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Zhigang Suo (Harvard) and Yibin Fu (TJU and Keele)

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Authors: Martine Ben Amar and Min Wu

Title: *Growth of living fibrous tissues: from biofilms to fibrosis*

Abstract: Morphologies of soft materials in growth, swelling or drying have been extensively studied recently. Shape modifications occur as the size varies transforming ordinary spheres, cylinders and thin plates into more or less complex objects. Existence of fibers exacerbates this complexity, giving anisotropy to the growth process itself. The growth is coupled to the environment, for bacteria the substrate, in pathology the healthy tissue. In pathological situations such wound-healing or desmoplastic tumor growth, the immune system reacts with a battery of morphogenetic gradients, making a new tissue full of collagene and eventually sending active cells also called muscle-like cells. All these factors contribute to a high level of compressive stress at the origin of patterns and deformity. Biofilm patterns can be explained by a simple growth law of a disc containing initially bacteria with moderate adhesion to a rigid substrate. The initially circular geometry is lost during the growth expansion, contour undulations and buckling appear, ultimately a rather regular periodic focussing of folds repartition emerges. We can explain quantitatively these morphological instabilities as bifurcations of the circular solutions where the anisotropic growth compete with the adhesion. The substrate plays a critical role limiting the geometry of the possible modes of instabilities and anisotropic growth, adhesion and toughness compete to eventually give rise to wrinkling, buckling or both. Due to the substrate, we show that the ordinary buckling modes, vertical deviation of thin films, are not observed in practice and a competitive pattern with self focussing of folds can be found analytically. For the pathological cases, it turns out that the wrinkling process dominates the growth, deforming the tissues and exacerbating the immune system which reacts via passive (fibroblast) and active cells (myo-fibroblast). I will show that the consequence is a huge increase of the stiffness, which stops spontaneously when the healing is achieved but not in case of implants or tumors. Naive estimations can be given explaining difficulties encountered in drug treatments, for example.

Authors: Davide Bigoni and Panos A. Gourgiotis

Title: *Discontinuities, localization, ellipticity vs. stress channelling in extreme Cosserat materials*

Abstract: Materials with extreme anisotropy display stress channeling and strain localization, effects that can be exploited in different technologies, for instance, in mechanical wave guiding, stress wave shielding, and invisibility cloaking. Theoretically, stress channelling was pioneered by Pipkin (1984) and Spencer (1984), who demonstrated that stress does not diffuse in materials with extreme orthotropic stiffness ratio, and was found to

occur in masonry models by Bigoni and Noselli (2010a; b). In the limit when the stiffness ratio between different material directions tends to zero, the equations governing equilibrium reach the elliptic boundary and the stress percolates through null-thickness deformation bands. In this situation, the material microstructure sets the percolation thickness and becomes a dominant factor. Our aim is to analyze stress channelling, strain localization, and the emergence of discontinuities in extremely anisotropic elastic materials governed by couple-stress elasticity. The theory of couple-stress elasticity, also known as Cosserat theory with constrained rotations, is the simplest gradient theory in which couple-stresses make their appearance. In particular, the couple-stress theory assumes an augmented form of the Euler-Cauchy principle with a non-vanishing couple traction, and a strain-energy density that depends upon both the strain and the gradient of rotation. Such assumptions are appropriate for materials with granular structure, where the interaction between adjacent elements may introduce internal moments. In this way, characteristic material lengths may appear representing the material microstructure.

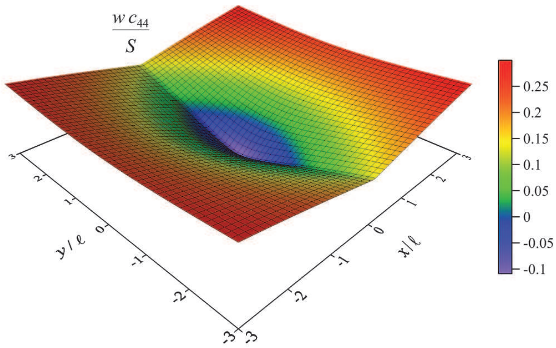

Figure 1: The folding of a Cosserat continuum at failure of ellipticity

An investigation of loss of ellipticity, emergence of discontinuities (as pioneered by Hill, 1961) and use of the perturbative approach (in the spirit of Bigoni and Capuani, 2002; 2005) shows that Cosserat effects can explain unexpected phenomena, such as for instance the folding of an elastic continuum, Fig. 1, but also the formation of chessboards faults.

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References

[1] Bigoni, D., Capuani, D., 2002. Green's function for incremental nonlinear elasticity: Shear bands and boundary integral formulation. J. Mech. Phys. Solids 50, 471-500.

[2] Bigoni, D., Capuani, D., 2005. Time-harmonic green's function and boundary integral formulation for incremental nonlinear elasticity: Dynamics of wave patterns and shear bands. J. Mech. Phys. Solids 53, 1163-1187.

[3] Bigoni, D., Noselli, G., 2010a. Localized stress percolation through dry masonry walls. Part i-experiments. Eur. J. Mech. A-Solid 29, 291-298.

[4] Bigoni, D., Noselli, G., 2010b. Localized stress percolation through dry masonry walls. Part ii-modelling. European Journal of Mechanics-A/Solids 29, 299-307.

[5] Hill, R., 1961. Discontinuity relations in mechanics of solids. Progress in solid mechanics 2, 245-276

[6] Pipkin, A.C., 1984. Stress channelling and boundary layers in strongly anisotropic solids, in: Spencer, A.J.M. (Ed.), Continuum theory of the mechanics of fibre-reinforced composites. Springer Vienna, pp. 123-145.

[7] Spencer, A.J.M., 1984. Continuum theory of the mechanics of fibre-reinforced composites. Springer.

Authors: Shengqiang Cai

Title: *Shape bifurcation of a dielectric elastomeric balloon subject to electro-mechanical loading*

Abstract: Dielectric elastomer, an active soft material, has been recently widely explored to make diverse devices, ranging from soft robotics to biomimetic systems. Among all the applications, dielectric elastomeric balloon is one of the most commonly adopted structures. Electro-mechanical responses of dielectric elastomeric balloons with different shapes and material properties have also been analyzed by different researchers. Recently, an intriguing deformation mode of dielectric elastomer balloon has been observed in experiments, which we believe is associated with certain electro-mechanical bifurcation. In the talk, I am going to present our theoretical and numerical results on electro-mechanical bifurcation of a dielectric elastomeric balloon subject to different electro-mechanical loadings.