RESEARCH ON PERFORMANCE OF MESH BUMPER AGAINST SPACE DEBRIS

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ABSTRACT As a kind of lightweight shield, mesh bumper had been used to protect International Space Station(ISS) against space debris. In some documents, it is concluded that meshes comminute hypervelocity projectiles with efficiencies comparable to contiguous targets. This is partially validated by hypervelocity impact experiments in the paper, and the hypervelocity impact characterization of mesh bumper is studied by numerical simulation, it is found that mesh bumper can effectively comminute projectile and disperse debris cloud. Next, the sensitivity of major variables such as impact velocity, the area-density of single mesh bumper, and multi-layer mesh bumper will be studied.

KEYWORDS space debris mesh bumper protection performance numerical simulation

1. INTRODUCTION

Since man walked into the space age on 4 October 1957, the space activities have created a very large number of fragments of varying sizes over the years. Space debris concentrate mostly in low earth orbit region between 200 and 2000 km altitude, next in geostationary orbit region and navigation satellite region. So spacecraft and large space structures in low earth orbit are seriously threatened by space debris. To promote the survival probability for spacecraft in the Micro-Meteoroid and Orbital Debris(MMOD) environments, it is the primary measure to design appropriate shield for spacecraft against MMOD. Many advanced shields have been adopted in ISS, for example, whipple shields are used to protect parts of U.S Laboratory Common Module (CM), "Unity" Node 1 module, and Russian Service Module (SM), nextel/kevlar "stuffed whipple" shields are used to protect forward/side areas of U.S. modules, ESA Columbus and NASDA Japanese Experimental Module(JEM), mesh double-bumper shields are used to protect parts of Russian Functional Cargo Block (FGB)[1].

In the shields applications for ISS, mesh bumper is used as a part of lightweight and high-performance shield, such as stuffed whipple for JEM, mesh double-bumper shield for FGB. Earlier studies revealed that meshes comminute hypervelocity projectiles with efficiencies comparable to contiguous targets[2,3,4]. In the paper, the tests validate partially it. Moreover, hypervelocity impact (HVI) character of mesh bumper is researched detailedly by numerical simulation. For this, the HVI character of mesh bumper is compared with equivalent area-density plate of mesh.

2. HPPERVELOCITY IMPACT TESTS

HVI tests are conducted with a two-stage light gas gun at China Aerodynamics Research and Development Center(CARDC). The test configurations are shown in Fig. 1. All of the test samples are made of aluminum LF6, and projectile is 5.0mm-diameter sphere. In test 1, the projectile impacts normally targets with velocity of 5.987km/s. In test 2, the projectile impacts normally target with velocity of 6.095km/s.

The detailed results of test 1 and test 2 are shown separately in Fig. 2 and Fig. 3. Although rear wall in test 2 has twice thickness of rear wall in test 1, bumper in test 2 has half area-density of bumper in test 1.

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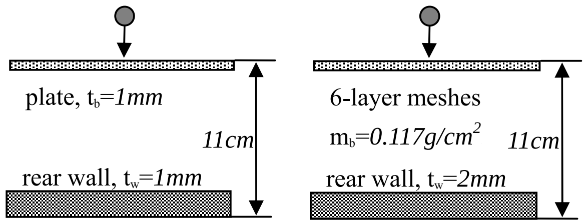
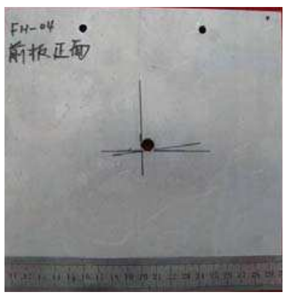
Based on damage of rear walls and dispersion of debris cloud in tests, it is concluded that mesh bumper can effectively comminute, decelerate projectile and disperse debris cloud.

