DEBRIS CLOUD CHARACTERISTICS OF MONO- AND MULTI-PLATES UNDER HYPERVELOCITY IMPACT

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ABSTRACT

To create a better understanding of the debris characteristic of spacecraft that is shielded by typical structure walls, the mono- and multi-plates under hypervelocity impact are carried out by using the test and numerical simulation method. The shadowgraphs of debris clouds, velocity, dimension and mass distribution of debris are presented as well.

It is observed that, the number of fragments increases with projectile and target's dimension and impact velocity. The number of small debris increases more rapidly with the increase of impact velocity than that of large debris. It is also concluded that a number of large debris will break off from main structure in multi-plates impact, with 100m/s magnitude of separating velocity.

1. INTRODUCTION

Spacecraft's main structure is basically constituted by various plates and shells, which is vulnerable to hypervelocity impact because lightweight structure walls offer a low penetration resistance against impact of particles. Under hypervelocity impact condition, initial debris and second debris will be produced, which distinctly influence the damage effect[1-5]. This paper takes a test and numerical simulation approach to study the characteristic of debris cloud that produced by mono- and multi-plates under hypervelocity impacts.

2. TEST ARTICLES

These tests have been carried out at Range A, at Hypervelocity Ballistic Range Laboratory of Hypervelocity Aerodynamics Institute (HAI), China Aerodynamics Research and Development Center (CARDC). The main parameters are shown as Tab.1.

Hypervelocity impact tests are performed with a 7.6mm two-stage light gas gun. 2A12 aluminum plates is employed as targets with 0° impact angle. The projectiles are aluminum spheres and lexan cylinders. The projectile velocity has been recorded by speed measuring system before it impact the target, which triggering the laser source of the shadowgraph system to get debris cloud pictures.

In order to collect the debris, the paraffin plates are applied as soft recovery media. There are 5 pieces of paraffin board fixed on the side and rear direction of the target to retrieve the fragments of the debris clouds. While carrying on multi-plate impact tests, fragments will be splashed to the side direction, so the paraffin board on four sides of the target is needed respectively in principle, but due to shadowgraph pictures are needed, the laser beam shouldn't be blocked in horizontal direction, so the paraffin board are installed only on the upper and lower sides, the recovery data must be extended while calculating mass and quantity of the side direction fragments. The target and debris recovery configuration are shown in Fig. 1.

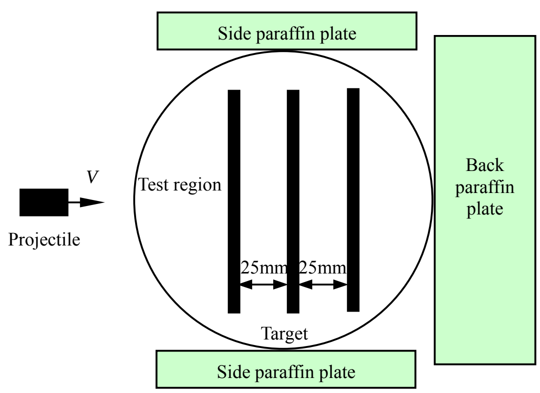

Figure1. Target and debris recovery configuration

3. TEST RESULTS AND ANALYSIS

3.1. Mono-plate test

After the aluminium sphere impacts the mono-plate target, a round hole with trimming edge is punched on the aluminium board, with no crackle and tear phenomenon. The projectile and part of target are broken into solid particles, with the majority flying forward in form of the debris cloud, while a small part is squirted backward. Because the axial velocity of the debirs cloud is greater than its radial velocity, it will expand and swell gradually in flight, take the form of ellipsoid. The typical debris

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cloud shadowgraph is shown in Fig. 2.

Table 1 Parameters of the test

Test No.	Target	Projectile	Velocity
T1	2A12 aluminum plate，thickness δ=1.44mm	2A12 aluminum sphere，dia. ϕ2.75mm	4.4km/s
T2	2A12 aluminum plate， δ=2.42mm	2A12 aluminum sphere，ϕ 4.50mm	4.4km/s
T3	2A12 aluminum plate， δ=2.42mm	2A12 aluminum sphere，ϕ 4.50mm	5.8km/s
T4	Three layers 2A12 aluminum plate assemblies δ=1.44mm，spacing S=25mm	lexan cylinder，ϕ 7.6mm×12.0mm	4.0km/s
T5	Three layers 2A12 aluminum plate assemblies δ=1.44mm，spacing S=25mm	lexan cylinder，ϕ 7.6mm×12.0mm	5.7km/s

