Pesquisa Brasileira em Odontopediatria e Clinica Integrada 2018, 18(1):e3892
DOI: http://dx.doi.org/10.4034/PBOCI.2018.181.26
ISSN 1519-0501

OPEN ACCESS

ORIGINAL ARTICLE

Influence of Functional Clinical Temperature over Compressive Strength and Diametral Tensile Strength of Various Luting Cements

Satheesh B. Haralur[1], Sami Saeed Al Shahrani[2], Rakan Mohammed Al-Ahmri[2], Sultan Amer Al Yazid Assiri[2], Ahmed Hassan Al Gufily[2]

[1]Associate Professor, Department of Prosthodontics, College of Dentistry, King Khalid University, Kingdom of Saudi Arabia.
[2]Intern Dentist, College of Dentistry, King Khalid University, Kingdom of Saudi Arabia.

Author to whom correspondence should be addressed: Satheesh B. Haralur, Department of Prosthodontics, College of Dentistry, King Khalid University, Kingdom of Saudi Arabia. Phone: +966555835386. E-mail: hb_satheesh@yahoo.com.

Academic Editors: Alessandro Leite Cavalcanti and Wilton Wilney Nascimento Padilha

Received: 23 November 2017 / Accepted: 08 February 2018/ Published: 15 February 2018

Abstract

Objective: To estimate the effect of temperature over the physical properties of commonly used luting cements. **Material and Methods:** The two set of cylindrical shaped cement samples measuring 12mm X 6mm and 4mm X 8mm were fabricated from non-eugenol zinc oxide, glass ionomer, zinc phosphate, Zinc polycarboxylate, resin cements. These two sets of samples were utilized to test compressive and diametral tensile strength respectively. Forty cement samples from each mold were fabricated and distributed between 14, 22, 37 and 55^{0}C (N=10). The samples were tested under universal testing machine, and data subsequently analyzed using One-way ANOVA and Tukey multiple comparison's statistical methods at $p > 0.05$. **Results:** The higher temperature resulted in noticeable reduction in the compressive strength of non-eugenol -zinc oxide, Zinc-phosphate, Zinc poly carboxylate cements. The highest compressive strength was recorded for non-eugenol zinc oxide (8.08 Mpa) at 37^{0}C, Zinc phosphate (91.01Mpa) at 14^{0}C, and for zinc polycarboxylate (83.06 Mpa) at 37^{0}C. The comparative values for respective cements at 55^{0}C were 6.40Mpa, 59.80Mpa, and 52.88 Mpa. The higher temperature had insignificant effect on the compressive strength of glass ionomer cement, while composite resin cement indicated minor deterioration. **Conclusion:** The relative mouth temperature influences the physical properties of the luting cements.

Keywords: Dental Cements; Compressive Strength; Tensile Strength; Temperature.

CC BY

Introduction

The luting cements performs as the adhesive between casting and tooth structure; holds them together [1]. They are essential to seal the space between restoration and tooth, thereby prevents the microleakage. Previous authors described the ideal requisites of luting cement as biocompatible, less water soluble, adhesive, radiopaque, aesthetic and easy for manipulation [2].

The dental literature reports indicate none of the luting cements satisfies all the requirements of ideal cement. In the contemporary dentistry plethora of luting cements are available for the dentist to select. Besides the biocompatibility and aesthetic requirements, the luting cement should resist the functional occlusal forces and resultant cyclic fatigue for lifetime [3]. The mechanical properties like compressive strength, flexural strength, diametral tensile strength, modulus of elasticity, fracture toughness and hardness are considered as predictors for the longer clinical performance of the luting cements [4].

The in-vitro tests to evaluate the physical properties are routinely conducted in the room temperature of approximately at 23^{0}C. The ISO 4049 recommends the preparation and testing of specimens at 23±1^{0}C and controlled relative humidity greater than 30%. Reports from earlier research indicated, the tooth structures, and dental restorations are exposed to the diverse range of temperature due to the ingestion of hot and cold liquids. The results from the previous research showed the temperature extremes observed in the maxillary anterior region and mandibular molar regions at 62.6^{0}C [5].

A previous study recorded the temperature beneath the restorations ranging from 9-52^{0}C [6]. The temperature variations are recognised to hasten the degradation process like absorption, solution and disintegration of restorative materials. The compressive strength and modulus of elasticity of luting cement are also affected due to temperature variation and consequently; it decreases the clinical performance of the indirect restorations.

