# Techniques of shrinkage stress reduction in dental restorations

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ABSTRACT: Shrinkage stresses cause major problems in the dental restoration practice. New techniques of stress reduction at the restoration-tooth interface are proposed. The propositions are tested for bonded inlay restorations using finite element analysis, based on the ABAQUS software. Mechanical properties of photo-cured material, dentin, enamel and pulp are based on the data given in the literature. Two kinds of restorations are taken into account: Class I and Class II. The paper consists of two parts. At first, polymerization shrinkage for restoration with classical incremental technique is investigated. Here, the Huber-Mises stress distributions in the whole tooth for two classes of restorations are presented. Next, two methods of stress reduction based on a selective light curing of restoration are investigated. Both methods provide significant reduction of Huber-Mises stresses in restoration and tooth tissue, especially in the Class I restorations.

Key words: Dental restorations, Shrinkage stress, Stress reduction, Finite element method

## 1 INTRODUCTION

Widely used amalgam is nowadays replaced by resin-based composite materials, which are esthetical and do not demand special cavity shaping. The most popular type of restoration is the photo-cured composite resin restoration. Under UV radiation, free radicals are created in the resin and the free-radical polymerization is started. Features of photo-polymerization process are fastness of polymerization at room temperature and limited depth of polymerization. For dental composites the layer thickness is limited to 2 mm, and the cure process to 20 seconds. One of the main disadvantages of the resin-based restorations is a polymerization shrinkage that occurs during the process. It results in high residual stresses in the restoration and the tooth, which can cause microleakages [1]. The polymerization shrinkage occurs due to the replacement of relatively weak long-distance intermolecular Van der Waals bonds by strong, shorter, covalent bonds between the carbon atoms of different monomer units.

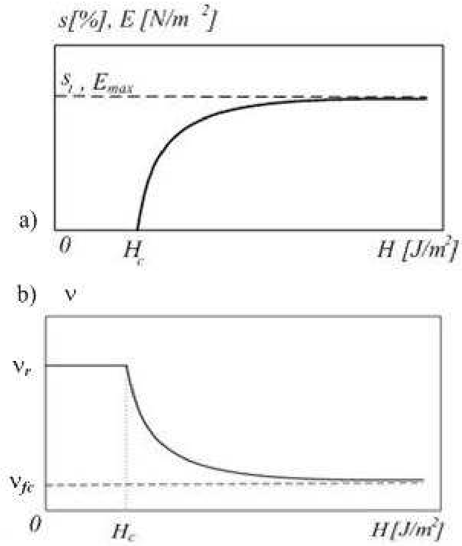


Fig. 1. Polymerization shrinkage *s*, Young's modulus (Eq. 1-2) and Poisson's ratio (Eq. 3) vs. light exposure *H*

The above microscopic process of conversion from monomer to polymer fraction leads to macroscopic changes of density of the material. The volumetric shrinkage (Fig.1) depends on the light exposure *E* applied during the curing process, according to the rule [2]:

$$s(H) = s_t\left(1 - e^{-K_s(H - H_c)}\right), \tag{1}$$

where: $H_c$ – critical exposure (exposure which starts polymerization), $s_t$ – total shrinkage of fully cured resin, $K_s$ – material constant.
Evolution of Young's modulus (Fig. 1) is described by the equation analogical to the relation (1), [3]

$$E(H) = E_{max}\left(1 - e^{-K_E(H - H_c)}\right), \tag{2}$$

where: $E_{\max}$ – Young's modulus of the cured material, $K_s$ – material constant. A similar relation is assumed for the Poisson coefficient [3] (Fig. 1):

$$\nu(H) = \nu_{fc} + (\nu_r - \nu_{fc})e^{-K_\nu(H - H_c)}, \tag{3}$$

where: $\nu_{fc}$ – Poisson's ratio of fully cured material, $\nu_r$ – Poisson's ratio of the resin, $K_\nu$ – constant.
There are several ways to reduce the shrinkage stresses: application of new low-shrinkable materials, application of special layer shaping (e.g. wedge-shaped techniques) and application of new curing methods (e.g. "soft-start" curing lamps) [1]. The problem of layer shaping was investigated by other authors using FEM methods [4,5]. Below, a new method of polymerization shrinkage reduction is presented.

## 2 MODELLING OF CLASS I AND CLASS II RESTORATIONS

The aim of simulations is to reveal the relation between stresses in different types of restorations. All simulations of the shrinkage stress, by means of the ABAQUS system, are performed for restorations of Class I and Class II (Fig. 2).

