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# On the deformation behavior of human dentin under compression and bending

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ABSTRACT

The cause of difference in deformation behavior of human dentin under compression and bending is discussed. Mechanical properties of dentin under these deformation schemes are compared. Microstructural study of fracture surfaces of samples and cracks in dentin is carried out, too. Dentin behaves like a brittle solid under bending, whereas it exhibits various types of response from brittle to highly deformable under compression that depended on the geometry of sample (d/h ratio of a cubic sample). It is shown that the quantity of cracks on the compressed sample increases when its elasticity and plasticity grow up, whereas under bending the failure of sample occurs due to the advancement of dominant crack. Deformation and crack growth are the channels for the accommodation of applied stress in dentin. Crack growth is the leading one when the level of tensile stress in sample is dominant, whereas deformation becomes the leading channel when compression stress is dominant. However, in both cases contribution of the concurrent channel cannot be ignored. This feature is caused by the ductile fracture mode of dentin on the mesoscopic level.



## 1. Introduction

Human tooth may be used as the object for elaboration of biomimetics due to its unique mechanical and corrosion properties that are caused by complicated hierarchic structure of tooth hard tissues [1–3]. Therefore, searching for the relationship between microstructure and macroscopic properties of tooth hard tissues is an important step in this direction. The hard basis of a tooth is dentin, which consists of 50% inorganic (basically, calcium hydroxyapatite), 30% organic components (collagen fibers etc.) and 20% water [4]. There are three scales in the structure of dentin. The first is collagen fibers and calcium hydroxyapatite in the nano-crystalline state; the second is network-like structure of collagen fibers in intertubular dentin. And the third is dentin tubules surrounded by a highly-mineralized cuff (peritubular dentin) [5–7].

Experiments have shown that human dentin is practically undeformed brittle substance under bending when considerable tensile stress is applied to the sample [8–10]. On the contrary under compression (when the level of tensile stress in a sample is considerably lower) dentin exhibits various types of deformation behavior, which depends on the d/h-ratio of cubic sample. At d/h ~10, dentin samples demonstrate the high elasticity (up to 40%) and the considerable plasticity (up to 18%) despite their high strength (up to 800 MPa), while at d/h ~0.4, they behave like a brittle solid [11,12]. Despite considerable shape effect, no size effect was revealed in dentin. It allows concluding that the shape effect is not an experimental artifact that is usually caused by an interaction between compression plates and surfaces of sample. It is important to note, that orientation of the dentin tubulars did not influence the mechanical properties of dentin including shape effect [12]. No microstructure study of the dentin samples after the test was carried out in this research and, as a result, the findings were limited by the description of mechanical behavior of dentin only. Soft biological tissues and some filled polymers (rubbers) are demonstrated the same elasticity and plasticity, but their strength is considerably lower. It is unclear whether what mechanism is responsible for such unique combination of the mechanical properties of this biological mineral-rock-like material.

The aim of this work is analysis of deformation behavior and microstructure of human dentin under compression and bending for searching the source of its unusual mechanical properties. These deformation schemes allow describing the bulk properties of dentin as a biocomposite, whereas the indentation testing is limited by local area of sample, where mesoscopic and microscopic levels are acted in the stress accommodation only. Small volume of dentin in a human tooth is the main cause why macroscopic tensile testing cannot be carried out correctly. Therefore, such deformation scheme was not included in this research. Naturally this problem is also important for the dental science, because premolars and molars are subjected by compressive

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stress only, while the labial teeth (incisor and canine) undergo by both compression and bending under mastication of food [13]. It is important to note that dentin of intact teeth never undergoes by the point loading due to enamel.

## 2. Materials and methods

### *2.1. Sample preparation*

Forty of intact (caries free) human teeth, which have been extracted according to the medical diagnosis and the Ethic Protocol of the Urals State Medical Academy at Yekaterinburg from the mature patients (25–40 years), were used in this work. Sample preparation technique has been described elsewhere [12]. Dentin samples for mechanical tests have been cut with the help of diamond saw under water irrigation according to the scheme given in Fig. 1. They were grouped in to two sets. The first one is for the compression tests, while the second one is for the bending. The surfaces of samples have been abraded by the abrasive paper with the abrasive grain size of 10 μm for removing the damaged layer. Samples of the first set (10 pieces per each d/h ratio) possess the different d/h ratio (Fig. 2) from 0.4 to 9.8 (10 pieces per d/h ratio). The second set contains 20 samples with the size of 0.8 × 2 × 12 $mm^3$.

