Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

Rectors:

E. Guazzelli (Marseille) - A. Soldati (Vienna) - W. A. Wall (Munich)

PROGRAMME 2022

“ ...The purpose of the Centre is to promote, on a non-profit basis, research in the Mechanical Sciences and related multidisciplinary sciences, favour the exchange, diffusion, and application of the most advanced knowledge in this field, establish active relations with similar national, or international institutions, enlist the cooperation of the most qualified scientists and researchers throughout the world, set up research laboratories and libraries, organize courses and seminars of a high scientific level ...”

from the Statute of the “International Centre for Mechanical Sciences”.
CISM, Chap. I, Art. 1.

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PROGRAMME 2022

Udine, Italy

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The Charles Doering Session

Composite Manufacturing Processes: Analyses, Modelling and Simulations

May 2 - 6, 2022

Fiber reinforced composites are increasingly being used in the aerospace and automotive industry to cope with lightweighting challenges and meet high performance standards. The manufacturing processes are essential for the quality of the final composite. Simulation of composite manufacturing processes requires experimental analysis and modelling of the transformations involved. These simulations can prevent a time consuming and expensive "trial and error" process design. During the process, the phenomena concern fibrous materials in large deformation and the flow of resin into the fibrous reinforcement. They depend on heat transfer and sometimes phase change. Experimental analysis, modelling and simulation of physical phenomena during composites forming are the objectives of the course. It will concern in particular composite materials for structural parts. The analysis of forming of the reinforcement without resin (dry preform) and with non-hardened resin (prepreg) will be considered as well as thermomechanics and consolidation of the composite during prepreg forming and flow processes in composite materials. This course is aimed at Ph.D. students and Master students in the field of composite engineering. Researchers interested in composite forming are also welcome to attend this course.

The main points to be covered in this course are as follows:

1. Draping of fibrous preforms and prepregs.

Forming of continuous fiber reinforcements leads to specific mechanical problems because of the relative slippage between the fibers and the quasi-inextensibility of the fibers. The following topics are included in this theme:

• Mechanical tests for fibrousreinforcements (shear, biaxial tension, bending, transverse compaction).
• Constitutive law for textile reinforcements (Hyper elasticity, hyper viscoelasticity...)
• Simulations of preform deformation at macro, meso and microscale.
• Specific finite elements, locking of textile materials
• Full field strain measurements (DIC) and Micro CT analyses of internal geometry
• Beyond the classical Cauchy approach. Generalized continuum mechanics.

2. Liquid composite moulding One of the most efficient composite manufacturing method is to impregnate the fiber reinforcement (the preform) by liquid flow of matrix material. Analysis and simulation of this flow within the fibrous preform constitutes a broad scientific field necessary for modeling of composite manufacturing processes.

• Permeability (measure and virtual)
• Multi-scale flow models
• Saturation
• Investigation by X-ray CT
• Simulation techniques: FE- Control Volume, FE-Level Set, Pure FE

3. Thermo mechanics, Thermo kinetics and Couplings Composite forming processes

are carried out at high temperature and the coupling between mechanical and thermal behavior is important. Consolidation and crystallization of the resin are also coupled with the forming deformation

- Multi-scale and multi-physical models and algorithms
- Curing, crystallization, polymerization
- Residual stresses
- Coupling algorithmic

Invited Lecturers:
Philippe Boisse (Lyon, France), Christophe Binetruy (Nantes, France), Pierpaolo Carlone (Salerno, Italy), Luise Kärger (Karlsruhe, Germany), Kyosev Yordan (Dresden, Germany), Stepan V. Lomov (Leuven, Belgium).

Coordinators: P. Boisse and L. Kärger.

Physically Based Modelling of Superconductors and their Most Advanced Applications

May 16 - 20, 2022

Modern low and high temperature superconductors are extensively used to build technologically advanced scientific instruments, including medical devices as well as means of mass transport or low-loss energy transmission lines. Typical type II low temperature superconductors, massively used to construct superconducting magnets operating in liquid (4.2 K) or superfluid (below 2.17 K) helium, are the niobium based alloys and intermetallic compounds, e.g. Nb-Ti, Nb3Sn, or more recent magnesium based compounds like the magnesium diboride MgB2. Another popular class of superconducting materials are the high temperature superconductors, like Rare-Earth (RE) based REBCO or Bismuth based BiSCCO, that are applied at much higher temperatures, up to the temperature of liquid nitrogen (77 K). Generally, low temperature superconductors are used to build superconducting coils, forming the most critical parts of complex superconducting magnets, and integrated in Magnetic Resonance Imaging (MRI) or nuclear magnetic resonance (NMR) instruments, or magnets for large science experiments such as superconducting particle accelerators and fusion devices. Though high temperature superconductors have extraordinary high-field properties, so far their application has been restricted to superconducting cables and current leads, transferring the current from ambient temperature to cryogenic conditions.
The present course is focused mainly on low and high temperature superconductors. The contents stretch from the material microstructure and the constitutive description to real large-scale applications in the particle accelerators (e.g. Large Hadron Collider, LHC), or in the modern fusion devices (e.g. International Thermonuclear Experimental Reactor, ITER Tokamak). The course begins with a broad introduction to superconductors (materials, types of superconductors, flux pinning centers, parameters of critical surface, etc.), covers the physical background of superconductivity (phase transition, Meissner effect, BCS theory, Cooper mechanism, Josephson effect, etc.), the physical, mechanical

and thermodynamic properties of low and high-temperature superconductors (e.g. the effect of strains on the critical surface). Next, the constitutive modelling of superconductors and related sheath and structural materials operating at extremely low temperatures is developed, including plastic strain induced phase transformation, discontinuous plastic flow and evolution of micro-damage fields (of technological and radiation origins). Finally, interaction of superconductors and magnetic fields is explained, and optimization of superconducting coils against the quality of magnetic field is discussed. The course is concluded by the most recent applications of modern superconductors in the technologically advanced instruments and devices (e.g. particle accelerators, medical imaging instruments, fusion based energy devices, etc.).

