COMPRESSIVE STRENGTH OF THREE TYPES OF PIT AND FISSURE SEALANTS (AN IN-VITRO COMPARATIVE STUDY)
Ruheyza Shwan Shahswar¹,*, Sazan Sherdil Saleem²

1- Department of Pedodontics, Orthodontics, and Preventive Dentistry (POP), College of Dentistry, Hawler Medical University
2- Department of Pedodontics, Orthodontics, and Preventive Dentistry (POP), College of Dentistry, Hawler Medical University

ARTICLE INFO
Article History:
Received: 29/08/2018
Accepted: 27/11/2018
Published: 26/12/2018

Keywords:
PFS, compressive strength, stress, FEM, SPSS

*Corresponding Author:
Ruheyza S. Shahswar
ruheyza@gmail.com

ABSTRACT
This research presents an experimental and theoretical investigation of compressive strength and stress distribution of three different types of pit and fissure sealants (PFS). The PFS had been divided into three major categories, i.e. resin-modified glass-ionomer (RMGI), resin-based PFS, and compomer Sealant, for each given type, commercial brands photac fil quick aplicap (3M ESPE), ultraseal XT hydro (Ultradent), and compoglass F (Ivoclar Vivadent) have been selected, respectively. Thirty samples, which were divided into three groups (ten specimens for each PFS type) were loaded in compression until failure. The SPSS (Statistical Package for the Social Science) version 23 program was used to perform the statistical analysis and assess the difference between the compressive strength of each study group.

The results of the experiment showed that the compressive strength of the resin-based PFS overcomes the RMGI and compomer sealant by 116% and 30% respectively. By using ABAQUS program performed the 3D finite element model (consisting 13050 elements and 14508 nodes) to evaluate the effect of chemical composition on the compressive strength of the PFS and compared stresses with the experimental results. The results of the analysis of these two methods showed that the vertical stress values differ even by 100% at stress concentration zones. This research showed that the filler fraction and particle size and uniformity of the filler distribution are the main determining factor affecting the compressive strength of PFS.

1. INTRODUCTION
Selection of the type of pit and fissure sealants for a specific clinical case becomes a priority task against preventive dentistry because it may effect on the long-term treatment result and the patient satisfaction with the result of the work. The mechanical properties of PFS play the decisive role in achieving this goal, especially the strength of the material under compression. The primary goal of using these materials is to coat and seal the pits and fissures which were used for preventing the teeth from the harmful bacteria and subsequent caries. In recent decades, many attempts have been made to prevent the
development of caries, in particular, occlusal caries, since it was once generally recognized that the pits and fissure in the teeth would be infected with bacteria within ten years of the eruption in the mouth. (Babu et al., 2014; Cohen and Sheiham, 1988; Subramaniam et al., 2008).

Since the first PFS was produced in 1922 (History and Evolution of Pit and Fissure Sealants), the composition of these materials have changed to improve them, and several modified types have been introduced with the purpose of enhancing their mechanical properties and expanding their clinical applications (Beauchamp et al., 2008). The mechanical properties of dental materials, in general, and PFS, in particular, have been investigated since their development, and the problems have remained up to now (Cattani-Lorente et al., 1999; Xie et al., 2000; Xu and Burgess, 2003). Durability and retention of PFS, apparently, are associated with their mechanical strength (Aratani et al., 2005; Lerech et al., 2017).

It is important to ensure that the mechanical properties of the material are strong enough to withstand the mastication load. It is believed that the chemical composition of PFS materials played a significant role in their mechanical properties and their subsequent success of the application in dentistry (Cildir and Sandalli, 2007a; Feigal, 2002; Geiger et al., 2000; Nunn et al., 2000). Moreover, when comparing materials that are brittle and generally weak in tension, compressive strength is a useful benchmark (Cattani-Lorente et al., 1999; Xu and Burgess, 2003).

Given the fact that over the last decades a lot of scientific works have been devoted to the mechanical properties of these materials (Bayne et al., 1998; Beun et al., 2012, 2008; Crisp et al., 1976), but yet, the correlation between chemical composition and compressive strength of various PFS has not been widely studied. Based on this, in this study, the uniaxial compressive strength of three categories of these materials was compared.

