ANALYSIS OF SHRINKAGE STRESSES IN LIGHT-CURED DENTAL RESTORATIONS

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1. Introduction

Among the popular types of dental restorations are the photo-cured dental resin composite inlays. In spite of many qualities, one of the main disadvantages of the resin-based restorations is a shrinkage that occurs during the cure process. It results in high residual stresses in the restoration and the tooth, which can cause microleakages [1]. The most unfavourable stresses are the tensile and shear stresses located at the restoration-enamel interface. To reduce the shrinkage stresses, specific restorative techniques are used. One of them is applying the composite in a few layers instead of one layer. It appears a question whether the layering technique really reduces the polymerization shrinkage stresses [2]. To answer for this question, behaviour of cured polymer layers in the dental cave are described in terms of simplified analytical formulae. As the macroscopic measure of the conversion degree at time t, temporary volumetric shrinkage $s(t)$ is taken. In the case of the light-curing process, the volumetric shrinkage s depends on the light exposure H applied during the curing process. Simultaneously we observe evolution of Young's modulus E and Poisson's ratio ν. One can assume simple exponential functions describing s, E and ν as functions of H [3]. To simulate volumetric changes of the material, its temporary elastic properties are assumed and the thermal expansion analogy is used.

1. Model of the incremental filling

The tooth-cavity is assumed to be Class II, which may be modelled under the plain strain conditions as a rectangular opening (dimensions $2a\times b$), with rigid walls and bottom (Fig. 1). A full adhesion of restoration and the tooth tissues is assumed. The cave may be filled and next irradiated into two ways. One can fill the whole cavity before irradiation (Fig. 1a), or one can do it in two steps. At first, half of the prepared cavity is filled and irradiated (Fig. 1b). Next, the second layer is placed on the cured previously layer and irradiated (Fig. 1c).

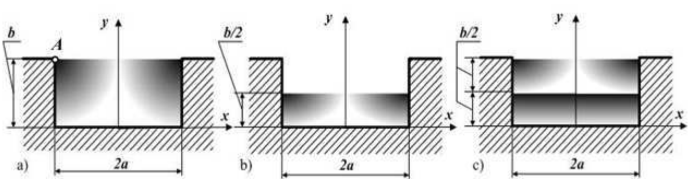

Fig. 1. Two ways of tooth-cavity restoration: in one step (a) and in two steps (b-c).

In our model, displacements of particles of considered resin layer, appearing during the curing process are expressed in terms of polynomials, prescribed at each point $\boldsymbol{x}$ of the layer. The polynomials satisfy the applicable boundary conditions at the walls and bottom of the cavity. The stress boundary conditions on the upper surface of the resin are satisfied approximately using the principle of minimum elastic energy. When half of the cavity is filled or irradiated, Young modulus E, Poisson ratio ν and the volumetric shrinkage s are introduced as step-functions prescribed on the whole cross-section of the filled cavity. As a consequence, the stresses, strains and displacements are given explicitly as combinations of polynomials and step-functions of s, E and ν. Such an approach enables to watch an influence of basic parameters describing the restoration process.

2. Results

Consider a case, when each of polynomials describing horizontal and vertical is determined by 9 coefficients, the cavity dimensions are a = b=1 mm, s = 0.01, E = 4800 MPa and ν = 0.25. Then, in the case of one-layer restoration, the tension stresses $\sigma^{(1)}_{xx}$ and the shear stresses $\sigma^{(1)}_{xy}$, along the cavity wall, are described by third order polynomials. For two layers restoration, the corresponding stresses $\sigma^{(2)}_{xx}$ and $\sigma^{(2)}_{xx}$ are described by combinations of third order polynomials and step-functions. The results are close to those obtained from FEM analysis with ABAQUS. In Figure 2, stresses $\boldsymbol{\sigma}^{(1)}$ and $\boldsymbol{\sigma}^{(2)}$ are presented as functions of non-dimensional variable $0<\eta=y/b<1$.

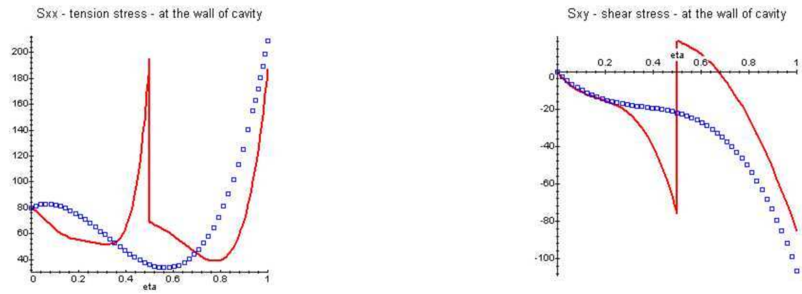

Fig. 2. Comparison of stresses $\boldsymbol{\sigma}^{(1)}$ (point-lines) and $\boldsymbol{\sigma}^{(2)}$ (continuous lines) at the cavity wall.

It is known from dental practice, that the point with the coordinate $\eta = 1$ (A at Fig. 1) is the most probable place where a leakage may appear. For this place, we have: $\sigma_A{}^{(2)}{}_{xx}/\ \sigma_A{}^{(1)}{}_{xx}$ = 0.89, and $\sigma_A{}^{(2)}{}_{xy}/\ \sigma_A{}^{(1)}{}_{xy}$ = 0.80. The result suggests that the layering of the composite material with successive irradiation may decrease maximal shrinkage stresses. Indeed FEM simulations of more realistic model of the restoration with one, two and four layers confirm this hypothesis (Fig. 3).

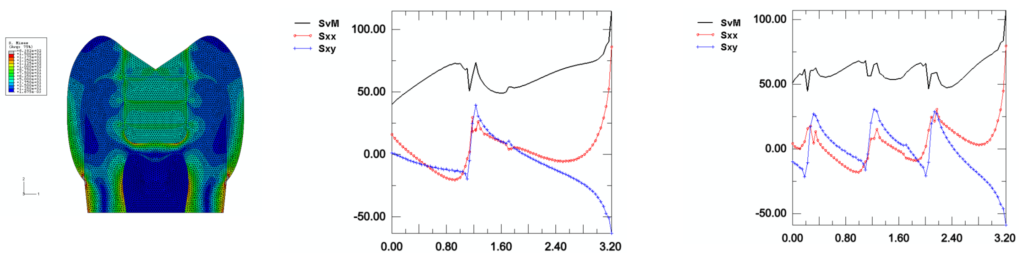

Fig. 3. FEM model of the 4-layers tooth restoration and stresses at the cavity wall for 2 and 4 layers.

Now, the comparison of stress components at the point A, gives the following results: $\sigma_A{}^{(2)}{}_{xx}/\ \sigma_A{}^{(1)}{}_{xx}$ = 0.88, $\sigma_A{}^{(2)}{}_{xy}/\ \sigma_A{}^{(1)}{}_{xy}$ = 0.81, $\sigma_A{}^{(4)}{}_{xx}/\ \sigma_A{}^{(1)}{}_{xx}$ = 0.83, and $\sigma_A{}^{(4)}{}_{xy}/\ \sigma_A{}^{(1)}{}_{xy}$ = 0.76.

6. References

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