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EFFECT OF SPEED OF LOADING ON COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH OF DENTAL RESIN-COMPOSITES

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ABSTRACT

Objective: To investigate the effect of speed of loading on compressive strength and flexural strength for a range of dental resin-composites of varied composition.

Materials and Methods: For compressive strength testing, fifteen cylindrical specimens (4 mm diameter × 6 mm length) were prepared from each material using stainless steel split molds. Each specimen was irradiated from top and bottom in the mold and from radial direction after removing from the mold (40 s each) using a visible light curing unit (Optilux 501, Kerr, Orange Co., USA) with irradiance of 650 mW/cm^2. For flexural strength testing, fifteen bar-shaped specimens (25 mm length x 2 mm width x 2 mm height) were prepared from each material using stainless steel split molds. Each specimen was irradiated in five overlapping sections (40 s each) on the upper and lower surfaces starting from the center of the specimen using the visible light curing unit described above. Specimens were stored in distilled water at 37°C in an incubator for 24 h. Loading of specimens until fracture, for both compressive strength and flexural strength, was carried out in a universal testing machine (model 3365, Instron, High Wycombe, UK) at three different cross-head speeds: 1 mm/min (n = 5), 3 mm/min (n = 5) and 5 mm/min (n = 5). Data were analyzed using a One-way ANOVA and Bonferroni *post-hoc* test.

Results: Considering all cross-head speeds applied, mean data for compressive strength ranged from 349 to 434 MPa, and for flexural strength ranged from 84 to 182 MPa. Linear regression analysis revealed a strong positive correlation between the applied cross-head speeds and both the compressive strength and flexural strength values.

Conclusions: Changing the cross-head speed resulted in variation in strength values of the investigated resin-composites. The values of compressive strength and flexural strength depend principally on the extent of filler loading and the type of resin system.

KEYWORDS: Compressive Strength, Flexural Strength, Resin-composites, Cross-head Speed, Filler Loading, Resin System.

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INTRODUCTION

The use of resin-composites as restorative filling materials in load-bearing areas is increasing. This means that these materials are subjected to masticatory forces of a considerable magnitude [1, 2]. Clinical performance and laboratory evaluation are the main approaches to understand and prove the reliability of a dental material [3].

Successful application of dental materials as load-bearing structural components of restored teeth requires adequate mechanical properties. Thus general mechanical characterization of such materials is essential. The most useful starting point is to examine their stress-strain properties [4].

Measurement of mechanical properties such as strength and modulus of elasticity is important for characterizing - in part - a resin-composite material and helps to predict the clinical performance and durability of its restoration [5]. The filler particles - in terms of composition, shape, content, interparticle spacing, and surface treatment - determine, to a great extent, the mechanical properties of resin-composites [6]. In addition to the filler system, monomer system of the resin matrix also influences the mechanical properties of these materials [7].

Moreover, mechanical properties of such materials are influenced by the surrounding environment. The degradation process initiated by the water and the presence of a constant load generated by the masticatory system on the surface of the resin-composite material can start and propagate interfacial debonding, matrix cracking, filler dissolution, filler particle dislodgment and superficial flaws [8, 9].

For a resin-based restoration to be successful, it must be capable of resisting both masticatory and parafunctional stresses and maintaining its integrity while transferring stresses to the tooth structure, particularly in case of expecting stresses of high magnitude. In addition, this material must function in a complex environment characterized by fluids of varying composition and pH, varying temperature conditions and cyclic mechanical forces [10]. It was reported that the stresses falling on the dental restoration may be one or a combination of three basic types; compressive, tensile and shear stresses[11].

Strength has been considered an essential mechanical property of a dental restorative material[12]. Strength values of resin-based restorative materials are usually related to their composition[13], irradiation time and packing procedures [5, 14]. Strength properties have been utilized to characterize and compare resin-composite materials [15].

