Static Stress Analysis for Three Different Types of Composite Materials Experimentally and Numerically

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**Original Article*

Abstract— It is important to analyze and compare the stresses induced in different composite material types during load application to know which type of composite will behave as preferred under the loading in the same circumstances. This study was aimed at measuring and comparing the stresses induced in Filtek ™ Z350 XT (3M ESPE) composite, Tetric EvoCeram ® (ivoclar vivadent) composite and BRILLIANT ™ NG (Coltène/Whaledent) composite experimentally and numerically. Data were analyzed statistically by One-way ANOVA test and Least Significant Difference (LSD) test. One-way ANOVA test and LSD test results showed a highly significant difference ($P<0.001$) presented between groups A and B, groups A and C and between groups B and group C. The Stress induced in BRILLIANT ™ NG composite after load application was the lowest stress value followed by Tetric EvoCeram ® composite and followed by Filtek ™ Z350 XT composite which was the highest stress value experimentally and numerically.

Index Terms— Stress Analysis, Strain Gauge, Data Acquisition, ANSYS.

1 Introduction

THE objective of stress analysis is generally to decide if the element or assortment of elements, commonly referred to as the structure, behaves as preferred under the agreed loading. For instance, this can be managed when the resolute stress from the functional force(s) is less than the tensile yield strength or under the weariness power of the material [1].

It is important to analyze and compare the stresses induced in different composite material types during load application to know which type of composite will behave as preferred under the loading in the same circumstances.

Also analysis of stress generated in composite is important in order to detect the areas of high stress, which could be more susceptible to strain and elastic deformation and overcome and control the stress areas [2].

3M™ ESPE™ Filtek™ Z350 XT Universal Restorative System is a visible light-activated nano-composite designed for use in anterior and posterior restorations. All shades are radiopaque. The restoration is available in a wide variety of Dentin, Body, Enamel and Translucent shades. It is packaged in syringes and single-dose capsules [3] (see Table 1). Tetric EvoCeram is a light-curing, radiopaque, nano-hybrid composite indicated for anterior and posterior restorations. The filler technology employed in Tetric EvoCeram is based on an optimum blend of different fillers and filler sizes [4] (see Table 2). BRILLIANT NG is a universal nano-hybrid composite aimed at simplifying the technique of application, achieving excellent aesthetic results indicated for both the anterior and posterior regions. Its pre-polymerised particle filling, in addition to high nanometric particle content, produces optimum consistency for manipulation and modelling along with a noticeable decrease in shrinkage and easily achievable high gloss surfaces. Its duo shade system allows it to obtain two shades from the same syringe [5] (see Table 3).

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TABLE 1

FILTEK™ Z350 XT COMPOSITE RESTORATIVE MATERIAL USED IN THIS STUDY [3].

Manufacture	3M /ESPE (USA)
Composite Type	Nanocomposite
Method of activation	Visible Light cure
Resin Components	The resin contains bis-GMA, UDMA, TEGDMA, and bis-EMA resins, PEGDMA.
Filler Loading (Wt/Vol)	78.5% by weight (63.3% by volume)
Filler Type	silica and zirconia
Range of cluster particle size	0.6 – 10 µm.
Mean particle size of cluster filler	20 nm silica and 4 to 11 nm zirconia particles
Curing Time	20 sec.
Shade	A2 dentin
Flexural modulus	11348 MPa
Poisson's ratio (γ)	0.30

TABLE 2

TETRIC EVOCERAM COMPOSITE ® RESTORATIVE MATERIAL USED IN THIS STUDY [4].

Manufacture	Ivoclar vivadent (Liechtenstein)
Composite Type	Nanohybrid
Method of activation	Visible Light cure
Resin Components	Dimethacrylates (17-18% weight).
Filler Loading (Wt/Vol)	75-76% weight - 53-55% volume.
Filler Type	Barium glass, ytterbium trifluoride, mixed oxide and prepolymer
Range of filler particle size	Between 40 nm - 3,000nm
Mean particle size	550 nm
Curing Time	20 sec.
Shade	A2 universal
Flexural modulus	10000 MPa
Poisson's ratio (γ)	0.33

TABLE 3

BRILLIANT ™ NG COMPOSITE RESTORATIVE MATERIAL USED IN THIS STUDY [5].

