The linear polymerisation shrinkage effect of chemical activated composite resin using different bonding agents on the dimensions of the tooth cavity

Marry Siti Mariam[1], Arief Cahyanto[2*]

[1]Department of Oral Biology, Faculty of Dentistry Universitas Padjadjaran, Indonesia
[2]Department of Dental Material, Science, and Technology, Faculty of Dentistry Universitas Padjadjaran, Indonesia

ABSTRACT

Introduction: This study was aimed to determine the effect of the linear polymerisation shrinkage of composite resin using different bonding agents on the dimension of the tooth cavity. **Methods:** Fifty-four extracted human premolar teeth, both maxillary and mandibular were used and divided into three groups (A, B, and C) into eighteen specimens. The conventional cavity was prepared, and all cavities were bevelled. In Group A, only the bevel was etched, and the enamel bond was applied to it. Group B was treated with the same procedure as group A, but the dentin bond was used instead of enamel bond. Group C, the whole cavity was etched, dentin bond was applied on the bevel and the cavity walls. The reference points were placed in the vestibular and lingual palatal region as occlusal as possible on the enamel. The Silar® composite resin (microfilled, chemically activated), etching agent (gel etch), enamel and dentin bond system were employed for the preparation and filing of the cavities. The cavity was filled with composite, and the specimens were immersed in 0.02% chlorhexidine gluconate solution at the room temperature. The distance between both reference points was measured before and after filling procedures. **Results:** Group A showed the least shrinkage with a mean of 0.14%, group B showed a larger shrinkage with the average of 0.24% and the largest shrinkage was found in group C with the average of 0.26%. The difference between groups B and C was not statistically significant given at the point of 0.05 significance level, and the difference between groups A, B, and C was significant at the 0.01 significance level. From the mathematical modelling using the stress-strain equation, the results showed that the tensile stress in restrained of Silar® composite was higher than the enamel (19.80 MPa > 10.34 MPa) thus lead to cracks in the enamel. **Conclusion:** The acid etching on dentin is not improving the retention and marginal adaption of restorative resin. The use of enamel bond system gives a better effect on the adhesion strength compared to the dentin bond system.

Keywords: Composite resin, polymerisation shrinkage, tooth cavity dimension.

p-ISSN: 1979-0201; e-ISSN: 2549-6212; Available from: http://jurnal.unpad.ac.id/pjd/article/view/25915
DOI: 10.24198/pjd.vol32no1.25915
Submission: Jan 24, 2020; Accepted: Mar 30, 2020; Published online: Mar 31, 2020

[*]Corresponding author: Arief Cahyanto, Department of Dental Material, Science, and Technology, Faculty of Dentistry Universitas Padjadjaran, Indonesia. Jalan Sekeloa Selatan I, Indonesia, 40132. Phone: +6281219602295; Email: arief.cahyanto@fkg.unpad.ac.id

INTRODUCTION

The term composite refers to a three-dimensional combination of at least two chemically different materials with a distinct interface separating the components. The classification of composite resin are traditional composites, microfilled resin, and hybrid composites.[1] In these resins, micro fillers are used derived chemically by hydrolysis and precipitation and consist of very finely dispersed radiolucent glass spheres. Originally these particles have an average size of 0.04 μm. Recently the size of the utilized filler Particles has been increased to about 0.05 - 0.1 μm. This characteristic has a large influence on polymerization shrinkage.[2]

Many factors influence the polymerization shrinkage such as fillers content, cavity preparation, hygroscopic expansion, etc. The fillers in current dental composites function to reinforce the polymer and reduce the overall shrinkage on the setting, but they do not prevent the build-up of stress.[3] Cavity margins in enamel are bevelled or chamfered when the acid etch technique is used for composite restoration. This would tend to distribute the shrinkage force over an area of the bevelled enamel.[4] The new cavity design adhesive restoration could reduce shrinkage because of decreased cavity volume.[5] In some resin, the contraction will be compensated by the following hygroscopic expansion, however, only etching of the enamel will ensure a better marginal adaptation.[6]

