Jo https://doi.org/10.26682/sjuod.2022.25.2.39
urnal of University of Duhok., Vol. 25, No.2(Pure and Engineering Sciences), Pp 425-435, 2022

COMPARISON OF THE MECHANICAL PROPERTIES FOR FIBER REINFORCED AND BULKFILL COMPOSITES

DELAN SIDQE SALEEM* and ALI MOAYID RASHEED**
*College of Dentistry, University of Duhok, Kurdistan Region–Iraq
**College of Dentistry, University of Mosul–Iraq

(Received: September 7, 2022; Accepted for Publication: November 27, 2022)

ABSTRACT
purpose: To assess and compare specific mechanical characteristics including ; flexural strength (FS), fracture toughness (FT) and diametral tensile strength (DTS) of two short fiber reinforced composites formulation (SFRCs) (everXPosterior and everXFlow , GC Corporation ,Tokyo, Japan) with one of conventional bulkfill composite (CBF) (Tetric ^{R} N-Ceram, Ivoclar Vivadent AG, Schaan, Liechtenstein).
Methods: The properties investigated were flexural strength (FS), fracture toughness (FT), and diametral tensile strength (DTS) following ISO standards. For each investigated test the prepared specimens were divided in to three groups, G1 were fabricated from conventional bulkfill composite (Tetric^{R} N-Ceram, Ivoclar Vivadent AG), G2 were fabricated from SFRCs (everXPosterior, GC Corp) and G3 from SFRCs (everXFlow, GC Corp). Consequently, they were incubated in distilled water at 37°C for 24 h before operating the mechanical tests. The specimens were assessed in a universal material testing machine at 1.0 mm/min crosshead speed until failure. The data were be statistically evaluated with SPSS (Statistical Package for Social Science Ver.25) using Analysis Of Variance (ANOVA) followed by a Tukey HSD^{a} test to define the differences between the tested groups.
Results: The SFRC everXPost. and everXFlow exhibited significantly higher flexural strength (100.2 MPa, 99.1 MPa) and fracture toughness (1.23 MPa $m^{1/2}$, 1.16 MPa $m^{1/2,}$) values respectively than bulk fill conventional composite (Tetric^{R} N-Ceram)(58.2 MPa, 0.6 MPa $m^{1/2}$). The DTS of everXFlow was statistically superior (54.3 MPa) than the everXPost. composite (44 MPa) and conventional bulkfill (Tetric^{R} N-Ceram) composite (37.3MPa).
Conclusion: According to the obtained results the SFRCs everXPost. and everXflow showed better mechanical properties than conventional bulkfill composite and could be applied well in posterior restorations.

Keywords: Fiber reinforced composites, Bulkfill composites, Flexural strength (FS), Fracture toughness (FT) , Diametral tensile strength (DTS) .

INTRODUCTION

As a consequence of elevated patient and clinician demands for natural esthetics, composites resin are often used on posterior teeth, where significant mechanical problems arise under function (Kramer et al., 2016). Studies report that particulate-filled resin composite materials that have particle fillers still experience issues when used in high-stress bearing regions due of their lack of toughness (Kassem et al., 2012; Lassila et al., 2018). Numerous researches have been done on methods of reinforcing to improve resin composites and address limitations.

Bulkfill composites were developed for large posterior restorations to overcome the mechanical characteristics and depth of cure constraints of conventional composite resin (Czasch and Ilie, 2013). It is possible to placed bulk-fill resin composites rather than using the incremental approach since they demonstrated a suitable depth of cure at 4 mm (Zorzin et al., 2015).

Another development in dental composite innovation to enable its usage in challenging clinical situations is the production of short fiber reinforced composite (SFRCs) materials, in which the filler system is potentiated with short glass fibers to inhibit crack progression (Garoushi et al.,2013; Lassila et al.,2018).These SFRCs composed of e-glass fibers, resin matrix and inorganic fillers (Bijelic-Donova et al.,2016).The resin matrix in this composite have linear polymethylmethacrylate (PMMA); this matrix formed a semi-interpenetrating polymer network (semi-IPN) during polymerization, which results in good bonding properties (Tsujimoto et al.,2016; Bijelic Donova et al.,2016). The short glass fibers integrated into the resin matrix are either in millimeter-scale fiber and have matrix resin of bisphenol-A-glycidyl methacrylate (Bis-GMA), and triethylene glycol dimethacrylate (TEGDMA) such as (everXPosterior) composite in high aspect ratio, which give improved mechanical qualities that intend to be comparable to natural tooth structures (Garoushi et al.,2012; Alshabib et al.,2019) or these short glass fibers are presented in micrometer-scale fiber (everX Flow) that contains Bis-EMA and UDMA resin, and filler loading of 70% by weight with highly fracture toughness (Lassila et al.,2020).

