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Investigation of thermal stresses in dental restoration by mathematical method

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Abstract

Heat changes cause thermal stresses in the restorations made of different materials. These stresses can become high in the vicinity of the contacts between different materials. The aforesaid thermal stresses can add up with stresses caused by mechanical loads, they can cause cracks in the dental structures and thus can lead much shorter life-span during use. The purpose of this research is the mathematical determination of the thermal stresses in the structure due to variable temperatures inside the mouth for the metal-supported porcelain restorations. It has been found that as the temperature increases, stress values increase at a fixed distance. The stress values in the ceramic and dentin regions reach higher magnitudes than those in metal and cement layers. At 55 °C, the stress value in the ceramic layer was calculated as 67.37 MPa. It has been concluded that there is a linear relationship between stress rising rate and temperature.

Keyword: Dental restorations

1. Introduction

Due to trauma, decaying, periodontal troubles and anomalies by birth, both tissue losses and missing teeth affect the biomechanical equilibrium of the chewing system in a negative way. Thus the functional charge distribution present in the mouth is deteriorated. To put this relationship in order, prophylactic restoration of these shortcomings is required. Nowadays many different materials are used in restorative and prophylactic treatments. In restorative treatments, metallic, ceramic and composite based filling are used whereas metal–plastic, ceramic, metal–ceramic, ceramic–ceramic-based dental materials are generally employed. Implant materials located in the jaw are also of different kinds.

Despite the fact that these restorations could be done directly inside the mouth, indirect methods are used more often. For the restorations prepared by indirect methods, a dental lab outside the clinic is required. Lab applications, being different from the restorations prepared by direct methods, require different heat treatment temperatures and times. Thus whatever the type of the material is, it is exposed to different physical effects upon heating. Besides that, these permanent dental restorations placed in the mouth following the preparation undergo a temperature change between −5 and +55 °C during daily use. Though the change range is not much large, since the exposure is chronic and frequent, it can lead to failure during use.[1,2]

It is known that heat exchange in the restorations made of different materials can reach large values and cause thermal stresses changing with high gradients. The magnitude of these stresses can become high in the vicinity of the contacts between different materials and change with high gradient. The aforesaid thermal stresses can add up with stresses caused by mechanical loads and due to their variable characteristics, they can cause cracks in the dental structures thus can lead much shorter life-span during use.

The purpose of this research is the mathematical determination of the thermal stresses in the structure due to variable temperatures inside the mouth for the metal-supported porcelain restorations. The literature data shown in Table 1 were used for the calculations.[3–8]

2. Materials and method

This particular study on thermal stresses is based on metal-supported porcelain structures adhered with resin siman. In addi-

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Table 1
The properties of the materials[3–8]

Materials	E (MPa)	α ($\times 10^{-6}$/°C)	ν
Ceramic	6.890	13.8	0.28
Metal	20.500	14	0.33
Cement	2.240	30	0.35
Tooth (dentin)	1.860	11.4	0.31

tion, thermal stresses caused through the physical and mechanical characteristic thickness of this free structure due to the temperature variation were investigated.

For the mathematical investigation of the thermal stresses, stress–strain state of a free dental structure was shown in the form of a plate in Fig. 1.

Let us assume a plate of arbitrary platform and of constant thickness 2 h. The plate is completely free of surface traction and the stresses depend on the thickness only, that is $T = T(z)$. Under these conditions it can be supposed that the stress components will be of the following form. The thermal stress components formed in the middle of the plate due to the temperature variation through the physical and mechanical characteristic thickness of the free plate will be of the following form:

$$\sigma_x = \sigma_y = f(z), \qquad \sigma_z = \tau_{xy} = \tau_{yz} = \tau_{zx} = 0 \tag{1}$$

The equilibrium equations are identically satisfied for stress components of this form. For strain components criteria for satisfying the equilibrium could be expressed as follows:[9]

$$\frac{d^2}{dz^2}\left[\frac{1-v}{E} f(z) + \alpha T\right] = 0 \tag{2}$$

where α is thermal expansion coefficient of the plate material. The solution of the Eq. (2) can be given as follows:

$$\sigma_x = \sigma_y = \frac{C_1 E}{1-v} + \frac{C_2 E}{1-v} z - \frac{E\alpha T}{1-v} \tag{3}$$

