

# Colloquium Final Report

## N. 633 – Nonlinear Metamaterials and Smart Structures

Dates and location: 27/05/2024 - 29/05/2024, Lyon, France

Chairperson **Alireza TURE SAVADKOOHI** (Université de Lyon, ENTPE, LTDS  
UMR CNRS 5513)

Co-Chairperson **Daniele ZULLI** (University of L'Aquila), **Jaroslav LATALSKI**  
(Lublin University of Technology)

### Conference fees

- Regular registration **500.0 €**
- Student registration **350.0 €**
- Late registration regular **550.0 €**
- Late student registration **400.0 €**

What other funding was obtained? - **Le Centre Lyonnais d'Acoustique (Labex CeLyA) of the Université de Lyon (2000 €) - Lublin University of Technology (2000 €)**

What were the participants offered? - **The book of abstracts**

- **Four coffee breaks**

- **Three lunches**

- **Visit to "Basilique Notre-Dame de Fourvière"**

- **Gala dinner at the Bulle-Restaurant de Fourvière**

Number of members of Euromech (reduced registration fee) **29**

Number of non-members of Euromech (full registration fee) **17**

### Applicants (members)

- Sébastien Baguet
- Davide Bigoni
- Simon Chesné
- Camila da Silveira Zanin
- Jean-François Deü
- Issam Doghri
- Jean Flosi
- Emmanuel Gourdon
- Mélissandre Huguet

---

#### PRESIDENT

Professor Marc Geers  
m.g.d.geers@tue.nl

---

#### VICE PRESIDENT

Professor GertJan van Heijst  
g.j.f.v.heijst@tue.nl

---

#### SECRETARY GENERAL

Professor Jacques Magnaudet  
jacques.magnaudet@imft.fr

---

#### MANAGEMENT ADVISOR

Sara Guttilla  
sara.guttilla@euromech.org

---

#### TREASURER

Stefanie Reese  
euromech@ifam.rwth-aachen.de

- Dotan Ilssar
- Guillaume James
- Nikolaos Karathanasopoulos
- Varvara Kouznetsova
- Ivana Kovacic
- Siddhant Kumar
- Aurélie Labetoulle
- Claude-Henri Lamarque
- Jarosław Latałski
- Sylvain Meille
- Louis Mesny
- Andrzej Mitura
- Maxime Morell
- Pedro Ribeiro
- Ondrej Rokos
- emanuele sarpero
- Alireza Ture Savadkoohi
- Jerzy Warminski
- Jan Zeman
- Daniele Zulli

## **Applicants (non members)**

- Arthur Barbosa
- Paolo Biscari
- Jean-Fabien Capsal
- Sébastien Cuff
- Andrea De Flaviis
- Andrei Faragau
- Giovanni Iarriccio
- Mohammad Iqbal
- Jovana Jovanova
- Hasnaa Kibach
- Matthieu Leroux
- Colin Lesenne
- Bruno Lombard
- Léo Pradier
- Mohammad Shojaee
- Sarah Souheil Gebai
- Zhan Zhelev

## **Scientific Report**

Metamaterials and advanced composites are modern materials engineered to benefit from mono- or multi-physics interactions. Typically they are designed to obtain novel functionalities or non-classical extraordinary structural properties that are not observed naturally, both in micro and macro scale behaviors. The customized unique features may comprise zero or negative mechanical properties such as Poisson's ratio, rigidity, mass, shear modulus etc., or extreme values of electrical parameters like effective permittivity and permeability.

All these factors can contribute to e.g. response bandgaps, where the system halts to respond or responds in a controlled manner against external excitation, or to induced strains and energy localizations in structures. The design requirements can be even extended to developing metamaterials with time-dependent and adaptive coefficients.

The core topic of this colloquium was “designing and exploiting induced adaptive or constant nonlinearities” in metamaterials and composite structures for improving their behaviors beyond the classical linear domains. The goal is to achieve desired responses such as shock/strain/noise mitigations, resonance shifting, energy localization and/or focalization phenomena. Some specific examples of such materials are pure mechanical metamaterials, piezo-based systems, shape memory alloys, electroactive polymers and magnetoactive/magnetorheological elastomers.

The colloquium intended to cover a large range of developments expanding from pure analytical and numerical studies to experimental results. Engineering applications comprise a wide spectra of mechanical, electromechanical, vibro-acoustical, pure acoustical and optical systems focusing on control of low to high frequencies modes for noise and vibration isolations and localisation of energies.

The colloquium sessions were focused on:

Architected mechanical metamaterials: Exploitation of nonlinearities in elastic and/or inelastic domains in microscale for creation of extraordinary responses in macroscale.

Smart materials/composites: Designing/programming nonlinearities for multiple state shock and vibration/wave control, sensing or for creation of intelligent inter-modal energy exchanges.

Computational mechanics for design of nonlinear metamaterials and composites: topology optimisation, model-driven and data-driven techniques, homogenisation, etc.

Studying and analyses of nonlinear waves in nonlinear metamaterials and composites via analytical and numerical tools such as bifurcation theory, multiple scale method, etc.

The colloquium hosted three keynotes from three different European countries:

- Prof. Davide Bigoni, University of Trento, Italy. Title of talk: Designing solids from structures.

- Prof. Varvara Kouznetsova, Eindhoven University of Technology, The Netherlands. Title of talk: Subharmonic energy exchange in non-linear locally resonant metamaterials.

- Prof. Pedro Ribeiro, University of Porto, Portugal. Title of talk: Using curvilinear fibres to enhance the dynamic response of composite panels.

