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Assessment of creep and compressive strength: bulk-fill versus conventional composites

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Abstract

Backgrounds Creep of composite restorations is affected by their exposure to oral fluids. This study sought to assess the effect of media (water and 75% ethanol) and time storage on creep and compressive strength of bulk-fill and conventional composites.

Methods Twenty-five samples (4 × 6 mm) were fabricated of X-tra fil (bulk-fill) and Estelite Sigma, Grandio SO and Z250 composites (conventional) and divided into five groups ($n = 5$) according to the storage condition; no storage, 24 h of water storage, 24 h of ethanol storage, 30 days of water storage and 30 days of ethanol storage at 37 °C. Following dynamic creep (1–50 MPa, 0.25 Hz, 30 min, 450 cycles), compressive strength was measured.

Results Estelite Sigma and Z250 conventional composites showed the highest creep (0.0193 mm and 0.0178 mm, respectively) after 24 h of ethanol storage. GrandioSO had the highest creep (0.0148) after 30 days of ethanol storage ($P < 0.05$). No difference was noted in creep of X-tra fil when stored in different conditions ($P = 0.065$). Compressive strength following dynamic force application was in the following order: Z250 > GrandioSO > Estelite and X-tra fil. Storage medium had no significant effect on compressive strength. The highest compressive strength was noted in samples stored for 30 days irrespective of the storage medium.

Conclusions Alcohol and water storage increased the creep of conventional composites. Creep of bulk-fill composite was not affected by the storage time or medium. Compressive strength of conventional and bulk-fill composites was not influenced by the storage medium but increased over time.

Keywords Composite resins, Viscoelastic substances, Media, Compressive strength

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Background

Composite resins are among the highly demanded restorative materials for esthetic dental treatments [1]. Creep and compressive strength are among the most important mechanical properties to evaluate composite restorations. The compressive strength of restorative materials is especially important in the chewing function, because many of the chewing forces, especially in the posterior teeth, are of a compressive type. Accordingly, having dental composites with sufficient compressive strength is considered a desirable mechanical property [2, 3].

Restorative materials undergo some degrees of deformation or creep when subjected to intraoral dynamic stresses. When the amount of creep exceeds a standard tolerable threshold, it can pose a threat to the marginal seal of the restoration, which is considered an important criterion for evaluating the success of restorative materials [1]. As a result, creep is one of the most important mechanical properties, especially in posterior composite restorations [4].

Creep and compressive strength are affected by chemical composition of composites and exposure to oral fluids [5]. Composite restorations are frequently exposed to chemical agents present in the saliva, food products and drinks. Acidic foods and drinks can cause severe wear of composite resins. Environmental factors can cause softening of resin matrix and subsequent dislodgement of filler particles [6]. It has also been demonstrated that creep and viscoelastic recovery of composites increase following water storage [7].

Bulk-fill composite is suitable for use in class I and class II cavities as well as in teeth requiring a core build-up. Use of bulk-fill composites has greatly increased in the recent years due to their easy and fast application [8]. However, their mechanical properties particularly compressive strength and creep have not been well investigated and compared with those of conventional composites [9]. Poor clinical service and inadequate durability of polymer-based materials could be related to the high magnitude of creep deformation. Some recent studies showed that bulk-fill composite exhibited creep and recovery within the acceptance range in comparison with conventional composite, however increased filler loading decreased the creep magnitude of bulk-fill composites [10].

The mechanical properties of bulk-fill composites and the factors influencing them have been explored in the literature [11, 12]. However, while much of the research has concentrated on flowable bulk-fill composites, studies on high-viscosity bulk-fill composites remain limited. Furthermore, most existing studies have assessed the visco-elastic properties of these materials using the static creep method. In contrast, our study utilized the dynamic creep test technique to evaluate these characteristics.