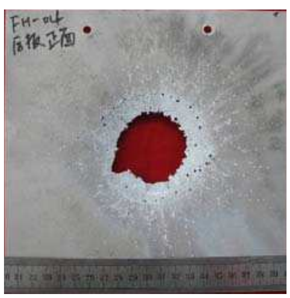


test 1 test 2

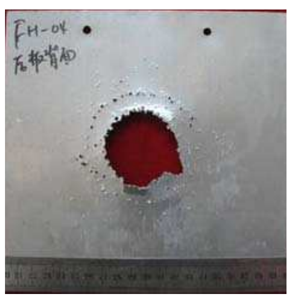
Figure 1. test configurations



front of AL plate

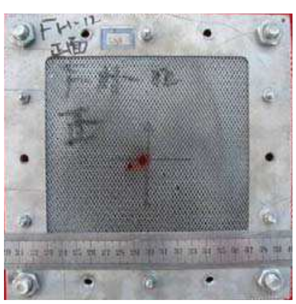


front of rear wall

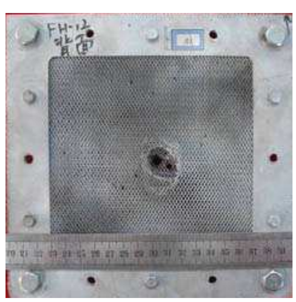


back of rear wall

Figure 2. results of test 1

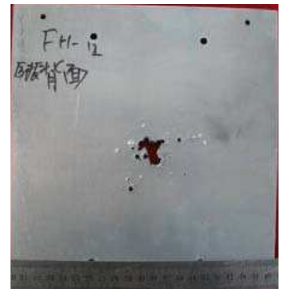


front of mesh



back of mesh

front of rear wall



back of rear wall

Figure 3. results of test 2

3. MESH BUMPER MODEL

The configuration of single mesh is shown in Fig. 4, a diameter of the wires "D" and gap between the wires "S" can design a special mesh[4]. Based on the special "D" and "S", simulation model of single mesh is founded as shown in Fig. 5.

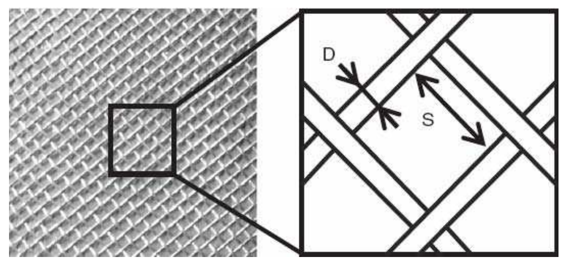


Figure 4. configuration of single mesh

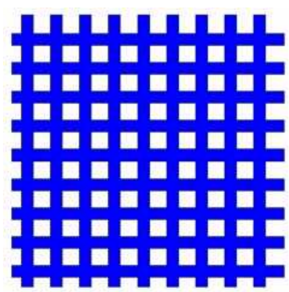


Figure 5. simulation model of single mesh

4. MESH BUMPER SIMULATION

The projectile is a 3.0mm-diameter sphere which is composed of aluminum 6061-T6 with density of 2.7g/cm^3, furthermore impact velocity of projectile is 6.5km/s. The time of calculation is 1μs.

The mesh is composed of 0.3mm-diameter aluminum 2024-T4 wires in a square pattern, 30 by 30 wires every 2.5 cm by 2.5 cm, 0.56 mm gap between wires, with area- density of 0.047 g/cm^2, the density of aluminum 2024-T4 is 2.785g/cm^3.

Equivalent area-density plate of the single mesh is 0.17mm-thickness aluminum 2024-T4 plate.

When the projectile impact normally targets, the simulation results of the single mesh and the equivalent area-density plate are shown separately in Fig. 6 and Fig. 7. When the projectile impact targets with angle of 30^o, the simulation results of the single mesh and the equivalent area-density plate are shown separately in Fig. 8 and Fig. 9.

The 2-layer mesh is composed of two single-meshes with cross gap as shown in Fig. 10. Equivalent area-density plate of the 2-layer mesh is 0.35mm-thickness plate. When the projectile impact normally targets, the simulation results of the 2-layer mesh and the equivalent area-density plate are shown separately in Fig. 11 and Fig. 12.

The detailed results are shown in Tab. 1.

