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A new concept of blast hardened bulkheads: feasibility study of aluminum foam attached BHBs

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ABSTRACT

In the situation that an anti-surface missile attacks a warship, an internal blast occurs. This blast ruptures a ship's watertight bulkheads, the damage propagates to adjacent areas, and the ship finally sinks. Therefore, we apply Blast Hardened Bulkheads (BHBs) which maintain the ship's survivability against an internal blast. In this study, a new concept of BHBs with applying aluminum (Al) foam is proposed and its feasibility is examined. Key ideas for BHB designs are reviewed firstly and the basic features of Al-foam materials are surveyed. Concepts and advantages of the Al-foam BHBs are presented and internal blast tests are conducted to check the effectiveness of the new concept. Finally, the results are analyzed in detail and compared with numerical simulations using LS-DYNA.

1. INTRODUCTION

Naval warships should overcome extensive and extreme combat situations. Survivability of the ship has been considered an important factor in order to minimize damage and protect the capability, crew, and mobility of the vessel. As a field of survivability, we apply vulnerability-hardening techniques in order to endure under situation assault by an anti-surface missile. For example, recently-built battle ships are equipped with Box Girders, a structure to maintain the residual strength of a damaged hull, and Blast Hardened Bulkheads (BHB) which maintain the ship's buoyancy against an internal blast.

The BHB is a structural bulkhead which maintains watertight ability, even if there is an internal blast. BHBs play an important role that includes not only maintaining watertight ability but also separating vital equipment – such as engines, electric generators, and combat system cabinets – which were installed dually. For the conventional BHBs, we generally increase the thicknesses of the upper and lower parts that connect the bulkhead to the decks. Therefore we can expect "large-deformation and plastic-membrane behavior" which can absorb more shock energy than elastic

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behavior. Although this method has been verified as being reliable in by many cases, costly renovation is necessary in order to apply BHB for operating warships. Moreover it causes a serious increase in weight and needs a special and difficult welding that maintains strength.

In this study, “aluminum foam attached BHB” was proposed. It not only reduces shock energy conveyed to a structural bulkhead but also has benefits for naval ships – lightness, easiness of manufacture, sound & vibration absorption, heat cutoff, electromagnetic shield. Subsequently, we conducted a chamber model blast test in which an internal blast on a warship is assumed. The results of the experiment were compared with numerical analysis using LS DYNA, a commercial FEM program. Finally, we examined the reliability of the computer simulation and the constitutive model of the metallic foam material.

2. ALUMINUM FOAM ATTACHED BHB

2.1 MATERIAL PROPERTIES OF ALUMINUM FOAM

Aluminum foam is an ultralight metal whose shape is similar to sponge and density is 0.2 ~ 0.5g/cm^3. This material is manufactured in accordance with the following procedure: 1) melting aluminum ingots, 2) adding foaming agents such as TiH_2, 3) pouring into a mold and cooling. Its porous structure enables it to absorb shock energy by compressive plastic behavior. In contrast with conventional shock-absorption structures such as honeycomb-core or corrugated-core panels, the foam has an isotropic feature, which is independent with respect to direction of shock loading. It has a good many other characteristics such as sound & vibration absorption, heat cutoff, electromagnetic shield, and recyclability. Therefore, demand for this novel material is increasing in the commercial fields as well as military – protective facilities of military & commercial buildings, armored vehicles, and filler of crushable bumper for general vehicles.