The fracture related materials parameters, including resistance to crack propagation, deformation under occlusion and materials marginal deterioration, are often assessed by measuring the fundamental characteristics of fracture toughness and flexural strength (Heintze et al.,2017).

On the other hand, the tensile strength of composite resin is crucial since dental restorations are expos-ed to tensile tensions from transverse or oblique loading of their complex geometric forms. And because of brittleness of composite material, it is difficult to measure the traditional tensile strength test. Diametral tensile strength test is performed as an alternative to the traditional one (Anusavice, 2003).

Because of, the reasons for composite restoration failure, according to Alvanforoush and colleagues, have changed from elevated proportion of recurrent caries and wear to more important character for fractures of restoration, fractures of teeth, and root canal therapy (Alvanforush et al., 2017). And in light of the advancement of newer procedures and materials, clinicians frequently lack clarity when it comes to selecting the best alternatives or materials to produce the greatest results. So the aim of present study was to assess and compare specific mechanical characteristics of two direct composite restorations that are often utilized (bulkfill composite and two formulations of SFRCs) in stress-bearing regions.

1. MATERIALS AND METHODS

1.1 Materials

Materials consumed in this study are shown in Table 1.

Table (1): Materials, manufacturer, chemical constitutions of the resin matrix and filler content by volume and weight %

N	material	Type	Manufacture (Lot. no.)	Resin	Filler
1	EverXFlow Bulk shade	SFRC(flowable)	GC Corporation, Tokyo ,Japan (2109131)	Bis-MEPP, UDMA TEGDMA	46 vol%,70 wt%, (total inorganic fibre and filler content).E-glass micro fibres (average L140 µm and Ø6 µm , barium silicate glass
2	EverX Posterior	SFRC(packable)	GC Corporation, Tokyo, Japan (2103012)	Bis-GMA, PMMA, TEGDMA	57 vol%, 76 wt% (total inorganic fibre and filler content). E-glass fibres (average L0.5-2 mm and Ø 17µm), barium borosilicate.
3	Tetric^{R} N-Ceram Bulkfill	Bulk Fill (CBF)	Ivoclar Vivadent AG, Schaan, Liechtenstein (X27314)	BisGMA Bis-EMA UDMA	53-55vol%, 75-77wt% barium glass ,ytterium trifluoride mixed oxide, and prepolymer.

Abbreviations: **Bis-MEPP** bisphenoleA ethoxylate dimethaacrylate ,**Bis-GMA**:bisphenal A-diglycidyl ether dimethaacrylate;**TEGDMA**:triethyleneglygoldimethacrylate; **Bis -EMA**: Bishenol A polyethylene glycol diether dimethaacrylate, **UDMA**:urethanedimethacrylate;**PMMA**:polymethyl methacrylate**.**

1.2 Methods

Preparation of Samples for Mechanical Tests

Three tests were performed: flexural strength (FS) (n=36), fracture toughness (FT) (n=36), and diametral tensile strength (DTS) tests (n=18). For each investigated test, the prepared specimens were distributed in to three groups, Specimens G1: TetricR N-Ceram Bulkfill, G2: everX Posterior and G3: everXFlow composites resin.

1.2.1 Flexural Strength (FS) Test/

The flexural properties of the composites resin were examined in the line with the International Standards Organization (ISO 4049-2019) (Pałka et al.,2020), composite resin from each group (n=12) was condensed into a plastic mold with dimensions 2*2*25 mm (Bar-shaped specimens), set at a glass slide, and irradiated with light cure (Flexi Light ,R&S ,France).The light intensity was 1500 mW/cm²with 10 second on four separated parts on each upper and lower side. These specimens then incubated at 37˚C for 24 h before performing the mechanical examinations.

The 12 specimens per test group were exposed to a three-point bending test using a universal testing machine (Model K0313,Gester International CO.,LTD, China) at 1.0 mm/min cross speed till the fracture of specimens occur. The specimens were placed on a three-point bending apparatus with a span dimension of 20 mm, and Flexural strength (FS) was calculate from the following formula (Lassila et al., 2020): $FS=3Fm\ I\ /2bh^{2/////}$Where the Fm was the load applied (Newton) at the peak point of the load-deflection curve, I: the span dimension (20 mm), b: the width of the specimens (2mm) and h was the thickness of the specimens (2mm). The developed data were exposed to One-Way analysis of variance (ANOVA) and TukeyHSD Test was utilized to define differences between the groups.

1.2.2 Fracture Toughness (FT) Test/

Fracture toughness was established in accordance to the technique defined in ASTM specification E-399-90 for single-edge V-notch beam (SEVNB) specimen manipulated in transverse bending (Aldhuwayhi et al.,2021) Fig.1. Specimens (n=12) for each material were prepared in a plastic mold (2.5*5*25 mm), a razor blade was used to make a notch (0.5mm width and 2.5mm notch depth) .

