Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

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

PROGRAMME 2021

" ...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 2021

Udine, Italy

CONTENTS Page

CONTENTS Page

The Erwin Stein Session

Optimization of Shape and Material Properties: Advanced Mathematical Methods and 3D

April 12 - 16, 2021

3D printing has opened the possibility to create functional end-use parts of a complexity that could not be achieved with traditional manufacturing technologies. It thus represents a promising step towards ways of optimizing and saving materials, reducing costs and environmental impact.
While additive manufacturing is being continually improved, a major thrust in research is devoted to the optimal design of composite and micro-architected materials with unprecedented properties.
This course will present some advanced mathematical tools for modelling both the elastic and inelastic behaviour of solids, and applications related to the engineering technology of additive manufacturing.
In particular, Gamma-convergence rigorously justifies the use of phase field models to approximate quasistatic crack growth in brittle materials. In order to identify significant parameters or cavities to predict the optimal shape of a printed object, topology optimization will be considered.
The mechanical properties of materials and structures obtained by these methods will be analysed, and a particular attention will be devoted to the study of instability phenomena in periodic composites and to the propagation of elastic waves in micro-architected materials.
Effective fracture properties of heterogeneous solids will be studied in view of applying 3D printing techniques to design materials with improved failure properties. Numerical methods used in this context will be also presented.
The course is addressed to master students, PhD students, postdocs and young researchers. It can be of interest also to engineers and professionals as it provides an insight into the tools at the basis of numerical methods largely used in practice.

Invited Lecturers:
Dorin Bucur (Le-Bourget-Du-Lac, France), Gianni Dal Maso (Trieste, Italy), Laura De Lorenzis (Braunschweig, Germany), Massimiliano Gei (Cardiff, UK), Laurent Ponson (Paris, France), Elisabetta Rocca (Pavia, Italy).

Coordinators: Giovanni Noselli (Trieste, Italy) and Rodica Toader (Udine, Italy).

Fluid Mechanics of Planets and Stars

April 19 - 23, 2021

Understanding the dynamics of planetary and stellar fluid layers - including the atmosphere of the Earth and other planets, iron cores, and stellar convective and radiative zones – remains a tremendous interdisciplinary challenge, relying on common knowledge in fundamental fluid mechanics. A few of the numerous open questions include:

• What are the basic physical mechanisms responsible for climate circulation, and how can they be parameterised to reliably predict global climate change?

• What are the prevalent force balances and physical mechanisms behind natural large-scale features such as Jupiter's Great Red Spot and bands?

• What are the relevant driving forces and flow regimes in conducting planetary cores for explaining the generation of large-scale magnetic fields by dynamo action?

• How are the various types of waves propagating in the stellar interiors generated, what influence do they have on stellar evolution, and how can they be used to probe interiors via asteroseismology?

Interdisciplinary research in geo- and astrophysical fluid dynamics is also intrinsically multi-method. Indeed, the main obstacle to quantitative modeling and understanding of planetary and stellar flows stands in the extreme character of the involved dimensionless parameters. Relevant studies thus rely on the principle of dynamical similitude and scaling laws, sustained by theory, experiments and numerical simulations.

Much research effort has been devoted to understanding planetary and stellar flows within the various communities of Mechanics, Applied Mathematics, Engineering, Physics, Planetary, Atmospheric and Earth Sciences, and Astrophysics. But progress has mostly been confined to each separate domain, with only marginal cross-fertilisation. The objective of this school is to go beyond this state, by providing participants with a global introduction and an up-to-date overview of all relevant studies, fully addressing the wide range of involved disciplines and methods.

The course will be organized in three parts. The first will focus on fundamental aspects of fluid mechanics in geo- and astrophysical flows, including introductory material as well as current cuttingedge research, with a focus on instabilities, turbulence, and waves. The second part will focus on concrete applications to topical geo- and astrophysical problems, with lectures focusing on planetary interiors, atmospheres, and stars. Finally, the third part will involve practical numerical sessions using the open-source solver Dedalus (http://dedalusproject.org). Participants will learn to set up and run numerical simulations on their laptops related to the research problems discussed in the lectures.

The targeted audience for this school is PhD students, postdocs, and young researchers, working in departments of Mechanics, Applied Mathematics, Engineering, Physics, Planetary, Atmospheric and Earth Sciences, and Astrophysics. A background in fluid dynamics will be assumed for each participant, but no specific knowledge in any of the application domains or in computational methods will be requested. Each participant will be given the opportunity to present her/his work during a flash talk presentation, followed by a poster session.

