

# Influence of storage temperature on vickers microhardness of resin composite

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## Abstract

**Introduction:** The purpose of this study is to evaluate the effect of three storage temperatures on microhardness of high and low viscosity bulk-fill materials and compare them with conventional resin-based composite materials.

**Materials and method:** Six composite resin-based materials were used in this study (TN, TNB, TNF, FZ250, FB and FBF) samples were subdivided into three groups based on the pre-curing storage temperature (5°C, 23°C and 37°C). Light polymerization for each material was performed based on the manufacturer's recommendation using Bluephase G2 curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) in a high-intensity mode with an irradiance of 1200 mW/cm<sup>2</sup>. Vickers hardness values of top and the bottom surfaces of each sample were evaluated using (NOVA 130 series, Vickers and Knoop hardness testing instrument) under a 200 g load with a dwell time of 10 sec. Also three indentations with the random distance of 1 mm were taken from the top and the bottom surfaces of each sample and a mean Vickers hardness (VHN) value were calculated (n=18 top and n=18 bottom). The mean bottom/top ratio was calculated by dividing VHN of the bottom surface by VHN of the top surface.

**Results:** When the tested materials were stored at room temperature (23°C) before testing in the present study, they failed to reach the minimum 80% of the mean bottom to top hardness value ratio except for FZ250 and FBF, where they reached 97.8% and 83.2% respectively. Where in samples that were stored refrigerated at 5°C all the materials have reached the minimum 80% of the mean bottom to top hardness value ratio except for FBF (77.3%) and TB (77.2%). On the other hand, the only material that reached the minimum 80% of the mean bottom to top hardness value ratio when the materials were stored at 37°C was FZ250 (93.5%).

**Conclusion:** Despite the promising results from this preliminary study, regarding improvement of microhardness with refrigerated composite resins, further research has to be conducted. The enhancement of hardness values associated with preheated composites could be beneficial in countries with warm climate such as Saudi Arabia. The association of pre-cooled composite resin and the use of the LED curing units could be recommended to improve resin-based composite hardness. Further research is needed to evaluate the other mechanical properties and whether or not they are influenced by storage temperature.

**Keywords:** Composite resin; Bulk fill; Light cure; Temperature; Vickers microhardness

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## Introduction

Resin-based composite materials have been used in dentistry for many years and they are considered a successful replacement of posterior amalgam restorations [1]. Bulk-fill materials have been introduced to the market with an attempt to overcome some of the disadvantages of 2 mm incremental packing by being

able to be placed as a bulk of 4 mm thickness. Currently, two classes of bulk-fill materials are available in the market, viscous and flowable [2,3]. Due to the simplified procedure of bulk fill resin materials, more practitioners are interested in using them [4]. The main advantages of bulk fill resin materials are the increased depth of cure that could be related to their high translucency [5], low polymerization shrinkage stress as a result of

modifications in the filler content and organic matrix with the help of advanced technology [6].

Hardness as well as flexural strength and modulus of elasticity, are all improved with increased filler volume in resin-based composite materials. Filler size and weight also affect different composite characteristics [7-10]. Several studies reported improvement of mechanical properties of preheated composites as a result of increased rate of cure and a higher degree of conversion, although the effect of preheating could vary according to the brand of material [11,12]. The high viscosity of packable composites would make marginal adaptation a critical issue, especially if heavily filled materials were used [11]. The viscosity of resin-based composites is temperature dependent and directly related to the handling characteristics of the composite [13-15].

Rheology studies indicated that resin composites, being visco-elastic materials by nature, respond to an increase in external temperature according to the Arrhenius equation, which results in the exponential decrease in their viscosity [15-17]. As a result of decreased paste viscosity, free radicals and propagating polymer chains become more mobile and react to a greater extent, resulting in a complete polymerization reaction and greater crosslinking. The increase in polymerization may lead to improved mechanical properties and increased wear resistance [13,18,19]. Also, preheated composites have a better surface hardness and greater depth of cure [20,21]. The recent literature reported that by increasing the temperature of composite resins with high filler loading before polymerization, the flowability of the composite resin would be enhanced. Moreover, as a result of enhanced flowability the placement and adaptation of composites will be facilitated, thus increasing the durability of the restoration [22,23].

Although storing resin-based materials refrigerated is a common practice to increase their shelf life as recommended by the manufacturers, few studies have investigated the effect of cooling of resin-based composites and their results were controversial. Darnoch et al. reported that the degree of conversion is increased at a 60°C and decrease at 3°C [24]. On

the other hand Walter and his group reported that the pre-cooling of the composite resin might decrease the shrinkage [12]. Other studies found no adverse effects from using materials directly from refrigerated storage [25,26]. Lack of literature and the fact that manufacturers usually recommend keeping the composite syringes inside the refrigerator justifies the investigation in the present study on the effect of pre-cooling on the microhardness of the tested composite resins. The purpose of this study is to evaluate the effect of three storage temperatures on microhardness of high and low viscosity bulk-fill materials and compare them with conventional resin-based composite materials. To evaluate the curing efficiency of various resin-based composite materials in the present study, Vickers hardness measurements were performed [27].

