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Estimation of stresses in layers of dentures' relining materials

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ABSTRACT

Purpose: Durability tests of materials relining dentures should be carried out in conditions reflecting the real loading that accompanies bite force transmission. The influence of geometry resulting from a denture foundation shape on real stresses in relining has not been so far found.

Design/methodology/approach: Using FEM modeling, identified were the stress levels in relining layers in conditions reflecting biting loading for two opposite cases of bone foundation atrophy.

Findings: The equivalent Huber-Mises` stresses have not reached their critical values, although tangential stresses on the interfacial where relining is bonded with denture base have reached 440kPa, which, for some of the commercial types of relining denotes the bonding strength.

Research limitations/implications: The linear elastic mechanical characteristics were assumed. Hence, during further research, taken into account should be the "stiffening" of characteristics in the upper loadings range, which is typical for silicones.

Practical implications: In case of a convex foundation the biggest danger will be caused by any bond defects occurring in the central area because in that area shear of bond has reached the highest values.

Originality/value: Values of stresses components identified in this paper reflect the real shear conditions of relining bonding with denture base and might constitute a determinant for strength tests.

Keywords: Biomaterials; Denture relining; Strength; Biting load

MATERIALS

1. Introduction

One of the basic tasks bio engineering is the strength analysis structures bearing loads during contact with human body tissues [1-4]. An example here can be soft layers of materials relining hard saddles of dentures, the aim of which is to limit the injuries of mucous membrane foundation soft tissue [5]. Biting loadings borne by the material of relining layer along with biological factors of oral cavity limit the time of their effective functioning [6-11].

The basis of durability evaluation for materials is the construction strength analysis carried out in order to determine stresses levels, which really occur during denture exploitation, paying attention especially to defining stress state components. Difficulties in determining uniform loading conditions in biomechanical systems incline to carrying out strength analyses in model conditions [12]. Relatively effective tool in this respect are FEM analyses [13-16].

The aim of this research was to determine, by means of a FEM analysis, stresses occurring in denture relining layer that accompany the real biting loads. Special attention has been paid to the changeable geometry of relining layers resulting from the anatomic variety of denture bearing area shapes.

2. Methodology

FEM model analysis of relining layers bearing biting loads has been carried out on two models representing cases of various alveolar ridges shape: strong atrophy with flat slopes and well preserved with steep slopes, hereinafter referred to as atrophied and embossed foundation. In Fig. 1. models with cross-section showing the assumed material groups are presented. Model conditions have been selected in such a manner that the only one variable in the system is the examined geometry of the relining layer resulting from the shape of foundation. Assumed was the thickness of relining layers of 2mm in both models, introduced „at the cost" of denture saddles. Value of app. 2mm is, in practice treated as the most effective one.

Analyzed was the case, where the cooperating relining and mucous membrane are characterized by the same elastic modulus E=5 MPa, with Poisson's ratio ν=0.49. For acrylic resin of the denture saddles, Young modulus E=2000 MPa and ν=0.3 was assumed. Cortical bone elasticity has been described with Young modulus E=17 GPa; whereas the spongy bone E=600 MPa; with Poisson's ratio equal ν=0.3 in both cases.

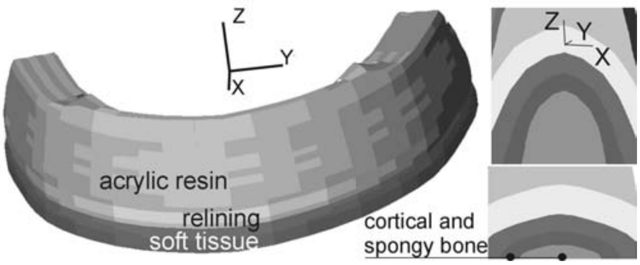

Fig. 1. View of models with cross-sections showing material groups and assumed in the analysis shapes of alveolar ridges representing atrophied and embossed foundation.

