IMPACT DEFORMATION OF FUNCTIONALLY GRADED CELLULAR SOLIDS

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Summary *The purpose of this paper is to investigate the in-plane deformation of the functionally graded cellular solids (FGCS) under impact loading. Finite element simulations are carried out by using FEM software ABQUS/EXPLICIT. Honeycomb is used as a representative cellular solid, where the gradient of the yield stress in the parent material is introduced. The load is applied from the strong edge or weak one, respectively. A constant velocity is given to the impact plate varying from 3 to 200m/s. By analyzing the deformation profiles, three basic deformation modes (I, II, III) are found for FGCS. Based on the three basic modes, two analytical models are proposed. Theoretical derivation is carried out by applying the shock theory. Further FEM simulations with an initial impact velocity are carried out. Comparison is made between the FEM and theoretical results and it shows reasonable agreement.*

INTRODUCTION

Due to their high stiffness to weight and strength to weight ratios, cellular solids are widely used in engineering applications, especially under dynamic loading conditions. Previous studies [1-4] mainly focused on the honeycombs with homogenous materials. Very few studies, experimental, numerical or analytical, have been carried out for cellular solids with graded properties. For functionally graded cellular solids (FGCS), a gradual increase in the cell size distribution or material yield stress can influence many properties such as mechanical shock resistance and thermal insulation. As a result, it is valuable to open another venue to explore the mechanical properties of FGCS.

FINITE ELEMENT MODEL

The finite element model is represented in Figure 1a. The structure is composed of 16 layers in the X1 direction and 15 in the X2 direction. The cell is regular with the same edge length $l = 2.7$mm and the corresponding angle between edges 120^0. The total length in the X1 direction is 0.08m. The wall-thickness of the cells and the density of the material are 0.2mm and 2700kg/m^3, respectively. Thus, the relative density of the honeycomb is $\rho = 2t\rho_s / \sqrt{3}l = 230.85$kg/m^3. The out-of-plane width of the honeycomb is *b*=0.9mm. The material of the cell wall is assumed to be elastic, perfectly plastic with *E*=69GPa, and *v*=0.3, where *E* and *v* are the Young's modulus, Poisson ratio of the material, respectively. Figure 1b shows the distribution of the material's yield stress when the difference of the yield stress of the material between adjunct layers is $\Delta\sigma_{ys} = 5$MPa . The virtual line represents the average yield stress of the structure. The velocity applied at the impact plate varies from 3 to 200m/s.

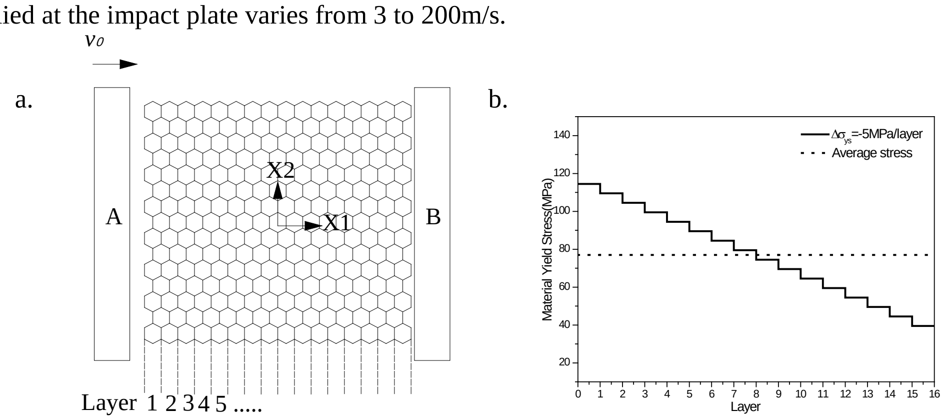

Figure 1 a) Finite element model of the graded hexagonal honeycomb structure (FGCS), b) Distribution of the material yield stress of FGCS ($\Delta\sigma_{ys} = -5$MPa)

DEFORMAITON MODES AND ANALYTICAL MODELS

By analyzing the deformation profies, three basic deformation modes (I, II,III) are found. When the impact velocity is low, the deformation is dominated by the quasi-static stress of the honeycomb structure. Under this condition, the deformation occurs from the weaker layer to the stronger layers. When the impact velocity increases to high values, the inertia effect begins to influence the deformation process so that deformations are found from both the supporting and the loading edge. Mode III occurs when the impact velocity is very high. In this condition, the deformation is dominated

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by the inertia effect and the quasi-static yield stress may be neglected. Figures 2a and 2b shows the typical deformation process of I mode and III mode at different instants, repectivley. δ is the displacement of the impact plate and l_0 is the total length of the structure. It should be noted that the three modes are only valid for the impact at the strong end only.

