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Investigating Correlations Between Translucency And Surface Hardness In Lithium Alumina-silicate (LAS) Dental Glass-Ceramics

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ABSTRACT: Lithium aluminum silicate (LAS) glass-ceramics materials are promising or under investigation in the field of dental restorations, but are not currently the most widely used due to their aesthetic performance. However, their materials often exhibit lower hardness under intensive contact conditions compared to alternative prosthetic crown systems. This study aims to determine an optimal temperature–time schedule for the nucleation and crystallization processes of Li–Al–Si glass, as well as clarify the correlation between translucency and surface hardness .The heat treatment protocol was designed based on differential thermal analysis (DTA) results and established thermal protocols. Nucleation was performed at a fixed temperature of 520°C for durations ranging from 0 to 60 minutes. Crystallization stages were conducted at 750°C and 900°C to evaluate the impact of crystal density (nucleation) and crystal growth (crystallization) on the materials properties. Vickers hardness (HV) was measured, with the highest value (~7.66 GPa) observed in samples treated at 750°C. The results indicate that optimal translucency (HTP) is achieved through a fine, homogeneously distributed crystalline phase, whereas uncontrolled crystal growth at higher temperatures leads to a decrease in the translucency parameter (TP), increasing opacity.

Keywords: glass-ceramics, LAS , aesthetic performance, Translucency

1. INTRODUCTION

Glass-ceramic materials are advanced materials used in Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems and are a modern and advanced technology in the field of dentistry [1]. While lithium silicate glass-ceramics are currently the most widely used systems clinically, lithium aluminum silicate (LAS) systems are emerging as promising candidates due to their unique set of properties such as high chemical strength, low coefficient of thermal expansion, excellent biocompatibility ($LiAlSi_2O_6$) and ($LiSi_2O_5$) [2,3]. These properties are attributed to the presence of crystalline phases, such as spodumene ($LiAlSi_2O_6$), which can be obtained by controlling the nucleation and crystal growth stages [4,5]. Nevertheless, the successful use of a dental Computer-Aided Design/Computer-Aided Manufacturing CAD/CAM system depends not only on the precision of the machining system but also on the characteristics of the material [6,7]. Suitable dental materials must combine good intrinsic mechanical strength with the ability to be shaped using a Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system [8]. However, CAM milling can cause surface damage to the restoration, weakening its mechanical strength. Modern studies from 2025 and 2026 have confirm the continual evolution of lithium alumina-silicate (LAS) systems, focusing on optimizing their microstructural properties to contest the increasing aesthetic and functional demands of modern restorative dentistry [9]. The aesthetic success of a dental mending is firstly committed to by its translucency, which is not an ingrained property of the material lone but is firstly ruled by its microstructure, including crystal size, magnitude fraction, and dealing out. That microstructure dictates how light is scattered or transmitted through the material. In addition, the mechanical honesty of the restoration is ultra-critical. The Hardness is an intrinsic material property that mirrors the material's resistance to localized plastic deformation. While this study focuses on surface hardness as a major indicator of mechanical resistance, it is acknowledged that breaking toughness and wear resistance are equally ultra-critical for the full neutral validation of dental ceramics. Expected to the specific focus on the

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connection between optical translucency and limit mechanical strength, those additional properties were completely the current range but last essential for future comprehensive realization. In general, determining the optimal temperatures for crystallization and nucleation depends on the composition of the glass ceramic. Previous studies have reported various hardness values for similar, such as 8.1-8.4 GPa [10], 8.07 GPa [11], 6.88±0.39 GPa [12] and 5.3 GPa [13]. However, describing these LAS glass-ceramics as having low to medium mechanical properties must be contextualized by comparing them to standard dental ceramics like zirconia. To evaluate aesthetics, The CIE Lab colour system is used, where L represents brightness, a represents the green-red axis, where positive values indicate red and negative values indicate green, and b represents the blue-yellow axis, [14]. This system is currently one of the most widely used methods for measuring colour in dentistry [15] An important concept Accurate determination of tooth color is a key and important factor in the success of cosmetic and restorative treatments, and modern digital applications have contributed to improving color matching accuracy and reducing reliance on human assessment [16,17]. This research focuses on determining an optimal temperature–time schedule for the nucleation and crystallization processes of Li–Al–Si glass, as well as clarifying the correlation between translucency and surface hardness in dental lithium alumina-silicate glass-ceramics. For improve mechanical properties, the plinth glass underwent a controlled two-step heat-treatment operation. The applied thermal protocol was designed according to differential thermal analysis results, producer specification, and apposite findings reported in earlier studies.

