Post-cure irradiation of pit and fissure sealant by diode laser

Part II

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_Introduction

Due to its peculiar anatomical shape, the occlusal surface is highly susceptible to carious lesions.[1] Several methods of prevention have been tried to reduce its prevalence.[2] A widely used technique affecting the caries incidence is fissure sealing[3], in which the fissure systems are sealed with a material. This material is retained on the enamel surface either by the acid etch technique (resin sealants) or through chemical bonding (GIC sealants).[4] The preventive benefits of such treatment rely directly upon the sealant's ability to thoroughly fill pits, fissures, and/or anatomical defects, as well as to remain completely intact and bonded to enamel surfaces without marginal micro leakage at the resin-tooth interface and consequent development of a carious process underneath the sealant material.[5,6]

The majority of resin materials utilised in restorative dentistry today consists of a methacrylated resin matrix (i.e. usually a blend of several resins) that is mixed with various glass filler particles. Bis-GMA continues to be the most used monomer for manufacturing present day composites; whether alone or in conjunction with other resin matrices. As a general rule, the lower the mean molecular weight of the monomer or monomer combination, the greater the percentage of shrinkage. Because Bis-GMA is highly viscous, in order to facilitate the manufacturing process and clinical handling it is diluted with less viscous monomers (low molecular weight) which are considered viscosity controllers, such as ethylene glycol dimethacrylate (EGDMA), triethylene glycol dimethacrylate (TEGDMA), or urethane dimethacrylate (UDMA).[7,8]

The chemical composition affects mainly the material behaviour during exposure to different oral conditions such as temperature, pH, stress, pressure, and humidity. The total amount of shrinkage, the rate of shrinkage, and the elastic modulus (i.e., stiffness) of the composite are just some of the factors that influence the degree of stress and strain (i.e., deformation) induced at the adhesive interface during composite polymerisation which result in shrinkage.[9] Shrinkage depends solely on the organic matrix and on the number of reactions that take place. It rises with the degree of conversion and falls with increasing monomer molecular weight.[10]

The filler particles are added to the organic phase to improve the physical and mechanical properties of the organic matrix, so incorporating a percentage of the filler as high as possible is a fundamental aim. The filler reduces the thermal expansion coefficient and overall curing shrinkage, provides radio-opacity, improves handling and improves the aesthetic results.[11] Improving the fluidity of composite resins is an important issue, so there are various options: lowering the viscosity of the monomeric component[12], adjusting the filler components, or improving the surface treatment of the filler.[13] The findings of clinical trials indicate that unfilled sealant performs better than filled sealants. In some cases, the manufacturers have added fillers to resin sealants

Groups	Group 1 control	Group 2	Group 3	Group 4
Treatment	Artificial caries	Laser+ artificial caries	Fissure sealant +artificial caries	Fissure sealant +diode laser +artificial caries

Table 1_Grouping.

as fluoride. In general, variation in the filler content heavily affects thermal expansion, thermal conductivity, polymerisation shrinkage, and mechanical strength of the sealant material.[14] Decreasing the filler loading eventually weakens the physical properties of resins, such as microhardness and wear resistance.[15]

Nowadays, the vast majorities of resin-based materials cure or polymerise by initiating free radical generation with a visible light curing device.[16] The manufacturers tried to develop light sources that will give the greatest conversion with the least curing stress, as this helps to improve the functional and aesthetic results of composite materials. Four types of polymerisation sources have been developed and applied: quartz tungsten halogen (QTH) lamps, light emitting diodes (LED) units, plasma-arc lamps and argon-ion lasers.[17]

LED's use a combination of two different doped semiconductors instead of a hot filament.[17] The spectral output of blue LED conveniently falls within the absorption spectrum of camphoroquinone.[18] Therefore, they do not require filters to produce blue light and they convert electricity into light more efficiently.[19] They produce less heat so no cooling fan is required and they can be smaller and cordless.[20]

