Promotion IUF 2016
Rapport d'activité (2016-2021)

NOM : MADEO
PRÉNOM : Angela
DATE DE NAISSANCE : 22/08/1981
GRADE : Professeur des Universités
DISCIPLINE PRINCIPALE : Mécanique/Génie Civil
CNU : 60
UNIVERSITÉ OU ÉTABLISSEMENT D'APPARTENANCE : INSA-Lyon
UNITÉ DE RECHERCHE D'APPARTENANCE : GEOMAS

CATÉGORIE : JUNIOR

THÉMATIQUE DE RECHERCHE : MILIEUX CONTINUS ENRICHIS ET MÉTAMATÉRIAUX

RÉSUME SCIENTIFIQUE À PROPOS DE LA RÉALISATION DU PROJET DE RECHERCHE IUF (2 pages maximum) :

Engineering metamaterials showing unorthodox behaviors with respect to wave propagation are recently attracting attention for their innumerable astonishing applications. In this project, we have been particularly interested in those metamaterials that can inhibit wave propagation in particular frequency ranges which are known as "frequency band-gaps".

To the authors' knowledge, a systematic treatment of band-gap modeling based on the spirit of Enriched Continuum Mechanics is still lacking and deserves attention. The idea of using enriched continuum theories to describe microstructured materials needs to be fully developed in order to achieve a simplified modeling and more effective conception of large-scale engineering "metastructures" made up of metamaterials as building blocks. This will allow for the design of real, large-scale engineering structures which are able to resist to vibrations and shocks.

Theoretical models accounting for any single element of such metastructures rapidly show their limits both in terms of complexity and computational performances. We developed and used a new enriched continuum model, called "Relaxed Micromorphic", allowing to describe the behavior of metastructures in the simplified framework of continuum mechanics.

Enriched numerical simulations have been conceived and performed consisting of both classical simulations (Bloch-Floquet analysis) and novel enriched simulations based on the new relaxed micromorphic model. The comparison of the results of these discrete versus enriched-continuum simulations enabled the calibration of the relaxed micromorphic parameters by inverse approach.

The numerical results have also been compared to experimental tests realized on metamaterials which have been produced by additive manufacturing. The dynamic experiments allowed us to determine the metamaterial's band-gap properties and to provide a further validation of the new model.

This project has gone beyond the traditional microscopically-based approaches by using enriched continuum models for the description of band-gap metamaterials with the introduction of only few (frequency- and scale-independent) homogenized parameters additionally to the classical shear and bulk moduli. The project also established a closed loop of theoretical, numerical and experimental investigations, cross-comparing results and achievements thus obtaining a comprehensive procedure for validating and assessing the developed solutions towards full scale experimental testing. As such, the project ultimately delivered not only high-quality scientific fundamental research in terms of modeling and design, but also allowed us to design and produce new advanced architectured metastructures for elastic wave control.

The results achieved during the IUF period have been of great importance for the obtention of an ERC Consolidator grant (META-LEGO, n°101001759), recently awarded to the PI.

PRODUCTION SCIENTIFIQUE DE LA PÉRIODE 2016-2021 :