Models were loaded with a axial force of 100N in the area of incisor, canine and molar. At the bottom of the bone, on the whole length separated from the mandibular arch, assumed was model fixation, whereas on interfacial with mucous membrane, assumed was an ideal adherence. Analysis covered stress patterns in relining layer only. As incisor loading resulted in the highest stress level in relining material, the analysis of the influence of alveolar ridge shape on stress distributions was carried out for this load case.

3. Results

In Fig. 2-3 presented is a comparison of Huber-Misses's equivalent stresses patterns and components of „sx" stresses (in the area of incisors direction X corresponds with the backwards-forwards). Equivalent stresses in case of a flat alveolar ridge are concentrated in the zone of relining bonding with denture margin from the outer lip side. In case of an embossed alveolar ridge, generally, equivalent stresses reach significantly lower values, however the most distortional deformed and sheared are the areas adhering to mucosal surface.

Different influence of foundation shape is observed in case of „sx" stresses patterns. Here, contrary to the case of equivalent stresses: for the embossed alveolar ridge the „sx" stresses are higher than in case of an atrophied one. Similar tendencies to the „sx" component are shown by the vertical stresses („sz" compression), as well as stresses („sy") acting lengthwise to mandibular arch. Values of tangential stresses on the surface between relining and the saddle decide about the damaging of the bonding between them. In the area of incisors these are the maximum values of „sx" and „sy" components.

For extreme foundation shapes shown on the graph in Fig. 4 juxtaposed are the values of equivalent (Huber-Misses) stresses, those of compression in relining material and absolute values of maximum circumferential stresses („sx") and longitudinal („sy").

The results of FEM model research depend on simplifying assumptions imposed by the abilities of computational technique, especially numerous in case of models that are complex, as far as their geometry and used materials are concerned. Biomechanical systems belong to these models. For the purposes of this analysis, separated from the mandibular bone was only the part constituting denture supporting zone. This assumption limits an analysis possibility of stresses in bone, which result from its total bending and torsion. It does not however, significantly influences comparative studies of stresses in relining materials. Similarly, simplified outline of denture teeth does not have any significant importance for the analyzed phenomenon, just as the anisotropic of mechanical characteristics of mandibular bone tissue that occurs in reality. Because of insignificant flowing effects in case of silicones, in applications of a long-term relining commonly forced out all plasticized acrylic materials now, mainly used for temporary relining, an assumption of linear elastic features gives a good approximation of characteristics. Nevertheless, in the upper range of loads, these materials show stiffened characteristics, hence for the assumed stresses values they will be underestimated, especially in areas of hydrostatic stress state.

The most significant influence on results of the model experiment has the manner, in which the model is loaded and supported. In this research, intentionally, unfavorable values of biting loads were assumed, because 100N correspond to the upper range of complete tissue supported dentures. Assumption of a complete denture adherence to its foundation limits researches results to the situation of a stable denture support by foundation, in which transmission of biting loads does not lead to a local lost of adherence or to slip on the mucous membrane surface.

On the basis of model results, no exceedance of dangerous values levels of equivalent stresses has been found for relining materials. Similarly, compression in the worst case does not exceed 0.5 MPa. For most of the commercial relining silicones it denotes at least a quadruple safety margin.

Therefore, the root-causes of relining failures should not be sought in exceeding of permissible stresses in the material itself. Also values of tangential stresses on interfacial bond do not exceed the strength for most of relinings . Although, these values are closer to the dangerous level than the ones of the relining material. For some commercial relining, the strength of the connection with methacrylates of denture base does not exceed 1MPa, or even can equal app. 800 kPa [17], or even slightly below 500 kPa [18]. Therefore, there remains a small safety margin or none at all. For most of the constructions 20-30% of safety margin may be sufficient.

Nevertheless, such an evaluation does not take into account any changes of material characteristics, which take place in oral cavity environment. Changes caused by cyclic biting loads are also imposed by biological factors.