This research focused on the compressive strength, as the most important mechanical property of materials for dentistry, depending on their type and chemical composition. Simultaneously with the experimental test, the modelling of the tested samples was simulated in the environment of the ABAQUS computer complex, then investigated the stress field at specified sections of the samples on the base of the finite element method (FEM). Which in turn, allows having a complete image of the distribution of the stresses in the body of the materials and their direction.

Accordingly, the present study aimed to evaluate and compare the compressive strength of three different types of the PFS (photac fill, ulraseal XT hydro, and compoglass F) after 24 hours of storage in distilled water at 37°C according to ISO and ANSI/ADA specifications, then performed the statically axially loading test and analysis done by equilibrium equations, as well as, used FEM, so as to find the material of choice for stress-bearing areas.

2. MATERIAL AND METHODS

2.1. Materials

The selected materials used in this study have been divided into three major categories, i.e. resin-modified glass-ionomer (RMGI), resin-based PFS, and compomer sealant, for each given type, commercial brands photac fill (3M ESPE), ulraseal XT hydro (Ultradent), and compoglass F (Ivoclar Vivadent) have been selected, respectively (Table 1).
Table 1 Characteristics of the used pit and fissure sealants.

| PFS Type | Brand Name     | Manufacturer       | Color | Filler Wt. % | Mean Filler Size µm | Composition |
|----------|----------------|--------------------|-------|--------------|---------------------|-------------|
| RMGI     | Photac Fil Quick Aplicap | 3M ESPE, Deutschland | A3    | 76-77        | 5-7                 | Powder: (Na, Ca, Al, La Fluorosilicate Glass), activator (amin). |
|          |                |                    |       |              |                     | Liquid: monomer, oligomer, copolymer acid (acrylic and maleic acid), water. |
| Resin-Based | Ultrasel XT hydro | Ultradent, Douth Jordan, UT, USA | Opaque White | 53           | <0.001- >1 | Filler: Al₂O₃<0.4%wt, TiO₂<0.3%wt, Na₂PO₃F<0.2%wt. |
|          |                |                    |       |              |                     | Matrix: Triethylene Glycol Dimethallylate (TEGDMA)<20%wt |
|          |                |                    |       |              |                     | Diurethane Dimethacrylate (DUDMA)<8%wt, Methacrylic acid (MAA)<1%wt. |
| Compomer | Compoglass F   | Ivoclar Vivadent Schaan, Liechtenstein | A2    | 80.5         | 0.2-3               | Filler: Ytterbium Trifluoride, Ba-Al-Fluorosilicate Glass, and Spheroid mixed oxide 80%wt, initiators, stabilizers and pigments <0.20%wt. |
|          |                |                    |       |              |                     | Matrix: Dimethacrylate 19.30%wt. |

2.2. Preparation of Specimens

In this research, a cylindrical mold with double open ends (height=6mm and diameter=4mm) according to “ISO 6874 for the testing of the polymer-based pit and fissure sealants” using stainless-steel two-parts mold were used to make samples with standardized size h/d≤10 to avoid buckling, unwanted deformations, and failure (Figure 1-a). Ten samples from each material were used for the compressive strength using the universal testing machine Gunt-Hamburg WP 300, with measuring ranges force: 0…20kN, graduation: 0.5kN, and travel: 0…20mm, graduation: 0.01mm.

The form was filled, in three consecutive layers, by material, approximately with 2 mm thickness.

Polymerization of each layer was carried out with a visible light curing unit with 1mm distance for 20 seconds at 1200mW/cm² by
Shahswar R and Saleem S. /ZJPAS: 2018, 30 (6): 107-117

Samples were stored in their mold for one hour before having their thickness and diameter measured. Each sample was transferred to plastic test tubes containing 3ml of distilled water. All samples and containers were incubated at 37°C for 24 hours, Figure 1-c, d (Cildir and Sandalli, 2007b).

The compressive strength test of different fissure sealants was measured using the universal mechanical testing machine Gunt-Hamburg WP 300. The specimens were placed between the bottom support block and top loading bar with 4 mm in diameter, and a compressive load was applied axially at cross-head speed of 1mm/min to the specimen at the age of 24 hours (ISO 6874:2015 - Dentistry - Polymer-based pit and fissure sealants) (Figure 1-e, f).