The hypotheses of the current study are that the degree of creep varies among different composite materials, and that the creep behavior of composites differs under various storage conditions. Additionally, it is hypothesized that the compressive strength of different composites will vary, and that storage conditions will also influence the compressive strength of these materials. Therefore, this study aimed to assess two mechanical properties namely dynamic creep and compressive strength of X-tra fil (Voco, Cuxhaven, Germany) bulk-fill composite with high filler content and Estelite Sigma (Tokuyama, Tokyo, Japan), Grandio SO (Voco, Cuxhaven, Germany) and Z250 (3 M, XXX, USA) conventional composites after 24 h and 30 days of storage in water and ethanol.

Methods

This experimental study was conducted on one bulk-fill and three conventional composites. The characteristic and method of application of composite resins used in this study are shown in Table 1.

Fabrication of samples

By means of stainless-steel molds, composite cylinders were fabricated measuring 4 mm in diameter and 6 mm in height/thickness. Sample size was calculated to be 25 samples in each group to achieve 80% power of study. Glass microscope slides, covered with transparent Mylar matrix strips were positioned at the upper and lower

Table 1 Characteristics of the materials used in this study

Type of composite	LOT number	Filler content	Shade	Application mode	Manufacturer	Matrix	Filler
X-tra fil	1,350,262	86wt% 70.1v%	Universal	Bulk-fill	VOCO GmbH, Cuxhaven, Germany	Bis-GMA, UDMA, TEGDMA, MMA, Bis-EMA	SiO_2, Glass, Oxide
Estelite	608E	82wt% 71v%	A2	Incremental	Tokuyama Dental Corporation, Tokyo, Japan	Bis-GMA، TEGDMA	zirconia-silica
GrandioSO	1,224,390	87wt% 71.4v%	A2	Incremental	VOCO GmbH, Cuxhaven, Germany	Bis-GMA, UDMA, TEGDMA,	silicon dioxide and glass ceramic
Z250	N586632	82wt% 60v%	A2	Incremental	3 M Nederland B.V, P.O. Box 1002, 2600 BA Delft	Bis-GMA, UDMA, Bis-EMA	zirconia-silica

surfaces of the specimen. Each conventional composite (Estelite, GrandioSO and Z250) specimen were built incrementally in layers of 2 mm thickness and irradiated for 10, 20 and 20 s respectively using Demetron LC light curing unit (Kerr, Orange, CA, USA) with a light intensity of 650 mW/cm^2. Bulk-fill composite (X-tra fill) was applied as 4 and 2 mm thickness increments and light cured for 10 s. Excess material was removed using a 600-grit silicon carbide paper under wet condition.

Samples were then evaluated under a stereomicroscope (Carl Zeiss, Germany) at ×20 magnification to ensure absence of cracks or voids. Defective samples were replaced with intact ones. Samples were divided into five groups ($n = 5$) according to the storage condition (no storage, 24 h of water storage, 24 h of ethanol storage, 30 days of water storage, 30 days of ethanol storage) at 37 °C in incubator.

Creep test

For measurement of dynamic creep, samples were subjected to cyclic loads between 1 and 50 MPa (0.012–0.628 KN) with 0.25 Hz frequency for 30 min (450 cycles) utilizing 9600 Dartec testing machine (Dartec Ltd., Sheffield, UK) as described in previous studies [9, 10]. This machine was capable of recording time, load and length per second. The maximum and minimum stroke values were used to calculate the length change (ΔL) per second. By dividing ΔL by the primary length of the samples (6 mm), the amount of creep per second was obtained. By multiplying the number of cycles (450) by 4 (duration of each cycle), 1800 values were obtained for each sample and the final value after applying the final cycle for each sample was reported as the dynamic creep value.

Compressive strength test

Samples were stored in their respective media for 24 h after creep test and were then subjected to compressive strength test according to ISO 4049. Compressive strength of the samples was measured using a universal testing machine (Z020, Zwick Roell, Ulm, Germany) at a crosshead speed of 1 mm/min.

Statistical analysis

Descriptive statistics were used for data analysis. Normality of the data was checked using Shapiro-Wilk test. To assess the effect of type of composite and the storage conditions on creep and compressive strength, Two-way or One-way ANOVA was used depending on the presence or absence of the interaction effect. Pairwise comparisons were made using the Scheffe test. The Pearson's correlation coefficient was applied to assess the correlation of creep and compressive strength. Data were analyzed using SPSS version 18 (Microsoft, IL, USA) and $P < 0.05$ was considered statistically significant.