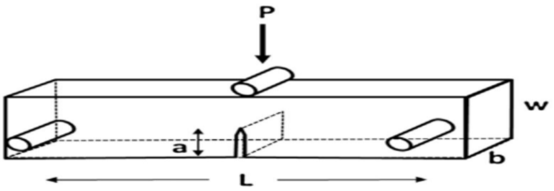

Fig. (1): Geometry of Specimen For The SEVNB Technique of Determining Fracture Toughness(Ilie et al., 2017).

Composites materials from each group were compacted in to the mold between two strip sheets, pressed with a glass plates, and exposed to light cure for 10 sec set at 1500 mW/cm2 light irradiance average on each upper and lower sides. After that, the hardened specimens were cautiously removed from the mold and stored in 37°C distilled water for 24 h in the incubator. Proximately after storage the three -point bending test was performed with a universal testing machine at a crosshead speed of 1.0 mm/min until specimen fracture. The fracture toughness FT (MPa $m^{1/2}$), was calculated from the following equation: (Tanaka et al., 2020): FT= (PQ*S)/ (B*W3/2)*f (a /W)

PQ=peak load (N), L= span (m), B=specimen thickness (m), W=specimen width (m), and a=crack length. Because it is difficult to measure crack length exactly, the crack length was taken to be the distance from the base of the notch to the opposing surface of the specimens (2.5 mm). Here f (a /W) is a function of a /W and is calculated according to ASTM E-399-90 as follows:

(a/W)=3(a/W)1/2[1.99-(a/W)*(1-a/W)*(2.15-3.93a/W+2.7a2/W2]/2(1+2a/W)(1-2a/W)3/2.

1.2.3 Diametral Tensile Strength (DTS) Test

Specimens (*n* = 18) from each tested composite materials were prepared in the same way in the line with ISO (ISO 4104 ‑1984) (Sihivahanan and Nandini, 2021). The specimens were obtained by filling the composite materials in a cylindrical plastic mold (4mm in diameter and 6 mm in height) and pressing them between two glass slides covered with strips of polyester. The polymerization was carried out using a photo curing source with 1500 mW/cm² intensity for 10 sec from the upper and lower sides. After light curing the specimens were separated from the mold. Finally, and before being tested, they were stored in incubator at 37 °C for 24 hours.

In the universal testing machine, each tested specimen was sited with its longitudinal side between the plates of the testing apparatus Fig.2. They were exposed to compression loading until failure at 1 mm/min crosshead speed. The DTS were calculated in MPa according to the following formula (Sihivahanan and Nandini, 2021):

$DTS= 2F/\pi lD$

Where: F is the maximum applied load in newton (N); D is the diameter of the specimens in mm (4mm) ,l is the length of the specimen in mm(6mm), and $\pi = 3.1416$.

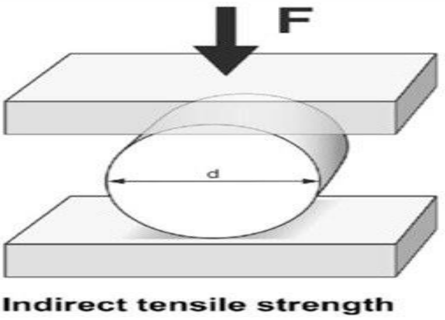

Fig. (2): Test set-up for Indirect Tensile Strength (d = diameter, F = Force) (Rohr&Fischer, 2017).

2. RESULTS

2.1. Flexural Strength (FS) Test

The descriptive statistics of the Flexural Strength (FS) for three types of dental resin composites were estimated and revealed on Table 2 and Fig.3.

Table (2): Mean and SD Values of The Flexural Strength (MPa) of, Tetric^R N-Ceram Bulk fill, everX Post., and everX Flow composite resins

Samples	No.	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Tetric^R N-Ceram Bulkfill	12	58.2955	26.81083	7.73962	41.2607	75.3303	31.56	125.04
EverX Post.	12	100.2814	34.45391	9.94599	78.3904	122.1723	63.44	184.80
EverX Flow	12	99.1579	22.40169	6.46681	84.9246	113.3913	68.95	153.54
Total	36	85.9116	33.89911	5.64985	74.4418	97.3814	31.56	184.80