The colloquium covered in total six sessions. The scientific programme of the event for each day was as it follows:

Day 1: 27 May 2024:

Session 1 chaired by Prof. Jean Francois Deü with the following presentations:

- Design and properties of metastructures for vibration isolation purposes  
I. Kovacic, Z. Kanovic, V. Rajs, L. Teofanov

- Prestressed nonlinear resonant auxetic metamaterial for dynamic isolation  
M. Collet, A. Pyskir, Z. Dimitrijevic, C.-H. Lamarque

-Modular-topology optimization of compliant structures and mechanisms

J. Zeman

- Unifying the design space of metamaterials by deep generative modeling

S. Kumar

- Configuration dependent properties of straw-based truss metamaterials

D. Ilssar, D. M. Kochmann

- Composite metamaterials for aerospace structures

G. Iarriccio, M. Molaie, A. Zippo, V. Cannillo, F. Pellicano

Session 2 chaired by Prof. Pedro Ribeiro with the following presentations:

- Nonlinear dynamics of an active shallow arch

J. Latałski, J. Dubicka-Nowak

- Multiscale modeling of metamaterial beams using a micromorphic beam theory

M. Shojaee, O. Weeger

- Real-time adaptation of a hybrid nonlinear energy sink: simulation and experimental validation

L. Mesny, R. Alcorta, S. Chesné, S. Baguet

- Digitally programmed nonlinear electroacoustic resonators

E. Gourdon, M. Morell, E. De Bono, M. Collet, A. Ture Savadkoohi, C.-H. Lamarque

Session 3 chaired by Prof. Varvara Kouznetsova with the following presentations:

- Traveling localized waves in granular metamaterials

G. James (The assumed presenter registered but was not able to attend due to health problem).

- Effective dynamics for low-amplitude transient elastic waves in a 1D periodic array of non-linear interfaces

C. Bellis, B. Lombard, M. Touboul, R. Assier

- Nonlinear metastructure design for energy localization: a solitonic approach

A. Barbosa, N. Kacem, N. Bouhaddi

- Analysis of the response of damped and parametrically driven, strongly anharmonic Klein-Gordon chains

Y. Starosvetsky (The assumed presenter sent his abstract but he was not able to attend the colloquium).

Day 2: 28 May 2024

Session 4 chaired by Prof. Ivana Kovacic with the following presentations:

- Nonlinear vibrations of a multistable piezoelectric shell

J. Warminski, L. Kloda, D. Melnyk, A. Mitura, J. Latałski

- Nonlinear vibration modeling and analysis of thin structures with piezoelectric transducers for sensing, actuation, and passive shunt damping

J.-F. Deü

- Noise and vibration suppression in vibratory pile driving using locally resonant metamaterials

A.B. Faragau, A. Tsetas, A.V. Metrikine, A. Tsouvalas

- A beam-like model for the buckling and post-buckling analysis of a thin pipe

A. Casalotti, M. Ferretti, A. Luongo, D. Zulli

-Magnetically controlled microstructural buckling of mechanical metamaterials

T. Feehilly, R. H.J. Peerlings, M. G.D. Geers, O. Rokoš

- Toward digitally programmed meta-systems with enforced nonlinear responses: an example in electro-acoustics

E. De Bono, M. Morell, M. Collet, E. Gourdon, A. Ture Savadkoohi, C.-H. Lamarque

Session 5 chaired by Prof. Jan Zeman with the following presentations:

- Unified elasto-plasticity theory for crystalline hyperelastic solids

P. Biscari

- Metastructures designed for impact loading

J. Jovanova

- Strain-rate dynamic performance of architected polymer-based composite materials: experimental, numerical and machine learning insights

N. Karathanasopoulos, A. Singh, O. Al-Ketan

- Metamaterial mandibular implants for reduced stress shielding and bone resorption

H.C.V.M.S. Veluvali, J.-I. Heins, J. Kraeima, M. Witjes, N. Grigor, P.R. Onck, A.O. Krushynska

Day 3: 29 May 2029

Session 6 chaired by Prof. Jerzy Warminski with the following presentations:

- Multiscale modeling of polymer solids and structures additively manufactured with selective laser sintering

I. Doghri, M. Haddad, D.A. Hun

- Fabrication and properties of non-linear multi-materials

G. Baeza, J. Chevalier, S. Meille

- Energy recovery from bistable shell vibrations using MFC patch

A. Mitura, J. Warminski

- Fully printable plasticized fluorinated terpolymers for active mirror morphing control

C. Lesenne, D. Audigier, P.-J. Cottinet, M. Q. Le Cottinet, J.-F. Capsal

- Programmable multilevel nanophotonics with phase-change materials

F. Bentata, C. Laprais, L. Berguiga, N. Baboux, P. Genevet, G. Saint-Girons, X. Letartre, S. Cuff

The organizers of this colloquium would like to address their special thanks to:

1- EUROMECH

- Officers: Prof. M. Geers, Prof. G. Jan Van Heijst, Prof. J. Magnaudet, Prof. S. Reese
- The management Advisor: Dr. S. Guttilla

2- Organizing institutes:

- ENTPE-LTDS (France)
- University of L'Aquila (Italy)
- Lublin University of Technology (Poland)

3- Labex CeLyA and Institut Carnot Ingénierie@Lyon

4- INSAVALOR:

- M. Personne, P. Jorio

5- The support team (our PhD students):

- M. Huguet, A. De Flaviis, H. Kibach, A. Labetoulle, M. Morell, E. Sarpero

## Number of participants from each country

<b>COUNTRY</b>	<b>PARTICIPANTS</b>
United Arab Emirates	1
Netherlands	5
Bulgaria	1
Germany	1
Poland	3
France	26
Switzerland	1
Italy	4
Serbia	1
Portugal	1
Czech Republic	1
Belgium	1
<b>TOTAL</b>	<b>46</b>

Please send this report in electronic form to the Secretary General of EUROMECH, within one month after your Colloquium.