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Internal-structure-model based simulation research of shielding properties of honeycomb sandwich panel subjected to high-velocity impact☆

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ABSTRACT

Honeycomb sandwich panel has been widely used in aerospace and aeronautic engineering as load-bearing components. Cost-effective shielding structure can also be built based on honeycomb sandwich panel. The shielding properties of honeycomb sandwich panel subjected to high-velocity impact is of great concern to spacecraft design. Three dimensional internal-structure-based simulation research of honeycomb sandwich panels under high-velocity impact is carried out. The point-type internal structure model is constructed, where the impacted area is refined to capture localized deformation and improve the accuracy. The internal structure model is validated by experimental results and empirical formula. Then typical impact processes are simulated to investigate the cutting and channeling effect of the honeycomb core on the projectile. Projectile mass, impact velocity and internal-structure parameters of the honeycomb core are varied to obtain their influences on the channeling effect of the fragmented projectile. The thickness of the honeycomb core influences is found to affect much on the shape of the hole on the rear facesheet. Three empirical equations with respect to impact parameters and internal structure parameters are presented based on numerical results and the dimensional analysis.

1. Introduction

The honeycomb material has been widely applied in engineering fields, such as aerospace engineering and aeronautic engineering, so dynamic responses of honeycomb sandwich panel under different loading conditions are of great interest to scientists and designers. The threat from high-velocity impact to spacecrafts can be very frequent from space debris and meteoroid [1]. As the major load bearing components, honeycomb sandwich panels can also serve as cost-effective shielding structure [2] against impact loading for the functional components inside the spacecraft. The responses of honeycomb panel subjected to high-velocity impact, in addition to the mature researches of statics and low-strain-rate dynamics, should be paid more attention to, since the mechanisms of high-velocity impact and low-velocity impact are quite different. The damage is highly localized during high-velocity impact. Some typical results, such as perforation, spalling, and debris cloud behind the target panel, appear in high-velocity impacts.

The channeling effect of honeycomb core and the ballistic limit of honeycomb panel are often focused, especially in the experimental researches. Sennett and Lathrop [1] found that the honeycomb core has an obvious channeling effect on the debris cloud, implying that the debris cloud after impact spreads a very limited range. The channeling effect can decrease the shielding capability compared to double facesheet structure without honeycomb core. The shielding performance of honeycomb panel for the inside components was also investigated [3–6]. The damage and the signal change in the circuits of the cable bundles behind are emphasized [4–6]. Based on the experimental results, the trajectory and the distribution angles of the debris cloud were expressed as functions of material parameters and impact velocities [7].

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In the field of ballistic limit studies, Taylor et al. [8] found that the inclined angles have little effect on the damage of honeycomb panel. Double-layer honeycomb core [2,9] was developed by inserting an extra facesheet in the middle of a honeycomb core. It coincided with the anticipation that the honeycomb panel with double-layer core was found to have better shielding effects than single-layer core [2,9]. The empirical equations for ballistic limits were obtained from experimental results [3,4,10]. Schonberg et al. [11] extrapolated and validated the ballistic limit equation in the range that initial experimental data did not cover. They found that the ballistic limit equation was conservative in predicting the perforation.

Relatively high cost and difficulties in reproducing and capturing results in experiments arouse the interests in numerical methods. The traditional numerical methods have different difficulties in solving high-velocity impact problems due to strong nonlinearity. Mesh-based Lagrangian methods, such as finite element method (FEM), suffer from severely distorted elements which can lead to reduction in time step size and even abrupt computation collapse [12]. Erosion schemes remove the distorted elements, so that the computation can be resumed, but severe accuracy decrease may exist and the total mass is no longer conserved.

The recently fast-developing meshfree particle methods overcome existing difficulties of mesh-based method in large deformation problems. Smoothed particle hydrodynamics (SPH) method, one of meshfree particle methods, was widely used since it was embedded in commercial softwares such as LS-DYNA [13]. Taylor et al. [9] used AUTODYN software to study the performances of different numerical methods. The mesh-based Lagrangian method and SPH method can obtain nearly the same channeling results in 2D simulation. But meshfree models can show more details during the impact process, because no erosion schemes are needed. 3D models for oblique impacts showed that the inclined angles have little effect on the damage of rear facesheet owing to the channeling effect of honeycomb core. Another research by Ryan et al. [14] suggested a method of measuring fragment configuration, which can be used to describe the morphology of the debris cloud quantitatively.