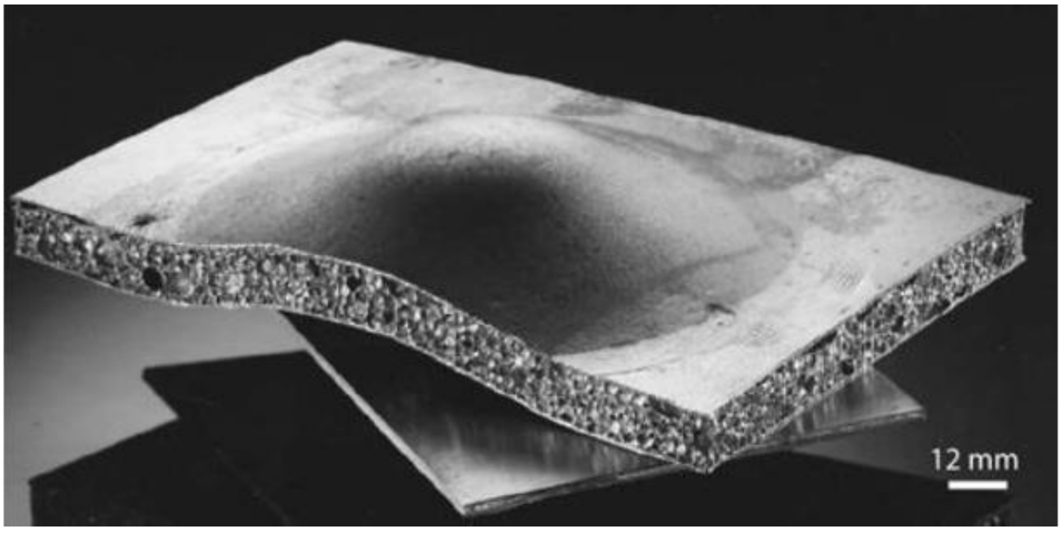


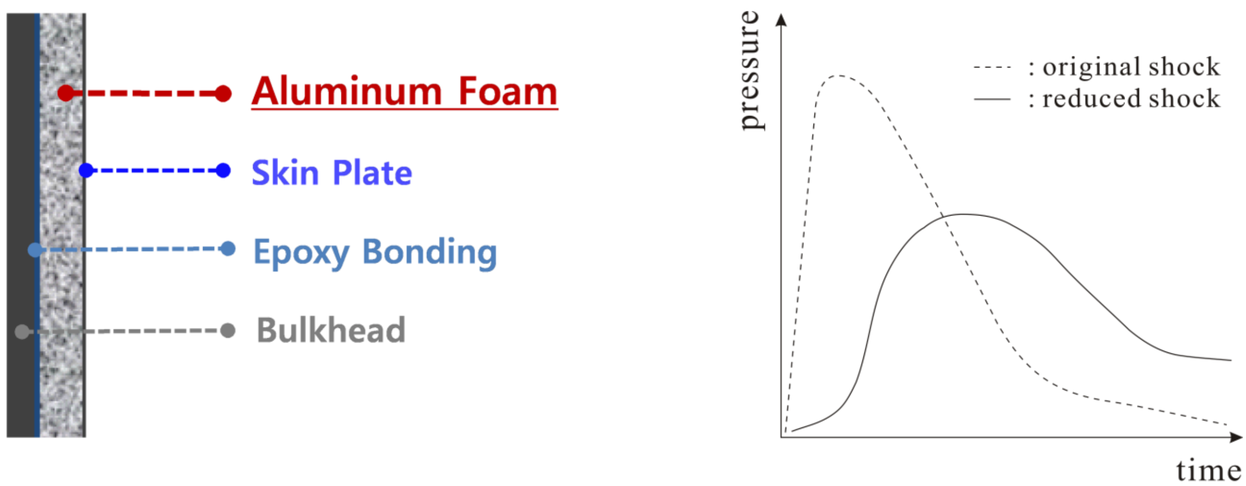
Fig. 1 Aluminum foam sandwich panel (www.tms.org)

2.2 CONCEPTS OF ALUMINUM FOAM ATTACHED BHB

A phenomenon of internal blast differs from an open field blast. Initially, a reflected shock pressure is imparted to hull structures. Subsequently, quasi-static pressure (QSP) is followed since over-pressured gases are bounded in structural volumes. The non-hardened bulkhead is deformed rapidly due to initial shock, and bending stress is concentrated at the upper and lower corners. Eventually, the bulkhead ruptures at the corners. Also notable is the fact that the peak pressure of reflected shock is not uniform but concentrated on corner 2~3 times larger than center, and bending stress concentration is intensified.