Because of majority of the masticatory forces falling on the dentition are of a compressive nature, compressive strength of a restorative dental material has a particularly important role in the mastication process [16]. Flexural strength is a measure of material resistance to withstand tensile forces. Materials with high flexural strength provide restorations with higher resistance to fracture of the margins or the bulk [17].

In stress-bearing occlusal areas, materials with low strength values deform more under masticatory stresses and may undergo catastrophic failure. High strength is required to withstand deformation and cuspal fracture [18]. Consequently, knowledge of the strength properties of many resin-composite materials is important in understanding and expecting their clinical behavior [19].

The primary objective of this study was to investigate the effect of speed of loading on the compressive strength and flexural strength of some resin-composite materials of different types (Conventional, Flowable and Bulk-fill). The null hypotheses were: (i) there will be no difference in strength values between resin-composites with different composition and (ii) varying the speed of loading (cross-head speed) will have no effect on the strength values of the investigated resin-composites.

MATERIALS AND METHODS

Five resin-composites (three conventional, one flowable and one bulk-fill) were investigated in this study. Materials and manufacturers' details are listed in Table 1.

Specimen Preparation and Measurement of Compressive Strength

Fifteen cylindrical specimens (4 mm diameter × 6 mm length) were prepared from each material using stainless steel split molds. Glass microscope slides, covered with transparent polystyrene matrix films, were positioned at the upper and lower surfaces of the specimen. Each specimen was cured from top and bottom in the mold (40 s each) using a visible light curing unit (Optilux 501, Kerr, Orange Co., USA) with irradiance of 650 mW/cm^2.

After removing the specimen from the mold, excess material was trimmed by hand-grinding with P800 grit Silicone Carbide (SiC) abrasive paper. Each specimen was further cured from the radial direction (40 s each) and stored in distilled water at 37°C in an incubator for 24 h. Loading of specimens until fracture was carried out in a universal testing machine (model 3365, Instron, High Wycombe, UK) at three different cross-head speeds: 1 mm/min ($n = 5$), 3 mm/min ($n = 5$), and 5 mm/min ($n = 5$). The compressive strength ($\boldsymbol{\sigma}_c$ - MPa) was calculated by dividing the maximum force applied to fracture the specimen by the cross-sectional area according to the following equation [16, 20]:

$$\sigma_C = \frac{4F}{\pi D^2}$$

Where F (N) is the load at fracture, D (mm) is the diameter of the specimen.

Specimen Preparation and Measurement of Flexural Strength

Fifteen bar-shaped specimens (15 mm length x 2 mm width x 2 mm height) were prepared from each material using stainless steel split molds. The resin-composite material was packed (conventional) or injected (flowable) into the mold and pressed with a glass microscope slide, covered with a transparent polystyrene matrix film. Each specimen was cured in five overlapping sections (40 s each) on the upper and lower surfaces starting from the center of the specimen using the visible light curing unit described above. After curing, specimens were removed from the mold and abraded by hand with 800 grit SiC abrasive paper to remove the excess material and stored in distilled water at 37°C for 24 h before loading.

TABLE (1) Investigated resin-composites; product code, material composition and manufacturers' information.

Product	Code	Type	Manufacturer	Resin System	Filler (wt %)
GrandioSo	**GS**	Conventional	Voco, Cuxhaven, Germany	Bis-GMA, Bis-EMA, TEGDMA	89
Filtek Supreme XTE	**FS**	Conventional	3M ESPE, St. Paul, MN, USA	Bis-GMA, UDMA, TEGDMA, PEGDMA, Bis-EMA	79
Venus Diamond	**VD**	Conventional	Heraeus Kulzer GmbH, Hanau, Germany	TCD, di-HEA, UDMA	81
Venus Flow	**VF**	Flowable	Heraeus Kulzer, Hanau, Germany	Bis-GMA, TEGDMA	62
SureFil SDR Flow	**SF**	Bulk-fill	Dentsply Caulk, Delaware, USA	EBPADMA, TEGDMA	68

Loading of specimens until fracture was carried out in the same universal testing machine described above using a three-point bending method with a 20-mm span at three different cross-head speeds: 1 mm/min (*n* = 5), 3 mm/min (*n* = 5) and 5 mm/min (*n* = 5). The load at fracture and specimen dimensions were used to calculate the flexural strength (σ_f - MPa) according to the following equation [21,22]:

$$\sigma_f = \frac{3FL}{2bh^2}$$

Where *F* (N) is the load at fracture, *L* (mm) is the distance between the supports, *b* (mm) is the width, and *h* (mm) is the height of the specimen.