The hardening of composite resin begins when reaction between initiator and amine accelerator at room temperature to initiate the polymerization reaction. The polymerization reaction starts very shortly after the monomer and polymer are mixed before the gel point. The polymerization shrinkage causes volumetric and dimensional change. The linear shrinkage dental restorative composite resin by using a mechanical dilatometer on cylindrical specimens range between 0.5 to 1.2% corresponding to a volume shrinkage of approximately 1.5 to 3.6%.[7] Dickson[3] determined volumetric for conventional composite resin approximately 1.2 to 2.1% equivalent to linear shrinkage, 0.4 to 0.7%,[7,8] and for micro filled resin 2 to 4.5 volume %, 0.8 to 1.9 linear%.

The hardening shrinkage of composite resin can cause marginal defects. Furthermore, this phenomenon increases the difficulties in obtaining adhesive bonding.[2,4] When a resin filling material is fastened to the etched enamel shortly after mixing, the enamel surrounding the cavity will be pulled in central direction.[6,9] This contraction contributes to a shearing force that can cause marginal cracks on enamel itself.

The shrinkage will not only cause volumetric and dimensional change but also the build-up of large stresses.[4] In many cases the stresses are so high, that causes: internal stress probably can cause micro-cracks at the filler-matrix interface or between the matrix, marginal gaps between restorative filling and cavity walls, and cracks on enamel. The force exerted by the polymerization contraction of some composite resin is sufficient to fracture enamel when the bond strength of the resin is greater than the tensile strength of enamel itself.[10]

Therefore, from the above-mentioned statement, the presence of this study was to determine the effect of the linear polymerization shrinkage of composite resin on the dimensions of the tooth cavity. This study would investigate whether the polymerization shrinkage could cause: cracks in the enamel, marginal gaps between the cavity wall and composite restoration, or micro-cracks at the filler matrix composite.

METHODS

In this study, fifty-four extracted human premolar teeth both maxillary and mandibular were used and divided into three groups (Group A, B, and C) of eighteen specimens. The etching agent, two bonding agents and the composite resin used for the preparation and filling of the cavities are presented in Table 1.

A conventional cavity was prepared and all cavities were bevelled. The reference points were placed in the vestibular and the lingua palatal region as occlusal as possible on the enamel (Figure 1) and were used to determine any possible change occurring in the linear distance between these two points before and after the cavity was filled with a composite resin. The composite resin (a microfilled, chemically activated), the etching

agent (gel etch), two bonding agent (enamel and dentin bond system) were used for the preparation and filling of the cavities. In the Group A, only the bevel was etched and enamel bond was applied on it. The Group B was treated with the same procedure as group A but dentin bond was used instead of enamel bond. In Group C, the whole cavity was etched, dentin bond was applied on the bevel and the cavity walls. Afterwards, the cavity was filled with composite and the specimens were immersed in 0.02% chlorhexidine gluconate solution at the room temperature. The distance between both reference points were measured before and after filling procedures. The data was analysed using the difference means method, based on the student-t distribution.

Table 1. Product, batch numbers and manufacturers

Etching agent	Gel etch	MN - 55144	Manufacturers
Composite Resin	Silar Composite (Microfilled)	Paste A-3EF Paste B-3DEJ	3M Co, St. Paul MN
Enamel Bonding Agent	P10 Enamel Bond System	Based-1106G1 Cat.-1106G1	3M Co, St. Paul MN
Dentin Bonding Agent	Scotch Bond	Base-4UW1 Catalyst-4B1	3M Co, St. Paul MN

The experimental procedure can be divided into following steps:

Fabrication of specimen

Prior to embedding the teeth in self-curing acrylic, the occlusal of the tooth was filled with wax to keep the acrylic from entering the occlusal. After these teeth were embedded in the acrylic resin the teeth were positioned in a messing split mold in such a way that the mesial and distal of the tooth parallel to the horizontal plane of the mold. The slicing of the teeth is performed by a Leitz Microtome in slices of 3 mm in thickness, the object put into the position with the cusps as centrally as possible. After obtaining the slices, the coronal part of the teeth was freed from the acrylic and the wax in the occlusal was removed. The specimen was again immersed in 0.02% chlorhexidine gluconate solution and stored in a refrigerator. Because the slice was going to be placed between two glass plates, the sliced surfaces had to be polished to obtain a surface which was flat and clean. The polishing was performed using a polishing machine equipped with the abrasive paper of grain size 1200 microns and the interface between specimen and paper was lubricated using tap water. After polishing the thickness of the specimen was again measured with a micrometre. The thickness of the slices varied from 2.80 to 2.90 mm.

