The nature of interfaces in dental enamel: A FIB-STEM investigation

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Abstract

Biological materials are composite materials consisting of a hard, mineral phase and a softer organic phase. These two components are often arranged in a so-called hierarchical structure where the organic phase acts as an interphase in between the mineral components. The organic interphase provides nonlinear deformation mechanisms thereby turning inherently brittle materials into materials that can deform inelastically, redistribute stresses around defects and dissipate energy. Additionally these interphases can also deflect cracks and channel them into configurations in which their propagation is hindered or arrested, effectively toughening the material. [1], [2] Dental enamel is such a hierarchically structured material which consists of hydroxyapatite crystallites with a diameter of around 50 nm and a length of at least several micrometers [3]. These crystallites are then bundled together and form prisms (with a diameter of around 50 m) and interprismatic matrix that can be arranged in numerous ways. Enamel has been the subject of a large number of studies in the last decades with an effort to understand the structure-property relation. However, the focus has been the role of prism arrangement and organization whereas the nature of the interfaces is poorly investigated.

In the literature it is often suggested that enamel crystallites are glued together by protein [3] as well as that the prisms are surrounded by organic sheaths [3], [4]. To investigate the interfaces in enamel, samples of bovine enamel were prepared by focused ion beam (FIB) milling and then investigated by scanning transmission electron microscopy (STEM). The advantage of this method being that the location of interest can be precisely chosen. Additionally FIB milling combined with scanning electron microscopy (FIB-SEM tomography) was carried out to get a better understanding of the 3-dimensional structure. The structural analysis revealed that enamel prisms are not surrounded by a continuous organic sheath but that this interface is a discontinuous structure with frequent mineral on mineral contact. In some cases it can be seen clearly that the crystallites even curve from the interprismatic matrix into the prisms. The crystallites themselves are shown to be either in direct contact with each other, sometimes even fusing together, or are separated by some gaps. This work reveals new structural features of dental enamel that are important to understand the architecture and the mechanical properties of the material.

References

[1] F. Barthelat, Z. Yin, and M. J. Buehler, "Structure and mechanics of interfaces in biological materials," *Nat. Rev. Mater.,* vol. 1, Mar. 2016. doi:10.1038/natrevmats.2016.7

[2] F. Barthelat, "Architectured materials in engineering and biology," *Int. Mater. Rev.,* vol. 60, no. 8, pp. 413 - 430, Jan. 2016. doi:10.1179/1743280415Y.0000000008

[3] A. R. TenCate and A. Nanci, *Ten Cate's oral histology*. 7th ed., St. Louis: Mosby/Elsevier, 2008

[4] L. H. He, and M.V. Swain, "Understanding the mechanical behaviour of human enamel from its structural and compositional characteristics," *J. mech. Behav. Biomed.,* vol. 1, no. 1, pp. 18 - 29, Jan. 2008. doi:10.1016/j.jmbbm.2007.05.001