The clinical application of all ceramic restorations is on a constant rise due to aesthetic conscious contemporary society. The composite resin cements are regularly used for the cementation of partial and full veneer all ceramic crowns. In addition to the superior physical properties, the resin cements credited with improved bonding strength and enhancing the strength of ceramic restorations [7,8].

The previous researchers reported the significant reduction in physical properties of EBA-reinforced zinc oxide/eugenol cement at higher temperatures of 37^{0}C and 50^{0}C [9]. The de-cementation is recorded as the second major etiological factor in failures of indirect restoration preceded by secondary caries [10]. Hence the selection of luting cements requires careful considerations regarding the clinical situations and mechanical properties of luting cements. The eventual success of restoration to the larger extent depends on the accurate cement selection.

Though the multiple studies have evaluated the physical and mechanical properties of the luting cement; the dental literature is in further need of investigations to evaluate the physical properties of contemporary luting cements like composite resin during clinical functional

temperature. Hence, this in-vitro study was designed to with an objective evaluate the influence of heat over the compressive strength, diametral tensile strength of commonly used luting cements.

Material and Methods

In this in-vitro experimental study, the contemporary dental luting cements like non-eugenol temporary (Temp-Bond, Kerr Corporation, Orange, United States), zinc-phosphate (Harvard Dental International GmbH, Hoppegarten, Germany), zinc-polycarboxylate (Poly-F Plus, Dentsply IH Ltd, Weybridge, United Kingdom), glass-ionomer (AquaCem, Dentsply IH Ltd, Weybridge, United Kingdom) and composite resin (RelyX, 3M ESPE, Maplewood, MN, USA) were evaluated.

As reported by the earlier studies the intra-oral temperature recorded during the ingestion of hot and cold foods was between 14- 60^{0}C. This temperature range also well tolerated by the soft tissues and teeth. Hence, temperature selected for testing the luting cement sample was 14^{0}C, 23^{0}C, 37^{0}C and 60^{0}C.

The two cylindrical shaped silicone moulds were fabricated. The first mold was used to make cement cylinders with the dimension of 12 mm in height and 6 mm in diameter. The second mold was utilized to fabricate the cement sample with the dimensions of 4 mm height and 8 mm diameter [11].

The former samples were used for testing the compressive strength, and later samples were used for the diametral tensile testing. Total of 40 samples from each cylinder type were fabricated for every single cement; ten samples were randomly distributed to each temperature range of 14^{0}C, 23^{0}C, 37^{0}C and 60^{0}C. The cements were manipulated according to the manufacturer's instruction as described in Table 1. The materials required for fabrication of testing samples were weighted in a precision scale (Sartorius, Data Weighing Systems, Inc.Elk Grove, USA), and mixed with a plastic spatula on impervious paper.

Table 1. Description of the luting cement groups, and manipulation.

Group	Cement	Manufacturer	Steps of Application
I	Non-Eugenol Temporary	Temp-Bond NE, Kerr Corporation, Michigan, USA	Dispense equal length from base and activator tube. Mix it for 30 seconds, until homogenous color is achieved
II	Zinc- Phosphate	Harward normal setting, Harvard Dental International GmbH, Hoppegarten, Germany	The proportion of 1.5 gm was determined with precision weighing machine. Mixed on glass slab with sequential inclusion of powder portion of 1/8,1/8,1/4 and 1/2. The missing was completed in 90 seconds
III	Zinc- Polycorboxylate	Poly-F Plus, Dentsply DeTrey GmbH, Konstanz, Germany	The proportion of powder: liquid ratio was 5 gm: 1gm.Mixed for 15 seconds over the glass slab, with sequential addition of two ½ powder portions
IV	Glass-ionomer	AquaCem, Dentsply DeTrey GmbH, Konstanz, Germany	The proportion of powder: liquid ratio was 3.3 gm: 1gm.Mixed for 15 seconds over the glass slab
V	Composite Resin	Relyx Unicem, 3M ESPE,St. Paul, MN, USA	Equal amount of base/ activator paste missed on impervious paper for 15 seconds

Freshly mixed cement was poured into the silicone mold under vibration to avoid the inclusion of voids. The mold was slightly over filled and the glass plate was placed over the mold.