Invited Lecturers:
Daniela Boso (Padua, Italy), Luca Bottura (Geneva, Switzerland), René Flükiger (Geneva, Switzerland), Błazej Skoczen (Cracow, Poland), Józef Spałek (Cracow, Poland), Stefan Russenschuck (Geneva, Szwitzerland).

Coordinator: B. Skoczen

**Electro- and Magneto-Mechanics of Soft Solids:
Experiments, Modeling, and Instabilities**

June 6 - 10, 2022

Over the last two decades, increasing efforts have been devoted by numerous researchers in a wide range of fields to design new composite materials with enhanced coupled properties. Most of these efforts have focused on soft organic materials because of their potential to undergo large reversible deformations when subjected to a variety of external stimuli, such as electric and magnetic fields, temperature changes and chemical changes. The focus of this course will be on the electro- and magneto-mechanics of soft composite materials and structures. These may comprise hierarchical microstructures and/or micro-architectures spanning several length scales from the nano- to the centi-meter.
The focus of the course will be on magnetorheological elastomers (MREs) and dielectric elastomer composites (DECs), which are composite materials that comprise ferromagnetic and high-dielectric/conducting filler nano- and micro-particles embedded in a soft polymeric matrix. This gives rise to a coupled magneto- and electro-mechanical response at the macroscopic (order of millimeters and larger) scale when they are subjected to magneto- electro-mechanical external stimuli. While such MRE and DEC materials and devices can become unstable at some critical electro-magneto-mechanical loading, their response may be well controlled in the post-instability regime. This feature motivates the operation of these devices in this unstable region to obtain controlled pattern formation, soft robotic motion and artificial muscles, controllable band-gap acoustic and electromagnetic properties, energy harvesting as well as actively controlled stiffness (for cell-growth).
The topics of this Advanced School will include the presentation of experimental fabrication

and testing techniques for MREs and DECs, the derivation of thermodynamically-consistent coupled variational formulations, the numerical implementation and analysis of MREs and DECs as well as of their stability using homogenization techniques, theoretical coupled homogenization and phenomenological continuum theories. The course will emphasize the significance of an integrated experimental-analytical-numerical approach across the relevant length scales.
The Course will consist of intro-ductory lectures on the theoretical aspects of such materials, followed by lectures on more specialized topics given by eminent experts in the field of experiments, phenomenological and micromechanical modeling of active composites and structures, instabilities and energy harvesting. The course will close with recent examples showing the necessary but also powerful combination of experiments, numerics and theory to study the response of MREs and DECs and their instabilities.
The School is addressed to doctoral students, post-docs and early career researchers with interest in active soft materials. The course is designed to give an integrated experimental, numerical and theoretical viewpoint on such novel material systems as well as possible future research directions in this field.

Invited Lecturers:
Kostas Danas (Palaiseau, France), Yibin Fu (Staffordshire, UK), Massimiliano Gei (Cardiff, UK), Marc-André Keip (Stuttgart, Germany), Oscar Lopez-Pamies (Urbana, IL, USA), Zoubeida Ounaies (University Park, PA, USA).

Coordinators: K. Danas and O. Lopez-Pamies.

Instability and Bifurcation of Solids including Coupled Field Phenomena
25th CISM-IUTAM International Summer School

June 13 - 17, 2022

The purpose of this course is to provide a carefully crafted state-of-the-art overview of the fundamental theories, established models and ongoing research related to instability and bifurcation phenomena in solids undergoing finite deformations, including the effects of electric fields and growth. The course will be organized around several complementary and interacting themes. A comprehensive overview of the continuum theory of materials subject to large deformation will be presented, including the constitutive equations of nonlinear elasticity, elastoplasticity, Cosserat solids, electroelasticity, residually stressed and fibre-reinforced materials, and growth in biological systems.
The general theory of bifurcation, instability and non-uniqueness within the framework of the continuum theory of solids will be discussed as the setting for applications to specific examples.
The equations governing linearized incremental deformation fields superimposed on a known finitely deformed configuration will be highlighted. The tensors of elastic moduli for isotropic and anisotropic materials will be derived, including their important incompressible specialization, and associated expressions for the incremental

constitutive equations and boundary conditions will be provided. These are needed for the analysis of possible bifurcation of the equilibrium configuration into periodic patterns, and will be applied in order to obtain specific results for exemplary constitutive laws.
Particular applications that will be described are material, surface, interface and bending instabilities of diffuse type. The notion of strong ellipticity will be introduced, and phenomena, such as the appearance of shear bands, associated with loss of ellipticity of the governing equations will be described. Localized bifurcation phenomena will be examined in detail, including localized bulging of tubes, necking of plates, shear banding, creasing and folding. Appropriate numerical formulations will be provided in order to illustrate the solutions for a range of specific boundary-value problems.
A summary of the key equations of electroelasticity will also be given, leading to the corresponding incremental formulations of electroelasticity. In this context wrinkling of a thin film of dielectric elastomer, treated as a prototype actuator, can be generated by application of an electric potential between compliant electrodes on the surfaces of the film, leading to pull-in instability and dielectric breakdown, and therefore rendering the actuator ineffective. Thus, analysis of such instabilities will be included in the course since this is important for the design and integrity of such devices.
The methods of stability analysis have a wide applicability in the context of the mechanics of soft tissue, particularly as related to instabilities associated with growth and remodelling. In growth and development, instabilities are used constructively by nature for the formation of structures, such as in the folding of tissues to form different parts of the brain. Aspects of stability and instability that relate to growth and the possible development of pathologies will also be discussed.
The course is addressed to doctoral students and postdoctoral researchers in mechanical, civil and electrical engineering, materials science, applied physics and applied mathematics, academic and industrial researchers and practicing engineers.

