Ribbon Formation in Twist Nematic Elastomers

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Abstract

Introduction: Nematic Elastomers (NEs) possess both the elastic properties of rubbers and the orientational properties of liquid crystals. Those two properties makes the configuration of NEs very sensitive to isotropic-nematic phase transition [1]. The behavior of NEs can be well modeled within the theory of finite elasticity with distortions; here, the same model successfully used in [2], is tested against more fancy shapes formation; in particular, recent researches [3] showed that chirality plays a critical role in controlling the configuration assumed by macroscopic specimens. Our goal has been to replicate with numerical experiments the phenomena of shape formation in Twist Nematic Elastomers (TNEs): a flat bar evolves into helicoids and then jumps to ribbons while temperature changes. Use of COMSOL Multiphysics: Fabrication of TNEs undergo two key steps: imprinting of chirality at swollen state; cross-linking and solvent evaporation. We model the TNEs in the framework of 3D incompressible non-linear elasticity with large distortions, and we account for both chirality, de-swelling and temperature changes; constitutive assumptions for thermally-induced phase transition are given as explicit functions, by fitting experimental data (Figure 1 shows a typical phase diagram for NEs). We use two nested parametric sweeps node to solve the model; the first sweep generates a parametric geometry, the second one the temperature variation. In particular, the distortions related to the isotropic-nematic phase transition induces very large displacements. Results: We reproduce the whole process from solvent evaporation, inducing a large anisotropic de-swelling, to temperature variation, that yields additional large anisotropic distortions. Our key findings, in agreement with the experimental results in [3], show how a flat bar smoothly changes its shape into a helicoid and then rapidly buckles to a ribbon, when raising the temperature (Figure 2); moreover, this behavior is very sensitive to the aspect ratio of the cross section of the bar. Conclusion: Our results are noteworthy; we are able to replicate with great accuracy the experimental findings in [3], thus having a robust assessment of the physical model underling the numerical solutions. A promising application is in soft robotics: our model is able of describing the extremely large changes of configuration of a given specimen under external stimuli, and it could well be used in the designing of new engineered actuators having the capability of bending, twisting, and much more. Soft robots based on elastomers have a number of attractive features; among them, the nonlinearity in their motion produces complex actuation that can be properly designed.

Reference

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Figures used in the abstract

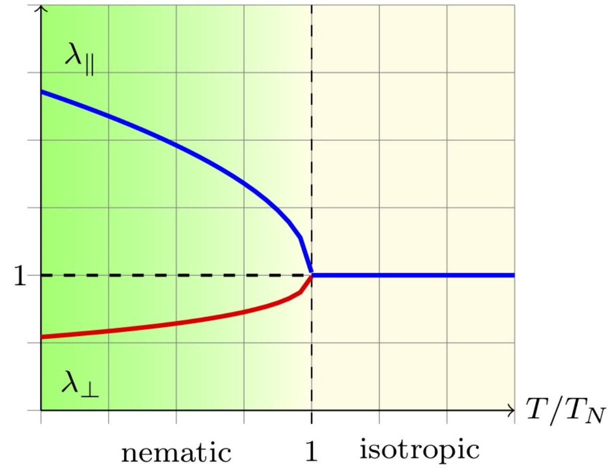

Figure 1: Phase diagram for NEs: lambda_par and lambda_orth are the stretches along the nematic orientation, and in the orthogonal plane, respectively; T/Tn is the ratio between the actual and the transition temperature.

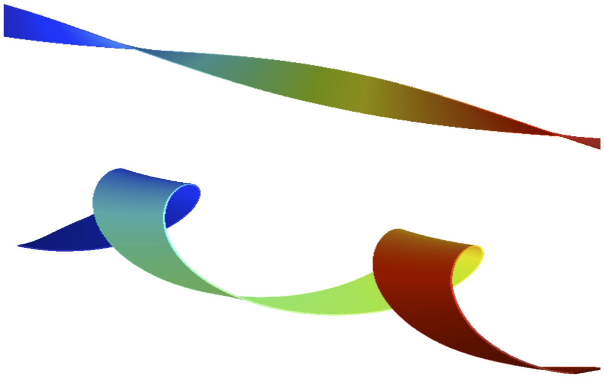

Figure 2: A thin bar of TNEs may assume different shapes according to its temperature; the transition from a flat shape (not shown) to a helicoid (top) is quite smooth; beyond a threshold temperature, the film buckles to a ribbon (bottom).