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THE INFLUENCE OF THERMAL TEMPERATURES ON THE TRANSLUCENCY AND FLEXURAL STRENGTH OF LITHIUM DISILICATE AT DIFFERENT THICKNESSES

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ABSTRACT

The production of dental restorations made from lithium disilicate via (CAD/CAM) technique necessitates thermal treating, a critical action that influences the optical and mechanical characteristics of ceramics. The main goal of this study was to investigate how using various thermal refinement processes and thicknesses affected the flexural strength and translucency of lithium disilicate glass-ceramic for CAD/CAM applications. This was achieved by taking the measurements of the total light transmission using a spectrophotometer through the specimens and determining the maximum loading at fracture using a piston-on-three-ball test. Results showed that thicker specimens exhibited reduced translucency and decreased flexural strength ($p < 0.05$). In addition, the biaxial flexural strength was highest in the thermally processed lithium disilicates at 820 degrees ($p < 0.05$). Nevertheless, for each temperature group, a significant difference was seen only between0.5 mm and 2 mm ($p < 0.05$). These results suggest that translucency and strength may be adjusted to suit clinical requirements by selecting appropriate thicknesses and thermal refining procedures.

KEYWORDS: lithium disilicate; translucency; flexural strength; thermal temperature; thickness.

INTRODUCTION

Lithium disilicate glass-ceramic is widely regarded as one of the leading materials for dental restorations, owing to its exceptional mechanical strength and attractive aesthetic characteristics[1]. Recently, (CAD/CAM) systems have emerged as the primary methods for the production of restorations using LD glass-ceramic. These systems exhibit reduced technical sensitivity, enabling the creation of more intricate and accurate restorations while simultaneously decreasing both time and expenses.[2,3]

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Additional heat processing is essential to produce dental restorations utilizing lithium disilicate within the CAD/CAM framework. The steps to make LD glass-ceramics for CAD/CAM include processing the material via milling then concluding heat treating known as crystallization [4] .

One way to make milling work better is by using partially crystallize lithium metasilicate (LM, Li2SiO3). This approach improves cutting efficiency, enhances efficiency during operation, and extends tool life for milling because of its moderate to low strength and hardness. [5] Subsequent heat treatment that follows milling alters the ceramic's structure, which in turn destabilizes LM and encourages the development and maturity of LD [6,7]. It is crucial to think about how supplementary heat treatment changes the optical and mechanical characteristics of LD when assessing the efficacy of ceramic treatments in dental clinics. (8).

Translucency is important in the process of assessment of the aesthetic results of dental ceramics. Light transmission has been identified as an effective approach for assessing the translucency of ceramics materials. [9]

Mechanical strength is crucial for dental restorations' clinical efficacy and durability [10,11]. The process of thermal treatment, which utilizes temperature to dissolve LD, causes variations in crystal size that subsequently impact the mechanical and optical characteristics of ceramics [12] .

Ceramic thickness, which is affected by the extent of tooth reduction, plays an essential part in determining the optical and mechanical characteristics of ceramic materials [13]. Prior research has identified the translucency parameter associated with dental ceramics., which comprises glass-ceramics and zirconia ceramics, is greatly affected by thickness, and that the value decreases as thickness increases [14]. Further, all of the ceramic materials that were tested cores made of glass infiltrated-aluminum-oxide, LD-reinforced glass-ceramic, and Y-stabilized zirconia showed an increase in biaxial flexural strength values with core thickness, irrespective of the effects of age [15]. According to another study, variations in thickness did not produce any significant impact on the flexural strength of two specific dental ceramic materials: [16] Understanding the mechanical and optical features at various thicknesses is vital for dental physicians to help them identify clinical scenarios that are ideal for LD applications and determine the amount of tooth reduction that is necessary. Thermally refined LD glass-ceramic for CAD/CAM has few studies examining its optical properties and flexural strength at various firing temperatures and thicknesses.