Manufacture	Coltène/Whaledent (Switzerland)
Composite Type	Nanohybrid
Method of activation	Visible Light cure
Resin Components	Methacrylates
Filler Loading (Wt/Vol)	80 weight % - 65 volume%
Filler Type	Dental glass, amorphous silica
Range of filler particle size	0.01-2.5µm
Mean particle size in (µm)	0.6 µm
Curing Time	20 sec.
Shade	A2 dentin
Flexural Modulus	9,000 MPa
Poisson's ratio (γ)	0.39

These products have been studied for causes of composite failure for example; polymerization shrinkage, microleakage, wear, surface roughness and polish retention but still there is a need to analyze the stresses induced in these types of similar composite material properties and indications in experimental and numerical methods because these stresses are important cause of composite failure [6,7].

2 MATERIALS AND METHOD

Experimental analysis included cavity preparation in the Brass block with a concave (U-shape) cavity which represent a class II cavity preparation. This cavity was used as a mold for sample preparation. The internal line and point angles of the cavity (mold) were rounded and the dimensions of the cavity (mold) were 10mm × 10mm × 10mm (Total height of the box × Width of the box occlusally × Length of the box occlusally). The internal diameter of "U" was 5 mm at the base of the box (see Fig. 1).

Fig. 1. Brass mold.

The mold was used to prepare forty five samples, fifteen samples for each type of composite material. So, three groups were prepared: Group A filled with Filtek ™ Z350 XT composite material, Group B filled with Tetric EvoCeram ® composite material and Group C filled with BRILLIANT ™ NG composite material.

Two millimeters increment of composite material was applied into the mold and condensed using composite condenser to remove voids. Every 2mm increment of composite material was cured with LED curing light for 40 seconds (20 second for each of the occlusal and proximal surfaces of the composite) to ensure adequate curing. Electrical strain gauge (Tokyo Sokki, Japan) was embedded in composite material horizontally at the same level in each sample [8] (see Fig. 2).

The final increment of composite material was covered with a composite celluloid strip and microscope glass slides during curing on the top of the strip in order to produce a flat smooth surface and to prevent the formation of oxygen-inhibited layer on the surface of the samples [9] (see Fig. 3). The composite restoration finished by Composite finishing burs using high speed hand piece with water cooling and Polyester abrasive finishing strips.

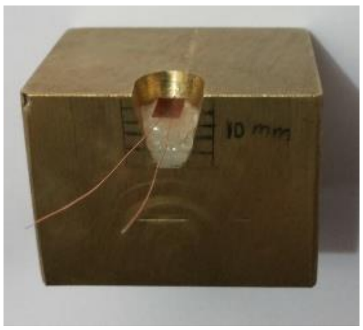

Fig. 2. Position of strain gauge.

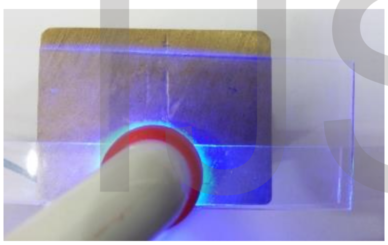

Fig. 3. Final increments of composite.

Static Load of 50 N was applied perpendicular to the center of the occlusal surface of composite restoration in each sample testing [10] [11].

The strain gauge was connected to a Wheatstone bridge with a signal amplifier which measures the strain during load application and gives the amplified signal from (0 to 4.8 volt) to LabJack data acquisition where a stream software gives the final values of strain with the aid of scaled equation of voltage. Then, the von Mises stress (effective stress) was calculated by using equations [12] [13] (see Fig. 4).

After testing each sample the composite material was removed completely by diamond fissure No. 850-014 and round burs No. 801-012 using high speed hand piece with water cooling and carbide round burs No.2 using low speed hand piece. The same procedure of sample preparation was repeated and the same brass mold was used in the preparation of each sample.

Fig. 4. Experimental circuit with testing device.