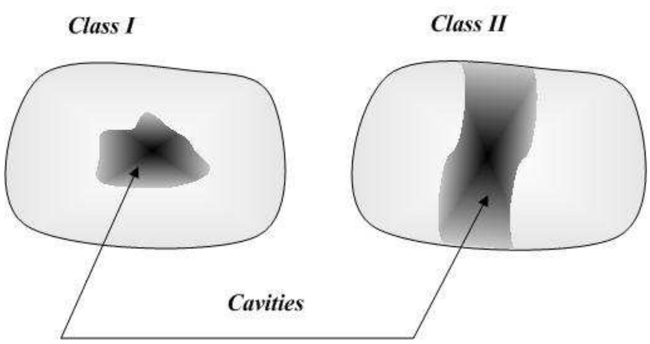


Fig. 2. Top view of Class I and Class II restoration

Both classes are modelled using the same geometry, with an assumption of axisymmetric model in the case of Class I, and plane strain model in the case of the Class II. The examined incremental restoration consists of four horizontal layers depicted in Figure 3. Mechanical properties of the tooth tissue, given in Table 1, are taken from the literature [6].

Table1. Mechanical data of the tooth tissue [6]

| | Young's modulus [MPa] | Poisson's ratio |
|---|---|---|
| Enamel | 80000 | 0.33 |
| Dentin | 18000 | 0.31 |
| Pulp | 2.07 | 0.45 |

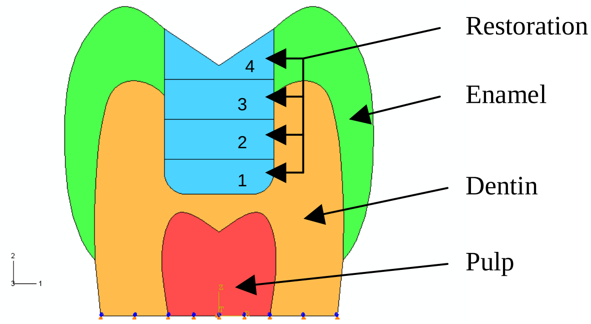


Fig. 3. Assumed tooth-restoration geometry

Properties of the restoration material are determined by Young's modulus – 4800 Mpa and Poisson's ratio – 0.25. Perfect bonding conditions between the composite and tooth, as well as between the layers of restoration, are assumed. The polymerization shrinkage is modelled by analogy to the thermal strain. In order to take into account both the normal and the shear stresses in the material, the Huber-Mises stresses are examined.

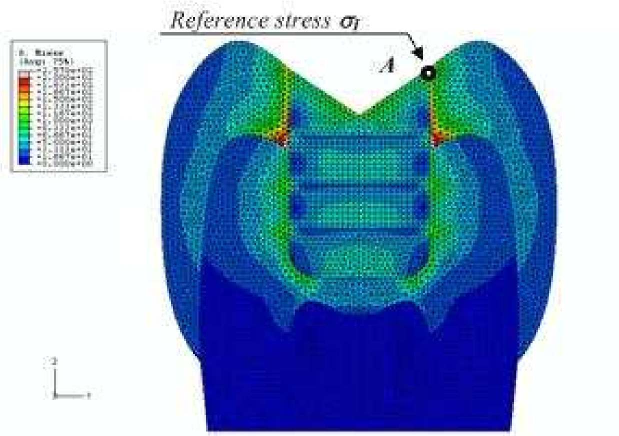


Fig. 4. Huber-Misses stress in Class I restoration

Results of calculations for the Class I restoration are shown in Figure 4. The highest stress $\sigma_I$ is situated at the point $A$ near the edge of the cavity. Here a microleakage may occur. The next numerical results will be referred to this point. One can observe essential differences between the stress distributions in Class I and Class II restorations (Fig. 5).

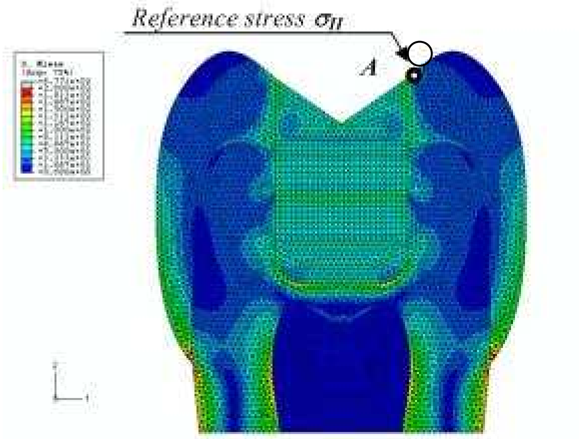


Fig. 5. Huber-Mises stress in Class II restoration

In the second case, an accumulation of stresses appears in the bottom part of the tooth, between the enamel and dentin. However, at the corresponding point *A*, the value of the stress $\sigma_{\mathrm{II}}$ is similar to the stress $\sigma_{\mathrm{I}}$. The stresses $\sigma_{\mathrm{I}}$ and $\sigma_{\mathrm{II}}$ will be assumed as the reference stresses for next simulations.