Conventional BHB, generally called “Curtain Type BHB,” is designed so that the thicknesses of upper and lower parts are increased in order to resist ruptures at the corner. Curtain type BHB utilizes large deformation without failure. It transforms the bending stress at the corners into membrane stress. Steel, which is generally used in shipbuilding, is able to endure much larger energy in the membrane and plastic condition than bending. Therefore curtain-type BHBs absorb shock energy according to this mechanism. Curtain type BHB, however, requires excessive and costly renovation in order to apply BHB for operating warships. Moreover, this BHBs increase a ship’s weight significantly because of curtain plates’ thicknesses – reach to 10~12*mm* (Stark and Sajdak, 2012), and needs particular methods of welding in order to maintain structural strength.

We can consider another method, applying energy-dissipating sacrificial materials. In accordance with “Engineering Support Report (ALION S&T, 2013),” a structure which is equipped with optimized-sacrificial materials can endure a larger blast impulse than a same-weight bulkhead. That is, it will be an appropriate approach to attach a shock-absorbing panel to a structure. From this viewpoint, “aluminum foam,” ultralight and shock-absorbable, can be considered (Fig. 2). By applying aluminum foam, shock waves conveyed to the bulkhead is not only reduced but also distributed corner-concentrated load uniformly. Moreover, we can apply BHB to operating warships easily.



(a) Simplified diagram of Al foam (b) Shock reduction by Al foam

Fig. 2 Aluminum foam attached BHB

3. CHAMBER MODEL BLAST TESTS

3.1 EXPERIMENTAL METHODS

A chamber was built in order to replicate its actual size of a ship's compartment. An internal blast was conducted by detonating spherical TNT in the chamber. Specimens were made equally to a ship's bulkhead to simulate physically, and its responses to the blast were examined. This experiment was designed for assessing BHB's performance. The chamber consists of a vent area for emitting gas, a specimen which simulated a real bulkhead, and confining parts. In order to conduct several tests with one chamber, it was designed as specimen-replaceable instruments. Mild steel (SS400) was utilized for materials of overall. We used spherical-shape TNT which causes the same magnitude of internal pressure with real warships in accordance with UFC Manual (2008). The explosive was placed at the center of the chamber. In order to analyze effects of Al foam, experiments were designed as 4 test cases: Normal type Al foam panels (density 0.2g/cm^3) were attached on 6*mm*-thickness-plane bulkheads, and thicknesses of the panels were varied. High tensile shipbuilding steel (AH36) was utilized for specimens. Finally, pressure gauges were installed to measure the loaded pressure on bulkheads. Acceleration sensors were prepared to measure dynamic deformation for all of the cases. The final deformation was measured after every blast.