Invited Lecturers:
Isabelle Baraffe (Exeter, United Kingdom), Keaton J. Burns (Cambridge, MA, USA), Michael Le Bars (CNRS, Aix Marseille Universiteit, France), Daniel Lecoanet (Evanston, IL, USA), Juan Pedro Mellado (Barcelona, Spain), Jérõme André Roland Noir (Zurich, Switzerland).

Coordinators: M. Le Bars and M. Lecoanet.

Composite Manufacturing Processes: Analyses, Modelling and Simulations

April 26 - 30, 2021

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 fibrous reinforcements (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 K rger (Karlsruhe, Germany), Kyosev Yordan (Dresden, Germany), Stepan V. Lomov (Leuven, Belgium).

Coordinators: P. Boisse and L. Kärger.

Advanced Theories for Deformation, Damage and Failure in Material

May 3 - 7, 2021

Numerical simulations are becoming an indispensable tool in many applications involving processing, manufacturing, and performance of metallic and composite materials. The corresponding tools are based on a number of fundamental relationships that were extracted from mechanics (and underlying physics). These relationships are universal with respect to materials but they are not adequate to solve boundary value problems in which constitutive descriptions of deformation and failure are essential.
The constitutive descriptions must not only account for the physical mechanisms but also for the input data needed for identification of the material coefficients. Thus, to accomplish this, the relationship between the variables and their rates must comply with the materials response within the framework set by mechanics and thermodynamic principles. A purely numerical description, which relates the state of a material to a set of data, is likely to be empirical. It leads to unreliable extrapolation of states, which are not included in the database.
Other considerations on constitutive models are the scale of the material features needed, the size of the structure and the associated computation time. The scale is dictated by the smallest microstructural information needed to characterize a product e.g., the grain size, which then enters simulations at the meso-scale. It is possible to envision cases were details at a finer scale are necessary, for instance for the manufacturing of micro-devices. Even if the idea of defining the constitutive description from the atomic scale is

scientifically and philosophically very attractive, it is usually not practical.
The course will focus on descriptions of critical states for advanced metallic materials and composites. The approaches taken for this purpose can be categorized as follows: strongly based on Continuum Mechanics, incorporating knowledge of microstructure, and applying homogenization and other numerical approaches. The course will introduce the classical approaches and treat the new developments in a critical manner. Obviously, application of advanced materials rests on efficient and physically based constitutive relations.
The following specific topics will be covered: Plastic behavior at non-proportional loading incorporating the influence of relevant microstructural features, numerical simulation of metal forming of advanced high strength steels, termination of elastic range of pressure insensitive and sensitive materials, anisotropic vs. isotropic initial yield/failure criteria, structural components subjected to high temperatures, mechanical and thermal cyclic loads on the components under creep conditions, phase mixture model for simulating the mechanical behavior of tempered martensitic steels at high temperatures, but moderate mechanical loads, discretization methods for elasto-plastic solids, integration of plasticity models for finite loading steps, volumetric locking for fully developed plastic flow, mechanisms based modelling of failure in composite materials, basic aspects of fracture mechanics, and fracture and damage criteria.
The course is addressed to Master Course students of Mechanical and Civil Engineering as well as Computational Mechanics, PhD-students, young scientists, and research engineers.

Invited Lecturers:
Holm Altenbach (Magdeburg, Germany), Artur Ganczarski (Cracow, Poland), Frédéric Barlat (Pohang, South Korea), Ren de Borst (Sheffield, UK), Ramesh Talreja (College Station, TX, USA), Ewald Werner (Munich, Germany).

Coordinators: H. Altenbach and A. Ganczarski.

Physically Based Modelling of Superconductors and their Most Advanced Applications

May 24 - 28, 2021

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 highfield 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 Skoczeń (Cracow, Poland), Józef Spałek (Cracow, Poland), Stefan Russenschuck (Geneva, Szwitzerland).

Coordinator: B. Skoczen.

Data-Driven Mechanics: Constitutive Model-Free Approach

May 31 - June 4, 2021

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: M. Ortiz and L. Stainier.

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

June 7 - 11, 2021

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 introductory 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.

