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The strength properties of human dentinoenamel junction

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ABSTRACT

Deformation behavior of human dentinoenamel junction (DEJ) was studied under shear testing at room temperature. Twenty samples with flat DEJ that contained dentin and enamel in the 1:1 proportion were cut from intact human teeth. DEJ was the shear plane in the samples which were divided into two equal parts under loading. Since deformation curves of the samples with DEJ could be approximated by straight lines and the sample failure occurred through unstable growth of cracks, the deformation behavior was treated as brittle. The shear modulus and the shear strength were 0.31 ± 0.04 GPa and 16.4 ± 3.0 MPa, respectively. SEM examination of fracture surfaces showed that cracks propagated in both the dentin and enamel parts of the samples. Hence, the mechanical properties of dentin and enamel were similar in vicinity of DEJ.

1. Introduction

Dentinoenamel junction (DEJ) is a natural interface between highly mineralized tooth tissues (dentin and enamel) that possess different mechanical properties. The width of DEJ is about 10 μm [1,2] and its profile is scalloped (the size of scallops varies from 25 μm to 100 μm) [2,3]. Deformation behavior of tooth enamel is brittle, whereas that of human dentin is elastic-plastic [4–8]. Despite this, both the hard tissues have similar compression strength [4,9–11]. Dentin and enamel contain directional structural elements, namely dentin tubulars and enamel rods, respectively, and, as a result, they can demonstrate orientational anisotropy of mechanical properties [6,12–15]. DEJ plays the key role in the human tooth as a biomechanic system, because it serves as a damper between the hard tissues having different mechanical characteristics. It gives considerable contribution into the deformation behavior of samples contained DEJ under compression as compared with that of dentin and enamel samples [9]. Specific properties of DEJ is the reason why dentin and enamel work together in human teeth throughout human life, however the mechanisms of this work are still unclear.

There is a lack of information on mechanical properties of DEJ in the literature. The most of data is devoted to mechanical behavior and fracture of DEJ under point loading including nanoindentation. They demonstrate that cracks do not penetrate from enamel to dentin due to the DEJ which suppresses crack growth [16–18]. Usually, cracks propagate along the DEJ on the enamel side, but sometimes they are able to penetrate into dentin not deeper than by 10 μm. In the human tooth there is a transition area of about 10 μm in width, where the sample hardness changes from the dentin hardness to the enamel hardness [1,19]. The tensile strength of samples with DEJ is 46.9 ± 13.7 MPa [20].

In the most of cases, the fracture of samples with DEJ occurs on the enamel side in vicinity of DEJ. Therefore, their tensile strength cannot be considered as a property that is ruled by the deformation behavior of samples with DEJ. The compression and bending tests allow to obtain some information on the DEJ contribution into the deformation behavior of samples with DEJ, however this contribution cannot be clearly separated from contributions of dentin and enamel [1,9,16,21,22]. Nanoindentation is the advanced technique which gives information only about some local volume of material in the surface layer of a sample. Therefore, it cannot correctly describe the macroscopic mechanical properties of tooth hard tissues including DEJ. Shear testing is a deformation scheme that allows to apply mechanical loading to some selected planes of a sample. Despite of the fact that DEJ possesses a complicated profile, there is almost flat DEJ on the backside of the tooth crown [23] and, therefore, the samples with planar DEJ can be prepared for shear testing. The aim of the present work is to study the deformation behavior of the samples contained planar DEJ under shear testing.

2. Materials and methods

Ten intact human teeth without visible damages were extracted from mature subjects according to the Ethical Protocol of

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Urals State Medical University (Ekaterinburg, Russia). Twenty samples with DEJ for shear testing were cut off by means of the diamond saw from the backside of tooth crowns under water irrigation. All samples contained dentin and enamel in the 1:1 proportion (Fig. 1(a)). The samples had the shape of a parallelepiped with sizes of $1.1 \times 1.8 \times 3$ mm^3. Abrasive papers were used for removing the damaged layer from their surfaces. Metallographic examination showed that the shape of DEJ was close to planar in all the samples and there were scallops of 10 μm in size in the DEJ (Fig. 1(b)). Shear tests were carried out at room temperature with the help of Shimadzu AGX-50 kN machine (loading rate was 0.1 mm/min). Trapezium-X was used for the data processing including statistics. The plane of shift coincided with the plane of DEJ in the sample. The shear modulus was calculated from the slope of deformation curves as a ratio of the shear stress and the shear strain. The maximal stress under testing was accepted as the shear strength of samples with DEJ. Scanning electron microscope (SEM) JEM 6390LV was applied for examination of fracture surfaces of the samples.

3. Results and discussion

Under shear loading, all samples break up into two parts. Failure of the sample always occurs in the shear plane and, therefore, it is close to the DEJ plane. A typical deformation curve is given in Fig. 2. Although the curve has a complicated shape, it can be approximated by a straight line. The shear modulus and the shear strength of samples with DEJ are 0.31 ± 0.04 GPa and 16.4 ± 3.0 MPa, respectively (see Table 1). The elastic deformation of the samples under shear testing is $5.4 \pm 0.6\%$, while their plasticity is zero. Hence, the deformation behavior of samples with DEJ may be considered as brittle or quasi-brittle due to their considerable elasticity.

