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NUMERICAL STUDY OF FOAM MICROSTRUCTURES AND THEIR VIBRATION BEHAVIOR

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As an acoustic material, foam can be sorted into different types according to their different microgeometry, based on the open-to-closed pores ratio. Previous experimental studies show that the different microgeometry types significantly influence the vibration behaviour of foams. Based on the tetrakaidecahedron shape, we use Finite Element Method (FEM) models to simulate unit cells of foams with different microgeometries by band structure analysis. The mode shapes, vibration eigenfrequencies, and frequency responses of three different types are compared. This study provides preliminary knowledge of how microstructure affects foams' vibration, especially on small-scale components.

Keywords: foam, vibration, band structure calculation

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1. Introduction

The tetrakaidecahedron, also known as Kelvin Cell, is a representative structure of foam pores [1]. It is composed of six quadrilateral faces and eight hexagonal faces. From the micrographs of foam materials, it is shown that most of the pores of the foam materials are indeed shaped as tetrakaidecahedron, and there are some studies on the acoustic properties of porous materials by using this shape [2][3][4]. The difference in shape of different types of foam materials can be reflected in the difference in the size of the pores on each face of the cell, which influence both acoustic and vibroacoustic behaviour of foams.

Band-gap engineering is a method which is widely used to predict and control phononic crystals [5]. Although the pores inside foam are arranged randomly, to investigate how the pore sizes on the faces influence the whole structure, the band structure calculation can be used on the periodic structure consisting of tetrakaidecahedron, which can be considered as simplified foam.

In this research, we use the 3D models based on the tetrakaidecahedron to investigate the mechanical behaviour of foams by band structure calculation in COMSOL. We would like to link the Micro-geometric structure of foams with their vibroacoustic behaviour, and this is initial research and a beginning on this topic.

2. Material and method

Figure 1 (a) shows the typical micrographs of foam materials. The left is reticulated foam, with large pores inside; the right one is totally closed foam. The two types of foams are two extreme situations of foams, in terms of open pore porosity. Previous study [6] found that the two types of foams have very different mechanical behaviours. From the figure, the inside pores are arranged randomly, but the shapes are very similar with the tetrakaidecahedron, which is shown in the Figure 1 (b).

(a) (b)

Figure 1: (a) Micrographs of foam materials. (b) Tetrakaidecahedron (Kelvin Cell).

2.1 Brillouin zone and the k-path

In the band structure analysis, the k-path are constructed from the irreducible part of the first Brillouin zone [7]. To calculate the band structure, the Brillouin zone and the k-path which is used in this research is shown in the Figure 2. The k-path used in this research is Γ-X-W-K- Γ-L-U-W-L-K | U-X, for make sure all possible eigenmodes are described. The distance between every two quadrilaterals facing each other is $2\pi/a$, and a equals to 0.37mm, which is from the data of foam samples.

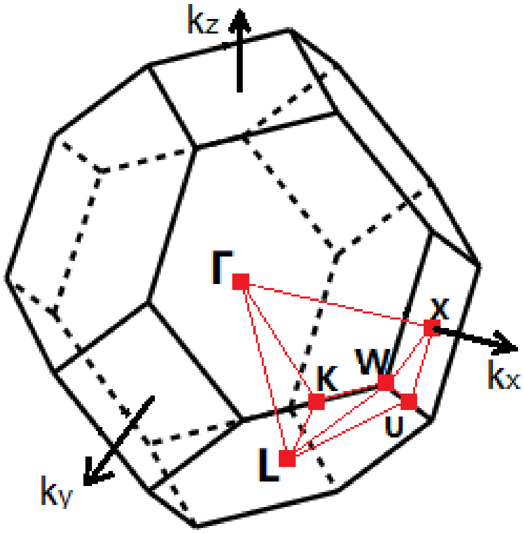

Figure 2: Brillouin zone and the k-path.