This research aims to assess the translucency and flexural strength of (LD) glass-ceramics subjected to heat processing at various firing temperatures for CAD/CAM applications. The thickness of the glass-ceramics is altered, and the treatments vary in terms of the amount of heat applied. To accomplish this, six distinct fire temperatures were used: 780 °C, 800 °C, 820 °C, 840 °C, and 860 °C, to refine thermally partially sintered LD specimens of 0.5 mm, 1.0 mm, and 2.0 mm thickness, respectively. The ceramics' microstructure and composition were examined using X-ray diffraction-(XRD), while their mechanical and optical properties were assessed. The proposed null hypotheses are these.; First, that LD glass-ceramics' translucency and flexural strength are unaffected by the thermal refinement temperature; second, that these attributes are unaffected by the ceramic's thickness.

MATERIALS AND METHODS

1-Sample Size Calculation

A power analysis was conducted to statistically test the null hypothesis, which claims that the groups being tested are statistically equal. We calculated the sample size for each subgroup using power estimates that were based on data from prior studies in this investigation a minimum of 5subjects

per group was necessary, assuming a normal distribution of response within each group with a standard deviation of 4.15.[36]

2-Ethical approval:

The research protocol obtained authorization from the Research Ethics Committee of the Faculty of Dentistry at Minia-University

3-Sample grouping:

A total of 75 disc-shaped samples, each with a diameter of 10 mm. Specimens were divided in to three main groups according to thickness: 0.5 mm, 1.0 mm, and 2.0 mm (25 samples per thickness). The groups were ordered into five subgroups (five for each) n= 5 according to firing temperatures:

Subgroup (I): Samples were subjected to 780˚C.

Subgroup (II): Samples were subjected to 800˚C.

Subgroup (III): Samples were subjected to 820˚C.

Subgroup (IV): Samples were subjected to 840˚C.

Subgroup (V): Samples were subjected to 860˚C.

4-Preparation of Glass Ceramic Blocks

A total of 75 disc-shaped samples, each with a diameter of 10 mm, were fabricated from partially crystallized (Amber-mill HASS, HASSBIO, Gangneung, Korea) utilizing a cutting machine (Isomet Low-speed, Buehler, USA) while maintaining continuous water cooling. These samples were produced in three distinct thickness: 0.5 mm, 1.0 mm, and 2.0 mm (25 samples per thickness). Each sample faced a comprehensive series of surface grinding and polishing procedures using wet silicon carbide paper with grits of 600, 800, 1000, and 1200 (Carbi Met, Buehler, USA) in a grinder/polisher machine (EcoMet 30, Buehler, USA). Subsequently, they were subjected to distinct heat treatments at five varying firing temperatures, with five specimens allocated to each temperature group. Following the firing process, each sample underwent a wet finishing process on both surfaces using 1200-grit silicon carbide paper in the grinder/polisher machine, followed by ultrasonic cleaning in distilled water for ten minutes, then dried using compressed air. The ultimate thickness of each specimen was measured with a digital Caliper (INSIZE, Jiangsu, China), which has an accuracy of ±0.05 mm.

5-Heat-Treatment Schedule:

Following a 3-minute standby period at 400˚C, the temperature was increased at a rate of 60˚C per minute to five distinct firing temperatures: 780, 800, 820, 840, and 860˚C, with a subsequent holding time of 15 minutes. This procedure was carried out utilizing a furnace.(Ivoclar Vivadent Programat- Schaan, Liechtenstein). The glass blocks (Prototype-HASS, Gangneung, Republic of Korea) were burned and subjected to heat treatment to promote crystallization in a sequential manner.

6-X-ray Diffraction (XRD):

The LD glass-ceramic's crystalline phases were identified by selecting and grinding into fine powder specimens that had undergone heat treatment at five distinct firing temperatures. The data for this experiment was collected using a CuKα radiation-powered X-ray diffractometer (X pert pro, USA:PW3040/60) with a scanning speed of 6°/min, covering the 2θ range of 10° to 60°.