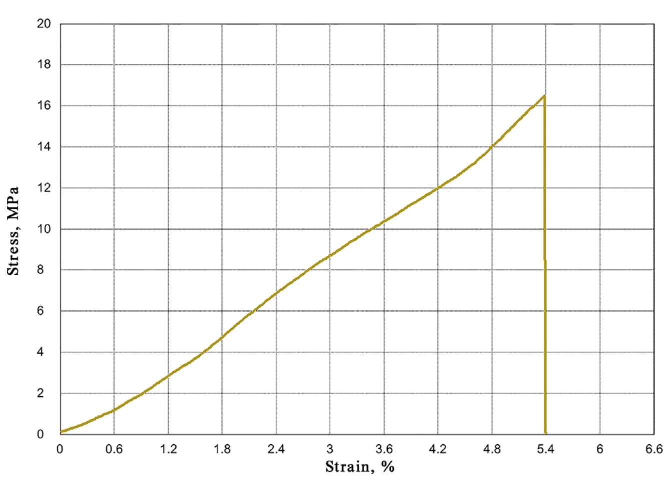

Fig. 2. Typical stress-strain curve of the sample under shear testing.

The mechanical properties of samples with DEJ under shear testing are lower than those of dentin and enamel having the same orientations of dentin tubulars and enamel rods (Table 1). The shear strength of samples with DEJ is ~2.5 times smaller than that of dentin and ~9 times smaller than that of enamel, whereas the shear modulus is ~2 and ~3 times smaller, respectively. Dentin and enamel are able to plastically deform whereas no plasticity is observed in samples with DEJ [14,15]. The elastic deformation of dentin is equal to that of samples with DEJ, while it is ~2 times smaller than that of enamel.

A SEM study of fracture surfaces of samples with DEJ has shown that both the dentin and enamel sides of the fracture surface are macroscopically smooth and parallel to the shear plane (Fig. 3). The crack trajectory passes either through both the dentin and enamel sides or there remain small dentin regions on the enamel side of samples with DEJ (Fig. 3(a) and (b)) and vice versa (Fig. 3(d) and (f)). Hence, we can conclude that the trajectories of magistral cracks in samples with DEJ are determined by the geometry of applied stress, while the contribution of microstructure of samples with DEJ to their fracture is insignificant. The enamel rods and the dentin tubulars are clearly visible on the fracture surfaces of the enamel side and the dentin side, respectively. The dentin side of fracture surface does not contain cracks and looks microscopically smoother than the enamel side of fracture surface. On the enamel side of fracture surface, a system of parallel cracks is observed (Fig. 3(c)). The crack growth occurs here in both the normal and parallel directions with respect to the enamel rods, while cracks always grow normally to the dentin tubulars on the dentin side (Fig. 3(d) and (f)). On the dentin side, there are shallow grooves which have the same orientation as the cracks on the enamel side (Fig. 3(e)). In vicinity of DEJ, cracks propagate along DEJ in enamel (Fig. 4).

Both the shear strength of dentin and shear strength of enamel are higher than the shear strength of samples with DEJ [14,15]. Hence, we can conclude that some mechanical properties of dentin and enamel decrease in vicinity of DEJ. Indeed, the microhardness of mantle human dentin and the microhardness of enamel also decrease near DEJ [1,19]. The width of the area, where the microhardness of samples with DEJ decreases, is about 10 μm. Our metallographic examination has shown that microstructure of the dentin side in vicinity of DEJ begins changing at the distance of 800 μm from the DEJ, while dentin tubulars disappear at the distance of 10 μm from the DEJ. However, the dentin tubulars and the enamel rods on the fracture surface of samples with DEJ look similar to the dentin tubulars and the enamel rods on the fracture

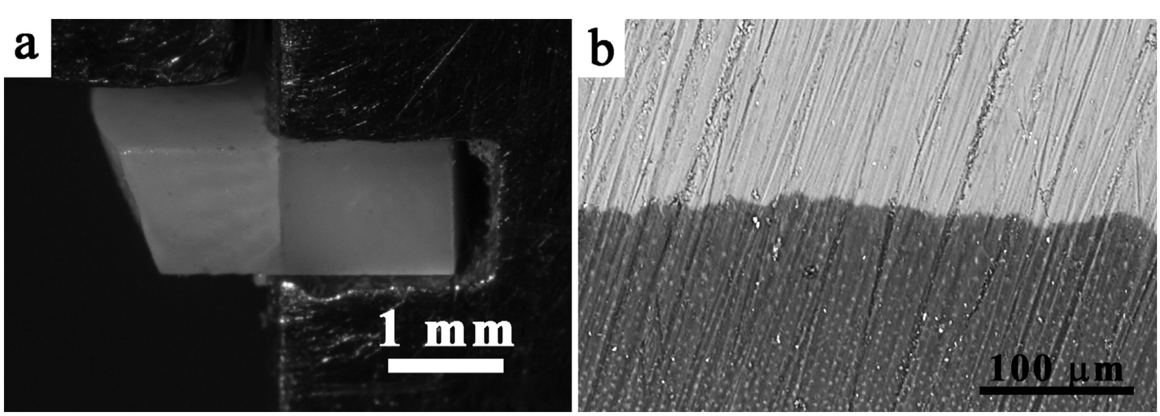

Fig. 1. Sample contained the DEJ for shear testing: a – general view; b – back surface of the DEJ. The DEJ is microscopically rough. There are some scallops in the DEJ.