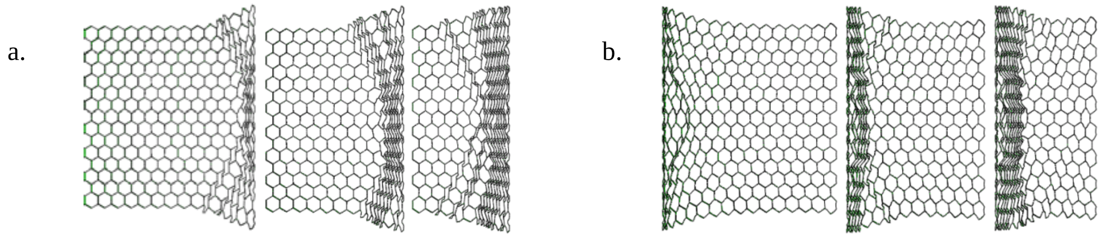

Figure 2. a) Typical deformation process of I mode (v=3m/s) b) Typical deformation process of III mode (v=50m/s); $\Delta\sigma_{ys} = -5\text{MPa}$, $\delta / l_0 = 0.25, 0.42, 0.59$

A graded cellular column, whose material's yield stress varies along the axial direction, is supposed to experience dynamic loading. Two typical scenarios are considered, which are shown in Figure 3. In the first scenario the graded cellular column together with an attached mass impinges on a rigid target; and in the second one the graded cellular column is directly impinged by a mass *G*. Theoretical derivation was carried out by applying the shock theory. The velocity and the dynamic stress behind the shock front are obtained in the terms of the displacement of the impinging mass.

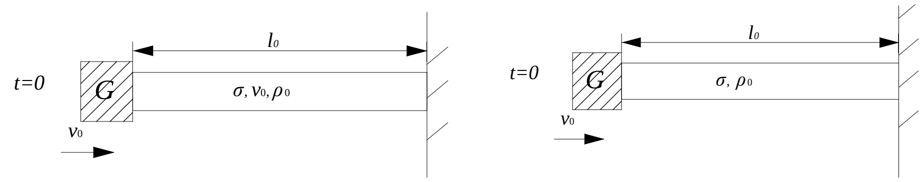

Figure 3. Two typical scenarios

The capacity of the energy absorption of the graded structure is compared with a homogenous cellular column. Theoretical results show that the capacity of energy absorption is enhanced when the initial impact end is weaker. Further finite element simulations are also carried out by using ABQUS/EXPLICIT. The analytical predictions are compared with the FEM results, showing reasonable agreement. Good agreements between the prediction and FEM reulsts are shown Figure 4 for the velocity varying with the mass displacement

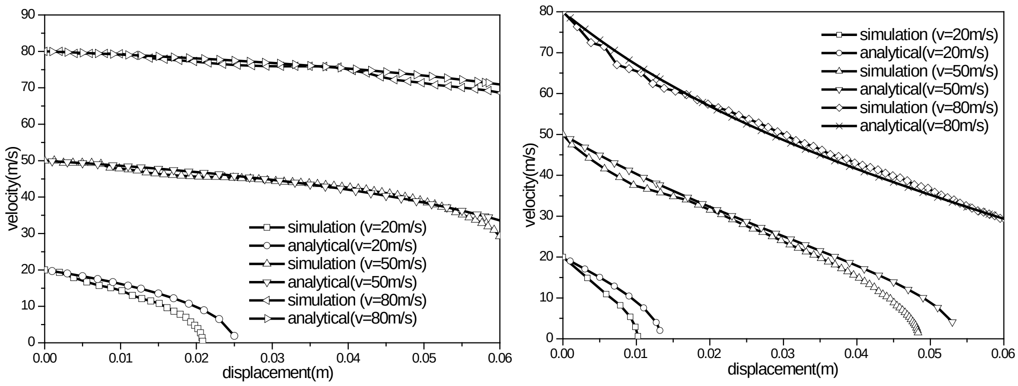

Figure 4 Comparisons of velocity varying with displacement of the impact mass (scenario I and II, *g*=1.56MPa/m)

CONCLUSION

Three basic deformation modes are found for FGCS under in-plane dynamic loading by analyzing the FEM deformation processes. Two analytical models are proposed. By applying the shock wave theory, the velocities varying with displacement of the impact mass are determined in closed form. Further FEM results show good agreement with the analytical results.

References

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