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The influences of aramid fibre and its compound with ceramic on shielding performance of stuffed layer

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ABSTRACT

Four kinds of aramid fibre and three compound modes of aramid with ceramic fibre were studied by hypervelocity impact tests respectively to probe the fabric layer with higher performance in space debris shield configuration. The aramid fibres include the Aramid-II manufactured in America, the Aramid-II, the Aramid-III and the PBO manufactured in China. Based on the above test results, the Aramid-III was chosen to compound with the basalt. The compound modes include hybrid weaving, affixing the Aramid-III and basalt fabric layers with the glue, and sewing them with the aramid thread. The configurations are impacted by the 5 mm-diameter Al projectile with the velocities of 4.5 km/s to 5.0 km/s. The test results show that the fabric layer containing Aramid-III fabric has equivalent shielding performance with the PBO fabric, and they are better than the other two stuffed layers containing Aramid-II fabric respectively under the equivalent areal density. The performance of stuffed layer is influenced by the adhesion degree of basalt and Aramid-III fibre. The three compound modes all improve the fabric adhesion degree, however, the over adhesion makes against dissipating the kinetic energy of debris cloud, which causes the performance to degrade.

1. Introduction

The stuffed layer comprised with ceramic and aramid fabric can intercept and crack the debris cloud with hypervelocity, and the fabric fragments cloud not damage the rear plate of shield configuration. The fabric is used as the stuffed layer of shield configuration on spacecraft for its low density and good performance. Nextel, basalt, and SiC are the familiar ceramic fibre, and Kevlar and PBO are the familiar aramid fibre. Several kinds of ceramic fabric materials [1–5], the location of fabric layer [3,4], and the mechanism of ceramic and aramid fabric intercepting and cracking the debris cloud [4] were studied. In order to lighten the additional weight used to fix and support the fabric layer, the plastic foam [4,5], the metallic foam [6,7], the Al honeycomb and Al mesh [8] were used to brace the fabric layer. Meanwhile, some new concepts of stuffed shield configurations with higher performance were proposed. According to the study results of the crater depth, radius and ejected mass for debris impacting solid structure [9] and fluid decelerating debris cloud effectively [10], the concept of honeycomb fluid-gas filled shield [11] was proposed. The concept of N-shape configuration was proposed [12], which was formed by inclining the middle layer of parallel triple-wall configuration for dispersing the debris cloud in bigger area.

With the rapid development of fibre technology, the Aramid-III fibre has the advantages of tensile strength, elastic modulus and fracture elongation [13] compared with the Aramid-II fibre called as Kevlar fibre, and the PBO fibre also has the good performance and fire resistance [14]. The basalt fibre has good performance of cracking debris cloud with mature technology and low cost. The performances of the stuffed layers comprised by the basalt and different aramid fabrics are studied, which are woven by the Aramid-II fibre made in America, the Aramid-II, Aramid-III and PBO fibre made in China respectively. The adhesion degree of ceramic and aramid fabric improved their shielding performance [4], and the hybrid weaving of two different kinds of fibre can improve the friction performance and the abrasion impedance between the fibres [15,16]. In order to study the influence of improving the fibre adhesion degree on their performance, three kinds of fibre compound mode are studied by hypervelocity impact test. The first is the hybrid basalt/Aramid-III fabric, and the other two are the several layers of Aramid-III and basalt fabric affixed with the glue and sewed with the aramid thread respectively. The test results provide reference for the aramid material choosing of stuffed layer and fabric structure optimization.

2. The design of shield configuration

The sketch of target configuration is shown in Fig. 1. The bumper

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Nomenclature

d_B	the perforation diameter of the bumper
d_P	the diameter of the projectile
h_R	the bulge height of the rear plate
V_P	the velocity of the projectile
ρ_{FL}	the areal density of the fabric
ρ_{SL}	the total areal density of the stuffed layer structure

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. When the projectile velocity ranges from 4.5 km/s to 5.0 km/s, it would be cracked into fragments with smaller size by the bumper, and the cracking and intercepting performance of stuffed layer on the fragments would be embodied in the test. According to the test results in Ref. [8], the rear plate of the configurations in the text would be critical perforation when they are impacted by the 5 mm-diameter Al projectile with the velocities of 4.5 km/s to 5.0 km/s, which is convenient to compare the configuration performance.

There are four types of stuffed layer structures as described below and with details provided in Table 1. Along the impact direction of debris cloud, the first structure is several layers of basalt and aramid fabric. The second structure is several layers of hybrid basalt/Aramid-III fabric, the weaving sketch of which is shown in Fig. 2. The third structure is fabric layers sewed with the aramid thread by hand, and the distances of the two adjacent threads are about 10 mm which is shown in Fig. 3. The fourth structure is fabric layers affixed with the glue, the rigidity of which is improved like the plate shown in Fig. 4.

