EGYPTIAN
DENTAL JOURNAL
Vol. 64, 2491:2499, July, 2018
I.S.S.N 0070-9484
Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics
www.eda-egypt.org • Codex : 44/1807

SURFACE ROUGHNESS AND HARDNESS OF DENTAL RESIN-COMPOSITES INTENDED FOR BULK-FILL PLACEMENT

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ABSTRACT

Objective: To evaluate the surface roughness and hardness of high and low consistency bulk-fill resin-composites and to compare them with other conventional resin-composites.

Materials and Methods: The study was divided into five groups according to type of resin-composite as follows: group I: Low consistency bulk-fill SureFil SDR Flow (SF), group II: Low consistency bulk-fill Venus Bulk Fill (VB), group III: High viscosity bulk-fill Tetric EvoCeram, group IV: Conventional Beautifil Flow Plus F03 (BF) and group V: Conventional GrandioSo (GS). A total of 10 disc-shaped specimens (15 mm diameter × 2 mm thickness) were prepared from each material for both surface roughness and hardness testing. Specimens were stored in distilled water for 24 hours before testing. For the determination of surface roughness values, Surface Profile Gage (Positector, SPG, Deflesko Corporation, New York, USA) was used. Hardness testing was carried out using Digital Microhardness Tester (Zwick/Roell, IDENTEC, ZHVμ-S, West Midlands, England). Data were analyzed using a One-way ANOVA and Bonferroni *post-hoc* test. $P < 0.05$ was considered statistically significant.

Results: Considering different filler loading, monomer system and consistency of the material, the hardness values ranged between 49.8 and 97.3 (VHN) and the surface roughness ranged between 5.6 and 17.1 (μm). One way ANOVA revealed a significant differences between the studied materials for surface roughness ($P = 0.000$) and microhardness ($P = 0.000$). Bonferroni *post-hoc* test revealed significant differences between surface roughness results of all studied resin-composites ($p < 0.05$). There was also significant differences between hardness values of all investigated resin-composites ($P = 0.000$) except between SF and VB ($P = 0.701$). Significantly greater hardness and surface roughness were recorded for materials with higher filler loading than those with lower filler loading.

Conclusions: Within the range of studied resin-composites, the values of surface roughness and hardness were principally dependent on the extent of filler loading, the type of resin system and the material consistency.

KEYWORDS: Hardness, Surface roughness, Resin-composites, Bulk-filling, Incremental filling, Filler loading, Consistency.

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INTRODUCTION

It became a mandatory task for the dental profession to provide the patient with a restoration with adequate physical and mechanical characteristics. In addition, the patient should face no or minimal discomfort both at the restoration time and when in service. Because of the great advances, both in manufacturing and application, the resin-composite restoratives have become the materials of choice for direct esthetic restorations [1].

Clinical performance and durability of a restorative resin-composite is governed, to a great extent, by their resistance to degradation and distortion in the oral environment [2]. It is well-established, as well, that mechanical properties of a restorative material are majorly influenced by the environment to which they are exposed together with their chemical composition [3].

For a long time, resin-composite restoratives have been applied to the dental cavities in thin layers or increments - 2 mm or less - which is known as "incremental-filling technique" [4]. Limiting the resin increment to a thickness of 2 mm or less enhances penetration of curing light and provides adequate polymerization of the material [5]. This, in turn, improves the mechanical properties, reduces cytotoxicity, and maximizes marginal adaptation [6, 7]. One more advantage for the incremental-filling technique is the ability to minimize the amount of shrinkage and resulting stress during polymerization of the resin-composite. Adhesive failure of tooth/restoration bonding could arise if the polymerization stress was high. Debonding may result in gap formation, microleakage, secondary caries and pulpal inflammation [8-10].

There have been, however, some problems reported for the incremental-filling technique. These include: i) long time is required to complete the restoration which may cause some discomfort to the patient, ii) proper isolation at the time of filling must be maintained to achieve successful restoration, iii) it is prone to incorporate voids or contamination between layers of restoration, and iv) bond failure between increments may take place [11, 12]. With respect to the isolation during bonding and filling steps, the restoration integrity could be disrupted during placement of successive layers if the patient moved his/her tongue over a layer and introduced saliva. For a successful direct resin-composite restoration placed by the incremental technique, care must be taken that every single layer of the material is placed properly in terms of shape, thickness, and curing [13, 14].

