Postprint of: Misra A., Hild F., Eremeev V., Design of metamaterials: Preface, MECHANICS RESEARCH COMMUNICATIONS, Vol. 127 (2023), 104036, DOI: 10.1016/j.mechrescom.2022.104036

Design of metamaterials: Preface

By a *metamaterial* we usually mean a composite material whose properties are mostly determined by inner structure rather than properties of its constituents, see e.g. [1–4]. These inner structures may be conceived such that the resultant metamaterial can ''...meet a specific purpose governed by a desired specific behavior that is described by a given set of evolution equations ... '' [4]. Among various types of metamaterials it is worth to mention the so-called those with a beam-lattice motif. These metamaterials are motivated by the desire to mimic crystalline lattice structure and exhibit a range of prospective properties such as energy absorbance, noise damping, high strength-to-weight ratio. A typical example of such materials are foams [5]. For proper description of many of the metamaterials, enhanced continuum models are required, such as strain gradient [6,7], micropolar, and micromorphic [8] models. as exemplified in [3,4] which discuss a variety of applications of these models. Indeed sound theoretical framework, that can link micro and macro-scales, form a necessary bedrock for the discovery and rational design of exotic and innovative metamaterials [9]

The possibility to realize metamaterials has received an impetus due to the recent advances in additive technologies which permits their manufacture with *a priori* designed properties. This extends significantly the class of available composite materials with complex inner structure which could be very useful in applications. It is worthwhile to also note that the developments in new experimental technologies such as Digital Image Correlation (DIC) and Digital Volume Correlation (DVC) combined with high resolution imaging are providing increasingly inquisitive tools for empirical verification. Together the extended computational techniques based upon enhanced theoretical models, advanced manufacturing and 3D printing, and DIC/DVC analyses of high fidelity multi-scale/multi-modal imaging provide a powerful tool for design, manufacturing and further studies of metamaterials.

This special issue ''Design of metamaterials'' collects several papers that have presented theoretical, numerical, and experimental studies of metamaterials. Effective properties of metamaterials were discussed in [10,11]. In [10] the complete set of elastic moduli of linear strain gradient elasticity was provided using asymptotic homogenization. Nonlinear properties of bio-inspired elastic networks were achieved through computational homogenization in [11]. A numerical homogenization approach is also utilized to investigate the scaling of Young's modulus and yield strength with relative density of cubic-octet (CO) plate-lattices [12]. Nonlinear dynamic deformations of pantographic beam-lattice metamaterials were studied in [13,14] from the experimental and computational point of view, respectively. Linear dynamics of mass-in-mass chain model of an acoustic metamaterial is analyzed in [15]. As we mentioned above, strain gradient and micromorphic models may be relevant to study beam-lattice metamaterials including deformation localization and material instabilities. As the latter phenomena are closely related to strong ellipticity, such studies were provided in [16,17]. Connections between material instabilities and ellipticity within strain gradient ellipticity were discussed in [16], whereas ellipticity conditions within these two models were compared in [17]. Experimental verification of a chiral metamaterial with a granular motif that conforms to the Cosserat or micropolar elasticity is presented in [18]. This chiral metamaterial is designed using the micro–macro correlations obtained through the granular micromechanics approach. The metamaterial was fabricated using 3D printing and the theoretically predicted response, obtained from a continuum model as well as from micro-macro granular micromechanics model, was verified using DIC [18].

References

[1] T.-C. Lim, Auxetic Materials and Structures, in: Engineering Materials, Springer, Singapore, 2015.

[2] T.J. Cui, D.R. Smith, R. Liu (Eds.), Metamaterials, Springer, New Yourk, 2010.

[3] R. Lakes, Composites and Metamaterials, World Scientific, New Jersey, 2020.

[4] F. dell'Isola, D.J. Steigmann, Discrete and Continuum Models for Complex Metamaterials, Cambridge University Press, Cambridge, 2020.

[5] L.J. Gibson, M.F. Ashby, Cellular Solids: Structure and Properties, second ed., in: Cambridge Solid State Science Series, Cambridge University Press, Cambridge, 1997.

[6] A. Bertram, S. Forest (Eds.), Mechanics of Strain Gradient Materials, Springer International Publishing, Cham, 2020.

[7] A. Bertram, Compendium on Gradient Materials, Springer, Cham, 2023.

[8] A.C. Eringen, Microcontinuum Field Theory. I. Foundations and Solids, Springer, New York, 1999.

[9] F. Dell'Isola, A. Misra, Principle of VirtualWork as foundational framework for metamaterial discovery and rational design, C. R. Mecanique (2022) (in print).

[10] B.E. Abali, B. Vazic, P. Newell, Influence of microstructure on size effect for metamaterials applied in composite structures, Mech. Res. Commun. 122 (2022) 103877.

[11] D.A. Orlova, A.Y. Panchenko, S.L. Omairey, I.E. Berinskii, Computational homogenization of bio-inspired metamaterial with a random fiber network microstructure, Mech. Res. Commun. 124 (2022) 103930.

[12] C.S. Ha, M.-T. Hsieh, The effect of geometric imperfections on the mechanical response of isotropic closed-cell plate-lattices, Mech. Res. Commun. (2022) accepted.

[13] M. Laudato, L. Manzari, P. Göransson, I. Giorgio, B.E. Abali, Experimental analysis on metamaterials boundary layers by means of a pantographic structure under large deformations, Mech. Res. Commun. 125 (2022) 103990.

[14] E. Turco, Modeling nonlinear beams for metamaterials design in a dynamic setting, Mech. Res. Commun. 117 (2021) 103786.

[15] A.V. Porubov, I.D. Antonov, On control of harmonic waves in an acoustic metamaterial, Mech. Res. Commun. 116 (2021) 103745.
[16] V.A. Eremeyev, Strong ellipticity conditions and infinitesimal stability within nonlinear strain gradient elasticity, Mech. Res. Commun. 117 (2021) 103782.
[17] V.A. Eremeyev, E. Reccia, Nonlinear strain gradient and micromorphic one-dimensional elastic continua: Comparison through strong ellipticity conditions, Mech. Res. Commun. 124 (2022) 103909.
[18] I. Giorgio, F. Hild, E. Gerami, F. Dell'Isola, A. Misra, Experimental verification of 2D cosserat chirality with stretch-micro-rotation coupling in orthotropic metamaterials with granular motif, Mech. Res. Commun. (2022) 104020.

Anil Misra [*]
University of Kansas, 5104B Learned Hall, 1530 W. 15th Street, Lawrence, KS 66045-7609, USA
E-mail address: amisra@ku.edu.

François Hild
École normale supérieure Paris-Saclay 4, avenue des Sciences 91190, Gif-sur-Yvette, France
E-mail address: francois.hild@ens-paris-saclay.fr.

Victor A. Eremeyev
University of Cagliari, Via Marengo, 2, 09123 Cagliari, Italy
Gdańsk University of Technology, ul. Gabriela Narutowicza 11/12, 80-233 Gdańsk, Poland
E-mail address: eremeyev.victor@gmail.com.

---

[*] Corresponding editor.