Invited Lecturers:
Martine Ben Amar (Paris, France), Davide Bigoni (Trento, Italy), Michel Destrade (Galway, Ireland), Luis Dorfmann (Medford, MN, USA), Yibin Fu (Staffordshire, United Kingdom), Raymond W. Ogden (Glasgow, United Kingdom).

Coordinators: L. Dorfmann and R. W. Ogden.

Architectured Materials: Design Principles and Effective Properties

June 20 - 24, 2022

Architectured materials are defined at the threshold between structures made from discrete elements and continua. In these materials, topological interactions of the building blocks are essential. The material is composed from phases or objects of dissimilar properties, which are assembled into a structure designed to achieve pre-defined properties, such as improved toughness, increased ductility, or specific wave properties, such as cloaking.
A sub-class of architectured materials is formed by mechanical metamaterials. The term

metamaterials is used to denote materials or structures with special dynamic properties. This term currently indicates materials with pre-designed multiscale architecture, which exhibit unusual static and dynamic properties associated with large local deformations, presence of multiple metastable states and instabilities. The microstructure of these materials is predominantly of lattice type, i.e. it is made from beams. Metamaterials derive their properties not from those of the base material, but rather from the architecture of their microstructure. The density, shape, size and spatial arrangement of the constituent components are responsible for the enhanced behavior observed at the macroscale.
Other examples of architectured materials are topologically interlocked materials made from independent blocks that interact at contact points and are assembled such to hold together, and materials with hard and soft periodic domains, as in nacre and bone. These materials have properties that cannot be achieved with conventional continuum composites. Nacre and bone have toughness much larger than that of the predominant hydroxyapatite phase due to the presence of small amounts of soft material (collagen). Topologically interlocked materials are flexible and exhibit toughness larger than that of the material of the constituent blocks because interfaces act as traps for cracks.
A special class of architectured materials have stochastic microstructure. Stochasticity reduces the sensitivity to flaws and reduces the constraints imposed on the process of fabrication. Topologically interlocked materials with stochastic structure are similar to a puzzle of locked objects and their properties are in-between those of a microcracked continuum and of granular material. If the building blocks have large aspect ratio, the ensemble becomes a random fiber network, whose properties are determined by the connectivity and topological interactions between fibers. Many biological and engineering materials are network materials: connective tissue, the extracellular matrix, elastomers, nonwovens, etc.
This course will outline the concepts underlining the function and design of architectured materials and will overview the methods and tools required for the design and material performance evaluation.
A broad range of examples will be discussed, including metamaterials, topologically interlocked, fibrous and highly heterogeneous continua.
The course is addressed to graduate students and postdoctoral researchers in mechanics and materials, and to established researchers interested in the emerging field of architectured materials.

Invited Lecturers:
François Bartelat (Colorado Boulder, CO, USA), Jean-François Ganghoffer (Metz, France), Muamar Kadic (Besan on, France), Daphne Klotsa (Chapel Hill, NC, USA), Catalin Picu (Troy, NY, USA), Hilal Reda (Beirut, Lebanon).

Coordinators: J. F. Ganghoffer and C. Picu.

Exploiting the Use of Strong Nonlinearity in Dynamics and Acoustics
CISM-AIMETA Advanced School

June 27 - July 1, 2022

In engineering and related fields, linearity or weak nonlinearity are typically assumed. These approaches require linear generating solutions for averaging or multi-scale asymptotics to be applied. Still, strong or even non-linearizable stiffness or damping nonlinearities occur often in engineering practice, e.g., due to clearances, impacts, friction, material composition, or geometry/kinematics, with nonlinear responses often having no analogs in linear or weakly nonlinear theory. Yet, ever-accelerating needs for lighter, faster, compact, robust, and high-performing engineering systems, set heavy demands for continuously expanding performance envelops under harsh, uncertain and poorly predictable environments. These needs cannot be addressed by current approaches, and this calls for a new paradigm-shifting concept based on the exploitation of strong nonlinearity to open new unprecedented paths for effective and robust design in ways heretofore unattainable in traditional settings.
In the last two decades exploitation of strong nonlinearity has been actively explored in fields such as energy absorption and harvesting, wave propagation, modulation and arrest, blast and seismic mitigation, micro- and nano-resonators, fluid-structure interactions, and acoustic metamaterial design. However, predictive analysis of strongly nonlinear systems is still a major challenge, as, apart from rare cases of integrability, exact or even approximate solutions are missing. Some methods exist for stationary solutions, e.g., nonlinear normal modes and discrete breathers, but nonstationary processes are more difficult to model and understand; yet, in many applications such processes are highly important. As such, the idea of exploiting strong nonlinearity in dynamical and acoustical systems has transitioned from a few early theoretical works to a diverse theoretical and experimental body of current research, and the field now seems mature enough to warrant an advanced CISM course.
The need for such a course is further underscored by the fact that accounting for, understanding of, and designing with nonlinearities is becoming an emerging universal trend in engineering practice, and is predicted to be even more so in the future. Accordingly, the aim of this course is to provide the latest ideas and approaches in strongly nonlinear dynamical and acoustical systems, and discuss appropriate modelling tools and practical examples highlighting the non-standard and non-stationary aspects of this challenging, yet so promising area.
The course is structured along three main didactic themes: (i) Foundations – Basic notions, concepts, models and benchmark problems in strongly nonlinear systems (Gendelman, Rega, Vakakis); (ii) Methodology – Advanced analytical and numerical tools for exploiting the strongly nonlinear dynamics and acoustics (Cochelin , Gendelman, Kerschen, Rega, Vakakis); and, (iii) Applications – Addressing practical and diverse problems where the ideas and

methods related to strong nonlinearity become necessary (Cochelin, Kerschen, Krack, Vakakis, Vestroni). The course is addressed to graduate students, interested faculty, researchers and professionals.

Invited Lecturers:
Bruno Cochelin (Paris, France), Oleg V. Gendelman (Haifa, Israel), Gaetan Kerschen (Liege, Belgium), Malte Krack (Stuttgart, Germany), Giuseppe Rega (Rome, Italy), Alexander F. Vakakis (Urbana, IL, USA), Fabrizio Vestroni (Rome, Italy).