2.2 COMSOL setup

Figure 3 shows the unit cell geometry used in this research. The simulation includes two parts: Firstly, the unit cell is introduced to a finite element model in COMSOL for the structural mechanics eigenmode simulation; secondly, the frequency response of the array of cells with excitation at one side is calculated, with the symmetry boundary condition, to evaluate the transmission of the simplified foams. As initial research, only the solid part of the geometry is considered. The material of the structure is set-up as polyethylene, which is a common foam skeleton material. To compare the size of the pores on the faces, the three different situations are shown as Figure 3 (a) – (c): totally closed cell, open cell with ϕ 0.04mm pores on all faces, and open cell with ϕ0.04mm pores on quadrilateral faces, ϕ0.08mm pores on hexagonal faces, respectively. These three types we will call them as Type A, Type B, and Type C, respectively. The thickness of all the faces is 0.00488mm, which is from the data of a real foam sample.

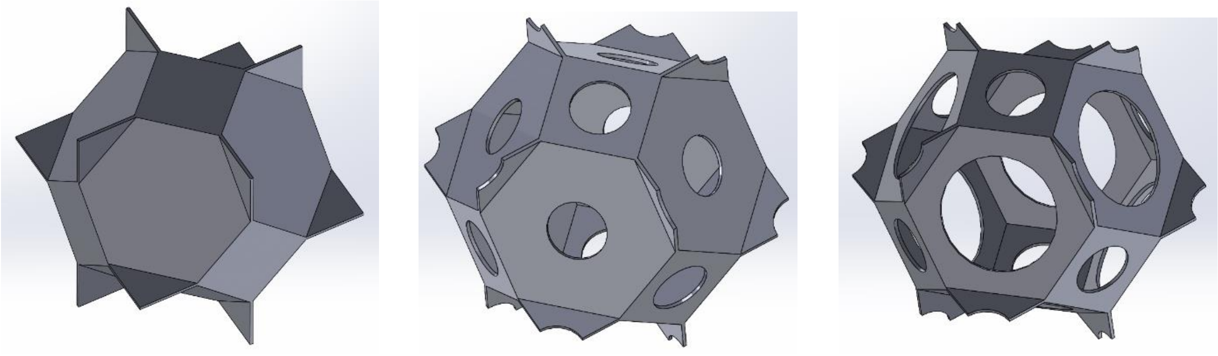
(a) (b) (c)

Figure 3: 3D models used in this research. (a) is totally closed cell, Type A; (b) is open cell with ϕ0.04mm pores on all faces, Type B; (c) is open cell with φ 0.04mm pores on quadrilateral faces, and φ 0.08mm pores on hexagonal faces, Type C.

3. Result and discussion

3.1 Band structure calculation

Figure 7 to Figure 9 shows the results of the band structure analysis, which are Type A, Type B and Type C, respectively.

Similarly to the mode shapes shown in the previous section, the band structure of Type A and B are very similar. The difference between Figure 7 and 8 is there are more peaks at the velocity trasmission plot of Type B at higher frequency.