The depth of cure is dependent on different cofactors such as filler particle size and distribution, colour and optical translucency of the composite, and refractive index ratio of the single components being used.[21, 22] Curing light is absorbed and scattered by composite resins, resulting in higher light intensity at the top than the bottom surface.[23] For this reason, Bayindir and Yildiz found significantly different top and bottom surface hardness values, whereby those of the top surface were consistently higher than those of the bottom surface.[24]

Full polymerisation of the material is determined by the degree of conversion of monomers into polymers, indicating the number of methacrylated groups that have reacted with each other during the conversion process.[25] The application of heat, as an additional polymerisation method, increases the conversion rate of monomers, reflecting in improvement of surface hardness, compressive, modulus of elasticity and flexural strength. Composites submitted to heat might present internal stress relief, especially at the interface between organic matrix and inorganic particles.

This would increase the adhesion between both of the two phases and the cross linking between the methacrylate groups.[26] In the past, the most commonly used method as a secondary treatment is heating in a furnace as a means to improve the degree of conversion.[27] The used ovens and stoves must have temperatures ranging from 60 to 170 °C, and a heating time varying from seven minutes to one hour.[28]

Also, laser was used as an additional curing method to potentiate the material properties as CO_2 laser as its effect mainly consists of heat action.[29] Diode lasers are in the category of devices that emit light from semiconductor materials.[30] They are portable, compact surgical units with efficient reliable benefits. Diode lasers have a wavelength between 805 and 980 nm. They can be used in the continuous as well as pulsed mode.[31]

The current study was conducted as a morphological and microhardness evaluation of the effect of the post curing application of diode laser (980 nm) on specific fissure sealing material in caries prevention.

_Materials and method

Sample preparation

Forty extracted caries-free permanent molars (wisdoms) and premolars were used in the current study. Extraction had been done for orthodontics treatment. Selected teeth were cut into two halves bucco-lingually with a low speed diamond disc, which were divided into groups (Tab. 1).

_Surface treatment

Artificial caries

The specimens of all groups were individually submitted to the process of the caries induction using artificial caries media (6 % hydroxyethyl cellulose to a 50 m mole lactic acid solution) of 4.5 pH for seven days.[32] The specimens were then washed and kept in distilled water.

Laser irradiation

In groups 2 (sound enamel) and 4 (fissure sealing material), occlusal depressions of the experimental

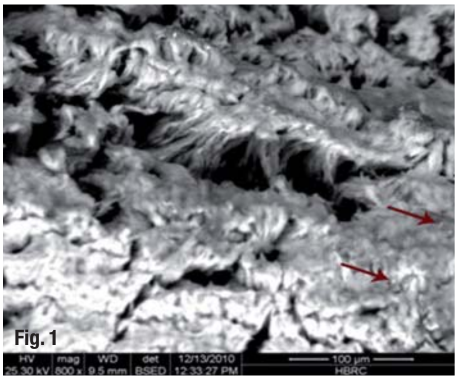


Fig. 1

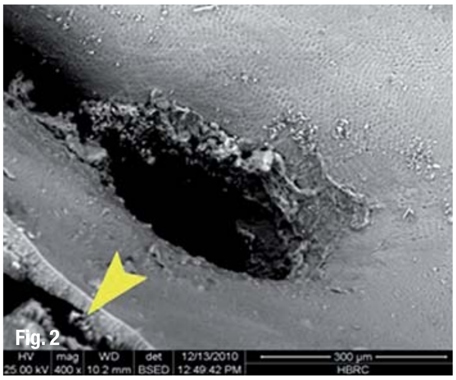


Fig. 2

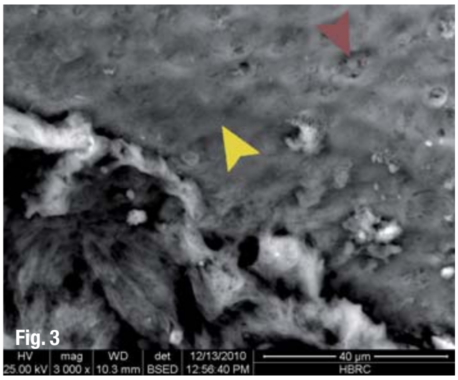


Fig. 3

Fig. 1_ESEM image of group 1 showed carious enamel surface with aggregated granules (red arrows) (BSED) x800.