Numerical analysis was done by using ANSYS 16.1 - (2015) (finite element tool) software that was used to create the 3-dimensional models that represented the same materials and dimensions used experimentally (see Fig. 5).The physical characteristics of the composite models were inserted in the software which included Elastic modulus and Poisson's ratio (γ). Analysis was selected in finite element method according to boundary conditions. A mesh size and an element size were estimated during the study [14] (see Fig. 6). The stresses were calculated at static load of 50 N with the ANSYS 16.1 – (2015) software.

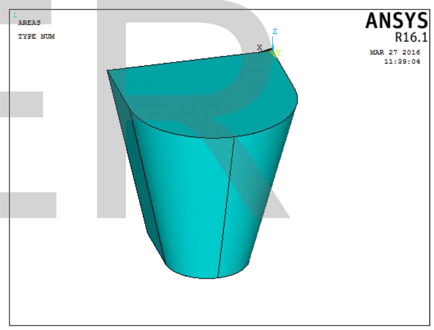

Fig. 5. Composite model.

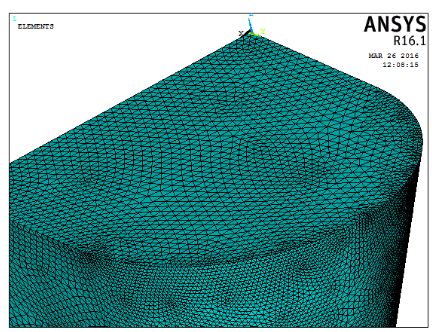

Fig. 6. Composite model meshing.

3 Results

Experimental Stress Analysis Results showed that the Stress induced in group C (BRILLIANT ™ NG composite) has the lowest mean value (253.7793) followed by group B (Tetric EvoCeram ®

composite) which has mean value of (269.8161) and followed by group A (Filtek ™ Z350 XT composite) which has the highest mean value of (289.6407). The statistical analysis of data by One-Way ANOVA showed a highly significant difference (P < 0.001) among all experimental groups. These results presented in (see Table 4).

TABLE 4

ONE-WAY ANOVA TEST OF EXPERIMENTAL STRESS ANALYSIS MEAN VALUES FOR ALL GROUPS.

ANOVA

Groups

	Sum of Squares	DF	Mean Square	F	P-value	Sig.
Between Groups	9681.134	2	4840.567	1860.576	.000	HS
Within Groups	109.269	42	2.602			
Total	9790.403	44				

The data revealed from One-Way ANOVA test were analyzed by LSD (Least Significant Difference) test. The results of LSD test showed that there was a highly significant difference (P<0.001) presented between (group A and group B), (group A and group C) and (group B and group C) (see Table 5).

TABLE 5

LSD TEST FOR ALL GROUPS.

Multiple Comparisons

Dependent Variable: Samples	(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	P-value	Sig.
LSD	Group A	Group B	19.82460*	.58897	.000	HS
		Group C	35.86133*	.58897	.000	HS
	Group B	Group C	16.03673*	.58897	.000	HS

*. The mean difference is significant at the 0.05 level.

Numerical Stress Analysis Results (ANSYS Results) showed that the Stress induced in BRILLIANT ™ NG composite has the lowest stress value (253 Pa) followed by Tetric EvoCeram ® composite which has a stress value of (269 Pa) and followed by Filtek ™ Z350 XT composite which has the highest stress value of (289 Pa) (see Fig. 7 to 9).

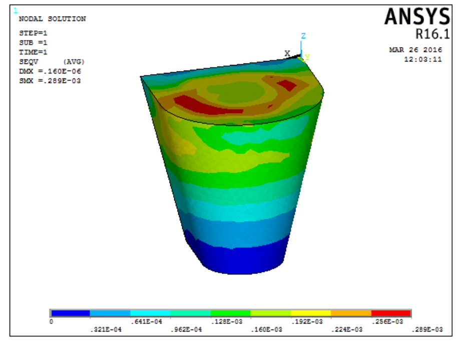

Fig. 7. Stress analysis results of Filtek ™ Z350 XT composite after load application using ANSYS software.

