, and the optical parameters were measured.[4] The total discoloration of the specimens (Delta E) was calculated using the following formula. The results were analyzed using ANOVA at p<0.05.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

Results

According to the findings, the highest compressive strength was observed in the Z250 group, while the lowest was found in the Trimed group. The compressive strength differences between groups were not statistically significant (p=0.435) (Table 2).

Table 2 - The mean and standard deviation of compressive strength (MPa) in the investigated groups

composite	Sample count	Mean	SD	Min	Max
Z250	10	386.826	59.4	306.7	514.1
Trimed	10	276.915	31.14	219	327.8
Denfill	10	313.402	42.53	240.5	384.4

In addition, the highest flexural strength was observed in the Z250 group, while the lowest was found in the Denfil group. The differences between groups were statistically significant (P=0.03) (Table 3), and post-hoc pairwise tests were performed accordingly (Table 4).

Table 3 - The mean and standard deviation of flexural strength (MPa) in the composite specimens

composite	Sample count	Mean	SD	Min	Max
Z250	10	157.5	20.4	130	176.6
Trimed	10	116.6	3.4	112.9	120.4
Denfill	10	140.08	30.5	102.9	171.5

Table 4 - The post hoc test results for flexural strength in the composite specimens

Pair	P-value
Z250-Trimed	0.025
Z250-Denfil	0.42
Trimed-Denfill	0.23

Table 5 shows the microhardness amounts for the investigated groups. Microhardness was measured both at the surface and bottom of the specimens. The highest amount of microhardness at the specimen surface belonged to the Z250 group, while the lowest was observed in the Denfil group. Similarly, for the specimen bottom, the Z250 group exhibited the highest microhardness, while the Denfil group exhibited the lowest microhardness. The hardness differences between the surface and bottom of the specimens were statistically significant in all groups (P<0.05) (Table 5, 6, 7).

In order to evaluate the filler distribution in Trimed composite, The Lapping method was done (Figure 1).

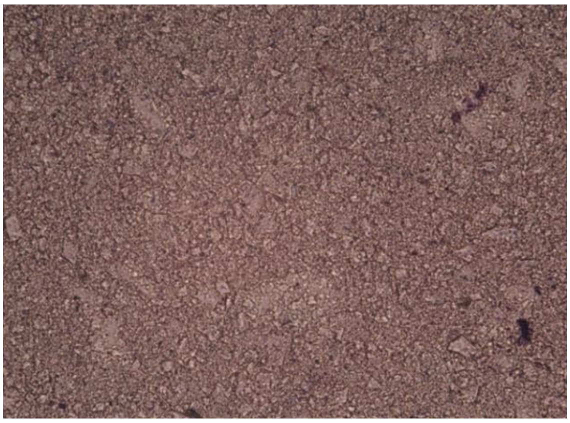

Figure 1: Filler distribution of Trimed composite using the Lapping method

Table 5 - Microhardness means and standard deviations for composite specimens

Composite	Sample count	Mean (top of sample)	Mean (Button of sample)	SD (top of sample)	Mean (Button of sample)	microhardness top/buttom
Z250	5	80.1	75.6	7.6	5.2	94%
Trimed	5	68.6	47.9	6.3	5.1	69%
Denfil	5	59.3	33.9	4.5	2.7	57%
P.value		0.019		0.000008		

ΔE values of the specimens compared to the A2 Vita Classical Shade Guide were reported as Trimed (2.398), Z250 (3.744), and Denfil (8.162), respectively. The highest discoloration after immersion in tea belonged to Trimed (5.06), Z250 (5.4), and Denfil (9.2), respectively.

Table 6- Post hoc test results for the surface microhardness of composite specimens

Pair	Difference	SE	Q	Lower Cl	Upper Cl	Critical Mean	P-value
Z250-Trimed	11.46	3.63	3.15	-4.31	27.24	15.77	0.1441
Z250-Denfil	20.76	3.63	5.7	4.98	36.54	15.77	0.01604
Trimed-Denfil	9.3	3.63	2.55	-6.47	25.07	15.77	0.2452

Table 7- Post hoc test results for the bottom microhardness of composite specimens

Pair	Difference	SE	Q	Lower Cl	Upper Cl	Critical Mean	P-value
Z250-Trimed	27.68	2.60	10.63	16.38	38.98	11.297	0.0007
Z250-Denfil	41.68	2.60	16.01	30.38	52.98	11.297	0.00007
Trimed-Denfil	14	2.60	5.3	2.70	25.297	11.297	0.020

Discussion

In the present study, three types of composites, Z250, Trimed, and Denfil, were subjected to various laboratory tests, including compressive and flexural strength, color stability after immersion in tea, and the Vickers microhardness test.

According to the results, Z250 exhibited the highest compressive and flexural strength among the tested composites. This can be attributed to its higher filler content and the optimal distribution of both micro and nano fillers. Previous studies have demonstrated a strong correlation between filler content and mechanical strength in composites, particularly when high filler content enables improved polymeric network formation and better stress distribution during force application.

The three-point flexural strength test used in this study revealed differences between the materials (Tables 3 and 4).[5-8] The aim of autoclaving composites is to improve polymerization and flexural strength.[8] The results of this study demonstrated no significant improvement in the flexural strength of autoclaved Trimed composite. This observation suggests that the primary issue affecting the mechanical properties of Trimed is related to the filler-matrix bond and not solely to the polymerization depth, as reported in previous studies.[9, 10]

One of the most significant properties of dental composites, particularly for aesthetic restorations, is color stability. According to numerous studies, the human eye can detect a ΔE color difference of less than 1, but in dental procedures, a ΔE greater than 3.3 is generally considered acceptable.[11, 12] In this study, discoloration (ΔE) was measured using the A2 Vita Classical Shade Guide as a reference. Trimed exhibited the least color deviation, followed by Z250 and Denfil. The better performance of Trimed in terms of color stability may be attributed to its glass filler system, which possesses inherent color properties and blends with natural tooth color more effectively.