Fig. 2_ESEM image of group 2 shows pitted surface and destructed unlased part (arrowhead) x400.

Fig. 3_ESEM image of group 2 showed the nearby enamel with typical keyhole appearance (arrowheads) (BSED) x3,000.

samples were irradiated using diode laser irradiation of 980 nm wave length, 2 W power for 15 sec, in contact mode (Quanta system, Italy) and optic fiber transmission system. The fiber tip was positioned perpendicularly to the occlusal pit and fissure areas. Laser irradiation was performed by hand, screening the enamel surface in a uniform motion.[33]

Sealant material

Groups 3 and 4 were treated with Clinpro pit and fissure sealing material, unfilled and fluoride releasing type (3M ESPE, USA).

Curing process

A DEMI LED was used to photocure the resin sealant. These curing lights have a light intensity of approximately 1,100 mV/ cm^2 and emit light in the wavelength range of 450–470 nm (sds Kerr, USA). The curing time is up to 20 seconds.

Environmental scanning electron microscope analysis

The specimens were examined occlusally and proximally using an ESEM (Inspect S ESEM, FEI).

Microhardness detection

Surface hardness was measured using Vickers microhardness tester (HMV-2 Shimadzu, Columbia, US). Measurements were done proximally at the depth of the fissure and at the lateral sides of the fissure depth. Indentations were made with the long axis of the Knoop diamond perpendicular on the inner enamel surface laterally and at the depth of the fissures. Each group underwent a load of 19.61 N, applied for 20 sec in order to evaluate the variations of surface hardness eventually caused by laser treatment in comparison with unlased enamel. The hardness values were calculated automatically by a computerised machine.

Statistical analysis

The data were gathered and analysed using ANOVA (Analysis Variance) test. Statistical results were processed by SPSS software (17.0, SPSS Inc., Chicago, USA).

_Results

Environmental scanning electron microscope analysis

Disappearance of the normal architecture of the enamel structure was detected clearly. Few enamel crystalline aggregations reprecipitated on the decayed surface indicating the massive demineralisation of enamel. Rods and interrod regions in group 1 were detected at the wall of the fissure due to loss of the surface rodless enamel (Fig.1).

Contrarily, melted irregular areas of the irradiated occlusal grooves were detected in specimens of group 2 (Fig. 2). However the high pH of the artificial caries media used, preservation of the surface integrity was observed clearly in most of the examined specimens (Fig. 3).

As in group 1, loss of the enamel integrity was detected in group 3. The sealant surface revealed widely distributed voids and cracks with variable sizes (Fig. 4). Multiple aggregations of enamel crystals which reprecipitated on the sealant surface indicated a massive demineralising effect of the artificial caries media. Intimate contact between the enamel and the sealant was noticed, barring few cracks extended from the sealant to the adjacent enamel (Fig. 5). The lateral wall of that enamel exhibited atypical enamel rods and interrod regions (Fig. 6). The lateral borders of the sealant material did not show a normal separation, but erosion was observed at its border which may be due to the fluoride-releasing effect of the sealant material.