Large computational cost spent on searching neighbor particles sharply increases the computational burden of SPH. Many numerical researches on honeycomb panel with SPH employed only 2D axisymmetric models [9] based on an isotropic assumption of honeycomb panel. When the facesheet is made of anisotropic material or the impact is oblique, however, 3D model for the honeycomb core is demanded [9,14]. An efficient meshfree method, therefore, is highly desired to simulate large-scaled 3D high-velocity impact problems.

Material point method (MPM) is one type of meshfree methods. MPM was proposed by Sulsky et al. [15] as an extension of particle-in-cell method to solid mechanics. Lagrangian points and Eulerian background grids are both employed in MPM computation. Lagrangian points carry all the physical variables, such as the mass, the velocity, the stress and the strain. Lagrangian points describe the deformation and the boundary of the material. The use of Lagrangian points avoids the difficulties in Eulerian method that history variables are not easy to trace and the problems caused by convection terms. Eulerian background grid is used to solve momentum equations and to calculate spatial derivatives, which overcomes the shortcomings in Lagrangian method that large deformation causes element distortion. So MPM owns both the advantages of the Lagrangian and Eulerian methods but overcome their difficulties. MPM can be very efficient for the problems of extremely large deformation and moving discontinuities. On one hand, the critical time step size in MPM is controlled by the background element size, which does not change during the simulation, so the critical time step size will not decrease much even when the material is extremely compressed. On the other hand, no neighbor point search is needed in MPM, so the heavy computational burden of searching process in SPH method is saved. Ma et al. [16] compared MPM and SPH in detail, and they pointed out that the efficiency of MPM is much higher than that of SPH. They also obtained MPM results more accurate than SPH results in impact simulations.

MPM has been successfully applied in the problems of low-velocity impact [17], dynamic fracture [18,19], fluid–structure interaction [20], and high-velocity impact [21–23]. The foam material has randomly sized and distributed voids, which poses great challenges to mesh-based discretization of material internal structure. The reconstruction of material point model for the internal structure of foam material is much easier. Gong et al. [22] constructed the internal structure model of aluminum foam and successfully simulated the high-velocity impact problems based on the material point internal structure model. Liu et al. [23] combined the nano-scale molecular dynamics and the material point method to obtain better parameters for the equation of state under high temperature and high pressure in the hyper-velocity impact process. In our previous work [24], the high-velocity impact of micron particles on the aluminum plate is investigated with material point method. Empirical formulations of cavity dimensions were obtained based on a series of simulations with varying parameters.

In this paper, the dynamical responses of honeycomb sandwich panel under high-velocity impact are studied with MPM-based internal structure model. MPM formulation, the construction of internal structure model, and the material models adopted in the paper are given in Section 2. In Section 3, MPM model is validated by comparing with existing experimental results. The analysis of numerical results of high-velocity impact are discussed in detail in Section 4. Also the influences of the projectile mass and the impact velocity are investigated. The influences of the internal structure parameters of the honeycomb core are studied in Section 5. Three empirical equations are obtained using dimensional analysis in Section 6. Section 7 concludes the whole paper.

2. Model description and simulation method

2.1. The internal structure of the honeycomb material

The honeycomb sandwich panel is usually composed by three parts including the front facesheet, the honeycomb core and the rear facesheet, as shown in Fig. 1. The left part in Fig. 1 is the side view, and the right part shows the in-plane cross section. t_f and t_r

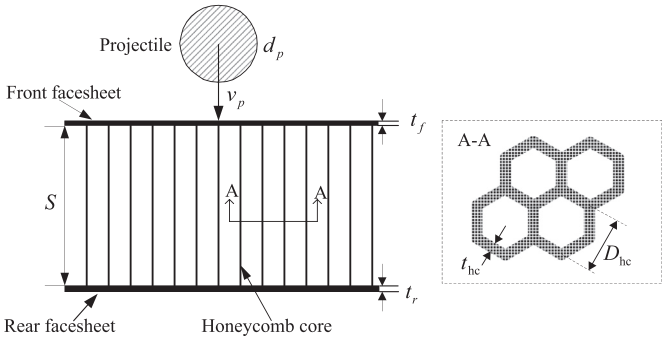

Fig. 1. The structure of the honeycomb panel.