7-Translucency Measurement:

Using a spectrophotometer (Cary 5000,Agilent Technologies,USA) Figure 1. we measured the total light transmission through the materials at wavelengths ranging from 400 to 700 nm to determine their transparency. We measured each sample three times and then multiplied the findings by 100 to get the average percentage of total transmission (T%). The value of Lsource was recorded as a baseline for each measurement,The calculation of (T%) was performed utilizing the specified formula:

{T% = (Lspecimen/Lsource) × 100. Lsource}

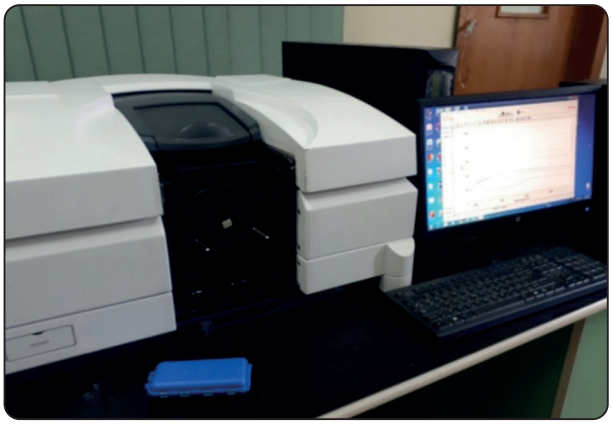

Fig. (1) Spectrophotometer

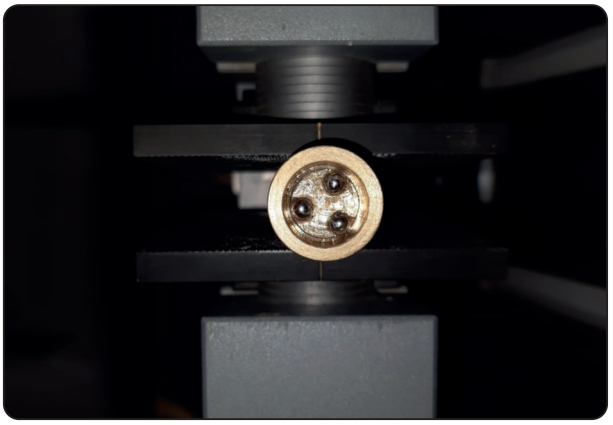

Fig. (2) A piston-on-three-ball test mounted to lower part of instron testing machine

8-Biaxial Flexural Strength:

An Instron-3345 universal testing equipment was used to conduct a pistonon-three-ball test in accordance with the International Organization for Standardization (ISO) 6872:2015 standard in order to ascertain the biaxial flexural strength [16]. Figure 2

Samples were set in the middle of support circle atop three 3-mm-diameter steel balls that were 120° apart. By use of a 1.2 mm-diameter flat punch-shaped rod, a force of 1 mm/min was applied to the specimen's center until fracture was achieved. Biaxial flexural strength was determined by calculating the peak load at failure (MPa). Figure 3

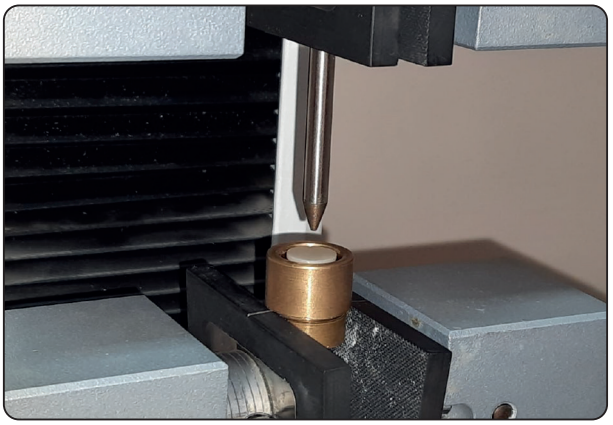

Fig. (3) Biaxial Flexural Strength for Specimens

9-Statistical Analysis:

The descriptive data on flexural-strength and translucency were shown as means ± standard deviation. The data exhibited a non-normal distribution., as shown by the Shapiro-Wilk test, which is used to test for distribution normality in small samples (p-value less than 0.05). We used a Kruskal-Wallis test to conduct a comparison and contrast the groups since the study groups were totally independent of each other. We did it all over again if the findings revealed statistically significant variations across the samples. Statistical significance was defined as a p-value below 0.05.