Physics of Granular Suspensions: Micro-Mechanics of Geophysical Flows

June 14 - 18, 2021

The course is an exploration of the recent theoretical, experimental and numerical advancements in the modelling of non-Brownian granular suspensions. The quest is mainly motivated by the growing scientific and engineering interest in geophysical flows as a consequence of the climate change and the severe impact of hydro-geological catastrophic events on socio-economic activities. Among geophysical phenomena, the course focuses on water-saturated sub-aerial and sub-aqueous debris flows, hyper-concentrated flows, underwater turbidity currents, creeping and fluid-like movements of soil in landslides as well as on the sediment transport in rivers and along lake and ocean shores, both at the bed and in suspension.
Indeed, the presence of a liquid, which saturates the interstices between grains, formidably expands the parameter space of granular flows, the mixture exhibiting behaviours typical of either viscous shear-thinning fluids or dense granular flows depending essentially on the average distance between solid particles (i.e. the particle concentration), the relative velocity of particles and the electro-chemo-mechanical properties of the mixture components. The scope of the course is the investigation of the purely hydraulic problem, thus the liquid is water while particles are in general coarse and inert (non-colloidal and non-adhesive) and, therefore, only their mechanical properties are considered. Nonetheless, a brief excursus on the rheology of more complex suspensions is also planned for the sake of completeness.
The opening of the course is devoted to highlight the striking differences between (dry) granular flows and granular suspensions. Granular suspensions are first classified on the basis of the relative velocity of particles, namely of the particle Reynolds number, into “viscous” and “inertial”, which determines the nature of dominant fluid-solid interactions. Then, “dilute”, “semi-dilute” and “dense viscous suspensions” are distinguished which differ in the number concentration of particles and, therefore, on the role of inter-particle contacts. The dynamics of the granular suspensions under different boundary/initial conditions as well as different driving forces are investigated and modelled highlighting the most recent advancements in the subject. Continuum and discrete approaches are considered. The continuum approach comprises a single-phase, also referred to as “single effective fluid”, or two-phases which indicates that the “theory of mixture” is adopted. As for the discrete approach, it necessarily requires the use of numerical methods to solve the fluid-particle-coupled continuity and momentum equations. The coupling and the inter-particle contacts can be obtained with a point-particle approach

or, for “large particles”, by fully resolving the flow field around the particles. The effects due to the presence of turbulent vortices, to the poly-dispersion of particle size and to the particle shape are also considered. Finally, models are described and applied to the aforementioned geophysical flows.

Invited Lecturers:
Pascale Aussillous (Marseille, France), Sivaramakrishnan Balachandar (Gainesville, FL, USA), Julien Chauchat (Grenoble, France), Claudio di Prisco (Milan, Italy), Laurent Lacaze (Toulouse, France), Marco Mazzuoli (Genoa, Italy).

Coordinators: M. Mazzuoli and L. Lacaze

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

June 21 - 25, 2021

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, UK), Raymond W. Ogden (Glasgow, UK).

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

Exploiting the Use of Strong Nonlinearity in Dynamics and Acoustics

CISM-AIMETA Advanced School

June 28 - July 2, 2021

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 Gendelman (Haifa, Israel), Gaetan Kerschen (Liege, Belgium), Malte Krack (Stuttgart, Germany), Giuseppe Rega (Rome, Italy), Alexander Vakakis (Urbana, IL, USA), Fabrizio Vestroni (Rome, Italy).

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

Life in Flows

July 5 - 9, 2021

Whether in ocean or in air, biological organisms interact with a surrounding fluid, these interactions being often critical for their survival. How do these organisms sense surrounding flows? How do they react to this sensing information? And what are the forces applied from the flows to the organisms? Today, many of these fluid-structure interaction problems are not fully understood and a lot of research effort is devoted to unravel the complex mechanisms at play.
At the smallest scale are bacteria. Although they are the world’s smallest cells, they represent the bulk of the world’s biomass. Most bacteria are motile and swim with flagella, which consist of slender helical appendages rotated by specialized motors. We will provide an overview of the motility system for bacteria, of the coupling between

internal chemical osmotic state and sensory transduction at the molecular level, and the behaviour of cells in flows.

At a larger scale, we will look at plankton. The three main missions of any organism (growing, reproducing, and surviving) depend on encounters with food and mates, and on avoiding encounters with predators. Through natural selection, the behaviour and ecology of plankton organisms have evolved to optimize these tasks. We will offer a mechanistic approach to the study of ocean ecology by exploring biological interactions in plankton at the individual level.

We will then address insect flight. Starting from the Navier-Stokes equations governing the unsteady aerodynamics of flapping flight, we will build a theoretical framework to understand flight mechanics. This will lead to new interpretations and predictions of the functions of an insect's internal machinery that orchestrate its flight.

