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Crush dynamics of square honeycomb thin rubber wall

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ABSTRACT

Previous experimental study has proven that rubber honeycomb claddings with thin rubber core can be used to attenuate the water blast wave impinged onto ship hull. As a theoretical extension, the dynamic crush behavior of the square honeycomb core made by thin rubber wall is investigated in this paper. As the dynamic effects play a significant role in the behavior of core, several distinct dynamic effects are analyzed including inertial resistance, nonlinear elasticity, inertial stabilization of webs against buckling, and material viscosity. The influences of the initial imperfection shape and amplitude are discussed too. These effects are illustrated and quantified with the aid of detailed numerical calculations. Some preliminary attempts are also made on the theoretical prediction on the stress wave transmission process.

1. Introduction

Elastomers or rubber-like materials are often used to mitigate damage caused by impulsive or impact loads because of their low modulus, high damping characteristics and large extensibility [1]. In some preceding research works, the water blast attenuating performance of a rubber sandwich layer coated onto the hull of floating metal boxes has been experimentally investigated [2]. Test results show that the transmitted impulse at the initial stage can be reduced by 50% at its most, owing to the rubber wall flexibility and fluid–structure interaction mechanism. Consequently, both acceleration and strain peaks of the box induced by shock wave can be effectively reduced.

Though practical attenuating effects have been proven by test results, the acting mechanism of the rubber honeycomb claddings underwater blast environment is far from being illuminated. Irrespective of other factors such as wave transmission, reflection and fluid–structure interaction, knowledge about the crush behaviors of the core that is made by rubber thin wall is one of cornerstones to understand the whole complex transient dynamic process. Considerable efforts have been addressed to the crushing behavior of metal sandwich structures for applications where energy absorption is important [3–6], but research concerning the crush behavior of rubber wall is seldom found in literature. Dissimilar with purely metal structure, there is no distinct plastic yielding in rubber-like polymer. Its modulus is much lower than that of metal and material viscosity plays a more important role, especially in the high strain-rate conditions. These factors make the crush behavior of rubber wall very different from that of purely metal core. As a theoretical extension to the previous experimental works, this paper is mainly focused on the crush dynamics of the rubber core of the rubber honeycomb claddings when subjected to shock loads. A unit periodic cell is intercepted and its dynamic crush process under two types of compressive loads is numerically modeled using ABAQUS finite-strain package. As the dynamic effects play a significant role in the behavior of the core, several important and distinct dynamic effects: (i) inertial resistance, (ii) inertial stabilization of webs against buckling, and (iii) material strain-rate dependence, are illustrated and quantified.

2. Model and material constitutive behavior

2.1. Basic model

The rubber honeycomb claddings used to attenuate water blast wave can be thought as a kind of sandwich structure when considering hull plate and the coatings simultaneously. Dissimilar with all-metal sandwich structure, the core of the coating is thin flexible rubber wall. Fig. 1(a) shows the basic geometry of a single piece of coating, which is wholly molded using the neoprene and some other additives. To enhance strength and toughness, the outer face sheet is strengthened by interwoven nylon lines as that in automobile tire. In practical application, the coating is plastered onto the outer hull of ship piece by piece using special adhesive as shown in Fig. 1(b). When water blast wave impinges, the low density outer face along with the sound flexibility of rubber core

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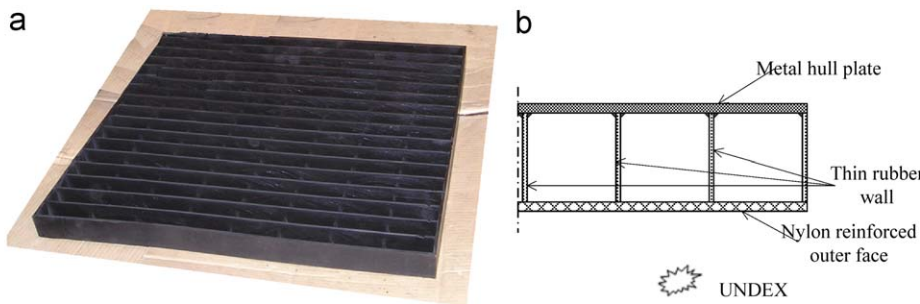

Fig. 1. (a) Basic geometry of the rubber coating and (b) installing style of the coating onto ship hull.

