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Effect of Preheating on Mechanical Properties of Different Commercially Available Dental Resin Composites

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Abstract

Background: This study aimed to reveal the effect of preheating on the surface microhardness and shear strength of composite materials used in the restoration of posterior teeth.

Methods and Results: There were 3 composite materials under the study: Estelite Posterior, Harmonize and Filtek Z550. To make static and dynamic tests of them, 120 filling samples were prepared. Of those, 60 samples were for surface hardness measurements and 60 samples were used to evaluate the shear strength of composite materials. We formed 12 study groups with 10 filling samples in each. Samples made off Estelite Posterior, Harmonize™, and Filtek™ were designated with E, H, and F capital letters, respectively; the «VH» abbreviation indicated static Vickers hardness testing and «SS» was assigned for dynamic shear testing; mark (°) was used when preheating was applied. Filling samples were made of heated (up to 60°C) and room-temperature (23-25°C) composite materials. The filling samples of EVH, E°VH, HVH, H°VH, FVH, and F°VH groups were subjected to a surface microhardness test. The samples of ESS, E°SS, HSS, H°SS, FSS, and F°SS groups were subjected to shear-strength assessment of materials. The surface microhardness of filling samples was measured using a ПМТ-3 Vickers hardness tester and the Vickers hardness number (VHN) was calculated. Dynamic tests were carried out using an UltraTester machine (Ultradent, Inc., USA) and shear test method until the shear-strength filling sample had completely failed.

After analysis of the obtained results, it was found that preheating had enhanced the surface hardness and mechanical strength of the composite materials used in the study. However, the positive influence of preheating was significant only in the EVH-E°VH, ESS-E°SS, HSS-H°SS, and FSS-F°SS groups in 1.48, 1.09, 1.33, and 1.16 times, respectively. In the HVH-H°VH and FVH-F°VH groups, the identified differences were not of significance despite the improvement in mean values at 1.1 and 1.1 times.

Conclusion: Preheating of light-curing resin-based composites is not equally effective for static and dynamic mechanical properties of materials for dental restoration. Preliminary laboratory tests could have helped before their clinical use.**(International Journal of Biomedicine. 2023;13(4):317-322.)**

Keywords: composite materials • preheating • Vickers hardness • shear strength

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Abbreviations

VH, Vickers hardness; **VHN**, Vickers hardness number; **SS**, shear strength.

Introduction

The limited lifespan of tooth-colored composite restorations caused by their early failure is one of the pressing problems in contemporary dentistry. This situation is multifactorial and may arise from the technological subtleties in the manufacturing process up to the unfavorable interplay of monomers, fillers, and photoinitiators in the composition of restorative systems. Sometimes, direct restoration of teeth can be technically sensitive, not to mention individual characteristics of mandible biomechanics and even minor aberrations in occlusion or tooth position in the arch of each patient.[1-7]

Many commercially available composites already have excellent physical properties, chemical stability, and functional and cosmetic characteristics, allowing them to act as a good alternative to expensive ceramic restorations. However, the insufficient strength of resin-based materials is the subject of constant study to improve them.[8-10]

In this regard, for more than half a century, studies have searched for better monomers or mixtures. Also, great attention is paid to the size and shape of filler particles with silane-coupling agents and their total weight and volumetric load. In the end, the proper compositions for new materials with exceptional physical properties may be found and used in restoring teeth in areas of high occlusal load.[11,12]

It is known that the physicochemical properties of composite restoration largely depend on the quality of the polymer matrix, and the amount of residual bonds is highly influenced by light and thermal energy. It has also been noted that heating composite materials before photoactivation can increase their degree of conversion by reducing the viscosity of loaded polymers and increasing the mobility of free radicals. At the same time, reducing the percentage of remaining double bonds in composite restorations will help to improve their chemical stability and mechanical strength.[12-14]

On the contrary, the increase in the conversion degree of double bonds may also be accompanied by high values of polymer volumetric shrinkage, which may cause marginal gap formation and microleakage of restorations. Furthermore, the high rate of polymerization in heated resin-based composites during photoactivation may contribute to the formation of polymer stress, which in turn has a negative effect on the physical properties of the final restoration.[13-17]