We will also address the mechanics, energetics and control of fish swimming. Fish routinely encounter unsteady flows in nature, such as when schooling or swimming behind a rock in a stream. We will show how fish can sense the flow through their lateral line and how they can extract energy from their environment.

At the largest scale, we will examine collective animal motion, a ubiquitous behaviour that can be found in insect swarms, starling murmurations, fish schools or even crowd phenomena. We will explain how large-scale order can emerge from local interactions, without any leader. We will also discuss the importance of the fluid interactions and how a group can react to a predatory attack.

Finally, we will examine the algorithms used by organisms to search the source of an odour in a flow. These algorithms can be very dependent on the size of the organism and on the sensing information at its disposal. On small scales, bacteria use biased random walk to swim up the gradients of concentration, but on larger scales, gradients are not a relevant information anymore. Moths and large crustaceans generally use different algorithms combining "zigzagging" and "casting" behaviours.

Since the objective of this school is to introduce the topic of "Life in Flows", particular attention will be paid to biological concepts. We will also allocate time for attendees to present their own research via short talks. The targeted audience for this school will be PhD students, postdoctoral, and young researchers in departments of Physics, Biophysics, Applied Mathematics and Engineering.

Invited Lecturers:
Howard C. Berg (Harvard, USA), Christophe Eloy (Marseille, France), Charlotte K. Hemelrijk (Groningen, The Netherlands), Thomas Kiørboe (Lyngby, Denmark), James C. Liao (Gainesville, FL, USA), Z. Jane Wang (Ithaca, NY, USA).

Coordinators: C. Eloy and E. Lauga.

Metamaterial in Acoustics, Elastodynamics and Electromagnetism

July 12 - 16, 2021

A revolution is currently taking place in physics and engineering through the manufacture of metamaterials and metasurfaces with the aim of achieving full control of waves. This was made possible by conceiving and designing new materials whose macroscopic behavior results from a specific structure, often periodic, at the microscopic scale. Typical examples are the band-gap materials and the double negativity metamaterials which are based on the local resonance (of the Mie, Minnaert or Helmholtz's type) of a subwavelength building block repeated periodically. These materials have found numerous practical applications among which cloaking, lensing, super-resolution, quantitative imaging in the near field, shielding, perfect absorption.

In acoustics, a well known example is inspired by the pots used in the ancient greek theaters and later on in churches and mosques to control the acoustic of the places; these pots are Helmholt'z resonators and they are thought nowadays as the key to soundproof wall design.

More recent examples are related to the shielding of regions from waves tanks to recent advances in the design of metamaterial based devices. This is the case of the so-called anti-seismic wedge formed by a forest of trees able to convert the destructive surface waves into mainly harmless downward propagating bulk waves. Another striking example is the design of gigantic « wave breakers » to surround and protect a region from swell and stormy waves. The efficiency of such belts becomes a vital prerequisite to viable and sustainable floating cities which are sought in the foreseeable future.

The purpose of this course is to provide an introduction to well known techniques and to introduce more advanced, state-of-the-art techniques, able to tackle the challenges of the metamaterials by providing a mathematical framework able to explain the observed extraordinary properties of meta-structures and useful to help optimize these properties. These include transformation optics/ transformation elastodynamics, classical and modern homo-genization methodologies, asymptotic and spectral analysis, variational methods, layer potential techniques, as well as modern multi-mathematics. Particular attention will be paid to present practical applications that illustrate the workings and effectiveness of the introduced techniques and discussions on the breakthroughs and the remaining open questions on topical issues in acoustics, electromagnetism, elasticity and in the context of water waves. Bearing these objectives in mind, academic experimental studies as well as commercial devices will be presented during the course. Overall this is a joint effort from a diverse group of lecturers working on different aspects of metamaterial modelling, to report the current state-of-the-art in the field and form a collaborative network and shared knowledge platform in an area where there is still considerable room for research.

The course is addressed to a broad public: graduate students, doctoral students, young researchers and practicing engineers. Since a major part of the course will be devoted to theoretical and numerical modelling, a sound mathematical basis is expected and basic knowledge of wave theory is recommended.

The topics explore the applications in Engineering and Physics, showing the

interconnections with acoustics, electromagnetism, elasticity, water waves that are normally treated as independent topics.
Both theoreticians and experimentalists from the academic and industrial sectors are expected to gain useful knowledge from attending the course.