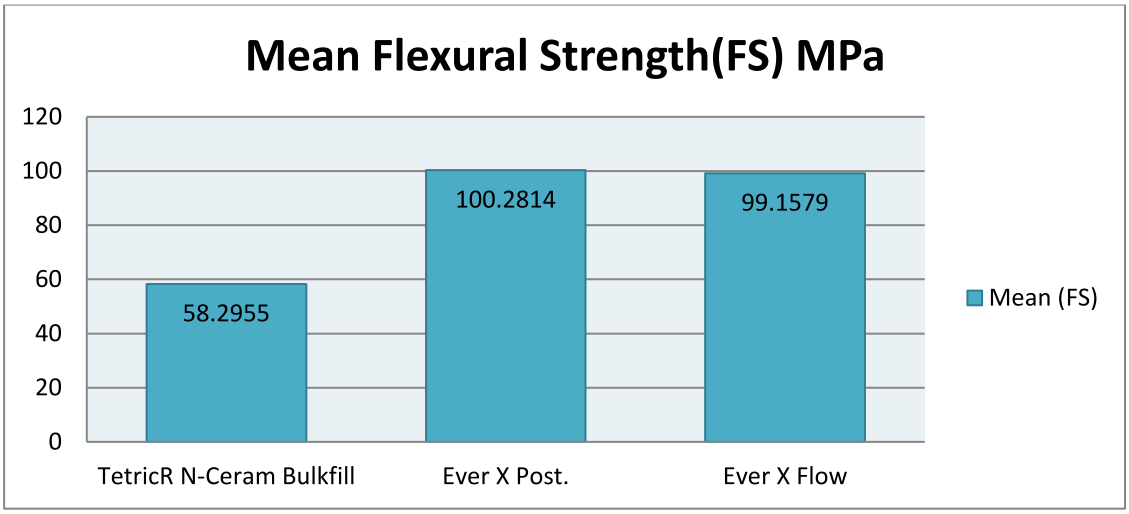

Fig. (3): Mean Flexural Strength (MPa) of Experimental Groups

The One-Way Analysis of Variances (ANOVA) indicated that there is a significant differences between three tested composites (p=.001) as revealed in the Table 3.

Table (3): One-way ANOVA of FS test, Between Three Tested Composites

	Sum of Squares	df	Mean square	F	Sig.
Between Groups	13735.231	2	6867.615	8.557	.001
Within Groups	26485.012	33	802.576		
Total	40220.243	35			

Tukey HSD post hoc test indicated that the eveXflow composite resin and everXPost.had significantly higher FS than Tetric^R N-Ceram Bulkfill composite (58 MPa). Although both everXFlow (99.1MPa) and everXPost. (100.2MPa) were not statistically significant from each other, but everXFlow had the lowest flexural strength value as shown in Table 4.

Table (4): Tukey HSD^a Test of The Experimental Groups

VAR00003 Sample	No.	Subset for alpha = 0.05 1	 2
Tetric^R N-Ceram Bulkfill	12	58.2955	
EverXflow	12		99.1579
EverXpost.	12		100.2814
Sig.		1.000	.995

2.2. Fracture Toughness (FT) Measurement

The descriptive statistics of the fracture toughness (FT) for three types of dental resin composites were presented at Table 5 and shown graphically in Fig.4.

Table (5): Mean and SD values of the Fracture Toughness (MPa m$^{1/2}$) of, Tetric^{R} N-Ceram Bulk fill, everX Post., and everX Flow composites

Samples	No.	Mean	Std. deviation	Std.error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Tetric^{R} N-Ceram Bulkfill	12	.6842	.18262	.05272	.5681	.8002	.40	1.02
Ever X Post.	12	1.2313	.36353	.10494	1.0004	1.4623	.68	1.99
Ever X Flow	12	1.1630	.32358	.09341	.9574	1.3686	.61	1.90
Total	36	1.0262	.38193	.06366	.8969	1.1554	.40	1.99

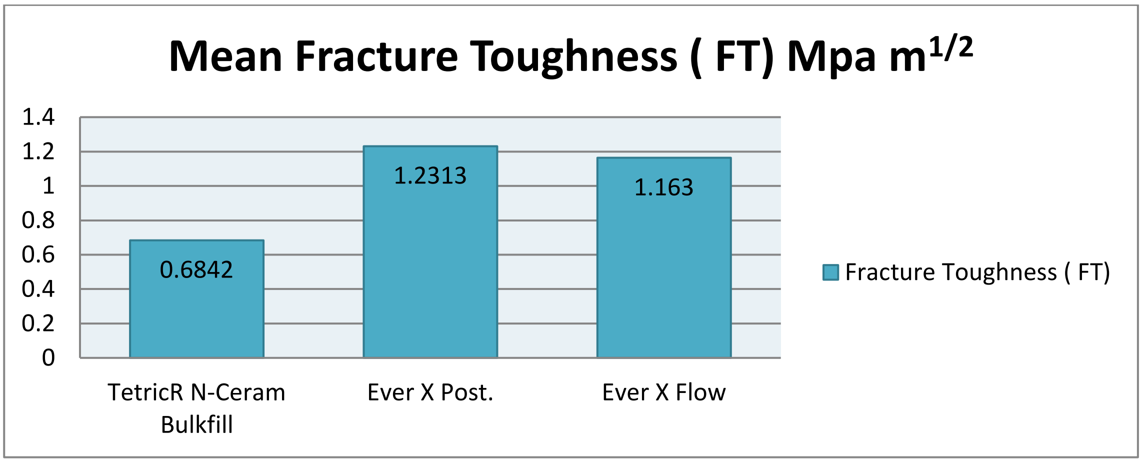

Fig. (4): Mean Fracture Toughness (MPa m$^{1/2}$) of Experimental Groups

The ANOVA denoted that there is a significant differences between three tested composites (p=.000) as presented in the Table 6.