Coordinators: O. V. Gendelman and A. F. Vakakis.

Convection and Deformation in Porous Media: Geophysical and Biological Flows
26th CISM-IUTAM International Summer School

July 11 - 15, 2022

Flow and transport in porous media are relevant for many geophysical, industrial, and biological applications, including carbon sequestration, glacial drainage, papermaking, transport across vascular walls, and bacteria motility. Predicting the evolution of these systems is difficult because of the interplay between different physical features, such as complex flow patterns, convection and reaction, and transformation of the porous matrix through deformation and phase change. In addition, flow and transport in porous media are governed by physical processes that span a wide range of length and time scales. Rapidly increasing computational power has recently enabled threedimensional, high-resolution and time-dependent simulations of these flows at both the pore-scale and the Darcy-scale, producing an entire branch of flourishing research into multiphase flow in porous media. Experimental progress has also been substantial, thanks to improved measurement techniques inboth 2D and 3D. Therefore, it is now useful to review the many studies on the subject to provide an overview of the current state of the art, and to put future research paths in perspective.

This course will provide an overview of the most up-to-date modelling approaches, numerical simulations, and experimental methods used to study the dynamics and properties of porous media flows characterized by convection and deformation.

Fundamentals of transport in porous media will be presented, including upscaling techniques, thermodynamics of two-phase mixtures, Lagrangian interpretations, fractional diffusion, non-locality and memory.

Time-dependent evolution of convection-driven flows in different configurations will be analyzed, with reference to geophysical and industrial applications and with particular attention to the dynamics and structures of convection, effect of porous media properties on convection and transition from 2D to 3D convection. An overview of experimental and numerical techniques for convective flows in porous media will be presented and reviewed.

Principles of the coupling between flow, transport, and deformation in porous media will be presented. The small-deformation limit and classical linear poroelasticity will be discussed in the context of subsurface flows. Large-deformation poromechanics

will be discussed in the context of polymeric hydrogels (including swelling and drying phenomena), paper-pulp suspensions (including viscoelasticity and plasticity), and granular media (including friction and rearrangement).
The implications of deformation for the dispersion and mixing of solutes will be considered. Two-phase flows will be considered, including capillary and wettability effects. Phase-field approaches will be introduced in the context of multiphase solidification problems (including ice, methane clathrates, and lava) and applied to the growth and migration of gas bubbles in soft porous media.
The course is addressed to graduate students and researchers in applied mathematics, physics and chemical/mechanical engineering.
The advanced topics and the presentation of current progress in this very active field will also be of considerable interest to senior researchers and industrial practitioners having a strong interest in understanding the multiscale complex behavior of such multiphase flows.

Invited Lecturers:
Pietro de Anna (Lausanne, Switzerland), Marco De Paoli (Vienna, Austria), Xiaojing (Ruby) Fu (Pasadena, USA), Duncan Hewitt (London, UK), Matteo Icardi (Nottingham, UK), Sylvie Lorthois (Toulouse, France), Chris MacMinn (Oxford, UK).

Coordinators: M. De Paoli and C. MacMinn.

Materials and Electro-Mechanical and Biomedical Devices Based on Nanofibers

July 18 - 22, 2022

In engineering and related fields, linearity or weak nonlinearity are typically assumed. These approaches require linear generating solutions for averaging or multi-scale asymptotics to be applied. Still, strong or even non-linearizable stiffness or damping nonlinearities occur often in engineering practice, e.g., due to clearances, impacts, friction, material composition, or geometry/kinematics, with nonlinear responses often having no analogs in linear or weakly nonlinear theory. Yet, ever-accelerating needs for lighter, faster, compact, robust, and high-performing engineering systems, set heavy demands for continuously expanding performance envelops under harsh, uncertain and poorly predictable environments. These needs cannot be addressed by current approaches, and this calls for a new paradigm-shifting concept based on the exploitation of strong nonlinearity to open new unprecedented paths for effective and robust design in ways heretofore unattainable in traditional settings.
In the last two decades exploitation of strong nonlinearity has been actively explored in fields such as energy absorption and harvesting, wave propagation, modulation and arrest, blast and seismic mitigation, micro- and nano-resonators, fluid-structure interactions, and acoustic metamaterial design. However, predictive analysis of strongly nonlinear systems is still a major challenge, as, apart from rare cases of integrability, exact or even approximate solutions are missing. Some methods exist for stationary solutions, e.g., nonlinear normal modes and discrete breathers, but nonstationary pro-

cesses are more difficult to model and understand; yet, in many applications such processes are highly important. As such, the idea of exploiting strong nonlinearity in dynamical and acoustical systems has transitioned from a few early theoretical works to a diverse theoretical and experimental body of current research, and the field now seems mature enough to warrant an advanced CISM course. The need for such a course is further underscored by the fact that accounting for, understanding of, and designing with nonlinearities is becoming an emerging universal trend in engineering practice, and is prRecently, there has been a strong interest in the development of new micro- and nanomaterials, in particular, nanofibers (NFs), for biomedical applications. The aim of this course is to provide state-of-the-art information on the development of nanofiber-based materials and devices for advanced biomedical purposes. With this objective, the course aims at covering the design of fibrous nanomaterials at the forefront of biomedical sciences reviewing the most important areas from fiber fabrication modeling to their final application.
Core-shell fibers with healing agents are key element for self-healing vascular composite materials used to sustain mechanical properties and for corrosion protection. Sustainable NF-based triboelectric nanogenerators comprised of biopolymers will also be discussed. Soft thermo-pneumatic artificial muscles and actuators with the embedded NFs impregnated with ethanol and blister-like thermo-pneumatic soft actuators, which deflect in response to heat supplied to their bottom are an important step toward NF-based soft robotics. Metallized NFs are electrically conductive and highly transparent materials, which hold great promise as three-dimensional heaters, sensors, and treatment of aneurysmal subarachnoid hemorrhage.
Optical, electronic, and photonic properties of NFs can also be highly important for electro-mechanical and biomedical devices. Based on a variety of functional compounds such as conjugated polymers, organic light-emitting molecules, dyes, piezo-polymers, etc., NFs can be used as building blocks of miniaturized dielectric waveguides, optical amplifiers, solid-state lasers, active fiber optics, and surface-coating elements of great relevance for lab-on-chip architectures, electro-mechanical devices, wearable and implantable technologies.
Electrostatic interactions between polyelectrolytes and increased entropy resulting from counter-ion release are the main driving forces for polyelectrolyte complexation. We discuss formation of NFs from polyelectrolyte complexes as a function of polymer molecular weight and concentration, and solution ionic strength and pH. The applications of polyelectrolyte complex fibers for actuation and drug release will be discussed. We will show several approaches of modeling hydrodynamic transport of nanofibrous suspensions and experimental methods used for evaluating their interactions in micro and nanoscale environment. We will also discuss properties of materials for cancer treatment developed over the past few decades.
NFs are used for developing new composite materials. They have proven to be one of the most effective ways to improve toughness of matrix polymer and the delamination resistance of structural composites. It is hence important to understand the mechanics of NFs and their related materials.
This course is directed towards senior year undergraduate students, graduate students,