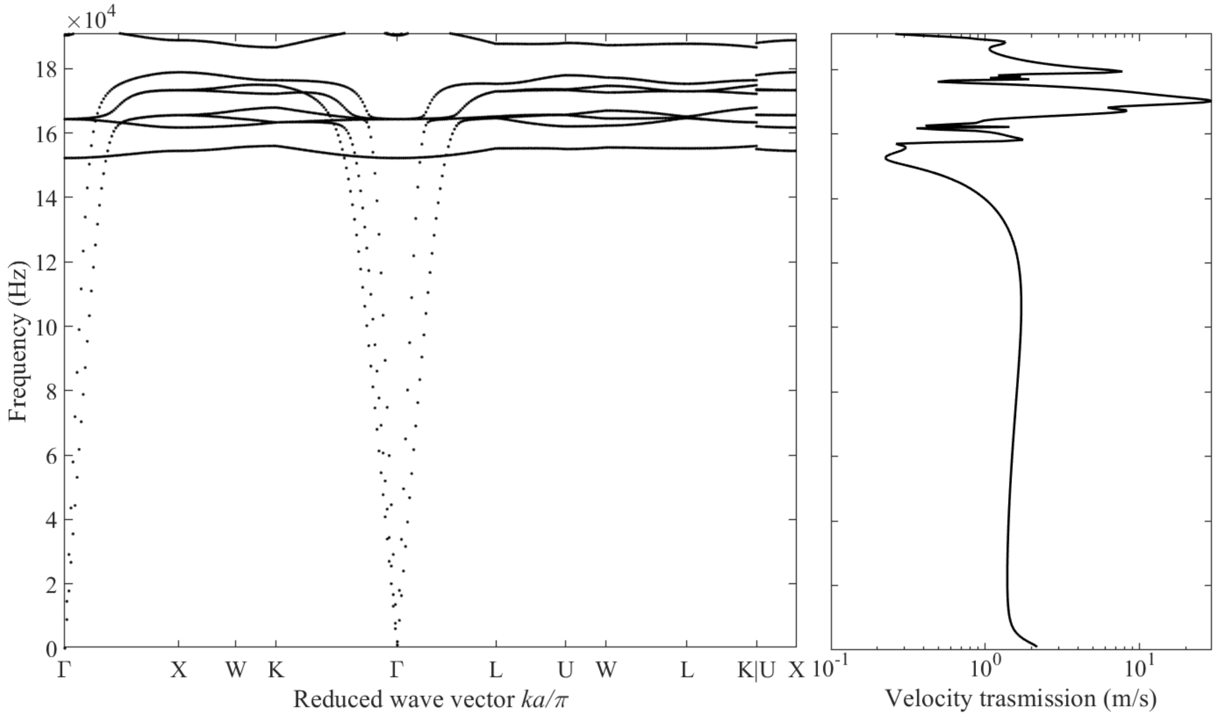

Figure 7: Simulated band structure of the Type A and velocity transmission.

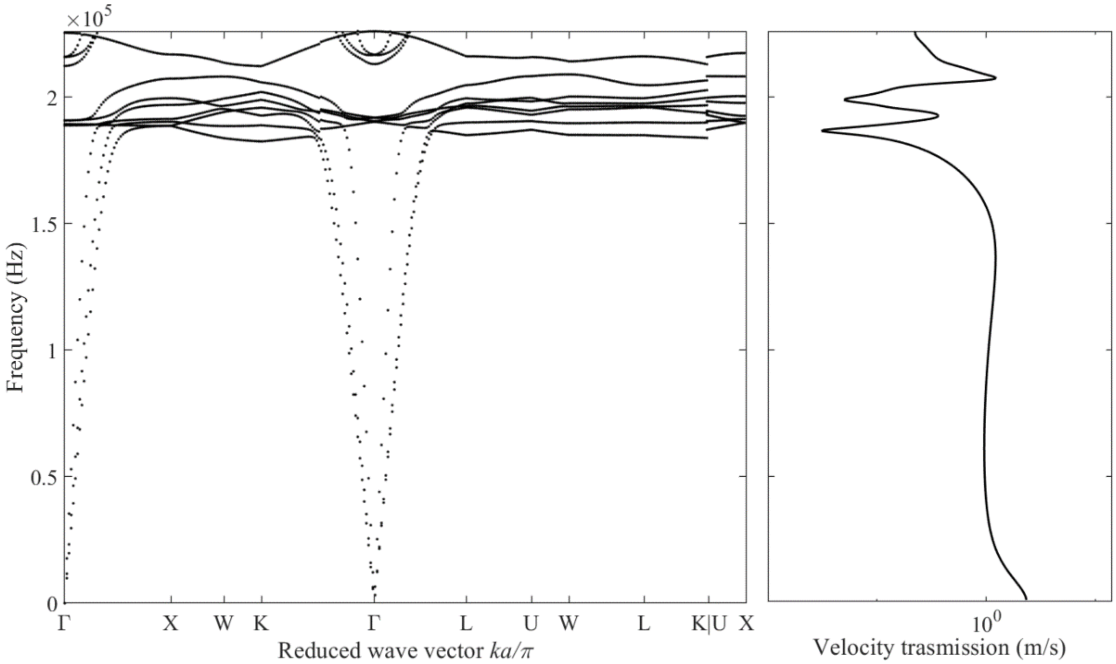

Figure 8: Simulated band structure of the Type B and velocity transmission.

And the band structure of Type C has significant difference with the others. Considering the structure of Type C is more similar with the reticulated foam, which is shown in the Figure 1(a) left, it can explain the difference of the vibroacoustic behaviour of reticulated foams in some measurements. And the same as previous section, there also should be a threshold between Type B and Type C.