Preparation of the cavity and the positioning of the reference points

A conventional cavity was prepared with a regular fissure bur under water spray, to a depth of 3.5 mm and a buccolingual width of 2.5 mm. The form of the cavity was rectangular, the walls presenting a 90-degree angle to the floor. All cavities were bevelled over a distance of 1 mm. On one of the sliced surfaces, the reference points were placed using the smallest round diamond bur which is placed on a parallelometer Bachmann. The points were placed in the vestibular and lingual-palatal region as occlusal as possible on the enamel (Fig.1). These reference points are used to determine any possible change occurring in the linear distance between these two points before and after the cavity was filled with composite resin.

Filling procedure

Fifty-four specimens were prepared and divided into three groups (A, B, C) of eighteen specimens. Group A, only the bevel was etched and enamel bond was applied on it. Then the cavity was filled with the composite resin. Group B, same procedure as group A but the dentinal bond was used instead of enamel bond. Group C, the whole cavity was etched, the dentinal bond was applied on the bevel and the cavity walls. Subsequently, the cavity is filled with composite. To protect the reference points from any contamination during

the etching and application of the bonding agents, Vaseline was applied to it. After the cavity filling is completed, the Vaseline was removed using a little brush, soap and water spray. Each specimen was placed between two glass plates which are clamped together with a plier. The etching was performed for one minute. Then the specimen was washed with the water spray for one minute and thoroughly dried using compressed air. Immediately afterward a bonding agent was applied as indicated above (see classified groups).

The weight ratio between the base and catalyst has to be unity. To obtain this ratio the amount of composite was determined using a Wentzler digital balance. The maximum time of the composite is limited to 15 seconds and the application of the composite resin was completed in 40 seconds. The cavity was slightly overfilled using a syringe, then the free surface of the filling is covered by a plastic matrix and varying force was applied to the matrix using finger pressure. The handling and application of the bonding agent and composite resin were performed according to the recommendation specified by the manufacturer. When the composite resin was completely hardened, the specimens were immersed again in 0.02% chlorhexidine gluconate solution at room temperature.