Table (6): One-way ANOVA of FT Test, Between Three Tested Composites.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.133	2	1.067	11.843	.000
Within Groups	2.972	33	.090		
Total	5.106	35			

Tukey HSD post hoc test indicated that the eveXflow composite resin and everXPost.had significantly higher mean FT value than Tetric^{R} N-Ceram Bulkfill composite (0.6 MPa m$^{1/2}$). Although both everX Flow (1.1 MPa m$^{1/2}$) and everXPost (1.2 MPa m$^{1/2}$) were not statistically significant from each other, the everXFlow had the lowest fracture toughness value as shown in Table 7.

Table (7): Tukey HSD[a] Test of The Experimental Groups

VAR00003	No.	Subset for alpha = 0.05	
		1	2
Tetric^R N-Ceram Bulkfill	12	.6842	
EverXflow	12		1.1630
EverXpost.	12		1.2313
Sig.		1.000	.843

2.3. Diametral Tensile Strength (DTS)

The descriptive statistics of DTS for three types of dental resin composites were presents on Table 8 and Fig.5.

Table (8): Mean and SD values of the diametral tensile strength (Mpa) of, Tetric^R N-Ceram Bulk fill, everX Post., and everX Flow composite resins.

Samples	No.	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Tetric^R N-Ceram Bulkfill	6	37.3415	4.53526	1.85151	32.5821	42.1010	31.97	44.90
Ever X Post.	6	44.0021	8.06756	3.29357	35.5357	52.4685	33.67	57.23
Ever X Flow	6	54.3096	4.91417	2.00620	49.1525	59.4667	47.45	60.23
Total	18	45.2177	9.15893	2.15878	40.6631	49.7724	31.97	60.23

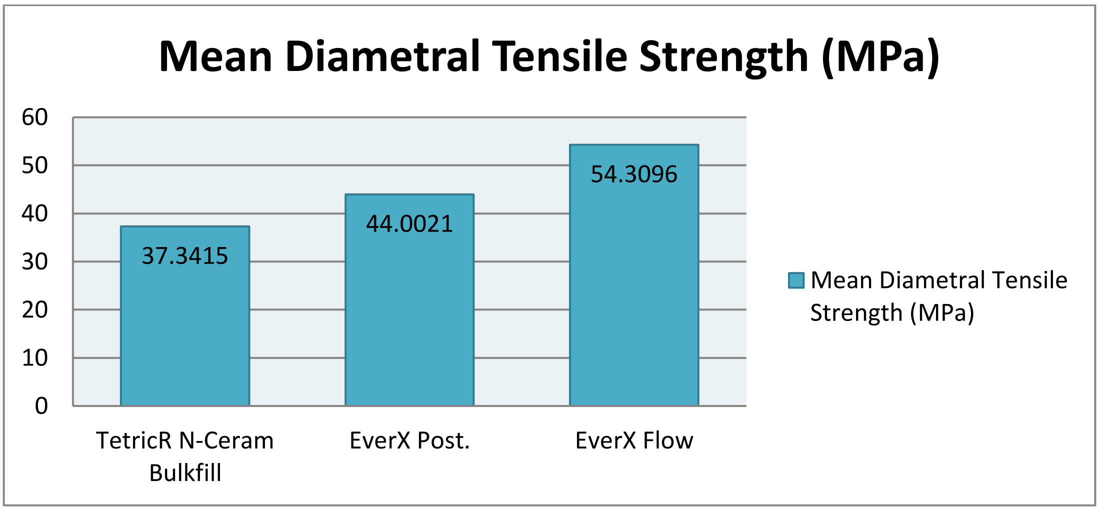

Fig. (5): Mean Diametral Tensile Strength (MPa) of Experimental Groups

ANOVA indicated that a significant differences between three tested composites (p=.001) were presented as shown in the Table 9.

Table (9): One-way ANOVA of DTS Test, Between Three Tested Composites.

	Sum of Square	df	Mean Square	F	Sig.
Between Groups	877.045	2	438.523	11.981	.001
Within Groups	549.016	15	36.601		
Total	1426.061	17			

Tukey HSD post hoc test indicated that the eveX flow composite resin had significantly higher mean DTS (54.3MPa) than everXPost. (44 MPa) and Tetric^R N-Ceram Bulk fill (37.3MPa). Although both everXPost (44 MPa) and Tetric^R N-Ceram Bulk fill (37.3MPa) were not staistically significat from each other, but Tetric^R N-Ceram Bulk fill had the lowest diametral tensile strength value as shown in Table 10.

