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IMPACT CRUSHING BEHAVIORS OF FUNCTIONALLY GRADED HONEYCOMB STRUCTURES WITH DEFECTS

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Due to the superior characteristics, honeycombs are extensively used as energy absorption and noise reduction devices. In this work, the concept of functionally graded materials is introduced to the honeycomb structures by changing the thickness of cell walls. On the other hand, it is rather difficult to avoid the defects in manufactured honeycombs because of the processing technique. The imperfections of missing cell walls are introduced to illustrate the influences of defects on the impact crushing of the functionally graded honeycombs. Both the deformation modes and energy absorption of the functionally graded honeycombs with defects are studied. The results show that there always is a critical value for the compression strain. When the compression strain is less than the critical value, the energy absorption abilities for the positive density gradient are much stronger than those for the negative ones. Nevertheless, the honeycombs with the negative density gradient will absorb more energy when the compression strain is larger than the critical value. Moreover, the energy absorption capacity would be weakened with the increasing of the defect ratio. The deformation modes are sensitive to the defect location, the concentrated defects always results in the local deformation bands.

Keywords: honeycomb, defects, impact behaviour, plastic deformation, density gradient

1. Introduction

In recent year, with the characteristics of light weight, good shock absorption capability and ease of fabrication, the honeycomb structures have drawn a lot of attention [1–4]. Due to the superior properties, the honeycomb systems have shown various potential applications such as aerospace, architecture, electrical techniques and biological engineering, etc. Therefore, the importance of these structures is realized and both theoretical and exponential works are carried out.

It's well known that it is rather difficult to avoid the defects in manufactured honeycombs. During the past several years, the effects of defects on the mechanical property in honeycomb structures have been received a lot of attention. Chen and Ozaki reported the Stress concentration phenomenon with defects in a honeycomb structure [5]. Chen et al. studied the influence of six different types of morphological imperfection on the hydrostatic yield strength and deformation mechanisms [6]. Ajdari et al. discussed the elastic-plastic behavior of cellular materials with defects. It was found that the yield strength of the cellular structure could be softened by the introduction of missing walls [7]. Zhang et al. studied the influence of the defect location and ratio on the dynamic crushing of metal honeycombs [8]. Nakamoto et al. analyzed the effects of the linear rigid inclusions arrangement on the in-plane impact behavior of honeycomb structures [9].

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 triangular honeycombs with defects is investigated.

2. Analysis model

As shown in Fig.1(a), the two-dimensional honeycomb structure is composed of equilateral triangular cells. The bottom of the honeycomb model is fixed and the top side is impacted by a rigid plate with the velocity of 80m/s. 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 [17]. The side length of unit cell is l=4.5mm shown in Fig.1(b), the thickness of cell walls t = 0.5mm for homogeneous honeycombs but is a variable for functional graded honeycomb models on the basis of the same relative density.

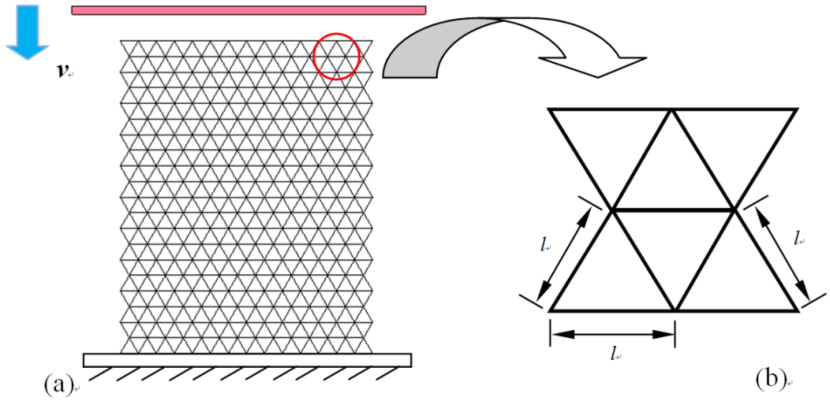

Figure 1: Analytical model: (a) the honeycomb structure with the impact plate and (b) the unit cell.