Most resin-based materials available on the market mainly contain bisphenol-A-glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), and bisphenol-A-ethoxylated-glycidyl dimethacrylate (Bis-EMA). The properties of these monomers have been well studied separately and are not of particular interest. However, their mixtures are the subject of ongoing research.[18]

Besides the organic matrix, the strength of a composite filling is predetermined by the amount and size of filler particles. In particular, the improvement in the mechanical properties of composite materials with high filler load has been confirmed by the results of static and dynamic tests.[19]

The main objective of other studies was to assess the influence of filler particle shape on the shrinkage stress kinetics of composite resins during polymerization. It was found that the spherical shape is preferable and does not contribute to the occurrence of high shrinkage stress, compared to irregularly shaped particles. At the same time, the kinetics rate of polymer stress varies depending on the particle size of the dispersed phase.[20,21]

The amount of internal stress and its kinetics directly depend on the filling material's temperature during polymerization. Evidence indicates that the mechanical properties of dental restorative composites can be improved by increasing their degree of conversion. However, most of these data are based on the results of static trials, which cannot provide insight into the behavior of a composite restoration under dynamic loading, which usually occurs during the functional activity of the masticatory muscles.[22-26]

The main feature of static tests, in comparison to dynamic, is they do not lead to the destruction of specimens. The most common static trial used in dentistry is the assessment of surface hardness of fillings. However, to perform dynamic tests on composites, testing machines are necessary that can evaluate the resistance of the filling material to bending, compression, torsion, shear, etc.[25-28]

In this regard, this study aimed to reveal the effect of preheating on the surface microhardness and shear strength of composite materials used in the restoration of posterior teeth.

Materials and Methods

There were 3 composite materials under the study (Table 1). To make static and dynamic tests of them, 120 filling samples were prepared. Of those, 60 samples were for surface hardness measurements. They were cylindrical with a diameter of 5.5±0.05 mm and a height of 2.5±0.1 mm (Figure 1). The other 60 samples were made in the shape of circular rods with an average cross-sectional diameter of 2.47±0.05 mm and length of 8.23±0.1mm (Figure 2). They were used to evaluate the shear strength (SS) of composite materials.

Table 1.

Composite materials under the study

Composite Material	Basic Composition	Lot
Estelite Posterior (E)	Matrix: Bis-GMA, TEGDMA and Bis-MPEPP. Filler load SiO_2-ZnO_2 (84 wt%): mean particle size 2 μm (0.1-10 μm)	W1923
Filtek™ Z550 (F)	Matrix: Bis-GMA, UDMA, Bis-EMA, PEGDMA and TEGDMA. Filler load SiO_2-ZnO_2 (82 wt%): mean particle size 3 μm	NC54995
Harmonize™ (H)	Matrix: Bis-GMA, Bis-EMA and TEGDMA. Filler load SiO -ZnO_2 (81 wt%): particle size 0,05-400 μm	9768511

Bis-EMA - bisphenol-A-ethoxylated-glycidyl dimethacrylate; Bis-GMA - bisphenol A-glycidyl methacrylate, Bis-MPEPP - bisphenol A polyethoxy methacrylate, PEGDMA- polyethylene glycol dimethacrylate, TEGDMA - triethylene glycol dimethacrylate, UDMA- urethane dimethacrylate.

Fig. 1. *Filling samples for Vickers hardness evaluation*

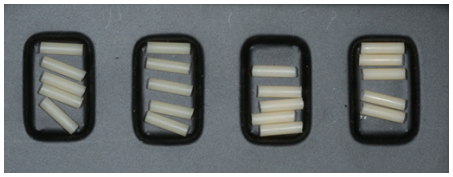

Fig. 2. Filling samples for shear strength assessments.

Thus, 12 study groups were formed with 10 filling samples in each. Samples made off Estelite Posterior, Harmonize™, and Filtek™ were designated with E, H, and F capital letters, respectively; the "VH" abbreviation indicated static Vickers hardness testing and "SS" was assigned for dynamic shear testing; mark (°) was used when preheating was applied.

Filling samples were made of heated (up to 60°C) and room-temperature (23-25°C) composite materials. Preheating was carried out on a calibrated appliance representing a heating glass tray (Figure 3). The design of the heater made it possible to polymerize composite materials at 60°C.

Fig. 3. *Appliance for heating dental composites.*

Photoactivation of the light-cured materials was carried out following the manufacturer's instructions using a VALO cordless curing light (Ultradent Products, Inc., USA) in standard mode.