Table (10): Tukey HSD[a] Test of The Experimental Groups

VAR00003	No.	Subset for alpha = 0.05	
		1	2
Tetric^R N-Ceram Bulkfill	6	37.3415	
EverXPost.	6	44.0021	
EverXFlow	6		54.3096
Sig.		.171	1.000

DISCUSSION

In the present study the mechanical characteristics of two types of short fiber reinforced composite SFRCs (everXFlow, everXPosterior ,GC Corporation, Tokyo, Japan) and commercially available bulkfill composite (Tetric^R N-Ceram Bulkfill, Ivoclar Vivadent) were evaluated for flexural strength, fracture toughness and diametral tensile strength.

Flexural strength is the highest stress that a material can withstand under a bending force before failing. Because composite resins are sensitive to tension and compression stresses, particularly when used to restore cavities under stress, flexural strength is crucial for composite materials (Eronat et al., 2009).

Fracture toughness on the other hand, is a mechanical property that represents brittle materials' resistance to catastrophic crack spread under an applied force, and as a result, it describes the material's damage tolerance (Kim and Okuno , 2002) .

In this study, the short fiber reinforced composites SFRCs everXPost. and everXFlow displayed significantly higher flexural strength (100.2 MPa, 99.1 MPa) and fracture toughness (1.23 MPa $m^{1/2}$, 1.16 MPa $m^{1/2}$) values than bulk fill conventional composite (Tetric^R N-Ceram)(58.2MPa ,0.6 MPa $m^{1/2}$). These exceptional qualities of the short fiber reinforced composites (SFRCs) are a result of the fiber fillers' reinforcement effect, which is dependent on the stress transmission from the polymer matrix to the fibers as well as the behavior of each fiber as a crack stopper. Additionally, it appeared that the random direction of fibers inside the resin matrix and the development of a fiber network had improved the material's capacity to withstand fracture propagation and to lessen the stress intensity at the crack tip, where cracks tend to spread unpredictably from. As a result, it is possible to anticipate a rise in flexural characteristics and fracture toughness (Lassila et al., 2019). These findings were consistent with other research that found that everX Posterior has superior fracture toughness values when compared to various commercial hybrid and bulk fill composites resin (Bijelic-Donova et al., 2016). This was also in line with findings by Lassila et al. and Shouha et al., which demonstrated that experimental short fiber reinforced flowable resin composites outperformed traditional particle filler resin composites in terms of fracture toughness and flexural qualities (Shouha et al.,2014; Lassila et al.,2018).

The millimeter gauge SFRCs (everX Posterior) exhibited higher flexural strength (100.2 MPa) and fracture toughness (1.23 MPa $m^{1/2}$) values which were no significantly different than the flexural strength (99.1 MPa) and fracture toughness (1.16 MPa $m^{1/2}$) of the flowable micrometer gauge SFRCs (everX Flow). A fiber must transfer stress from the polymer matrix to the fibers in order to effectively reinforce polymers (Vallittu, 2015). To achieve this, the fibers must have an aspect ratio between 30 and 94 and a length that is equal to or more than the critical fiber length (Lassila et al., 2016).The primary elements that might enhance or degrade the mechanical characteristics of fiber reinforced composites are aspect ratio, critical fiber length, fiber loading, and fiber orientation (Fennis et al.,2005). The ratio of fiber length to diameter is known as the aspect ratio (l/d). Critical fiber length (lc) is the shortest length of high aspect ratio fiber fillers necessary to successfully strengthen the resin composite. There must be sufficient adhesion between the fiber and matrix, in order for the load to be transmitted to the stronger fiber, which is how the fiber really acts as reinforcement. The micrometer scale SFRC (everX Flow) had an aspect ratio of more than 30 because the diameter of microglass fibers used was 6 µm and the length in spectrum of 200–300 µm (Lassila et al., 2018, 2019).It has been also concluded that for enhanced FRCs, the critical fiber length could be as much as 50 times the diameter of the fiber (Lassila et al., 2018). The diameter of glass fibers used in this research is 6 µm and the critical fiber length should be, therefore, around 300µm. The millimeter scale SFRC everX Posterior had fiber (Ø17 µm) length distribution between 0.3, 1.5 -2mm, which is within the range of the required aspect ratio and the estimated critical fiber length Garoushi et al., 2013; Bijelic-Donova rt al.,2016).Therefore, it is not unexpected that adding short fiber fillers to a resin matrix improved the material's flexural strength and fracture toughness properties.

However, several earlier study found greater results for fracture toughness and flexural strength of the flowable micrometer scale SFRCs (everX Flow) in comparison with everX Posterior (Lassila et al.,2020) this may due to diffenece in the fiber length of the millimeter scale SFRC used in present and previuos study .As earlier, a short fiber length between 1.3 and 2.0 mm was described for the everX Posterior (Garoushi et al.,2013) , while two different ranges of short fiber length values were reported for the same material, that is 0.3– 1.5 mm (Lassila et al.,2016) and 1.0–2.0 mm(Abouelleil et al.,2015).