Statistical analysis

Data for compressive strength and flexural strength were analyzed using a one-way analysis of variance (ANOVA) with the significance level established at ($p \leq 0.05$). The Bonferroni *post hoc* test was used to determine the differences in compressive strength and flexural strength between groups. Linear regression analysis was performed to investigate relationship between investigated strengths and the applied cross-head speeds and between strength values and the filler loading of the corresponding materials.

RESULTS

Mean values and standard deviations of the compressive strength and flexural strength for the investigated resin-composites are listed in Table 2 and presented in Figures 1 and 2 respectively.

Mean data for the compressive strength ranged from 349 to 427 MPa at a cross-head speed of 1 mm/min, from 358 to 429 MPa at a cross-head speed of 3 mm/min, and from 367 to 434 MPa at a cross-head speed of 5 mm/min. For the flexural strength, data ranged from 84 to 175 MPa at a cross-head speed of 1 mm/min, from 96 to 178 MPa at a cross-head speed of 3 mm/min, and from 105 to 182 MPa at a cross-head speed of 5 mm/min.

The highest compressive strength was shown by GS followed by FS and VD and and the lowest values were recorded for SF followed by VF. The case for the flexural strength was exactly the same as the compressive strength.

Statistical analysis revealed significant differences between the investigated resin-composites at the three cross-head speeds applied; at 1 mm/min, ($p = 0.012$), at 3 mm/min, ($p = 0.009$), and at 5 mm/min, ($p = 0.006$).

Bonferroni *post-hoc* test revealed significant differences between GS and both of VF and SF but not with FS and VD. Similarly, FS exhibited significant differences with both of VF and SF but not with GS and VD. On the other hand, VD did not show significant differences with any of the investigated materials. This applies for both compressive strength data as well as flexural strength data.

From the data recorded, with increasing the cross-head speed, all investigated resin-composites, systematically, exhibited greater mean values for both compressive strength and flexural strength as shown in Table 2 and presented in Figures 1 and 2.

Variation in cross-head speed had a greater influence on the results of materials with flowable consistency than those with conventional consistency. This means that increasing the cross-head speed produced greater values in the strength data (both in compressive strength and flexural strength). This can be clearly visible in case of GS and FS compared to VF and SF.

Linear regression analysis revealed a strong ($r^2 = 0.993$) positive correlation between the applied cross-head speeds and the compressive strength values as shown in Figure 3 as well as the flexural strength values ($r^2 = 0.996$) as presented in Figure 4. Strength data of VD were taken as representatives for other studied materials.

For a group of investigated materials (GS, FS and VF) having, nearly, the same resin system (Bis-GMA, TEGDMA) and varied filler loading, linear regression analysis revealed a strong positive correlation between their compressive strength values (MPa) and the filler loading ($r^2 = 0.975$), and between their flexural strength and the filler loading ($r^2 = 0.963$) as shown in Figures 5 and 6 respectively.

TABLE (2) Mean data and standard deviations of compressive strength and flexural strength for the investigated resin-composites at three different cross-head speeds. Each strength value represents the mean of five measurements.