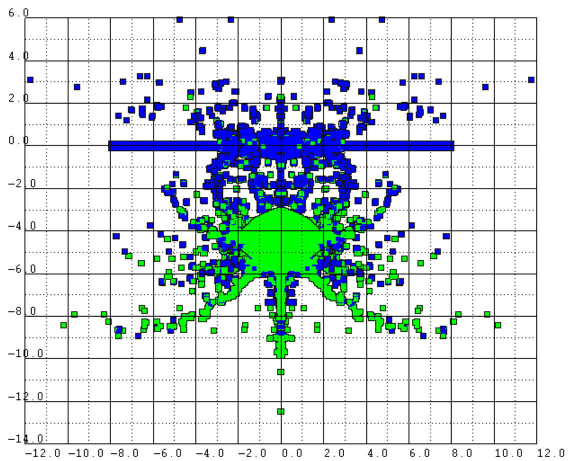


Figure 6. result of single mesh,0º

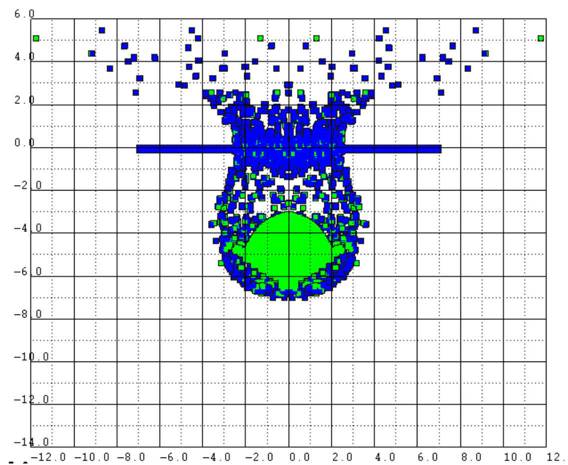


Figure 7. result of 0.17mm-thickness plate,0º

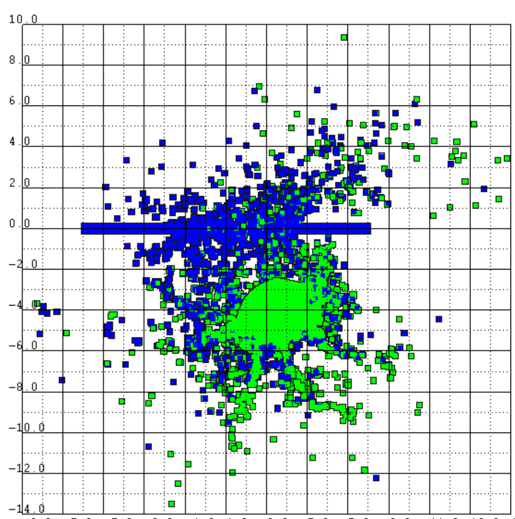


Figure 8. result of single mesh,30º

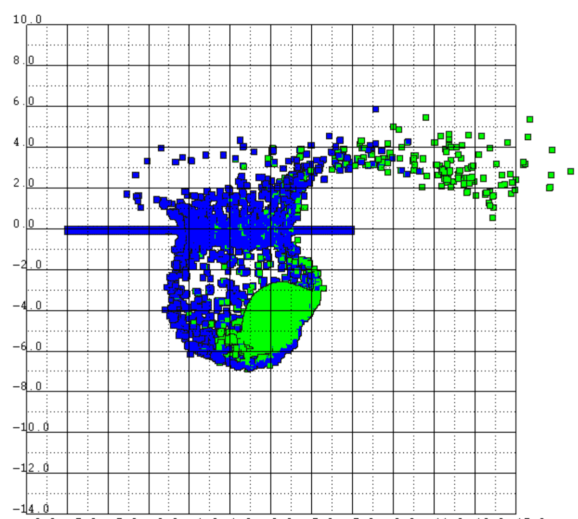
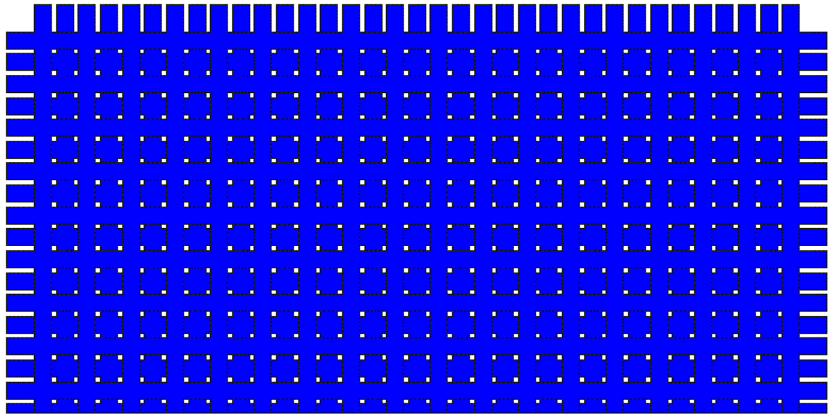


