Deconstructing the Auxetic Behavior of Paper

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ABSTRACT

We report here the auxetic (negative Poisson’s ratio) response of cellulose based fiber networks. Auxetic materials grow fatter when stretched and are extremely rare in nature. It has been reported that fibrous paper increases in thickness when stretched in planar direction. Recently, researchers have also induced auxetic behavior in polyurethane foams, expanded PTFE and ultra-high-molecular-weight polyethylene. By measuring the thickness variation with stretch in different types of paper, we determined their Poisson’s ratio to be negative (0 to -3.0). We propose that the mechanism of this auxetic response stems from the non-woven network structure of cellulose fibers having rich hydroxy surface. During compressive stages of papermaking, hydrogen bonding between fibers locks them into a crumpled microstructure which expands when stretched. Auxetic behavior arising from surface chemistry of polymeric fiber networks is a novel concept that can potentially be applied to new material designs and product development techniques.

BACKGROUND

- Assuming isotropic material, typical Poisson’s ratio values for:
  - Metals, Plastics etc. = 0.3
  - Rubber, Elastomers = 0.5
- Cork is close to Zero
- For isotropic and linear elastic materials
  - Natural Auxetic
  - Synthetic Auxetic
- Anisotropic Materials can have higher magnitudes of \( v \)
- Multiple values of \( v \)
  - Bones / Skins
  - Lakes’ Foams
  - Arteries
  - Expanded PTFE
  - Certain Rocks
  - UHMW-PE

Sample: Uncoated Paperboard

EXPERIMENTAL PROCEDURE

- Sample: Rectangular, gauge length 10 cm, width 2 cm
- Instron 5566, 10 kN load cell
- Rate of extension: 0.5 mm/sec, stretched until failure
- Reported thickness at center of sample
- Thickness measured at several strain intervals

RESULTS: THICKNESS VS EXTENSION PLOTS

RESULTS: POISSON’S RATIO VALUES

APPLICATIONS OF AUXETIC MATERIALS

- Composites
- Filtration Defouling
- Mattresses and Strong Domes
- Packaging
- Ballistic Protection
- Prosthetic surgical implants