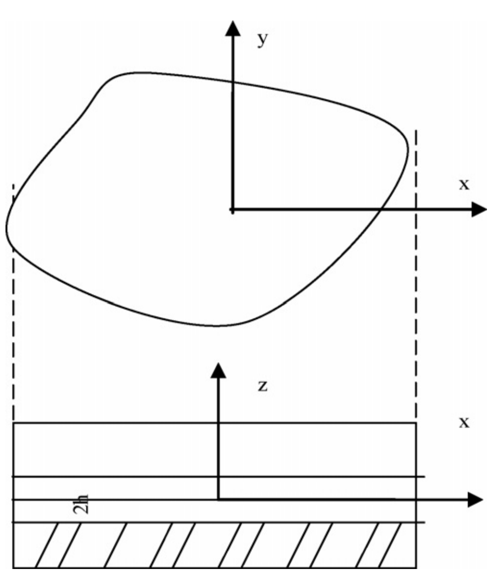

Fig. 1. The scheme of the plate.

where, E is the elastic modulus of the plate material and ν is Poisson's ratio. Integral constants, C_1 and C_2 in Eq. (3) are determined by the condition of zero force and zero moment of the force on the sample:[9]

$$\int_{-h}^{h} \sigma_x \, dz = \int_{-h}^{h} \sigma_x z \, dz = \int_{-h}^{h} \sigma_y \, dz = \int_{-h}^{h} \sigma_y z \, dz = 0 \tag{4}$$

Regarding Eq. (3) and applying Eq. (4) for all cases it can be written:

$$C_1 \int_{-h}^{h} \frac{E}{1-v} dz + C_2 \int_{-h}^{h} \frac{E}{1-v} z \, dz - \int_{-h}^{h} \frac{T\alpha E}{1-v} dz = 0 \tag{5}$$

$$C_1 \int_{-h}^{h} \frac{E}{1-v} z \, dz + C_2 \int_{-h}^{h} \frac{E}{1-v} z^2 \, dz - \int_{-h}^{h} \frac{T\alpha E}{1-v} z \, dz = 0 \tag{6}$$

From the above equation system, Eq. (5) and (6), the solution could be found.[9]

Assuming α, ν and E are constant, Eq. (3) could be expressed in a better-known form as follows:

$$\sigma_x = \sigma_y = \frac{\alpha E}{1-v}\left\{-T + \frac{1}{2h}\int_{-h}^{h} T \, dz + \frac{3z}{2h^3}\int_{-h}^{h} Tz \, dz\right\} \tag{7}$$

By using the equations obtained, thermal stresses formed at the connection of metal–ceramic, which is widely used in dental treatments, were investigated with the condition that the temperature variation is homogeneous. Eq. (3) obtained above for all cases was applied to dental applications. For this application, values from Table 1 were employed.

3. Results and discussion

By using the data shown in Table 1, stress values were calculated. The stress curves as functions of temperature were drawn. Figs. 2–5 show the calculated stresses as a function of the distance values for different temperatures for ceramic, metal, cement and dentin layers respectively. Assuming homogeneous temperature, as can be seen from the Figs. 2–5, as the temperature increases, stress values increase for the distance from the bottom of the layer.

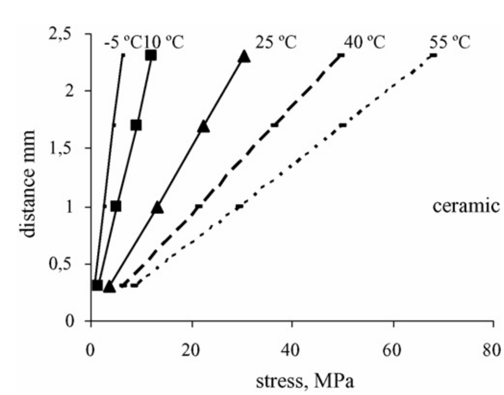

Fig. 2. The distance–stress curves for the ceramic region of the plate at different temperatures.