Figure 9. result of 0.17mm-thickness plate,30º



a planform

b section

Figure 10. simulation model of 2-layer mesh

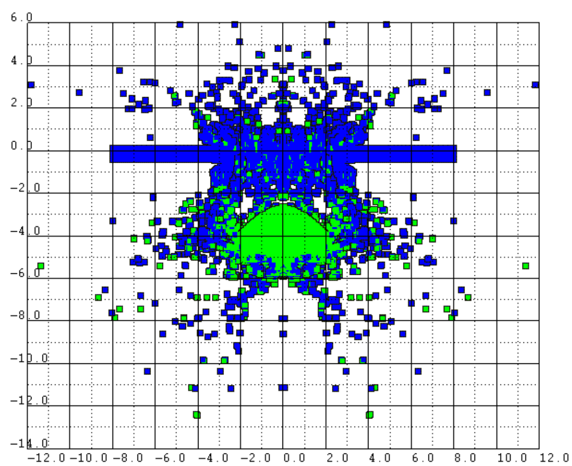


Figure 11. result of 2-layer mesh, 0º

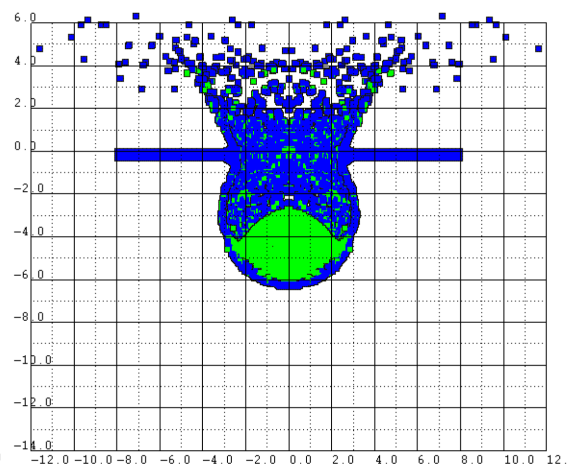


Figure 12. result of 0.35mm-thickness plate,0º

Tab. 1. HVI character of mesh and equivalent area-density plate

target	ejecta		debris cloud		projectile debris	
	Y-direction mm	X-direction mm	Y-direction mm	X-direction mm	Y-direction mm	X-direction mm
single mesh 0º	0~5.9	-11.7~11.7	-12.4~-0.3	-10.2~10.2	-5.8~-3.0	-2.0~2.0
0.17mm plate, 0º	0~5.5	-11.8~11.8	-7.0~-0.17	-3.6~3.6	-6.3~-3.1	-2.1~2.1
single mesh 30º	0~9.3	-4.8~14.8	-13.5~-0.3	-8.2~11.5	-6.0~-2.5	1.2~5.5
0.17mm plate, 30º	0~5.9	-4.1~18.4	-6.9~-0.17	-2.2~5.6	-6.0~-2.7	1.6~5.3
2-layer mesh 0º	0~5.9	-11.8~11.8	-12.4~-0.6	-11.4~11.4	-5.8~-2.6	-2.4~2.4
0.35mm plate,0º	0~6.3	-11.6~11.6	-6.32~-0.35	-3.2~3.2	-6.0~-2.7	-2.5~2.5

According to Fig. 6~Fig. 9 and Fig. 11~Fig. 12, mesh produces less ejecta than equivalent area-density plate. Though the diffusional area of debris cloud of mesh is larger than equivalent area-density plate, in debris cloud of mesh, there are some regions in which there are more fragments than other region. But when projectile impacts obliquely single mesh or normally 2-layer mesh, there are less regions in which there are more fragments.

5. CONCLUSION

The HVI character of mesh bumper and equivalent area-density plate is preliminarily studied by HVI test and numerical simulation. Mesh is more effective in dispersing debris cloud than plate and slightly better in lowering the velocity of projectile, this is resulted by cross wires and grid cutting, moreover fragments of mesh's self are less than plate. But in debris cloud of mesh, perhaps there are some regions in which there are more fragments than other region.

Based on above work, the sensitivity of major variables such as impact velocity, the diameter of wires and gap between wires will be studied, afterward the HVI character of multi-layer mesh will be researched.

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