Lately, there are numerous studies that suggest fewer increments or even "bulk-filling" could give equal results to that of the incremental-filling technique. A new class of dental resin-composites were launched to the dental market by several manufacturers [11, 12, 15, 16]. It was said that these restoratives can be applied to the dental cavities in a thickness of 4 mm and polymerized as a single increment. These resin-composites, keeping the desired properties, can save a lot of restoration time, minimize treatment efforts, and remove a lot of stress for both dentist and patient [17].

It has been reported that the "bulk-fill" resin-composites may require more additional features than conventional ones. To enable the clinician to achieve the whole restoration with a single increment, a bulk-fill resin-composite should have above-average translucency to the curing light. This will enable the light to deeply penetrate to the bottom of the restoration and cure it effectively [18, 19]. In addition to this, there should be close matching between the refractive index of the filler particles and that of the resin matrix to improve the translucency [20, 21] and to prevent light scattering that may take place at the filler/resin interface causing some opacity of the material [22, 23].

Other strategies to increase the depth of cure of these materials were approached by some dental manufacturers. These include: i) the use of modified monomers which may play a crucial role to adjust the setting process and thus control polymerization stress as in case of SDR materials [24], and ii) the addition of more potent photo-initiator systems as in case of Tetric N-Ceram which contains monoacylphosphine oxide (TPO) and an additional photoinitiator system (Ivocerin-a dibenzoyl germanium compound) that can provide higher photo-curing activity. Because of the higher absorption of visible light over a wider range of wavelengths from 370 to 460 nm, an enhanced degree of conversion in deeper layers of the material and a greater depth of cure can be achieved [25-27].

Several investigations have been conducted to evaluate these resin-composites and to compare them with those placed incrementally. The properties investigated for these materials include polymerization shrinkage [28], microleakage [11], marginal adaptation [29], interfacial stresses [30], and others.

Hardness and surface roughness are amongst the several mechanical properties that can express the resistance of a material to occlusal forces. Hardness measures the ability of a material to withstand permanent indentation or penetration. Hardness testing has been applied to the restorative materials to predict their wear resistance and their ability to abrade or be abraded by the opposing tooth structure or material [31]. Because of the intimate relationship between hardness and other physical properties, it has been used by dental researchers for characterizing and ranking of dental restorative materials [32].

Surface roughness is an essential property when evaluating a dental restoration. This is because a rough surface enhances accumulation of dental plaque and food debris on the restoration and its tooth. This, consequently, causes gingival inflammation and initiation of secondary caries. In addition, roughness diminishes the restoration gloss and causes discoloration and surface degradation [33-35]. Therefore, this study was conducted to evaluate the hardness and surface roughness of some "bulk-fill" resin-composites and to compare them with other conventional materials. The null hypothesis was: there will be no difference in surface roughness and hardness values between bulk-fill resin-composites - either with low or high consistency - and conventional resin-composites.

MATERIALS AND METHODS

Five resin-composites were investigated in this study. Three bulk-fill materials; two with low consistency and one with high consistency were used. Also two conventional resin-composites, one with low consistency and another with high consistency were used (Table 1).

Specimen preparation

A total of 10 disc-shaped specimens (15 mm diameter × 2 mm thickness) were prepared from each material for both surface roughness and hardness testing. The material was packed (high consistency) or injected (low consistency) in a suitable metallic mold. Glass microscope slides, covered with transparent polystyrene matrix films, were positioned at the upper and lower surfaces of the specimen and pressed under hand pressure to extrude excess material. Curing of specimens was carried out from top and bottom at overlapping points for 40 s each using a visible light curing unit (Optilux 501, Kerr, Orange Co., USA) with irradiance of 650 mW/cm^2. Excess material around the mold was removed by wet-grinding both sides of the specimens with a sequence of P800, P1000, P1500, P2000 grit Silicone Carbide (SiC) abrasive paper. Specimens were removed from the mold and stored in distilled water for 24 hours before testing.

