05/2009

special update equipment

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Scientific Information

Topic: **Cooling Shock Protection CSP reduces tension in the ceramic materials**

Title: **Scientific fundamentals on the CSP function in the new Programat P700/G2 ceramic furnace**

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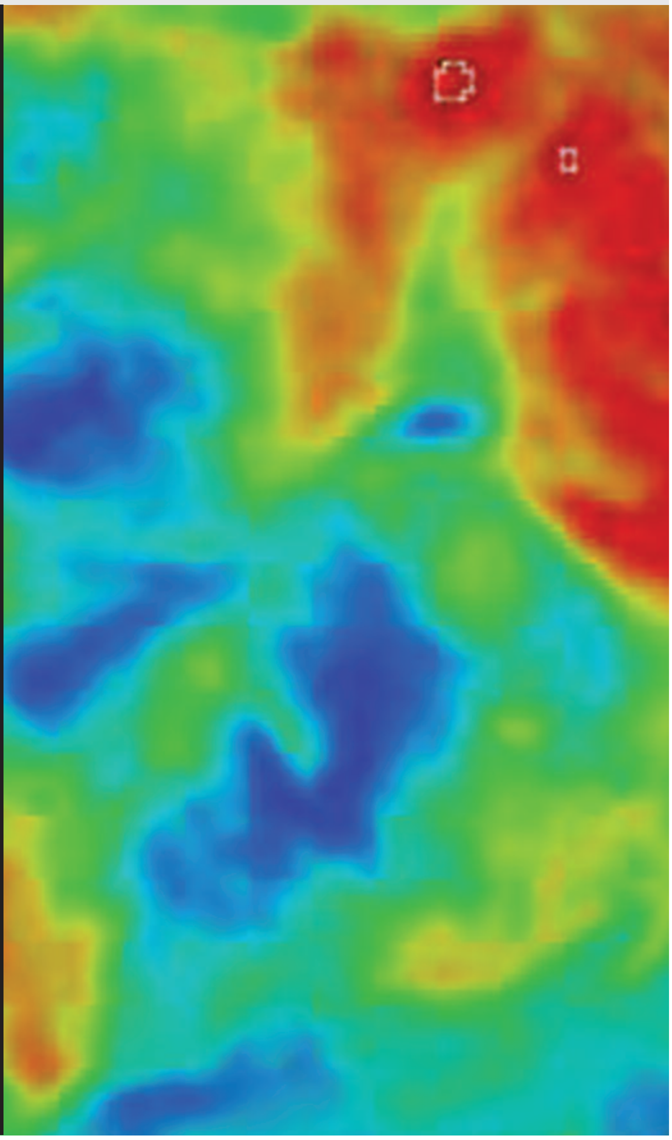
The ceramic furnace is the most important tool of the ceramist lab technician. Setting an incorrect firing temperature quickly destroys the work of hours. Therefore, the firing performance of the dental furnace must be checked regularly. DIN 13905 Part 1 and 2, for example, describe the calibration of the firing performance and final temperature.
Hence, lab technicians make every effort to exactly meet the requirements as far as the temperature increase rate, holding temperature and holding time are concerned. Moreover, an experienced technician will immediately be aware of a diminishing furnace performance simply by the appearance of the restoration. However, the fact that the firing process is not complete at the end of the holding time is widely overlooked, because little importance has been attributed to the cooling process to date. This is critical in so far as the errors that loom in this respect cannot be identified visually. CSP makes the cooling process more reliable.



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Cooling Process

The cooling process is the beginning of a very essential phase for the restoration. During the cooling phase, the stress profile of the restoration is developed, which may be decisive for its reliability. In this context, a differentiation between desired and undesired stress is necessary. There are basically three mechanisms, which overlap in practice [1], responsible for the occurrence of desired internal stress, i.e. macroscopic stress that affects certain areas of the restoration without the external application of force.

1. Fusion stress

Stress resulting from different coefficients of thermal expansion (CTE) is utilized in multi-layer systems. With the somewhat stronger shrinkage of the framework material compared to the veneering material, compressive stress is created within the veneering material and, accordingly, tensile stress in the framework material. The reason for this approach is the fact that the framework material, irrespective of ceramic or metal, is usually able to withstand higher tensile stress than the veneering ceramic, which typically exhibits a high glassy content. Furthermore, the glaze is adjusted in such a way that it is under compressive stress after cooling. This, in turn, increases the thermal shock resistance and counteracts the development of cracks by a point transmission of compressive force to the surface.