Invited Lecturers:
Habib Ammari (Zürich, Szwitzerland), Sebastien Guenneau (London, UK), Agnès Maurel (Paris, France), Kim Pham (Paris, France), Sanghyeon Yu (Seoul, South Korea), Hai Zhang (Hong Kong).

Coordinators: H. Ammari and A. Maurel.

Materials and Electro-Mechanical and Biomedical Devices Based on Nanofibers

July 19 - 23, 2021

Recently, there has been a strong interest in the development of new micro- and nano-materials, 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.

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.

The Masanobu Shinozuka Session

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

August 30 - September 3, 2021

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.

Bone Cell and Tissue Mechanics

September 6 - 10, 2021

Bone is a remarkable material: it is strong yet lightweight, can adapt itself to changes in mechanical loading, lasts for a lifetime and can repair itself after a fracture. Although biology has revealed many secrets of how bone cells can form and remove bone tissue, the mechanisms that control these processes, and the role of mechanical loading in this, are still not well understood. The goal of this course is to provide state-of-the-art information on this topic. To do so, the course will review the entire area of bone cell and tissue mechanics at all three commonly distinguished levels of structural organization of bone: the bone organ level, the bone tissue level and the bone cell level. The course will be of a multi-disciplinary nature and include topics like bone biology, imaging and computational modeling.
At the bone organ level, the focus will be on the diagnosis of bone strength using imaging and computational techniques. Bone remodeling at this level is often considered as an optimization process that adapts bone density and shape to the mechanical loading conditions.

Hypothetical models that are developed to describe such adaptations of bone are discussed. At the tissue level, bone can form remarkable complex porous architectures. This capability enables bone to adapt to a wide range of mechanical conditions, is resembled by its hierarchical organization and reflected by a wide spectrum of material properties bone can take on. Methods to visualize and model the complex structures of this living mineral tissue in 3D in-vivo have become available only over the last two decades. Hypothetical models describing how these structures evolve, how they can adapt to mechanical loading and how they can be affected by bone diseases are discussed.

At the level of the cell, promising candidates for the mechanosensory system will be discussed, as well as possible signaling pathways for the communication between bone cells. At this level, the porosity of the bone tissue itself also becomes an important factor since it is assumed that fluid flow plays an important role in the mechanosensory system. Recently developed techniques for visualizing such small structures, as well as techniques for stimulating and manipulating cells, such as microfluidics devices for bone cell mechanobiology studies, 3D printing of bone stimulating implants, and tissue engineering of bone to create humanized 3D models are discussed.

Besides being informative, it is hoped that the course will function as a forum for the exchange of data, philosophy, and ideas across disciplinary divides and so provide further stimulus for a comprehensive approach to the problems of bone mechanics. To further facilitate this, we will organize a student poster-pitch presentation at the end of the first day. Also, there will be a question and answers session at the end of all other days where student can ask questions to the teachers, and where the teachers will stimulate discussions. The target audience are graduate students, PhD candidates and young faculty members. We expect an audience as diverse in background as the lecturers, that is to say spanning across the professional spectrum from biomedical and structural engineers, to biologists, veterinarians and orthopaedic and dental surgeons.

Invited Lecturers:
Georg Duda (Berlin, Germany), Peter Fratzl (Potsdam, Germany), Jenneke Klein Nulend (Amsterdam, The Netherlands), Ralph Müller (Zürich, Switzerland), Gwendolen Reilly (Sheffield, UK), Bert van Rietbergen (Eindhoven, The Netherlands).

Coordinator: B. van Rietbergen.

Batteries - Basic Principles, Experimental Investigations and Modeling Across Scales

September 20 - 24, 2021

Batteries are considered to be a key technology in a future energy and mobility system based on renewable and fluctuating energy sources. Depending on the application, the specifications for energy density, power density, safety and lifetime of batteries can vary considerably. Therefore, the need for optimization tools to balance application specific conflicting constraints on batteries is obvious. In addition, the demand for rapid developments of new energy storage materials and battery designs requires the transi-