As the rigidity of fabric is poor, the adhesion degree of fabric layer placed and piled together is hard to keep, the influence of which on shielding performance could be eliminated by adding the Al honeycomb core with areal density of 321.2 g/m^2 between the stuffed fabric layer and the rear plate [8] in targets 8–1, 9–1, 11–1. The composition of the stuffed structure is shown Table 1, and all fabric are tabby. The average areal densities of fabrics are listed in Table 2, which are measured several fabrics of 1 m^2 respectively by the scale with the accuracy of 0.1 g. The hybrid fabric is designed and woven, however, the other fabrics are chosen from the market for cost economy. According to the test results, the PBO fabric has the same performance of intercepting debris cloud compared with the Aramid-III fabric under the equivalent areal density, however, its performance will degrade quickly under the space radiation, therefore the Aramid-III is chosen to compound with the basalt.

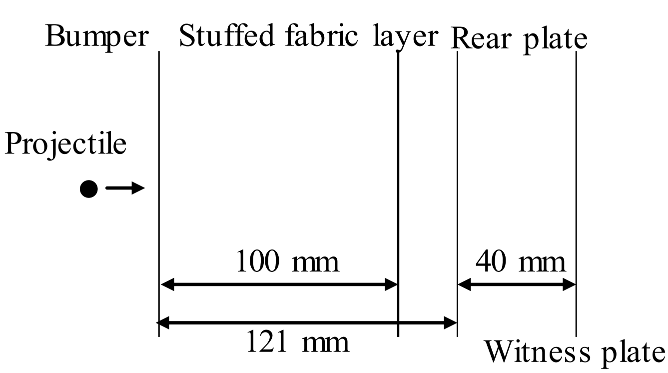

Fig. 1. The sketch of target configuration.

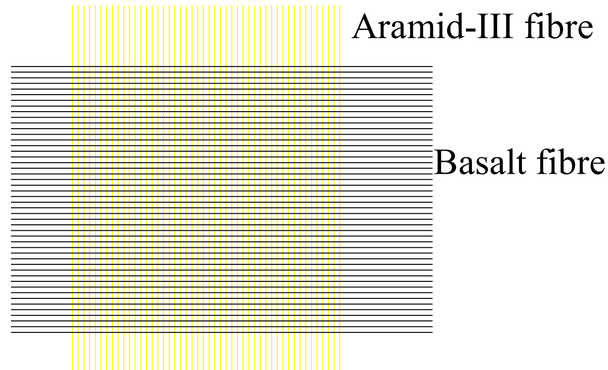

Fig. 2. The sketch of hybrid fabric.

3. Measurement method and test equipment

3.1. Criterion of shield configuration damage

As the rear plate will be damaged less when the stuffed layer has better performance, the perforation size and the bulge height are measured to denote its damage degree. The performance of shield configuration is better with the increase of impact velocity during the range of 2.6 km/s to 6.5 km/s [17] as the same projectile is cracked more thoroughly and the debris cloud disperses in larger area.

3.2. Test equipment

The tests are carried out on the HVI Range equipped with the two-stage light gas gun in China Aerodynamics Research and Development

Table 1
The composition of the stuffed structure.

NO.	Composition of the stuffed structure	ρ_{SL} g/m^2
1–2	6 layers totally, 1 layer of basalt fabric following 1 layer of Aramid II-A fabric repeatedly	1490.4 ± 0.5
2–1	6 layers totally, 1 layer of basalt fabric following 1 layer of Aramid II-B fabric repeatedly	1476.0 ± 0.5
3–1	6 layers totally, 1 layer of basalt fabric following 1 layer of Aramid III-A fabric repeatedly	1170.3 ± 0.5
3–2	6 layers totally, 1 layer of basalt fabric following 1 layer of Aramid III-A fabric repeatedly	1170.3 ± 0.5
3A-1	6 layers totally sewed with the aramid thread, 1 layer of basalt fabric following 1 layer of Aramid III-A fabric repeatedly	1175.3 ± 0.5
3B-1	6 layers totally affixed with the glue, 1 layer of basalt fabric following 1 layer of Aramid III-A fabric repeatedly	1270.0 ± 0.5
4–1	9 layers totally, 1 layer of basalt fabric following 2 layers of Aramid III-A fabric repeatedly	1470.0 ± 0.5
5–1	6 layers totally, 1 layer of basalt fabric following 1 layer of PBO fabric repeatedly	1185.0 ± 0.5
6–1	6 layers of the hybrid basalt/Aramid-III fabric	1224.0 ± 0.5
6A-1	6 layers of hybrid basalt/Aramid-III fabric sewed with the aramid thread	1229.0 ± 0.5
6B-1	6 layers of hybrid basalt/Aramid-III fabric affixed with the glue	1324.0 ± 0.5
7–1	3 layers of basalt fabric and 1 layer of Aramid III-C fabric	1190.5 ± 0.5
8–1	6 layers totally + Al honeycomb core, 1 layer of basalt fabric following 1 layer of Aramid III-A fabric repeatedly	1491.5 ± 0.5
9–1	6 layers of hybrid basalt/Aramid-III fabric + Al honeycomb core	1545.2 ± 0.5
10–1	9 layers totally, 1 layer of basalt fabric following 2 layers of PBO fabric repeatedly	1500.0 ± 0.5
11–1	6 layers totally + Al honeycomb core, 1 layer of basalt fabric following 1 layer of PBO fabric repeatedly	1506.2 ± 0.5
12–1	3 layers of basalt fabric and 3 layers of Aramid III-A fabric	1170.3 ± 0.5