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# Development of Micromechanical Properties Across Carious Areas of Human Tooth and Dental Filling

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**Abstract:** The main focus of this paper is to describe the distribution of micromechanical properties (reduced modulus $E_r$ and hardness $H_{it}$) of human tooth treated with dental filling. The enamel and secondary dentin are carious and exhibit a decrease in the values of mechanical properties and following application of amalgam filling causes inconsistent interconnection of individual layers. The analysis was carried out on 2 samples of teeth n.37, extracted due to presence of an advanced stage periodontitis chronica. The amalgam-treated samples come from a woman (48 years) and a man (26 years). The most observable differences occur in the dentin area, where $E_r$ values differ as much as $\sim$ 30 GPa in the central area and $\sim$ 8 GPa in the dentin-amalgam interface. Differences in the area of enamel are not as significant, ranging from $\sim$ 103 GPa in the central area to $\sim$ 91 GPa in the enamel-amalgam interface. The mean $E_r$ of amalgam filling is $\sim$ 65 – 71 GPa.

**Keywords:** Human Tooth; Tooth Filling; Dental Caries; Nanoindentation; Elastic Modulus.

## 1 Introduction

Teeth are a very important part of a functional complex of the human, they are used mainly for food comminution and for articulation of some consonants. From the morphological point of view, a human tooth consists of three basic parts - the root, the neck and the crown. This study is focused only on the chewing surface of the crown damaged by tooth decay. The crown consists of dentin and enamel. Dentin is a heterogeneous material composed of tubular, peritubular and intertubular part and contains dentinal tubules with Tomes fibers [1]. Enamel is a highly mineralized tissue (with 95 - 98 % of inorganic materials) formed by the prismatic crystals, which extend in the perpendicular direction to the enamel surface [1].

The primary reason of treating a tooth with amalgam filling is the formation of dental caries, which are associated with the demineralization of dentin and enamel, the following degradation of the tissues and creation of cavities. Demineralization is most commonly initiated by the pH decrease which is caused by bacterial transformation of saccharides into weak organic acids [2]. The resulting growth and spreading of the decay has to be stopped by careful drilling, cleaning and closing the cavity. Modern technology provides us with many methods of effective treatment. A few of the most widely used materials are amalgam filling, composite filling and glass ionomer cement [4]. Application of a quality and suitable filling with regards to the relations between material characteristics of the filling and tooth [5] can ensure a successful treatment of the carious tooth and stop the progression of the decay towards pulp cavity and tooth root.

## 2 Methodology

For our study of the tooth micromechanical properties analysis in the filling locality we used tooth labeled by the *Two-digit* system No. 37, from the 48 years old woman - tooth No. 1 (tooth decay intervened only to the enamel part), and from the 26 years old man - tooth No. 2 (tooth decay pervaded through enamel to dentin structure). In both cases the tooth contains a conventional amalgam filling (amalgam y2) and was extracted for the advanced state of periodontitis chronica. Different chemical composition of the amalgam filling from various producers with corresponding mechanical properties can influence the functionality and long-term stability in the tooth cavity.

Essential components of the used dental materials are [3]:

- enamel – fluorohydroxyapatit $M_{10}(PO_4)_6(OH)_2$ (where "M" element can be represented by baryum, stroncium or calcium),
- dentin – collagen fibrils of the I. Type, glycosaminoglycans and hydroxyapatit $Ca_{10}(PO_4)_6(OH)_2$,
- amalgam – filling composition may vary according to the respective producer and primarily results from the combination of silver, tin and copper. Chemical composition of standard mixtures is given in Tab. 1.

Tab. 1: The basic chemical composition of dental amalgam [3].

| Material | Chemical element [%] | | | | |
|---|---|---|---|---|---|
| | Ag | Sn | Cu | Zn | Hg |
| Conventional (y2 amalgam) | 66-73 | 25-29 | 6 | 2 | 3 |
| With increased content of Cu (non y2 amalgam) | 40 | 25-29 | 10-30 | 2 | 3 |

Determination of micromechanical parameters was performed using nanoindentation method which allows measurement of calcified parts of enamel, peritubular and intertubular dentin separately which proves the structural dependency of the dentin on mechanical behavior. Measurements were made in transversal sections of the tooth crown in the filling area. Analysis of micromechanical properties (reduced elastic modulus $E_r$ and hardness $H_{it}$) was performed in the laboratories of Faculty of Civil Engineering, CTU in Prague, using the instrumental hardness tester NHT CSM Instruments equipped by Berkovitch corpuscle.