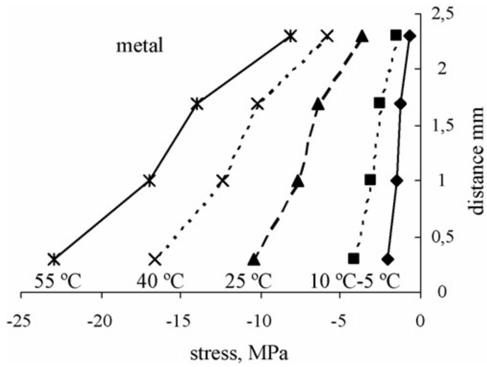

Fig. 3. The distance–stress curves for the metal region of the plate at different temperatures.

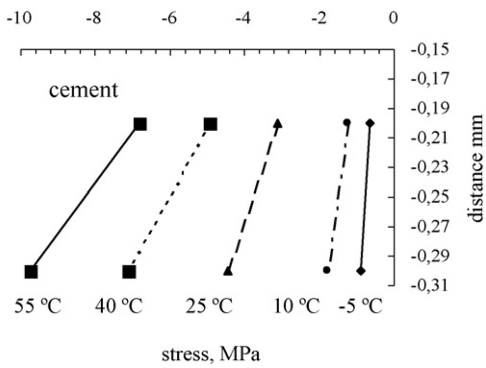

Fig. 4. The distance–stress curves for the cement region of the plate at different temperatures.

Figs. 6–10 illustrate the stress variations as a function of layer distance in the temperature range from −5 to +55 °C. The stress values in the ceramic and dentin regions reach higher magnitudes than those in metal and cement layers. The stress values of the ceramic and dentin regions are close to each other, though the stress value of the dentin region is a bit higher. For example, at 25 °C, the stress value at ceramic region is 30.62 MPa whereas that at dentin layer is 33.16 MPa. At 55 °C, the stress value in the ceramic layer was calculated as 67.37 MPa (Table 2). It has been concluded that there is a linear relationship between stress rising rate and temperature.

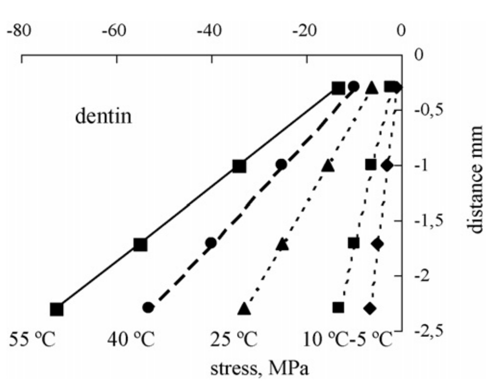

Fig. 5. The distance–stress curves for the dentin region of the plate at different temperatures.

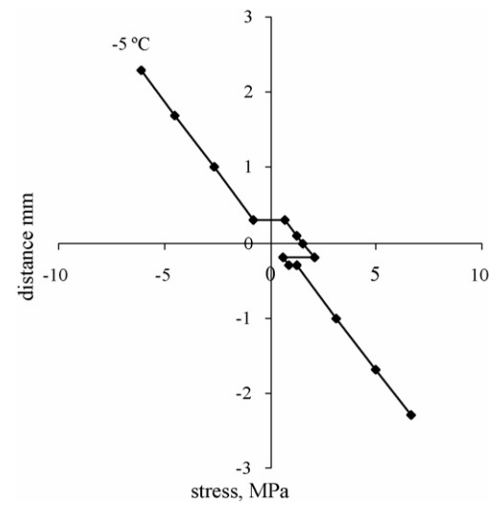

Fig. 6. The stress formed in the structure vs. distance at −5 °C.

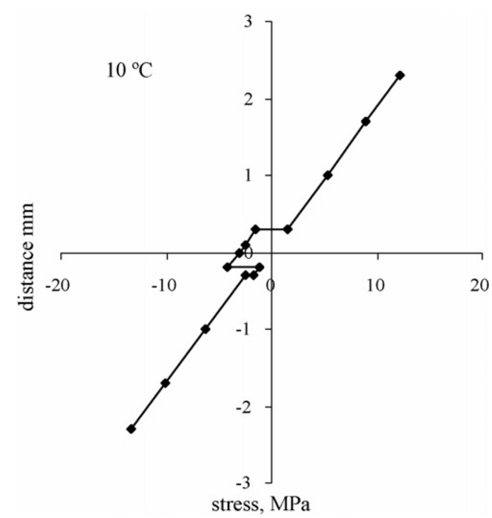

Fig. 7. The stress formed in the structure vs. distance at 10 °C.