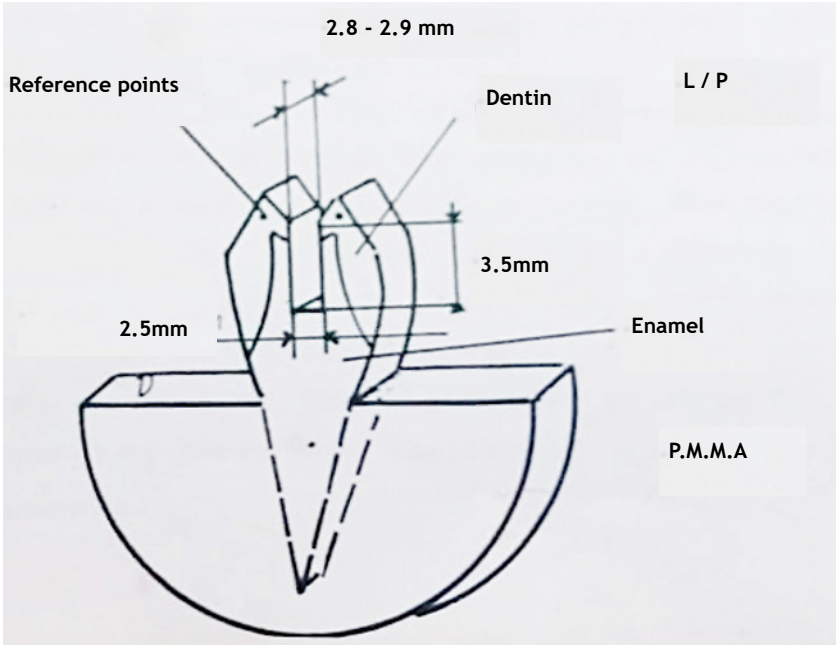

Figure 1. Preparation of the cavity and the positioning of the reference points

Measuring method for the determination of the distance between reference points

Measuring device

To determine the distance between the reference points, a precision microscope equipped with 3 directional position indication systems is utilized for the relative movements of its elements (supporting table and binocular) represent a cartesian coordinate system designated XYZ (Fig. 2). A position in the measurement space of the microscope is determined by 3 coordinate values which are displayed on three reversible counters. This position information can be directly transferred to a computer through of a special interface.[3]

Measuring procedure

There are two methods for measuring the distance between two reference points; first, the direct distance measurement from one point to the other and secondly, the distance measurement using an equation. Direct distance measurement from one point to the other, with this method the first reference point is aligned with the rotation axes of the rotary stage. The coordinate of this reference point is set to zero and the rotary stage is rotated until the line connecting the two

reference points is collinear with the x-axis (Figure 2). The x coordinate of the second reference point will then represent the distance between the reference points. This method is cumbersome due to the difficulty of aligning the centre of the first reference point with the rotation axis of the rotary stage so that significant errors can be introduced and a lot of time is needed. For more convenience is used the distance measuring combination with an equation (Figure 3).

Distance measurement using an equation

In this method, the specimen is placed beneath the light microscope and the (x,y) coordinates of both the reference points are determined. To obtain the distance of the coordinate value between two reference points can be calculated using the following equation[11]:

$$D = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad \text{.....(Equation 1)}$$

D : distance between the reference points
X_1, Y_1 : coordinate values of first reference point and can be read on the X and Y counters
X_2, Y_2 : coordinate values of the second reference point and can be read on the X and Y counters. (Figure 2 & 3)