Tensile strength is the ability of a material to bear a maximum load in the form of stretching or pulling without breaking (Anusavice and Shen, 2012). The tensile strength of elastic and brittle materials is often measured using this test (Huang et al., 2012). For a restoration material to be employed in a clinical setting and withstand the force of chewing in the oral cavity, it must have a high diametral tensile strength (Della Bona et al., 2008)

In this study the results of this test (DTS) presented that the micrometer scale SFRCs (everX Flow) was statistically superior (54.3 MPa) DTS compared to the millimeter scale SERC everXPost.(44 MPa) and conventional bulkfill composite (37.3MPa) .These results possibly occurred due to high tensile strength of glass fibers joined with the highest proportion of fibers (25wt.%) in the composite matrix compared to only 9wt.% in everX Post.Composite and no fiber reinforcement in Tetric N-ceram composite. The results obtained from this study were in accordance with the study done by Sihivahanan & Nandini who had shown improved DTS of the everX Flow compared to the conventional bulkfill composite (Sihivahanan & Nandini,2021) .

The mean of the DTS value of everXPost. was lower (44 MPa) than everXFlow dental composites but not satistically significant than conventional bulk fill composite (37.3 MPa). The low fiber volume contents (9wt %) of the everX Post.composite which is important for the optimal reinforcement of the polymers may be the reason for the obtained results. It is also a known fact that only fibers oriented along the loading path during tensile testing of FRCs contribute to the strength of composites, thus it is not surprised that there was no discernible difference between the FRCs and conventional composites.

CONCLU SION

Depending on the results of present study and in the terms of mechanical properties, we can conclude that the fiber reinforced composites resin used (everXPost . and everXFlow) have better flexural strength and fracture toughness properties than conventional bulkfill composites

(Tetric^R N-Ceram) composite resin,with regard to dimetral tensile strength, everXFlow composites have superior dimetral tensile strength than everXPost and Tetric^R N-Ceram composites resin.

REFERENCES

Abbasi, M., Moradi, Z., Mirzaei, M., Kharazifard, MJ., & Rezaei, S. (2018) .Polymerization shrinkage of five bulk-fill composite resins in comparison with a conventional composite resin. JDent (Tehran),15,365-374.

Abouelleil,H., Pradelle, N., Villat, C., Attik,N., Colon, P., & Grosgogeat,B. (2015). Comparison of mechanical properties of a new fiber reinforced composite and bulk filling composites. Restor. Dent. Endod. 40, 262–270.

Aldhuwayhi, S. D., Sajjad, A., Bakar, W. Z. W., Mohamad, D., Kannan, T. P., & Moheet, I. A. (2021). Evaluation of Fracture Toughness, Color Stability, and Sorption Solubility of a Fabricated Novel Glass Ionomer Nano Zirconia-Silica-Hydroxyapatite Hybrid Composite Material. International Journal of Polymer Science, *2021*.

Alshabib, A., Silikas, N., & Watts, DC. (2019). Hardness and fracture toughness of resin-composite materials with and without fibers. Dent Mater ,35,1194-1203.

Alvanforoush, N., Palamara, J., Wong, RH., et al.(2016). Comparison between published clinical success of direct resin composite restorations in vital posterior teeth in 1995–2005 and 2006-2016 periods. Aust Dent J ,62,132–145.

Anusavice, K. J., and Shen, H. R. (2012). Phillips' Science of Dental Materials. 12th ed. (St. Louis: Elsevier), 58 -277.

Anusavice, KJ. (2003). Phillips: science of dental materials. 11th ed. St. Louis: W B Saunders.

Bijelic-Donova, J., Garoushi, S., Lassila, LV., Keulemans, F., & Vallittu, PK. (2016). Mechanical and structural characterization of discontinuous fiber-reinforced dental resin composite. J Dent ,52,70-78.

Czasch, P., & Ilie, N. (2013). In vitro comparison of mechanical properties and degree of cure of bulk fill composites. Clin Oral Investig,17, 227-235.

Della Bona,A., Benetti,P., BorbaM., & D. Cecchetti,D.(2008). *Braz. Oral Res.* 22, 84–89.

Eronat, N., Candan, U., &Türkün, M. (2009). Effects of glass fiber layering on the flexural strength of microfill and hybrid composites. J Esthet Restor Dent, 21(3),171-8.

Fennis, WM., Tezvergil, A., Kuijs, RH., Lassila, LV., Kreulen, CM., & Creugers, NH., et al.(2005). In vitro fracture resistance of fiber reinforced cusp-replacing composite restorations. Dent Mater ,21, 565-572.

Garoushi, S., Lassila, LV., & Vallittu, PK. (2012). The effect of span length of flexural testing on properties of short fiber reinforced composite. J Mater Sci Mater Med ,23,325-328.