tion to a rational, knowledge- based battery development strategy based on validated models and sophisticated simulation tools.
The challenge is to describe mathematically all electrochemical, physical and mechanical processes necessary for an efficient and safe operation of batteries, which, for such highly complex electrochemical storage devices means to model and couple processes on a large range of scales.
The course will cover theoretical methods as well as experimental insights on these different scales. Atomistic theories allow investigating thermodynamic and electrochemical stability of materials and combination of materials. They provide fundamental electrode material parameters and transport mechanisms and give insights in the reaction kinetics of chemical reactions. A very crucial factor for stability and power density of batteries is the choice of the electrolyte. Finding the right compromise between electrochemical stability, excellent transport properties and forming interfaces which support the reaction kinetics at positive and negative electrodes is a challenging task. The method of choice to investigate the behavior of electrolytes is molecular dynamics simulation (MD), either ab initio MD or classical MD with fine-tuned force fields for the electrolyte under investigation. For optimizing the structural design of the electrodes and the cell design from nanometer to cm scale continuum theories are necessary to describe the complex interplay of transport, reactions and mechanical processes during operation of the battery. To allow for a systematic coupling of continuum theories and underlying atomistic theories it is important to derive continuum models within rigorous theoretical concepts.
The course will give an introduction in state-of-the-art continuum modeling and simulation techniques for electrochemical as well as mechanical processes on electrode and device scale.
This part will be complemented by an overview over experimental techniques for investigating battery behavior and validating continuum theories of batteries. On the largest scale, the system scale, simulation tools are required which maintain the essential features of the underlying detailed models but are systematically simplified to allow for a real time control of the battery operation in order to guarantee safety and preserve lifetime of the battery. The description of the art of model reduction and real time simulations of battery responses on system requests rounds up this CISM course.
The course aims at doctoral students as well as (junior) researcher, from different backgrounds, both from academia and industry. In the afternoon of the first day, a poster/slide flash will be held to give participants the opportunity to briefly present their interest or working area. This will enable fostering a collegial discussion during the course..

Invited Lecturers:
Oleg Borodin (Adelphi, MD, USA), David A. Howey (Oxford, UK), Jürgen Janek (Gieen, Germany), Arnulf Latz (Ulm, Germany), Yue Qi (East Lansing, MI, USA), Wolfgang A. Wall (Munich, Germany).

Coordinators: A. Latz and W. A. Wall.

Computational Mechanics for Novel Designs of Advanced Materials
CISM-ECCOMAS Advanced School

October 4 - 8, 2021

Recent technological advancements open up possibilities of optimizing the functional behavior of structures in engineering applications by adding a stage of design at the material scale. For instance, additive manufacturing enables a superior control in the shaping and patterning of material constituents. This modern rationale poses the question of developing:
1) novel paradigms for material micro/nanostructure,
2) novel methods for the optimization of material topology,
3) novel manufacturing techniques.

The combination of multiple and contrasting materials, with differences in elastic and inelastic responses, is a challenging strategy that could lead to new classes of smart behaviors. For instance, this approach is followed by Nature, where biological tissues are hierarchically optimized by means of chemo-biological mechanisms. Hence, the significance and the need of novel material design approaches has been highly increasing in recent years.

Computer-assisted techniques allow to speed-up and reduce the costs of optimization procedures for material topology and constituents' properties. The predictive capabilities of numerical simulations are highly affected by the accuracy and robustness of constitutive models and how effectively constitutive formulations are translated into computational environments. Therefore, the development of advanced computational approaches for the analysis and the modelling of material responses arises as an emergent and urgent topic.

The workflow for the design of advanced materials is associated with major issues which involve several aspects at the cutting edge of Computational Mechanics. From the engineering point of view, the optimization of computer-assisted techniques is crucial and it is based on the delicate balance between accuracy, robustness and cost. To reach this goal, a solid understanding of methodological aspects and a wide knowledge of available approaches are essential.

The aim of the course is to present theoretical fundamentals, the current state-of-the art, and future directions of "computational approaches for the analysis of the mechanics of materials" with the aim of "providing a modern perspective on in silico tools for the design of advanced materials". The homogenization problem will be faced coupling multiscale and multiphysical analyses. Advanced computational approaches will be presented, highlighting advantages and disadvantages of traditional and novel techniques in different case studies. Materials for modern engineering demands will be focused, spanning from metamaterials, through smart hydrogels and magneto-mechanically coupled composites to MEMS. The described theoretical and methodological approaches will allow to discuss aspects of key importance through the entire material production process: starting at the design stage, through topology optimization, *up to* material manufacturing.

The course will appeal to doctoral students and postdoctoral researchers from academia and industry with an interest in the constitutive modeling of multiphysical and/or multiscale response of materials, and with a background in engineering or in material sciences.

Invited Lecturers:
Marc Geers (Eindhoven, The Netherlands), Michele Marino (Hannover, Germany), Jörg Schröder (Essen, Germany), Ole Sigmund (Lyngby, Denmark), Stanislaw Stupkiewicz (Warsaw, Poland), Peter Wriggers (Hannover, Germany).