The mold was kept under a hydraulic bench (Wassermann Dental-Maschinen Gmbh, Hamburg, Germany) press with constant pressure of 10 kilograms during setting. According to ANSI/ADA Specification No. 96 [12], the cement sample mixing and subsequent setting for one hour was done under controlled temperature of 23±2°C and relative humidity of 50±10%. Post one-hour setting, the cement samples were removed from the mold and stored in distilled water at 37°C for next 23 hours. The temperature of the samples was maintained with the thermo-regulated water bath. The samples with large defects, voids and irregularity were discarded. The cylinder's ends were flattened with the fine-grit silicon carbide paper. The samples were examined for any defect by one clinician before including them in study.

Randomly selected 10 specimens per temperature variable of 14°C, 23°C, 37°C and 55°C were utilized for testing. The specimen temperature was regulated according to the group by placing them inside the thermostatically controlled water bath for fifteen minutes prior to the testing. The specimens were heated to desired temperature in water bath to prevent the desiccation of the cement during heating. The cement samples for compressive strength were placed vertically underneath the universal testing machine (Instron Corporation, Massachusetts, United States) at the crosshead speed of 0.5mm/min. Whereas the sample discs were placed diametrically between the metal plates for testing of the diametral tensile strength. The static load was applied until the fracture of the cement samples, and failure load was recorded.

The obtained data was analysed with SPSS 19 software (IBM Corp., Armonk, NY, USA). The one-way ANOVA and Tukey pair wise test were used for assessing the significant difference between the groups with $p < 0.05$.

Results

The temperature change had the different ranges of effect on all the luting agents tested during the study. The mean compressive and diametral tensile strength of different cement at the diverse temperatures is depicted in Table 2.

The compressive strength for Non-eugenol temporary cement was recorded at 3.51 Mpa at 14°C, was increased up to 8.08 Mpa at 37°C. The diametral tensile strength showed the similar trend with 2.02 Mpa, and 2.13 Mpa at 14°C and 37°C respectively. The diametral tensile strength was substantially affected at a higher temperature of 60°C with 0.93 Mpa. The Zinc phosphate cement showed the better compressive strength at 14°C with 91.01Mpa. The subsequent increase in temperature to 60°C resulted in the significant reduction up to 59.80 Mpa. The diametral tensile strength was recorded highest at 37°C with 5.20Mpa and at the higher temperature of 60°C it was reduced to 3.52 Mpa. Zinc Polycarboxylate cement recorded the mean compressive strength of 61.50 Mpa, 70.52 Mpa, 83.06 Mpa and 52.88 Mpa at 14°C, 22°C, 37°C, and 60°C respectively. The highest diametral strength of 7.09 Mpa documented at 37°C. The mean compressive strength for Glass-ionomer cement showed the highest value of 137.84 Mpa at 60°C, while the least compressive strength recorded at 14°C with 102.95Mpa. The highest diametral tensile strength was recorded at

37ºC with 11.78Mpa and at higher temperature of 60ºC it was reduced to 5.22 Mpa. The composite resin luting cements documented the higher mean compressive strength of 193.78 Mpa at 37ºC, and indicated the decline at 60ºC with 154.80 Mpa. The diametral tensile strength for composite resin also showed the similar tendency, the higher strength at 37ºC, with 47.86 Mpa and lowest value of 32.45 Mpa at 60ºC.

The one-way ANOVA analysis showed the statistically significant difference in both compressive and diametral tensile strength of all tested cements between varying temperatures.

Table 2. Mean compressive strength and Diametral tensile strength (Mpa) at different temperature and ANOVA results.

Cement	Testing	14ºC	22ºC	37ºC	60ºC	p-value
Non-ZOE Temporary	Compressive	3.51	5.36	8.08	6.40	0.001
	Diametral tensile	2.02	1.61	2.13	0.93	0.242
Zinc-Phosphate	Compressive	91.01	77.46	73.98	59.80	0.001
	Diametral tensile	4.24	4.92	5.20	3.52	0.001
Zinc-Polycorboxylate	Compressive	61.50	70.52	83.06	52.88	0.001
	Diametral tensile	5.14	6.99	7.09	5.22	0.001
Glass-Ionomer	Compressive	102.95	118.60	132.96	137.84	0.001
	Diametral tensile	4.74	6.95	7.82	5.22	0.001
Composite-Resin	Compressive	157.22	177.24	193.78	154.80	0.001
	Diametral tensile	35.53	44.44	47.86	32.45	0.001

The Tukey HSD multiple comparison (Table 3) also showed the statistically significant difference between all the luting cement groups at different temperature except for the diametral tensile strength in Non-ZOE luting cement. The other groups with no significant difference were compressive strength of zinc phosphate between 23ºC and 37ºC with p=0.423, glass ionomer at 37ºC and 60ºC with p=0.535, composite resin between 14ºC and 60ºC (p=0.888). The non-significant difference in diametral strength was observed in zinc Phosphate between 22ºC and 37ºC (p=0.423), Zinc polycarboxylate between 14ºC and 60ºC (p=0.918), 23ºC and 37ºC (p=0.878). The Glass ionomer cement showed the statistically insignificant difference for diametral strength at between 22ºC and 37ºC (p=0.019), 14ºC and 60ºC p=0.334), composite resin between 14ºC and 60ºC (p=0.014).