The relative density of honeycombs is given as [18]

$$\frac{\rho^*}{\rho_s} = 2\sqrt{3}\frac{t}{l}\left(1-\frac{\sqrt{3}}{2}\frac{t}{l}\right), \quad (1)$$

where ρ^* and ρ_s are the density of honeycomb structures and materials.

The density gradient γ is defined as [15]

$$\gamma = \frac{\rho_i - \rho_{i+1}}{\Delta L}. \quad (2)$$

3. Numerical results and discussions

3.1 Deformation modes for defect systems

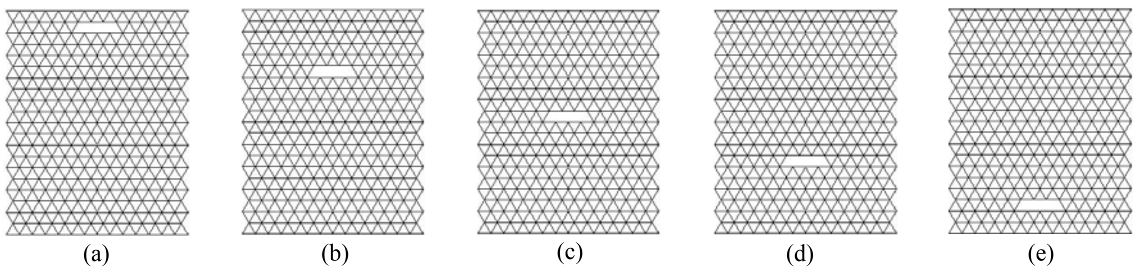

Figure 2: Consecutive cell walls missing defects corresponding to different gradient regions.

Defects are introduced by missing some consecutive cell walls. In Figs.2(a)–2(e), the honeycomb structures are divided into 5 equal regions along the impact direction. The thicknesses of cell walls in the same region are constant but follow the relation shown in Eq.(2) in different regions, which denotes the functional graded characteristics of the honeycomb systems. In order to study the influence of defects on the deformation mode and energy absorption ability of honeycomb structures, the defects are located in different graded parts, which are shown in Figs.2(a)–2(e).