## Materials and Methods

Four bulk-fill materials with different viscosities (high and flowable) have been tested, while two nanohybrid composites materials served as control. The specimens were subdivided into three subgroups according to the storage temperature before their use, {subgroup 1=storage at room temperature 23°C, subgroup 2=preheating temperature 37°C and subgroup 3=precooling temperature 5°C}. Materials specifications are presented in table (Table 1). Samples were prepared using a custom-made cylindrical mold with 5 mm diameter and 4 mm height for bulk fill materials and 2 mm height for nanohybrid composites. Thick glass slab was used as a base for the mold and composite resins were backed as one increment. To ensure a smooth surface of the samples with no need for finishing and polishing, a myler strip and a glass slide were placed over the composite resins before curing. Light polymerization for each material was performed based on the manufacturer's recommendation using Bluephase G2 curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) in a high-intensity mode with an irradiance of 1200 mW/cm<sup>2</sup>. The distance between the light source and the material was constant throughout the experiment process as 1 mm, which represented the thickness of the glass slide. The samples were dry stored in a light-proof container for 24 h. in an incubator at 37°C to complete the polymerization process before testing.

To determine the microhardness of composite resin materials used in this study, Vickers hardness values of top and the bottom surfaces of each sample were evaluated using (NOVA 130 series, Vickers and Knoop hardness testing instrument) under a 200 g. load and a dwell time of 10 sec. Three indentations with the random distance of 1 mm were taken from the top and the bottom surfaces of each sample and a mean Vickers hardness (VHN) value were calculated (n=18 top and n=18 bottom). The microhardness was determined through measuring the diameters of indentation which was produced by the pyramidal square-base diamond indenter. The mean bottom/top ratio was calculated by dividing VHN of the bottom surface by VHN of the top surface.

**Statistical analysis**

Data were analyzed using SPSS version 21.0 (IBM Inc., Chicago, USA) statistical software. Descriptive statistics (mean and standard deviation) were used to describe the quantitative variable (measurement of the top, bottom and ratio) of microhardness of resin composite materials. Student’s paired t-test was used to compare between the mean values of top and bottom measurements of each of the six materials. One-way analysis of variance was used to compare the mean

values in relation to the categorical variables (six types of materials and three levels of storage temperature), followed by Tukey’s multiple comparison test. General linear model was used to identify the effect of type of material and level of temperature on the top, bottom and ratio measurements. A p-value of <0.05 was used to report the statistical significance of results.

**Results**

The study has evaluated the effect of three levels of storage temperatures on the measurements (top, bottom and its ratio) of microhardness among the six types of materials which consists of high and low viscosity bulk-fill materials and conventional resin-based composite materials. For each material 18 samples were prepared. And, these samples were tested at three levels of storage temperatures (23°C, 5°C and 37°C). The comparison between the top and bottom surfaces mean values of measurements in each of the tested materials (TN, TB, TBF, FZ250, FB and FBF) at each of the three levels of storage temperatures (23°C, 5°C and 37°C) shows highly statistically significant difference in the mean values, where the mean values of top surface measurements are statistically significantly higher than the bottom surface measurements in all the six materials and at all the three levels of storage temperature (Table

**Table 1:** Materials specifications.

Material	Resin	Filler	Photoinitiator	Filler %	Curing time	manufacturer
Filtek bulk fill flowable composite (FBF)	BisGMA, BisEMA, Procry-lat, UDMA	Zirconia or silica, ytterbium trifluoride	Camphoroquinone	64.5 wt% / 42.5% vol	20 sec	3M ESPE
Tetric N-Flow Bulk fill (TBF)	monomethacrylates and dimethacrylates	barium glass, ytterbium trifluoride, and copolymers	Ivocerin	68.2 wt% / 46.4 vol%.	10 sec	Ivoclar Vivadent
Tetric N-Ceram (TN)	BisGMA, UDMA, TEGDMA, EthoxylatedBis-EMA	Barium aluminium silicate glass, ytterbium trifluoride, mixed oxide, Prepolymer	Camphoroquinone	80-81 wt.%/ 55-57 vol.%	10 sec	Ivoclar Vivadent
Tetric N-Ceram Bulk fill (TB)	dimethacrylates	barium glass, prepolymer, ytterbium trifluoride and mixed oxide	Ivocerin	75-77% wt. / 53-55% vol	10 sec	Ivoclar Vivadent
Filtek Bulk fill posterior (FB)	AUDMA, UDMA and 1, 12-dodecane-DMA	Zirconia/silica, ytterbium trifluoride	Camphoroquinone	76.5% wt / 58.4% vol	20 sec	3M ESPE
Filtek Z250 (FZ250)	BIS-GMA, UDMA, Bis-EMA	zirconia/silica	Camphoroquinone	82% wt / 60% vol	20 sec	3M ESPE

