A hybrid discrete-continuum model to explain the remarkable defect tolerance of soft collagenous tissues

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ABSTRACT

Soft collagenous tissues are generally considered tear resistant and tolerant of existing flaws and defects [cf. 1, 2]. This insensitivity is vital for body tissues, that typically experience frequent smaller injuries during life while subject to a wide spectrum of loads. In a medical context these properties become important as they relate to the risks of tissue failure as a consequence of cutting, perforation or suturing.

A hybrid discrete-continuum finite element modelling approach has been developed to analyse the near fields of crack-like defects in soft collagenous tissues, complemented by a large set of macroscopic and in-situ microscopic fracture experiments [3]. The computational approach makes use of a discrete fibre representation in the vicinity of the defect while efficiently modelling the remote regions by a calibrated hyperelastic model. The combination of this computational tool with dedicated experiments was used to shed light on the remarkable defect tolerance of collagenous tissues and to study the applicability of classical fracture mechanics concepts to these materials.

The results show that soft collagenous tissues can tolerate defects up to the order of millimetres without significantly reducing their overall strength. This defect tolerance of the network is achieved even though the fibres from which it is formed are brittle. Moreover, the region affected by the presence of the defect is very narrow. Both simulations and experiments identify the drastic densification of the network in the near-field [4] as a key mechanism, facilitated by the strong reorientation of fibres that are stiff in tension but have little resistance to compression. The study further reveals that the determination of the energy for tearing [5] as a classical metric of fracture toughness requires specimens with very large dimensions, probably beyond the tissue portions typically available in experiments. Moreover, this classical concept is shown to be inadequate for the analysis of defects with dimensions typical for biomedical problems such as holes and loads generated by surgical sutures.

This study thus identifies soft collagenous tissues as a peculiar, apparently self-contradictory type of material that is macroscopically very defect tolerant although it might consist of brittle constituents and localises the influence of defects to a very narrow zone. While applied to collagen networks here, the hybrid approach may serve to analyse and help designing other fibre network materials with dedicated fracture properties.

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