Effect of veneering thickness and repeated firing on the flexural strength and translucency of lithium disilicate glass ceramic

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Abstract:

Objective: To evaluate effect of veneering thickness and repeated firing on the flexural strength and translucency of lithium disilicate glass ceramic.

Materials and methods: Sixty-three-disc specimens were divided; each group have 21 discs specimens. First group was lithium disilicate core 1 mm with no veneering coverage, second group the lithium disilicate core was veneered by 0.5 mm nano flouroapatite glass ceramic. Third group was lithium disilicate core veneered by 1 mm nano flouroapatite glass ceramic. Each group was subjected to repeated firing cycles (3, 5, 7). Seven-disc specimens for each firing cycle were used to measure translucency then flexural strength. The degree of color difference between the compared colors was expressed in ΔE units. The total color difference, according to L*, H*, C* coordinates, was calculated. Then change in TP (ΔTP) which is the difference between first and second sample regarding thickness and firing cycles was measured to determine the acceptability threshold. Then fracture load was applied to all specimens fixed on 3 balls fixture under static compressive loading using universal testing machine to determine the flexural strength. The results were tabulated and statistical analysis was performedusing repeated way ANOVA method.

Results: Regarding value, chroma and hue, in 3 firing cycles value means revealed a significant difference in the comparison between 1 mm, 1.5 mm (P=0.001) thickness and between 1 mm, 2 mm (P=0.001) but non-significant difference was shown between 1.5 mm and 2 mm (P=0.325). While chroma and hue showed significant difference in comparison between 1 mm, 1.5 mm and 2 mm (P=0.001). However, in 5 firing cycles, value showed significant difference between 1 mm, 1.5 mm and 1 mm, 2 mm (P=0.001) and also between 1.5 mm, 2 mm (P=0.016), and chroma also showed significant difference between 1 mm, 1.5 mm, 2 mm (P=0.001), and hue showed significant difference between 1 mm, 1.5 mm (P=0.027), and also between 1 mm, 2 mm and 1.5 mm, 2 mm. However, in 7 firing cycles, value showed significant difference in comparison between 1 mm, 1.5 mm (P=0.001) and 1 mm, 2 mm (P=0.001) but non-significant difference was revealed between 1.5 mm, 2 mm (P=0.053). While chroma showed significant difference between 1 mm, 1.5 mm and 2 mm (P=0.001), while hue showed significant difference in comparison between 1 mm, 1.5 mm (P=0.001) but non-significant difference was found between 1 mm, 2 mm (P=0.11) and 1.5 mm, 2 mm (P=0.148). Translucency parameters revealed a significant difference (P=0.001) between different firing cycles with different thickness. Flexural strength showed no significant decrease with increasing firing cycles from 3 to 5 firing cycles in the same 1 mm thickness (P=0.153) and showed significant decrease on increasing firing cycles from 3 to 7 cycles (P=0.001) and 5 to 7 cycles (P=0.005). While in 1.5 mm thickness showed significant decrease in flexural strength on increasing firing cycles from 3 to 5 cycles (P=0.013) and from 3 to 7 cycles (P=0.001) and showed no significant decrease on increasing firing cycles from 5 to 7 cycles (P=0.073). While in 2 mm thickness showed significant decrease in flexural strength on increasing firing cycles from 3 to 5 cycles (P=0.015), 3 to 7 cycles (P=0.001) and 5 to 7 cycles (P=0.03).

Conclusions:

1- Translucency decreased on increasing the firing cycles and increasing the veneering thickness.
2- Flexural strength increased on increasing veneering thickness and decreased on increasing the firing cycles.

Keywords: Lithium disilicate, nano flouroapatite glass ceramic, translucency, flexural strength.

Introduction

Over the last years dental ceramics field had released rapidly in material properties and manufacturing methods. They are used for restoring damaged, decayed, or missing teeth. An important advancement is the introduction of glass ceramics withexcellentesthetic and mechanical characteristics as well as and advancementsin computer based design and manufacturing technology.[1]

Metal-free ceramic restorationis a popular restorative choice, predominantlydue to structural and esthetic features that are linkedto improved materials'characteristicsand manufacturing technologies which allowed for monolithic and multilayer ceramic restorations, with high crystalline content.[2]

Lithium disilicate are esthetic dental materials known by high strength, enhanced translucency and color matching with natural teeth, thus has led to usage of lithium disilicate glass ceramics in different dental fields like veneers and anterior, posterior crowns.[3]

Nano-flouroapatite and feldspathic glass ceramics are oftenutilized as veneering porcelain coatings on zirconia or lithium disilicate glass ceramics due to their superior esthetic properties and biocompatibility.