2). The comparison of the mean ratio of the bottom and top surface measurements among the six study materials (TN, TB, TBF, FZ250, FB and FBF) shows high statistically significant difference (F=67.342; p<0.0001). The pair wise comparison among the six materials shows the mean ratio values of the two materials; FZ250 and FB to be significantly higher than the three materials (TN, TB and TBF), whereas the mean ratio values of the three materials (TN, TB and TBF) are significantly lower than the other four materials. Moreover, there is no significant difference between the mean ratio values of FBF material and the other two materials (FZ250 and FB) (Table 3).

The comparison of the mean ratio of the bottom and top surface measurements among the three levels of storage temperature (23°C, 5°C and 37°C) not considering the

type of material, shows highly statistically significant difference (F=43.292, p<0.0001). The pair wise comparison among the three levels of temperature indicates that the mean ratio values are different with each other (Table 4). There is no statistically significant difference in the mean values of top side measurements among the three levels of storage temperature (23°C, 5°C and 37°C) not considering the type of material (F=0.654, p=0.521) (Table 5).

**Generalized linear model**

The comparison of the mean values of top, bottom measurements and its ratio, in each of the six materials (TN, TB, TBF, FZ250, FB and FBF) across the three levels of storage temperatures 23°C, 5°C and 37°C) and also the comparison of the mean values of the top, the

**Table 2:** Comparison between the mean values of Top and Bottom side measurements among the six study materials at three levels of temperature.

Type of Material and level of temperature	Side of measurement		Mean difference	t-value	p-value	95% CI for difference of mean
	Top	Bottom				
<b>23<sup>o</sup></b>						
TN	50.40(0.20)	27.48(0.23)	22.92	347.09	<0.0001	22.76,23.04
TB	56.41(0.19)	32.59(0.25)	23.82	391.60	<0.0001	23.69,23.94
TBF	42.27(0.21)	26.33(0.24)	15.96	197.76	<0.0001	15.76,16.10
FZ250	90.39(0.20)	88.46(0.24)	1.93	28.54	<0.0001	1.78,2.06
FB	60.55(0.19)	45.42(0.19)	15.13	277.11	<0.0001	15.01,15.25
FBF	30.49(0.32)	25.37(0.21)	5.12	48.52	<0.0001	4.90,5.34
<b>5<sup>o</sup></b>						
TN	46.37(0.22)	40.38(0.22)	5.99	67.53	<0.0001	5.79,6.17
TB	48.42(0.22)	37.38(0.27)	11.04	135.71	<0.0001	10.87,11.20
TBF	33.49(0.20)	28.40(0.27)	5.09	72.85	<0.0001	4.94,5.22
FZ250	91.57(0.19)	87.59(0.19)	3.98	63.99	<0.0001	3.82,4.11
FB	63.61(0.21)	56.31(0.20)	7.30	105.84	<0.0001	7.16,7.45
FBF	30.52(0.24)	23.61(0.29)	6.91	100.48	<0.0001	6.77,7.05
<b>37<sup>o</sup></b>						
TN	40.56(0.23)	29.38(0.24)	11.18	141.60	<0.0001	11.01,11.34
TB	45.55(0.21)	35.33(0.23)	10.22	131.36	<0.0001	10.05,10.38
TBF	38.44(0.26)	28.51(0.31)	9.93	94.98	<0.0001	9.71,10.15
FZ250	92.40(0.19)	86.42(0.23)	5.98	78.14	<0.0001	5.82,6.14
FB	65.31(0.15)	50.44(0.18)	14.87	236.70	<0.0001	14.74,15.0
FBF	32.33(0.18)	23.55(0.26)	8.78	104.74	<0.0001	8.60,8.96

**Table 3:** Comparison of mean values of Ratio of Bottom: Top sides measurements among the six study materials.

Levels of temperature	Ratio (Bottom: Top) Mean(Sd.,)	F-value	p-value
TN	0.714(0.13)‡	67.342	<0.0001
TB	0.708(0.09)‡		
TBF	0.737(0.09)‡		
FZ250	0.956(0.02)*		
FB	0.802(0.06)*		
FBF	0.778(0.04)		

\*Significantly higher than other materials; ‡Significantly lower than other materials

bottom measurements and its ratio at each of the three storage temperatures (23°C, 5°C and 37°C) among the six materials (TN, TB, TBF, FZ250, FB and FBF) shows highly statistically significant difference (Table 6) (Figure 1). The model with the top measurement values along with the six materials and three levels of storage temperatures shows high statistically

significant difference (F=155222.26; p<0.001) and also the interaction of levels of storage temperature and type of material (F=5044.15; p<0.0001). This indicates that the top side measurement values are significantly changing across the type of material and the level of storage temperature (Figure 2). Similar pattern was observed with the bottom measurement values

**Table 4:** Comparison of mean values of Ratio of Bottom: Top sides measurements across the three temperature levels of observation.