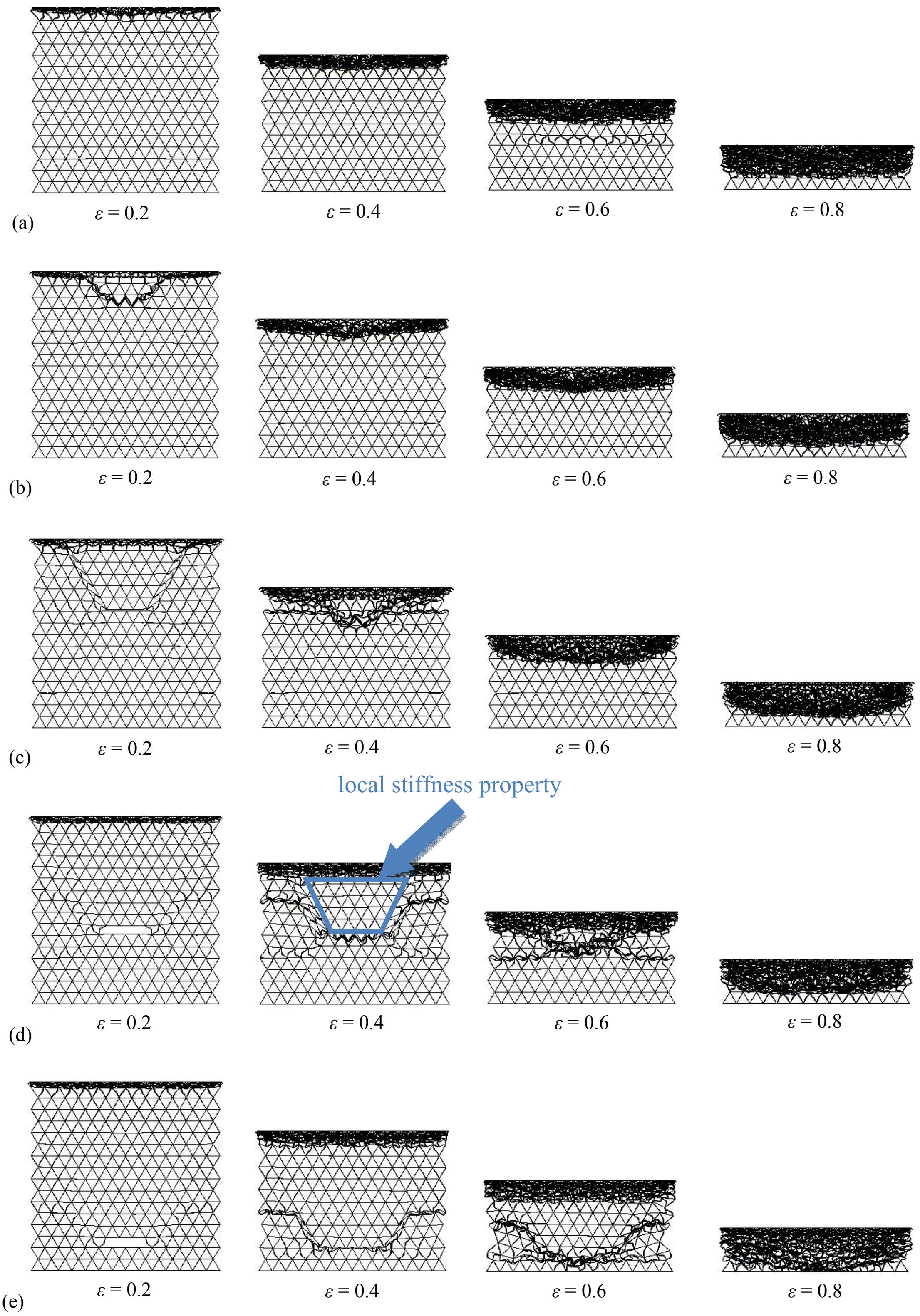

Figure 3: Deformation modes for different defective locations in the honeycombs with $\gamma = -0.01$.

Figs.3(a)–3(e) show the deformation process of honeycomb structures with $\gamma = -0.01$, which correspond to the consecutive defects placed in different gradient regions in Figs. 2(a)–2(e), respectively. It can be seen that all of first the deformation bands for different fives cases occur from the impact sides.

