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Dynamic impact behaviors of functionally graded lattice structures

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ABSTRACT

With the characteristics of light weight, high strength, good shock absorption ability, the lattice structures have drawn a lot of attention [1-9]. On the other hand, functionally graded materials are typically inhomogeneous composite materials, which can apply to extremely working conditions [10-15]. In this paper, the design concept of functionally graded materials is introduced to the lattice structures, in order to accomplish the multi-function optimization design of the lattice materials. The impact performances of the functional graded lattice structure with regular and staggered quadratic cells are studied, respectively. Under the different impact velocities, the influences of the cell arrangements on the deformation modes and energy absorption are analyzed. The results shows that for the same relative density and impact velocity, the lattice structures with regular arrangement is superior to the ones with staggered arrangement on the energy absorption ability. The reasons are revealed by the micro structures of the cells and the macroscopic deformation mechanism. Moreover, the influences of the density gradients on the deformation modes and the energy absorbing abilities are investigated. This paper is helpful for the design and analysis of the mechanical characteristics of the lattice materials and structures.

Keywords: Lattice structure, Functionally graded materials, Energy absorbing
I-INCE Classification of Subject Number: 35

1. INTRODUCTION

Lattice structures have the advantages of low density, light weight and remarkable energy absorption ability. They are widely used in packaging, construction, shipping, aviation, electrical techniques and biological engineering, etc. [1–4]. Therefore, the lattice stuctures have drawn a lot of attention, and many researches have been carried out.

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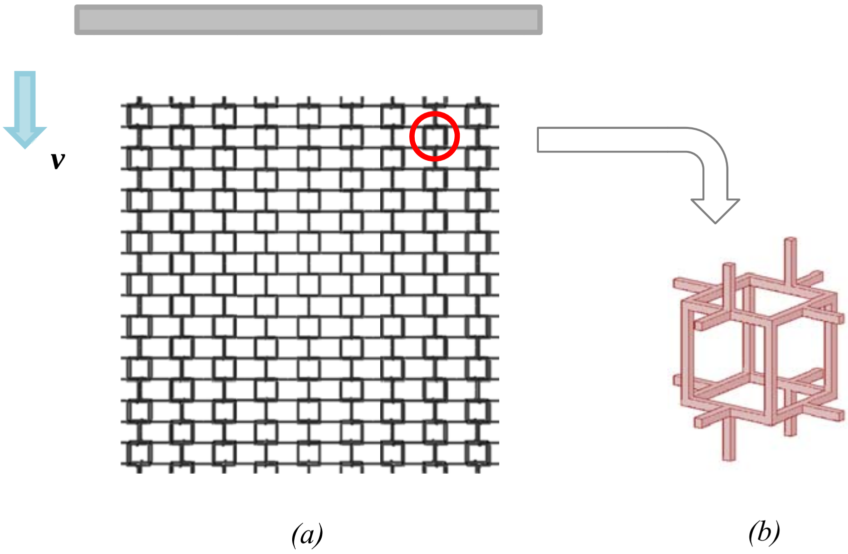
Functionally graded material (FGM) is a new type functional material, many studies have been reported on these materials over the last few decades [10–16]. In the present paper, with the functionally graded properties, the in-plane dynamic crushing of the lattice structures is investigated.

2. ANALYSIS MODEL

As shown in Fig.1(a), the lattice structure is composed of the cells given in Fig.1(b). The bottom of the honeycomb model is fixed and the top side is impacted by a rigid plate. The material constants used in the calculation are the Young's modulus E = 69 GPa, yielding stress σ_s=76MPa, the mass density ρ =2700g/cm^3 and the Poisson ratio v = 0.3. The dimention of each cell is 1cm × 1cm × 1cm, the edge length of cube frame 5 mm and the cross section is square.



(a) (b)

Figure 1. Analytical model: (a) the lattice structure and (b) the unit cell.

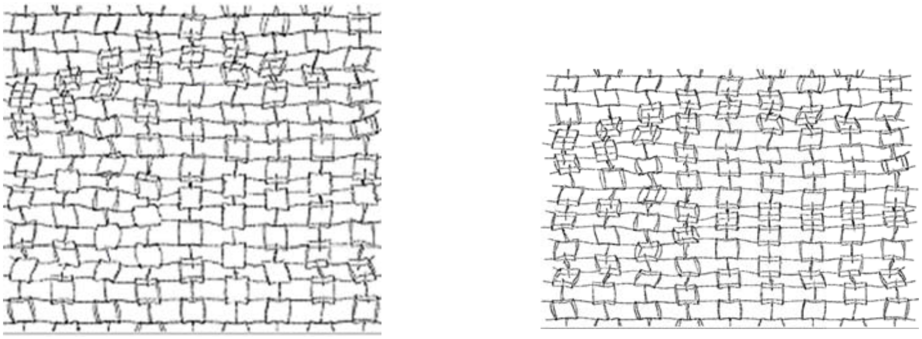
3. NUMERICAL RESULTS AND DISCUSSIONS

3.1 Deformation modes

The crushing behaviours will be different, due to the influences of the impact velocity, the cell dimension, the cell arrangement, and so on.

