Elastic Modulus of Human Dental Enamel from Different Methods

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ABSTRACT

Knowing the elastic modulus of human dental enamel is of high importance since dental filling materials should possess equal mechanical properties as enamel itself. If this demand is not fulfilled, the interaction between filling and enamel is not equivalent, so that healthy enamel could be simply abraded during chewing. Hence it is astonishing that the literature shows a big variety of suggestions for the elastic modulus. This paper will give a short overview about some existing results (maybe not all) and tries to compare and evaluate them. The experiments have been done too, trying to make it more easy for the experienced reader to make up his own mind about the elastic modulus of human dental enamel.

Keywords: Dental Enamel, Elastic Modulus, Hydroxylapatite, Indentation, Texture

INTRODUCTION

Human teeth consist generally of two different parts; the upper part (crown) is covered by dental enamel, followed by dentine and the pulp with blood vessels and nerves when going to the inner. The lower part (root) with its cementum is giving the stability to the tooth to stick fixed in the bone of the jaw. Dental enamel is the most highly mineralised and hardest biological tissue in human body (Dorozhkin, 2007). It is made of about 97% hydroxylapatite (HAP) - Ca5(PO4)3(OH), which is hexagonal (Space Group P63/m). The lattice parameters are a = b = 9.418 Å and c = 6.875 Å.

Teeth are a very important component in human body. With decayed teeth the quality of daily living, food intake and social interaction is very much reduced. Hence healthy teeth are essential needed for digestion and their health plays also a high ranked role in social interaction. Applying normal medical care like oral hygiene or going to the dentist is not enough since even dental fillings themselves can harm the enamel of an opposite tooth hence by chewing the interaction of dental enamel and filling is not equivalent. In the worst case, the harder fillings can abrade the softer enamel. Hereby one can see the importance of knowing the mechanical properties (e.g., elastic modulus) of dental enamel and filling materials in detail.

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Materials and Methods

Ways Determining the Elastic Modulus

A common parameter for comparing materials properties is the elastic modulus, which represents the tendency to deform elastically when a force is applied to the sample. The elastic modulus can be determined in different ways. Most common it is derived directly from a tensile test or also from a compression test. Preparing samples of dental enamel for tensile tests is very difficult since dental enamel has a maximum thickness of about 2mm at the cusp of the tooth. Enamel itself is also quite brittle when it’s cut. Therefore the elastic modulus of dental enamel has been often determined with a different method. Most scientific papers dealing with the elastic modulus of enamel use the (macro-/ micro-/ nano-) indentation method (Fischer-Cripps, 2004; Oliver & Pharr, 1992). Hereby a hard tip (typically diamond), whose mechanical properties are known, is pressed into the sample whose properties are unknown. The load placed on the indenter tip is increased as the tip penetrates further into the specimen until it reaches a user-defined value. At this point, the load may be held constant for a period and / or removed. Force $F$ and penetration depth $h$ are recorded and plotted. The slope of the curve ($dF/dh$ respectively $dh/dF$, depending on the convention used) upon unloading is indicative of the stiffness $S$ of the contact. This value generally includes a contribution from both the material being tested and the response of the tip itself. The stiffness of the contact can be used to calculate the reduced elastic modulus $E_r$. The reduced modulus $E_r$ again is related to the elastic modulus $E$ of the sample through relationships from contact mechanics which are explained in detail in various other papers (Ang et al., 2009; Ge et al., 2005; Habelitz et al., 2001; He et al., 2006). Another method determining the elastic modulus is using acoustic impedance methods (Lees, 1968; Reich et al., 1967). Since wave velocities within a material depend on the elastic properties of the material, a relationship between density, single crystal elastic constants, wave speeds and elastic modulus has been established. The elastic modulus can then be determined by measuring the speed of waves (typically ultrasonic’s) travelling through the sample. An alternative method calculating the elastic modulus is by using the information of preferred orientation of crystallites in combination with single crystal elastic constants. The orientation of crystal planes is hereby e.g., determined with x-ray diffraction and the orientation distribution function (odf) is calculated using methods like the series expansion method (Bunge, 1993) or the direct inversion method WIMV (Matthies et al., 1987). The information about the single crystals elastic properties (in case of HAP revealed from Katz, 1971) is then combined and weighted with the gained information about the orientation of these crystals from texture analysis. As a result one can get the elastic modulus depending on any direction since the particular preferred orientation of the crystals is considered (Park et al., 2001). By means of this compilation of methods one can see that there are a lot of different methods available. A short and maybe not complete literature review shows following that also the results for the elastic modulus of human dental enamel are very different.

Literature Review

Searching the literature for scientific papers about the elastic modulus of human dental enamel, one can find several readings. The papers can be divided into groups according to the method used. Since the HAP crystals in dental enamel are not random distributed but built up regular ordered enamel prisms (Dorozhkin, 2007; Raue & Klein, in press), it seems logical that the value of the elastic modulus should vary depending on the direction in which it is measured (Raue & Klein, 2011). Also the anisotropic elastic properties of the HAP single crystal contribute to a direction depending elastic property of the polycrystal. Hence most authors are giving minimum and maximum values for the elastic modulus of
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