Levels of temperature	Ratio (Bottom: Top) Mean(Sd.,)	F-value	p-value
23°	0.718(0.15)*	43.292	<0.0001*
5°	0.851(0.06)*		
37°	0.779(0.07)*		

\*Significantly different from each other

**Table 5:** Comparison of mean values of top sides measurements across the three temperature levels of observation.

Levels of temperature	Top measurements Mean(Sd.,)	F-value	p-value
23°	55.08(18.65)	0.654	0.521
5°	52.33(20.71)		
37°	52.43(20.72)		

**Table 6:** Comparison of mean values of Top, Bottom, and Ratio of Bottom: Top sides measurements across the three levels of temperature in each of the six study materials.

Type of Material	Levels of temperature			F-value	p-value
	23°	5°	37°		
<u>Top measurement</u>					
TN	50.38(0.20)	46.36(0.22)	40.56(0.23)	8961.85 12045.07 6440.43 462.57 2791.45 299.96	<0.0001 <0.0001 <0.0001 <0.0001 <0.0001 <0.0001
TB	56.41(0.20)	48.42(0.23)	45.55(0.22)		
TBF	42.26(0.22)	33.48(0.20)	38.43(0.27)		
FZ250	90.38(0.21)	91.57(0.19)	92.39(0.19)		
FB	60.55(0.20)	63.61(0.22)	65.31(0.15)		
FBF	30.48(0.32)	30.52(0.25)	32.33(0.18)		
F-value	138271.20	188869.31	204764.31		
p-value	<0.0001	<0.0001	<0.0001		
<u>Bottom measurement</u>					
TN	27.48(0.24)	40.38(0.23)	29.38(0.25)	15068.04 1562.68 338.70 366.03 13829.58 329.78	<0.0001 <0.0001 <0.0001 <0.0001 <0.0001 <0.0001
TB	32.59(0.26)	37.38(0.28)	35.32(0.24)		
TBF	26.33(0.24)	28.40(0.28)	28.51(0.32)		
FZ250	88.46(0.25)	87.59(0.19)	86.41(0.23)		
FB	45.42(0.20)	56.31(0.20)	50.43(0.18)		
FBF	25.36(0.22)	23.61(0.23)	23.54(0.26)		
F-value	192140.99	172324.67	157636.94		
p-value	<0.0001	<0.0001	<0.0001		
<u>Ratio(Bottom: Top)</u>					
TN	0.545(0.004)	0.870(0.008)	0.724(0.007)	9678.36 6061.98 2727.61 774.95 5773.58 378.14	<0.0001 <0.0001 <0.0001 <0.0001 <0.0001 <0.0001
TB	0.577(0.004)	0.772(0.007)	0.775(0.007)		
TBF	0.623(0.007)	0.848(0.009)	0.741(0.010)		
FZ250	0.978(0.003)	0.956(0.003)	0.935(0.004)		
FB	0.750(0.003)	0.885(0.004)	0.772(0.004)		
FBF	0.832(0.013)	0.773(0.009)	0.728(0.010)		
F-value	9644.03	1775.27	1863.00		
p-value	<0.0001	<0.0001	<0.0001		

( $F=154196.87$ ,  $p<0.0001$ ;  $F=3230.94$ ,  $p<0.0001$ ) and also with the ratio values ( $F=4855.118$ ,  $p<0.0001$ ;  $F=2233.33$ ,  $p<0.0001$ ) (Figure 3).

In the top surface measurement mean values, among the six materials, FZ250 has higher mean values and its value is higher at 37°C when compared with other two levels of storage temperature (Figures 4 and 5). In the bottom surface measurement mean values, FZ250 material has higher mean values and its value is higher at 23°C when compared with other two levels of storage temperature. Moreover, in the ratio measurement mean values, among the six materials, the FZ250 material has higher mean values and its value is higher at 23°C when compared with other two levels of storage temperature. After this material, in the

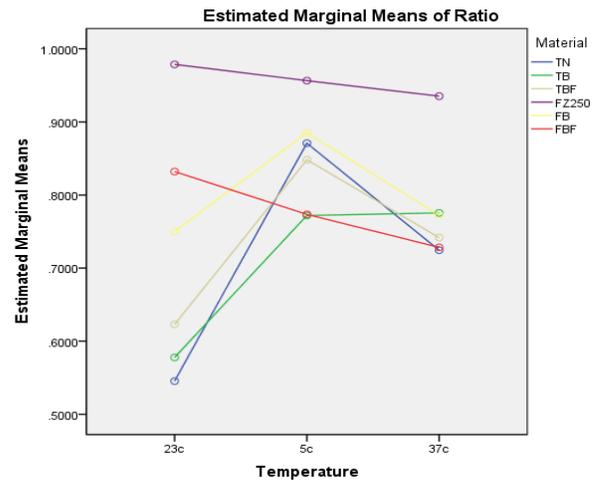


Figure 3: Estimated marginal means of the ratio of bottom: top surfaces.

