Probing the effect of bone microstructure via 3D-printing

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Motivation

The hierarchical structure leads to a unique combination of mechanical properties (e.g. stiffness, strength and toughness) [2-4].

Focus on microscale toughening mechanisms

- Implement the main microscale toughening mechanism in de novo composites, by replicating the microstructural features involved in the process

Objectives

- Obtain an increase in toughness
- Achieve an optimal strength-toughness balance

Methods

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- Material selection: materials with markedly contrasting properties
- Testing of base materials
- Role of the osteon-like reinforcement:
  - Reduce the stress concentration at crack tips
  - Promote a nonlinear crack path
  - Cause the formation of stress-induced microvoids (i.e. dissipation mechanisms)
- Successful design:
  - Mimic the fundamental bone microscale toughening mechanisms
  - Increase in toughness with respect to the base materials (7-15 times)

- Use dual jet material technology to print composites, whose reinforcement and matrix are a mixture of the two base materials
- Find the optimal combination of the base material and the optimal reinforcement/matrix stiffness ratio to get the largest amplification in toughness and the best toughness-strength balance
- Build numerical models, able to predict the behavior, to be used for future design
- Print composites with random osteon distribution

Results

- Failure modes for all the composite topologies
  - Crack branching
  - Crack deflection
  - Fiber bridging
  - Unrecracked ligament bridging

- Optimal combination of mechanical properties: increase in toughness and strain; good strength and stiffness performance

- 15 times higher than the soft material and 7 times higher than the stiff one
- Composites with stiff matrix show the largest amplification in toughness (these cases are similar to the bone one, where the matrix is stiffer due to a higher degree of mineralization)
- The best performance is given by the Est composite type (elliptical inclusion-stiff matrix)

Remarks and future work

- Osteons mimicked as circular-elliptical inclusions
- Osteon vol. fraction (i.e. 60 %) equal to that of cortical bone [5]

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References


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