Results

Table 2 shows the creep means (± standard deviation) of the four composites in different storage conditions. The Shapiro-Wilk test confirmed normal distribution of data. Thus, parametric tests were applied to assess the effect of type of composite and storage conditions on the creep values. Two-way ANOVA showed that the interaction effect of type of material and storage conditions was statistically significant ($P < 0.001$). Thus, One-way ANOVA was applied for within group analyses.

Comparison of storage conditions on creep for each composite

Storage conditions had a significant effect on the creep of Estelite Sigma, GrandioSO and Z250 composites ($P < 0.001$); however, this effect was not significant on X-tra fil ($P = 0.065$). Scheffe post hoc test showed that except for the case of Estelite Sigma creep after 24 h of alcohol storage, there is no significant difference in creep values of Estelite Sigma in the afore-mentioned four conditions ($p > 0.05$). As indicated in Table 2, the creep value of GrandioSO after 30 days of alcohol storage was significantly greater than the values in the afore-mentioned four conditions ($P < 0.001$).

In Z250, minimum creep was noted in the immediately tested group followed by 24 h of water storage, 30 days of water storage and 30 days of alcohol storage. Samples stored for 24 h in alcohol had the highest creep. Pairwise comparison of storage conditions revealed significant differences ($P = 0.001$) between 24 h and 30 days of alcohol storage in compared to other groups.

Table 2 The creep (m/m) of composites in different storage condition

Composite	No storage	24 h		30 days	
		Water	Ethanol	Water	Ethanol
X-tra fil	0.0101 ± 0.0003^{aA}	0.0110 ± 0.0004^{a}	0.0104 ± 0.0007^{aAC}	0.0103 ± 0.0005^{a}	0.0111 ± 0.0009^{aBD}
Estelite	0.0113 ± 0.0003^{aB}	0.0117 ± 0.0006^{a}	0.0193 ± 0.0007^{bAB}	0.0113 ± 0.0005^{a}	0.0122 ± 0.0006^{aAC}
GrandioSO	0.0101 ± 0.0007^{aC}	0.0104 ± 0.0005^{a}	0.0109 ± 0.0007^{aBD}	0.00099 ± 0.0012^{a}	0.0148 ± 0.0003^{bAB}
Z250	0.0089 ± 0.0002^{aABC}	0.0105 ± 0.0002^{a}	0.0178 ± 0.0007^{bCD}	0.0106 ± 0.0002^{a}	0.0147 ± 0.0007^{cCD}

*Different lowercase letters in each row and same capital letters in each column indicate the significancy

Table 3 Compressive strength (MPa) of composites in different storage conditions

Material	No storage	24 h		30days	
		Water	Ethanol	water	ethanol
X-tra fil	$23.15^{A} \pm 0.37332$	344.62 ± 5.3^{A}	297.09 ± 43.1^{aA}	376.32 ± 11.5^{bA}	326.29 ± 30.8^{A}
Estelite	387.18 ± 16.7^{aB}	389.10 ± 13.4^{B}	396.81 ± 20.5^{B}	432.43 ± 20.9^{bB}	418.47 ± 27.5^{B}
GrandioSO	415.88 ± 42.9^{B}	400.06 ± 53.9^{BC}	387.06 ± 52.3^{aB}	431.02 ± 23.1^{B}	456.92 ± 20.8^{bC}
Z250	449.45 ± 52.6^{C}	444.88 ± 16.7^{C}	454.04 ± 29.1^{C}	486.65 ± 32.3^{A}	478.08 ± 23.8^{C}

*Different lowercase letters in each row and different capital letters in each column indicate the significancy

Comparison of composites creep under each storage condition

Comparison of creep among different storage conditions by One-way ANOVA revealed significantly different creep values of materials immediately and after 24 h and 30 days of alcohol storage ($P < 0.001$).