2.3. Methods

Done comparative analysis of three different sealant materials by using the analytical calculation of the performed tests and FEM. Next statistical analysis was performed on the test results.

a) Experimental method

Maximum failure load was recorded for each specimen and divided by the net cross-sectional area to determine the compressive stress in MPa by using the following equation:

\[ \sigma = \frac{P}{A} = \frac{P}{\pi d^2/4} = \frac{4P}{\pi d^2} \]

where P is the failure load, in Newton; d is the average measured diameter of the specimen, in mm, and A is the net cross-sectional area (mm²) of samples (Aratani et al., 2005; Cildir and Sandalli, 2007a; Walsh et al., 2014).

b) Finite element modelling and simulation of the PFS by ABAQUS software

The mechanical properties of the materials obtained during the experimental testing became the input data for numerical analysis. Performed the numerical modelling of the cylinder shape (h=6mm, d=4mm) in the ABAQUS computer complex environment. Then illustrated the comparison of these two different methods and outlined the findings and conclusions.

To achieve the more accurate results, after meshing, the samples are subdivided into 13050 3D small elements of simple shapes connected by 14508 nods. The mechanical properties of the PFS, input data, such as modulus of elasticity, density, poison’s ratio, .. for the modelling were taken from the test results. Thus stress of all small elements was calculated, and there was a complete oblique of
the stress-strain state of the entire sample (Figure 2).

![Figure 2 Meshed FE model and loading and supporting illustration of the tested sample](image)

c) **Statistical Calculation**

The SPSS (Statistical Package for the Social Science) version 23 program was used to perform the statistical analysis and assess the difference between the compressive strength of each study group. One-way ANOVA was conducted to examine mean comparison, and then the posterior test was carried out through Duncan test.

### 3. RESULTS

The compressive strengths of all types of PFS materials are shown in Figure 3 and displayed in Table 2. The results of the statistical analysis demonstrated significant difference within a group (p<0.05), at the same time the significant difference between groups (Figure 3). In which resin-based PFS showed the highest compressive strength value (264 MPa).

![Figure 3 Mean Value and standard deviation of the Compressive Strength of three different types of PFS.](image)

| Material Group | Commercial Brand | N  | Mean Compressive Strength±SD MPa | 95% Confidence Interval for Mean | Min  | Max  | p     |
|----------------|------------------|----|----------------------------------|---------------------------------|------|------|-------|
| RMGI           | Photac Fil       | 10 | 122±18                           | 109.51                          | 135.29 | 149 | <0.05 |
| Resin-Based    | Ultraceal XT hydro | 10 | 264±19                           | 250.01                          | 277.59 | 290 | <0.05 |
| Compomer Sealant | Compoglass F     | 10 | 202±27                           | 182.42                          | 221.78 | 237 | <0.05 |

Table 2 Compressive strength of the three types of PFS.
The complete illustrative image of the stress distribution could not be achieved without the help of a powerful computer program like ABAQUS. For this purpose, all of three kinds of PFS were modelled and simulated under surface loading applied to the top face of the specimens, such as applied during testing (Figure 2). The derived results in the form of stress field, as well as the distribution of stress in the body of the materials and stress concentration zones (bottom of the tested samples), are presented in Figures 4 and 5.

Table 3 Post Hoc tests- Tukey HSD and Duncan tests for compression strength.

| Test      | PFS            | N   | Subset for alpha = 0.05 | Duncan groupinga |
|-----------|----------------|-----|------------------------|------------------|
|           |                |     | 1          | 2          | 3          |               |
| Tukey HSD | Photac Fil     | 10  | 122                   |                |             |
|           | Compoglass F   | 10  | 202                   |                |             |
|           | Ultraseal XT hydro | 10 | 264                   |                |             |
|           | Sig.           |     | 1.000                 | 1.000          | 1.000      |
| Duncan    | Photac Fil     | 10  | 122                   | A              |
|           | Compoglass F   | 10  | 202                   | B              |
|           | Ultraseal XT hydro | 10 | 264                   | C              |
|           | Sig.           |     | 1.000                 | 1.000          | 1.000      |

a there is no group with the same letter – there is a significant difference between groups
Figure 4 Vertical stress $\sigma_z$ (MPa) distribution in the body of three categories of PFS and stress concentration at the bottom of the tested samples. a) Photac Fil, b) Ultraseal XT hydro, c) Compoglass F

Figure 5 Comparison of the vertical stresses calculated by analytic and FE methods
4. DISCUSSION

It is well known that the mechanical characteristics of the PFS are strongly associated with the filler content, filler distribution, particle size, and type. As well as coupling between particles and matrix are also factors that influence mechanical properties such as strength and modulus of elasticity (Obici et al., 2005).