Coordinators: M. Marino and J. Schröder.

Transport Phenomena on Textured Surfaces: Fundamentals and Applications

October 11 - 15, 2021

In the past two decades numerous laboratories have microfabricated surfaces with the chemical and textural properties to mimic superhydrophobic surfaces (SHs) found in nature, the most well-known being the self-cleaning properties of the lotus leaf. This has been made possible by the continuing advances in nano/micro fabrication technology. This Advanced School will bring together engineers, physicists, chemists and applied mathematicians in a multi-physics framework.
Adopting a holistic approach coupling momentum, heat, mass and charge transport phenomena the lecturers comprise 2 applied mathematicians, 2 mechanical engineers, a physicist and a chemist: together they bring theoretical and experimental perspectives to the topic.
The fundamentals of the physical and chemical phenomena exploited to suspend liquids in the Cassie (unwetted) state on SHs will be covered. We address the conditions required, and technologies developed, to maintain the Cassie state and those which cause transition to the (sometimes desirable) Wenzel (wetted) state. Transport phenomena physics related to droplets on SHs and flows of liquids over them will be emphasized.
For droplets on SHs, the fundamental microfabrication principles including those based on polymer processing technology will be surveyed. Ice prevention and enhancing boiling and condensation heat transfer will be points of emphasis, as will electrowettability-based dynamic control and enhancement of general phase change phenomena. Various approaches to suppress or exploit Leidenfrost phenomena to, e.g., suppress critical heat flux or pump droplets, will be studied. SHs with multifunctional properties such as photo-catalytic activity, anti-reflectivity, abrasion resistance and antisoiling characteristics will be treated.
In studying external/internal flows over SHs, the course will include a rigorous derivation of the governing equations and boundary conditions, resolution of surfactant, Marangoni, thermocapillary and molecular phenomena and possible meniscus deformations. Comparison of theoretical models to experiments will be made with implications for key engineering parameters.

The course is suitable for graduate students, academics, engineers in industry. The techniques used will span mathematical modelling ideas and numerical schemes, through to experimental procedures and understanding the fundamental physical principles. Applications will be emphasised throughout.

Invited Lecturers:
Vaibhav Bahadur (Austin, TX, USA), Darren Crowdy (London, UK), Marc Hodes (Medford, MA, USA), Alan Lyons (New York, NY, USA), Demetrios Papageorgiou (London, UK), David Quéré (Paris, France).

Coordinators: D. Crowdy and M. Hodes.

Metal Additive Manufacturing:
Fundamentals, Modeling, Materials, and Implementation

October 18 - 22, 2021

Additive manufacturing (AM) of metals offers highest production flexibility, almost unlimited freedom of design and the potential for pointwise control of microstructure and mechanical properties. However, a sub-optimal choice of process parameters often leads to high residual stresses, dimensional warping, porosity, undesirable microstructures or even failure of the part during production. The main objective of this course is to convey the physical fundamentals of metal AM processes, the basics of process implementation and monitoring, material aspects as well as modeling and simulation techniques on different length scales.
The course begins with an overview of existing metal AM processes comprising powder bed fusion additive manufacturing (PBFAM), e.g. selective laser melting (SLM), selective laser sintering (SLS), electron beam melting (EBM), directed energy deposition (DED), binder jetting (BJ), and material droplet printing (MDP). After conveying the physical fundamentals, potential fields of application and the technical implementation, means of monitoring and process control are presented. Different types of defects in metal AM are categorized and strategies for defect detection via in-situ and ex-situ metrology (e.g. X-Ray computer tomography CT, density inspection, geometry control) are discussed. Moreover, the course will convey essential material aspects such as the principles, mechanisms and kinetics of solidification as well as the fundamentals of equilibrium and non-equilibrium thermodynamics. Phase formation and microstructure control, alloy design, powder metallurgy and process-microstructure-property correlations will be discussed in the context of metal AM and compared to conventional casting. A further focus of the course lies on modelling and simulation approaches in metal AM, covering the underlying modelling assumptions, governing equations, discretization strategies as well as numerical aspects (e.g. balance of computational efficiency and solution accuracy). Specifically, modelling strategies for the mechanics, radiation transfer, heat transfer and sintering kinetics in powder beds are discussed. Moreover, mesoscale thermo-hydrodynamics modelling and simulation approaches aiming at the

prediction of melt flow instabilities and final part properties such as surface roughness, layer-to-layer adhesion and residual porosity are conveyed. Eventually, part-scale thermo-solid-mechanics modelling and simulation approaches aiming at the prediction of residual stresses, thermal strains, constitutive behavior and dimensional warping at the length scale of entire design parts are presented.
Each set of lectures will start from the respective basics but will then quickly move on to cutting-edge research topics. The lectures are primarily designed for doctoral students of mechanics, engineering, material sciences and physics with a strong interest in the different research aspects of metal AM. However, they are equally suited for young and senior researchers, who would like to gain a comprehensive overview in an efficient compact course format. It might also be interesting for practicing engineers working on high-level industrial applications of metal AM.