researchers, engineers and practitioners in industry. It will be of special importance for those interested to develop novel devices and models based on nanofibers from the in-depth and comprehensive exposition of physical foundations of such devices and related phenomena.edicted to be even more so in the future. Accordingly, the aim of this course is to provide the latest ideas and approaches in strongly nonlinear dynamical and acoustical systems, and discuss appropriate modelling tools and practical examples highlighting the non-standard and non-stationary aspects of this challenging, yet so promising area.
The course is structured along three main didactic themes: (i) Foundations – Basic notions, concepts, models and benchmark problems in strongly nonlinear systems (Gendelman, Rega, Vakakis); (ii) Methodology – Advanced analytical and numerical tools for exploiting the strongly nonlinear dynamics and acoustics (Cochelin , Gendelman, Kerschen, Rega, Vakakis); and, (iii) Applications – Addressing practical and diverse problems where the ideas and methods related to strong nonlinearity become necessary (Cochelin, Kerschen, Krack, Vakakis, Vestroni). The course is addressed to graduate students, interested faculty, researchers and professionals.

Invited Lecturers:
Karen De Clerck (Ghent, Belgium), Tomasz A. Kowalewski & Filippo Pierini (Warsaw, Poland), Marco Lauricella (Rome, Italy), Dario Pisignano (Pisa, Italy), Alexander L. Yarin (Chicago, IL, USA), Eyal Zussman (Haifa, Israel).

Coordinators: T. A. Kowalewski and A. L. Yarin.

Fluid Flow and Phase Change of a Solid

July 25 - 29, 2022

This course aims to study the interaction between a fluid flow and the phase change of a solid.
The phase change may be a phase transition or a dissolution/ precipitation phenomenon. The growth or erosion of the solid depends on the flux of heat or/ and concentration at the fluid/solid interface. In numerous situations of interest those are controlled by the fluid flow. Because a wavy topography modifies the flow in the vicinity of the interface, the coupling between the topography, the flow and the rate of phase change may control the shaping of the solid and lead to pattern formation. One adds another level of complexity when taking into account that the fluid density and buoyancy are functions of the temperature and the concentration. Moreover, one has to tackle both the transport of heat and concentration when considering the crucial example of ice melting in a salty water.
These mechanisms are responsible for shaping natural systems on a large scale and give rise to plethora of patterns and growth forms. Melting of ice cover has environmental consequences in a context of global warming to determine the long-term evolution of the sea ice and glaciers. In geomorphology, the carving of soluble rocks like limestone, gypsum, or salt by water creates networks of caves, stone forests and other intricate patterns of the karstic landscapes.

Solidification and convection processes are driving the melt dynamics in Earth's outer core and mantle. Winds shape icy ripples and dunes on the polar cap of Mars. Some of the mechanisms presented here for the phase change of a solid apply also to other hydrodynamic problems at interfaces. Evaporation at the interface between a liquid and the atmosphere is in fact analogous to a dissolution phenomenon, because the saturated vapor pressure plays the role of a saturation concentration. Additionally, in two phase systems, buoyancy instabilities can be triggered by dissolution or precipitation.
In addition to shaping the natural systems, phase transitions in advective flow are also important for a number of engineering applications. In hydrology, understanding of flow-driven dissolution is crucial for the risk assessment of contaminant migration out of underground reservoirs or the dam stability problems. The control of flow instabilities is a challenge in the processes of carbon dioxide sequestration. Control of solidification plays a key role in metallurgy and crystal growth, but also for the prevention of scaling in geothermal power plants or icing prevention in aircrafts or photovoltaic devices.
The School is mainly addressed to doctoral students, post-docs and early career researchers interested in environmental fluid mechanics, but remains open to the researchers of other profiles in physics, physical chemistry, geophysics or engineering. Seniors researchers and practicing engineers are also welcomed.

Invited Lecturers:
Michael Berhanu & Sylvain Courrech du Pont (Paris, France), Pierre-Yves Lagrée (Paris, France), Cyprien Soulaine (Paris, France), M. Grae Worster (Cambridge, UK), Piotr Szymczak (Warsaw, Poland), Laurence Rongy (Bruxelles, Belgium).

Coordinators: M. Berhanu, S. Courrech du Pont and P. Szymczak.