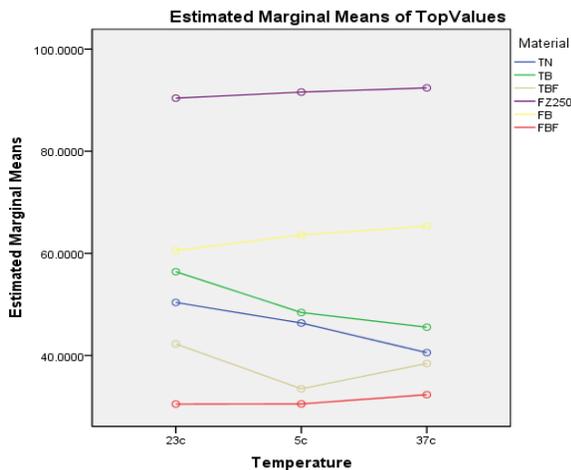


Figure 1: Estimated marginal means of top surface.

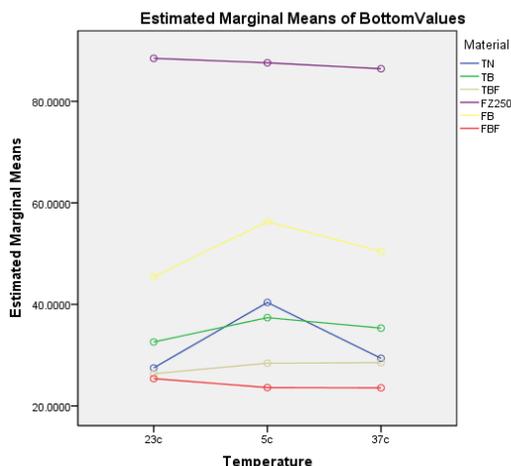


Figure 2: Estimated marginal means of bottom surface.



Figure 4: VH indentation of top surface FZ250 at room temperature.

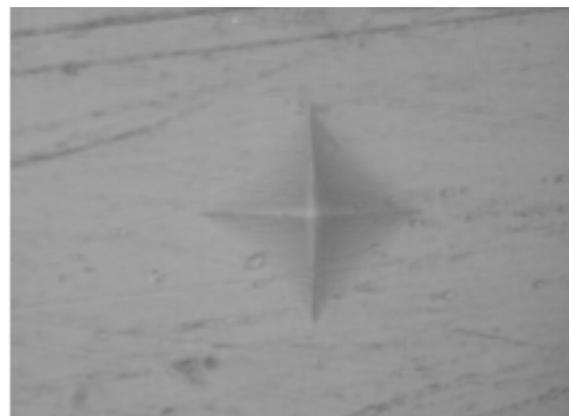
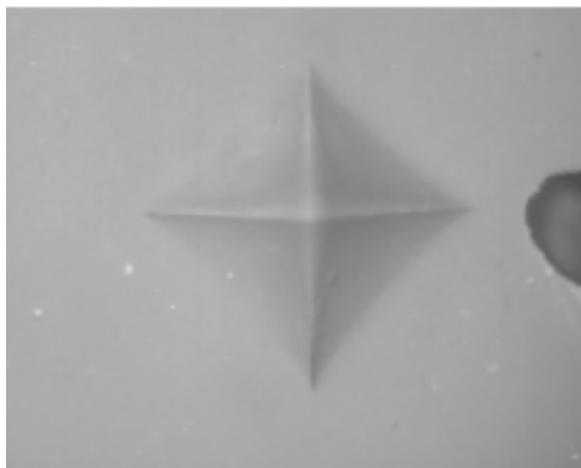


Figure 5: VH indentation of bottom surface FZ250 at room temperature.

ratio measurement of mean values similar pattern was observed in the FBF and FB materials, but the higher



**Figure 6:** VH indentation of top surface TN at room temperature.



**Figure 7:** VH indentation of bottom surface TN at room temperature.

mean ratio values at 5°C with FB material and at 23°C with FBF material. For all other three materials (TN, TB and TBF) the ratio of mean values is higher at 5°C and 37°C storage temperatures when compared with the ratio of mean values at 23°C storage temperature (Figures 6 and 7).

## Discussion

Hardness tests are the most frequently used method to evaluate the curing depth and the polymer cross-linking of dental composites [28-33]. As well as the polymer cross-linking of dental composites [34,35]. Additionally, the microhardness data for a specific material provide information on its wear, polishability and abrasive effect on antagonist's teeth [36]. The Vickers microhardness test (VHN) has been commonly

used to evaluate the hardness of dental materials, as it is usually used for brittle materials and small film thickness materials. Hardness is often expressed in percentage; the surface hardness is always compared to 100%, which represents the maximum surface hardness. An acceptable curing depth is achieved if bottom hardness corresponds to at least 80% of the top surface hardness [37]. Experience has shown that the simple hardness measures (top and bottom) correspond well to the more thorough hardness profile measurements [38].