Following the ISO 4049 protocol, after photoactivation, the prepared samples were immersed in water and stored at 37°C for 24 hours. Mechanical tests were carried out after this period of time.

The surface microhardness of filling samples was measured using a ПМТ-3 Vickers hardness tester. A 100-gram load was applied for 10 sec. In each sample of VH groups, 9 imprints were arbitrarily made on the top surface. The diagonals of square indentations were fixed in microns. Measurements were made on images (Figure 4) obtained using a scanning electron microscope SEM-EVO MA 15 (Zeiss, Germany). To get a clear image from the surface of the filling samples, they were sputtered with gold using a Q150R ES appliance (Quorum Technologies, UK).

The Vickers hardness number (VHN) was calculated according to the following formula: $VHN = 1.854 \times (F/D^2)$, where F is the applied load (measured in kilograms-force) and D^2 is the area of the indentation (measured in square millimeters) (Figure 4), which yields the VHN in the units of kg/mm^2.

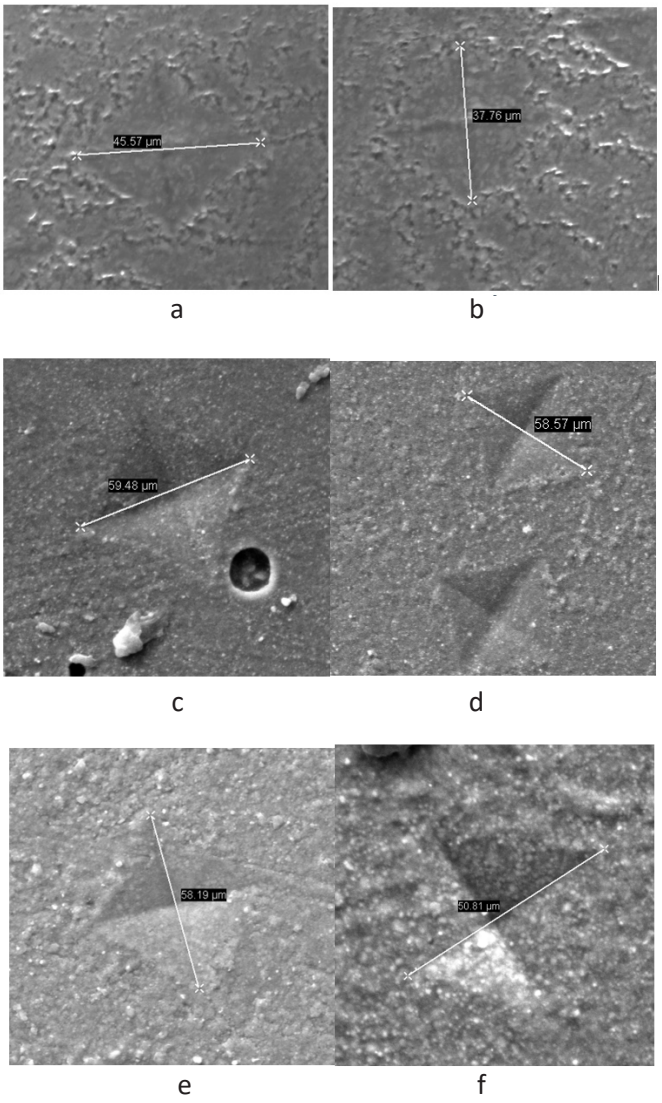

Fig. 4. *a - EVH; b - EºVH; c - HVH; d - HºVH; e -FVH; f - FºVH*

Dynamic tests were carried out using an UltraTester machine (Ultradent, Inc., USA) and shear test method until the shear-strength (SS) filling sample had completely failed. For this purpose, a steel adapter was made, which was fixed in the test clamp-base after it was mounted on the lifting platform.

The adapter resembled a barrel into which the shear-strength filling sample was inserted (Figure 5). The platform lifting speed was 0.1 mm/min. The peak load values were captured in pounds (lb).