Resin Composite	**Cross-head Speed (mm/min)**	**Mean Compressive Strength (MPa)**	**Standard Deviation (compressive)**	**Mean Flexural Strength (MPa)**	**Standard Deviation (flexural)**
GrandioSo	**1**	427	15	175	6.1
	3	429	21	178	7.5
	5	434	18	182	5.8
Filtek Supreme XTE	**1**	413	22	161	6.9
	3	417	19	164	7.5
	5	421	16	168	6.7
Venus Diamond	**1**	392	25	137	6.3
	3	398	23	142	8.1
	5	406	28	146	7.2
Venus Flow	**1**	365	27	102	7.5
	3	373	17	112	4.9
	5	382	23	123	8.3
SureFil SDR Flow	**1**	349	19	84	6.9
	3	358	21	96	8.7
	5	367	24	105	7.9

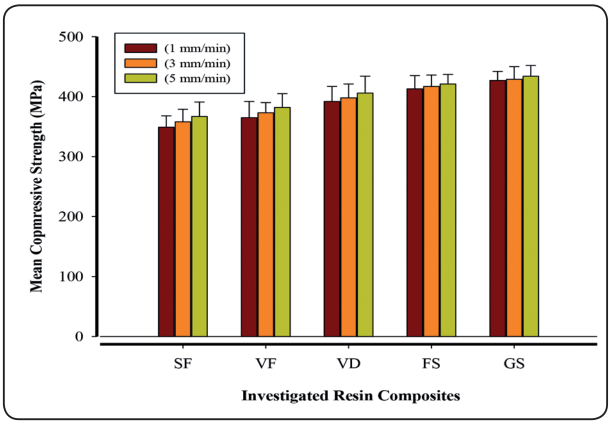

Fig. (1) Error bar showing mean compressive strength for the investigated resin-composites at three different cross-head speeds. Each bond strength value represents the mean of five measurements.

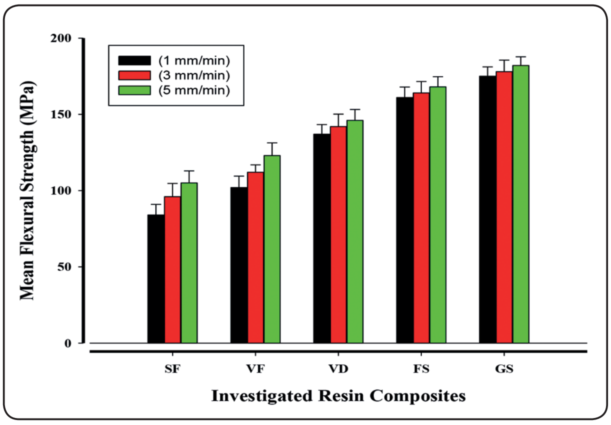

Fig. (2) Error bar showing mean flexural strength for the investigated resin-composites at three different cross-head speeds. Each bond strength value represents the mean of five measurements.

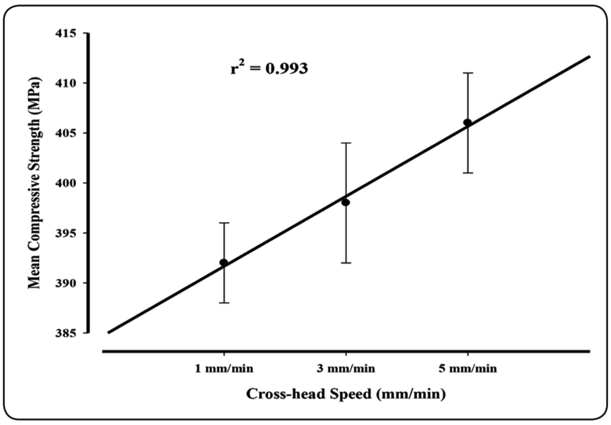

Fig. (3) Linear regression analysis for Venus Diamond (VD) - as a representative of the other materials - revealed a strong positive correlation between compressive strength values (MPa) and the applied cross-head speeds.