Finally, group 4 revealed intact tooth and restoration integrity related to the lased part (Figs. 7 & 8). Contrarily to group 3, where the sealant surface and enamel were destructed totally, the sealant revealed slightly irregular surface with few small voids and cracks in group 4. The bond between the sealant and the enamel seemed to be intact and revealed a neglected effect of acid on the restoration. Sporadic areas of melted sealant were clear at the interface, masking some of the enamel rod ends (Fig. 9). The lased enamel also showed intermittent melted areas which appeared as a homogenous layer that masked the enamel rod ends (Fig. 10). Destruction of the unlased part of the enamel surface was detected near the intact lased part, but there was also clear and intact smooth sealant surface free of voids and cracks. Contrarily to group 3, the difference of the sealant surface reflected the laser effect as even the inherent defects of the sealant surface can be detected easily.

Statistical analysis

Statistical analysis of the microhardness data was made using the ANOVA test in order to compare the resulted data from the examined groups. Results were presented as mean ± standard deviations and a p-value of less than 0.05 was considered as statistically significant (Tab. 2). The degree of demineralisation and the ability of each group to resist caries were reflected as changes in the microhardness measurements. The comparison of the groups showed highly significant differences ($p = 0.0001$). As a result, the Post-Hoc test and the Pairwise test were done as multiple comparisons in order to determine the most significant mean in reference to the measured control group scores. Also, comparing all the groups with reference to the artificial caries group, group 4 showed a highly significant difference ($p = 0.0001$). No significant difference was detected between group 1, group 2 and group 3. The opposite was found when comparing all groups and group 4 ($p > 0.05$) which means that the main positive effect was owing to laser only.

_Discussion

Caries is a pathologic process of external origin involving softening of the hard tissues and proceeding to the formation of a cavity.[35] Microscopically, caries begins with the integration of enamel prisms after decalcification of the interprismatic substances, events which lead to the accumulation of debris and microorganisms. When the process reaches the dentino-enamel junction, it spreads laterally and also penetrates the dentin along the dentinal tubules.[3]

Group	Mean ± standard deviation S.D.
1	79.250 ± 33.9894
2	191.890 ± 22.7996
3	77.360 ± 11.4723
4	1069.30 ± 486.693*

** Statistically significant value*

Table 2_Vickers microhardness tests results.

Unfortunately, incipient lesions in tooth pits and fissures respond less favourably to fluoride therapy than lesions isolated to smooth surfaces. Today, there is a wide choice of different sealing materials used clinically. In 1990, Jensen demonstrated that fluoride releasing sealants had a slightly higher retention rate after one year than the sealant without fluoride.[35] In this study, the 3M™ ESPE™ Clinpro fissure sealant was used (light-cured, nearly unfilled, and of low viscosity with a colour-change feature). Also, it contains a patented soluble organic fluoride source. BIS-GMA/TEGDMA resins are the main components.[36]

Clinpro fissure sealant contains only 6 % fillers which are mainly fluoride. The effect of this fluoride is clinically beneficial because it exerts a protective action on the tooth along the tooth restoration interface.[37] The fluoride is released as long as the gel layer exists. Consequently, the protective action is effective until there is the gel layer around the filler particle. The dissolution of the gel layer produces loss of the filler particle and then cavity formation[38] which strongly affects the integrity and the main structure of the restoration. In this study, ESEM micrographs of group 3 reflected the later negative effect of fluoride releasing on the material surface that showed in voids, cracks and loss of bonding at the sealant enamel interface. Massive destruction of the enamel surface and the lowest surface hardness was also detected in this group, which reflected the inability of the sealant material to provide enough protection to the sealed enamel.

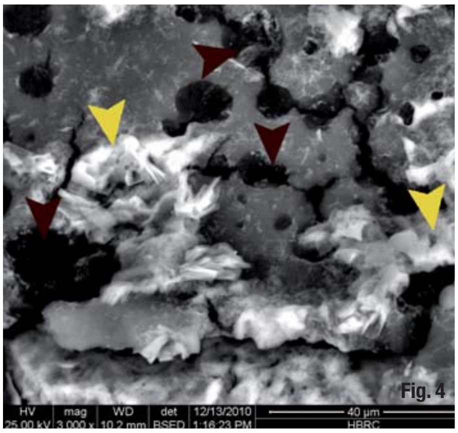


Fig. 4

Fig. 4_ESEM image of group 3 showed multiple voids on the sealant surface (red arrows) and reprecipitated enamel crystals (yellow arrows) (BSED) x3,000.