2. MATERIALS AND METHODS

"The lithium alumina-silicate (LAS) glass system LiO2-Al2O3-SiO2 was subjected to a controlled multi-stage heat treatment operation". Samples with standardized dimensions (14mm width x 12mm thickness x 18mm height) were used to assess the effect of heat treatment on both the microstructure and mechanical properties of the material". The thermal protocol was accepted based on Differential Thermal Analysis (DTA) results and apposite literature, as elaborate in Table1. The specimens were designed based on several premature studies involving differential analysis of glass crystals.

2.1 HEAT TREATMENT

The heat treatment program was designed constructed on Differential Thermal Analysis (DTA) results of the LAS glass to warranty a systematic transformation into glass-ceramics. The specific temperatures (520°C, 750°C, and 900°C) were strictly guided by Differential Thermal Analysis (DTA) results to pinpoint the glass transition (Tg) and summit crystallization (Tc) temperatures accurately. The operation was classified into two major stages:

1) Nucleation stage: the effect of soaking time on the nucleation density. The temperature was preserved at a fixed nucleation point of (520°C), while the soaking time varied from (0 to 60 minutes). That step is critical for inducing the formation of sufficient nuclei within the glass matrix before the subsequent growth stage.

2) Crystallization stage: The second stage investigated the controlled crystal growth as a function of temperature and time. Two crystallization temperatures, 750°C to 900°C, were selected to study the gradual transition of the microstructure for each temperature, the soaking time ranged from 0 to 60 minutes, as detailed in Table 1. The main aim of that multi-stage agreement were:

a) To evaluate the influence of nucleation density on the subsequent crystallization kinetics.

b) To determine the optimal crystallization temperature and duration.

They above designed the profile of heat treatment to assess the imp act of nucleation and crystallization on both the mechanical and translucency parameter. Furthermore, a constant heating rate of 10°C/min was preserved to ensure thermal equilibrium, followed by gradual furnace cooling to room temperature to alleviate residual inner stresses and prevent micro-cracking.

Table 1 Heat treatment tailored by the examined samples

Profile ID	Description	Nucleation Stage (520°C) Hold Time	Crystallization Stage 1 (750°C) Hold Time	Crystallization Stage 2 (900°C) Hold Time
Raw Glass	Amorphous	0 min	0 min	0 min
Profile 1	Nucleation Only	0 min	—	—
Profile 2	Extended Nucleation	60 min	—	—
Profile 3	Nucleation & Low Temp Crystal 1	0 min	0 min	—
Profile 4	Nucleation & Low Temp Crystal 2	60 min	0 min	—
Profile 5	Nucleation & Extended Low Temp Crystal	60 min	60 min	—
Profile 6	Multi-stage 1	0 min	0 min	0 min
Profile 7	Multi-stage 2	0 min	0 min	60 min
Profile 8	Optimized Multi-stage	60 min	0 min	60 min

2.2 HARDNESS MEASUREMENT

Heat-treated glass-ceramic specimens were prepared and polished using silicon carbide papers followed by diamond pastes to achieve a mirror-like surface. The surface hardness was determined using a digital Vickers hardness (HV) tester. Hardness is considered an intrinsic material property reflecting the material's resistance to localized plastic deformation. A diamond pyramidal indenter was used to create indentations on the specimen surface under a controlled load of 19.6 N (2kgf), which is suitable for preventing excessive cracking in glass-ceramic materials. The indenter was held on the surface for a dwell time of 15 seconds. For warrant statistical reliability, five different regions were choosing on any specimen, and the medium of these readings was on record. The Vickers hardness was calculated using the following equation [18,19]:

$$Hv = 1.8544 \frac{P}{d^2} \quad (1)$$

"Where (P) is the applied load (kgf) and d is the average diameter length of the indentation (mm). The results were recorded in HV and converted to (GPa) for comparative analysis".