PUBLICATIONS IN INTERNATIONAL JOURNALS OF RANK A

1. G. Rizzi, P. Neff, A. Madeo (2022). **"Metamaterial shields for inner protection and outer tuning through a relaxed micromorphic approach."**. Philosophical Transactions of the Royal Society A), accepted. Preprint at arXiv preprint arXiv:2111.12001
2. G. Rizzi, M.V. d'Agostino, P. Neff, A. Madeo (2021). **"Boundary and interface conditions in the relaxed micromorphic model: exploring finite-size metastructures for elastic wave control"**. Mathematics and Mechanics of Solids, DOI: 10812865211048923
3. G. Rizzi, G. Hütter, H. Khan, I.D. Ghiba, A. Madeo, P. Neff. (2021) **"Analytical solution of the cylindrical torsion problem for the relaxed micromorphic continuum and other generalized continua (including full derivations)."** Mathematics and Mechanics of Solids: 10812865211023530. https://arxiv.org/pdf/2105.00963
4. G. Rizzi, G. Hütter, A. Madeo, Patrizio Neff (2021). **"Analytical solutions of the cylindrical bending problem for the relaxed micromorphic continuum and other generalized continua"**. Continuum Mechanics and Thermodynamics, 33.4 (2021): 1505-1539.
5. G. Rizzi, G. Hütter, A. Madeo, Patrizio Neff (2021). **"Analytical solutions of the simple shear problem for certain types of micromorphic continuum models"**. Archive of Applied Mechanics, 91.5: 2237-2254.
6. G. Rizzi, H. Khan, I.D. Ghiba, A. Madeo, P. Neff, (2021) **"Analytical solution of the uniaxial extension problem for the relaxed micromorphic continuum and other generalized continua (including full derivations).**" Archive of Applied Mechanics https://doi.org/10.1007/s00419-021-02064-3
7. G. Rizzi, M. Collet, F. Demore, B. Eidel, P. Neff, A. Madeo (2020). **"Exploring metamaterials' structures through the relaxed micromorphic model: switching an acoustic screen into an acoustic absorber"**. Frontiers in Materials 354, DOI: 10.3389/fmats.2020.589701 https://www.frontiersin.org/articles/10.3389/fmats.2020.589701/abstract
8. A. Aivaliotis, D. Tallarico, A. Daouadji, P. Neff, A. Madeo (2020). "**Frequency- and angle-dependent scattering of a finite-sized meta-structure via the relaxed micromorphic model"**. Archive of Applied Mechanics, DOI: https://doi.org/10.1007/s00419-019-01651-9
9. M. V. d'Agostino, G. Barbagallo, I.-D. Ghiba, B. Eidel, P. Neff, A. Madeo, (2020). "**Effective Description of Anisotropic Wave Dispersion in Mechanical Band-Gap Metamaterials via the Relaxed Micromorphic Model**". Journal of Elasticity, Vol.139, pp 299–329. DOI: https://doi.org/10.1007/s10659-019-09753-9
10. A. Aivaliotis, D. Tallarico, M.V. d'Agostino, A. Daouadji, P. Neff, A. Madeo, (2019). "**Microstructure-related Stoneley waves and their effect on the scattering properties of a 2D Cauchy/relaxed-micromorphic interface**". Wave Motion, Vol. 90, pp. 99-120. DOI: https://doi.org/10.1016/j.wavemoti.2019.04.003
11. P. Neff, B. Eidel, M. V. d'Agostino, A. Madeo, (2019). "**Identification of scale-independent material parameters in the relaxed micromorphic model through model-adapted first order homogenization**". Journal of Elasticity. DOI: https://doi.org/10.1007/s10659-019-09752-w. .

12. G. Barbagallo, D. Tallarico, M.V. d'Agostino, A. Aivaliotis, P. Neff, A. Madeo, (2018). "**Relaxed micromorphic model of transient wave propagation in anisotropic band-gap metastructures**". International Journal of Solids and Structures, 162, 148-163. DOI: https://doi.org/10.1016/j.ijsolstr.2018.11.033. Preprint ArXiv: https://arxiv.org/abs/1810.01750 .
13. A. Madeo, G. Barbagallo, M. Collet, M.V. d'Agostino, M. Miniaci, P. Neff, (2018). "**Relaxed micromorphic modeling of the interface between a homogeneous solid and a band-gap metamaterial: new perspectives towards meta-structural designs**". Mathematics and Mechanics of Solids, DOI: https://doi.org/10.1177/1081286517728423. Preprint ArXiv: https://arxiv.org/pdf/1708.02258.pdf.
14. A. Madeo, M. Collet, M. Miniaci, K. Billon, M. Ouisse, P. Neff, (2018). "**Modeling phononic crystals via the weighted relaxed micromorphic model with free and gradient micro-inertia**". Journal of Elasticity. DOI: https://doi.org/10.1007/s10659-017-9633-6. Preprint ArXiv: https://arxiv.org/abs/1610.03878.

Book Chapters

15. A. Madeo, P. Neff, (2019). 'Dispersion of waves in micromorphic media and metamaterials'. Handbook for Nonlocal Continuum Mechanics for Materials and Structures, 713-739.

Conferences

* I did not intervene in conferences starting from 2020, due to Corona pandemic.