When the tested materials were stored at room temperature (23°C), they failed to reach the minimum 80% of the mean bottom to top hardness value ratio except for FZ250 and FBF, where they reached 97.8% and 83.2% respectively. Where in samples that were refrigerated at 5°C all the materials have reached the minimum 80% of the mean bottom to top hardness value ratio except for FBF (77.3%) and TB (77.2%). On the other hand, the only material that reached the minimum 80% of the mean bottom to top hardness value ratio when the materials were stored at 37°C was FZ250 (93.5%). These results are in agreement with a previous study where they showed that at room temperature only 50% to 75% conversion of monomers could be achieved [22,39]. Low monomer conversion rate reduces the mechanical strength of restoration and oxidation of unsaturated monomers may give rise to composite color changes as well as allergic reactions. An increase in the degree of conversion improves surface hardness, flexural strength, modulus, fracture toughness, diametral tensile strength and wear resistance [40].

In the current study, the hardness values of the bottom surface of all tested materials at the different storage temperatures were lower than the hardness values of top surfaces. This can be related to the proximity of top surfaces to the light source and thus receiving higher energy density [41-44]. Another explanation could be due to the insufficiency of curing time that was recommended by the manufacturers and followed in this study. These findings are in agreement with Aldossary et al., results, where the tested samples which were cured for 10 sec, failed to reach the accepted hardness ratio [45]. Others studies had also suggested increasing the polymerization time more than the manufacturers'

recommendation to improve the bulk fill materials performance especially the hardness value [30,46,47]. If we look deeper to the result of the top and bottom hardness values for the materials that failed to reach the 80% hardness ratio at 23°C, we can observe an enhancement in the hardness values at the bottom surfaces of the samples at 5°C and 37°C.

The enhancement in the preheated samples high could be explained by the fact that temperature increase results in increased molecular mobility and thus; the postponement of diffusion, controlled propagation and reaction diffusion controlled termination and auto deceleration, thereby allowing the system to reach higher limiting conversions before verification. Moreover, the temperature increase could result in higher crosslinked polymer network or oligomeric network formation [13,18]. Another explanation could be related to the effect of temperature increase in reducing the rate of the polymerization process before reaching the final degree of conversion; therefore less unreacted residual monomer remains free accordingly it leads better mechanical properties [30,48]. Preheating of resin-based materials prior to their use, will lower their viscosity and help in the handling properties, this will lead to better adaptation to cavity walls [49].

The results of the present study of the mean hardness ratio of bottom and top surface among the three levels of storage temperature (23°C, 5°C and 37°C) not considering the type of material, shows that the best hardness ratio was obtained with the refrigerated samples at 5°C (85.1%), which has a highly statistically significant difference from the other groups ( $F=43.292$ ,  $p<0.0001$ ). A possible justification for the improvement of hardness of refrigerated resin composites is that samples were less affected by the heat generated by the curing unit, generating less stress during its polymerization [30]. These results suggest that the refrigeration allowed the composite resin to react similarly to the “soft start polymerization method” because, the low temperature could have proportioned less monomer mobility, decreasing the reaction velocity and providing an extension of the pre-gel phase without decreasing hardness values [50]. Another study demonstrated that cooling before light-curing did not result in differences in hardness for the composite resins after polymerization. Also, it was

observed that the pre-cooling of the composite resin might decrease the shrinkage [12]. It was reported that surface hardness of composite resin material is influenced by resin matrix, filler type and filler loading and degree of conversion [51]. And the results of the current study reflect that where FZ250 has the highest filler content (60% Vol) exhibit the highest mean hardness ratio among all the tested materials at the different storage temperatures.

## Conclusion

Within the limitations of this study, the association of pre-cooled composite resin and the use of the LED curing units could be recommended to improve resin-based composite hardness. The enhancement of hardness values associated with preheated composites could be beneficial in countries with warm climate such as Saudi Arabia where this study took place since manufacturers’ recommendations about storing conditions could be less strictly followed.

Preheating and precooling could affect the hardness of the resin composite materials, but it mainly depends on the type of composite resins used. Further research is needed to evaluate the influence of the storage temperature on the other mechanical properties. Despite the promising results from this preliminary study, regarding improvement of microhardness with refrigerated composite resins, further research has to be conducted keeping the molds at 37°C to simulate the intraoral conditions in a better manner.

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## References

1. Lazarchik DA, Hammond BD, Sikes CL, Looney SW, Rueggeberg FA. Hardness comparison of bulk-filled/transtooth and incremental-filled/occlusally irradiated composite resins. *J Prosthet Dent* 2007; 98(2): 129-140.