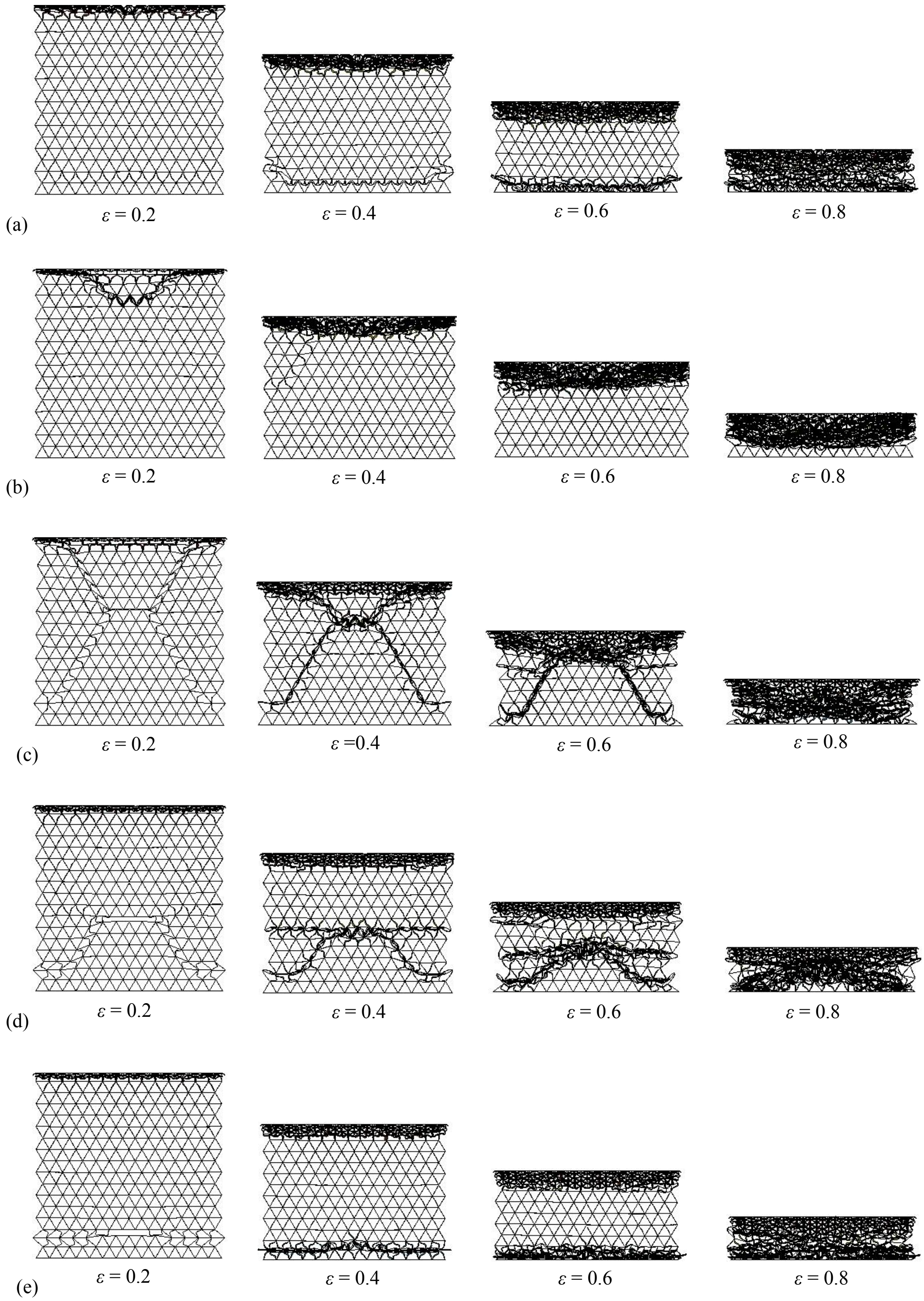

Figure 4: Deformation modes for different defective locations in the honeycombs with $\gamma = 0.01$.

The deformation for the defects location is presented in Fig.3(a). The row in which the defects locate has been crushed before the effect of defects is shown. Then, it performs in the same manner in which no defects exist shown in Fig.2(b). In Figs.3(b) and 3(c) for the defect location, the deformation bands with isosceles-trapezoid-shape are appear and develop. The bottoms of the isosceles-trapezoid-shape are along defect location in both figures. As the compression deformations in Figs.3(b) and 3(c) increases, the bottoms of isosceles-trapezoid-shape turns to be curved, which is presented in Fig.3(b) (corresponding to $\varepsilon = 0.2$) and Fig.3(c) (corresponding to $\varepsilon = 0.4$).

In Figs.3(d) and 3(e) when $\varepsilon = 0.4$, for defects location, the most important feature is that the deformation bands with the upper half X-shape can be observed and the lower side of the deformation bands are long the defects. As the compressions proceed in Figs.3(d) and 3(e), the deformation bands turn to be completely X-shape which is shown in Fig.3(d) (i.e. $\varepsilon = 0.6$) and inverted π-shape which is shown in Fig.3(e) (i.e. $\varepsilon = 0.6$). Finally, the honeycomb structures are completely densified.

Moreover, as shown in Fig.3(d) when $\varepsilon = 0.4$, the cells in the upper half X-shape behave nearly non-deformation with impact loading. However the ones being out of the upper half X-shape turn to deform. This phenomenon is called local stiffness property. It can be concluded that compared with the perfect honeycomb structures, the defect position plays an important role on the deformation modes.

