Poisson's function of single-wire entangled materials : below 0 in traction and above ½ in compression

B. GADOT[a,b], O. RIU MARTINEZ[a], S. ROLLAND DU ROSCOAT[a], L. ORGEAS[a], D. RODNEY[c]

a. Laboratoire Sols, Solides, Structures, Risques, CNRS-Université de Grenoble Alpes, France)

b. Laboratoire Science et Ingénierie des Matériaux et Procédés, CNRS-Université de Grenoble Alpes, France

c. Institut Lumière Matière, CNRS-Université Claude Bernard Lyon 1, France (david.rodney@univ-lyon1.fr)

Abstract :

The mechanics of fibrous materials is both complex and intriguing. Here, we explore one class of such materials, made of the disordered entanglement of a single long fiber (see Fig. 1a). This architected material is of both fundamental and technological interests. From a theoretical point of view, this system can be seen as a disordered material, akin to glasses, but with very long (possibly infinite) ranged correlations transmitted along the single fiber. From an applied point of view, this material is a potential replacement for sintered materials, because with comparable porosities, entangled structures are highly ductile while sintered powders are often intrinsically brittle.

We study the mechanics of single-wire materials using a combination of experiments and simulations. Experimentally, we produce cylindrical samples by entangling a single fiber made either of NiTi, polyamide or copper. Spatial homogeneity and stress relaxation are achieved by series of thermomechanical treatments that allow to first transform the wire into a coil and then entangle the coil. The samples are subjected to cycles of compressions followed by unloading, tracking the local deformations in the samples with optical cameras and x-ray microtomography. Numerically, we employed Kirchhoff's elastic rod theory to simulate the same mechanical cycles on both numerical substitutes of the experimental samples (i.e. cylindrical samples of geometry and density comparable to the experiments) and idealized samples with a cubic and periodic geometry (see Fig. 1b).

We will discuss our main observations on the mechanical properties of the single-wire systems. First, stress-strain curves show a prolonged regime of non-linear elasticity and a marked hysteresis between compression loading and unloading (see Fig. 1c). Also, by tracking the sample shape variations, we observe surprising non-monotonous variations of the sample volume, both in the experiments and in the simulations (see Fig. 1d). At the local level, we use image analysis to follow the evolution of the

local orientation of the fiber and of the number and orientation of the contacts, the latter two quantities also showing non-monotonous behaviors.

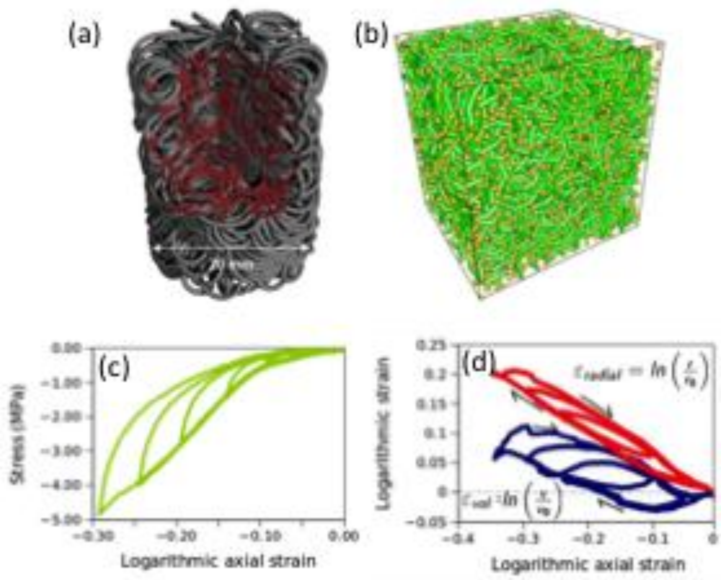

Figure 1: Mechanics of single-wire materials: (a) Example of a NiTi entangled, (b) Numerical analogue in a 3D periodic simulation cell, (c) Typical stress-strain curves during compression cycles, (d) Variation of the volumic and radial strains during compression cycles.

In particular, we show that this material exhibits at finite strains an unexpected variation of its Poisson's function, beyond the usual bounds: Poisson's function is above ½ in compression and below zero in tension. This material is thus reversibly compress dilatant in compression and auxetic in tension. This means that the structure expands laterally in both traction and compression and so rapidly in compression that its volume increases. This unusual variation of Poisson's function arises from the interplay between the elongation of the coiled segments that constitute the entanglement and fiber rearrangements due to steric effects.

This work illustrates that a property (Poisson's function not limited to 0 or ½), rare in bulk materials, can be readily obtained in "simple" architected materials and opens the way to developing architectures with very large, negative but also positive, Poisson's functions.

Mots clefs : Entangled materials, architected materials, Poisson's function, fiber mechanics