Towards the design of soft periodic porous structures for acoustic applications

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Abstract

Porous materials such as polyurethane foams, glass wool, jute, synthetic fibers are widely used in industrial noise control. It is well understood that the microstructure of the porous media largely affects its macroscopic response [1]. Due to the nature of the foaming process, it is difficult to control the microstructure of the foams beyond a certain limit and therefore it is difficult to obtain predictable macroscopic performance, especially in initial design phases. This fact has inspired the use of periodic foam or lattice structures for sound absorption [2]. Periodic foams are made of unit cell which is having periodic repetition in three dimensional domain as shown in Fig. 1.

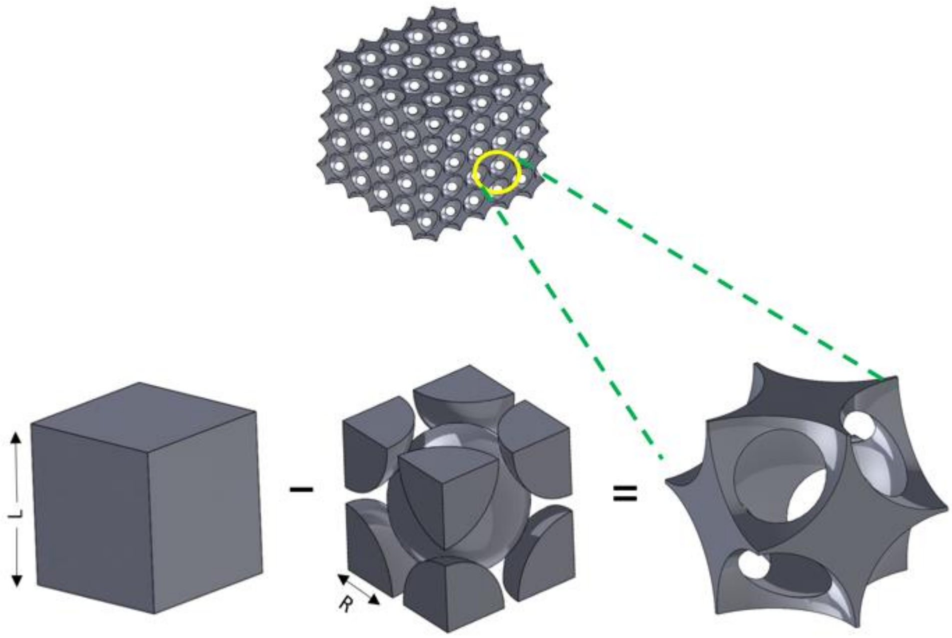

Fig. 1: Concept of periodic foam structure using body-centric (BCC) unit cell configuration

The periodic nature of these materials offers control over the microstructural properties of the porous material and thereby control over the macroscopic acoustic responses such as absorption coefficient and transmission loss. Recently, Deshmukh et al. [2] used the concept of periodic foam microstructure to obtain a predictable macroscopic response. Three different unit cell geometries viz. BCC, FCC, and A15 are used to create the periodic configuration and their macroscopic performance is compared based on the popular Johnson-Champoux-Allard (JCA) model. Later, these configurations are additively manufactured using polymer and metal as a base material in order to experimentally validate their macroscopic performance. The JCA model assumes the skeleton part of the porous material as elastically rigid (motionless) and therefore neglects the effect of structural modes on macroscopic acoustic response. However, porous materials with low elastic modulus, very small strand thickness, and/or high porosities, can have strong fluid-structure interaction, and therefore the rigid-skeleton assumption may lead to inaccuracies in predicting the responses of these soft materials.

In the present study, the use of periodic configurations to control the structural modal effects on sound absorption has been demonstrated based on Biot-uP formulation. Three unit cell configurations from Deshmukh et al. [2] are taken here for study. Their modulus values are computationally predicted using homogenisation approach. Predicted modulus values along with the microscopic JCA parameters of three configurations are used to carefully study the effects of structural modes on absorption coefficient. A parametric study on these three configurations has been performed by changing their porosity and the unit cell size. It is found that the effect of structural modes enhances with the increase in porosity as well as a decrease in unit cell size. However, it has been shown that the effect of structural modes on macroscopic acoustic response can be tuned (as per the application requirement) through careful selection of unit cell, porosity, and cell size. In order to prove the concept of *a priori* prediction of macroscopic poroelastic response, a periodic structure made of A15 unit cell configuration has been additively manufactured using a soft polymer material PIC 100 [3].

Two types of measurements (i.e. acoustical and structural) are carried out on the additively manufactured sample. In the first experiment, the absorption coefficient of the sample is measured using the two-microphone impedance tube method. Predicted absorption coefficient results based on the Biot-uP model are found in agreement with that of experimental results as shown in Fig. 16 in Deshmukh et al. [3]. However, due to the weak coupling between the air and fabricated sample as well as due to the higher value of loss factor, the effect of structural resonance is damped in the absorption coefficient graph. Therefore in the second experiment, vibrations of frame induced due to sound excitation are measured using accelerometer placed on front surface of the sample and results are shown in Fig.18 in Deshmukh et al. [3]. The measured frame displacement per unit incident pressure is found in agreement with that obtained using the Biot-uP model. The discrepancies between the Biot-uP model and the experimental results could be due to the manufacturing inaccuracies as well as difficulty in mimicking the structural boundary conditions during measurements [3]. However, *a priori* prediction of these acoustics and structural responses should be underlined once again, these macroscopic responses are predicted even before the fabrication of a sample and therefore the use of soft periodic porous structure can significantly reduce the design cycle time for material selection.

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References

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