Mentioned should be the main impacts of individual variety of chemical content, viscosity, amount and pH of saliva, bacterial flora, preferred diet, denture cleaners and thermal cycles.

Model results are therefore consistent with the observed real problems of: pre-mature wear, in respect of the forecasted exploitation period in oral cavity, lost of fixed bond between denture acrylic resin and relining silicone, or accelerated material degradation processes on the interface of the tribological pair - silicone / mucous membrane.

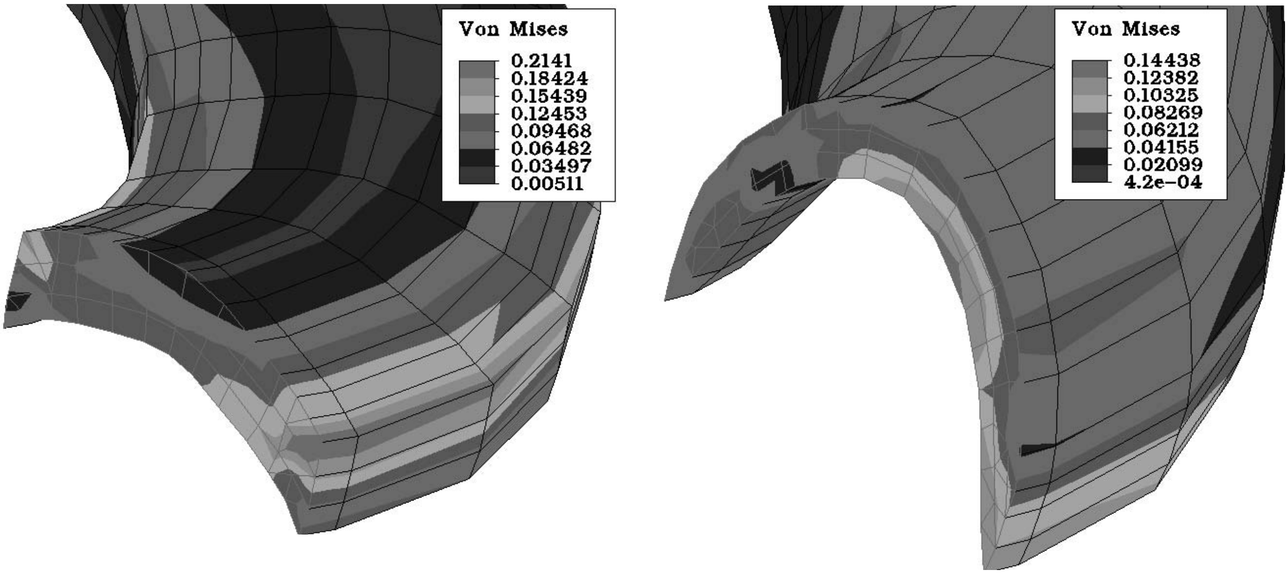

Fig. 2. Comparison of Hubera-Mises's equivalent stresses (MPa) patterns in a 2mm thick relining layer depending on the shape resulting from the degree of atrophy of prosthetic foundation