RESULTS

X-ray Diffraction Analysis:

The X-ray diffraction (XRD) patterns of the LD glass-ceramic were studied at a range of firing temperatures. Notable peaks were seen at 2θ values of 23.85, 24.39, and 24.88, indicating that the LD crystalline phase was the predominant one. Specimens exposed to elevated temperatures demonstrated an increased peak intensity of LiDi. Also, firing temperatures from 780 to 840°C showed a rise in the SiO2 corresponding peaks, which subsequently fell somewhat at 860°C.

Table 1 displays the main particle size of LiDi at various firing temperatures. The major particle

TABLE (1) The main particle size (in nanometers) of LD glass-ceramics at various firing temperatures (in degrees Celsius).

Temperature	780	800	820	840	860
Primary Grain Size	27.6± 4.9	31.4±1.8	33.76± 3.6	34.8±2	36.7±8

size increased as the firing temperature rose, which varied between 27.6± 4.9nm at 780°C and 36.7±8.0 nm at 860°C.

Translucency

Figure 4 demonstrates the influence of firing temperatures and thickness on the apparent translucency of glass-ceramic specimens made of lithium disilicate.

Figure 5 shows that the translucency varies with the given firing temperatures and thicknesses. When tested at temperatures ranging from 780 to 840 degrees Celsius, 800 to 820 degrees Celsius, and 820 to 840 degrees Celsius, the 0.5 mm specimens exhibited significant changes in translucency. The 1 mm specimens demonstrated significant differences in translucency when subjected to tests conducted at temperatures spanning from 780 to 840, 780 to 860, and 820 to 860°C. Between 780 and 800°C, 780 and 860 °C, and 840 to 860 °C was a statistically significant range for the 2 mm specimens.

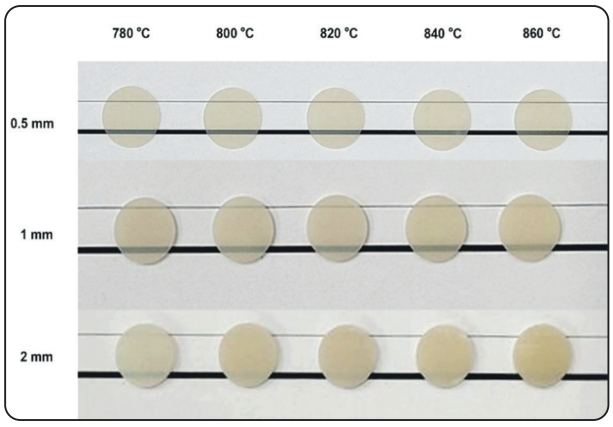

Fig. (4) The influence of firing temperatures and specimen thickness on their perceived translucency.

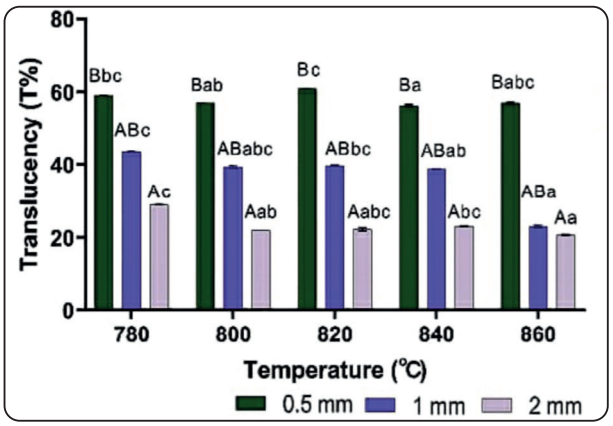

Fig. (5): An analysis of translucency (T%) was conducted across various specified firing temperatures (°C) and thicknesses (mm).

It was showed that the translucency reduced as the thickness increased while examining the various firing temperature groups' metrics. There was a statistically significant difference in the translucency values among the groups of target firing temperatures, even within each temperature range ($p>0.05$).

Identical letters (capital letters for comparisons of translucency across different thicknesses at the same firing temperature and small letter for comparisons of translucency across different temperatures at the same thickness) denote homogeneous portion within the test groups ($p>0.05$).

Table 2 shows the relationship between thickness and translucency as a function of temperature. Translucency decreased significantly ($p<0.05$) when the specimen diameters grew from 0.5 mm to 2 mm. Different sets of firing temperatures did not exhibit a statistically significant difference ($p > 0.05$) in the translucency values.