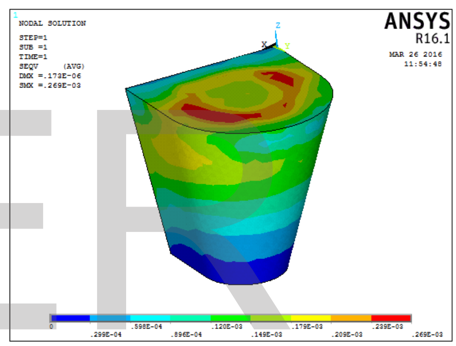

Fig. 8. Stress analysis results Tetric EvoCeram ® composite after load application using ANSYS software.

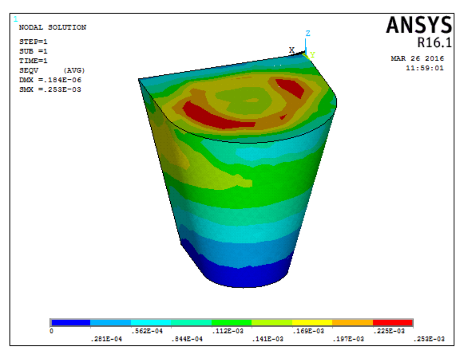

Fig. 9. Stress analysis results BRILLIANT ™ NG composite after load application using ANSYS software.

4 Discussion

The most significant changes in commercial composites in recent years were modifications of the filler system [15]. The size of filler particles incorporated into the resin matrix of commercial composites has continuously decreased, resulting in nanohybrid and nanofilled materials with improved material properties. Nanohybrid composites are hybrid resin composites containing finely milled glass fillers and discrete nanoparticles or nanofillers in Prepolymerized filler form [16].

The performance of nanohybrid composites is material-dependent which may be attributed to the fact that some composites with nanofillers added to conventionally filled hybrid type composites have been classified as nanohybrid composite resins [17].

Stress induced in composite is an important factor to be considered when selecting composite resin materials for clinical use because tooth and restorations are always subjected to both flexural and compressive forces during the chewing procedure [18].

The compressive and flexural strength induced in composite reflect resistance to stresses that act in the composite material and the evaluation of these properties is important for restorations used in posterior teeth. The stress analysis is particularly important because of chewing forces, and its clarification is complex as tension and shear forces act concurrently inside the composite material [18].

Stress induced in composite restoration and stress distribution in composite model are also effected by cavity preparation design [2].

In this study, cavity that was made in a mold of Brass (copper and zinc metal alloy) represents class II cavity design was used for experimental stress analysis of composite materials. Brass can give smooth finished surfaces of prepared cavity in addition to its dimensional stability. The main reason for using artificial model rather than natural teeth in this study was to minimize the effects of the significant variations in cavity preparation and geometries of natural human teeth. In addition, the use of artificial model of certain size facilitates the coordination with the size of strain gauge [2].

Strain gauge was used in this study in order to get more accurate results of stress analysis because it takes advantage of the physical property of electrical conductance and its dependence on the conductor's geometry. When an electrical conductor is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end. The position of strain gauges was marked on the proximal side of the brass block in order to get the same level in each sample [19]. Filtek ™ Z350 XT, Tetric EvoCeram ® and BRILLIANT ™ composite materials were used in this study because these products have been studied for causes of composite failure for examples; polymerization shrinkage, microleakage, wear, surface roughness and polish retention but still there is a need to analyze the stresses induced in these types of similar composite materials properties and indications in experimental and numerical methods because these stresses are important cause of composite failure. Each two millimeters increment of composite material was applied into the mold and condensed using composite condenser to remove voids and cured with LED curing light for 40 seconds (20 second for each of the occlusal and proximal surfaces of the composite) to ensure adequate curing [2]. In order to produce a flat smooth surface and to prevent the formation of oxygen-inhibited layer on the surface of the sample, the final increment of composite material was covered with a composite celluloid strip and microscope glass slides during curing on the top of the strip [9].

A testing device (test rig) was used in this study because it has been designed to simulate the environments of static loading with constant load value [10] [11]. The position of load application was identified on the occlusal surface of composite restoration using a pencil and a ruler by lines markings were inscribed on external wall on top side of the brass block to insure the same position of load application in each sample [2].