Surface roughness testing

For the determination of surface roughness values, Surface Profile Gage (Positector, SPG, Deflesko Corporation, New York, USA) (Figure 1) was used. It is a hand-held electronic instrument

TABLE (1) Investigated resin-composites and manufacturers' information.

Product	Type	Resin System	Filler wt%	Manufacturer & Lot Number
Group I: SureFil SDR Flow (SF)	Bulk-fill (low consistency)	EBPADMA, TEGDMA	68	Dentsply Caulk, Milford, Delaware, USA (1003011)
Group II: Venus Bulk Fill (VB)	Bulk-fill (low consistency)	UDMA, EBADMA	65	Heraeus Kulzer GmbH, Hanau, Germany (10028)
Group III: Tetric EvoCeram Bulk Fill (TE)	Bulk-fill (high consistency)	Dimethacrylate co-monomers	80	Ivoclar Vivadent, Schaan, Liechtenstein (PM0213)
Group IV: Beautifil Flow Plus F03 (BE)	Conventional (low consistency)	Bis-GMA, TEGDMA	67	Shofu Inc., Kyoto, Japan (041008)
Group V: GrandioSo (GS)	Conventional (high consistency)	Bis-GMA, Bis-EMA, TEGDMA	89	Voco, Cuxhaven, Germany (1048014)

EBPDMA: Ethoxylated Bisphenol-A-Dimethacrylate, TEGDMA: Trithyleneglycol Dimethacrylate, UDMA: Urethane Dimethacrylate, Bis-GMA: Bisphenol A Glycidyl Dimethacrylate, Bis-EMA: Bisphenol A Ethyl Methacrylate.

that measures the peak-to-valley height of the surface profile of cleaned and polished surfaces. It consists of PosiTector body and built-in probe. The gage is turned on and its probe is carefully applied to the surface to be measured. Five readings were taken for each specimen and then averaged. The mean of the ten examined specimens was taken as the surface roughness of the material.

Fig. (1) Surface Profile Gage used for determination of surface roughness.

Vickers microhardness testing

After completing the surface roughness testing, the same specimens were used for determination of hardness values. Hardness evaluation was conducted using Digital Microhardness Tester (Zwick/Roell, IDENTEC, ZHVμ-S, West Midlands, England) (Figure: 2), by applying a load of 200 g for 10 s. Each specimen was fixed in a clamping apparatus and positioned in a manner that the indenter tip will be perpendicular to the specimen surface to be tested. Each specimen was subjected to five indentations equally-spaced over a circle. Care was taken to make the indentation not closer than 1 mm to the adjacent indentations or the margin of the specimen. The average of the five indentations was then calculated. The mean of the ten examined specimens was taken as the hardness of the material.

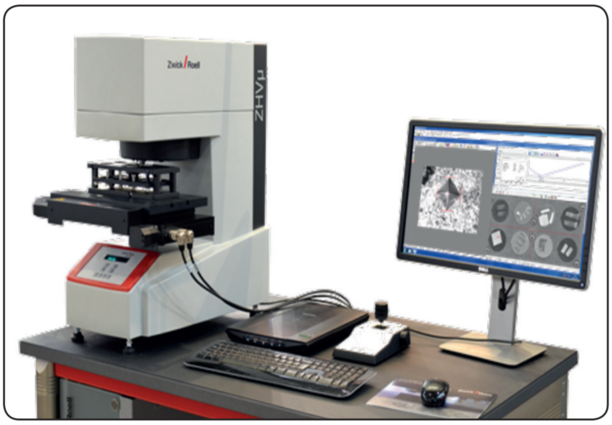

Fig. (2) Digital Microhardness Tester used for determination of hardness.

Statistical analysis

The data were collected, tabulated and statistically analyzed by an IBM compatible personal computer with SPSS statistical package version 20 (SPSS Inc. Released 2011. Armnok, NY: IBM Corp.). Surface roughness and hardness data of investigated resin-composites were analyzed using a one-way analysis of variance (ANOVA) with the significance level established at $p < 0.05$. The Bonferroni *post hoc* test was used for multiple comparisons.