TABLE (2) The relationship between thickness and temperature in relation to translucency (T%).

Thickness (mm)		**0.5**	**1**		**2**
		54.18 ±1.66 [c]	38.71±3.36 [b]		25.44 ±3.76 [a]
Temperature (˚C)	**780**	**800**	**820**	**840**	**860**
	44.93± 12.09 [a]	40.67± 26.19[a]	42.12±15.89[a]	38.35 ± 15.52[a]	37.15 ± 13.67[a]

Similar superscript letters denote homogeneous subsets within the experimental groups (p>0.05).

TABLE (3) The correlation between thickness and temperature in relation to biaxial flexural strength (MPa) are as follows:

Thickness (mm)		**0.5**	**1**		**2**
		587.18 ± 91.87 [b]	652.69 ± 128.9 [c]		509.38 ± 85.56 [a]
Temperature (˚C)	**780**	**800**	**820**	**840**	**860**
	537.47 ± 123.23[a]	565.11 ± 135.44[ab]	835.34 ±129.71[c]	612.35± 101.48[c]	575.67±53.16[b]

Similar superscript letters denote homogeneous subsets within the experimental groups (p>0.05).

3-Biaxial Flexural Strength:

As seen in Figure 6, biaxial flexural strength was evaluated over a range of firing temperatures and thicknesses. For the 0.5 mm specimens, there was no significant difference in biaxial flexural strength across the temperature groups. Temperature pairings that produced substantially different biaxial flexural strengths for the 1 mm specimens were as follows: 780°C and 820°C, 780°C and 840°C, 800°C and 820°C, 820°C and 860°C, and 840°C and 860°C. The biaxial flexural strength varied considerably throughout many temperature ranges, similar to the 2 mm specimens, including 780°C to 820°C, 780°C to 840°C, 780°C to 860°C, 800°C to 820°C, 800°C to 840°C, and 800°C to 860°C.

There was a clear downward trend for specimens with thicknesses of 1mm, 0.5mm, and 2mm, indicating that the biaxial flexural strength was much higher in the 780°C group. Biaxial flexural strength was significantly lower in the 800°C and 820°C groups for 2mm specimens compared to the other two thickness categories. Treatment of 1mm specimens at 840°C and 860°C resulted in significantly better biaxial flexural strength than the other two thickness groups.

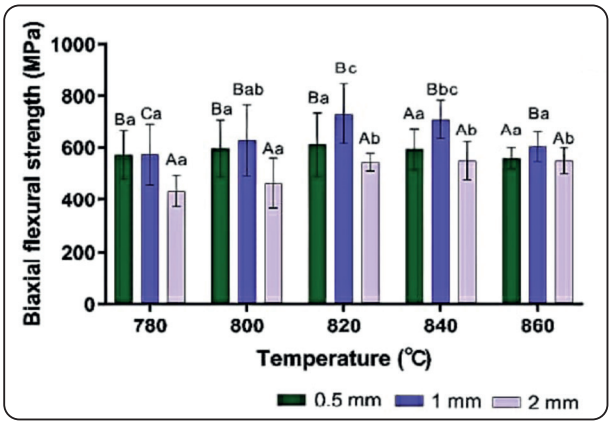

Fig. (6): A comparative analysis of biaxial flexural strength (MPa) was conducted at various designed firing temperatures (°C) and thicknesses (mm).

Identical letters (Capital letters for comparisons of biaxial flexural strength across different thicknesses at the same firing temperature and small

letters for comparisons across different temperatures at the same thickness) signify homogeneous portion within the test groups ($p > 0.05$).

As a function of specimen thickness and firing temperature, the biaxial flexural strength is shown in Table 3. According to the findings, specimens with thicknesses of 1mm, 0.5mm, and 2mm exhibited considerably greater biaxial flexural strength, which subsequently decreased in that sequence ($p < 0.05$). From 820°C to 840°C, 860°C, 800°C, and 780°C, the biaxial flexural strength was significantly higher, however it started to decline after that ($p < 0.05$).