Two predominant types of PFS (materials are available: resin-based sealants and glass ionomer cement (Ripa, 1993; Singh et al., 2011).

Moezzyzadeh (2012) concludes: “Various filler particle sizes can result in increased number of fillers within the composite matrix which subsequently confers extra strength because there is a direct relationship between the increased compressive strength of composites and increased number of fillers”. At the same time, other points of view do not agree with Moezzyzadeh. The filler content may be considered as a factor; however, the filler type and its fraction may have the stronger effect on the mechanical properties than the percentage of the filler because Compoglass F which had a high filler content 80.5% wt. (Table 1) was not as strong as Ultrasound XT hydro which had a filler content 53% (Taher, 2001).

The experimental results of this study presented in Table 2 showed that the Ultra seal XT hydro had significantly highest compressive mean value (264MPa), while the photac fil had significantly lowest compressive mean value (122MPa) and this agrees with the study of Xiaoming Xu and John O. Burgess (2003) that observed significantly higher strength of resin-based dental sealant in comparison to GIC dental sealants.

Based on previous work, it can be noted that tri-ethylene-glycol-dimethacrylate (TEGDMA) and bisphenol A-glycidyl methacrylate (BISGMA) are the backbone molecules of composite resin. TEGDMA is a linear co-monomer which terminates with two functional methacrylate groups identical to those terminating Bis-GMA. After polymerization, acrylic bonds are created with Bis-GMA as well as with other molecules of TEGDMA, and also with the mineral filler particles, by means of a coupling agent grafted on these filler particles and also having a terminal functional methacrylate group. A tridimensional network is thus formed, characterized by a high mechanical and chemical resistance (Meyer, et al. 1998).

The result of the present study showed that the compressive strength of the resin-based material overcomes the RMGI and compomer sealant by 116% and 30% respectively.

The findings of this study agree with Meyer et al. (1998) and El-Kalla and Franklin Garcia-Godoy (1999) that the compomer had higher compressive strength than RMGI, because the polyacid-modified composite resins absorbed less water than the resin-modified glass-ionomer cement, so the water diffuses more slowly through the polyacid-modified composite resin specimens.

Also, the higher mechanical strength of compomers can be interpreted by the fact that compomers have their glass particles silanated to bond covalently to the polymer matrix. It is easy to note, that compressive strength increase by moving from glass ionomers and resin-modified glass ionomers to compomers and composite resins. On the other hand, this work proves that the filler content cannot be the only and decisive factor affected on the compressive strength of the PFS. In general, the difference between the test results of all types of PFS depends on the some other factors, such as, water content, calcium amount, variability of monomers, dehydration of the specimen during the testing, presence of hydrophilic, and sometimes the complex of these factors plays the decisive role in determining the strength of
the material under compression (Meyer et al., 1998; Munhoz et al., 2016; Uno et al., 1996).

The multivariate results indicated that the chemical composition of material had a significant influence on their micro-mechanical properties. Certainly, the presence of calcium as an integrating part in the photac fill is a clear indication that its strength is lower than other tested materials (Xu and Burgess, 2003).

In this work, the specimens are tested by the applied centric-axially compressive load. Thus, it was imitated the chewing pressure on the tooth. During the test, the material is compressed into the barrel shape. As a result of the loading, the tensile stress occurs in horizontal directions, and as a result, the samples collapsed.

The biomechanics has more ambitious goals to investigate the stress state of the PFS using numerical methods and simulation of the samples to have a clearer idea about the behavior of materials in the chewing process. It is of fundamental importance in the field of dental biomechanics to know how the applied load is transferred to the stress and what is the pattern of the distribution of all kinds of the stress within the tested specimens (Natali, 2003).