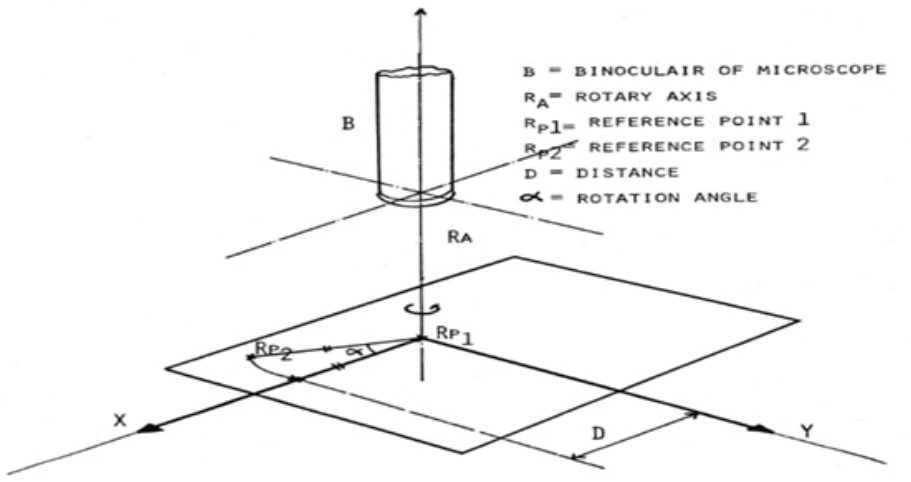

Figure 2. Direct measurements of the distance between reference points

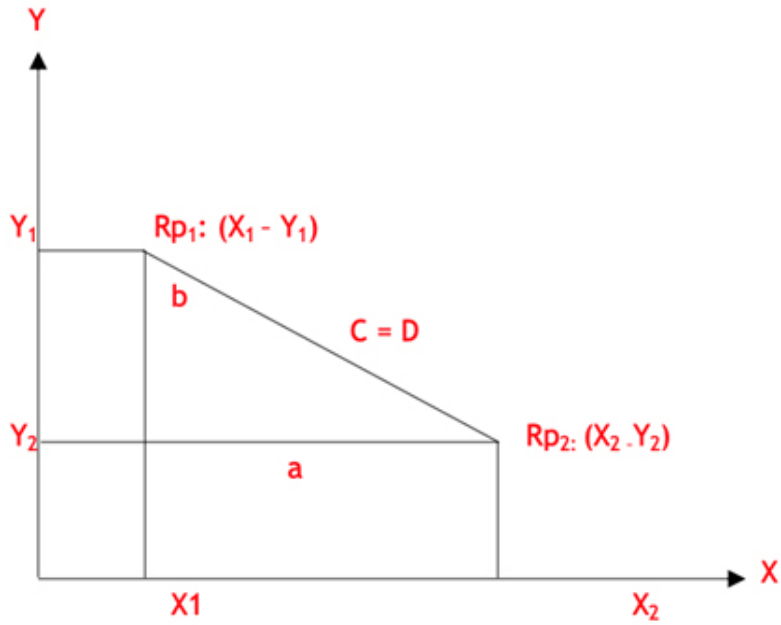

Figure 3. Method for obtaining distance equation

The method for obtaining distance equation is more convenient because less time is needed as shown in equation 1. The obtained coordinate values are directly transferred to the computer where a program determines the distance using the above equation and displays this result on its screen. By this, the fatigue of the observer is decreased. Therefore, several errors will be avoided.

RESULTS

The results showing the change of the distance between the reference points before and after filling the cavity and the statistical data using t-test compared between groups are presented in Table 2 and 3.

The figure of distance between reference points and overall findings are summarized in figure 4 and 5. The linear shrinkage data determined from the changes of distance data was analyzed using the difference of means method based on the student t distribution. The distance change between reference points before and after filling procedures were analyzed and compared for all groups. Group A showed the least shrinkage with a mean of 0.14 %, group B showed a larger shrinkage than group A with a mean of 0.24 %, and the largest shrinkage was found in group C with the mean of 0.26. The difference between groups B and C was not statistically significant at the 0.01 and 0.05 significance level.

Table 2. The mean linear shrinkage data of Group A, B, and C

Group	Mean (%)	Standard deviation (%)	Range (%)
A	0.14	0.05	0.09 - 0.26
B	0.24	0.03	0.20 - 0.28
C	0.26	0.03	0.21 - 0.31

Table 3. Statistical data using t-test compared between groups

Group comparison	T-test	α = 0.01	α = 0.05
AB	5.869	Significant	Significant
BC	1.639	Not significant	Not significant
AC	7.075	Significant	Significant

Figure 4. Distance between reference points before and after filling with composite
X = distance between reference points before filling with composite
X' = distance between reference points after filling with composite
(X- X') = change of the distance between reference points before and after filling procedure (X'< X)

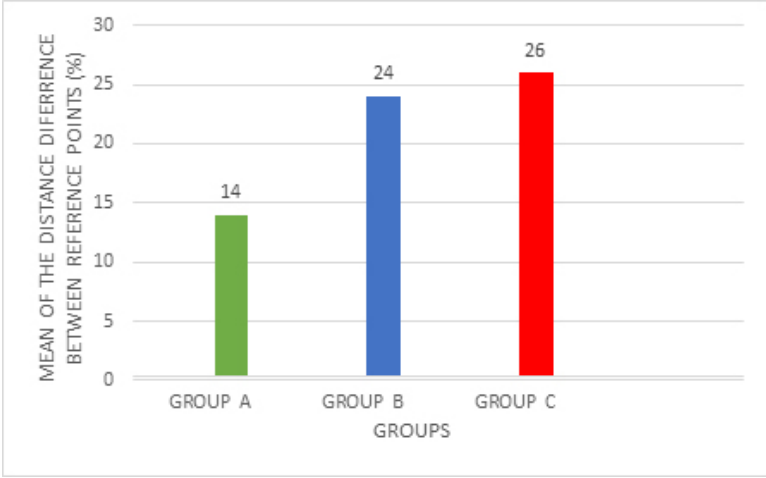

Figure 5. Histogram presenting the mean of the distance difference between reference points (%) for groups A, B, and C