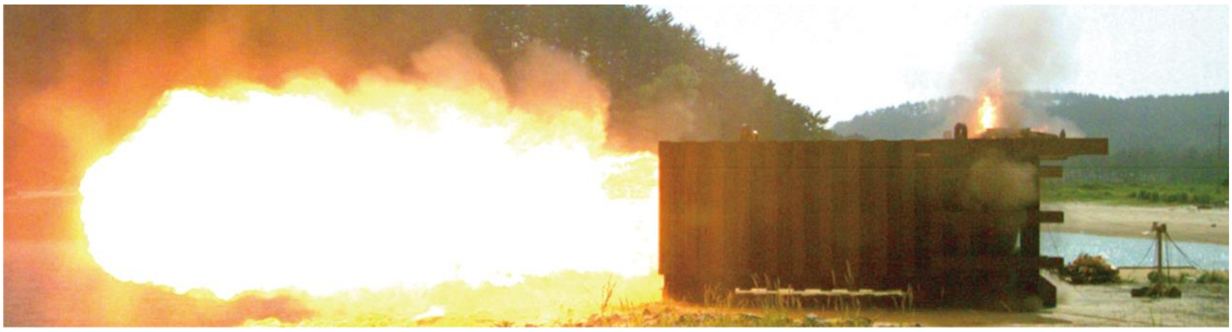


Fig. 3 Chamber model internal blast test

3.2 EXPERIMENTAL RESULTS

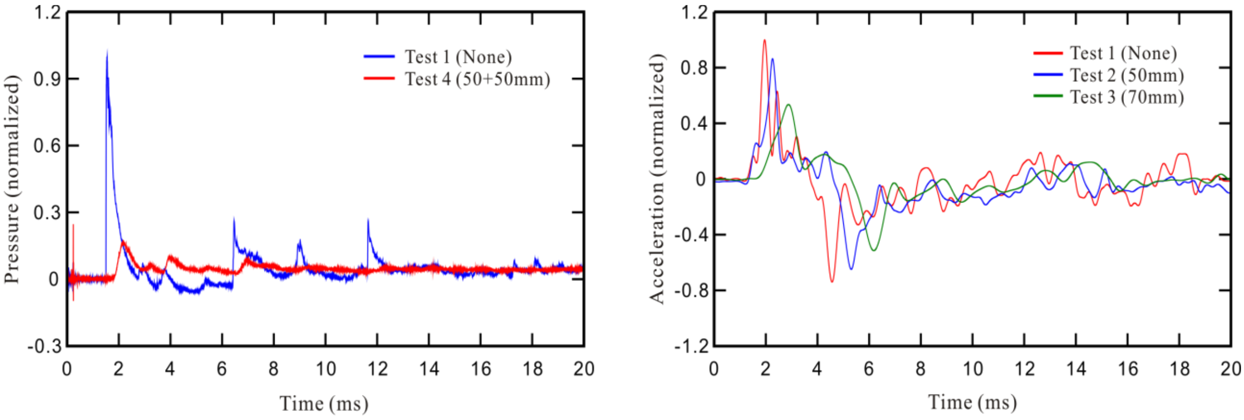
During the chamber blast tests, plastic deformations were observed in all cases but there is not any rupture. Compared with a case of bared bulkhead, a peak pressure which passed through Al foam panels was reduced to 1/6 (Fig. 4-(a)). Deforming accelerations of plates' center points were decreased as the thickness of Al foam panels increased as well (Fig. 4-(b)). The remaining deformations were decreased as the thickness of Al foam panel increased (Table 1).

3.3 NUMERICAL ANALYSIS OF EXPERIMENTS

We numerically analyzed the chamber model blast tests using LS DYNA. Solid elements were used to model structural parts of Al foam and wedges, and shell elements were used for other structures. The AUTOMATIC_SURFACE_TO_SURFACE

Table 1 Final deformation (Plate Center) of Al foam BHB

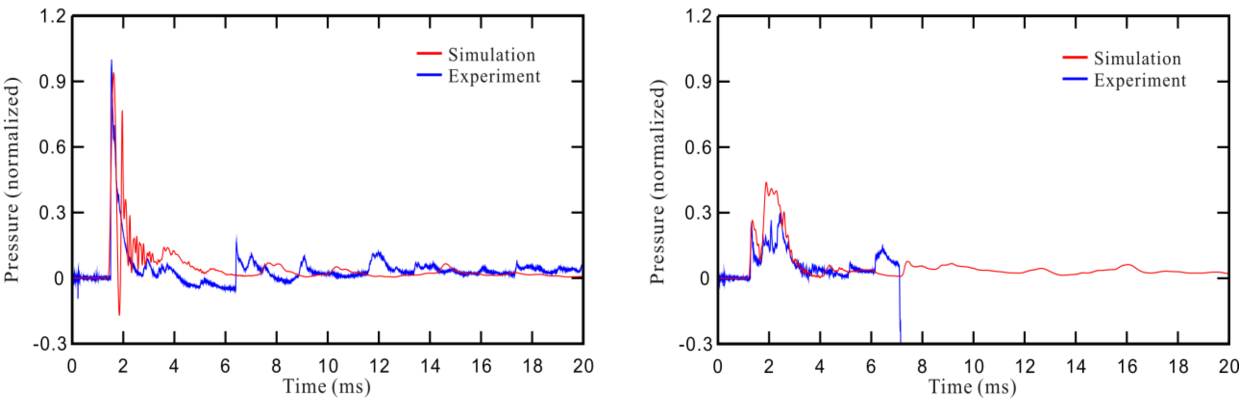
No.	Test 1 (None)	Test 2 (50*mm*)	Test 3 (70*mm*)	Test 4 (50+50*mm*)
Deformation (Plate center)	322 *mm*	312 *mm*	276 *mm*	284 *mm*