1. PLENARY TALK: A. Madeo, "Towards the engineering design of metamaterials' structures through micromorphic enriched continuum modeling". SAM symposium: symposium on acoustic metamaterials, October 9-11 2019, Ischia, Italy.
2. A. Madeo, "Transparent relaxed micromorphic description of anisotropy in metamaterials". Workshop on metamaterials: from Optics to Geophysics. April 15-17 2019, Marseille, France. Invited by Bruno Lombard.
3. A. Madeo, M.V. d'Agostino, "Transparent relaxed micromorphic description of anisotropy in metamaterials". GDR MECAWAVE Scientific Event, October 5th 2018, Marseille, France. Invited by Bruno Lombard.
4. A. Madeo, "Anisotropic wave dispersion in band-gap metamaterials via the relaxed micromorphic model". GAMM conference, February 18-22, 2019, Vienna, Austria.
5. A. Madeo, "Dispersion and band-gaps in micromorphic media and metamaterials". ESMC 2018, July 2-6, 2018, Bologna, Italy.
6. A. Madeo, "Enriched continua and engineering metamaterials". ETAMM 2018, June 18-22, 2018, Krakow, Poland.
7. A. Madeo, "Effective description of anisotropic wave dispersion in mechanical metamaterials via the relaxed micromorphic model". GAMM conference, March 19-23, 2018, Munich, Germany.
8. A. Madeo, "Transparent relaxed micromorphic description of anisotropy in metamaterials", 17TH GAMM seminar on microstructures. January 25th-26th, 2018, Florence, Italy.
9. Alexios Aivaliotis, Gabriele Barbagallo, Marco Valerio d'Agostino, Angela Madeo, Ali Daouadji, Patrizio Neff, "Relaxed micromorphic modeling of composite materials exhibiting bad-gap behaviors". ICCS20, 4-7 September 2017, Paris, France.
10. A. Madeo, G. Barbagallo, M. V. d'Agostino, A. Aivaliotis, P. Neff, "Dispersion and band-gaps in micromorphic media and metamaterials". ICMM5 2017, 15th June 2017, Rome, Italy.
11. Gabriele Barbagallo , Marco Valerio d'Agostino , Ali Daouadji, Salim Belouettar, Philippe Boisse, Angela Madeo, "Fibrous composite reinforcements as second gradient materials" ICMM5 2017, 15th June 2017, Rome, Italy.
12. M.V. d'Agostino, A. Madeo, P. Neff, G. Barbagallo, I.-D. Ghiba, "Anisotropic dispersion and band-gaps in mechanical metamaterials via the relaxed micromorphic model". ICMM5 2017, 15th June 2017, Rome, Italy.
13. M.V. d'Agostino, A. Madeo, P. Neff, B. Eidel, G. Barbagallo, I.-D. Ghiba, "Anisotropic wave dispersion and band-gaps in mechanical metamaterials via the relaxed micromor- phic model". ISDMM 2017, 27th June 2017, Lyon, France.

14. Gabriele Barbagallo , Marco Valerio d'Agostino , Ali Daouadji, Salim Belouettar, Philippe Boisse, Angela Madeo, “Fibrous composite reinforcements as second gradient materials” ISDMM 2017, 27th June 2017, Lyon, France.
15. A. Madeo, G. Barbagallo, M. V. d’Agostino, A. Aivaliotis, P. Neff, “Dispersion and band-gaps in micromorphic media and metamaterials”, ISDMM 2017, 27th June 2017, Lyon, France.
16. A. Madeo, P. Neff, “Modeling wave propagation in real phononic crystals via the relaxed micromorphic model”. GAMM joint annual meeting, March 6-10, 2017. Weimar, Germany.
17. A. Madeo. “Modeling Wave Propagation in Non-local Band-gap Metamaterials via the Relaxed Micromorphic Model”. Advances in mechanical metamaterials, Trento 10-11 october 2016. Invited by Prof. Davide Bigoni and Marco Miniaci.
18. A. Madeo. “Dispersion and band-gaps in micromorphic media and metamaterials” Colloque sur l’homogénéisation et les milieux continus généralisés en régime dynamique, 6-7 octobre 2016, Laboratoire de Mécanique et Acoustique, Marseille, France Marseille. Invitée par Bruno Lombard.
19. A. Madeo, “Modeling wave propagation in non-local band-gap metamaterials via the relaxed micromorphic model”. Emerging Trends in Applied Mathematics and Mechanics Perpignan (ETAMM), May 30 - June 3 2016, Perpignan, France
20. A. Madeo, P. Neff, “The relaxed micromorphic model for band-gaps description in mechanical metamaterials”. GAMM and DMV joint annual meeting, March 7-11, 2016. Braunschweig, Germany.
21. A. Madeo, P. Neff, D.I. Ghiba, G. Rosi, “The relaxed micromorphic model for band-gaps description in mechanical metamaterials”. GAMM and DMV joint annual meeting, March 7-11, 2016. Braunschweig, Germany.
22. A. Madeo, P. Neff, I.D. Ghiba, G. Rosi. “Wave Propagation In Relaxed Micromorphic Continua: Modeling Meta-materials Exhibiting Frequency Band-gaps”. 15th GAMM-Seminar on Microstructures. January 22-23, 2016, Institut Henri Poincaré, Paris
23. A. Madeo. “The relaxed micromorphic model for the description of band-gaps in mechanical metamaterials”. Congrès Français d'Acoustique, Propagation d'onde dans les milieux hétérogènes, 11-15 april 2016. Invited by S. Naili

ENCADREMENT DOCTORAL (Direction de thèses) :

1. Félix DEMORE (2022, INSA-Lyon / Ecole Centrale de Lyon)
2. Alexios AIVALIOTIS (defended: 2019, INSA-Lyon).
3. Gabriele BARBAGALLO (defended: 2017, INSA-Lyon).

AUTRES AVANCÉES SIGNIFICATIVES AU COURS DE LA PÉRIODE :

The results obtained during the IUF project have been of great importance as preliminary results for the obtention of the ERC Consolidator grant META-LEGO n° 101001759, recently awarded to the PI.

PRIX ET DISTINCTIONS SCIENTIFIQUES OBTENUS AU COURS DE LA PÉRIODE (indiquer les dates) :

2021- 2026: ERC Consolidator grant META-LEGO n° 101001759

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