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Study on shield configuration stuffed with the integrated fabric layer and its bracing structure

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ABSTRACT

Two alternative techniques to brace the fabric layers stuffed in high-performance shield configurations are evaluated by hypervelocity impact tests respectively. Al honeycomb core and Al mesh are proposed to brace the fabric layers separately. There are four types of stuffed layer structures. The first structure consists of two kinds of fabrics, one layer of basalt fabric followed with one layer of Aramid-III fabric repeatedly. The second type is the first one plus Al honeycomb core. The third type contains several layers of basalt fabric and one layer of Al mesh. The fourth type is similar to the third one, while the stuffed layer is sewed with the aramid thread. For the target configurations, the bumper and the rear plate are 1mm-thick Al plate and the stuffed layer is 100 mm from the bumper. The targets are impacted by Al projectile with the diameters about 5 mm, and the velocities range from 4 km/s to 5 km/s. According to the test results, the fixing and support structure weight of the fabric layer is lightened by using the Al honeycomb core. The Al honeycomb core absorbs and dissipates the kinetic energy of debris cloud effectively, however, its channel effect aggravates the perforation damage on the rear plate. For the fourth structure, the Al mesh plays the role of fixing and supporting basalt fabric, but the performance of stuffed layer intercepting debris cloud is reduced.

1. Introduction

Whipple shield configuration was proposed in 1947 by Fred L. Whipple and its improved configurations [1] have been widely applied to the on-orbit spacecraft since then. The stuffed fabric layer is used on the spacecraft shield configuration extensively, which can intercept and crack the debris cloud effectively, and the fabric debris will not damage the rear plate. To improve the performance of the stuffed fabric layer, several kinds of fabric materials [2–6], the location of fabric layer [4,5], and the assembling mode of ceramic fabric and aramid fabric [5] were studied. One method used to fix the fabric layers within a stuffed shield configuration involved adding an Al alloy to support structure which increased overall mass by 35% [7]. In order to lighten the additional weight, the plastic foam [5,6] and metallic foam [7,8] were used to support the fabric layer, but the plastic foam restricted the debris cloud dispersing. The Al foam cracked and intercepted the debris cloud effectively, however, its density was high.

The Al honeycomb core plays the role of energy-absorption [9] with low areal density. There is enough distance between the bumper and the rear plate for the debris cloud to disperse completely, so the Al honeycomb core is proposed to fix and support the fabric layer in the test.

The Al mesh took the advantages of low density and simple configuration, so it was proposed to shield debris cloud [10]. In view of the configuration stability and toughness, the Al mesh is proposed to support the fabric layer in the test. The evenness of Al mesh is a little poor for its toughness. When basalt fabric and Al mesh are sewn together, their adhesion degree is improved, and their support structure mass is reduced.

Shields consisting of stuffed layers braced by Al honeycomb core and Al mesh have been compared under hypervelocity impact tests. The test results support the conclusion that an integrated design incorporating Al honeycomb in the support structure will improve the performance and reduce the mass of stuffed Whipple shields incorporating fabric intermediate layers.

2. The design of shield configurations

The sketch of target configurations is shown in Fig. 1, there is no support structure between the stuffed layer and the rear plate in Configuration I, but the Al honeycomb core is placed between the stuffed layer and the rear plate in Configuration II. The bumper and the rear plate are 1 mm-thick Al 6061-T6 plate, and the size of all the layers are 200 mm × 200 mm. The projectile is 2A12 sphere.

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Nomenclature

a	= the length of side for the honeycomb core cell	s	= the distance of two parallel Al wires in the mesh
d_{Al}	= the diameter of the Al wire	S	= the distance between bumper and rear plate
d_P	= the diameter of the projectile	t	= the thickness of honeycomb wall
h	= the height of the honeycomb core	V_P	= the velocity of projectile
h_R	= the bulge height of the rear plate	V_D	= the velocity of vanguard leading edge debris cloud
		ρ	= the material density of honeycomb core
		ρ_{SL}	= the total areal density of the stuffed layer structure

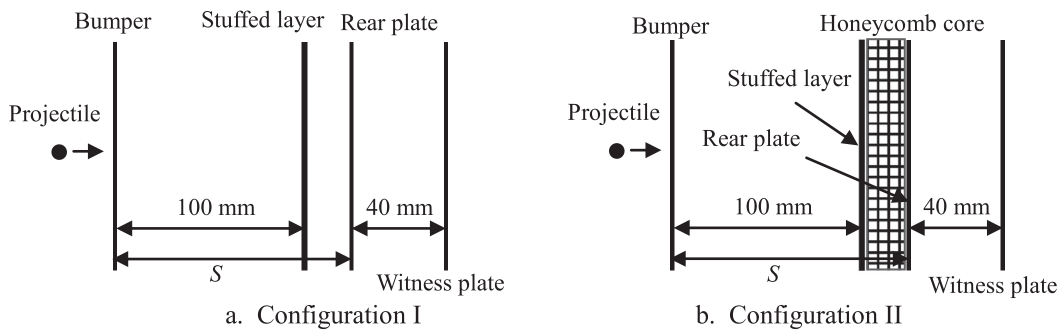

Fig.1. The sketch of target configurations.

