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Research Paper

Systematic numerical investigation of the role of hierarchy in heterogeneous bio-inspired materials

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ABSTRACT

It is well known that hierarchical structure is an important feature in biological materials to optimise various properties, including mechanical ones. It is however still unclear how these hierarchical architectures can improve material characteristics, for example strength. Also, the transposition of these structures from natural to artificial bioinspired materials remains to be perfected. In this paper, we introduce a numerical method to evaluate the strength of fibre-based heterogeneous biological materials and systematically investigate the role of hierarchy. Results show that hierarchy indeed plays an important role and that it is possible to "tune" the strength of bio-inspired materials in a wide range of values, in some cases improving the strength of non-hierarchical structures considerably.

1. Introduction

It is known that many biological materials and organisms display fascinating physical and mechanical properties, which have up to now been hard to replicate in artificial materials and systems. One of these is the ability to combine exceptional strength and toughness, which occurs for example in nacre, bone and dentine (Espinosa et al., 2011; Pugno, 2006; Wegst and Ashby, 2004), or the smart adhesion which is found in spiders and geckos (Autumn et al., 2000; Autumn and Peattie, 2002; Foelix, 1996; Tian et al., 2006). An important feature underlying these properties is thought to be material structure and hierarchy (Fratzl and Weinkamer, 2007; Lakes, 1993). A prime example of this is spider silk, whose hierarchical structure ranges from nanostructure to macrostructure and consists of an amorphous network of chains and β-sheet crystals constituted by poly-(Gly–Ala) and poly-Ala domains (Ackbarow et al., 2007; Keten et al., 2010). Molecular dynamics and atomistic simulations have shown how the specific structure and bonding at molecular level affects macroscopic properties like strength and toughness (Bratzel and Buehler, 2012; Keten et al., 2010; Nova et al., 2010).

Aside from spider silk, a great number of biological materials are inherently structurally hierarchical. The hierarchical structure of tendon, taken from Riley (2005) is shown in Fig. 1a. Another example is the case of bone, where variability at the nanometre level lies in the shape and size of mineral particles, at the micron level in the arrangement of mineralised collagen

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