### *2.2. Microstructural examination*

The back surfaces of samples have been examined by means of the light and scanning electron microscopes (SEM) JSM-6390 prior and after each test. Examination has shown that prior testing the samples did not contain any damages. No dominant orientation of the dentin tubulars was detected in them due to complicated distribution of the tubulars in human teeth. Examination of microstructure of dentin ahead of the crack tips was carried out using transmission electron microscope (TEM) JEM-2010. Thin foils were prepared by means of mechano-chemical thinning. Cracks in thin foils of aluminum were used as the etalon of ductile crack.

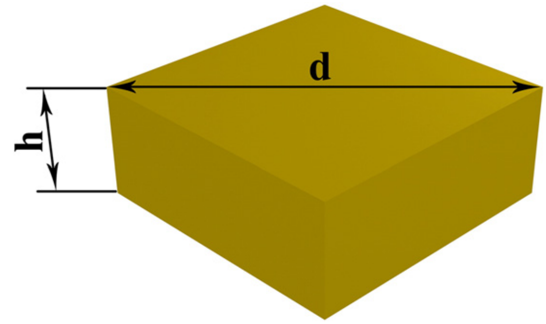


**Fig. 2.** Geometrical characteristics of dentin samples for compression test.

### *2.3. Mechanical testing*

Shimadzu AGX-50kN facility has been used for the room temperature (~25 °C) mechanical tests. Both compression and three point bending (distance between the prisms is 8 mm) were carried out under a loading rate of 0.1 mm/min, which was optimal for the samples with such size. Earlier, the rate dependence of mechanical properties of human dentin under compression was studied [12]. No sufficient difference in mechanical behavior was obtained. In spite of this fact, the constant loading rate was used in all tests. The size of the samples has been controlled by the instrumental microscope UIM-21 (precision of measurement 1 μm).

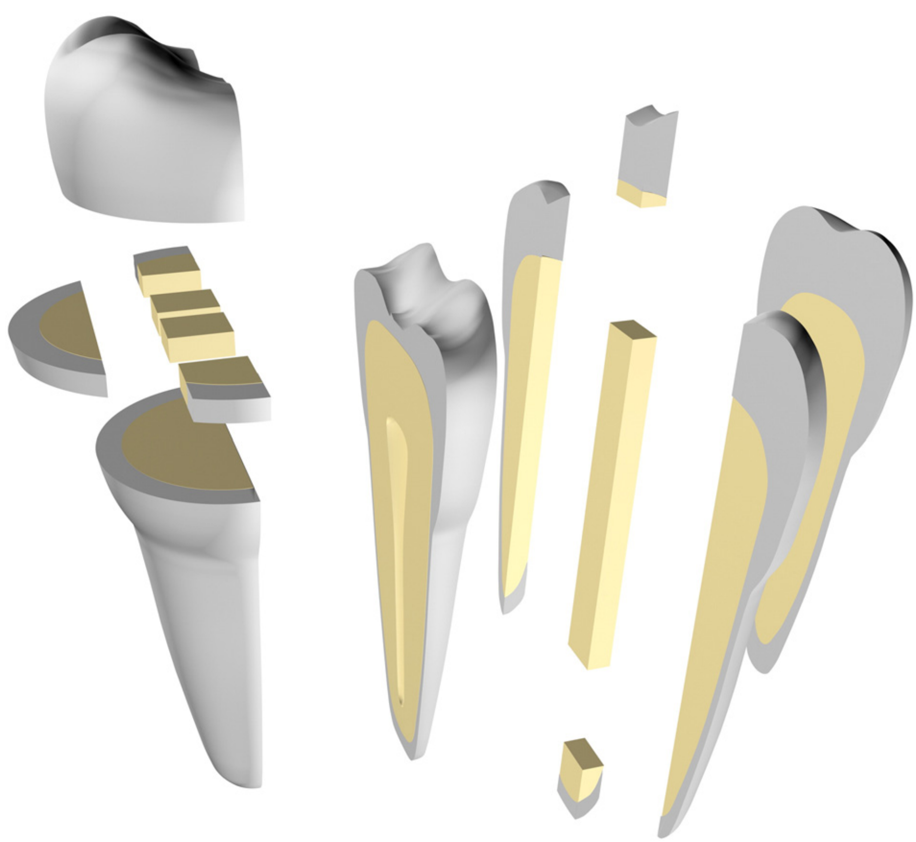

**Fig. 1.** Scheme of cutting off a tooth for the preparation of samples for compression test and bending.