There are four types of stuffed layer structures, as described below and with details provided in Table 1. The first structure contains two kinds of fabrics, one layer of basalt fabric followed with the other one Aramid-III fabric repeatedly along the impact direction of the debris cloud. The second structure is similar to the first one except adding a layer of Al honeycomb core shown in Fig. 1b. The third structure is that several layers of basalt fabric and one layer of Al mesh. The fourth structure is achieved by sewing the third one with the aramid thread.

The configuration sketch of honeycomb core is shown in Fig. 2, which is fabricated by sticking the Al films. The red lines denote the superposition of two Al films. The areal density of the honeycomb core is $8ht\rho/(3 \times 1.732a)$. The geometric size of the Al honeycomb core shown in Fig. 3 is $h = 20$ mm, $a = 10$ mm, $t = 0.04$ mm. The Al honeycomb core deforms without restriction slightly.

The Al mesh is woven by the Al wires ($d_{Al} = 0.25$ mm, $s = 0.9$ mm). There is no aramid-III fabric in the third and the fourth structure taking the toughness of Al mesh into consideration. The distances of the two adjacent aramid threads are about 10 mm for the fourth structure, which is shown in Fig. 4. The target configurations are shown Table. 1. The areal densities of different materials used in the stuffed layer are listed in Table. 2.

3. Measurement method and test equipment

3.1. Criterion of target configuration damage

If kept the same impact parameters, the rear plate will be damaged less when the stuffed layer has better performance. Perforation and bulge can be used to evaluate the damage degree of the rear plate. The perforation size and the bulge height of the rear plate are also measured. With the similar perforation, the damage of the witness plate will be compared. For shield configuration stuffed with fabrics, its shielding performance is better with the increasing of impact velocity during the range of 2.6–6.5 km/s [11] as the projectile is cracked more fully and the debris cloud is dispersed in larger area under higher impact velocity.

3.2. Test equipment

The tests are carried out on the HVI Range with launching bore of 7.6 mm in China Aerodynamics Research and Development Center (CARDC), as shown in Fig. 5. When the projectile flies through the chamber, changes of flying velocity can be ignored as the pressure in the chamber is lower than 50 Pa, and its average velocity is measured by the light screen system, which makes use of diverse light screens' time differences when projectile flies through the measurement area and shelters the light beam. Projectile velocity uncertainty is smaller

Table1
The target configurations.

Target no.	Configuration	S (mm)	Composition of the stuffed layer	ρ_{SL} (g/m^2)
04	I	121	8 layers total of basalt A and aramid III-60 fabric	1534.8
05	II	121	8 layers total of basalt A and aramid III-60 fabric + honeycomb core ($h = 20$ mm)	1856
03	II	121	6 layers total of basalt A and aramid III-60 fabic + honeycomb core ($h = 20$ mm)	1474.3
A1-1	I	121	8 layers total of basalt A and aramid III-80 fabric	1590.8
B1-1	II	121	8 layers total of basalt A and aramid III-80 fabric + honeycomb core ($h = 20$ mm)	1912
3-2	I	121	6 layers total of basalt B and aramid III-100 fabric	1170.3
8-1	II	121	6 layers total of basalt B and aramid III-100 fabric + honeycomb core ($h = 20$ mm)	1491.5
8A-1	II	111	6 layers total of basalt B and aramid III-100 fabric + honeycomb core ($h = 10$ mm)	1330.9
01	I	121	4 layers of basalt A fabric and 1 layer of Al mesh	1598.4
D-2	I	121	4 layers of basalt A fabric and 1 layer of Al mesh	1598.4
D-3	I	121	4 layers of basalt A fabric and 1 layer of Al mesh	1598.4
D1-1	I	121	4 layers of basalt A fabric and 1 layer of Al mesh sewed with the thread	1603.4
D1-2	I	121	4 layers of basalt A fabric and 1 layer of Al mesh sewed with the thread	1603.4