Garoushi, S., Säilynoja, E., Vallittu, P., & Lassila, L. (2013) .Physical properties and depth of cure of a new short fiber reinforced composite. Dent Mater, 29,835–841

Garoushi, S., Säilynoja, E., Vallittu, P., & Lassila, L. (2013). Physical properties and depth of cure of a new short fiber reinforced composite. Dent Mater,29, 835-841.

Heintze, SD., Ilie, N., Hickel, R., Reis, A., Loguercio, A., &Rousson, V. (2017). Laboratory mechanical parameters of composite resins and their relation to fractures and wear in clinical trials —A systematic review. Dent Mater,33, 101-114.

Huang, SH., Lin, LS., Fok, AS., & Lin, CP.(2012). Diametral compression test with composite disk for dentin bond strength measurement – finite element analysis. Dent Mater,28,1098–104.

Ilie, N., Hilton, T. J., Heintze, S. D., Hickel, R., Watts, D. C., Silikas, N., ... & Ferracane, J. L. (2017). Academy of dental materials guidance—Resin composites: Part I—Mechanical properties. Dental materials, *33*(8), 880-894.

International Organization for Standardisation. ISO 4104. (1984). Dental zinc polycarboxylate cements. ISO, Geneva.

IS*O 4049:2019* Dentistry—Polymer-Based Restorative Materials; International Organization for Standardization: Geneva, Switzerland.

Kassem, AS., Atta, O., & El-Mowafy, O. (2012). Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. J Prosthodont ,21,28–32.

Kim, KH., & Okuno, O.(2002). Micro fracture behavior of composite resins containing irregular-shaped fillers. J Oral Rehabil,29,1153-1159.

Kramer, MR., Edelhoff, D., & Stawarczyk, B. (2016). Flexural strength of preheated resin composites and bonding properties to glass-ceramic and dentin. Materials (Basel) ,9,83.

Lassila, L., Garoushi, S., Vallittu, PK., & Säilynoja, E. (2016). Mechanical properties of fiber reinforced restorative composite with two distinguished fiber length distribution. J Mech Behav Biomed Mater, 60,331-338.

Lassila, L., Keulemans, F., Säilynoja, E., Vallittu, PK., & Garoushi, S. (2018) .Mechanical properties and fracture behavior of flowable fiber reinforced composite restorations. Dent Mater,34,598–606.

Lassila, L., Keulemans, F., Vallittu, P. K., & Garoushi, S. (2020). Characterization of restorative short-fiber reinforced dental composites. Dental Materials Journal, 39(6), 992-99

Lassila, L., Säilynoja, E., Prinssi, R., Vallittu, P., & Garoushi, S. (2019).

Characterization of a new fiber-reinforced flowable composite. *Odontology*, 107(3), 342-352.

Pałka, K., Kleczewska, J., Sasimowski, E., Belcarz, A., & Przekora, A. (2020). Improved fracture toughness and conversion degree of resin-based dental composites after modification with liquid rubber. Materials, 13(12), 2704.

Rohr, N., & Fischer, J. (2017). Effect of aging and curing mode on the compressive and indirect tensile strength of resin composite cements. *Head Face Medicine*, 13(1), 22.

Shouha, P., Swain, M., & Ellakwa A. (2014). The effect of fiber aspect ratio and volume loading on the flexural properties of flowable dental composite. Dent Mater ,30,1234–44.

Sihivahanan, D., & Nandini, V. V. (2021). Comparative evaluation of mechanical properties of titanium dioxide nanoparticle incorporated in composite resin as a core restorative material. The Journal of Contemporary Dental Practice, *22*(6), 686-690.

Tanaka, C. B., Lopes, D. P., Kikuchi, L. N., Moreira, M. S., Catalani, L. H., Braga, R. R., ... & Gonçalves, F. (2020). Development of novel dental restorative composites with dibasic calcium phosphate loaded chitosan fillers. Dental Materials, *36*(4), 551-559.

Tsujimoto, A., Barkmeier, WW., Takamizawa, T., Latta, MA., & Miyazaki, M. (2016) .Mechanical properties, volumetric shrinkage and depth of cure of short fiber-reinforced resin composite. Dent Mater J, 35, 418-424

Tsujimoto, A., Barkmeier, WW., Takamizawa, T., Latta, MA., & Miyazaki, M. (2016) .Bonding performance and interfacial characteristics of short fiber-reinforced resin composite in comparison with other composite restoratives. Eur J Oral Sci, 124, 301-308

Vallittu, PK. (2015). High-aspect ratio fillers: fiber-reinforced composites and their anisotropic properties. Dent Mater, 31, 1-7.

Zorzin, J., Maier, E., Harre, S., Fey T, Belli R, & Lohbauer U et al. (2015). Bulk-fill resin composites: polymerization properties and extended light curing. Dent Mater ,31,293-301.