2. Temporary or transient heat stress

Transient heat stress is caused by inhomogeneous heating or cooling during the heating or cooling phase. This temporary stress is more pronounced the higher the heating rate or cooling rate is and the higher the CTE is. The heat conductivity and the heat storage capacity of the material also play a role. The highest stress occurs in the massive areas of the restoration, since the temperature equalization is slowest there. During temperature increase, compressive stress is produced on the outside, while tensile stress occurs on the inside. During the firing process, the ceramic is free of stress, since stress is reduced by a viscous flow process at temperatures above T_g. Below T_g, temporary tensile stress occurs on the outside during cooling, which disappears again as soon as the restoration has completely cooled down to room temperature.

3. Cooling stress or residual stress

The development of cooling stress is closely linked to the specific characteristics of glass and the glass transition. Its parallel is the thermal tempering of flat glass. In this process, a pressure tempering of the glass surface is achieved by a high cooling rate in the temperature range around T_g. The stress build-up begins when the temperature profile drops below T_g and the glass surface passes from the visco-elastic to its purely elastic phase. In contrast, the hot core can only dissipate the developing transient heat stress by viscous flowing so that, at first, the cool surface is in a mechanical balance with the hot core. Subsequently, the surface and core zone contract in a different manner, i.e. the core contracts considerably more, which results in compressive stress on the outside and tensile stress on the inside. The residual stress only occurs towards the end of the cooling process, when the surface has already cooled down to room temperature, but the core zone continues to cool down and contracts in the process. The resulting compressive stress σ_D in the surface equals the sample thickness to the second power and is proportional to the cooling rate (Figure 1).

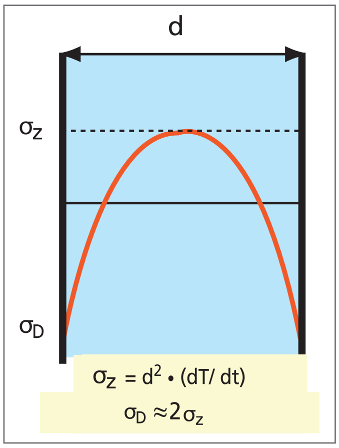

Fig. 1: Stress distribution across the glass thickness on a quenched glass pane

CSP Versus Long-Term Cooling

Now, what is the difference between long-term cooling and Cooling Shock Protection?

During **long-term cooling**, slow cooling is conducted slightly below the firing temperature or another holding time is added. At this temperature, the sinter process has already been completed and the outer geometry of the restoration set. However, on a microscopic level, certain components of the microstructure may mature, since a temperature-related balance exists between the glass phase and the crystalline component of a glass-ceramic. For example, the CTE of ceramics containing leucite may be purposefully influenced by long-term cooling as more or less leucite crystals are brought to precipitate.

With the **CSP** function, the cooling rate in the range of the glass transition temperature is drastically reduced, which enables the reduction of the build-up of residual stress. Figure 2 depicts the cooling rate of an IPS e.max CAD restoration with and without CSP. Without CSP, the maximum cooling rate is over 200°C/min. This may lead to uncontrolled residual stress in those materials the glass transition of which takes place at this temperature. With CSP, however, the cooling phase is linearized. The maximum cooling rate is still 100°C/min, but now at a temperature below the glass transition temperature. This clearly reduces the residual stress.

