Instabilities and Elastic Waves in Fiber Composites Undergoing Finite Deformations

Viacheslav Slesarenko, Pavel Galich, and Stephan Rudykh[1]

Laboratory for Mechanics of Soft Materials

Department of Aerospace Engineering

Technion – Israel Institute of Technology

First, we study the mechanical behavior of fiber composites (FCs) undergoing finite deformations. Compressive loadings may lead to development of elastic instabilities at different length-scales. To estimate the critical strains corresponding to the onset of the macroscopic or long wave instability associated with the loss of ellipticity, we obtain the homogenized response for transversely isotropic (TI) FCs, and evaluate the effective tensor of elastic moduli. Thus, the onset of long-wave instabilities is predicted by a close form explicit expression in terms of the material properties and volume fractions of the constituents [1]. The analytical estimations are compared with 3D finite element simulations showing an excellent agreement. However, instabilities may develop at smaller length-scales first [2]; to capture the onset of these *microscopic* instabilities, we utilize the Bloch-Floquet analysis. Through the analysis, we have found the dependence of the critical strain and critical wave-length on material composition and properties of the constituents [3]. Moreover, we have found configurations, where fibers buckle into a 3D helical mode when the critical stretch is reached. Furthermore, we experimentally observed the existence of these macroscopic and microscopic modes of instabilities in 3D printed composites [2, 4]. In addition, we show that the microscopic instabilities in the composites with *rate-dependent* phases can be significantly tuned by the applied strain rate. Through the experiments on 3D printed laminates, and through the numerical simulation of the visco-hyperelastic composites, we demonstrate the existence of various instability-induced wavy patterns corresponding to the identical deformed state of the identical soft composites [4]. Thus, the admissible range of tunable microstructures can be achieved through exploiting the rate-dependent behavior of soft constituents.

Second, we analyze the effect of finite deformations on small amplitude elastic waves propagating in the FCs [5]. We derive long wave estimates for elastic waves propagating in finitely deformed laminates and 3D TI FCs. The long wave estimates show a good agreement with the dispersion relations obtained through the Bloch wave analysis [6]. Finally, we examine the influence of deformation on band gaps in layered composites [7].

[1] Email: rudykh@technion.ac.il

REFERENCES

[1] S. Rudykh and G. deBotton, Instabilities of Hyperelastic Fiber Composites: Micromechanical Versus Numerical Analyses. *J. Elasticity* **106**, 123–147 (2012)

[2] Y. Li, N. Kaynia, S. Rudykh and M. C. Boyce, Wrinkling of Interfacial Layers in Stratified Composites. *Adv. Eng. Mater.* **15** (10), 921–926 (2013)

[3] V. Slesarenko and S. Rudykh, Microscopic and macroscopic instabilities in hyperelastic fiber composites. *J. Mech. Phys. Solids*, **99**, 471 – 482 (2017)

[4] V. Slesarenko and S. Rudykh, Harnessing viscoelasticity and instabilities for tuning wavy patterns in soft layered composites. *Soft Matter*, **12**, 3677 – 3682 (2016)

[5] S. Rudykh and M.C. Boyce, Transforming Wave Propagation in Layered Media via instability-induced Wrinkling Interfacial Layer. *Phys. Rev. Lett*. **112**, 034301 (2014)

[6] P. I. Galich, V. Slesarenko and S. Rudykh, Shear wave propagation in finitely deformed 3D fiber-reinforced composites. *Int. J. Solids Struct.*, **110 – 111**, 294 – 304 (2017)

[7] P. I. Galich, N. X. Fang, M. C. Boyce and S. Rudykh, Elastic wave propagation in finitely deformed layered materials. *J. Mech. Phys. Solids*, **98**, 390 – 410 (2017)