The veneering thickness has a noticeable affection on the strength and color of lithium disilicate glass ceramic, also repeated firing cycles change mechanical and physical properties of lithium disilicate.[4]

Translucency is one of the most significant optical characteristicsthat affect color of the tooth and its simulation to natural appearance, that is mainly affected by composition of material, microstructure and crystalline contents.[5]

Most recently, dental manufacturers and laboratories introduced high translucent lithium disilicate ceramics and nano flouroapatite glass ceramic veneer coverage of lithium disilicate core that ensure superior translucency depending on thickness and number of firing cycles.[6]

Flexural strength is the stress in a material just before it yields in a flexure test, the biaxial flexural strength is detected by support of a disc specimen on 3 metal spheres placed at equal distances from each other and from disc center. A rounded end piston is used to apply the load on the center of the opposite surface.[7]

The thickness of ceramic overlay and the cooling rate at temperatures exceeding the glass transition temperature. The nature of stresses(compressiveversus tensile), influences ceramics' strength where compressivestressenhances strength whiletensile stressenhancescrack propagation under occlusal loads.[8]

The most important factors to get better contour, color, and esthetic features is repeated firingswhich are essential for fabricatingall-ceramic restorations. The influence of repeatedfiring on porcelain adhesion is stillindistinct. Remaining stresses couldpossiblyundergo accumulation during heating and cooling firing processes, predominantlydue to the cooling rate and the difference in coefficient of thermal expansion.[9]

Materials and Methods

Specimen Preparation: Heat pressed lithium disilicate glass ceramics (e.max shade A_2), nano flouroapatite glass ceramics (IPS Ceram Ti_1transepta incisal) discs were designed digitally by Auto Meshmixer (Meshmixer version 3.5, Auto desk, California USA) to give three STL (Standard Tessellation Language) files first with 1 mm thickness core, second with 1 mm thickness core and 0.5 mm veneering porcelain and third file is 1 mm core and 1 mm veneer. The resultant STL file was transferred to be milled by Arum Doowon milling machine (Arum version 5x-400 Daejaeon, Arum dentistry, Korea). Discs wax pattern were prepared by Millbox application (Millbox version 2020, CIM system manufacturing, Milano, Italy) to be ready for milling.

The 1 mm discs was used to prepare all specimen while 1.5 mm, 2 mm discs will be used as an indicator for mold fabrication for buildup of veneering layer with different thickness.

Specimens grouping: Sixty-three-disc specimens were divided; each group have 21 discs specimen. First group was lithium disilicate 1 mm with no veneering coverage, second group the ceramic core was veneered by 0.5 mm nanoflouroapatite glass ceramic, third group the glass ceramic core was veneered by 1 mm nanoflouroapatite glass ceramic.

Each group was subjected to repeated firing cycles (3, 5, 7). Seven-disc specimens for each firing cycle were used to measure translucency then flexural strength.

Veneer buildup: Lithium disilicate discs that act as control group 1 mm were inserted in two pre-fabricated stainless mold one with anoveralldepth of 1.5 mm and the second mold with a total depth of 2 mm with same dimensions of mold 12 mm.

The goal of not changing the core thickness while veneering porcelain'sthickness was altered to assess the influence of veneering thickness on color and strength thoughits clinical simulation.The remaining depth filled with nanoflouroapatite glass ceramic veneer in both molds to accommodate the remaining 0.5 mm space in the first mold and 1 mm space in the second mold. Nanoflouroapatiteunderwentmixing with respective liquid tillthe consistency became creamy,thenwas applied to lithium disilicate core in drop shaped increments followingwashing from dirtyor greasysubstance then underwent adequate condensation until all the space was completely filled.

First layer is the foundation layer that was used to increase bond strength between the core and veneer also decrease shrinkage after firing.Then begin firing on the foundation program using programat P500 for 10 mins (Programat P500, Ivoclarvivadent, Leichtenstein).

Repeated firing: removal of veneered slices from the mold was performed by moving the scale anticlock wise as shown in Figure 20 and put it in a ceramic firing furnace at the first firing cycle on 730°C using programat P500 program 17 for 15 mins (Programat P500, Ivoclarvivadent, Leichtenstein).