DISCUSSION

Thermal refinement is a crucial part of the CAD/CAM process for creating LiDi dental restorations. There is a strong correlation between the mechanical and optical characteristics of LiDi and its treatment at high temperatures, which may dissolve it. There is a strong correlation between the thickness of the ceramic material and these properties. The goal of this research was to determine the translucency and flexural strength of LiDi glass-ceramics designed for CAD/CAM applications over a variety of firing temperatures and thicknesses. To accomplish this, LiDi samples were subjected to thermal refining at five distinct temperatures (780, 800, 820, 840, and 860 °C) before being evaluated for biaxial flexural strength and translucency. The samples had varying thicknesses of 0.5, 1.0, and 2.0 mm. Thicker specimens were less translucent, and the findings demonstrated a linear decline in flexural strength from 1.0 mm to 2.0 mm. Since thermal refinement temperature influenced both translucency and flexural strength, the null hypotheses were also rejected. When heated, LiDi undergoes a phase change, as shown by equation [18]:

Lithium amorphous + Lithium metathesis = Lithium crystalline.

The most recent XRD findings show that greater firing temperatures lead to larger LD volume fractions. Similarly, the SiO2 volume percentages increased as the firing temperature did; they were highest between 780 and 840°C and then significantly decreased at around 860°C. One possible explanation for these findings might be because β-cristobalite first expands at the expense of the amorphous matrix, as it begins to form at the junction of the LM and the amorphous matrix. As both LM and β-cristobalite are consumed, it is believed that LD occurs at the border between the two in the subsequent stage [19]. Furthermore, these study's findings are in agreement with previous research showing that as the firing temperature of LD glass-ceramics rises, LD crystals transform from tiny, spherical particles into larger, elongated rod-like structures. Due of the poor interaction between LM and SiO2, there are likely not many nucleation sites, which in turn limits the development[20-21]

The results of the current study align with the established findings, a large body of prior research has shown that translucency diminishes with increasing thickness [14,22] . Thicker materials absorb more light, therefore they reflect less of it, according to the Beer-Lambert law. This might explain the phenomenon. Ceramics give off the appearance of impermeability because they disperse and diffusely reflect a great deal of the light that goes through them [9] . Because there are fewer particles per unit volume in thinner materials, they exhibit reduced opacity and less scattering compared to bulkier materials, according to earlier research [23] . While there was no statistically significant difference between the groups categorized by firing temperature, Table 2 reveals that translucency values varied substantially across the various thickness groups. This research suggests that firing temperatures are less important than thickness in determining translucency in LD glass-ceramics utilized in CAD/CAM applications. Scattering effects affected by crystal type and size could go unnoticed due to the fact that crystal size might not change much throughout firing temperatures [24]. Although Figure 3 shows statistical significance in comparisons between the

separate groups, which matches the findings of prior study, although Table 2 did not find any statistical significance.[8,24] .

A notable finding from this research is that flexural strength was somewhat reduced when the temperature increased from 820 to 860 degrees Celsius. Groups heated to 820 and 840 degrees Celsius were hypothesized to have larger, more elongated rod-like LD crystals responsible for the "interlocking effect" than groups heated to 780 and 800 degrees Celsius, which were thought to have smaller crystals. Because fractures are unable to propagate, the fracture propagation path is longer, and the energy required for crack propagation is dissipated, this

interlocking effect is believed to contribute to an increase in flexural strength.[25]

Internal residual strains may become apparent when the density of lowdensity (LD) glass-ceramics decreases below its crystallization temperature. This phenomenon occurs because the glass matrix and the LD phase have different coefficients of thermal expansion (CTEs). In contrast to the CTEs of the glass matrix, which range from 12.2-12.8 × 10–6/K (26-28), the CTEs of the LD phase are measured to be 10.1-10.8 × 10–6/K [26-28]. The increased residual stress due to higher temperatures and larger crystal sizes may lead to microcracking, large fractures at the crystal boundaries, and internal crystal dislocations. Because of the ease with which fractures may propagate under these circumstances, the flexural strength of glass ceramics is reduced [29,30]. An additional unpleasant consequence of crystallization is the formation of irregular crystal particles at very high crystallization temperatures. A typical consequence of this process is microcracking, which may decrease the flexural strength of materials crystallized at 860 °C due to residual stresses [29]. In contrast, the groups crystallized at 820 °C and 840 °C, exhibited a notable "interlocking effect" and reduced residual stress, resulting in superior flexural strength. The observed biaxial-flexural strength reduced in the sequence of 1mm, 0.5mm, and 2mm specimens, aligning with previous research that indicated minimal impact of increased thickness on the flexural strength of ceramic materials beyond a certain thickness threshold.[15-16]