Studies have indicated that discoloration can be simulated by immersing specimens in tea for 72 hours, equivalent to three years of tea consumption.[13] While all composites exhibited some degree of discoloration, Denfil (9.2) exhibited the greatest discoloration, which could be related to its higher resin matrix content. In contrast, the discoloration observed in Trimed (5.06) and Z250 (5.4) suggests that they may be more appropriate for aesthetic restorations in patients exposed to staining agents, such as tea, coffee, or tobacco.

The Vickers microhardness test provided valuable insights into resistance to abrasion and durability of the composites.[14] Z250 exhibited the highest surface microhardness, followed by Trimed and Denfil. The high microhardness of Z250 is likely attributed to its high filler content, enhancing its resistance to surface degradation and making it an appropriate option for oral regions with high occlusal forces. Evidence suggests that Z250 resin composite, with a high filler content (82% by weight), demonstrated superior resistance to abrasion after repeated abrasion, which is consistent with the current study's microhardness amount. In this study, microhardness amount was measured both at the surface and bottom of the specimens, and the surface-to-bottom ratio of microhardness was also reported. This ratio was higher for Z250 composite compared to Trimed and Denfil composites. Indeed, increased polymerization time leads to improved microhardness amount. It is likely that the behavior of these composites is generally improved with enhanced polymerization.

Despite some shortcomings in mechanical strength, Trimed exhibited relatively high microhardness, which is likely attributable to the glassy structure of its fillers, suggesting that Trimed may perform acceptably regarding resistance to abrasion, although further improvements in its mechanical durability are required.

Denfil, with its lowest microhardness, appeared to be inappropriate for posterior restorations where resistance to abrasion is of paramount importance. The lower filler content and potential differences in the polymeric matrix composition may be the reason for reduced hardness and consequently its diminished ability to withstand abrasive forces in the oral environment. The filler content analysis revealed that Z250 and Trimed composites had filler weight percentages close to the manufacturers' claims, while Denfil exhibited a lower weight percentage. This difference in filler content is significant, as a higher filler loading typically leads to improved mechanical properties, such as strength and hardness, due to better stress distribution and reduced degradation of the polymeric matrix. [15]

The lapping method used to assess the filler distribution in Trimed composite revealed an inhomogeneous filler distribution, which was characterized by the dispersion of coarse particles, and fine particles did not adequately fill the intervening space (Figure 1). This inhomogeneity in filler distribution likely contributed to the Trimed mechanical limitations, particularly its lower compressive and flexural strength. The filler size and distribution optimization could significantly enhance the mechanical performance of Trimed composites.

The findings of this study have several significant clinical implications. The superior mechanical properties of Z250 make it an excellent choice for high-stress areas, such as posterior restorations. Its high microhardness and resistance to abrasion suggest that it can maintain long-term integrity, even in challenging environments.[16] Moreover, the Z250 greater resistance to discoloration makes it a versatile composite for both aesthetic and functional restorations.[17]

Despite having lower compressive and flexural strength, Trimed still demonstrated relatively good color stability and microhardness, suggesting that it may be appropriate for anterior restorations or low-stress areas where aesthetics are a priority. However, further improvements in the filler-matrix bond could enhance its overall mechanical performance and expand its clinical applications.

Denfil, exhibiting the lowest mechanical performance in multiple tests, may be more appropriate for temporary restorations or areas not subjected to occlusal forces. Its susceptibility to discoloration also limits its use in highly visible areas, making it more appropriate for temporary restorations.

In the current research, the accuracy of the filler weight percentage in composites was investigated using the burn-out method and a 1.10000 digital scale. The filler weight percentages were found to be Z250 (79%), Trimed (75%), and Denfil (66.07%). In this regard, Z250 and Trimed composites exhibited better compatibility with the filler percentages declared by the manufacturer.

Given the limitations observed in the present study, several areas require further investigation. Future studies should examine the impact of different polymerization methods, such as the use of additional polymerization lights or longer polymerization times, to optimize the mechanical properties of composites like Trimed. Advanced techniques, such as Fourier Transform Infrared Spectroscopy (FTIR), can be employed for a more accurate assessment of the polymerization degree and filler-matrix interactions.[18]

It is hoped that through further research and evaluation of properties, such as polymerization shrinkage, water adsorption, and long-term degradation under oral conditions, a more comprehensive understanding of the performance of domestic composites can be achieved, leading to improvements in clinical outcomes.

Conclusion

Based on the results of this study, Trimed composite can be promising for clinical use. However, further laboratory and clinical investigations are required to improve the production of domestic composites.

Acknowledgements: We would like to present our sincere gratitude to our supervisor professor, Dr Amir Ghasemi for his guidance.

Author Contributions: A.V.: Conceptualization, Methodology, Investigation, Supervision, Project Administration, Funding Acquisition and N.G.: Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, writing – Original Draft, writing – Review & Editing and M.N.: Methodology, Software Writing – Original Draft.

Funding: No funding was received for this research.

Ethical Approval Code: The research protocol was approved by the ethics committee of the Dental Research Center of Shahid Beheshti University of Medical Sciences (Ethics No. IR.SBMU.RIDS.REC.1396.464).

Informed Consent Statement: Not applicable.

Using AI: No artificial intelligence has been used in any part.

Data Availability Statement: *No new data were created in this study*.

Conflict of Interest: The authors declare no conflict of interest.

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