Pairwise comparison of immediately tested materials by Scheffe test revealed minimum creep in Z250 followed by GrandioSO and X-tra fil. The highest creep was noted in Estelite. The difference in this regard between GrandioSO and X-tra fil was not significant ($P = 0.999$) but they had significant differences with Z250 and three other materials in this respect ($P < 0.05$).

Pairwise comparisons of materials after 24 h of alcohol storage showed minimum creep in X-tra fil and GrandioSO and these two groups were not significantly different in this regard ($P = 0.921$). However, Z250 and Estelite Sigma had the highest creep. Although they were not significantly different in this regard ($P = 0.162$), they had significantly higher creep values than the other two composites ($P < 0.05$).

After 30 days of alcohol storage, minimum creep was noted in X-tra fil and Estelite Sigma ($P = 0.244$). Z250 and GrandioSO were not significantly different ($P = 0.999$) but had higher creep than the remaining two composites ($P < 0.05$).

Compressive strength results

The mean and standard deviation of compressive strength values following the application of dynamic load in different composites subjected to different storage conditions are presented in Table 3.

Two-way ANOVA showed significant differences in the compressive strengths of the composites ($P < 0.001$). Also, different storage conditions yielded different compressive strength values in samples ($P < 0.001$); however, the interaction effect of storage conditions and type of material was not significant ($P = 0.239$).

The comparison of compressive strength values among different composites showed that there is a significant difference between different storages in Estelite Sigma ($p = 0.007$) and X-tra fil ($p = 0.002$), but no significant difference was observed in GrandioSO ($p = 0.106$) and Z250 ($p = 0.141$).

In Estelite Sigma, the results revealed significantly different between immediately and after 30 days of water storage ($P = 0.040$). In X-tra fil, there was a significantly different between 30 days of water storage and 24 h of alcohol storage ($P = 0.003$). In GrandioSo, there was a significantly different between 30 days of alcohol storage and 24 h of alcohol storage ($P = 0.005$). In other two-by-two analyses, no significant difference was observed.

Comparison of different storage conditions revealed minimum compressive strength following 24 h of alcohol storage, 24 h of water storage and immediately after fabrication of samples. Regarding the comparison of compressive strength in different storages, the results showed that in all storages, 4 composites have significant differences.

Pairwise comparison of immediately tested materials by Scheffe test revealed that there were significant differences between X-tra fil in compared to GrandioSO ($p = 0.021$) and Z250 ($p = 0.001$). In 24 h of water storage, there was significant differences between X-tra fil in comparison to Z250 ($p = 0.001$). In 24 h of alcohol storage, there was significant differences between X-tra fil in comparison to other three composites. In this storage, other comparisons were not significant. In 30 days of water storage, there was no significant difference between the Estelite Sigma and GrandioSO groups, but in other two-by-two comparisons, there was a significant difference between the composites, and the highest value was in the Z250. In 30 days of alcohol storage, there was no significant difference between the Estelite Sigma and GrandioSO ($p = 0.185$), and also between Z250 and GrandioSO ($P = 0.371$), but in other two-by-two comparisons, there was a significant difference between the composites. The highest mean was observed in Z250 and the lowest mean was observed in X-tra fil.

The Pearson's correlation coefficient showed that the correlation between creep and compressive strength was positive and statistically significant ($r = 198$, $P = 0.048$).

Discussion

Most previous studies have assessed the creep of flowable composites by measuring static creep [9, 13, 14]; whereas, we assessed viscoelasticity by measuring dynamic creep because in order to simulate the clinical settings, dynamic test is superior to static creep test [15, 16].

It was found that conventional composites exhibited the highest creep when stored in alcohol. In line with other literature, storage of composites in alcohol decreases their mechanical properties [17, 18]. Increased deformity or decreased mechanical strength can be explained by the penetration of ethanol into the polymer network, which causes expansion of material, elimination of monomers, oligomers and non-branched polymers and subsequent softening of material [19, 20].

To speed up the restorative process, using bulk-fill composite to fill deep cavities can enhance patient comfort. The implementation of this bulk-filling method saves significant time for both dentists and patients, making the restorative procedure more efficient. Our research indicates that the investigated bulk-fill composite performs better in comparison to conventional composites in terms of creep and compressive resistance, making it a viable alternative when time and convenience are of paramount importance.