2.3 COLORIMETRY AND TRANSLUCENCY

A digital colorimeter was used to quantify the optical properties of the (LAS) glass-ceramics specimens. The device measures the spectral analysis of light reflected from the sample, and converts it into digital values according to the CIE $L^*\ a^*\ b^*$ color space. In this system:

L^* : Represents lightness (0 = black, 100 = white)

a^* : Represents the green–red axis (negative values indicate green, positive indicate red)

b^* : Represents the blue–yellow axis (negative values indicate blue, positive indicate yellow)

To evaluate the translucency parameter (PT), each specimen was placed against two standardized backgrounds, a white (L*=97.8, a*=0.11, b*=0.18) and black background (L*=1.12, a*=0.12, b*=0.48). The translucency parameter value was calculated using the following equation [20, 21].

$$TP = \sqrt{(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_B)^2} \quad (2)$$

Where: "the subscripts 'W' and 'B' denote the color coordinates measured over the white and black backgrounds, respectively. According to this protocol, a higher TP value indicates a greater degree of translucency, whereas a lower value indicates that the material is more opaque" [22,23].

3. RESULTS AND DISCUSSION

3.1 MECHANICAL PROPERTIES INCLUDING HARDNESS

The measured mechanical properties, specifically Vickers hardness (Hv), are directly and predictably correlated with the crystalline phase development and can be compared to the translucency parameter. As the degree of crystallinity increases, hardness increases, while the translucency parameter (TP) typically decreases due to increased light scattering. The relationship between hardness and translucency parameter is generally inverse in this system. The Parent glass exhibited the lowest hardness value of 5.4 GPa, with a translucency parameter value (TP) of 37.78. This is attributed to its amorphous, non-crystalline structure, resulting in lower resistance to localized plastic deformation under load. The highest hardness values was observed in profile 5 (750°C for 60 minutes), reaching 7.66 GPa. This is to the optimized formation of the lithium alumina-silicate crystalline phase (LiAlSi2O6) within the glass matrix. A more aesthetically pleasing, translucent appearance can be achieved by controlling the volume fraction of crystallinity; However, this often results in a relative increase in hardness and. The best microstructure regarding mechanical properties was obtained in profile 5. Regarding optical properties, profile 3 exhibited the best translucency, corresponding to the highest (TP) value among the heat-treated samples, as a higher (TP) indicates greater light transmission. While surface hardness is an animated signal of wear resistance, it is recognized that fracture toughness (K_{IC}) is equally overcritical for withstanding applied forces. In this initial study, hardness was used as the essential mechanical benchmark, while (K_{IC}) testing is reserved for future inquest to provide a more comprehensive mechanical profile.

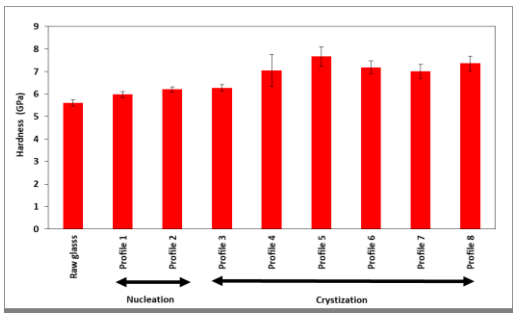

FIGURE 1 Hardness of the heat treatment 520°C, 750°C and 900°C for different times

3.2 OPTICAL PROPERTIES INCLUDING TRANSLUCENCY PARAMETER, TP

The colorimetric measurements of the heat-treated glass samples showed a clear variation in the coordinates (b*, L*, a*) and the translucency parameter (TP). This variation is directly attributed to the different heat treatment protocols applied. The parent glass showed an L* value of 42.6 and a TP of 38.453, While the parent glass is amorphous, its translucency is governed by the absence of light-scattering crystalline boundaries. Contrary to

crystallized ceramics, the lack of a crystalline structure in the parent glass typically allows for higher light transmission rather than absorption, unless specific opacities are present. An improvement in brightness and translucency was observed in profile 1 and profile 2, Specifically, Profile 2 reached a TP value of 62.18, the highest among all specimens. That notable raise in the translucency parameter indicates the formation of an extremely fine and homogeneously distributed crystalline phase, where the crystal magnitude is least than the wavelength of visible light, thereby reduce light propagation and preserve high transmittance. The positive increase in b* values indicates a slight shift toward the yellow spectrum, which is often desirable for natural dental aesthetics.

