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Effective elastic properties of 3D printed auxetic metamaterials

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Mechanical metamaterials are artificially produced structures that derive their properties from their periodically repeated structure rather than from mechanical properties of their base material [3]. Often, these structures are manufactured by 3D printing. Nowadays the additive manufacturing technology can be used for producing complex bodies with complicated shapes and various properties which cannot be produced by conventional technologies. Such structures can posses superior properties such as e.g. the negative Poisson's ratio [2]. These materials exhibit a counter-intuitive behaviour when under the uniaxial tension, the structure expands transversely and vice versa. Applications of 3D printed bodies can be found in mechanical, biomechanical or aerospace engineering.

This contribution is focused on study of elastic properties of a structure made by the Selective laser melting (SLM). SLM is one of a 3D printing method enabling manufacturing of complex metallic metamaterials. The studied sample is based on bcc crystal structure and is shown in Fig. 1, detail of the structure is in Fig. 2. The diameter of the spheres is 1.25 mm, the diameter of connecting cylinders is 0.625 mm. The size of the elementary unit cell was set 2 mm.

The structure was produced from the stainless steel SS 316L-0407 powder for additive manufacturing. The material properties of the printed material are slightly anisotropic, according to the producer the Young modulus varies in the horizontal and vertical direction of printing, but this was not included in our computation of the effective elastic properties. Only two parameters of the base material was taken into account, Young modulus of bulk material 167 GPa and Poisson's ratio of bulk material equal to 0.33.

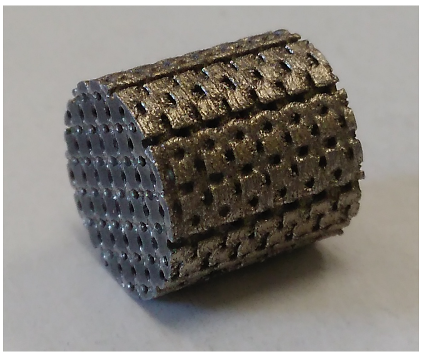

Fig. 1. Sample of metallic metamaterial

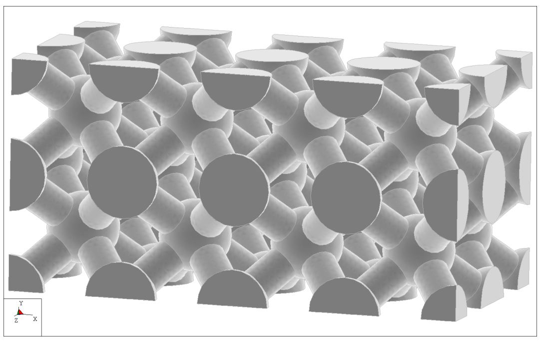

Fig. 2. Model of bcc structure

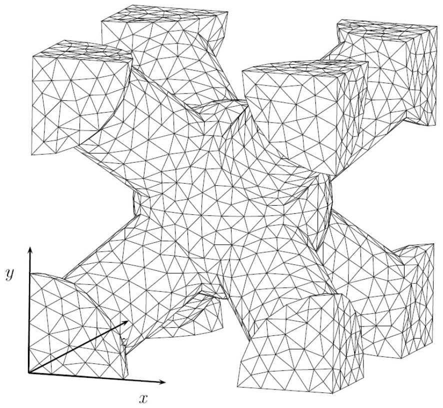

Fig. 3. FEM model used in REV for estimation of effective elasticity

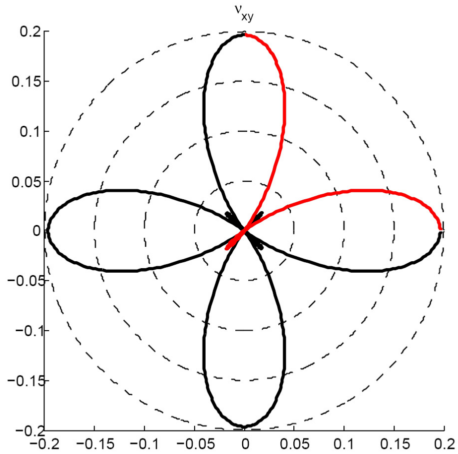

Fig. 4. Directional distribution of Poisson ratio in x, y plane

The effective elastic properties of the structure given by the elasticity tensor were obtained by the representative elementary volume (REV) homogenization method used in composites [1]. The FEM calculations were carried out on the model of the representative volume element, Fig. 3, in COMSOL Multiphysics computing software [4] by using the periodic boundary conditions to simulate the periodicity of the structure. Three simple deformation modes were used, plain strain mode, simple shear mode and pure shear mode. Three independent elastic constants $c_{11} = 17.5$ GPa, $c_{12} = 4.3$ GPa and $c_{44} = 10.3$ GPa were numerically determined.

The direction dependence of the Poisson ratio in $x - y$ plane is shown in Fig. 4. Its values for a quarter of plane are plotted in red line thus it can be clearly observed that the value of the Poisson's ratio in the direction of the axis x or y of the coordinate system given is 0.1966, in contrast with the value of the Poisson ratio in the diagonal direction, which is negative and its value is -0.0256. In future work, we plan to pay attention to the influence of effective elastic properties to the modelling of wave propagation in metallic metamaterials.

Acknowledgement

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References

[1] Hill, R., Elastic properties of reinforced solids: Some theoretical principles, Journal of the Mechanics and Physics of Solids 11 (5) (1963) 357-372.

[2] Lakes, R., Advances in negative Poisson's ratio materials, Advanced Materials 5 (1993) 1038-1040.

[3] Ren, X., Das, R., Tran, P., Ngo, T.D., Xie, Y.M., Auxetic metamaterials and structures: A review, Smart materials and structures 27 (2018) 023001.

[4] COMSOL Multiphysics Reference Manual, version 5.3, COMSOL, Inc, www.comsol.com