Table 3. Tukey HSD multiple comparison.

	Groups	Compressive Strength				Diametral Tensile			
Cement		14ºC	23ºC	37ºC	60ºC	14ºC	23ºC	37ºC	60ºC
Non-ZOE	14ºC		0.001	0.001	0.001		0.920	0.998	0.333
	23ºC	0.001		0.001	0.001	0.920		0.847	0.706
	37ºC	0.001	0.001		0.001	0.998	0.847		0.250
	60ºC	0.001	0.001	0.001		0.333	0.706	0.250	
Zinc-Phosp	14ºC		0.001	0.001	0.001		0.003	0.001	0.002
	23ºC	0.001		0.150	0.001	0.003		0.423	0.001
	37ºC	0.001	0.150		0.001	0.001	0.423		0.001
	60ºC	0.001	0.001	0.001		0.002	0.001	0.001	

CC BY

Zinc-Polycor	14ºC		0.001	0.001	0.001		0.001	0.001	0.918
	23ºC	0.001		0.001	0.001	0.001		0.878	0.001
	37ºC	0.001	0.001		0.001	0.001	0.878		0.001
	60ºC	0.001	0.001	0.001		0.918	0.001	0.001	
Glass-Ionomer	14ºC		0.001	0.002	0.001		0.001	0.001	0.334
	23ºC	0.001		0.001	0.001	0.001		0.019	0.001
	37ºC	0.001	0.002		0.535	0.001	0.019		0.001
	60ºC	0.001	0.001	0.535		0.334	0.001	0.001	
Compo-Resin	14ºC		0.001	0.001	0.888		0.001	0.001	0.014
	23ºC	0.001		0.001	0.001	0.001		0.005	0.001
	37ºC	0.001	0.001		0.001	0.001	0.005		0.001
	60ºC	0.888	0.001	0.001		0.014	0.001	0.001	

Discussion

The primary function of the luting cements is to retain the indirect restoration by filling up the gap between the prepared teeth and the restoration. The optimum physical and mechanical properties of luting cement is important for the long-term clinical service of restoration. Hence, the dental researchers are in constant pursuit of improving these properties of luting agents.

The dental restorations are exposed to the various stresses like compressive, shear and tensile stress from the masticatory process. Compressive strength of the luting cement is considered as the main criteria of success. Few clinical failures of the indirect restoration are also attributed to inadequate tensile strength of luting cements [13]. The diametral tensile test was measured in this study instead of direct tensile strength considering the technical difficulties involved in testing brittle materials like cements. The luting cements with adequate mechanical properties will transfer the forces from the crown to tooth structures without structural deformation, crack propagation, and with fewer possibilities of compressive or tensile failures [14]. The micro cracks in the luting cement layer will also lead to the interfacial microleakage and other consequences like periodontal diseases, dental caries, compromised aesthetics [15].

The dental restorations function under the complex situation like different temperature, liquids with varying pH and cyclic loading. As the temperature in oral cavity is influenced by the temperature of ingested food, it is prudent to understand the performance of luting cement at functional clinical temperatures. Previous authors reported the maximum temperature at 48.4ºC and minimum value at 18.9ºC [16] while others reported the highest temperature at 68.0ºC and lowest temperature of 15.4ºC [17]. The maximum temperature recorded by consumption hot fluid is around 70ºC and consumption of cold drinks reduced the temperature approximately to 0ºC [18]. Hence the temperature range of 14-60ºC were selected for testing luting cements.

The mechanism of retention varies greatly between cements. The non-adhesive cements derive the retention by mechanical interlocking within the irregularities in restoration and tooth structures. Thermoplastic deformation of these cements at a higher temperature significantly affects the physical properties of non-adhesive cements. The compressive strength of the non-eugenol cement was improved unlike the eugenol containing zinc oxide luting cements up to 37ºC, and

substantially reduced at 60^{0}C. The similar trend was observed diametral tensile strength also. The zinc phosphate unlike non-eugenol cement showed the highest compressive strength of 91.01 Mpa at 14^{0}C, and gradual reduction in strength was recorded with the subsequent increase in temperature.