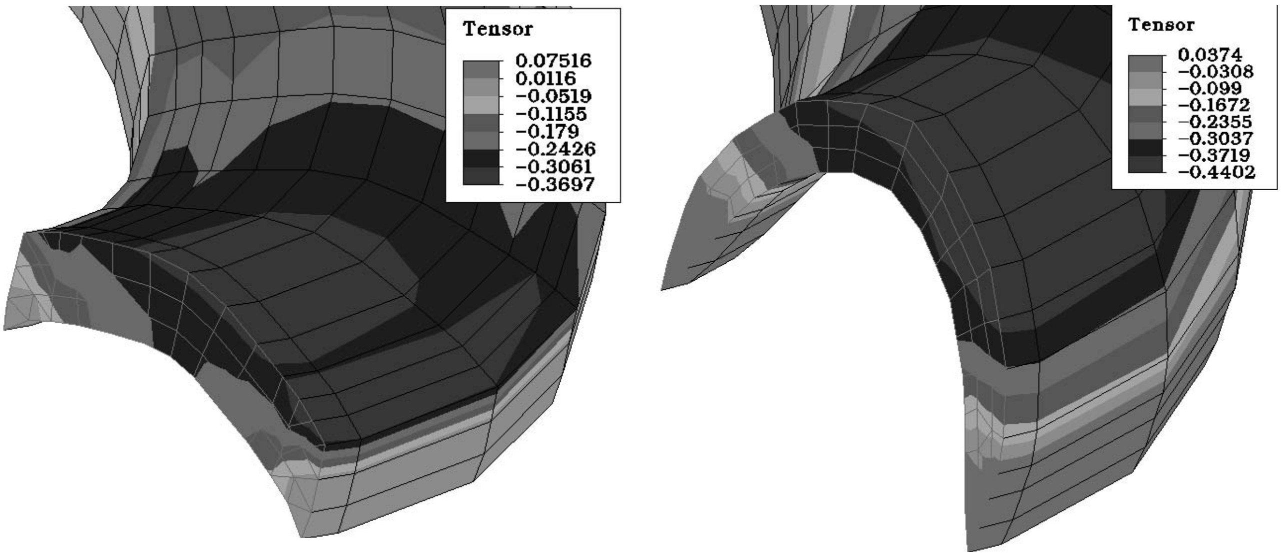

Fig. 3. Comparison of „sX" stresses components (MPa) patterns in 2mm thick relining layer depending on the shape resulting from the degree of atrophy of prosthetic foundation

There also occur a possibility of mechanical damages on surface caused during hygienic procedures, which along with wetting parameter of a give relining material might predispose a layer to an earlier degradation.

Additionally, the values of bonding strength given by producers, correspond to laboratorial conditions both because of the samples and the method in which the bond test is carried out. During real manufacturing of relining layer, forecasted can be a higher risk of bond failure, e.g. by means of impurities or less precise conditions of polymerization.

On the basis of the carried out analysis it can be said that in case of an embossed foundation the highest level of danger is caused by any bond failures occurring in central area, because the bonding shear there reaches the highest values. On the other hand, in case of a atrophied foundation, stresses values that are dangerous for bonding occurs not only in central area, but are also located on outer saddles margins. These are at the same time areas of the highest shear of the material itself.

Further laboratorial strength tests of relining materials should take into account the loading state reflecting the real shear conditions on the bond with denture saddle material and friction on the interface with mucous membrane.

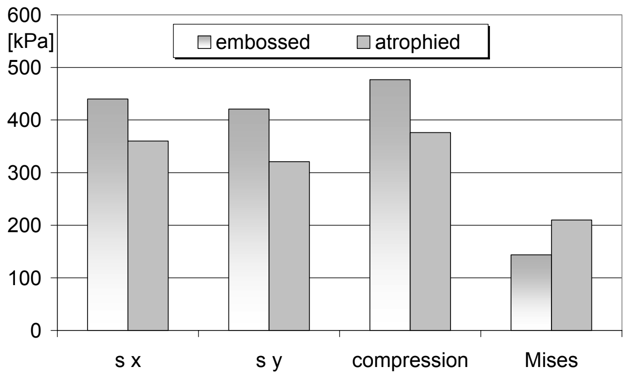

Fig. 4. Influence of prosthetic foundation shape on criteria shear stresses values on the surface of bond: relining / saddle („sx" and „sy") as well as material compression and Huber-Mises' equivalent stresses

4. Conclusions

In the assumed model conditions no exceeded critical stresses values for the material of the silicone relining layer has been found. Nevertheless, tangential stresses reach a dangerous level on the interface with denture basis, because in case of additional interaction on material by the environment of oral cavity, even twofold safety margin is obviously not enough here. Determined values of stresses components correspond with real shear conditions for a bond and denture basis and might constitute a determinant for strength tests of the usually used 2mm thick relining.

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