For the complete presentation and illustration of the stress distribution, a three-dimensional model of the samples was simulated by using the ABAQUUS software system, and as the result of the simulation, all types of stresses in the body of the material were investigated. Illustrated in Figure 4 specimen finite element model allowed to clearly identify the location of the stress concentration. As it can be seen from the Figure 4, the stress distribution is not completely uniform, even one cannot say that the samples were destroyed by the compressive stress, and as it is known, failure occurred because of the influence of the tensile stresses (Figure 4-b, c).

The FEM is one of the most powerful and effective approaches for analyzing and investigating the stress state of the materials under different types of loading. FEM is a theoretical technique which in its turn is the basis for computational analysis using software programs.

For a very long time, it has been proved that the numerical calculation is more accurate than the statically analysis. As is seen from Fig. 4-a, b, c, starting from the top surface, where the load is applied to the middle of the height of the sample, the value of the vertical stresses- is almost the same as in the static analysis. Then, in addition to approaching the bottom surface (supported plane), the value of the stress gradually grows and at lowest plane reaches its peak, which is more than 100% greater than stress on the upper plane (Figure 4). The first cracks and subsequent fractures of the samples were observed in these so-called, zones of stress concentration.

The results of this study revealed a strong correlation between individual specimens of the same type of PFS material, and commonly had a significant statistical correlation between different types of material groups.

5. CONCLUSION

In this work, theoretical and experimental approaches to investigating one of the most important mechanical properties of the PFS are used, and on the base of the in-vitro measurements and theoretical analysis it can be concluded that the PFS application have some physicochemical and mechanical characteristics that have to be taken into account by clinicians to provide adequate preventing sealing.
Ultraseal XT hydro and compoglass F showed higher compressive strength values, while lowest values were found for photac fil.

This research showed that the filler fraction and particle size and uniformity of the filler distribution are the main determining factor affecting on the compressive strength of PFS.

Finite element analysis by ABAQUS software makes it possible to reveal the place of stress concentration where the values of the vertical stresses significantly more than its values in the usual sections of the specimens.

REFERENCE

Aratani, M., Pereira, A.C., Correr-Sobrinho, L., Sinhoreti, M.A.C., Consani, S., 2005. Compressive strength of resin-modified glass ionomer restorative material: effect of P/L ratio and storage time. J. Appl. Oral Sci. 13, 356–359.

Babu, G., Mallikarjun, S., Wilson, B., Premkumar, C., 2014. Pit and fissure sealants in pediatric dentistry. SRM J. Res. Dent. Sci. 5, 253.

Bayne, S.C., Thompson, J.Y., Swift Jr, E.J., Stamatiades, P., Wilkerson, M., 1998. A characterization of first-generation flowable composites. J. Am. Dent. Assoc. 129, 567–577.

Beauchamp, J., Caufield, P.W., Crall, J.J., Donly, K., Feigal, R., Gooch, B., Ismail, A., Kohn, W., Siegal, M., Simonsen, R., 2008. Evidence-based clinical recommendations for the use of pit-and-fissure sealants: a report of the American Dental Association Council on Scientific Affairs. J. Am. Dent. Assoc. 139, 257–268.

Beun, S., Bailly, C., Devaux, J., Leloup, G., 2012. Physical, mechanical and rheological characterization of resin-based pit and fissure sealants compared to flowable resin composites. Dent. Mater. 28, 349–359.

Beun, S., Bailly, C., Devaux, J., Leloup, G., 2008. Rheological properties of flowable resin composites and pit and fissure sealants. Dent. Mater. 24, 548–555.

Cattani-Lorente, M.A., Dupuis, V., Moya, F., Payan, J., Meyer, J-M., 1999. Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass ionomer cement. Dent. Mater. 15, 21–32.

Cildir, S.K., Sandalli, N., 2007a. Compressive strength, surface roughness, fluoride release and recharge of four new fluoride-releasing fissure sealants. Dent. Mater. J. 26, 335–341.

Cildir, S.K., Sandalli, N., 2007b. Compressive strength, surface roughness, fluoride release and recharge of four new fluoride-releasing fissure sealants. Dent. Mater. J. 26, 335–341.