Current study found that varying optical properties and biaxial-flexural strengths of LiDi for CAD/CAM applications can be achieved by adjusting the firing temperature during the heating process and by altering the thickness. This adaptability allows for meeting diverse restoration requirements for teeth. In clinical practice, it is advisable to choose a more translucent ceramic for restoring teeth that are not discolored. More opaque ceramics should be used to repair teeth with discoloration or those held in place by metal supports[14] .

Generally, a minimum thickness of 2mm for LiDi is recommended to effectively cover up the appearance of an underlying discolored tooth [31]. The study's recommendation that 2mm LiDi specimens burned at higher temperatures may provide better masking effects is a feasible way to achieve acceptable aesthetic results. Furthermore, the mechanical properties of CAD/CAM Lidisilicate differ from that of traditional Li-disilicate, as the former must withstand mechanical stresses from the milling process following initial heat treatment, in addition to undergoing further thermal processing, which can influence both strength and translucency.

Dental ceramics' flexural strengths allow for the identification of certain clinical indications in accordance with the ISO 6872:2015 standard [17]. Because they all exceeded the minimal threshold of 300 MPa, the specimens examined here fulfill the criteria for Classes 1, 2, and 3 according to ISO standards. This lends credence to the earlier findings: heat treatment could only provide the Class 3 translucency required by ISO 6872:2015 requirements in low or high translucency lithium silicates[32].

Except for the 2mm specimens heated at 780°C (445.38± 59.47 MPa) and 800°C (473.36±87.52

MPa), all specimens exceeded the 500 MPa barrier and therefore passed the ISO criteria for Class 4. The Class 5 limit according to ISO standards is 800 MPa, yet none of the specimens tested were able to achieve this level. You shouldn't use these specimens as monolithic ceramics for prostheses that include four or more units of covered substructures. The findings of this research may serve as a standard since ISO 6872:2015 does not provide a flexural testing method. There are a number of legitimate flexural testing methodologies available, including the biaxial flexural strength test, the three-point bending test (3PBT), and the four-point bending test (4PBT) [33,34] The results of this study are consistent and aligned with all previous studies, and there are no results from any studies or research that contradict these findings regarding translucency and flexural strength.

Current study adhered to ISO; however, the methodologies employed did not fully replicate certain aspects of the oral environment, such as humidity, which could result in discrepancies between the findings of this study and those observed in an intraoral setting [35]. Additionally, the use of flat specimens, which do not reflect clinically relevant anatomical forms, presents another limitation. Future research could explore alternative flexural testing and translucency measurement techniques to facilitate comparative analysis. It may also be beneficial to conduct further investigations that assess the impact of various furnaces, thicknesses, compositions, and thermocycling conditions on the results. Furthermore, this research was managed in a laboratory setting, and the sample size was derived from existing literature without a power analysis, which constitutes a limitation. Subsequent studies that adhere to a power analysis based on the outcomes of this experiment are warranted. Moreover, additional research aimed at assessing the mechanical properties of lithium disilicate bonded with different adhesives would be advantageous.

CONCLUSIONS

This study presents several conclusions within its limitations:

1- The findings of this research demonstrate that a reduction in the thickness of Li. Disilicate constructed using CAD/CAM and a decrease in the temperature of thermal treatment result in increased translucency.

2- Conversely, when comparing thicknesses of 0.5,1.0 and 2.0mm, the samples with a thickness of 1.0mm exhibited the highest strength, with a temperature of 820 °C yielding the greatest strength among the tested temperatures of 780,800,820,840 and 860°C.

3- These results indicate that it is feasible to modify both translucency and strength in accordance with clinical requirements by choosing suitable thickness and thermal treatment.

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