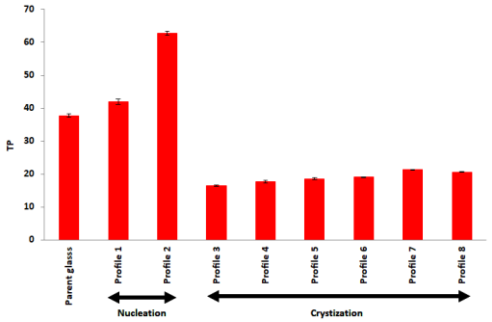

FIGURE 2 Translucency parameter (TP) of the heat treatment 520°C, 750°C and 900°C for different times

However, profile 3 and profile 4 showed a sharp decrease in TP values (ranging from 18 to 16), as shown in Fig.2. This is attributed to an increase in the crystallization rate and excessive crystal growth. The formation of larger and more compact crystals increases the refractive index mismatch and light scattering at the grain boundaries, which significantly decreases transmittance and increases opacity. For profile 5 and beyond, a slight stabilization in TP values was observed to about 21. This suggests the formation of a stable and more homogeneous crystalline matrix compared to the overgrown structures in profiles 3 and 4. The relationship between L* and TP demonstrates that translucency is not merely a function of surface reflectance [24], but is profoundly influenced by the internal microstructure, specifically the distribution, and size of the crystals. In conclusion, the best optical behavior, combining the highest translucency parameter (TP) with an appropriate colour balance [25, 26], was achieved in profile 2, making it the most suitable heat treatment conditions for dental glass-ceramic applications.

3.3 TYPICAL MICROSTRUCTURE OF NUCLEATED AND CRYSTALLISED SAMPLES (SEM)

The SEM micrographs (Figures 3) demonstrate a clear evolution of the microstructure from a smooth, fine-grained surface to a dense, interlocked crystalline network. Figure (b) shows a relatively smooth morphology with minimal scattering centers, which is consistent with the high translucency (TP) values observed in Profile 2. As the heat treatment progressed, Figure (a) reveals the uniform distribution of crystalline phases within the glass matrix. In the higher-magnification image, this interlocking network provides the structural reinforcement responsible for the peak in Vickers hardness (7.66 GPa), while simultaneously increasing light scattering, which accounts for the transition toward an opaque appearance in the more advanced crystallization profile.

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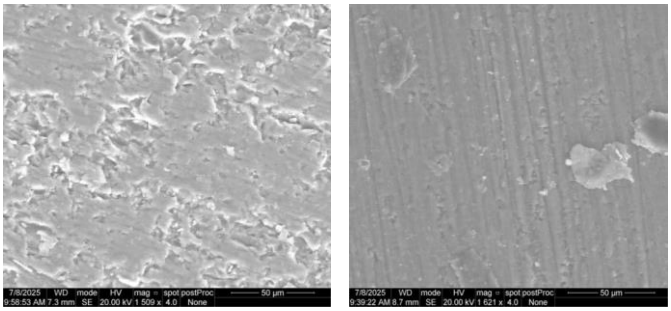

FIGURE 3 (a) Profile 2 showing a relatively smooth and fine microstructure, correlating with the highest translucency results. (b) Middle stage showing the primary formation of crystalline congregations

4. CONCLUSIONS

Treatment at (520°C) moves a critical part in begin nucleation stage, while it guide to not whole crystallization on its own, it is the optimal nucleation temperature when preserve for a drenched time of (60 minutes). That stage is necessary to construct a high nucleation density before the crystal growth stage. Furthermore, treatment at (900°C) in general guide to undisciplined crystal growth and a rough microstructure. That the immoderate growth increases light scattering, which reduce the translucency parameter (TP) and results in bottom mechanical performance compared to specimen treated at lower crystallization temperatures. The results appeared that specimens without a nucleation operation (non-nucleated) showed a lower translucency parameter (TP) value of (16.47), definition the glass-ceramic is more non-transparent. In variance, heat treatment that includes a controlled nucleation operation and optimal drenched time increases the translucency parameter (TP). The is confirms that the glass-ceramic enhances more translucent due to the formation of a excellent and specific crystalline microstructure that permit for better light transmission. In conclusion, achieving the best balance between Vickers hardness and aesthetic appearance requires precise control over the nucleation and crystallization stages to avoid excessive crystal growth. Future studies should research the long-term effects of the oral environment, such as artificial saliva and dietary acids, on the surface hardness and deterioration of these LAS glass-ceramics to confirm their clinical durability.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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