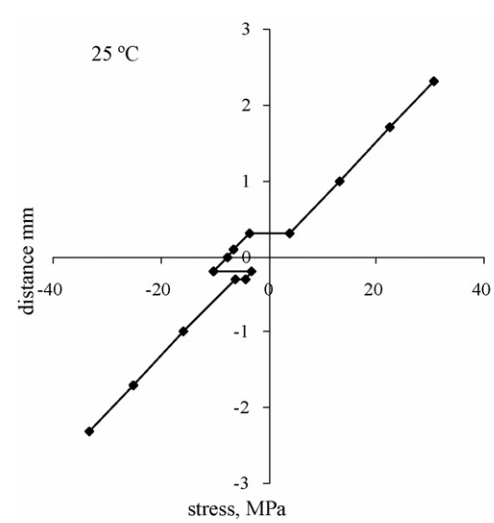

Fig. 8. The stress formed in the structure vs. distance at 25 °C.

Table 2
The stresses formed in the layer boundary versus temperature

Layer	H (mm)	−5 °C σ (MPa)	10 °C σ (MPa)	25 °C σ (MPa)	40 °C σ (MPa)	55 °C σ (MPa)
Ceramic	2.3	−6.12	12.25	30.62	49.0	67.37
	0.3	−0.74	1.49	3.72	5.96	8.19
Metal	0.3	0.74	−1.47	−3.69	−5.9	−8.11
	−0.2	2.08	−4.16	−10.41	−16.66	−22.9
Cement	−0.2	0.62	−1.24	−3.1	−4.95	−6.81
	−0.3	0.89	−1.78	−4.44	−7.10	−9.77
Dentin	−0.3	1.25	−2.5	−6.26	−10.01	−13.76
	−2.3	6.63	−13.26	−33.16	−53.05	−72.94

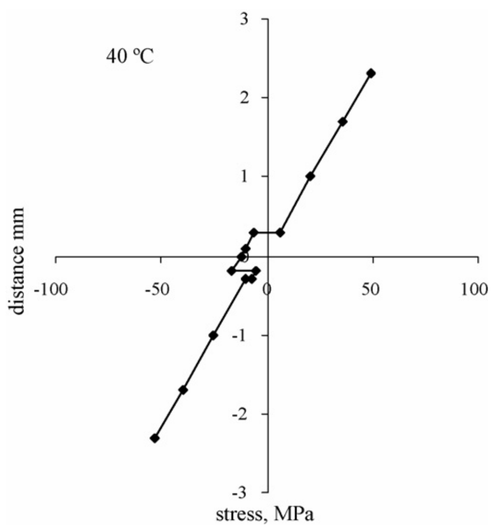

Fig. 9. The stress formed in the structure vs. distance at 40 °C.

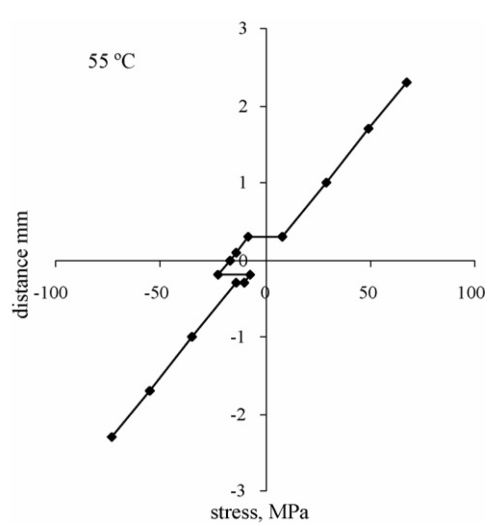

Fig. 10. The stress formed in the structure vs. distance at 55 °C.

4. Conclusion

As a result, the thermal stresses are formed in dental structures generally by the temperature, external effect or by both. Since the results of the external effects are known, we focused on the unusual temperature problems. For all the layers (ceramic, metal, cement and dentin regions) studied, it has been found that as the temperature increases, stress values increase at a fixed distance. The stress values in the ceramic and dentin regions reach higher magnitudes than those in metal and cement layers. At 55 °C, the stress value in the ceramic layer was calculated as 67.37 MPa. It has been concluded that there is a linear relationship between stress rising rate and temperature.

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