Numerical Study on Impact Resistance of Periodic Porous Structure

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Abstract. Based on the face centered cubic (FCC) and body centered cubic (BCC) structures, the effects of impact velocity on the deformation modes and stress-strain curves of periodic porous structures are studied by using the dynamic display nonlinear finite element method. The numerical simulation results show that under quasi-static loading, the overall deformation mode of face centered cubic structure presents a transverse "X" shape, while the overall uniform deformation of body centered cubic structure occurs. Under high speed loading, the two structures present layer by layer deformation. With the increase of loading speed, the stress plateau of the two structures increases, and the stress-strain curves fluctuate.

1. Introduction
Porous structure is a network structure composed of interconnected or closed-cell¹-². Due to its excellent mechanical properties, it is often used in energy absorption, sound insulation, tissue engineering scaffolds and other fields. Among them, porous structure is the most widely used in the field of impact protection³.

According to the regularity of microstructure, porous structure can be divided into random porous structure and periodic porous structure⁴. Because the cell shape of periodic porous structure is controllable, the designability is strong, and the mechanical properties are more stable, it has higher research value. S Yanze⁵ used the finite element method to analyse the dynamic response of a three-dimensional closed cell porous structure based on the tetrahedral model. The calculation results show that the impact velocity has a significant effect on the deformation mode and stress-strain curve of the porous structure. Z Zhijun⁶ through the finite element study of the hexagonal and irregular honeycomb, according to the impact velocity on the structural deformation mode, the deformation mode is divided into three types: low speed, transition and high-speed. It is considered that quasi-static deformation mode is the dominant factor in the low speed section, the inertia effect can be ignored and the inertia effect in the high velocity section is the main factor.

In this paper, three-dimensional periodic porous structures with open holes based on face-centred cubic structure and body centred cubic structure are established. By using dynamic display nonlinear finite element method and ABAUQS commercial finite element software, the influence of impact velocity on the deformation mode and stress-strain curve of the two structures is analysed.

2. Model

2.1. Geometric model
The structure design of FCC structure and BCC structure is to cut the circle with radius r on a cube
with side length \( a \) in different arrangement to generate the target structure. FCC structure is generated by cutting a quarter circle with radius \( r \) on each right angle of a cube and a half circle with radius \( r \) on each surface. BCC structure is generated by cutting a quarter circle with radius \( r \) on each right angle of a cube. Circle, the centre of the cube as the centre of a circle generated by cutting off a circle. The relative density of FCC structure and BCC structure calculated in this paper is 0.1, the side length of cube is 2mm, the radius of FCC structure is 0.77mm, and the radius of BCC structure is 0.974mm. In this paper, we first establish a single FCC and BCC structure, and then establish a lattice arranged porous structure in three directions. The geometric models of the two structures are shown in Figure 1. It should be noted that the number of cells may affect the mechanical response of the structure due to the boundary effect. The numerical study in shows that the \( 4 \times 4 \times 5 \) lattice array can provide a stiffness very close to the asymptotic linear modulus of the infinite array.

2.2. Finite element model

The numerical simulation of FCC and BCC structures was carried out using commercial finite element software ABAQUS/explicit 2020 to capture the compression response and failure behaviour of the two structures. The matrix material is aluminium, and its material parameters are: elastic modulus 70GPa, yield stress 80MPa, Poisson's ratio 0.33, density 2700kg/cm\(^3\), tangent modulus 30MPa. The FCC structure and BCC structure are modelled by linear tetrahedral element (C3D4), and the top and bottom rigid surfaces are modelled by discrete rigid element (R3D4). The rigid surface is used to simulate the loading surface and support surface, which aims to prevent the structure from passing through the support plane in the simulation process. The six degrees of freedom of the rigid surface ensure that the bottom structure can’t move or rotate in three directions, which can effectively simulate the bottom fixed support in physical experiments. In addition to the other five degrees of freedom in the vertical direction, the top rigid surface is constrained to compress the porous structure downward at a constant speed along the Z axis. The reaction and displacement of the reference point of the top rigid surface are recorded, and the load displacement curve is extracted after analysis. Taking FCC
structure as an example, the established finite element model is shown in Figure 2.

![Finite element model of porous structure](image)

Fig.2 Finite element model of porous structure

### 3. Results and discussion

The micro topological structure and performance of porous structure directly affect the deformation mode of the structure. When studying the impact resistance of porous structures, the deformation modes of the structures under different loading speeds are different. Figure 3 and 4 show the typical deformation modes of FCC structure and BCC structure under five different loading speeds. 0.01 m/s is the quasi-static loading speed, and the dynamic loading speed is 30 m/s, 70 m/s, 100 m/s, 150 m/s and 200 m/s. Under quasi-static loading, the elements on the diagonal of FCC structure collapse first, and then the shear band gradually shifts to the middle of the structure. The overall deformation mode of the structure presents a transverse "x" type, while the BCC structure presents an overall uniform deformation mode. Under dynamic loading, when the loading speed is less than 70 m/s, compression deformation band appears at the impact end of FCC and BCC structures, while the structure at the fixed end still remains static due to inertia. When the loading speed is greater than 70 m/s, the impact ends of FCC and BCC structures are fully compacted at first, and then the deformation zone moves to the fixed end layer by layer until the whole structure is compacted.

![Typical deformation modes of FCC structures](image)

(a) No load applied (b) medium/low speed loading (c) Under high speed loading

Fig.3 Typical deformation modes of FCC structures under different loading speeds

![Typical deformation modes of BCC structures](image)

(a) No load applied (b) medium/low speed loading (c) Under high speed loading

Fig.4 Typical deformation modes of BCC structures under different loading speeds
Figure 5 shows the nominal stress-strain curves of the two structures at different loading rates. It can be seen from the curves that the stress-strain curves of the two structures are completely different under different loading velocities. Under quasi-static loading and medium velocity loading, the nominal stress-strain curves of FCC structure and BCC Structure almost coincide, and there is no stress fluctuation in the platform area. The reason is that the force on the impact plate transfers slowly between the porous structures and the deformation of the porous structure is relatively uniform when the loading velocity is medium and low. Under high-speed loading, the stress plateau of both structures increases, and the stress fluctuation occurs in the platform area. This is because when the loading velocity is too high, the porous structure is compacted layer by layer with a certain acceleration, and the stress reaches the maximum when the collapsed cell of the upper layer enters the dense area.

4. Conclusion
The two structures show different deformation modes under the influence of loading speed during compression. Under quasi-static loading, the overall deformation mode of FCC structure presents a transverse "x" shape, while the overall deformation of BCC structure is uniform. Under high-speed loading, there are obvious stress fluctuations in the platform area of the two structures, but the fluctuation amplitude of the two structures is different, which is related to the cell size parameters. The stress plateau of the two structures increases with the increase of loading speed.

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