Mathematically, by using the equation relating the stress-strain (Fig. 6) variables in the elastic region of a material, it can be determined whether the measurement results can lead to crack formation in enamel or not. The mathematical modelling procedure is as follows:

S = e. E .....(Equation 2)

S : Stress (tensile stress is restrained).
e : strain analog to the change in dimension of the tooth cavity (0.24-0.26%).
E : modulus of elasticity of enamel (average modulus of elasticity of enamel is 82.50 MPa).[12]

From the above equation (Eq. 2), the stress which may develop when the polymerization shrinkage of Silar resin is S = 0.24 x 82.5 MPa = 19.80 MPa. As mentioned in the previous study that the tensile strength of enamel was 1500 psi.13 Then, the conversion factor is 1 psi = 6.895 x 10 Pa = 6.895 x 10 MPa. The tensile strength of enamel in MPa = 6.895 x 10 x 1.5 x 10 MPa = 10.34250 MPa ≈10.34 MPa. The tensile stress in the restrained microfilled resin is larger than the tensile strength of enamel (19.80 MPa > 10.34 MPa) so that it can be assumed that the tensile stress can lead to cracks in the enamel, however, the occurrence of cracks was not investigated in this study.

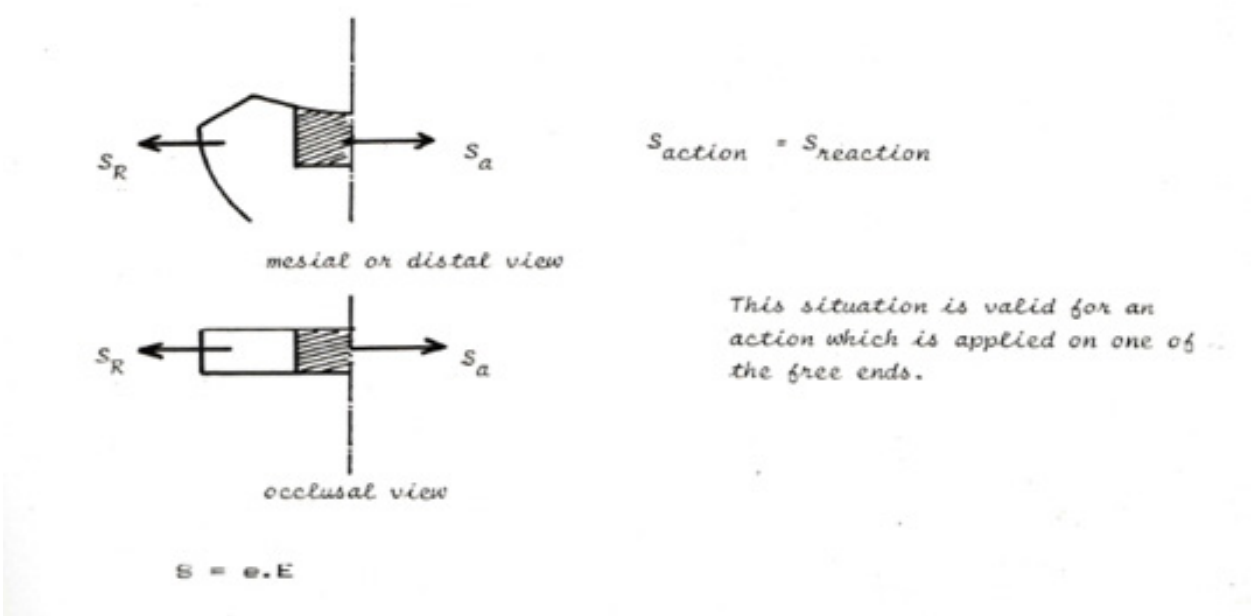

Figure 6. Relating the stress-strain variables in the elastic region of a material