Simplification of restoration procedures and reduction of treatment time are advantages of bulk-fill composites. The creep value in the bulk-fill composites have been studied previously by a focus on investigating the flowable bulk-fill composites, to the best our knowledge. In this study, however, we have focused on a creep value in a high-filler-volume bulk-fill composite (X-tra fill), as well as three conventional composites (one from same factory "Voco" and two other conventional composites common in the market).

Our results showed no significant change in creep of X-tra fil following the five tested storage conditions. These findings indicate that the effect of storage conditions on deformity depends on the type of composite. El-Safty et al. assessed four bulk-fill composites (X-tra base, Tetric EvoCeram Bulk-Fill, SureFil SDR flow and Venus Bulk Fill) and reported that storage conditions affected the creep; also, the creep of composite samples stored in water was higher than those stored in dry environment. The difference between our results and those of El-Safty et al. may be attributed to the different types of bulk-fill composites used [10]. However, since bulk-fill composites have been recently introduced, not much information is available on their resin matrix content and type of monomers. Therefore, more research is needed to reach the final conclusion.

Our study showed that storage in water and alcohol during time increased the creep of composites and the effect of alcohol was more prominent in this regard. In line with our findings, Garoushi et al. indicated that following water storage, unpolymerized monomers are released from the composite into water and are replaced with water. Higher moisture content affects plastic properties of composites and increases their creep [15]. Baroudi et al. mentioned that mechanical properties of composites improved over time due to increased cross-links [21]. Thus, it may be stated that in Estelite Sigma and GrandioSO, increased cross-links due to increased storage time somehow neutralized the effects of water and alcohol; however, this was not the case for Z250 and this difference can be attributed to the different types of composition. The interaction between nanoparticles and glass ceramic with a defined grit size may result in volumetric saturation of filler in GrandioSO. The actual increase in filler content is particularly evident when the filler content is viewed in relation to the proportion of resin. This proportion is 1:6.7 in GrandioSO. Also, Estelite Sigma novel photoinitiator (RAP) could enhance its properties.

From the results obtained from the immediate experiments, the lowest creep belonged to Z250 and GrandioSO, and X-tra fil ranked second. The highest creep belonged to Estelite Sigma. Studies have shown that the creep decreases by an increase in filler content [4, 22]. Decreased resin matrix due to high filler content and uniform distribution of filler particles can increase resistance to deformity and decrease creep [23]. However, the lowest filler content belonged to Z250 (82wt% and 60v%) while the highest filler content belonged to GrandioSO (87wt% and 71.4v%). It seems that filler content is one of the factors affecting deformity of composite and some other factors such as chemical composition, type of monomer, degree of conversion and incremental or bulk application all affect the viscoelasticity of composites [2].

Among samples stored in alcohol for 24 h and 30 days, the lowest creep belonged to X-tra fil bulk-fill composite and the highest creep belonged to Z250. This indicates the superiority of X-tra fil bulk-fill composite in terms of deformity compared to Z250 conventional composite following alcohol storage. Creep of X-tra fil bulk-fill composite was lower than that of conventional composites. Similarly, Marghalani and Watts reported lower creep-strain in bulk-fill (X tra-fil) composite compared to dimethacrylate-based composites. They showed that X tra-fil bulk-fill composite had higher viscoelastic stability because of high filler content [24].

In this study, we used 24 h and 30 days of water and ethanol storage at 37 °C. The rationale behind using 24-hours and 30 days water and ethanol storage at 37 °C stems from the reason that polymerization of the composites' restorations continues during 24 h, also, this helps better investigate the aging effects on the mechanical properties of the mentioned composites. Notably, this method aligns with the existing body of knowledge [17, 25].

It has been stated that creep of composites can vary from 1 to 6% depending on their filler volume percentage [4]. In our study, the creep of all four composites in all storage conditions was clinically acceptable since viscoelastic creep values less than 2% are acceptable for composites under stress [26].

