Mechanical behavior and structure of a Toco toucan beak

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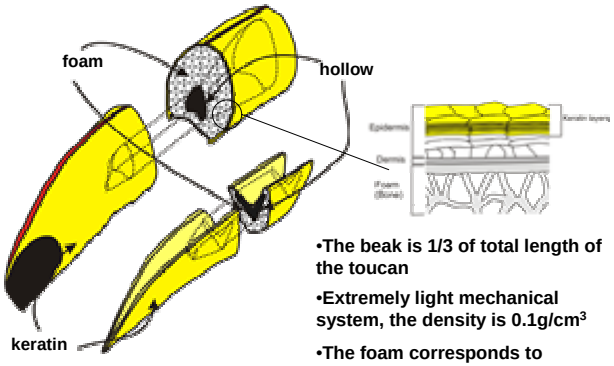
Research objectives

- **Examine the structure of the beak**
- **Identify the mechanical properties of a Toco toucan beak.**
- **Attempt to model mechanical properties as function of structure**

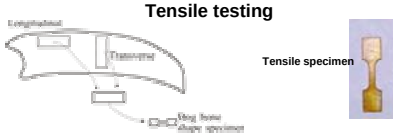


- **The beak is 1/3 of total length of the toucan**
- **Extremely light mechanical system, the density is 0.1g/cm^3**
- **The foam corresponds to approximately 21 % of the total weight of the beak**

Experimental techniques

- **SEM for Structural Analysis**
- **Mechanical Properties**
  - **Tensile testing**
  - **Compression testing**

Tensile testing

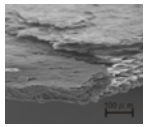


Compression testing

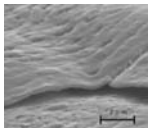
foam **shell** **Foam filled shell**

Exterior of beak (SEM)

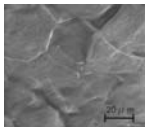
Figure (a) shows the exterior shell consisting of multiple layers of keratin scales. The thickness of each keratin scale is about 2~10 μm and the diameter is approximately 30~60 μm (Fig (b)). The keratin scales are hexagonal and overlap each other. Although this was not investigated, they seem to be joined by a glue. The total shell thickness varies between approximately 0.5 and 0.75 mm



(a) Multiple layers of keratin



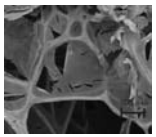
(c) Keratin scales



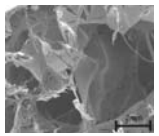
(b) Surface of keratin layers

Interior of the beak (SEM)

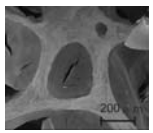
Figure (a) shows the inside of the beak. It is clearly a foam structure. Most of the cells in the toucan foam are sealed off by membranes with thickness of 2~25 µm. Thus, it can be considered a closed-cell system. The cell sizes vary and the closed-cell network is comprised of struts with the thickness of 70~200 µm with edge connectivity of three or four (Fig. (b) and (c)).



(b) Closed cell, edge connectivity 4



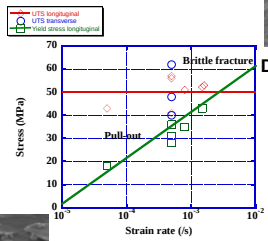
(a) Toucan foam

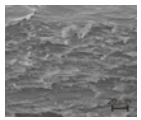


(c) Closed cell, edge connectivity 3

Strain rate dependant of fracture mode (keratin)

The yield stress and UTS are plotted as a function of the strain rate. The yield stress is sensitive to the strain rate and associated with the viscoplasticity of the interscale glue. When the yield stress approaches (or exceeds) the UTS, fracture of the scales is preferred over viscoplastic deformation of the glue





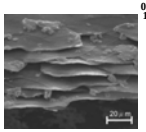
Deformation mode

Criterion for viscoplastic behavior of beak keratin

$$\sigma_t \geq \sigma_g$$

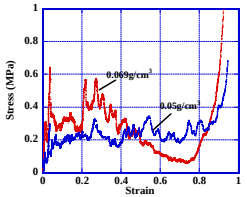
Strain rate dependant stress

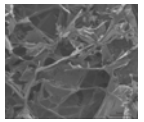
$$\sigma_g = k\,\dot{\varepsilon}^{\,m}$$



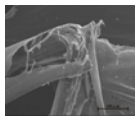
Pull-out mode

Fracture patterns of foam





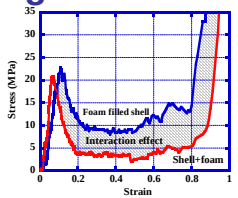
Viscoplastic deformation of toucan foam



Partial fracture (Green twig like fracture)

The synergetic effect of toucan beak

Foam core increases the force level of the beak and mechanical stability.

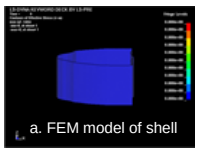


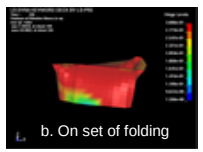
Shell+Foam

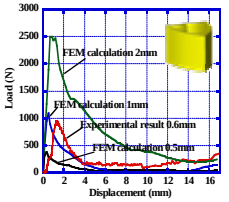
Foam filled shell

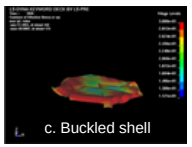
Finite Element Analysis

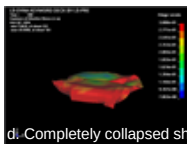
FEM simulation of beak shell under compression testing











FEM simulation of beak foam under compression testing