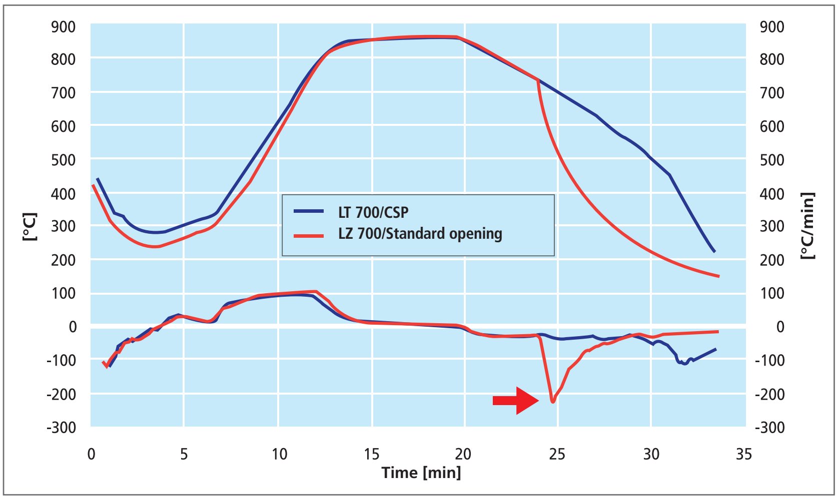

Fig. 2: Comparison between the cooling rate with CSP and without CSP (top: temperature course at the restoration in °C; bottom: 1^{st} dissipation = temperature change rate in °C/min)

Stress Optics

With the help of a photoelastic measuring device, residual stress can be made visible [2]. Figure 3 below shows the difference in fully anatomical crowns. The sample on the left was fired in the regular manner, while CSP was activated for the sample on the right. Yellow and red mean that residual stress is present, blue and green are areas with very little or without residual stress.

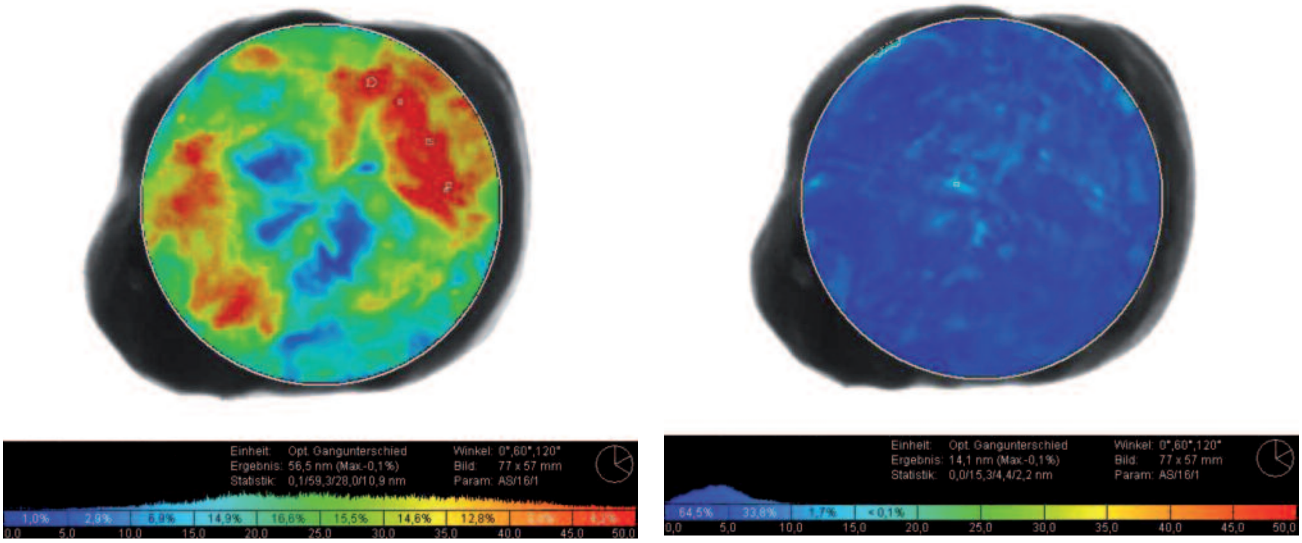

Fig. 3: Comparison of the residual stress: with CSP on the right, without CSP on the left

Conclusion

With Cooling Shock Protection, the cooling rate in the range of the glass transition temperature is reduced. This prevents undesired cooling stress. CSP renders the cooling process more reliable.

Literature

[1] from: Günther Nölle, Technik der Glasherstellung, 3rd revised edition Stuttgart: Dt. Verl. für Grundstoffindustrie, 1997

[2] Henning Katte, ilis GmbH, Erlangen; Präzise Messung der Spannungsdoppelbrechung in optischen Gläsern; Photonik 5/2008

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