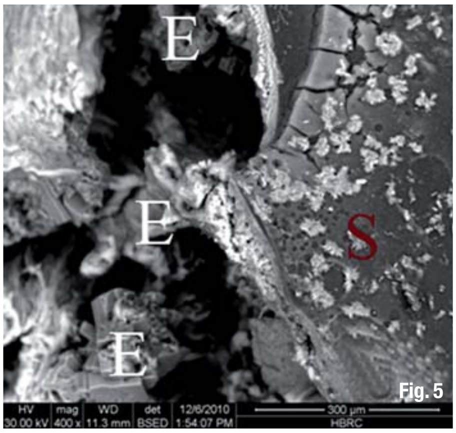


Fig. 5

Fig. 5_ESEM image of group 3 showed destructed enamel (E) and sealant (S) (BSED) x400.

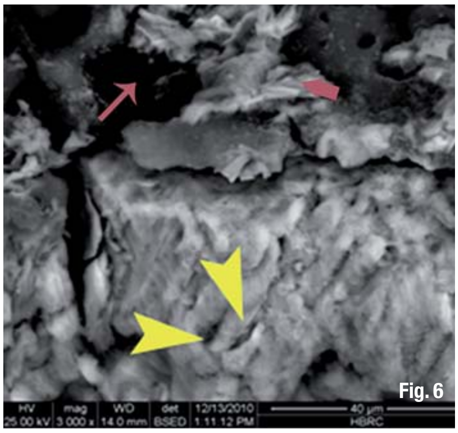
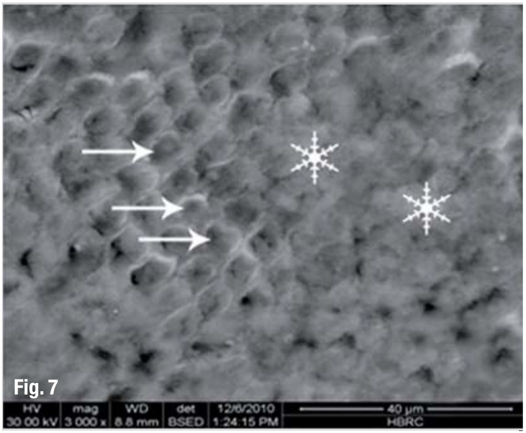


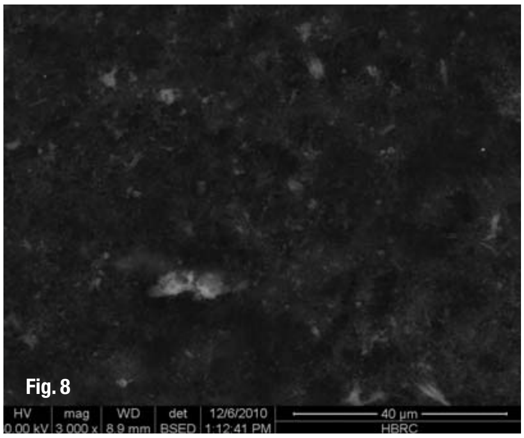
Fig. 6

Fig. 6_ESEM image of group 3 showed atypical rods and interred region (yellow arrowheads) at the interface, voids on the sealant surface (red arrow) and reprecipitated enamel crystals (red arrow head) (BSED) x3,000.

Fig. 7_ESEM image of group 4 showed the lased enamel with homogenous melted areas (asterisks) intermingled with the rod ends (arrows) (BSED) x3,000.

Fig. 8_ESEM image of group 4 showed smooth, clear sealant surface with minimal cracks or surface defects (BSED) x3,000.