The Kurt Magnus Session

Mechanics of Smart and Bio-Hybrid Gels: Experiments, Theory, Numerical Simulation

August 29 - September 2, 2022

The proposed course aims at creating a bridge between mechanics, chemistry, physics and biology to educate new scientists in the new and fast growing scientific framework of active soft matter. Many health treatments involving drug delivery and tissue transplant technology rely on a deep understanding of the physiological conditions of the living tissue involved. To achieve this, one needs to account for the coupling between the mechanical behavior of the tissue and its biochemical activity at multiple length scales, from intracellular mechanisms to tissue behavior at the organ level. In this framework, most of the scientific problems require cross-disciplinary expertise to be tackled, hence the emerging need for a new generation of scientists capable of combining fundamental concepts from different disciplines.
The course is aimed at researchers and graduate students in the fields of applied mathematics, mechanical and chemical engineering, physics, biology and biophysics.

Dr. Zhigang Suo will introduce the concept of hydrogel. Polymeric gels constitute a reliable physical model platform for most of the soft biological tissue constituting the human body hence this represents the foundation of this course. He will provide basic insight on the main mechanical properties of these materials such as adhesive strength, fracture toughness, fatigue resistance and viscoelasticity.
Dr. Alessandro Lucantonio will discuss the analytical and computational tools available today to describe the mechanical behavior of gels with particular focus on their poroelastic behavior, which couples elasticity of the polymer network and species diffusion.
Dr. Mattia Bacca will discuss the thermodynamics of active deformation for materials depicted as a microstructural evolution. The phenomenon emerges from a biochemical process, the activity of molecular motors powered by ATP hydrolysis, which alter the equilibrium state of the material, resulting in (active) macroscopic deformation.
Dr. Robert McMeeking will discuss the mechanics and thermodynamics of actin polymerization occurring within the cytoskeleton and the mechanics of cell adhesion. This will highlight the active and anisotropic characteristics of the material constituting living cells.
Dr. Antonio De Simone will provide an introduction of fundamental concepts on crawling and deformation driven locomotion of living systems. This will link the motility of a cell with its biochemical activity at the molecular level (actin- myosin, microtubule-dynein).
Dr. Nancy Forde lectures will provide insight into experimental techniques for characterization soft matter and measure molecular-scale phenomena. She will then provide theoretical and practical insight on micro rheology, single- molecule mechanics and other techniques to create synthetic molecular motors.
Finally, Dr. Anne Bernheim will provide insight into the theory and the experimental techniques utilized to recreate other cell-level mechanisms with in-vitro system and will conclude the course.

Invited Lecturers:
Mattia Bacca (Vancouver, Canada), Anne Bernheim (Be'er Sheva, Israel), Antonio De Simone (Trieste, Italy), Nancy Forde (Burnaby, Canada), Alessandro Lucantonio (Pisa, Italy), Robert M. McMeeking (Santa Barbara, CA, USA), Zhigang Suo (Cambridge, MA, USA).

Coordinators: M. Bacca and A. Lucantonio

Sports Physics and Technology
27th CISM-IUTAM International Summer School

September 19 - 23, 2022

In 1994 for his Dirac Memorial Lecture, Pierre Gilles de Gennes writes "The borders between great empires are often populated by the most interesting ethnic groups."
He then makes an analogy with his work on soft interfaces which lies between two forms of bulk matter. The same analogy holds for Sports Physics which lies at the border between four great empires, namely sports, biomechanics, physiology and physics. The purpose

of the school is to explore this territory and to illustrate its diversity and research potential. The course by Professor P.E. di Prampero on human locomotion will stand at the border between physiology and physics. The course will be devoted to a detailed analysis of the main energetic and physiological characteristics of the most common forms of human locomotion on land: walking, running and cycling.
The course by Professor A. Hosoi will stand at the border between data science and sport science e.g. how can machine learning and neural networks help basketball players make good decisions on the court? This type of practical question will be at the root of the discussion on the growing adoption of these types of new scientific tools in sports.
The course by Professor C. Cohen on the physics of motion control will explore the border between physics and biomechanics. Starting from field observations in weightlifting, the lectures will go through deep questions of force generation and the associated questions of the precision of the motion.
The course by Professor L. Bocquet on friction will stand at the border between physics and material science. In all racing sports, the goal of attaining the maximal speed is achieved via a deep empirical knowledge of friction reduction. The primary idea behind this course is to connect this knowledge to the associated underlying science.
The course by Professor A.R. Harland will stand at the border between design and mechanics and will include discussions of his own experience working with a wide range of partners including adidas, FIFA, International Cricket Council, BISFed and FIH.
Finally the course by Professor C. Clanet on the physics of races will explore the region between sport science, physical models and optimization. We will start from field data obtained during Olympic races in cycling, rowing, kayaking and swimming, derive simplified models which are able to recover the main observed features, and discuss model generalization.
Sports Physics and Technology will appeal to designers, engineers, PhD students and young researchers in physics, biomechanics, physiology, data analysis, and materials. The school will cover different aspects of sports using physics as the common denominator. Although the course is aimed at PhD students and young researchers in physics and sport sciences, the lectures will include sports applications and will be accessible to designers, engineers and sport scientists alike.
A poster session with 3 minute oral presentations of the posters will be included in the school. Participants will also be encouraged to present a 3 minute video. Prizes for the best posters and videos will be awarded.

Invited Lecturers:
Lyderic Bocquet (Paris, France), Christophe Clanet (Palaiseau, France), Caroline Cohen (Paris, France), Pietro Enrico di Prampero (Udine, Italy), Andy Harland (Loughborough, UK), Anette (Peko) Hosoi (Cambridge, MA, USA).

Coordinators: C. Clanet and A. Hosoi.

Mechanics of Strongly Inhomogeneous Multi-Component and Multi-Layered Structures

October 3 - 7, 2022

Advanced mathematical formulations, computational and hybrid schemes for modelling of strongly inhomogeneous multi-component and multi-layered structures, are within the focus of the program. The course is bringing together a broad multidisciplinary expertise inspired by numerous engineering applications, including, in particular, manufacturing and design of photovoltaic panels, laminated glass, and also lightweight vehicles, soft robots, energy harvesting devices, and bio-composites.