After ending first firing cycle buildup of veneer to full thickness was done for 1.5 mm and 2 mm diameter then repeated firing is done for second and third firing cyles then repeated firing divided according to each group on the same firing program on 720°C as shown in Figure 22 till the seventh firing cycle.

Translucency determination: The degree of color change between the compared values was calculated. The translucency parameters, according to L*, H*, C* coordinates, was calculated as shown in the equation:TP=$\sqrt{(\Delta L)2 + (\Delta H)2 + (\Delta C)2}$, while ΔL was the change in value, ΔH was the change in hue, and ΔC was the change in chroma.

Then change in TP (ΔTP) which is the difference between first and second sample regarding veneering thickness and firing cycles was measured to determine the change intranslucency according to change in veneering thickness and change in firing cycles.

Biaxial Flexural strength measurement: Before measuring the flexural strength, special fixture is made to hold the disc specimen with the same disc diameter 12 mm holding on three steel balls support positioned 120^o apart and each ball diameter is 3 mm with full average height of the fixture is 1.5 mm.

The fixture is fixated to the base of universal testing machine (Universal testing machine Instron 3345, Instron Co., USA) with a holding stainless pen from above with rounded tip 1.5 mm diameter which is the load cell of the deviceas shown in Figure 26, that was utilized to assess the biaxial flexural strength through applying compression stress with lithium disilicate surface is faced up. The static stress was applied at 0.5 mm/minutetilloccurrence of the fracture.

The maximum fracture underwentrecording at the first sign of fracture, which confirmed by alterations in deflection curve. The maximum load prior to fracture was utilizedfor calculating the 3-point flexural strength according to the equation given in the ISO 6872(2015):σmax=−0.238 7P(X−Y)/b2

Where σmax is the maximum center tensile stress in MPa, P is the total load causing fracture in Newton, and b is the specimen thickness in mm. X and Y underwentdetermination as follows:X=(1+ν) ln(r2/r3)2+[(1−ν)/2] (r2/r3)2, Y=(1+ν) [1+ln(r1/r3)2] +(1−ν) (r1/r3)2. Where ν is Poisson's ratio and is taken as the mean value between the Poisson's ratios of lithium disilicate (0.25), r1 is the support circle's radius (mm), r2 is the loaded area'sradius (mm), and r3 is specimen'sradius (mm).

Scanning Electron Microscope: Qualitative evaluation of surface topography and properties for two specimens in each group was doneusing SEM, the surfaces were wiped using ethyl alcohol and dried, specimens were fixed securely in a solution of a buffered chemical fixative in the SEM chamber (Scanning electron microscope version JEOL JSM-6360 LV, Japan) using a double-sided carbon tape.

Statistical analysis: Data were analysed by the statistical package of social science (SPSS) software for windows (version 24). The normality of data was first tested using Shapiro test.Repeated way ANOVA Test was used for parametric quantitative variables forcomparison between more than 2 groups.For all of the statistical tests in illustrated study, the threshold of significance (p-value) was 5% level.