2. Burgess J, Cakir D. Comparative properties of low-shrinkage composite resins. *Compend Contin Educ Dent* 2010; 2: 10-15.
3. Ilie N, Hickel R. Investigations on a methacrylate-based flowable composite based on the SDR technology. *Dent Mater* 2011; 27(4): 348-355.
4. Ilie N, Kessler A, Durner J. Influence of various irradiation processes on the mechanical properties and polymerisation kinetics of bulk-fill resin based composites. *J Dent* 2013; 41(8): 695-702.
5. Dentsply International. Surefil SDR Flow, Product Brochure 2011.
6. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G. Physico-mechanical characteristics of commercially available bulk-fill composites. *J Dent* 2014; 42(8): 993-1000.
7. Scougall-Vilchis RJ, Hotta Y, Hotta M, Idono T, Yamamoto K. Examination of composite resins with electron microscopy, microhardness tester and energy dispersive X-ray microanalyzer. *Dent Mater J* 2009; 28(1): 102-112.
8. Faltermeier A, Rosentritt M, Faltermeier R, Reichender C, Müssig D. Influence of filler level on the bond strength of orthodontic adhesives. *Angle Orthod* 2007; 77(3): 494-498.
9. Czasch P, Ilie N. In vitro comparison of mechanical properties and degree of cure of bulk fill composites. *Clin Oral Investig* 2013; 17(1): 227-235.
10. Bucuta S, Ilie N. Light transmittance and micro-mechanical properties of bulk fill vs. conventional resin based composites. *Clin Oral Investig* 2014; 18(8): 1991-2000.
11. Uctasli MB, Arisu HD, Lasilla LV, Valittu PK. Effect of preheating on the mechanical properties of resin composites. *Eur J Dent* 2008; 2: 263-268.
12. Walter R, Swift Jr EJ, Sheikh H, Ferracane JL. Effects of temperature on composite resin shrinkage. *Quintessence Int* 2009; 40(10): 843-847.
13. Daronch M, Rueggeberg FA, De Goes MF. Monomer conversion of pre-heated composite. *J Dent Res* 2005; 84(7): 663-667.
14. Knight JS, Fraughn R, Norrington D (2006) Effect of temperature on the flow properties of resin composite. *Gen Dent* 54(1): 14-16.
15. Lee JH, Um CM, Lee IB. Rheological properties of resin composites according to variations in monomer and filler composition. *Dent Mater* 2006; 22(6): 515-526.
16. Mjor IA, Gordan VV. Failure, repair, refurbishing and longevity of restorations. *Oper Dent* 2002; 27(5): 528-534.
17. Barnes H, Hutton J, Walters K. *An Introduction to Rheology* Elsevier, 1987.
18. Daronch M, Rueggeberg FA, De Goes MF, Giudici R. Polymerization kinetics of pre-heated composite. *J Dent Res* 2006; 85(1): 38-43.
19. Bagis YH, Rueggeberg FA. Effect of post-cure temperature and heat duration on monomer conversion of photo-activated dental resin composite. *Dent Mater* 1997; 13(4): 228-232.
20. Lucey S, Lynch CD, Ray NJ, Burke FM, Hannigan A. Effect of pre-heating on the viscosity and microhardness of a resin composite. *J Oral Rehabil* 2010; 37(4): 278-282.
21. Muñoz C, Bond P, Sy-Muñoz J, Tan D, Peterson J. Effect of pre-heating on depth of cure and surface hardness of light-polymerized resin composites. *Am J Dent* 2008; 21(4): 215-222.
22. Deb S, Di Silvio L, Mackler HE, Millar BJ. Pre-warming of dental composites. *Dent Mater* 2011; 27(4): e51-e59.
23. Osternack FH, Caldas DB, Almeida JB, Souza EM, Mazur RF. Effects of preheating and precooling on the hardness and shrinkage of a composite resin cured with QTH and LED. *Oper Dent* 2013; 38(3): E1-E8.
24. Daronch M, Rueggeberg FA, Moss L, de Goes MF. Clinically relevant issues related to preheating composites. *J Esthet Restor Dent* 2006; 18(6): 340-350.

