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Acoustic Metamaterial Behaviour of 3D Periodic Structures Assembled by Robocasting

Alena Kruisová[1,a], Hanuš Seiner[1,b], Petr Sedlák[1,c], Michal Landa[1,d], Benito Román-Manso[2,e], Pilar Miranzo[2,f], Manuel Belmonte[2,g]

[1]Institute of Thermomechanics, Czech Academy of Sciences, Dolejškova 5, 182 00 Prague 8, Czech Republic

[2]Institute of Ceramics and Glass (ICV-CSIC), Campus de Cantoblanco, Kelsen 5, 28049 Madrid, Spain

[a]alena@it.cas.cz, [b]hseiner@it.cas.cz, [c]psedlak@it.cas.cz, [d]ml@it.cas.cz, [e]mbelmonte@icv.csic.es, [f]pmiranzo@icv.csic.es, [g]mbelmonte@icv.csic.es

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Abstract: Ultrasonic measurements combined with numerical modelling are used to analyze the elastic and acoustic properties of morphologically complex ceramic bodies assembled by the Robocasting technique. It is shown that the micromechanics of the robocast periodic scaffolds leads to several metamaterial-like wave propagation phenomena. Besides the expectable prominent elastic anisotropy and the frequency band structure resulting from the periodicity of the scaffold, a wave-mode mixing is observed that disables the conventional distinguishing between quasi-longitudinal, quasi-shear, and pure shear modes for propagation in the symmetry planes of the structure. This paper proves the capability of Robocasting, as a versatile three-dimensional (3D) printing method, to produce tailored acoustic metamaterials with very low damping and outstandingly strong acoustic anomalies.

Robocasting is a free-form additive-manufacturing method for fabrication of cellular ceramic materials with regular complex architectures [1]. Besides the already well-explored suitability of the robocast scaffolds for applications in advanced filtering [2] or bone tissue engineering [3], these cellular materials posses also unique acoustic properties [4], similar to those of the so-called acoustic metamaterials. Among these properties, the frequency band-gap structure and the extremely strong anisotropy leading to refraction anomalies are the most noteworthy.

In this contribution, we present an analysis of vibrational properties and related macroscopic (effective) elasticity of robocast silicon carbide scaffolds densified by spark plasma sintering (SPS). The experimental method used for such an analysis is the resonant ultrasound spectroscopy (RUS,[5, 6]), that is, in combination with finite elements modeling (FEM), able to determine all independent anisotropic elastic moduli of the scaffold. The main part of the analysis is carried out on tetragonal architectures shown in Fig.1; however, due to the high versatility of the Robocasting method, several different architectures can be designed and prepared. As illustrative examples of this versatility, properties of scaffolds with monoclinic and hexagonal arrangements of the rods are presented, and compared to the tetragonal case.

It is shown that the analyzed scaffolds exhibit outstandingly strong acoustic anomalies, in particular in the acoustic energy focusing and acoustic wave mode mixing, and simultaneously also very low internal friction parameters, comparable to those of bulk silicon carbide ceramics. This makes the robocast materials promising candidates for applications in acoustic energy engineering, such as in lensing or cloaking devices.

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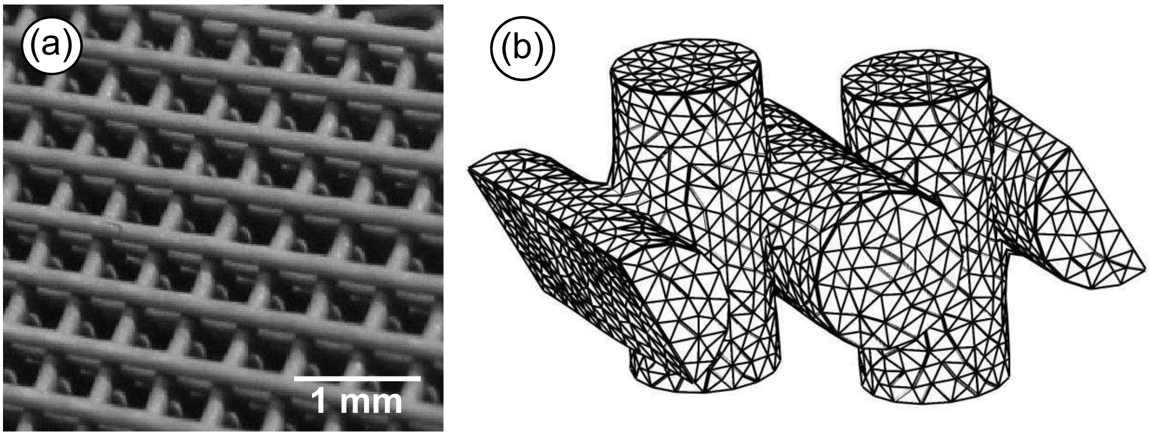

Fig. 1: (a) the regular structure of the robocast scaffold after the SPS; (b) a finite elements model of a scaffold under prescribed shear loading.

References

[1] K. Cai, B. Román-Manso, J. E. Smay, J. Zhou, M. I. Osendi, M. Belmonte, P. Miranzo, Geometrically Complex Silicon Carbide Structures Fabricated by Robocasting. J. Am. Ceram. Soc. 95 (2012) 2660–2666.

[2] B. Román-Manso, S. M. Vega-Díaz, A. Morelos-Goméz, M. Terrones, P. Miranzo, M. Belmonte, Aligned carbon nanotube/silicon carbide hybrid materials with high electrical conductivity, superhydrophobicity and superoleophilicity. Carbon 80 (2014) 120–126.

[3] P. Miranda, E. Saiz, K. Gryn, A. P. Tomsia, Sintering and robocasting of $\beta-$tricalcium phosphate scaffolds for orthopaedic applications, Acta Biomater. 2 (2006) 457–466.

[4] A. Kruisová, H. Seiner, P. Sedlák, M. Landa, B. Román-Manso, P. Miranzo, M. Belmonte, Acoustic metamaterial behavior of three-dimensional periodic architectures assembled by robocasting. Appl. Phys. Letters 105 (2014) 211904.

[5] R. G. Leisure and F. A. Willis, Resonant Ultrasound Spectroscopy. J. Phys.: Condens. Matter 9 (1997) 6001–6029.

[6] P. Sedlák, H. Seiner, J. Zídek, M. Janovská, M. Landa, Determination of All 21 Independent Elastic Coefficients of Generally Anisotropic Solids by Resonant Ultrasound Spectroscopy: Benchmark Examples. Exp. Mech. 54 (2014) 1073–1085.