Results: Value, hue and chroma were measured against black background to detect change in translucency level. Repeated way ANOVA test revealed that in 3 firing cycles value had a significant difference in the comparison between 1 mm, 1.5 mm (P=0.001) and between 1 mm, 2 mm (P=0.001) but non-significant difference was found between 1.5 mm and 2 mm (P=0.325). While chroma showed significant difference in comparison between 1 mm, 1.5 mm and 1mm, 2 mm and also between 1.5 mm and 2 mm (P=0.001) and also hue showed significant difference in comparison between 1 mm, 1.5 mm and between 1 mm, 2 mm and also between 1.5 mm and 2 mm (P=0.001). However, in 5 firing cycles, value showed significant difference between 1 mm, 1.5 mm and 1 mm, 2 mm (P=0.001) and also between 1.5 mm, 2 mm (P=0.016), and chroma also showed significant difference between 1 mm, 1.5 mm, 2 mm (P=0.001), and hue showed significant difference between 1 mm, 1.5 mm (P=0.027), and also between 1 mm, 2 mm and 1.5 mm, 2 mm. However, in 7 firing cycles, value showed significant difference (P=0.001)in comparison between 1 mm, 1.5 mm (P=0.001) and 1 mm, 2 mm;however non-significant difference between 1.5 mm, 2 mm (P=0.053). While chroma shows significant difference between 1 mm, 1.5 mm and between 1 mm, 2 mm and also between 1.5 mm and 2 mm (P=0.001), while hue showed significant difference in comparison between 1 mm, 1.5 mm (P=0.001) and no significant difference between 1 mm, 2 mm (P=0.11) and 1.5 mm, 2 mm (P=0.148).Change in translucency revealed a significant difference between different firing cycles with different thickness(P=0.001). Flexural strength showed no significant decrease with increasing firing cycles from 3 to 5 firing cycles in the same 1 mm thickness (P=0.153) and showed significant decrease on increasing firing cycles from 3 to 7 cycles (P=0.001) and 5 to 7 cycles (P=0.005). While in 1.5 mm thickness showed significant decrease in flexural strength on increasing firing cycles from 3 to 5 cycles (P=0.013) and from 3 to 7 cycles (P=0.001) and showed no significant decrease on increasing firing cycles from 5 to 7 cycles (P=0.073). While in 2 mm thickness showed significant decrease in flexural strength on increasing firing cycles from 3 to 5 cycles (P=0.015), 3 to 7 cycles (P=0.001) and 5 to 7 cycles (P=0.03).

Discussion: There is a high demand for natural teeth appearance these days. For this reason, there is a high demand for tooth-colored restorations, this led to all-ceramic systems which are metal-free restorations havingexcellent esthetic properties. Lithium disilicate is the material of choice because of its one of high aesthetic restorations with high strength that can be adhesively bonded.[10]Variant thickness was used 1 mm, 1.5 mm and 2 mm, according to the manufacturer. Preparations for anterior teeth must include a reduction of 1 mm at cervical region, 1.2 mm at axial walls, and 1.5 mm at incisal/occlusal margin; in posterior teeth, a reduction must be 1 mm at cervical region while 1.5 mm at other aspects. This appears inadequate to mask the color of ceramicsthat underwent cementation on a darker substrate, increasing ceramics' thickness enhancestheir opacities, reduces light transmission, allows light scattering, and decreases their translucencies, therefore reducing the effect of substrate color.[11]

Clinically, several factors can influencefracture resistance of ceramic crowns such as adhesive method, bonding surface treatment, composition, as well asceramic's thickness.In particular, the thickness plays a main role in determination ofFR. It wasshownthat monolithic zirconia crowns hadbetterFRandminimal invasive preparation of natural teeth when comparedto classical bilayer crowns. However, data regardingthe effect of the thickness of monolithic lithium disilicate ceramic crowns on FRremains scarce. Hence, the currentworkwas conducted for evaluation of the fracture behavior of monolithic crowns and lithium disilicate ceramics with various thicknesses.[12]

In studies on the repeated firing of glass ceramics, firing periods were limited to between one and nine times, the first firing is for eliminating micro-cracks and releasing stresses linked to grinding and polishing. The second and the third firings are essential for production ofrestorationsutilizing the staining or layering procedure, before installation in the oral cavity, the forth and succeeding firings are essential whenevera correctionfor the shape and the color isneeded. It was stated that, following the third firing, restorationsare ready to be installed in the oral cavity, the last 4 firings, following the third one, were reported to be important only whenevera correctionfor the shape and the color isneeded.[13]

Translucency of all ceramic restorations is very important; but, a perfect natural-like color is not ensured, lithium disilicate-reinforced glass-ceramic restorations are of interest because of their reduced refractive index, making themextremely translucent in spite of theincreased crystalline content. Consequently,theyare appropriate for full contour restorations and the greatest of esthetic demand.[14]

Mechanical properties of lithium disilicate have an important role to withstand the high mastication forces and become high resistant to fracture. Glass-ceramics showed satisfactory mechanical and biologiccharacteristicsincluding flexural strength, fracture load, reduced thermal conductivity as well as insignificant plaque accumulation. Ceramics are different in composition; mechanical and optical characteristics are affected by such structure and crystalline content. Thus reinforcement of lithium disilicate produces glass-ceramics having a flexural strength approximately 2–3 foldgreatercompared withthenon-reinforced restorations.[15]

Translucency parameter significantly decreased on increasing thickness. Repeated firings significantly affected the translucency of lithium disilicate glass-ceramic as a result the translucency increased with decreasing thickness.[16]The first null hypothesis that repeated firings and thickness would not influence the translucency of monolithic glass-ceramics was partially rejected.