The recent progress in material science, combined with growing demands of environmentally friendly technologies, stimulate increasingly strong interest in composite materials with high-contrast properties, as well as strongly inhomogeneous layered structures. The presence of strong contrast in material parameters, say, up to 10-5 in layer stiffness of photovoltaic panels, necessitates development of novel approaches to mathematical models governing their mechanical behaviour.

The course combines a number of theoretical approaches to studying high-contrast multi-component and multi-layered structures, including formulations based on physical assumptions, as well as asymptotic procedures. The course is also aimed at enriching the listeners with new developments in metamaterial synthesis, novel homogenisation techniques for periodic media, wave propagation in soft phononic crystals, and fatigue and fracture in soft materials.

In particular, the phenomenon of specific low natural frequencies arising as a consequence of strong inhomogeneity is discussed, along with a delicate treatment of boundary conditions, following from the appropriately adapted Saint-Venant's principle for a thin laminate. Also, an overview of the homogenization methods of continuous or discrete periodic media is provided, addressing successively various scenarios, e.g. strain-gradient formulations of fibre-reinforced media, non-conventional behaviour of reticulated structures etc., demonstrating that generalized continua may arise from modelling of high-contrast media. In addition, a class of meta-materials associated with pantographic micro-structures, that could bear large deformations while remaining in the elastic regime, is discussed. A related topic of large deformations, buckling and post-buckling deformations and their effects on wave propagation in soft phononic crystals and metamaterials is covered. Another related subject is concerned with analysis of modelling failure in soft materials, relying on the concept of bounding strain-energy by means of energy limiters.

The lectures are chosen to appeal to researchers, graduate students and postdoctoral fellows, specializing in Mechanical, Aerospace and Civil Engineering, as well as Applied Mathematics and Physics, with the focus on recent developments in the area of high-contrast elastic solids that have not been yet included in traditional university graduate courses. Both theoreticians and experimentalists are expected to gain useful knowledge from attending the course.

Invited Lecturers:
Holm Altenbach (Magdeburg, Germany), Claude Boutin (Lyon, France), Weiqiu Chen (Zhejiang, P.R. China), Francesco dell'Isola (L' Aquila, Italy), Danila Prikazchikov (Keele, UK), Konstantin Volokh (Haifa, Israel).

Coordinators: H. Altenbach and D. Prikazchikov.

Data-Driven Mechanics: Constitutive Model-Free Approach
CISM-ECCOMAS Advanced School

October 10 - 14 , 2022

The classical approaches to modeling and simulation in solid mechanics rely heavily on constitutive models. These provide constitutive equations, which complement the balance equations of field, or boundary-value, problems. Extensive ongoing research efforts are devoted in the scientific community to tune and ever improve constitutive models and equations for various classes of materials and various regimes of solicitation (loading amplitudes and rates, temperature, chemistry, …), as well as to identify associated parameters. Constitutive models thus present a very large diversity encompassing a wide range of applications, yet this variety also hints at the inherent epistemic uncertainty carried by these models. If the uncertainty associated to constitutive parameters can be quantified, the uncertainty associated to the models themselves is much more difficult to measure. From a more historical point of view, constitutive models were initially conceived to generalize experimental observations made on specific (typically homogeneous) loading regimes to more general loadings. With the recent progress in imaging techniques, experimental observations are nowadays much richer in information and existing constitutive models are sometimes incompatible with this abundance of data. Data-driven approaches have recently been developed to better exploit the large volumes of modern experimental measures, while attempting to avoid the bias induced by constitutive models. The present course will focus on a global data-driven approach, completely avoiding the use of models (statistical models or constitutive models), which could thus be labelled as model-free.
The proposed course will constitute a consistent and comprehensive introduction to the model-free data-driven paradigm for computational solid mechanics. After a general introduction to the data-driven paradigm, and how it fundamentally differs from the classical paradigm, the course will take students all the way from acquiring rich mechanical data sets, notably from imaging, to data-driven numerical simulation in nonlinear mechanics of structures. On the way, important aspects such as mathematical foundations of data-driven and machine learning methods, and the necessity and ways to account for the stochastic and imperfect nature of real-life data will be covered. Abundant data are also generated in multi-scale approaches, and the course will discuss how the data-driven paradigm may be relevant in that context as well. Finally, the current challenges in dealing with non-linearities and history-dependent behaviors will be discussed.

The course will also include a series of practical hands-on sessions, where the students will experiment with the data-driven approach, starting from a series of images from which to extract data, process it to construct a material database, and use this database in a data-driven simulation. A hands-on training session on coding data-oriented algorithms in the open source machine learning framework TensorFlow™ will also be proposed. Relevant software will be provided to participants for installation on their own computers.

Invited Lecturers:
Manuel Doblaré (Zaragoza, Spain), Marc-André Keip (Stuttgart, Germany), Michael Ortiz (Pasadena, CA, USA), Julien Réthoré (Nantes, France), Carola-Bibiane Schönlieb (Cambridge, UK), Laurent Stainier (Nantes, France).

Coordinators: Michael Ortiz and Laurent Stainier.

International Advanced Professional Training

Mechanics, Tribology in Manufacturing Processes

May 9 - 13, 2022

Tribology, the science of friction and wear between solids in contact, requires a multiscale modelling approach. On the one hand, friction and wear are systemic properties, i.e. not attached to a material but to a system. A tribosystem consists in a pair of solid bodies (their nature, manufacturing and surface finishing, shape...), the contact conditions (kinematics, loadings) and, critically, lubrication. On the other hand, surfaces are rough and this plays a major role through loading at asperity level and real area of contact. Tribology thus requires modelling at the macroscale – system scale – and at a microscale – typically the roughness scale, possibly going down to the atomic scale for the understanding of the fundamental interactions.
Manufacturing has a double interaction with tribology. Friction does govern a number of features of manufacturing processes: global forces and torques, machine power and strength requirement, material flow, tool deformation and machine vibrations (chatter) which impact product dimensions and quality, tool wear and surface quality of products... Reciprocally, manufacturing processes impart products with surface features (topography, composition, superficial properties, residual stresses...) which control their functionality.
Tribology in manufacturing is therefore a key engineering science subject. Chemistry is important for tribology (materials nature and properties, microstructural features, choice of lubricants); however tribology is strongly anchored in mechanics and generally taught in a Mechanical Engineering curriculum.
Numerical modelling has become a key tool in this field. Transmission of this know-how will be an integral part of the course:
- macroscopic process modelling discloses the working conditions of the interface;

- microscale numerical modelling gives precise, physics-based homogenized friction or wear models;
- FE2 approaches of mixed regime lubrication address multiple micro- mechanisms of lubrication.