RESULTS

Mean values and standard deviations of surface roughness and Vickers microhardness for the investigated resin-composites are listed in Tables 2 and 3 and presented in Figures 3 and 4, respectively. The surface roughness means ranged between 5.6 and 17.1 (μm). The highest surface roughness means were recorded for high consistency materials GS followed by TE, then conventional low viscosity BF followed by bulk fill low viscosity VB and SF materials. The microhardness values ranged between 49.8 and 97.3 (VHN). GS recorded the greatest hardness followed by TE and BE, then SF followed by VB.

One way ANOVA revealed a significant differences between the studied materials for both examined properties: surface roughness (P = 0.000) and microhardness (P = 0.000). Bonferroni *post-hoc* test revealed significant differences between surface roughness values of all studied resin-composites (p = 0.000). There was also significant differences between hardness values of all investigated resin-composites (P = 0.000) except between SF and VB (P = 0.701).

TABLE (2) Statistical analysis of surface roughness (μm) of studied resin-composites.

Resin-composite (Code)	Mean ± SD (μm)	F	P-Value
SureFil SDR Flow (SF)	5.6 ± 1.2^{a}	285.99	0.000*
Venus Bulk Fill (VB)	8.7 ± 0.9^{b}		
Tetric EvoCeram Bulk-Fill (TE)	13.2 ± 2.6^{c}		
Beautifil Flow Plus F03 (BE)	10.8 ± 1.6^{d}		
GrandioSo **(GS)**	17.1 ± 2.5^{e}		

Groups with different superscript letters are significantly different (P = 0.000).

TABLE (3) Statistical analysis of microhardness (VHN) of studied resin-composites.

Resin-composite (Code)	Mean ± SD (VHN)	F	P-Value
SureFil SDR Flow (SF)	52.1 ± 3.7^{a}	457.07	0.000*
Venus Bulk Fill (VB)	49.8 ± 2.9^{a}		
Tetric EvoCeram Bulk Fill (TE)	75.6 ± 4.3^{b}		
Beautifil Flow Plus F03 (BE)	63.8 ± 3.1^{c}		
GrandioSo (GS)	97.3 ± 3.6^{d}		

Groups with different superscript letters are significantly different (P = 0.000).

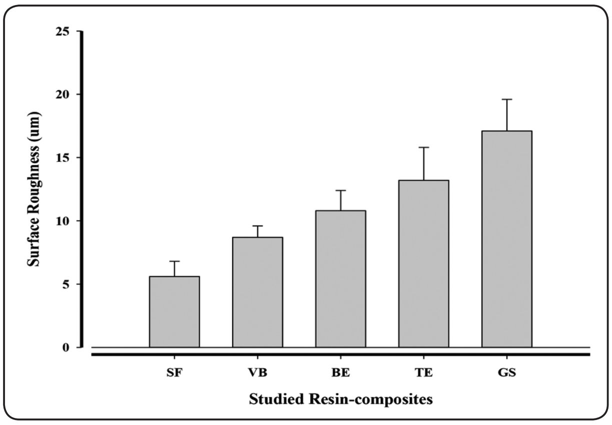

Fig. (3) Error bar showing means and standard deviations of surface roughness (μm) for studied resin-composites.

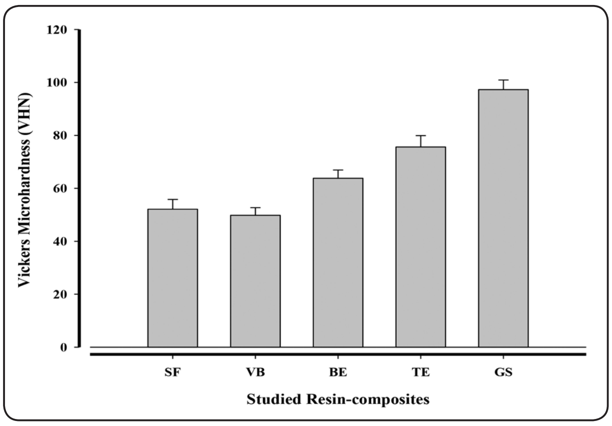

Fig. (4) Error bar showing means and standard deviations of Vickers microhardness (VHN) for studied resin-composites.

DISCUSSION

When choosing a restorative resin-composite for dental practice, it is essential to consider their mechanical properties. Hardness and surface roughness are among those properties that should be adequately provided in a restorative material for an acceptable clinical performance [36].