Regarding fracture resistance and flexural strength, this result showed that strength is increasing on increasing thickness and decreased by repeated firing.It was reported that an increase in fracture resistance would be accomplished when ceramic thickness is increased with a thickness range 1.0–1.2 mm.[17]

The result also showed significant change in the comparison between all the studied groups except for the comparison between 3 and 5 firing cycles in 1 mm thickness and comparison between 5 and 7 firing cycles in 1.5 mm. Gulden Sinmazisik[18] stated that, there has been a debate on whether different processing procedures would result in dissimilar strength of the final dental ceramic restoration.[19,20]

Within limitations of this study, standardization of the veneer layer after repeated firing need to be accurate and re-added to the desired thickness after each firing cycle. The usage of more types of glass ceramics with more variations in sample thickness and changing firing cycles will be critical to get the most translucent and high strength material.

Conclusions: Translucency decreased on increasing the firing cycles and increasing the veneering thickness. Flexural strength increased on increasing veneering thickness and decreased on increasing the firing cycles.

Table (1): L, C, H against black background

Firing cycles		1 mm Thickness	1.5 mm Thickness	2 mm Thickness	P total	P1	P2	P3
3 Firing cycles	L	76.35±0.30	78.57±0.33	78.76±0.21	≤0.001*	0.001*	≤0.001*	**0.325**
	C	11.17±0.17	13.41±0.17	15.16±0.21	≤0.001*	≤0.001*	≤0.001*	**≤0.001***
	H	92.20±0.44	90.91±0.32	86.70±0.28	≤0.001*	0.01*	≤0.001*	**≤0.001***
5 Firing cycles	L	75.23±0.21	77.39±0.20	77.86±0.22	≤0.001*	≤0.001*	≤0.001*	**0.016***
	C	13.19±0.14	14.74±0.16	16.47±0.15	≤0.001*	≤0.001*	≤0.001*	**≤0.001***
	H	85.82±0.30	84.95±0.42	82.26±0.32	≤0.001*	0.027*	≤0.001*	**0.001***
7 Firing cycles	L	74.65±0.17	76.92±0.20	77.39±0.21	≤0.001*	≤0.001*	≤0.001*	**0.053**
	C	13.67±0.16	15.49±0.18	16.82±0.17	≤0.001*	≤0.001*	≤0.001*	**≤0.001***
	H	80.90±0.46	83.59±0.30	82.48±1.51	0.005*	≤0.001*	0.11	**0.148**

Repeated measured ANOVA test

L: Value of color

C: Chrome of color

H: Hue of color

P1: Comparison between 1 mm and 1.5 mm thickness

P2: Comparison between 1 mm and 2 mm thickness

P3: Comparison between 1.5 mm and 2 mm

Table (2): Translucency parameter difference according to change in thickness and firing cycles

	1 mm Thickness	1.5 mm Thickness	2 mm Thickness	ANOVA P value	P1	P2	P3
3 Firing cycles	11.12±0.09	8.74±0.19	6.35±0.10	F=148.0 P≤0.001*	≤0.001*	≤0.001*	≤0.001*
5 Firing cycles	9.88±0.17	7.74±0.12	5.61±0.14	F=208.7 P≤0.001*	≤0.001*	≤0.001*	≤0.001*
7 Firing cycles	8.69±0.12	6.79±0.10	4.88±0.12	F=313.0 P≤0.001*	≤0.001*	≤0.001*	≤0.001*

P1: Comparison between 1 mm and 1.5 mm thickness

P2: Comparison between 1 mm and 2 mm thickness

P3: Comparison between 1.5 mm and 2 mm thickness

Table (3): Change in translucency for different thickness 1 mm, 1.5 mm and 2 mm

	Difference between 3 and 5 firing cycles (Group A)	Difference between 3 and 7 firing cycles (Group B)	Difference between 5 and 7 firing cycles (Group C)	ANOVA P value	P1	P2	P3
Thickness 1 mm	2.38± 0.09	3.26± 0.07	1.26±0.08	F=158 P≤0.001*	≤0.001*	≤0.001*	≤0.001*
Thickness 1.5 mm	1.13± 0.15	1.99± 0.11	0.95± 0.08	F=372 P≤0.001*	≤0.001*	0.007*	≤0.001*
Thickness 2 mm	1.06±0.13	1.61± 0.21	0.95± 0.35	F=42.11 P≤0.001*	≤0.001*	0.352	≤0.001*