Figures.2(a) and 2(b) show the deformation process of the lattice structure corresponding to the compressive strain ε = 0.15 and ε = 0.3, respectively. The first deformation band with inverted V-shape begins at the impact end illustrated in Figure 2(a). It's found that the inverted V-shape deformation band is related to impact velocity and the cross section dimension of the rod. The inverted V-shape deformation band takes shape closer to the impact end with the higher impact velocity and the bigger cross section dimension. Moreover, with the higher impact velocity and smaller cross section dimension, the more slender inverted V-shape deformation will be obseарved.

As the dynamic compression develops, an X-shape deformation band can be found in the middle of the lattice structure shown in Figure 2(b). The X-shape deformation band is sensitive to the impact velocity and the cross section dimension. Both the larger impact velocity and the smaller cross section dimension can lead to higher, more slender and later formed X-shape deformation band.



(a) $\varepsilon = 0.15$ *(b)* $\varepsilon = 0.3$

Figure 2. Deformation modes of the lattice structure.

3.2 Energy absorption

Figure 3 displays the influence of cross section dimension of the rod on the energy absorption ability of the lattice structures with impact velocity for v = 12 m/s. The absorption abilities of the lattice structures depend on the cross section dimension mightily. The structures with larger cross section dimension can absorb more energy in the all process of the crushing. It can be explained that it's more difficult to deform for the lattice structures with larger cross section dimension compared with those with smaller cross section dimension.

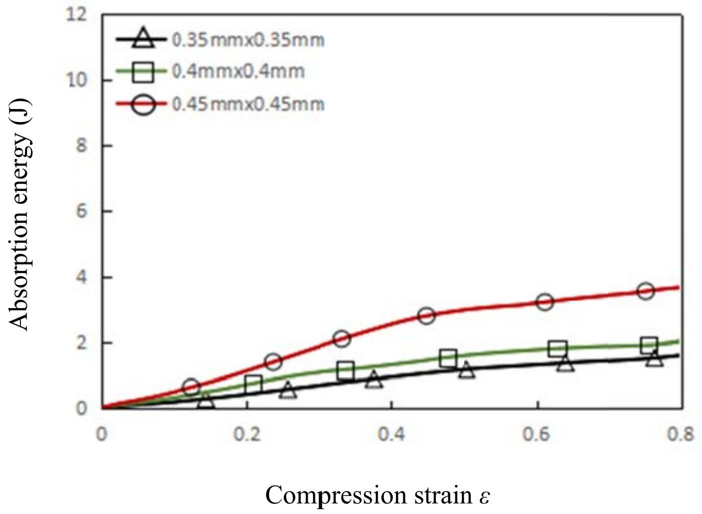


Figure 3. Energy absorption ability of lattice structures with v = 12 m/s.

Figure 4 shows the relationship between the absorption and the compressive strain with different cross section dimension based on impact velocity v=36 m/s. With the increasing of the impact velocity, the inertial effect becomes more and more notable.

More kinetic energy of the impact plate transform to the deformation energy of the lattice structure, which result in more energy absorbed.

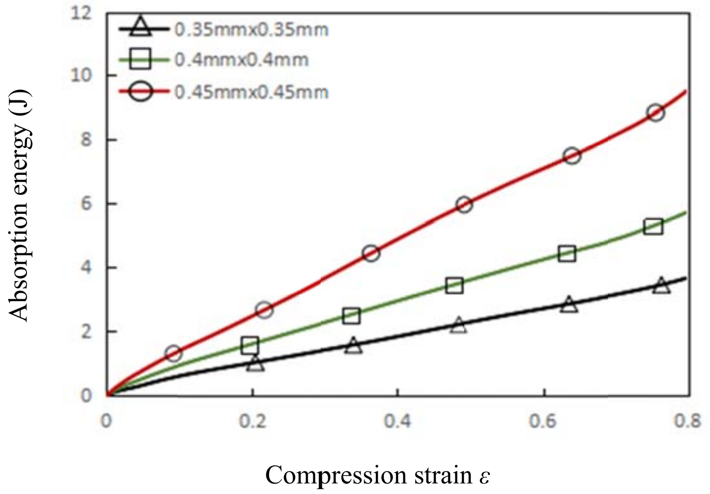


Figure 4. Energy absorption ability of lattice structures with v = 36 m/s.

4. CONCLUSIONS

The in-plane impact properties of the lattice structures are studied. Both effects of the impact velocity and cross section domension on the dynamic crushing characteristics are discussed. In the whole deformation procession, there are two distint deformation band. More slender inverted V-shape deformation will be obsearved with the higher impact velocity and smaller cross section dimension. Both the larger impact velocity and the smaller cross section dimension can lead to higher, more slender and later formed X-shape deformation band. The energy absorption ability can be strengthened by increasing the cross section dimension and the impact velocity.

5. ACKNOWLEDGEMENTS

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