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Assessment on energy absorption of double layered and sandwich plates under ballistic impact

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ABSTRACT

To study plastic deformation and energy absorption capability of monolithic, double layered steel plates and sandwich plates with steel skins and aluminum foam core, the quasi-static compressive experimental for four types aluminum foam with different density are carried out. The modified constitutive model is presented based on experimental results. The virtual tests using numerical simulation method by finite element code LS-DYNA were conducted with different impact velocities based on quasi-static experimental parameters. Energy absorption effect of projectile shape, skins thickness, core thickness and core densities on the plastic deformation and energy absorption capability of sandwich plates are discussed. It was shown that mechanics properties of aluminum foam with different density can be described accurately by modified constitutive model. For spaced type plate, the space between first layered and second layered targets have a significant impact on plastic deformation and energy capability. With the increase of impact velocity, the absorbed energy of plates first decreased from the ballistic limit to a minimum value and then increased monotonically.

1. Introduction

Optimization design of double layered and sandwich shields for protection against projectiles impact and penetration has long been of interest in military and civilian marine applications. As a potential improvement over monolithic plates, many different multiple layer configuration and sandwich plates has been proposed [1]. Sandwich structures, as a novel engineering application structures, which consist of two thin and stiff skins and a softer core such as aluminum foam, polyurethane, honeycombs, have attracted increasingly wide research interests due to their superior performance in terms of specific stiffness and strength, excellent energy absorption capability under impact/blast loading [2–4]. Given these advantages, during their service life, these sandwich plates may be subjected to high velocity impacts and penetration by low-mass fragments [5], for example, the warships potentially attacked by bullets and missiles (Fig. 1). Therefore, choosing a structure to improve the ballistic performance of the hull and bulkhead for fragment effects is very important, sandwich plates with aluminum-foam core have superior performance in terms of specific stiffness and strength, excellent energy absorption capability under impact/blast loading. These impacts and penetration include complex mechanical behavior, i.e. large deformation, erosion, high strain rate dependent nonlinear material behavior and fragmentation. As protective structures, energy absorption capability always is an important index. Although, a lot of investigations have been done on the energy absorption and penetration resistance of monolithic, double and sandwich plates by experimental, theoretical and numerical method, limited comparative studies on monolithic, double and sandwich shields were reported in the open literature.

Several aspects of the penetration resistance and energy absorption capability of monolithic, double-layered and sandwich plates are studied previously. Zhang and Deng et al. [6–8] investigated the effect of the air-gap between layers, the number, order and thickness of layers on the ballistic performance of steel plates by extensive experiments. Y.X. Peng et al. [9] proposed a reproducing kernel particle method (RKPM) to simulate the large deformation of a curved shell. According to the principle of virtual power, the governing equation of an arbitrary curved shell was derived. A.M. Zhang et al. [10–13] based on two benchmarks on underwater impacts, proposed a coupled SPHS-BEM method for the interaction of transient fluid-structures: the SPH shell (SPHS) was selected to discretize the shell structures and the second-order boubly asymptotic approximations (DAA2) of boundary element (BEM) was chosen to analyze flow-field. F.R. Ming et al. [14,15] proposed an integral model of a SPH shell with higher precision to get the

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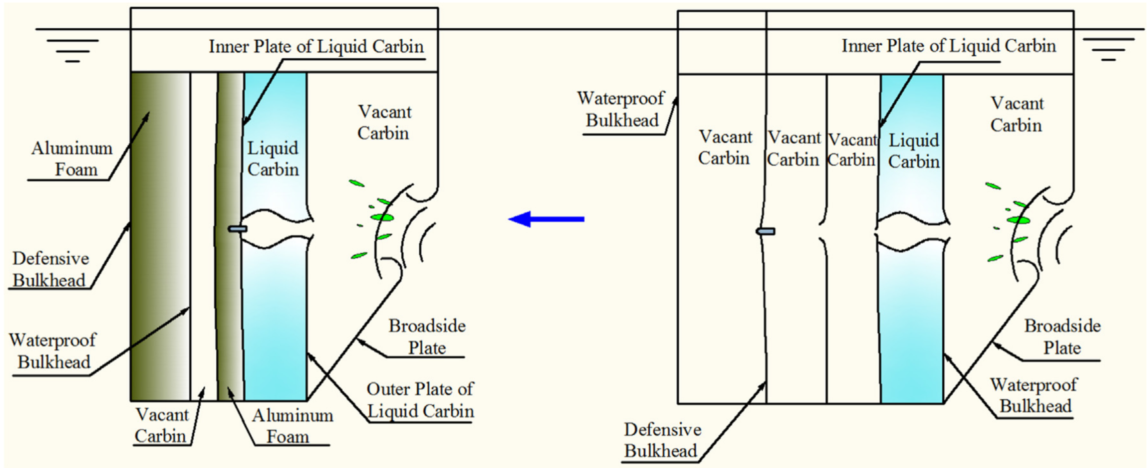

(a) Side structure of sandwich plate with aluminum foam core (b) Coventional side structure

Fig. 1. Scene of penetration of warship side structure.

nonlinear strain along the thickness direction. The FEM, global model and integral model of SPH shell was used to analysis of geometry and material to prove the feasibility and accuracy of the integral model.