F: Repeated measured ANOVA test, *significant p≤0.05

P1: Comparison between difference between 3 & 5 firing cycles and difference between 3 & 7 firing cycles

P2: Comparison between difference between 3 & 5 firing cycles and difference between 5 & 7 firing cycles

P3: Comparison between difference between 3 & 7 firing cycles and difference between 5 & 7 firing cycles

P1, p2, p3 by Paired t test

Table (4): Flexural strength (N) comparison between the studied groups

Flexural strength (N)	Group (A)	Group (B)	Group (C)	ANOVA P value	P1	P2	P3
Thickness 1 mm	380.44± 37.97	356.37± 25.10	304.47± 25.68	F=11.58 P=0.001*	0.153	≤0.001*	0.005*
Thickness 1.5 mm	412.40± 32.92	373.98± 17.46	347.56± 24.99	F=11.08 P=0.001*	0.013*	≤0.001*	0.073
Thickness 2 mm	451.21± 29.63	413.48± 29.10	380.44± 18.32	F=12.77 P≤0.001*	0.015*	≤0.001*	0.03*

Group A: 3 firing cycles.

Group B: 5 firing cycles.

Group C: 7 firing cycles.

P1: Comparison between group A and group B.

P2: Comparison between group A and group C.

P3: Comparison between group B and group C.

Figures

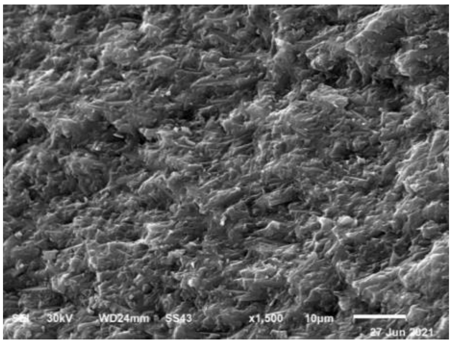

Figure 1: Lithium disilicate core 1 mm with no veneer covering layer in 3 firing cycles x1500 magnification

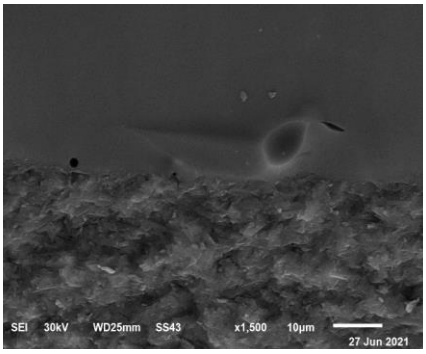

Figure 2: Lithium disilicate core 1 mm and veneer layer 0.5 mm in 3 firing cycles x1500 magnification

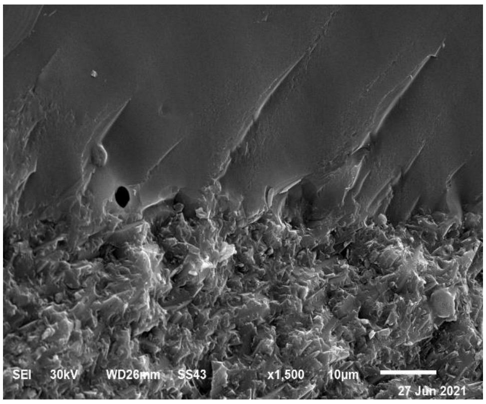

Figure 3: Lithium disilicate core 1 mm and veneer layer 0.5 mm in 7 firing cycles x1500 magnification

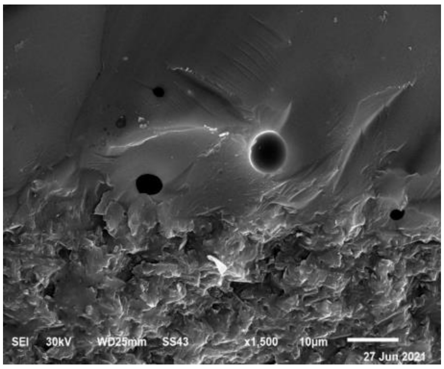

Figure 4: Lithium disilicate core 1 mm and veneer layer 1 mm in 7 firing cycles x1500 magnification

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