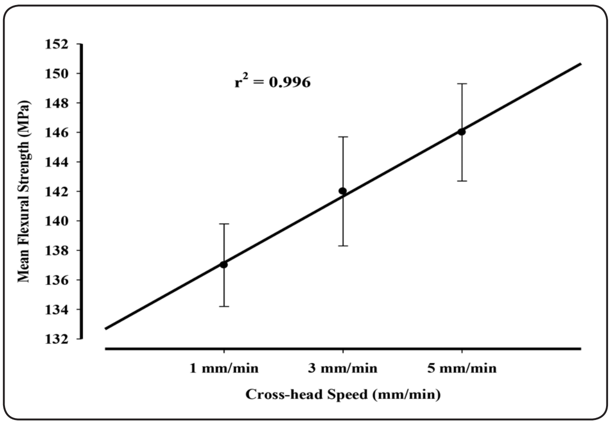

Fig. (4) Linear regression analysis for Venus Diamond (VD) - as a representative of the other materials - revealed a strong positive correlation between flexural strength values (MPa) and the applied cross-head speeds.

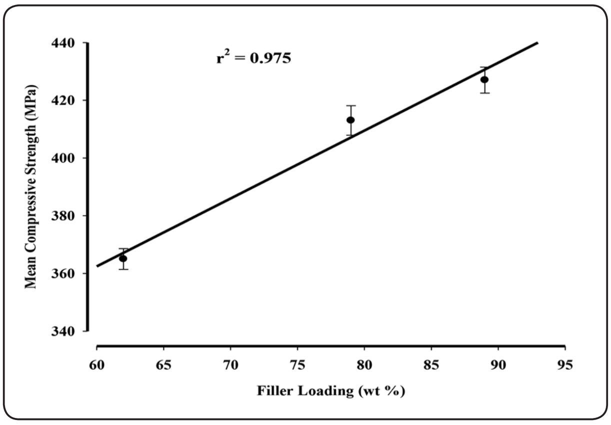

Fig. (5) For a group of investigated materials (GS, FS and VF) having the same resin system (Bis-GMA, TEGDMA) and varied filler loading, linear regression analysis revealed a strong positive correlation between their compressive strength values (MPa) and the filler loading.

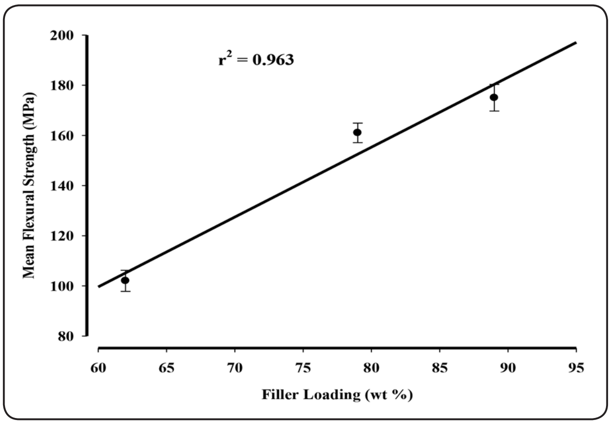

Fig. (6) For a group of investigated materials (GS, FS and VF) having the same resin system (Bis-GMA, TEGDMA) and varied filler loading, linear regression analysis revealed a strong positive correlation between their flexural strength values (MPa) and the filler loading.

DISCUSSION

Laboratory research and clinical trials are considered the main tools to characterize and evaluate the performance of resin-based restorative materials. An essential part of the critical evaluation of these materials is to examine their behavior under stress [23].

Restoring both anterior and posterior teeth with resin-composite materials is now an established clinical practice and the substitution of dental amalgam restorations by resin-composite restorations is increasing. The clinical performance and durability of these restorations are determined by many variables such as the filling technique, the patient’s oral habits, the masticatory loading, and the physical and mechanical characteristics of the restorative material used [24, 25].

It was reported that the loads in the local contact areas on the occlusal surface during chewing are about 66 N, and under extremely high bite forces these loads can reach 90 N [26]. These relatively high forces indicate that high stresses fall on dental complex during function. Therefore, knowledge of the deformation behavior of resin-composite materials is important for predicting the functional behavior of such restorative materials in the mouth[27].