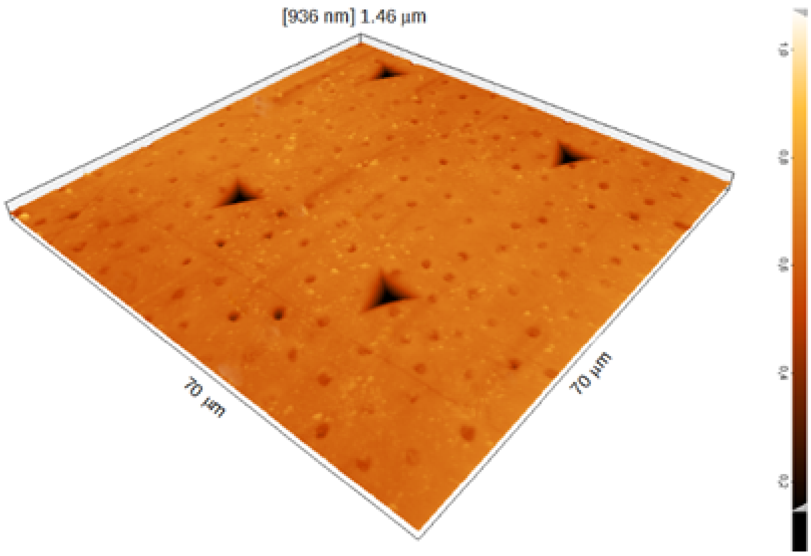
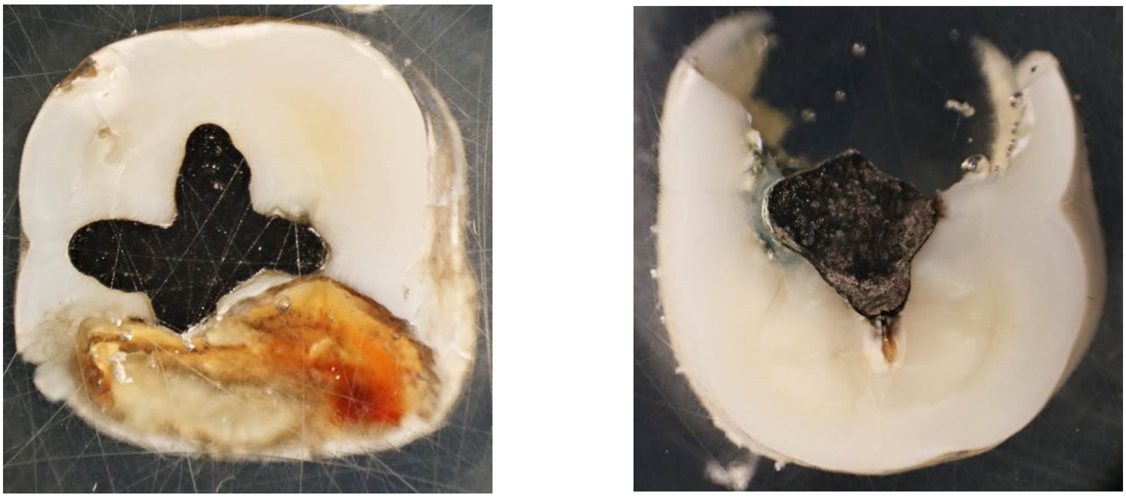



Fig. 1: AFM image of indent matrix in the dentin with visible tubules.

Samples were prepared by embedding in the eposy resin and subsequently polished in transversal section led by upper edge of the crown through the filling locality (Fig. 1). Loading was performed with controlled force up to its maximum size of 30 mN with 180 mN/min loading velocity, 10s action of constant 30 mN force and unloading part with 180 mN/min unloading velocity. The size of the force was determined for the expected depth of the indents in range of ∼800 – 1600 nm with regards to the significantly results influencing by the high porosity of the dentin structure. All indents were oriented in the direction of tooth longitudinal axis.

Individual transversal sections were made in various tooth levels because the specimens showed the different depth of dental material removal before the filling application. This fact causes a differences in measured material properties especially at the tooth - filling interface. While in case of tooth No. 1 the filling is in contact with the enamel, in case of tooth No. 2 the filling is in contact with dentin. Indent matrix were placed in the dentin wall center, medium surface of enamel, interface between dentin/enamel and filling and locality of amalgam filling, always in the dist-mesial direction.



(a) tooth No. 1 (b) tooth No. 2

Fig. 2: The optical microscope images of the tooth crown sections in the locality of dental filling.

