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Protective effect of polymer coating on the circular steel plate response to near-field underwater explosions

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ABSTRACT

To understand the intrinsic strong interaction between the soft coating and near-field underwater explosion, a series of comparative live fire tests are implemented. Nine steel circular plates with three configurations (i.e. rubber coated plate, foam coated plate and bare plate) are tested using 1.5 g PETN detonator. The stand-off between the plate center and explosive charge is ranged from 3.41 to 1.14 times of the maximum bubble radius. The transient strain history of the plate and acceleration history of the metal base fixture are monitored. The whole explosion process including local cavitation and bubble motion is recorded by an APX-RS high speed camera. Test results show that the compressibility of coating layer is the dominative factor that controls its protective performance in the shock wave loading phase. The more compressible foam coating distinctly reduce the shock wave intensity by local cavitation before enters the densification phase, while the explosion bubble shape and even the direction of water jet can also be changed. But the attenuation performance in the bubble loading phase is not as optimistic as that in the shock wave phase because more deformation space is required while the core has often entered the densification phase.

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1. Introduction

Sandwich structures are found to be capable of increasing the total anti-blast resistance. Their dynamic performance subjected to shock and impact loads becomes a hot topic in recent years. Early research works show that its good anti-blast resistance capability lies in two aspects. First, its good deflection capabilities provide volume to expand explosion gases and decrease the shock wave pressure [1,2]. And second, the progressive damage mode and energy absorbing mechanism of core permit relative small deformation of inner face plate [3–5]. The former merit may be more prominent if the blast medium is water. Xue [6] and Fleck [7] also estimated the momentum transmitted into a sandwich plate using the Taylor analysis [8] for a free standing front face sheet and drew some optimistically conclusions. Meanwhile, other research suggests that the benefits of employing sandwich construction for shock mitigation applications might be overestimated. E.g., Rabczuk [9] have investigated the response of sandwich beams subjected to underwater shocks by performing fully coupled FE fluid-structure interaction simulations. It is concluded that the final transmitted impulse is between the impulse according to the Taylor analysis if the face sheet is assumed to be free standing and that the entire sandwich structure is assumed to be free standing; and Liang [11] concluded that the classical Taylor model underestimates the mass of water by neglecting the reattachment process that occurs during stage II. Deshpande [12] made a deeply investigation on the one-dimensional shock response of sandwich plates subjected to an underwater pressure pulse. Both the propagation of an impinging acoustic shock wave within the fluid, and the propagation of a plastic shock wave within the sandwich core are accounted for. His analysis concluded that: (a) The momentum transmitted into the sandwich plates is substantially lower than that into a monolithic plate of same mass. (b) For a given core relative density, a smaller fraction of the shock impulse is transmitted into the sandwich plates with the bending-governed cores, which have lower compressive strength. Although the benefits of employing sandwich construction for shock mitigation applications might is not fully consistent, many experiment works still draw a positive conclusion. The experimental work by Wadley [13] showed that the impulse transferred to the fully supported sandwich structure is about 28% less than that transferred to a solid plate. In another test [14], the use of a crushable core in a fully back supported test configuration reduces the transmitted impulse by about 25% compared to that transmitted through a rigid, fully supported block. Schiffer [15] made a one-dimensional water tube test and concluded that the impulse imparted to water-backed sandwich plates can be dramatically reduced by increasing the initial hydrostatic pressure in the surrounding fluid.

Although very promising in underwater explosion protection, the metal sandwich structure is difficult to use in practice nowadays for its complex fabrication process. Therefore, the nonmetal structure such as composite and polymer are also selected as potential candidates [16,17]. In some preceding researches, the idea that coats the ship hull with a layer of protective soft rubber sandwich coating is experimentally investigated [18,19]. It is shown that the protective rubber coating with soft core can improve the shock environment of ship equipment and moderate hull damage caused by the shock wave loadings. While for low frequency bubble loads, the mitigating effect is discounted.

Above all these researches, the explosion loads considered are almost concentrated in far-field scenario. How the foam coating performs under near-field underwater explosions is seldom studied. In the near-field underwater explosions, the bubble effects and the strong local cavitation should be considered apart from the shock wave loading. Lee [20] showed that close-proximity charges can produce a complex shock interaction comprising several localized phenomena such as Mach reflection and rarefaction waves from the product bubble. In addition, the focused water jet from the bubble collapse was found to apply a much higher impulse than the shock in spite of the much smaller peak pressure. The bubble collapse phenomenon has been studied in more detail by Klaseboer [21] who examined the complex flow field and bubble dynamics associated with the collapse through both experiments and simulations. In addition to these phenomena, the well-known hull cavitation from shock-induced motion of the structure can also cause pressure cut-off, thus reducing the applied impulse [22]. Therefore, as the foam coating is easier to deform, the interaction between the soft foam and the bubble motion should be stronger and also needs to be considered. Aimed at the interaction between the soft foam and the bubble motion, a series of near-field live fire tests are made on foam coated metal plates in an artificial water tank using a detonator. The transient responses of steel