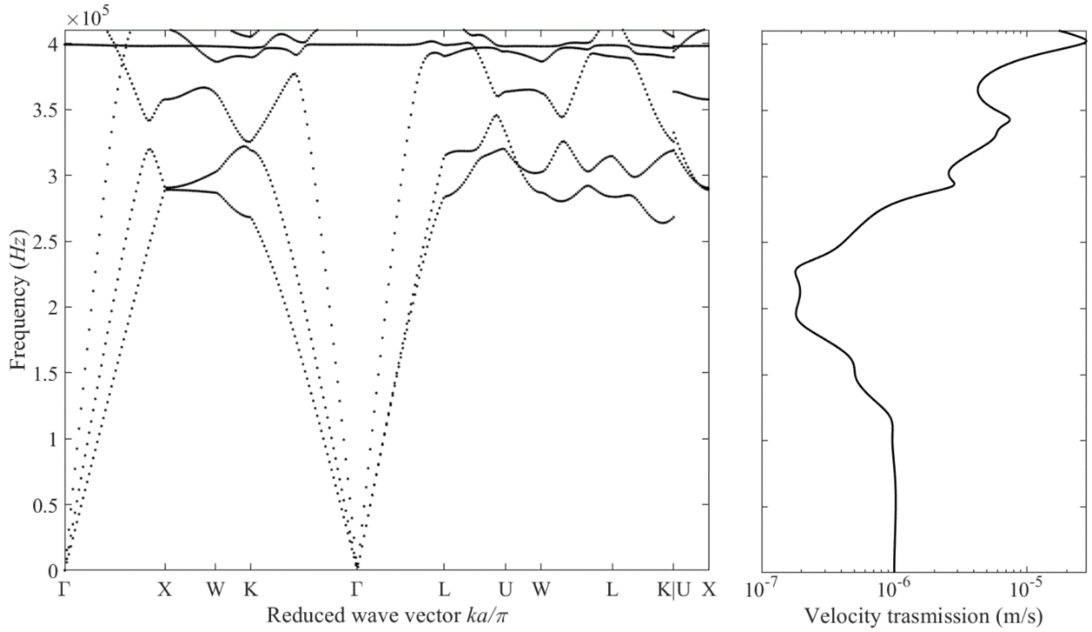

Figure 9: Simulated band structure of the Type C and velocity transmission.

3.2 Mode shape

From Figure 4 to Figure 6, the mode shapes of the above mentioned three models are showed, which is for the first three modes and labelled as (a), (b), (c), respectively.

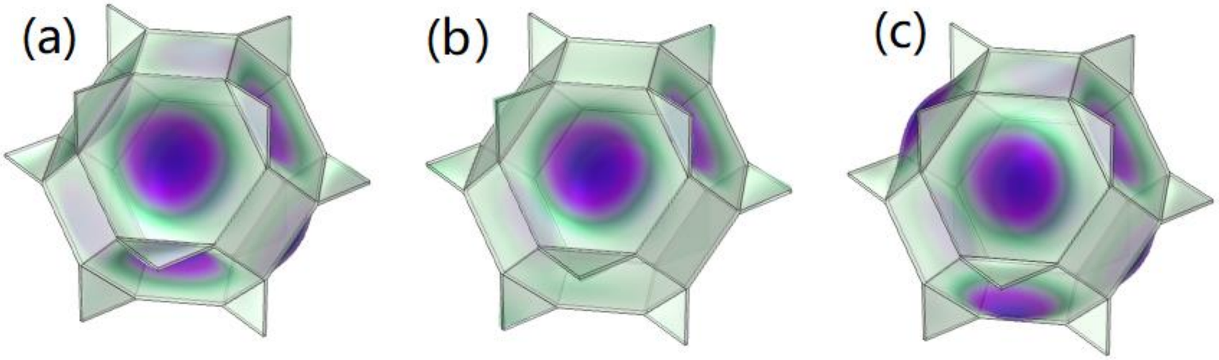

Figure 4: Deformation of the Type A for first three modes on 1.545e5 Hz, 1.619e5 Hz, 1.656e5 Hz, respectively.