## 3 TECHNIQUES OF SHRINKAGE STRESSES REDUCTION

The purpose of the presented techniques is to reduce stresses in the tooth-restoration interface, and in consequence, to avoid the microleakage appearance. Most important is stress reduction at the top of the surface of filling at the point *A*. The simplest way to achieve it is a modification of stress distribution in the upper layer of the restoration. Other layers ca be modified too, but it will prolong the time of the tooth restoration. Below, two techniques of shrinkage stress reduction by a selective light curing of restoration are presented.

### 3.1 *Masking technique*

The first technique is based on polymerization of the last composite layer by applying a mask and typical polymerization lamp commonly used in dentistry (Fig. 6). At first, the inner part of the layer 4 is irradiated and polymerised. Next, the mask is removed and the filling as a whole is irradiated. It is assumed that the areas which are not cured, do not interact with the tooth or other parts of the restoration. The masking technique provides high reduction of stresses in the restoration and enamel. For Class I restoration, reduction of the Huber-Mises stress in the point *A* is about 53% as compared with the classical layering technique (Fig.7).

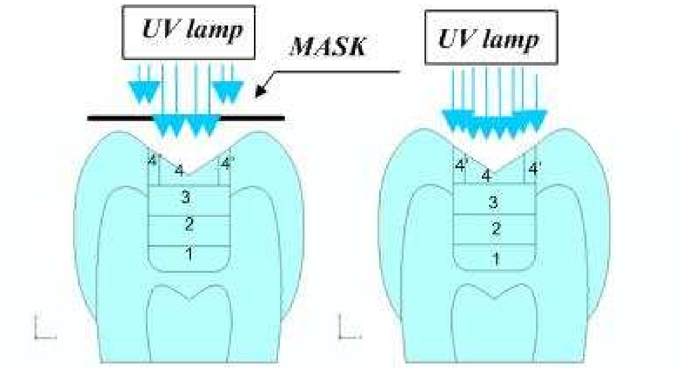


Fig. 6. Masking technique

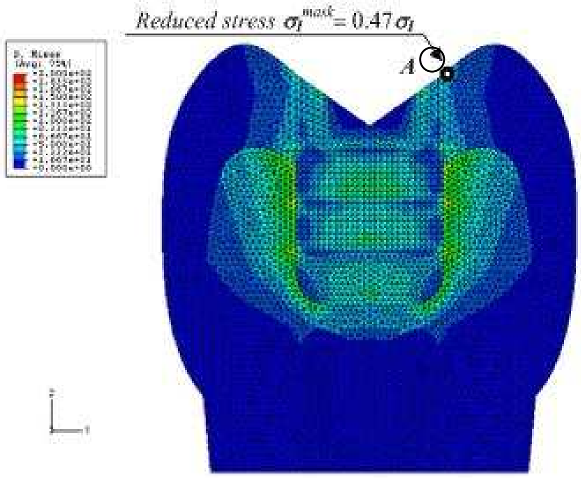


Fig. 7. Stress reduction in Class I restoration using mask

Results of simulation of the masking technique for the Class II restorations are shown in Figure 8. In this case, reduction of the Huber-Mises stress in the point *A* is about 22%. Insignificant reduction of stress accumulation in the lower part of the tooth is observed.