## 3 Results

The set of results were evaluated using the Oliver&Pharr methodology with simplifying assumption for isotropic elastic materials. Nanoindentation measurement results are shown in Tab. 2. Measured values are influenced by the size of the defect and by the depth of the filling. While sample No. 1 contains a filling which extends only into the enamel and the section was conducted at the enamel - filling level, the section level of the sample No. 2 was conducted throughout the enamel - dentin - filling level.

Tab. 2: The average mechanical properties of dental materials measured by nanoindentation ([1] at the dentin - filling interface, [2] at the enamel - filling interface).

| Material | Tooth No. 1 | | Tooth No. 2 | |
|---|---|---|---|---|
| | $E_r$ [GPa] | $H_{it}$ [MPa] | $E_r$ [GPa] | $H_{it}$ [MPa] |
| Enamel | $102.22 \pm 5.16$ | $4170.00 \pm 70.00$ | - | - |
| Dentin | - | - | $30.24 \pm 1.91$ | $1030.00 \pm 70.00$ |
| Interface | $91.14 \pm 4.58$ [2] | $4370.00 \pm 260.00$ [2] | $7.60 \pm 1.12$ [1] | $77.00 \pm 8.00$ [1] |
| Amalgam | $65.64 \pm 7.14$ | $2250.00 \pm 910.00$ | $71.21 \pm 5.6$ | $1810.00 \pm 210.00$ |

The values of the measured mechanical parameters of organic materials (Tab. 2) are dependent on the distance from the locality damaged by the tooth decay. The measurements demonstrated that the dental material (enamel, dentin) situated closer to the cavity of the tooth decay removal and the amalgam filling application achieves lower levels of mechanical properties. Lower quality of the dental material can be explained by a higher level of demineralization and insufficient removal of the affected tooth area.

The large inconsistency interconnection between amalgam filling layer and enamel/dentin material has been detected from the microscopic analysis. Simultaneously the considerable development of cracks was observed in the dental material (Fig. 2). This discontinuity and subsequent cracks development can be caused by large differences in mechanical properties of the partial materials, particularly where the enamel is much more fragile material than dentin (more prone to creation of passively distributed cracks). The extent and size of the cracks is larger in case of tooth No. 1, where the filling material is in the direct contact with the enamel. In case of tooth No. 2 the dentin violation range at the interface with filling material was much smaller. This fact can be explained by a significant differences in the stiffness of dentin and enamel, where the enamel has higher elasticity modulus, but it is very fragile material and therefore prone to mechanical damage.

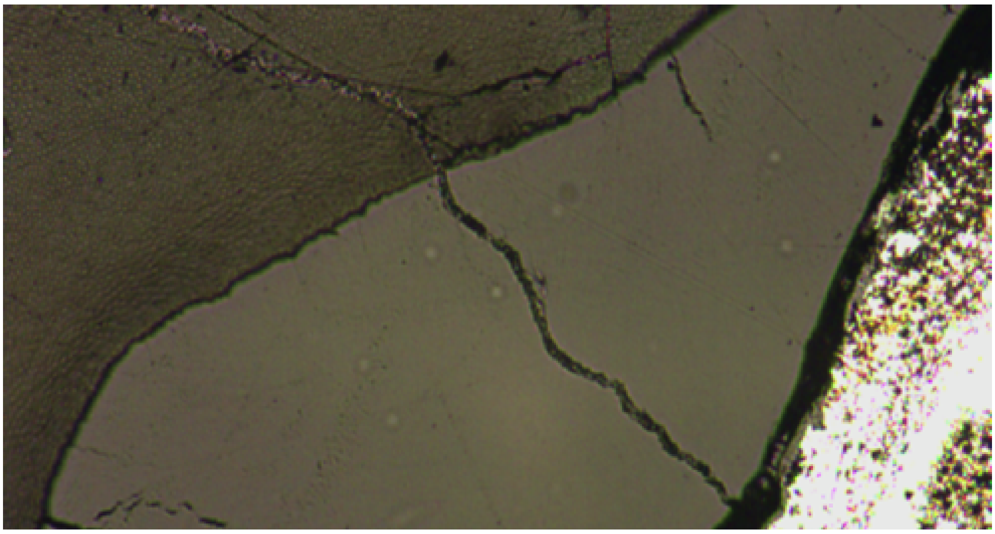


Fig. 3: Microscopic image of dentin - enamel - amalgam transversal section with extensive crack formation in the tooth No. 1.

## 4 Conclusion

The micromechanical properties through interfaces of different dental materials were reported. The trend of these properties indicates that the decrements are more significant the closer we move to the tooth decay. Dental tissues are sensitive materials that degrade when subjected to dental caries and should be, in such cases, treated with appropriate dental filling material to help preserve the lifespan of one's dentition.

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