DISCUSSION

Silar composite is a microfilled, chemically activated composite resin, which has a polymerization shrinkage of 3.5% volumetric and 1.47% linear.[3] In the study of Davidson[14], it was found that the volumetric contraction stress of Silar composite was in the range of 32 MPa. Due to this large contraction stress, in this study Silar composite was chosen as a restorative resin material, to determine the effect of the polymerization shrinkage in the occlusal cavity inlined with those different bonding agents. The result of the difference in distance between the reference points before and after the filling procedure (after 3 days immersion in solution) showed a change in the dimension of the tooth cavity ranging between 0.24 - 0.26%. From above-mentioned, the enamel surrounding cavity was pulled centrally as the material polymerized and shrinkage. If so, then the bond strength between the Silar composite with etched enamel is higher than the contraction strength which is caused by the polymerisation shrinkage of Silar composite

and there was no gap between the restorative resin and the etched enamel.

The problem lies in whether the adhesive strength of the resin is greater than the tensile strength of the enamel. If so then the tensile force occurs in the resin, acting mainly in a direction that is perpendicular to the long axis of the enamel prism, which can cause enamel fracture.[11] Some studies have reported that the force extracted by three contractions of some composite resins is sufficient to fracture the enamel that surrounds the etched cavities into which they have been locked. This would indicate that the bond strength of the resin to the etched enamel is greater than the tensile strength of the enamel.[10,15]

Mathematically, by using the equation relating the stress-strain variables in the elastic region of a material, it can be determined whether the measurement results can lead to crack formation in enamel or not. The mathematical procedure is as follows; if the average modulus of elasticity of enamel (E) is 82.5 MPa[16], and strain analog to the change in dimension of the tooth cavity (e = 0.24-0.26%). Stress which may develop when the polymerization shrinkage of Silar is restrained is 19.80 MPa. The tensile stress of enamel in MPa is 10.34 MPa. This means that the tensile stress in the restrained Silar composite is larger than the tensile strength of enamel (19.80 MPa >10.34 MPa), so that he polymerization contraction of microfilled, chemically activated composite resin, has a large probability of causing cracks in the enamel that surrounds the etched cavities.

From the previous studies, it can be concluded that the Scotch bond (dentin bonding agent) does significantly improve the bonding of composite to dentin.[17] In Group B and C after acid etching, the Scotch bond was applied, in order to increase the retention between the composite and the etched peripheral enamel (for group B) and between the composite and etched cavity walls (group C). The adhesion of Silar composite to Scotch bond treated dentin is 7 MPa.[9] In this investigation the stress of the restrained Silar composite (19.80 MPa) is greater than the adhesion strength of Scotch bond from Davidson investigation (7.00 MPa)[11], so the possibility of marginal gaps formation can occur.

The acid etching technique has proved to be an effective means of increasing the bonding strength between restorative composite resins and etched enamel. But in contrast to enamel, acid etching on dentin will not improve retention and marginal adaption of restorative composite resins.[11,18] The above facts correlate well with the results obtained from group C where the acid etching was performed on the dentin and enamel whereas in group B where the acid etching was only performed on the enamel. Statistically, there is no significant difference between the results of these two groups (significance level 0.05). The linear shrinkage of group A was the smallest compared to group B and C. One of the factors which could influence the results is the use of a different bonding agent, wherein group A the enamel bond system was used in contrast with group B and C. Since the difference between groups B and C compared to group A is statistically significant and the use of adhesion between Scotch bonds and enamel bonds must also be taken into account.

The importance of standard deviation (0.05) in group A might be due to the cavity design. In some cases, the flow of the composite resin to the surface (shrink centre) can be obstructed, causing an increase in polymerization pressure of the composite resin. The occurrence of this greater difference is the difference between the two measurement points recorded before and after polymerisation.

CONCLUSION

In conclusion, the polymerisation contraction of Silar composite has a large probability of causing cracks in the enamel that surrounds the etched cavities into which they have been inserted. The Scotch bond adhesive dentin agent is probably not strong enough to restrain the contraction stress produced by the polymerisation of Silar composite. Yet, this study confirmed that the use of enamel bond system gives a better effect on the adhesion strength compared to the Scotch bond. The acid etching on dentin alone, will not improve retention and marginal adaption of restorative resin.