In numerical stress analysis, the finite element (FE) solver like ANSYS 16.1 - (2015) software was used to deal with the composite restorations models and investigate the stresses that were induced in composite materials and compare between different types of composite materials according to the stresses induced, also to show the position of stress distribution due to load that was subjected on composite restorations and illustrate how and where the load can be applied, in addition to investigate the best element type that can be used to ensure the real ability and truth of the result to be depended on it and that can be made by using ANSYS software [14].

It is clearly shown in this study that stress induced in Filtek ™ Z350 XT composite with silica and zirconia filler (78.5% by weight - 63.3% by volume) and bis-GMA, UDMA, TEGDMA, bis-EMA and PEGDMA resins was more than stress induced in Tetric EvoCeram ® composite with barium glass, ytterbium trifluoride, mixed oxide and prepolymer filler (75–76% weight - 53–55% volume) and resin contains dimethacrylates, also it was more than stress induced in BRILLIANT ™ NG composite with dental glass, amorphous silica filler (80 weight % - 65 volume %) and methacrylates resin components in experimental and numerical stress analysis. The results of LSD test showed that there was a highly significant difference ($P<0.001$) presented between group A (Filtek ™ Z350 XT composite) and group B (Tetric EvoCeram ® composite), group A (Filtek ™ Z350 XT composite) and group C (BRILLIANT ™ NG composite) and between group B (Tetric EvoCeram ® composite) and group C (BRILLIANT ™ NG composite). This is in agreement with Sonwane and Hambire in 2015 and Awan in 2010 who stated that the type of filler and resin contents and the filler loading effect on stress induced in composite material after load application [20] [21] .

However, the results of this study may be attributed to the difference in filler size, as Filtek ™ Z350 XT nanocomposite with 20 nm silica and 4 to 11 nm zirconia mean particle size of filler, while Tetric EvoCeram ® nanhybrid composite and BRILLIANT ™ NG nanhybrid composite have larger mean particle size of filler. This coincides with Sonwane and Hambire in 2015 who stated that the size of filler particles has an effect on stress induced in composite and the composite with smaller mean particle size produce more stress and vice versa [20].

The difference in stress induced in different types of composite materials used in this study may be due to the differences in their flexural modulus and Poisson's ratio (γ), as Filtek ™ Z350 XT composite which showed the highest mean value of (289.6407) in experimental stress analysis and highest stress value of (289 Pa) in numerical stress analysis has the highest flexural modulus (11348 MPa.) and the lowest Poisson's ratio (γ) (0.30) while, BRILLIANT ™ NG composite which showed the lowest mean value (253.7793) in experimental stress analysis and lowest stress value of (253 Pa) in numerical stress analysis has the lowest Flexural modulus (9,000 MPa.) and the highest Poisson's ratio (0.39). These findings are in agreement with a study by Edwebi in 2015 which revealed that the stress increased in composite with higher flexural modulus and vice versa [22]. Also the results of this study are in agreement with a study by Rosatto et al. in 2015 which revealed that stress increased in composite with lower Poisson's ratio and vice versa [23] and in agreement with Bicalho et al. in 2014 who stated that the stress induced in different types of composite materials is effected by the differences in some properties of these types of composites [6]. Finally, this study revealed that the numerical stress analysis results (ANSYS results) confirm and agree with experimental stress analysis that make the results of this study more reliable.

5 Conclusions

According to the proposed methodology and based on the result of this study the following conclusion are drawn:
1. Stress induced in Tetric EvoCeram ® composite after load application was more than that of BRILLIANT ™ NG composite and less than that of Filtek ™ Z350 XT composite in experimental and numerical stress analysis. 2. Type of filler and resin contents and the filler loading effect on stress induced in composite material after load application. 3. Size of filler particles has an effect on the stress induced in composite and the composite with smaller mean particle size produce more stress and vice versa. 4. Stress increased in composite with higher flexural modulus and vice versa. 5. Stress increased in composite with lower Poisson's ratio and vice versa.

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