Resistance of dental restorative materials to degradation and distortion in the oral environment largely determines their durability and clinical performance [28]. Mechanical properties of resin-composites are influenced not only by their chemical composition, but also by the environment to which they are exposed [27].

Special care was taken to ensure optimum curing of the materials during specimen preparation. This requires adequate irradiance of the curing unit, enough curing time, proper determination of the thickness of resin-composite material to be cured, and the contact between the curing tip and the specimen. It was said that incomplete polymerization may produce a heterogeneous specimen that has an uneven stress distribution during loading which, in turn, adversely affects the results of the mechanical properties measured [15, 29].

In this study, the compressive strength and flexural strength, as considered critical mechanical properties of any restorative material, were evaluated for some resin-composites of different nature and varied composition under three different cross-head speeds. This was carried out to investigate the behavior of such materials when loaded at different speeds. Statistical analysis revealed significant differences between the investigated materials at all cross-head speeds applied for both compressive strength and flexural strength, therefore, the first null hypothesis was rejected.

Also, varying the cross-head speed when loading these materials resulted in different strength values, i.e., when the cross-head speed was accelerated from 1 mm/min to 3 mm/min and then to 5 mm/min, the examined resin-composite materials showed greater mean values for both compressive strength and flexural strength. The second null hypothesis, consequently, was rejected as well.

Greater strength values with higher cross-head speeds may be interpreted on the basis that resin-composite materials are considered viscoelastic materials. The viscoelastic materials are “strain rate-sensitive” which means that at higher rate of loading, these materials exhibit higher strength and lower permanent deformation.

Linear regression analysis for all examined materials revealed a strong positive correlation between the cross-head speed applied and the resulting strength value for both compressive strength and flexural strength. Linear regression analyses of VD - as an example - were presented in Figure 3 ad Figure 4 for both compressive strength and flexural strength, respectively.

Addition of inorganic fillers has been repeatedly reported to improve the resistance of resin-based restorative materials against mechanical degradation [30]. The particular characteristics of filler particles, such as nature, distribution, content, and size in resin-composite materials determine to a great extent their strength and resistance to fracture [27, 31]. The current study proved this information where materials with higher filler loading, such as GS and FS recorded greater values than those with lower filler loading, such as SF and VF both in compressive strength and flexural strength. In addition, for a group of investigated materials (GS, FS and VF) having the same resin system (Bis-GMA, TEGDMA) and varied filler loading, linear regression analysis revealed a strong positive correlation between their compressive strength values (MPa) and the filler loading as shown in Figure 5 and between their flexural strength and the filler loading as presented in Figure 6.

Moreover, deformation or fracture of resin-composite materials is greatly dependent on the monomer type and diluent concentration in the matrix formulation. For a given filler loading, resin-composites with rigid monomers, such as Bis-GMA, and low concentration of diluent, such as TEGDMA, exhibit greater strength values than do other resin-composites with other monomer type and higher diluent concentration [32, 33]. In this study, though SF has higher filler loading (68 wt%) than VF (62 wt%), the latter (VF) exhibited greater mean values in both compressive strength and flexural strength than the former (SF). This could be explained on the basis that VF has Bis-GMA in its resin formulation while SF is based on other monomer system.

Though compressive strength and flexural strength are important mechanical properties, selecting a material for restoring teeth, particularly in the posterior region, does not depend on these two properties alone. Instead, there are many other physical and mechanical properties that must be considered such as elastic modulus, hardness, resistance to wear, polymerization shrinkage, environmental degradation and esthetics [34].

CONCLUSIONS

- Resin-composites with different composition exhibited varied values of both compressive strength and flexural strength.
- Variation in cross-head speed resulted in variation in strength values of the investigated materials.
- The values of compressive strength and flexural strength depend principally on the extent of filler loading and the resin system.

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