These trends will be illustrated and their potential discussed in view of scientific knowledge as well as for practical application.

Through a multidisciplinary approach combining theory and practice, this course intends to provide its audience, academic researchers as well as R&D engineers from industry, with both the well-established bases of this particular field and advanced models and operational concepts illustrated by examples of recent and on-going research, including on how tribology may contribute to greener manufacturing.

The course is addressed, through its mixture of basic and advanced notions, to:
- MSc or doctoral students who can learn approaches useful for their thesis;
- young researchers completing their specialization in tribology of manufacturing;
- more experienced researchers in mechanical engineering or tribology who desire to enter this specific field;
- engineers from industry who want to add to their practical know-how an in-depth understanding of the underlying mechanisms.

In a poster session at the end of the first day, the attendants will be given an opportunity to present one of their research subjects through a brief pitch and a poster, to be discussed with other participants and with the experts. An attestation describing the content will be provided to students on demand in view of ECTS accountance, to be determined with their administration.

Invited Lecturers:
Oreste S. Bursi (Trento, Italy), Valerio Cozzani (Bologna, Italy), Ana Maria Cruz (Kyoto, Japan), Elisabeth Krausmann (Ispra, Italy), Roberto Nascimbene (Pavia, Italy), Fabrizio Paolacci (Rome, Italy).

Coordinators: V. Cozzani and F. Paolacci.

NaTech Risk: Management Strategies and Resilience Towards Technological Accidents Caused by Natural Events

September 5 - 9, 2022

The relevance and the potentially tremendous impact of technological accidents triggered by natural events, such as earthquakes, tsunamis, floods, etc., referred to as natural-technological (NaTech) events, was demonstrated, for instance by the 2011 Tohoku earthquake and the following Fukushima nuclear disaster in Japan or by the 2015 winter floods in UK which topped £5bn. NaTech scenarios may have severe direct consequences and long-term effects due to the release of hazardous chemicals or fuels, and/or of Chemical, Biological, Radiological, Nuclear and high yield Explosives (CBRNE) substances. The control and management of risk due to Natech events is among the requirements of the Seveso-III Directive (2012/18/EU), which regulates the

control of major accident hazards involving dangerous substances.
This course aims to offer to students, scholars, and practitioners a clear overview of the problems and the available solutions for the prevention and mitigation of Natech events, addressing both the control and management of risk and the enhancement of system resilience. The course will be a unique occasion to familiarize with this hot topic and to be in contact with the risk and resilience community.
Six learning units will be delivered. The first introduces the specific Natech hazards and the features of Natech scenarios in the process industry, providing a clear analysis of the current state of the art and of future challenges.
The second unit is focused on the vulnerability of industrial equipment to natural hazards. This important ingredient of Natech risk assessment is here analysed in depth, identifying possible damages caused by natural disasters to critical units and release modes of hazardous materials that may be triggered. Fragility analysis methods for industrial equipment are formulated and applied to specific examples.
The third unit is devoted to Natech risk assessment in process and chemical plants. Existing approaches (qualitative and quantitative) are discussed, and the role of the main ingredients (hazard, vulnerability, consequences) identified. Critical aspects, (e.g. cascading events) related to the consequence of damages caused by natural events (e.g. earthquake), are also discussed and examples pertaining to the process and energy industry are studied and discussed.
The mitigations strategies currently available to reduce Natech risk are analyzed in the fourth unit. More specifically, a cutting-edge technology is introduced, which is based on the concept of metamaterial. In particular, metamaterial-based technologies are presented in the light of the large advantages that this new technology offers. Examples of the new concept of meta-foundations are presented and a smart mitigation strategy to reduce the seismic risk of storage tanks containing hazardous material is discussed.
In the fifth unit, resilience concepts are formulated and applied to industrial plants, addressing specifically Natech events. A new general method for the quantification of resilience indexes, as economic losses and business continuity, is introduced and applied to case-studies addressing the process industry when impacted by severe natural events.
The last unit is dedicated to the role of safety barriers in Natech scenarios. The possible loss of integrity of safety barriers in Natech events is discussed. The role of utilities in assuring the availability of control, safety and emergency systems during intense natural events will also be addressed. The assessment of safety barrier performance will be analyzed in the light of the available key enabling models for Natech risk quantification and of methodologies currently available for the evaluation barrier performance. The role of safety barriers in protecting asset integrity and promoting system resilience will also be discussed.

Invited Lecturers:

Niels Bay (Lyngby, Denmark), Leonardo De Chiffre (Lyngby, Denmark), Laurent Dubar (Le Mont Houy, Valenciennes, France), Pierre Montmitonnet (Sophia Antipolis, France), Jean- Philippe Ponthot (Liège, Belgium).

National Advanced Professional Training

Coordinators: N. Bay and P. Martins.

National APT courses in the fields of Structural and Geotechnical Engineering, Surveying, Environmental, Bioengineering and Industrial Engineering will be given in Italian.
For all activities and meetings, please refer to our website.

Admission to Courses

Applications should reach CISM Secretariat no later than one month before the course. Name, degree, current address and course to be attended should be specified.
A limited number of academic participants, not supported by their own institutions, can be granted board and/or lodging upon application. Application for support must reach CISM Secretariat no later than two months before the course.
Detailed programmes, admission rules and on-line forms are available from the website.

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