25. Bausch JR, de Lange C, Davidson CL. The influence of temperature on some physical properties of dental composites. *J Oral Rehabil* 1981; 8(4): 309-317.
26. Hagge MS, Lindemuth JS, Broome JC, Fox MJ. Effect of refrigeration on shear bond strength of three dentin bonding systems. *Am J Dent* 1999; 12(3): 131-133.
27. Flury S, Hayoz S, Peutzfeldt A, Hüsler J, Lussi A. Depth of cure of resin composites: Is the ISO 4049 method suitable for bulk fill materials? *Dent Mater* 2012; 28(5): 521-528.
28. Poggio C, Lombardini M, Gaviati S, Chiesa M. Evaluation of Vickers hardness and depth of cure of six composite resins photo-activated with different polymerization modes. *J Conserv Dent* 2012; 15(3): 237-241.
29. Torres CRG, Souza CS, Borges AB, Huhtala MFRL, Caneppele TMF. Influence of Concentration and Activation on Hydrogen Peroxide Diffusion through Dental Tissues In Vitro. *Sci World J* 2013; 18: 1-5.
30. Osternack FH, Caldas DB, Rached RN, Vieira S, Platt JA, Almeida JB. Impact of refrigeration on the surface hardness of hybrid and microfilled composite resins. *Braz Dent J* 2009; 20(1): 42-47.
31. DeWald JP, Ferracane JL. A comparison of four modes of evaluating depth of cure of light-activated composites. *J Dent Res* 1987; 66(3): 727-730.
32. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. *Dent Mater* 2005; 21(1): 36-42.
33. Bouschlicher MR, Rueggeberg FA, Wilson BM. Correlation of bottom-to-top surface microhardness and conversion ratios for a variety of resin composite compositions. *Oper Dent* 2004; 29(6): 698-704.
34. Cenci MS, Pereira-Cenci T, Cury JA, Ten Cate JM. Relationship between gap size and dentine secondary caries formation assessed in a microcosm biofilm model. *Caries Res* 2009; 43(2): 97-102.
35. Fróes-Salgado NR, Silva LM, Kawano Y, Francci C, Reis A, Loguercio AD. Composite pre-heating: Effects on marginal adaptation, degree of conversion and mechanical properties. *Dent Mater* 2010; 26(9): 908-914.
36. Marovic D, Panduric V, Tarle Z, Ristic M, Sariri K. Degree of conversion and microhardness of dental composite resin materials. *J Mol Struct* 2012; 1044: 299-304.
37. Watts DC, Amer O, Combe EC. Characteristics of visible-light-activated composite systems. *Br Dent J* 1984; 156(6): 209-215.
38. Pilo R, Cardash HS. Post-irradiation polymerization of different anterior and posterior visible light-activated resin composites. *Dent Mater* 1999; 8(5): 299-304.
39. Ayub KV, Santos Jr GC, Rizkalla AS, Bohay R, Pegoraro LF, Rubo JH, et al. (2014) Effect of preheating on microhardness and viscosity of 4 resin composites. *J Can Dent Assoc* 2014; 80: e12.
40. Prasanna N, Pallavi Reddy Y, Kavitha S, Lakshmi Narayanan L. Degree of conversion and residual stress of preheated and room-temperature composites. *Indian J Dent Res* 2007; 18(4): 173-176.
41. Feng L, Carvalho R, Suh B. Insufficient cure under the condition of high irradiance and short irradiation time. *Dent Mater* 2009; 25(3): 283-289.
42. Caldas D, Almeida J, Correr-Sobrinho L, Sinhoreti M, Consani S. Influence of curing tip distance on resin composite Knoop hardness number, using three different light curing units. *Oper Dent* 2003; 28(3): 315-320.
43. Soh MS, Yap AU, Siow KS. The effectiveness of cure of LED and halogen curing lights at varying cavity depths. *Oper Dent* 2003; 28(6): 707-715.
44. Lindberg A, Peutzfeldt A, van Dijken JW.

- Effect of power density of curing unit, exposure duration, and light guide distance on composite depth of cure. *Clin Oral Investig* 2005; 9(2): 71-76.
45. Aldossary M, Roebuck Elizabeth M, Santini A. Bulk Fill Resin Composite Materials Cured with Single-Peak versus Dual-Peak LED LCUs. *Acta Medica Marisiensis* 2016; 62(1): 5-14.
  46. Zorzin J, Maier E, Harre S, Fey T, Belli R, Lohbauer U, et al. Bulk-fill resin composites: polymerization properties and extended light curing. *Dent Mater* 2015; 31(3): 293-301.
  47. Cohen ME, Leonard DL, Charlton DG, Roberts HW, Ragain JC. Statistical estimation of resin composite polymerization sufficiency using microhardness. *Dent Mater* 2004; 20(2): 158-166.
  48. Jin MU, Kim SK. effect of pre-heating on some physical properties of composite resin. *J Korean Acad Conserv Dent* 2009; 34(1): 30-37.
  49. Trujillo M, Stansbury JW. Thermal effects on composite photopolymerization monitored by realtime NIR. *J Dent Res* 2003; 82.
  50. Dall'Magro E, Correr ArB, Costa ArB, Correr GM, Consani RLX, Correr-Sobrinho Lo, et al. Effect of different photoactivation techniques on the bond strength of a dental composite. *Brazil Dent J* 2007; 21(3): 220-224.
  51. Galvao MR, Caldas SGFR, Bagnato VS, de Souza Rastelli AN, de Andrade MF. Evaluation of degree of conversion and hardness of dental composites photo-activated with different light guide tips. *Eur J Dent* 2013; 7(1): 86-93.