(a) Comparison of pressure history (Plate Right Lower)

(b) Acceleration history of Al foam BHB (Plate Center)

Fig. 4 Experimental results (pressure history and structural response)



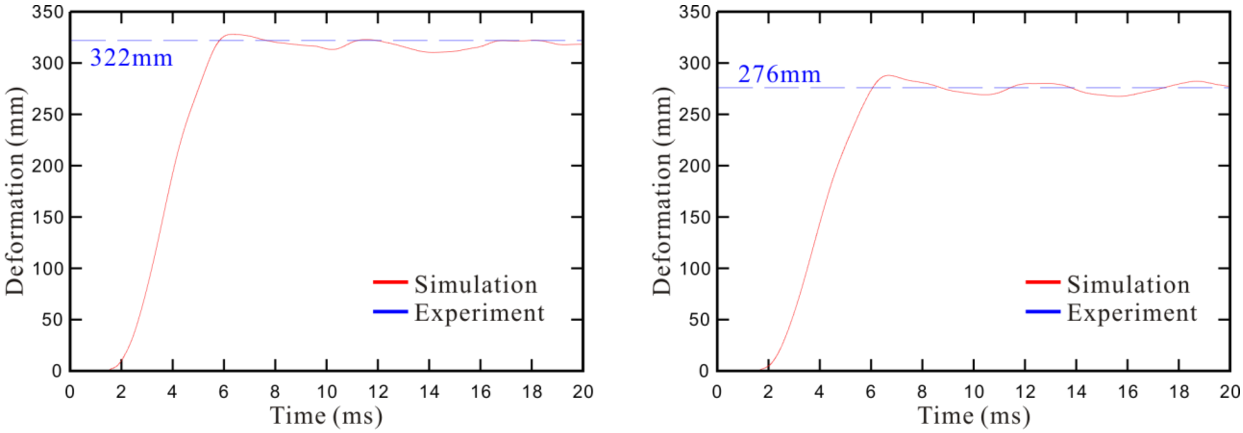
(a) Plate Right Upper

(b) Plate Center

Fig. 5 Pressure histories of Test 1 (simulation vs experiment)

option was used to model contacted surfaces. Air and explosives were modeled by using techniques of Fluid Structure Interaction (FSI) using Multi-Material Arbitrary Lagrangian and Eulerian (MMALE) and the MAT_CRUSHABLE_FOAM material model used for modelling of Al foam. The average size of elements was about 4~6*cm*, and the overall number of elements used was approximately 1,450,000.

The MMALE and FSI methods estimated pressures-history patterns and time durations of blast tests similarly (Fig 5). However, magnitudes of pressures sensitively depends on size of air-meshes – as sizes of meshes are larger, losses of pressures are larger. The MAT_CRUSHABLE_FOAM material model estimated similar responses of Al foam attached BHB blast tests. We can observe that displacements at plate center are similar in the numerical simulation and the blast test (Fig 6).



(a) Test 1 (None) (b) Test 3 (70mm)

Fig. 6 Simulation of deformation history (Plate Center)

3. CONCLUSIONS

In this study, we suggested Al Foam attached BHB as a new alternative. The concept of energy-dissipating sacrificial materials was introduced and a constitutive model of a metallic foam material was studied. We conducted chamber internal blast tests and examined responses of Al Foam attached BHB. Moreover, we studied the reliability of LS DYNA by comparing results of experiments and simulations. Finally, we concluded that LS DYNA simulation can be used practically for general cases. For future research, we plan to develop the design procedure of Al Foam panels and study high-performance Al Foams by conducting LS DYNA analyses.

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