Liang et al. [16] presented a protective method to reduce potential personnel injury from fracture and fragmentation of the structure, the application of polyurea coating on DH-36 steel plates. It was found that the energy absorption in the polyurea is almost entirely due to stretching and the polyurea plays a major role in terms of energy absorption for both the pointed and the flat projectiles. Jing et al. [17] investigated experimentally and numerically the dynamic response, energy absorption capability, deformation and failure of clamped aluminum face-sheet cylindrical sandwich shells with closed-cell aluminum foam cores. Experimental and numerical results indicated that the shock resistance of sandwich shells could be enhanced significantly by optimizing their geometrical configurations. Yang et al. [18] investigated the influence of the origami patterns on the energy absorption capability and the deformation mechanism of tubes under uniaxial loading by numerical and experimental method. The results indicated that the initial peak force of origami tubes would be significantly reduced, while the energy absorption capacity could be improved or maintained. Wang et al. [19] investigated the energy absorption efficiency (EAE) of CFRP laminates with different thickness by experimental and numerical methods. Comparative studies on EAE of CFRP laminate and 304 stainless-steel plates shown that EAE of CFRP laminates is higher than 304 stainless-steel plate. Dean et al. [20] analyzed energy absorption in thin(0.4 mm) steel plates during perforation by spherical projectiles of hardened steel. The results showed that the energy absorption is related to failure mode. Ahmad et al. [21] investigated the crush behavior and energy absorption response of foam-filled conical tubes subjected to oblique impact loading, aim at quantifying the energy absorption of empty and foam-filled conical tubes. Iqbal et al. [22] studied the ballistic performance of hemispherical aluminum shells and computed the energy absorption in different modes of deformation. It was found that the mechanics of deformation and energy absorption capacity to be significantly influenced by the shell thickness and projectile nose shape. Xu et al. [23] investigated perforation resistance of two types of polyethylene core sandwich structures by using experimental and numerical method. The failure mechanism, perforation behavior and distribution of energy dissipation were simulated and analyzed. Ivañez et al. [24] studied the high-velocity impact response of sandwich plates with E-glass fiber/polyester face-sheets and foam core, the contribution of the foam core on the impact behavior was evaluated by the analysis of the residual velocity, ballistic limit and damage zone. Hou et al. [25] studied the ballistic performance of metallic sandwich panels with Al skins aluminum foam core by quasi-static and impact perforation experiments, the effects of impact velocity, skin thickness, density of foam core and projectile shapes are study in detail. Dean et al. [26] investigated the energy absorption capability of sandwich panels with metallic fiber cores subjected to projectile penetration. The results indicated that the relationship between energy absorption and impact velocity was not monotonic (i.e. with the increase of impact velocity, the absorbed energy first decreased from the ballistic limit to a minimum value, then increased monotonically). Güden M et al. [27] analyzed the single aluminum foam tubes and multi-tubes by quasi-static compression tests. It was found that multi-tubes were more effective than single tubes at similar foam-filler densities.

A review of the literature reveals that the most researches considering only one or two cases under high velocity status. At the same time, many investigations highly depend on experimental results. Although experimental studies provide essential and intuitive information, since impact and penetration phenomena depends on numerous parameters, a comprehensive knowledge of its influence on ballistic behavior requires a widely test program, which is time consuming and expensive. In this paper, the Q235 Johnson-Cook constitutive parameters are introduced and analyzed, and then the quasi-static compression performance of aluminum foam was investigated by experimental in Section 2. Then in Section 3, the numerical tool and method were introduced and validated with experimental data obtained from other scientific literatures, numerical method including mesh generation, boundary conditions and contact definition. In Section 4, the high velocity impact response and energy absorption capability of monolithic, double-layered plates and sandwich plate with steel skins and aluminum foam core was investigated by numerical method based on quasi-static compression experimental results. The paper can provides the basis for the optimization design of the ballistic resistance characteristics and sandwich structures with aluminum foam core under different extreme loading.

2. Material properties

2.1. Q235 steel material properties

The monolithic, double-layered and skins of sandwich plates are made of Q235 steel which has been studied by many researchers, so the physical parameters are well known. The Johnson-Cook constitutive model [28] are suitable for various metal material and are widely used numerical calculation for metal material subjected to large