Acta Astronautica 127 (2016) 553–560

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/aa

Test study on the performance of shielding configuration with stuffed layer under hypervelocity impact

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ARTICLE INFO

Article history:
Received 22 April 2016
Accepted 19 June 2016
Available online 22 June 2016

Keywords:
Hypervelocity impact
Stuffed configuration
Ceramic fibre
Aramid fibre

ABSTRACT

In order to study the cracking and intercepting mechanism of stuffed layer configuration on the debris cloud and to develop stuffed layer configuration with better performance, the hypervelocity impact tests on shielding configurations with stuffed layer were carried out. Firstly, the hypervelocity impact tests on the shielding configuration with stuffed layer of 3 layer ceramic fibre and 3 layer aramid fibre were finished, the study results showed that the debris cloud generated by the aluminum sphere impacting bumper at the velocity of about 6.2 km/s would be racked and intercepted by the stuffed layer configuration efficiently when the ceramic fibre layers and aramid fibre layers were jointed together, however, the shielding performance would be declined when the ceramic fibre layers and aramid fibre layers were divided by some distance. The mechanism of stuffed layer racking and intercepting the debris cloud was analyzed according to the above test results. Secondly, based on the mechanism of the stuffed layer cracking and intercepint debirs cloud the hypervelocity impact tests on the following three stuffed layer structures with the equivalent areal density to the 1 mm-thick aluminum plate were also carried out to compare their performance of cracking and intercepting debris cloud. The mechanisms of stuffed layer racking and intercepting the debris cloud were validated by the test result. Thirdly, the influence of the stuffed layer position on the shielding performance was studied by the test, too. The test results would provide reference for the design of better performance shielding configuration with stuffed layer.

1. Introduction

Since the Whipple shield was proposed in 1947, many kinds of shields have been developed, such as improved Whipple shield [1] by improving the bumper and the rear plate, the stuffed Whipple shield [2] which was used on the on-orbit spacecraft widely, and the multi shock shield [3]. The performances of the stuffed Whipple shield impacted by non-metal projectile [4,5] and under different ambient temperature [6] were studied. Based on the characteristic that the ballistic limit of the shield under oblique impact was higher than that under normal impact [7], the stuffed configuration with non-parallel middle layer were studied [8–10] to improve the shielding performance by increasing the dispersing degree of debris cloud. Based on the study results of the crater depth, radius and ejected mass for debris impacting solid structure and fluid filled containment respectively [11–13], the concept of honeycomb fluid-gas filled shield [14] was proposed by Smirnov, Smirnova et al.

Compared with the Al plate of same areal density, the stuffed layer with fibre materials could intercept and crack the debris cloud effectively, meanwhile the rear plate of shielding configuration would not be damaged by the debris cloud produced by the stuffed layer fibre cracking, the damage degree of rear plate would be reduced significantly. Therefore, the stuffed layer composed with the ceramic fibre and the aramid fibre were used on the spacecraft shielding configuration widely. Nextel, Basalt, SiC are the familiar ceramic fibres which would be used on the shielding configuration, and Kevlar is the familiar aramid fibre. In order to probe the stuffed Whipple shield with better performance, hypervelocity impact tests on shielding configurations with the several stuffed materials and different structures were carried out [15], the new shielding configurations with stuffed layers of wood [16] and aerogel/fibreglass [17] were studied, too. The hypervelocity impact tests with velocity of about 6.20 km/s were carried out to research the stuffed layer position of the basalt fibre and Kevlar fibre [18], the test result showed that the shielding performance declined when the distance between stuffed layer and rear plate increased, and the influences of stuffed layer composed with SiC and Nextel were studied, too. The hypervelocity impact tests with impact velocity of about 6.20 km/s were also carried out to study the stuffed layer position of the SiC fibre and Kevlar fibre [19], however, the test result showed out the shielding performance was best when the stuffed layer was placed

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http://dx.doi.org/10.1016/j.actaastro.2016.06.037
0094-5765/

halfway between the bumper and rear wall comparing with that fore part and aft part.

For the references [18,19], their stuffed layer had different influences on the shielding performances because of the different stuffed layer materials. In order to study the mechanism of ceramic fibre and aramid fibre cracking and intercepting the projectile debris, and to compare shielding performances for the different stuffed layer positions, the hypervelocity impact test on the shielding configuration with stuffed layer of the Nextel and Kevlar fibre. In order to probe shielding configuration with higher performance, the tests on the three different configuration structures stuffed with fibre were also carried out, the mechanism of stuffed fibre layer racking and intercepting the projectile debris was validated, the influences of the compound mode and binding degree of ceramic fibre and aramid fibre in the stuffed layer on the shielding performances was founded. The test results would provide reference for the design of shielding configuration stuffed with fibre.