With respect to hardness, there has been a well-established knowledge between researchers that hardness increases significantly with higher filler loading [37]. It was also reported that hardness is intimately related to changes in polymer viscosity, polymer shrinkage, elastic modulus [38] and degree of conversion (DC) [39].

Hardness is not considered as an inherent material property, but rather a defined measurement procedure. Because of the simplicity with which hardness measurement is done, it is usually applied to examine and characterize resin-composites [40, 41]. Hardness can be defined as "macro-, micro- or nano-scaled" according to the applied load and the displacements obtained [42]. In the current study, the Vickers microhardness test was applied to evaluate the hardness of some "bulk-fill" resin-composites of low and high consistency and to compare them with other conventional materials.

In addition, determination of surface roughness for restorative resin-composites is an integral part of the comprehensive evaluation of the properties of these materials. This is because a rough surface of a restorative material can initiate and enhance accumulation of dental biofilms and residues of oral foods and drinks. This, in turn, not only may cause periodontal diseases and secondary caries but also diminish the restoration gloss and may cause discoloration and surface degradation [43, 44]. Therefore, some of "bulk-fill" resin-composites were submitted to surface roughness examination and compared with other conventional materials.

Statistical analysis revealed high significant differences in the surface roughness and hardness mean data between the bulk-fill resin-composite (with low or high consistency) and the conventional resin-composites (with low or high consistency), therefore, the null hypothesis was rejected.

In this study, the bulk-fill resin-composites behaved just like the conventional materials. This means that the bulk-fill resin-composite with high consistency exhibited greater hardness as well as higher surface roughness than another bulk-fill material with lower consistency. This was clear with TE, SF and VB. TE has higher consistency than the other two materials and recorded higher results in the examined two properties. In relation to the effect of filler loading on the properties of these materials, once again, they behaved like the conventional materials. TE has higher filler loading (80 wt%) than SF and VB (68 and 65 wt%, respectively) and exhibited higher hardness and surface roughness than the other two materials.

Comparing these materials with conventional resin-composites, the conventional resin-composite with higher filler loading and higher consistency (e.g. GS) showed greater hardness and higher surface roughness than the bulk-fill materials with lower consistency and lower filler loading (e.g., SF and VB). In this study, the reverse was true as well. This means that the bulk-fill material with higher filler loading and higher consistency (e.g., TE) exhibited higher hardness and surface roughness than conventional materials with lower consistency and lower filler loading (e.g., BE). In case of having the same consistency, filler loading was the main factor in determining the hardness of the material. This was clear in case of GS and TE which both having high consistency. Because GS has higher filler loading (89 wt%), it recorded greater hardness than TE that has lower filler content (80 wt%).

Though having low consistency and comparable filler loading, BE exhibited greater hardness (63.8 VHN) than SF (52.1 VHN). This could be justified on the basis of the monomer system upon which the material is based. BE is based on a monomer system of Bis-GMA and TEGDMA while SF is based on EPADMA and TEGDMA. Bis-GMA is a bulky and structurally rigid monomer that is very commonly incorporated into dental resin-composites, adhesives and fissure sealants. It can impart many desirable characteristics to the restorative material such as higher mechanical properties and better resistance to deformation [45, 46].

The results of our study revealed low hardness values for the low consistency bulk-fill resin-composites. This is in agreement with the instructions of the dental manufacturers who recommend the use of low consistency bulk-fill materials as liner (stress-relief) materials under the main restorative materials because of their low hardness.

Joining the two properties together while ranking and comparing the studied materials does not mean that greater values of both properties for a material is an advantage. Actually these two properties are opposite to one another in terms of desirable properties for a restorative material. Greater hardness is an advantage while greater surface roughness is a disadvantage.

CONCLUSIONS

- Within the range of studied resin-composites, filler loading was the main factor in determining the surface roughness and hardness between materials either bulk-fill or conventional.
- Resin system is an important parameter in the hardness value of a resin-composite.

ACKNOWLEDGEMENT

Authors are grateful to Mai Samy (a PhD candidate at the Biomaterials Department, Faculty of Dentistry, Tanta University) for her valuable technical support and assistance in testing procedures.

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