The lowest strength was recorded at 60^{0}C with 59.80Mpa. The setting reaction of Non-eugenol zinc oxide cement begins with hydrolysis of zinc oxide. Then it reacts with polymerized fatty acids leading to formation of a matrix of zinc polymerized fatty acids chelate with embedded un-reacted zinc oxide particles. The zinc oxide-eugenol cements possess the plastic strain above 15 % at 37^{0}C and increased creep properties at the higher temperatures. Hence the non-eugenol zinc oxide cements performs better at higher temperatures in comparison to eugenol containing cements. The non-eugenol cements are having other advantages like less dissolution and no inhibitory effect on polymerization of methacrylate resins [19].

Zinc phosphate and zinc polycarboxylate cements are considered as acid-base reaction cements. The powder is predominantly consisting of zinc oxide and magnesium oxide, whereas liquid composed of phosphoric acid and polyacrylic acid respectively. Both cement showed the marginal reduction in the compressive and diametral tensile strength at higher temperatures. The zinc phosphate had the higher strength at 14^{0}C with 91.01 Mpa; however, zinc polycorboxylate recorded maximum compressive s strength at 37^{0}C with 83.06 Mpa. The results from the study corroborated with previous finds that showed significant loss of strength at a higher temperature of 55^{0}C [9].

The glass ionomer luting cements are comprising of the polymer matrix with various embedded inorganic fillers. The polymer matrix are viscoelastic materials, and mechanical properties are significantly affected by temperature. The embedded inorganic fillers besides improving the mechanical properties like modulus of elasticity, they are reported to increase the glass transition temperature [20,21]. The researchers reported the increased temperature lead to relaxation of polymer matrix. This leads to decline in elastic modulus at a higher temperature.

Decline in the compressive strength to 154.80 Mpa and diametral tensile strength to 32.45 was observed in the composite resin cement at 60^{0}C. The composite resins are having glass transition temperature instead to melting point like metals and ceramics. The polymers behave like glass below the transition temperature and as super cooled liquid above transition temperature. The thermal energy results in polymer segmental motion and freedom lead to behaving like viscoelastic materials. Hence the dental polymers should possess the glass transition temperature above the clinical functional temperature. The presence of inorganic fillers, cross linking, residual monomer and degree of conversion affect viscoelastic behaviours of polymers. The large elastic deformation is due to polymer chain uncoiling, and it is facilitated by thermal activated process [22]. A previous study showed significant reduction of strength between 37-50^{0}C [23]. The result of the present study indicated the similar outcome as observed previously [23].

Limitation of the study includes the study is in vitro in nature, hence difficult to replicate the clinical situation. Intra-orally the restorations are exposed to various temperature along with liquids with fluctuating pH. The presence of liquids is known to influence the crack propagation and these

parameters were not included in the study. Since the combined effect of these conditions will provide the true data on clinical performance. The luting cement thickness differs due to clinical situations and mechanical properties of cements. The effect of temperature on parameters like retention at different luting cement thickness needs further evaluation.

Conclusion

The temperature variations affected the compressive and diametral tensile strength of all the luting cements evaluated in the study. The non-eugenol-zinc oxide, zinc phosphate and zinc polycarboxylate luting cements showed the marginal reduction in the compressive and diametral tensile strength at the higher temperature of 60ºC. The diametral tensile strength values of non-eugenol -zinc oxide cement at a different temperatures was statistically insignificant.

The glass ionomer cements showed no deterioration in its compressive strength at the higher temperatures, while it affected the diametral tensile strength to minor extent. The compressive strength values of glass ionomer cement at 37ºC and 55ºC was statistically insignificant. The composite resin luting cements showed the highest compressive and diametral tensile strength. It was not affected at 37ºC, but showed the decline in mechanical properties at 60ºC.