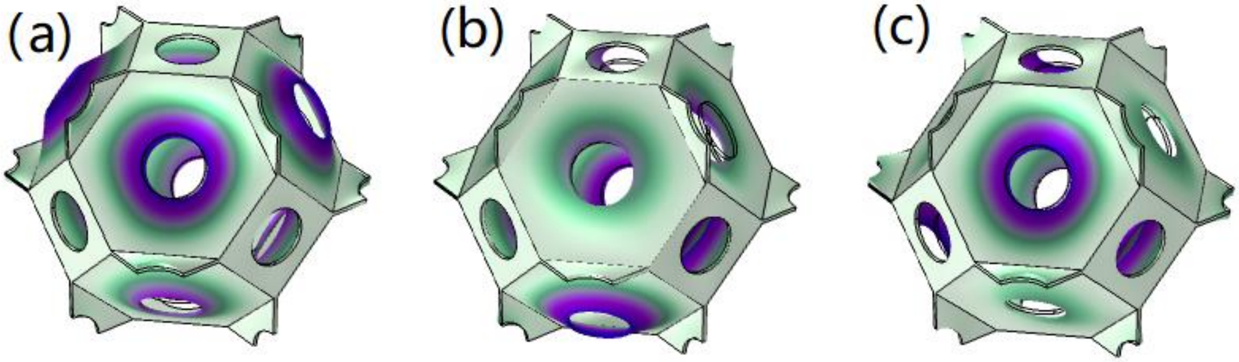

Figure 5: Deformation of the Type B for first three modes on 1.898e5 Hz, 1.8997e5 Hz, 1.9138e5 Hz, respectively.

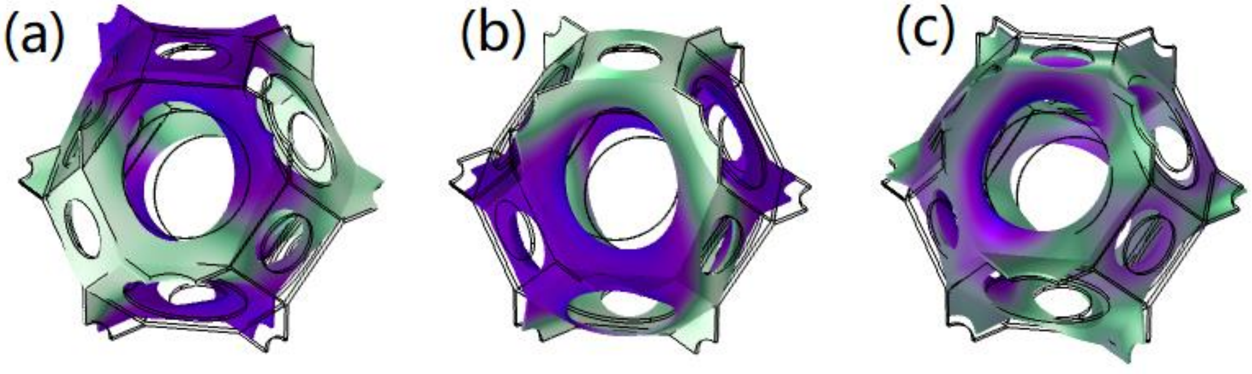

Figure 6: Deformation of the Type C for first three modes on 2.8904e5 Hz, 2.9054e5 Hz, 3.677e5 Hz.

Comparing the mode shapes, it is evident that Type A and Type B have very similar ones, despite Type A lacking holes on its faces. However, when the size of the holes on the hexagonal faces of Type B increases, the mode shapes of Type C become noticeably distinct from the other two types. This difference in mode shapes may be attributed to the reduced stability of the face as the hole size increases, which is worth exploring a potential threshold between Type B and Type C in the future.

4. Conclusion

In this paper, the initial study of the mechanical behaviour unit cell of foam by band structure analysis method is conducted, which can be a start of the simulation of the whole foam structure with the micro-geometric structure. The threshold between the Type B and Type C can be considered as a worthy direction to be studied in the future, and it will help us reveal why the reticulated foams have different vibroacoustic behaviour with others. Further research on supercell (combination of different single cells) will be carried out afterwards to gradually increase the randomness of the structure.

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