The curing process is affected by the composition of cured material and curing light. LED was used in this experiment in order to achieve a very narrow range of blue light which is more likely to be absorbed by chomphorquinone (450–500 and a peak at 465 nm). As a result, there is no overheating of the restoration. In order to achieve a maximum conversion rate, some authors recommended curing at lower intensities (< 500 mW/cm^2) within extended polymerisation intervals.[39] But with LED units providing output levels consistently between 1,500 to 2,000 mW/cm^2, polymerisation time can be reduced to 20 seconds.[40]

There are many factors that control the success of the sealing process, some of which depend on the tooth and the other depend on the material itself and the environment of the application. In this study, we used the traditional way of application mentioned in the sealant pamphlet. In single-paste visible light-cured materials, it has been supposed that the porosities are air introduced as the unpolymerised material is extruded through the nozzle of the syringe. The cured materials are characterised by different concentrations, dimensions and distribution of porosity. Often, dimensions and concentration of porosity decrease in light-cured materials when the unpolymerised paste is extruded through a needle. The smaller the needle's inner diameter, the more extensive is its effect. This rule, however, shows exceptions. In some cases, the extrusion through a small tip results in the decrease of large porosities and in an increase of small porosities. This is due to the fragmentation of large porosities.[41]

The small nozzle available with Clinpro™ sealant aiming to provide better introduction of the material into the fissure system caused an inherent defect in its application technique. Probably it is impossible to remove all porosities as the unpolymerised pastes contain 0.05–1.4 % porosities by volume. The stress induced by the polymerisation contraction also affects the success of the sealing process. Polymerisation contraction seems to be the cause of the cracks that were detected in group 3. Those cracks originated from both bubbles and the filler-resin interface as they are considered weak points. The filler does not shrink during the setting reaction, thus producing additional stress at the filler-matrix interface.[42]

Massive destruction of the enamel surface and the lowest surface hardness was detected as well as in group 1. This massive destruction was obvious due to the low pH of the used artificial caries media that reached 4.5. However, by using diode laser, the lased areas were not affected by this media (group 2). Also, increased microhardness levels that were detected in this group provide protection of these areas even with pH decay, especially with uncontrolled diseased patients, who are for example handicapped, have a high caries index or young permanent teeth. Patients prior to radiation therapy are also included.

According to the fissure system morphology, complete penetration of the etchant material into the fissure system is an essential step in the sealing retention. Converting the enamel surface into a hydrophilic highly reactive one, the etching process needs a highly penetrating etchant.[43] The most commonly used etchant is phosphoric acid; there have been reports on the insufficient penetration on the phosphoric acid etchant into the fissure system.[44] Also, failure to achieve a satisfactory bond for fissure sealants may be due to the lack of tag formation following etching due to the prismless structure of the fissure walls which had been demonstrated microscopically by Hoh et al.[45]

Wavelengths in the near infrared and red region of the visible spectrum are poorly absorbed by dental mineral, but they are optimally transmitted and scattered through the sound enamel. This holds true for diode lasers and Nd:YAG laser.[46,47] Laser and fluoride varnish showed 43 % inhibition of pits and fissure lesions and 80 % inhibition of smooth surface lesions compared to the untreated groups.[48]