2. The design of shielding configuration

2.1. Configuration I

For the configuration I, there were two shielding structures (shown in Fig. 1) in order to study the mechanism of the ceramic fibre and aramid fibre cracking and intercepting the projectile debris. The target structures were composed by bumper, stuffed layer, and rear plate. The bumper was Al 6061-T6 with thickness of 1 mm. The stuffed layer was composed by fibre composite materials. The rear plate was 5A06 with thickness of 2.5 mm. The distance between bumper and rear plate was 120 mm. The witness plate was 5A06 with thickness of 2 mm which was fixed on the position of 50 mm far from the rear plate. The Nextel and Kevlar were chosen as the stuffed layer fibre according to the stuffed layer materials used on the American spacecraft shielding configuration. The ceramic fibre of Nextel-550 was made in 3 M cooperation of American with the single layer areal density of 0.044 g/cm^2. And the single layer areal density of Kevlar was 0.0176 g/cm^2, which was same to aramid fibre used in the reference [19].

For the structure I-A, the stuffed layer was 3 layer ceramic fibre and 3 layer aramid fibre jointing together.

For the structure I-B, the stuffed layer was 3 layer ceramic fibre and 3 layer aramid fibre with the center distance of 40 mm.

2.2. Configuration II

Based on the test result of the configuration I, in order to probe stuffed shielding configuration with better performance and to validate the mechanism of stuffed layer fibre material cracking and intercepting debris cloud further, 3 kinds of target structures of configuration II were designed (shown in Fig. 2). The bumper was Al 6061-T6 with thickness of 1 mm. The second layer was stuffed layer with the areal density equivalent with the Al plate with the thickness of 1 mm. The rear plate was Al 6061-T6 with thickness of 1mm. The distance between bumper and rear plate was 120 mm. The witness plate was Al 6061-T6 with thickness of 1 mm which was fixed on the position of 35 mm far from the rear plate.

For the target structure II-A, the stuffed layer was composed by 7 layer Basalt+20 mm-thick foam. When the stuffed fibre layer was used on the spacecraft shielding configuration, the Al alloy frame and link construction were used to fix fibre materials, however, which would increase the total weight about 35% [20] for the shielding configuration. For the foam used in the construction II-A, it would decrease the debris cloud. Meanwhile, the foam assembled between the Basalt and the rear plate could support the Basalt fibre. The fixing structure and quality would be reduced if the configuration would be used on the space shielding configuration. The areal density of foam was 0.0355 g/cm^2.

For the target structure II-B, the stuffed layer was 14 layer configuration comprised by Basalt and Kevlar alternating in turn.

For the target structure II-C, the stuffed layer was 7 layer Basalt+7 layer Kevlar configuration, which were jointed together.

The stuffed shielding configuration was used on the China space station widely, and the configuration comprised by Basalt fibre and Kevlar fibre would be used as stuffed layer [19]. The Basalt fibre was used as the ceramic materials of stuffed layer for the configuration II, and the Kevlar fibre was used as the aramid fibre for structure II-B and structure II-C. The single layer areal density of Basalt and Kevlar were 0.032 g/cm^2 and 0.0076 g/cm^2 respectively.

2.3. Configuration III

The configuration III was designed to study the influence of the stuffed layer position on the shielding performance further, which was shown in Fig. 3. The material and compound mode of the stuffed layer were same to those of configuration I-A. The influence of stuffed layer position on the shielding performance would be studied by comparison tests between the configuration I-A and the configuration III.

For the above three configurations, the size of every layer of the configuration was 200 mm × 200 mm, which was big enough to intercept and crack the debris cloud for the test parameters that would be carried out.

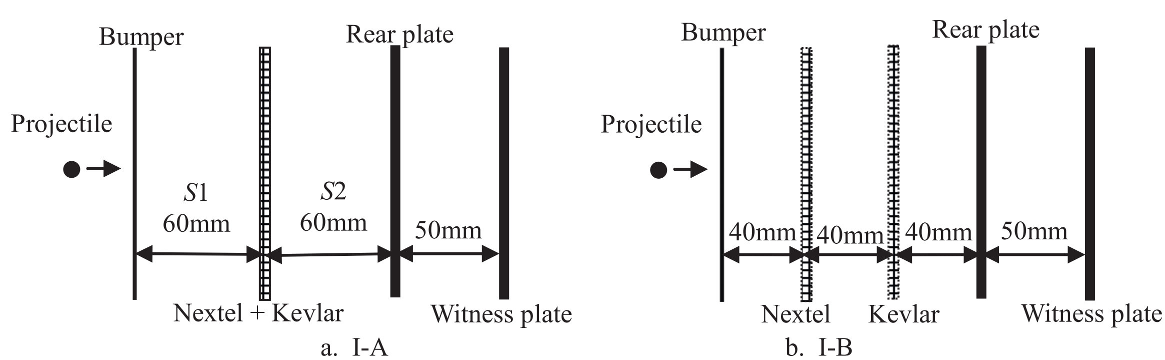

Fig. 1. The sketch of configuration I. a. I-A b. I-B.