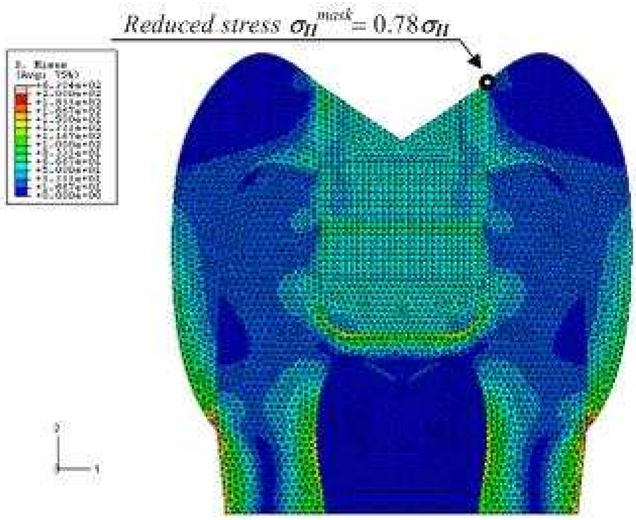


Fig. 8. Stress reduction in Class I restoration using mask

### 3.2 *Single hole technique*

One can achieve a stress reduction in a simpler way.

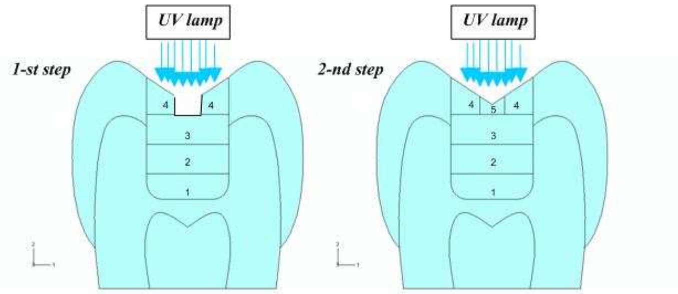


Fig. 9. Single hole technique

After polymerization of the first three layers and filling the fourth one, a single hole in the centre of the last layer is made (Fig. 9). When the resin around the hole is cured, the hole is filled with the resin, and the layer is cured again.

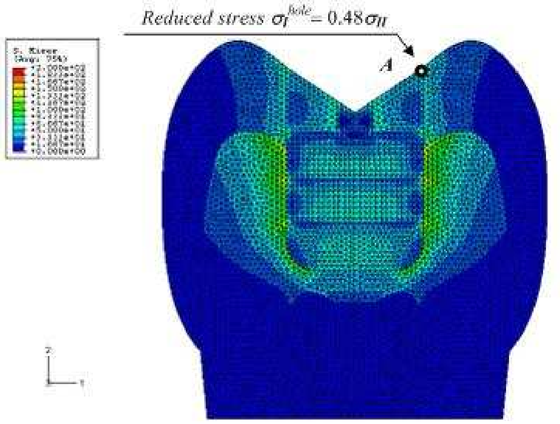


Fig. 10. Stress reduction in Class I restoration using single hole technique

For the Class I restoration, stress reduction equals 52%, and it is similar to that, which was achieved using the masking technique. The fact that the resin in contact with tooth tissue is cured first, may create good bonding conditions.

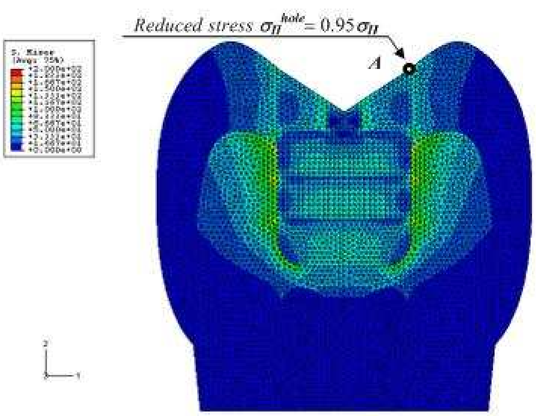


Fig. 11. Stress reduction in Class II restoration using single hole technique

The above technique is ineffective in the case of Class II restorations (Fig. 11). Stresses reduction is insignificant, 5% only. In this case, the masking technique is recommended.

## 4 CONCLUSIONS

Simple numerical simulations of shrinkage stress in dental restorations of Classes I and II are shown. Analysis of the classical incremental technique of restorations indicates a location of the highest stresses in the tooth tissues and restoration. Two simple methods of stress reduction are proposed: a "masking technique" and a "single hole technique". Numerical simulations show a significant reduction of stresses in the restoration and tooth tissues. Both methods are very effective for the Class I restorations. The first method is also effective for the Class II too. None of these techniques requires any complicated technological background, and the time of dental operation does not increase significantly. The proposed methods can be combined with other stress reduction techniques such as using lamps with modified light intensity. In the above simulations only the fourth layer of the restoration was modified. The effect of stress reduction may be increased if every single layer of the restoration will be modified. However, it will extend the time of the restoration process. Modification of the last layer only, does not take much time and significantly reduces the probability of microleakage.

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