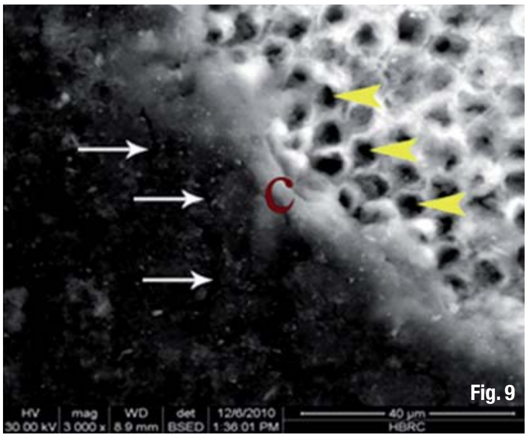


Fig. 9

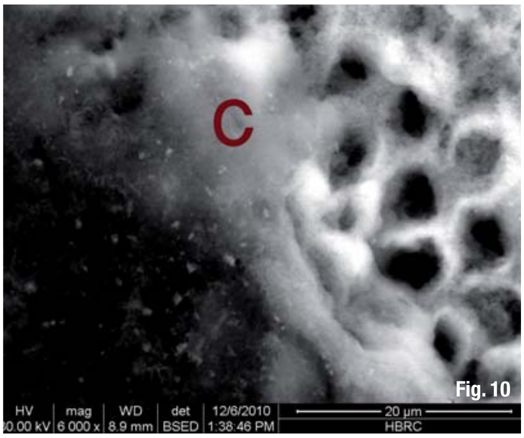


Fig. 10

Fig. 9_ESEM image of group 4 showed few cracks on the sealant (arrows) and enamel ends (arrowheads) at the interface (C) (BSED) x3,000.

Fig. 10_Higher magnification of the previous figure showed sporadic areas of melted sealant material at the interface (C) (BSED) x6,000.

In this study, a 980 nm diode laser was used in order to assess its ability to provide partial to complete closure of the occlusal depressions as an alternative method to pit and fissure sealants.

Some reports have shown that the low power red laser can induce caries prevention and as it does not promote heating, the mechanism of action must be different.[49, 50] ESEM micrographs revealed a great difference between lased and unlased ones. So far, no published data are available concerning the effect of a 980 nm high-power diode laser on enamel microhardness.[51] The resulting amorphous and heterogeneous tissues might be due to enamel melting and resolidification.[52] The low absorption coefficient of diode laser wavelength in enamel[53] showed a great benefit as it caused rapid elevation of the surface energy during exposure and rapid decay of temperature once stopped. As a result, the action needed is carried out, but in the same time it did not penetrate deeply so it did not affect the pulp or the underling structures.

The detected surface temperature also provides sterilisation of the fissure depth as streptococcus bacteria die at 60 °C. Group 2 also revealed irregular lateral walls of the pits that might be due to the presence of areas of melted enamel intermingled with carious enamel. In group 4, combination between laser and fissure sealant material was used. The use of different polymerisation methods as the application of heat for additional curing time after polymerisation increases the compressive, flexural strength, hardness, tensile strength and wears resistance.[26] This secondary curing procedure caused increase in the chain vibration amplitude, allowing free radicals and methacrylate groups to collide and establish covalent links, increasing the degree of conversion.[54]

Light cured materials have disadvantages such as limited depth of cure and poor distribution of degree of conversion (DC) in cured resin.[55] The high DC of the used sealant in this research could result from a light attenuation of the thinner sealant which is less than that seen in 2 mm composite increment. Another factor causing this higher DC might be a lower viscosity as fissure sealants have less filler content to penetrate into pits and fissures. This great DC of the used sealant was reflected into greater curing shrinkage and consequently, poor marginal adaptation.[36]

To overcome this shrinkage probability of the sealant, laser was applied to the sealant enamel interface areas to melt the enamel and the sealant material found at the interface as well as get rid of the possible gap formation by melting and recrystallisation of enamel layer at this interface. These findings were in accordance with Yoshiharu et al. who proved that the Knoop hardness at the surface of composite was increased with CO_2 laser super pulse irradiation 10 sec with 1 W after light curing.[29]

The fluoride content of the sealant may also increase the caries resistance due to the formation of flour apatite in order to overcome the failure of sealant enamel interface. Thus, the recorded microhardness in group 4 that was the greatest between the groups was explained by flour apatite crystals as well as the presence of melted enamel that caused the rod and interrod region._

Editorial note: A list of references is available from the publisher.

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