Cohen, L., Shulham, A., 1988. The Use Of Pit And Fissure Sealants In The General-Dental-Service In Great-Britain And Northern-Ireland. Brit Dent J 165, 50–53.

Crisp, S., Lewis, B.G., Wilson, A.D., 1976. Characterization of glass-ionomer cements I. Long term hardness and compressive strength. J. Dent. 4, 162–166.

El-Kalla, I.H., Garcia-Godoy, F., 1999. Mechanical properties of compomer restorative materials. Oper. Dent. 24, 2–8.

Feigal, R.J., 2002. The use of pit and fissure sealants. Pediatr. Dent. 24, 415–422.

Geiger, S.B., Gulayev, S., Weiss, E.I., 2000. Improving fissure sealant quality: mechanical preparation and filling level. J. Dent. 28, 407–412.

History and Evolution of Pit and Fissure Sealants [WWW Document], n.d. URL http://www.juniordentist.com/history-and-evolution-of-pit-and-fissure-sealants.html (accessed 5.11.18).

ISO 6874:2015 - Dentistry -- Polymer-based pit and fissure sealants [WWW Document], n.d. URL https://www.iso.org/standard/67595.html (accessed 5.12.18).

Lerech, S.B., Tarón, S.F., Dunoyer, A.T., Arrieta, J.M.B., Caballero, A.D., 2017. Compressive strength of glass ionomer and composite resin. In vitro study. Rev. Odontológica Mex. 21, e107–e111.

Meyer, J.-M., n.d. TEGDMA and Bisphenol-A: the same level of risk in dental medicine?

Meyer, J.M., Cattani-Lorente, M.A., Dupuis, V., 1998. Composers: between glass-ionomer cements and composites. Biomaterials 19, 529–539.

Moezzyzadeh, M., 2012. Evaluation of the compressive strength of hybrid and nanocomposites. Shahid Beheshti Univ. Dent. J. 30, 23–28.

Munhoz, T., Nunes, U.T., Seabra, L.M.-A., Monte-Alto, R., 2016. Characterization of Mechanical Properties, Fluoride Release and Colour Stability of Dental Sealants. Pesqui. Bras. Em Odontopediatria E Clin. Integrada 16, 149–158.

Natali, A.N. (Ed.), 2003. Dental biomechanics. Taylor & Francis, London ; New York.

Nunn, J.H., Murray, J.J., Smallridge, J., 2000. British Society of Paediatric Dentistry: a policy
document on fissure sealants in paediatric dentistry. Int. J. Paediatr. Dent. 10, 174–177.

Obici, A.C., Sinhoreti, M.A.C., Correr-Sobrinho, L., Góes, M.F. de, Consani, S., 2005. Evaluation of mechanical properties of Z250 composite resin light-cured by different methods. J. Appl. Oral Sci. 13, 393–398.

Ripa, L., 1993. Sealants revisited: an update of the effectiveness of pit-and-fissure sealants. Caries Res. 27, 77–82.

Singh, R.D., Chand, P., Jurel, S.K., Tripathi, S., 2011. Evaluation of Adhesive and Compressive Strength of Glass Ionomer Cements. J. Indian Prosthodont. Soc. 11, 210–214.

Subramanian, P., Konde, S., Mandanna, D.K., 2008. Retention of a resin-based sealant and a glass ionomer used as a fissure sealant: a comparative clinical study. J. Indian Soc. Pedod. Prev. Dent. 26, 114.

Taher, N.M., 2001. Mechanical properties of flowable composites. situations 2, 6–7.

Uno, S., Finger, W.J., Fritz, U., 1996. Long-term mechanical characteristics of resin-modified glass ionomer restorative materials. Dent. Mater. 12, 64–69.

Walsh, R.M., Woodmansey, K.F., Glickman, G.N., He, J., 2014. Evaluation of compressive strength of hydraulic silicate-based root-end filling materials. J. Endod. 40, 969–972.

Xie, D., Brantley, W.A., Culbertson, B.M., Wang, G., 2000. Mechanical properties and microstructures of glass-ionomer cements. Dent. Mater. 16, 129–138.

Xu, X., Burgess, J.O., 2003. Compressive strength, fluoride release and recharge of fluoride-releasing materials. Biomaterials 24, 2451–2461.