References

1. Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: A review of the current literature. J Prosthet Dent 1998; 80(3):280-301. doi: 10.1016/S0022-3913(98)70128-3.
2. Hill EE, Lott J. A clinically focused discussion of luting materials. Aust Dent J 2011; 56(Suppl 1):67-76. doi: 10.1111/j.1834-7819.2010.01297.x.
3. Lad PP, Kamath M, Tarale K, Kusugal PB. Practical clinical considerations of luting cements: A review. J Int Oral Health 2014; 6(1):116-20.
4. Oilo G. Luting cements: A review and comparison. Int Dent J 1991; 41(2):81-8.
5. Palmer DS, Barco MT, Billy EJ. Temperature extremes produced orally by hot and cold liquids. J Prosthet Dent 1992; 67(3):325-7. doi: 10.1016/0022-3913(92)90239-7.
6. Nelsen RJ, Wolcott RB, Paffenbarger GC. Fluid exchanges at the margins of dental restorations. J Amer Dent Assoc1952; 44:288-95. doi: 10.1016/S0002-8177(52)43006-8.
7. Ayyildiz S, Emir F, Pak Tunc E, Sen D. Shear bond strength of various luting cements to fixed prosthodontic restorative materials. Applied Adhesion Science 2015; 3(1):13. doi: 10.1186/s40563-015-0039-z.
8. Spazzin AO, Guarda GB, Oliveira-Ogliari A, Leal FB, Correr-Sobrinho L, Moraes RR. Strengthening of porcelain provided by resin cements and flowable composites. Oper Dent 2016; 41(2):179-88. doi: 10.2341/15-025-L.
9. Mesu FP. The effect of temperature on the compressive and tensile strengths of cements. J Prosthet Dent 1983; 49(1):59-62. doi: 10.1016/0022-3913(83)90239-1.
10. Walton JN, Gardner FM, Agar JR. A survey of crown and fixed partial denture failures: length of service and reasons for replacement. J Prosthet Dent 1986; 56(4):416-21. doi: 10.1016/0022-3913(86)90379-3.
11. Piwowarczyk A, Ottl P, Lauer HC. Laboratory strength of glass ionomer and zinc phosphate cements. J Prosthodont 2001; 10(3):140-7.
12. American National Standards/American Dental Association Specification no. 96 ANSI/ADA Specification no. 96. Dental Water-based Cements. Chicago: American National Standards/Americian Dental Association; 2012.
13. McKinney JE, Antonucci JM, Rupp NW. Wear and microhardness of glass-ionomer cements. J Dent Res 1987; 66(6):1134-9. doi: 10.1177/00220345870660060801.

14. Ghasemi E, Abedian A, Iranmanesh P, Khazaei S. Effect of type of luting agents on stress distribution in the bone surrounding implants supporting a three-unit fixed dental prosthesis: 3D finite element analysis. Dent Res J 2015; 12(1):57-63.
15. Anusavice KJ. Phillips' science of dental materials. 11th. ed. Philadelphia: WB Saunders; 1996. pp. 555-581.
16. Michailesco PM, Marciano J, Grieve AR, Abadie MJ. An in vivo recording of variations in oral temperature during meals: A pilot study. J Prosthet Dent 1995; 73(2):214-8. doi: 10.1016/S0022-3913(05)80164-7.
17. Youngson CC, Barclay CW. A pilot study of intraoral temperature changes. Clin Oral Investig 2000; 4(3):183-9. doi: 10.1007/s007840000040183.784.
18. Barclay CW, Spence D, Laird WRE. Intra-oral temperatures during function. J Oral Rehabil 2005; 32(12):886-94. doi: 10.1111/j.1365-2842.2005.01509.x.
19. Sakaguchi RL, Powers JM. Craig's Restorative Dental Materials. 13th. ed. St. Louis: Elsevier/Saunders; 2012. pp. 339-340.
20. Rodriguez F. Principles of Polymer Systems. 2nd. ed. New York: McGraw-Hill; 1982. pp. 213-218.
21. Nielsen LE, Lee BL. Dynamic mechanical properties of some polystyrene composites. J Compos Mater 1972; 6(1):136-46. doi: 10.1177/002199837200600110.
22. Papadogiannis Y, Boyer DB, Helvatjoglu-Antoniades M, Lakes RS, Kapetanios C. Dynamic viscoelastic behavior of resin cements measured by torsional resonance. Dent Mater 2003; 19(6):510-16. doi: 10.1016/S0109-5641(02)00098-2.
23. Ho CT, Vijayaraghavan TV, Lee SY, Tsai A, Huang HM, Pan LC. Flexural behaviour of post-cured composites at oral simulating temperatures. J Oral Rehabil 2001; 28(7):658-67. doi: 10.1046/j.1365-2842.2001.00734.x.