The deformation modes of honeycomb structures with $\gamma = 0.01$ are illustrated in Figs.4(a)–4(e). Similar to the case of $\gamma = 0$ and –0.01 discussed above, all of the deformation bands initiate at the impact sides. The dynamic deformation modes of honeycomb structures rely on the position of defects. For the same density graded structures (i.e. $\gamma = 0.01$), the introduction of the defects results in the crushing of fixed side becoming slowly. Furthermore, for the same location of the defects in Fig.4(b) (i.e. $\gamma = 0.01$) and Fig.3(b) (i.e. $\gamma = -0.01$), the deformation processes have similar behaviors. For the case that shown in Fig.4(c), the completely X-shape deformation band is clearly shown when $\varepsilon = 0.2$ and 0.4. With the crushing propagating downwards, the X-shape deformation band develops to a π-shape one.

Different from the upper half X-shape turning to the π-shape deformation band in Fig.4(c), the deformation band appears the π-shape from $\varepsilon = 0.2$ to $\varepsilon = 0.6$ in Fig.4(d). Moreover, although the defect locations are the same, the second deformation band in Fig.4(e) is the I-shape along the defect line, which is different from that in Fig.3(e). At the same time for the second deformation develops, the crushing in the impact side is still moving toward to the bottom and the cells is being completely densified. Based on the results of different deformation modes, it can be observed that both defect position and density gradient have significant influences on the deformation modes.

3.2 Energy absorption of graded honeycombs with defects

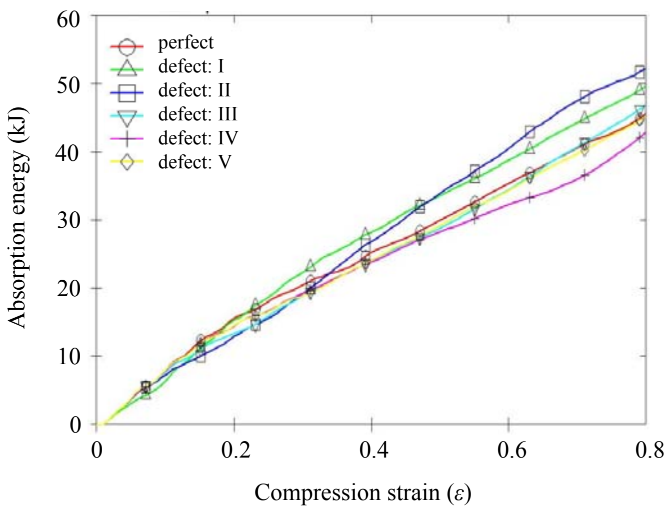

Figure 5: Energy absorption ability of graded honeycombs with $\gamma = 0.01$.

Fig.5 shows the influence of defect location on the energy absorption ability of graded honeycombs with density gradients for $\gamma = 0.01$. The absorption abilities behave almost the same at the early stage of crushing, in which that all of the deformation modes are similar for $\varepsilon < 0.1$. The energy absorption abilities for defects corresponding to Figs.4(a) and 4(b) are stronger than those for perfect and the other defect structures. This is because the defects in Figs.4(a) and 4(b) lead to the deformation band appearing in the upper part of the honeycomb structure, in which the cell near the impact side is thicker than those in other regions. The energy absorption for the crushing appearing in the upper part is more than that in the lower part.

4. Conclusions

The in-plane impact properties of functional graded honeycombs with defects are studied. Both effects of the defect location and density gradient on the dynamic crushing characteristics are discussed. For the perfect graded honeycombs, the second deformation band for graded honeycombs become quite different from those for the homogeneous one and it appears earlier with the density gradient increasing. The second deformation band appears earlier with the increasing of positive γ but decreasing of the absolute value for negative γ. When $\gamma = -0.01$, all of the first deformation bands for different defect locations occur from the impact sides. The second deformation bands appear with the isosceles-trapezoid-shape, upper half X-shape and completely X-shape for different defect locations. When $\gamma = 0.01$, according to the defect locations, first deformation bands are similar to the case of $\gamma = -0.01$. The deformation bands behave as the completely X-shape, π-shape and I-shape. For higher compression strains of gradient honeycombs, the energy absorption abilities for the increasing of the density gradient along the impact direction are much stronger than those for the decreasing of the gradient. For the case of the density gradient decreasing along the impact direction, the energy absorption for the crushing appearing in the upper part is more than that in the lower part. Both density gradient and defect location have significant influences on energy absorption ability.

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