According to the results, the efficacy of the storage medium on compressive strength was lower than the type of the material used [27]. Consequently, conventional composites showed superior performance over bulk-fill composites in terms of compressive strength. Therefore, it is recommended to have a more cautious choice in using bulk-fill composites in posterior dental restoration. This claim would however be more concrete by more detailed studies on this subject.

In our study, X-tra fil had the lowest compressive strength values and the highest compressive strength belonged to Z250 with significant differences with the corresponding values of other composites. This could be related to different chemistry of their organic matrix, affecting mechanical properties. Cebe et al. assessed several bulk-fill composites following storage in 75% ethanol for 30 days and reported release of matrix monomers. This release increased with time [25]. Similarly, Leprince et al. reported that the mechanical properties such as degree of polymerization, elastic modulus, surface roughness and flexural strength of bulk-fill composites after 24 h were lower than those of a conventional composite and similar to those of flowable composites [28]. These results could be related to their time intervals.

The results of compressive strength tests in our study showed that irrespective of the storage time, 75% alcohol and water had similar effects on compressive strength of composites. Controversy in results may be explained by the percentage of alcohol used. In the current study and that of Giorgio et al. [27], 75% alcohol was used as the storage medium but Aguiar et al. [29] stored samples in 100% alcohol. Although some studies contain same media, their test was differed. Aguiar et al. assess micro hardness as the best indirect indicator of degree of polymerization and may also be related to form stability during immersion in different mediums. According to Giorgio et al. 100% ethanol had higher capability for dissolving the polymer matrix compared to water and 75% alcohol [27].

Regarding the choice of 75% alcohol and how it relates to actual dietary intake, it should be noted that the US Food and Drug Administration recommends a 75 vol% ethanol/water solution as a suitable food simulator, effectively mimicking substances such as alcoholic beverages, fruits, and syrups, thus enhancing its clinical relevance. Furthermore, the solubility parameters of ethanol and Bis-GMA are nearly identical, resulting in the softening of the resins, with peak softening occurring at this 75% ethanol/water concentration. This is why we consider the 75% ethanol/water solution [25, 27].

Our results showed that compressive strength increased over time despite the effect of water and alcohol. Thus, these media probably had no significant effect on compressive strength, or their effects were neutralized by the changes in the curing of materials. Moreover, under compression stress plastic deformation may leads to these results. This increase in the share of elastic deformation in the specimen under compression leads to a change of its resistance to fracture.

In terms of limitations in this research we conducted the dynamic creep test over 450 cycles, time and financial constraints prevented us from testing at higher cycles. Given those dental restorations in a human mouth experience over 300,000 bites annually, the 450-cycle test we employed is roughly equivalent to the pressure experienced by dental restorations during half a day of biting. While higher-cycle tests would have provided greater validity by more closely simulating real-life conditions, our findings still offer valuable insights into the mechanical behavior of these composites. In addition, the sample size of this study was relatively small, which can affect the statistical significance of the results, so it is recommended to conduct a study with a larger sample size to achieve more valid results.

Furthermore, this is worthwhile mentioning that this research has focused on investigating the differences in mechanical properties between bulk-fill and conventional restorative composites, therefore different types of bulk-fill composites were not chosen. Although, increasing the diversity in choosing different types of bulk-fill composites would have enhanced the quality of this research which was not possible due to time and budget constraints.

Conclusions

The results of the present study suggested that alcohol and water storage increased creep of conventional composites and the effect of alcohol was greater than that of water. Creep of bulk-fill composite was not affected by the storage time or medium. Bulk-fill composites showed inferior performance over conventional composites in terms of compressive strength. Therefore, it is recommended to have a more cautious choice in using bulk-fill composites in posterior dental restoration. The compressive strength of composites was not influenced by the storage media but increased over time. However, further studies are recommended to reach more accurate results.

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Author contributions

Afrooz Nakhostin and Hossein Hosseini Toudeshky designed the method of the study and contributed to data analyzing. Afrooz Nakhostin and Narges Panahandeh collected the data and contributed to experimental studies,, literature search, data acquisition and writing manuscripts. Seyedeh Mahsa Sheikh-Al-Eslamian contributed to writing manuscript and manuscript editing. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not Applicable.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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