



## Engineering solutions for the 21st century's increasingly complex challenges

In the last 30 years there has been an extraordinary increase in simulation and modeling tools used by design engineers, decision makers and public services. Research in **mechanical and process engineering** has provided a significant contribution to progress in these areas.


Today's scientific and technological challenges arise from new issues: sustainable development, alternative resource management, green technologies, environmental impact reduction, risk management, health care...

The aim of Tec 21 Laboratory of Excellence is that our research contributes to developing new engineering solutions through:

# 3rd Summer school: MULTI SCALE APPROACHES AND MULTIPHYSICS COUPLINGS IN FLUID AND SOLID MECHANICS

September 13 to 20, 2018

Thursday 13	Friday 14	Saturday 15	Sunday 16	Monday 17	Tuesday 18	Wed. 19	Thursday 20
8:15 Welcome coffee	8:30 Coffee			8:30 Coffee	8:30 Coffee	8:30 Coffee	8:30 Coffee
8:45 Introduction	9:00 Active suspensions		Outdoor excursion	9:00 Numerical prediction of turbulent flows	9:00 High-tech lab-courses		9:00 Anne De Wit (University of Buxelles)
9:15 Turbulent flows	10:00 Heterogeneous materials	10:30 Poster session		11:30 Experimental solid-mechanics	<p><i>10 lab courses will be held in parallel sessions. The participant will attend two of their choice in groups of 4 to 5, on Tuesday and Wednesday</i></p> <ol style="list-style-type: none"> <li>1. Turbulence and particle transport</li> <li>2. Granular and porous materials</li> <li>3. Mechanics of blood circulation</li> <li>4. Dense flows</li> <li>5. Mechanics of fibrous materials</li> </ol>	Catherine Quillet (Univ. Grenoble Alpes)	
11:30 Multiphase flows		11:30 Lab-course presentations		12:30 Experimental solid-mechanics	<ol style="list-style-type: none"> <li>6. Biobased composites : elaboration and mechanical properties</li> <li>7. Wave turbulence</li> <li>8. Rheology of suspensions</li> <li>9. Bubble column and diphasic flows</li> <li>10. Viscoplastic surges over complex topography</li> </ol>	Davide Bigoni (University of Trento)	
12:30 Buffet lunch	12:30 Buffet lunch	12:30 Lunch in town		14:00 Experimental solid-mechanics	<p><i>A full description of the lab-courses is available in the detailed programme.</i></p>	François Nicot (IRSTEA Grenoble)	
14:00 Multiphase flows	14:00 Turbulence metrology	14:00 City tour and time off		15:15 Numerical solid-mechanics		13:30 François Charru (University of Toulouse)	
15:15 Colloidal suspensions					Patrice Le Gal (University of Marseille)		
16:30 Poster session	16:30 Poster session				JP Matas (Univ. Lyon 1)		
17:30 Cocktail					16:00 End of the school		
					19:30 Gala dinner in town		



## 11:00 From shear banding to folding: instabilities in ductile materials



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When a ductile material is subject to severe strain, failure is precluded by the emergence of shear bands, which initially nucleate in a small area, but quickly extend rectilinearly and accumulate damage, until they degenerate into fractures. Therefore, research on shear bands yields a fundamental understanding of the intimate rules of failure, so that it may be important in the design of new materials with superior mechanical performances.

Modelling of a shear band as a slip plane embedded in a highly prestressed material and perturbed by a mode II incremental strain, reveals that a highly inhomogeneous and strongly focussed stress state is created in the proximity of the shear band and aligned parallel to it. This evidence, together with the fact that the incremental energy release rate blows up when the stress state approaches the condition for ellipticity loss, may explain the rectilinear growth of shear bands and the reason why they are a preferred mode of failure for ductile materials [1,2]

A shear band of finite length, formed inside a ductile material at a certain stage of a continued homogeneous strain, provides a dynamic perturbation to an incident wave field, which strongly influences the dynamics of the material and affects its path to failure. The investigation of this perturbation is presented for a ductile metal, with reference to the incremental mechanics of a material obeying the  $J_2$ -deformation theory of plasticity (a special form of prestressed, elastic, anisotropic, and incompressible solid). It is shown that the presence of the shear band induces a resonance, visible in the incremental displacement field and in the stress intensity factor at the shear band tips, which promotes shear band growth. Moreover, the waves scattered by the shear band are shown to generate a fine texture of vibrations, parallel to the shear band line and propagating at a long distance from it, but leaving a sort of conical shadow zone, which emanates from the tips of the shear band, Fig. 1, [3].

The same mathematical tools developed for the analysis of shear bands in ductile materials will be shown to lead to folding and faulting in constrained Cosserat materials, when these have a strong anisotropy, so that they are close to the elliptic boundary. In fact, folding is a process in which bending is localized at sharp edges separated by almost undeformed elements and folding in these materials can originate from ellipticity loss, Fig. 2, [4-6]

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[1] D. Bigoni (2012) *Nonlinear Solid Mechanics Bifurcation Theory and Material Instability*. Cambridge University Press.

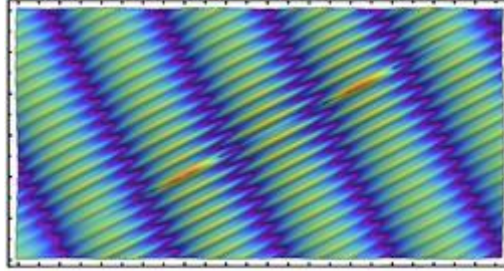
[2] Bigoni, D. and Dal Corso, F. (2008) The unrestrainable growth of a shear band in a prestressed material. *Proc. Royal Soc. A*, 464, 2365-2390.

[3] Giarola, D., Capuani, D. Bigoni, D. (2018) The dynamics of a shear band. *J. Mech. Phys. Solids*, In Press.

[4] D. Bigoni and P.A. Gourgiotis (2016) Folding and faulting of an elastic continuum. *Proc. Royal Soc. A*, 472, 20160018.

[5] P.A. Gourgiotis and D. Bigoni (2016) Stress channelling in extreme couple-stress materials Part I: Strong ellipticity, wave propagation, ellipticity, and discontinuity relations. *J. Mech. Phys. Solids* 88, 150-168.

[6] P.A. Gougiotis, D. Bigoni (2016) Stress channelling in extreme couple-stress materials Part II: Localized folding vs faulting of a continuum in single and cross geometries J. Mech. Phys. Solids 88, 169-185.



*Fig.1: Interaction of waves with two shear bands aligned on the same line*



*Fig. 2: Chevron folds in layered rocks near Millook Haven (UK) modeled as a constrained Cosserat material.*