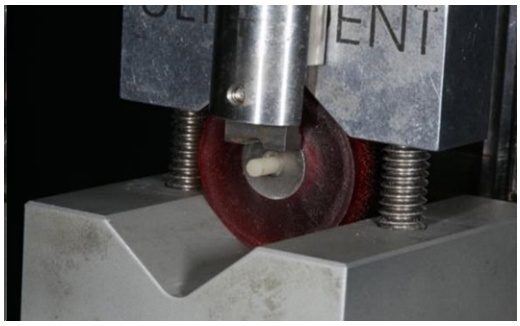

Fig. 5. *Steel adapter with inserted filling sample before the test.*

Statistical analysis was performed using the statistical software package SPSS version 21.0 (SPSS Inc, Armonk, NY: IBM Corp). For descriptive analysis, results are presented as mean±standard deviation (SD). The Mann-Whitney U Test was used to compare the differences between the two independent groups. A probability value of $P<0.05$ was considered statistically significant.

Results

The filling samples of EVH, EºVH, HVH, HºVH, FVH, and FºVH groups were subjected to a surface microhardness test. The samples of ESS, EºSS, HSS, HºSS, FSS, and FºSS groups were subjected to shear-strength assessment of materials. After analysis of the obtained results (Table 2), it was found that preheating had enhanced the surface hardness and mechanical strength of the composite materials used in the study. However, the positive influence of preheating was significant only in the EVH-EºVH, ESS-EºSS, HSS-HºSS, and FSS-FºSS groups in 1.48, 1.09, 1.33, and 1.16 times, respectively. In the HVH-HºVH and FVH-FºVH groups, the identified differences were not of significance despite the improvement in mean values at 1.1 and 1.1 times.

Table 2.

Influence of preheating on VH and SS of resin composites in vitro

Resin Composite	VHN (kg/mm^2)	Shear Strength (lb)
E *P-value* Eº	79.6 ± 15.3 0.000 118.1 ± 21.8	80.0 ± 5.4 0.002 87 ± 3.0
H *P-value* Hº	53.6 ± 7.3 >0.05 63.7 ± 15.0	54.2 ± 5.8 0.000 71.2 ± 4.5
F *P-value* Fº	73.8 ± 27.3 >0.05 87.5 ± 22.0	71.0 ± 4.9 0.000 82.5 ± 4.0

Discussion

Improving the quality of composite restorations is one of contemporary dentistry's main priorities. In this regard, the development of new materials and methods of their application will be relevant subjects for scientific research for many years.

It is known that preheating the composite material can significantly enhance the mechanical properties of restoration and its resistance to wear under masticatory load. In this regard, the positive results obtained from dynamic in vitro testing of the resin-based composite may shift the treatment plan strategy from an indirect approach to less invasive direct tooth-colored restoration.[27-31]

A diametrical load or split Hopkinson pressure bars are often used to evaluate the mechanical properties of composite dental resins under compressive load at different rates. According to them, a cylindrical sample is subjected to compression in a diametrical plane perpendicular to the longitudinal axis of the test sample.[26] This type of force distribution may closely simulate the incidence of stress encountered in Class 1 restorations. However, Class 2 composite restorations have a great chance of chipping the filling's mesial or distal occlusal margin due to the lack of supporting tooth wall and the risk of shear stress occurrence. As a result, the filling may fail when there is an occlusal load on one part of it and not on the other.[32]

Shear stress results from the action of forces directed at each other but in different planes.[33,34] In this regard, assessing the physical properties of materials by shear force in a cantilever system, rather than diametrically directed, could be more accurate, especially for the composites used in Class 2 cavity restoration.

Present research did not reveal all the subtleties of different behavior of composites in the study when the preheating approach was applied. However, certain observations were made which could be of particular value for daily practice.

For instance, the lack of a significant influence of preheating on surface microhardness of filling samples made off Harmonize™ and Filtek™ was presumably due to an insufficient filler load of their polymer matrix. This preliminary conclusion was drawn from similar tests performed with Estelite Posterior and its technical parameters, indicating heavier loading with SiO_2 and ZnO_2 nanoparticles, compared to other composites in the study.

On the contrary, a significant improvement in the shear strength of all studied materials after applying the preheating approach indicated an increased degree of conversion in them and no occurrence of significant internal stress, which was probably leveled out by the spherical shape of the filler particles.

Thus, the results of this study showed that applying a preheating approach for light-curing composites is not equally effective for static and dynamic mechanical properties of dental restorative materials, and that preliminary laboratory tests could have helped before their clinical use.

Conflict of Interests

The authors declare that they have no conflicts of interest.

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