REFERENCES

1. Phillips RW. Skinner's of dental materials. 11th ed. Philadelphia: W.B. Saunders; 2003. p. 490.
2. Gonçalves F, Pfeifer CS, Ferracane JL, Braga RR. Contraction stress determinants in dimethacrylate composites. J Dent Res. 2008;87:367–371. DOI: 10.1177/154405910808700404
3. Lambrechts P, Vanherle G. Observation and comparation of polished composite surfaces with the aid of SEM and profilometer. J Oral Rehabil. 1982;9:169. DOI: 10.1111/j.1365-2842.1982.tb01010.x
4. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin-composites: A systematic review. Dent Mater. 2005;21:962–970. DOI: 10.1016/j.dental.2005.04.018
5. Naoum SJ, Mutzelburg PR, Shumack TG, Thode DJG, Martin FE, Ellakwa AE. Reducing composite restoration polymerization shrinkage stress through resin modified glass-ionomer based adhesives. Aust Dent J. 2015;60:490–496. DOI: 10.1111/adj.12265
6. Milosevic M. Polymerization mechanics of dental composites - Advantages and disadvantages. Procedia Engineering. 2016;149;313-320. DOI: 10.1016/j.proeng.2016.06.672
7. Martim GC, Kupfer VL, Moises MP, dos Santos A, Buzzetti PHM, Rinaldi AW, et al. Physical-chemical properties of dental composites and adhesives containing silane-modified SBA-15. J Mech Biomed Mater. 2018;80:277-284. DOI: 10.1016/j.jmbbm.2018.02.009
8. Aqbaje LO, Shaba OP, Adeqbuluqbe IC. Evaluation of the mechanical and physical properties of a posterior resin composite in posterior adult teeth. Niger J Clin Pract. 2010;13(4):431-5.
9. Dauvillier BS, Aarnts MP, Feilzer AJ. Developments in shrinkage control of adhesive restoratives. Eur J Esthet Dent. 2000;12:291–299. DOI: 10.1111/j.1708-8240.2000.tb00238.x
10. Soares CJ, Faria-e-Silva AL, Rodrigues MP, Vilela ABF, Pfeifer CS, Tantbirojn D, et al. Polymerization shrinkage stress of composite resins and resin cements – What do we need to know? Braz Oral Res. 2017;31(suppl 1):e62. DOI: 10.1590/1807-3107BOR-2017.vol31.0062
11. Orwant J, Hietaniemi J, Macdonald J. "Euclidean distance". Mastering algorithms with Perl. O'Reilly Media, Inc; 1999. p. 426.
12. Lloyd CH, Iannetta RV. The fracture toughness of dental composites: The development of strength and fracture toughness. J Oral Rehabil. 1982;9(1):55-56. DOI: 10.1016/S0109-5641(87)80077-5
13. Bowen RL, Rodriquez JS. The tensile strength and modulus elasticity of tooth structure and several restorative materials. J AM Dent Assoc. 1962;64:378-387. DOI: 10.14219/jada.archive.1962.0090
14. Davidson CL, de Gee AJ. Relaxation of polymerization contraction stresses by flow in dental composites. J Dent Res. 1984;63:146-148. DOI: 10.1177/00220345840630021001
15. Gianini M, Soares CJ, Caryalho RM. Ultimate tensile strength of tooth structures. Dent Mater. 2004;20(4):322-9. DOI: 10.1016/S0109-5641(03)00110-6
16. Narayana V, Ashwathanarayana S, Nadig G, Rudraswamy S, Doggalli N, Vijai S. Assessment of microleakage in class II cavities having gingival wall in cementum using three different posterior composites. J Int Oral Health. 2014;6(4):35-41.
17. McLean DE, Meyers EJ, Guillory VL, Vandewalle KS. Enamel bond strength of new universal adhesive bonding agents. Oper Dent. 2015;40(4):410-417. DOI: 10.2341/13-287-L
18. De Munck J, van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, et al. A critical review of the durability of adhesion to tooth tissue: Methods and results. J Dent Res. 2005;84:118-32. DOI: 10.1177/154405910508400204