THERMAL CONDUCTIVITY OF IVORY, A NATURAL NANOCOMPOSITE

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There has been much recent interest in heat transport in nanostructures and, separately, in the structure, growth and properties of biological materials. The present work brings these topics together.

Large reductions in thermal conductivity, in comparison to bulk materials, have been observed in materials structured at the nanoscale level. These reductions are attributed to a combination of classical and quantum size effects that manifest themselves when the characteristic length scales in the nanostructured material become comparable to, or shorter than, the mean free path of the heat carriers in the bulk material [1]. In semiconductors and insulators the primary (or only, in the case of insulators) heat carriers are the lattice vibrations (*i.e.* phonons) and most of the heat is carried by phonons with mean free paths in the range of 1 – 100 nm at room temperature [2]. Thus, size effects on heat transport become important in nanostructured materials.

Biominerals (*e.g.* bones, shells, teeth) are known to exhibit excellent mechanical properties. They are natural composite materials with complex hierarchical structures, organized from the nanoscale up to the macroscale. The structure of elephant ivory has been described previously [3]. It is composed of hydroxyapatite-like derivatives embedded within a matrix of collagen fibril bundles and its basic structural units are nanometer-diameter cylinders. From the cross-section of a tusk along a transverse plane, the collagen fibrils have been observed to interweave along two radially distributed layers forming a network [3]. Within each layer, collagen fibril bundles (each *ca*. 1 μm radius) lie nearly parallel to one another and they are rotated from one layer to the next [3], analogous to the steps of a spiral staircase. Each bundle consists of collagen fibrils that range in radius from 30 to 100 nm, aligned longitudinally with a period of about 70 nm [3]. The fibrils consist of helical, collagen molecules approximately 1.2 nm in diameter and 300 nm in length [3]. While the thermal properties of biominerals have been relatively unexplored, one could expect that, in addition to excellent mechanical properties, biominerals also would exhibit interesting heat transport properties due to their novel structures.

Here we present measurements of thermal and mechanical properties (thermal conductivity, heat capacity, elastic modulus and flexural strength) of elephant ivory. While a rule of mixture approach predicts the room temperature heat capacity reasonably well, both this approach and a simple macroscale structural model for composites fail to adequately predict the thermal conductivity of ivory. Collected literature results for biominerals of similar composition are shown to exhibit similar behaviour. Analysis of these results is consistent with increased thermal boundary resistance associated with the nanostructure, suggesting that biomineral-like nanostructures could be useful in the design of materials with the unusual pairing of low thermal conductivity and high mechanical strength.

References:

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