Invited Lecturers:
Bianca Maria Colosimo (Milan, Italy), Jürgen Eckert (Leoben, Austria), Andrey Gusarov (Moscow, Russia), A. John Hart (Cambridge, MA, USA), Neil Hodge (Livermore, CA, USA), Christoph Meier (Munich, Germany).

Coordinators: C. Meier and A. J. Hart.

International Advanced Professional Training

Mechanics, Tribology in Manufacturing Processes

May 10 - 14, 2021

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 micromechanisms 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:
Niels Bay (Lyngby, Denmark), Leonardo De Chiffre (Lyngby, Denmark), Laurent Dubar (Budapest, Hungary), Pierre Montmitonnet (Sophia Antipolis, France), Jean-Philippe Ponthot (Liège, Belgium), Jose V. Lemos (Lisboa, Portugal).

Coordinators: N. Bay and P. Montmitonnet

Discrete Computational Mechanics of Masonry Structures

July 26 - 30, 2021

Masonry structures – collections of individual solid blocks with dry or mortared contacts – appear everywhere around us, from architectural heritage through historic or contemporary civilian buildings to traffic infrastructure. The assessment of their structural integrity poses serious challenges: due to their discrete built-up, usual continuum-based calculation methods are often incapable to reflect the mechanical behavior. In cases when the failure is caused by some kind of a local effect (cracks opening up between voussoirs, individual blocks sliding out etc.) the mechanics of the problem may better be captured by methods that consider the structure as a collection of discrete bodies.

Such methods are available in a wide variety today. The aim of the course is to give a detailed introduction to their theoretical fundaments, advantages and preferable fields of application, but also calling the attention to their limitations and disadvantages so that the participants of the course would build up a critical view of the choices they have when attacking a masonry mechanics problem. An explicit aim of the course is to give a sound basis for the participants to become able to develop their own methods, inspired either by classical graphical statics, or by any modern technique they find promising.

The course will focus on four main topics:

1) Computerized graphical statics methods

Graphical statics seemed to lose practical importance in the 2nd half of the XXth century when continuum-based numerical techniques and Limit State Analysis methods became widely applied in computerized manners. However, the recent decades brought a renaissance to the application of graphical statics in masonry analysis: powerful computer codes have been developed part of which are commercially available and part of which can be found as research tools.

2) Discrete element methods

DEM was born at the end of the 1960ies as an alternative to FEM. DEM considers the simulated material or structure not as a continuum but as a collection of separate bodies being able to detach, slide, partly or completely separate, and form new contacts when large displacements may lead to the rearrangement of contact topology. Possibilities to partial cracking and sliding makes DEM particularly advantageous for masonry failure problems.

3) Blocky models

The main drawback of DEM is that the analysis of whether new contacts are born in the system, simulations can be very computationally expensive. To avoid this, different blocky models have been suggested recently for problems when rearrangements of the topology are not expected, but the discrete built-up of the system is relevant (e.g. formation of partial cracks). These novel methods are considered as being in-between FEM and DEM.

4) Discrete dynamics

Masonry structures are sensitive to earthquakes: seismic analysis is a crucial issue in masonry mechanics. Damping and contact sliding are significant in their energy

dissipation and in the ability to adjust to ground displacements. Hence, special lectures will be devoted to the dynamics of masonry structures. In particular, lectures will focus on damping and large displacement dynamics which characterize the dynamic collapse of masonry structures.
Targeted audience: young researchers (including PhD students); engineers interested in high-level computational tools for masonry analysis.

Invited Lecturers:
Danila Aita (Pisa, Italy), Maurizio Angelillo (Salerno, Italy), Katalin Bagi (Budapest, Hungary), Philippe Block (Zurich, Switzerland), Matthew DeJong (Berkeley, CA, USA), Jose V. Lemos (Lisboa, Portugal).

Coordinators: K. Bagi and M. Angelillo.

National Advanced Professional Training

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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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