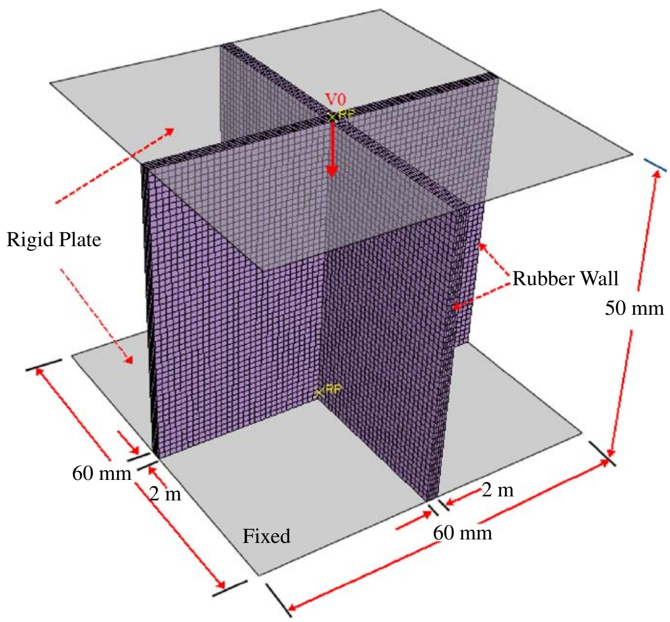

Fig. 2. Basic unit cell model with representative finite-element mesh.

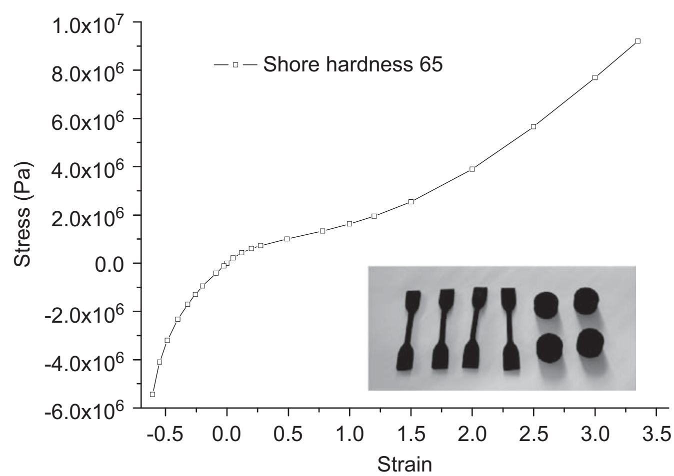

Fig. 3. Stress–strain curves of the neoprene used in rubber sandwich.

promise relative low impulse transmitted from outer fluid to the main hull structure [2]. Resultantly, the damage of the UNDEX to the floating structures can be greatly attenuated. Compared with purely metal sandwich structures, the energy absorbing capability of rubber honeycomb cladding is lower. But its simple building technique and easy maintenance merit make it become a good choice at least when applied to weak or medium shock environment.

The transient response of the hull with rubber honeycomb claddings subjected to water blasts is a very complex process as many dynamic processes, such as shock wave incidence and reflection, core buckling, hull motion and so on, are coupled one another in a very short moment. In this paper, our focus is only on the crush dynamics of the rubber core under impact loads and fluid-structure action is not considered. Without loss of generality, a unit periodic cell of the coating is studied. The finite-strain version of ABAQUS is selected as the numerical analysis tool, which is well suited for the transient dynamics and quasi-static analyses using an explicit integration approach.

The basic numerical model of the unit periodic cell is shown in Fig. 2. As its dimensions referred to the practical coatings, the cell is 50 mm in height and 60 mm in width, with two intersected thin rubber walls, both 2 mm in thickness. Eight node brick elements with reduced integration C3D8R are used in the calculations. As a representative mesh is shown in Fig. 2, five elements are taken through the web thickness and forty through the wall height. Two rigid plates, one movable on top and one fixed at bottom, are used to simulate the two face plates of the whole structure. Both rigid plates are ‘welded’ onto the lateral faces of the rubber walls and neither relative displacement nor rotation is allowed. The general contacts between web and rigid plate as well as web itself are defined to prohibit any penetration between solids.

2.2. Hyperelastic property of rubber

For the continuity of works, the rubber material of the actual rubber honeycomb claddings is still used here in the numerical model. The rubber used in the core is a kind of neoprene with shore hardness number 65 [2]. Neoprene, often produced by polymerization of chloroprene, is a kind of synthetic rubber with very sound flexibility and wearability. Some specimens cut from the coatings are tested on an INSTRON universal material testing machine. Fig. 3 shows the tested stress–strain curve. Both tensile and compressive behaviors are included. The specimen exhibit excellent flexibility as it can be elongated up to 300% without any visible damage. For the restriction of conditions, the biaxial and volumetric test data are unavailable. No further experiment is made on the high strain-rate loading condition too.

Strong dynamic effects come into play in the behavior of the core when subjected to shock loads. An important dimensionless parameter governing the inertial effects is V_0/c, where V_0 is the relative velocity of the sandwich faces, c is the elastic wave speed of the web material considered [6]. Unlike pure metal, the wave speed of the rubber is often changed with the current strain and