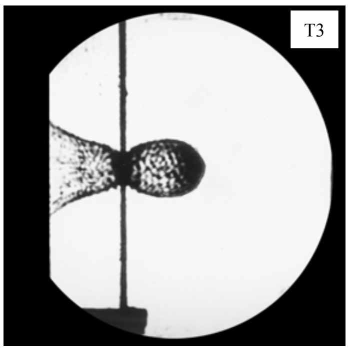


Figure2. Debris cloud in mono-plate test

The debris fragments will penetrate the paraffin board in small distances and then be stopped by medium resistance, form a round crater group on the surface. The recovered paraffin board shown in Fig. 3.

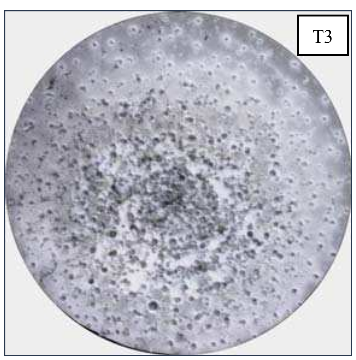


Figure3. Post-test Olefin plate in mono-plate test

It is found that the craters in the center area of the paraffin board is distributed intensively, larger than those others which around the center, proving the kinetic energy of fragments is relatively greater in the center. While along with the craters gradually sparse outwards, the crater size diminish accordingly, showing the kinetic energy of fragments outside is smaller than that of inboard.

3.2. Multi-plate test

The multi-plates used in these tests are three layers aluminium plate assemblies. Typical damage pattern is shown in Fig. 4. There is a round hole in the front plate which appear similar to mono-plate test, and large split hole in the second and the third plates of which the size is much greater than the diameter of projectile.

Fig. 5 presents a representative shadowgraph of the multi-plate impact tests. It can be seen that the cylindrical polycarbonate has been totally breaked up or even taken place phase transition when it impact the first plate, due to its low density and melting point. There’s a large amount of smoke and dust squirt backward from the first plate, mainly composed of three-phase mixture of solid, liquid, and gas, only contain a small quantity of large size fragments. The flying forward fragments form a initial debris cloud and impacts the second plate, producing more tinier splashing fragments backward, and form craters and holes on the second plate. These spattering fragments and initial debris cloud meet in plates’ gap space and reverse collide takes place, thus inducing more cracking of the fragments. Meanwhile, these fragments obtains radial velocity in the course of colliding each other, making debris cloud drawn along the radial direction, and expanding outwards close to the second plate. Because the fragment kinetic energy of the initial debris cloud is relatively high, it produces large amount hole damage in the center aera of the second plate, induced the strength reduction and the stress consentration. Under the intense shock loading of the debris cloud, the plate is torn from the weak place in the center, roll up backward and make the hole appear petal type. The debris which passes through the second plate will repeat the process described above among the second and third plates. Because debris velocity at this moment has already been greatly reduced, the perforation damage of the third plate will be reduced, but the shock loading time will be lengthened accordingly, the momentum that the petal damage area absorbed will increase too, which bend and distort the plate more obviously, and result in a larger hole at the center of the third plate.

Figure4. Damage of multi-plate

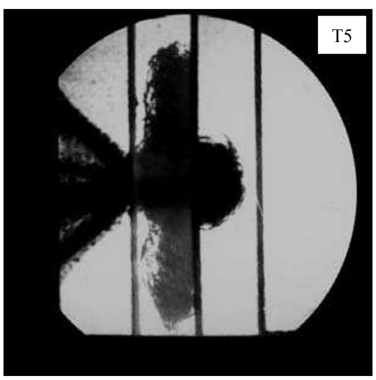


Figure5. Debris cloud of multi-plate test

The debris cloud, of which the kinetic energy that crossed the third plate has already reduced a lot, can be recovered harmlessly by paraffin board. The paraffin board that covered with black dust and crater is shown in Fig. 6, and the crater distribution has obvious regionalities. The distribution of craters on the paraffin board behind the third plate is different from that in mono-plate tests, as the small craters basically concentrate on the center district of the paraffin board, while the large craters are distributed around on an annular area. Obviously, small craters are formed by the fragments which penetrate the third plate directly or transform from the large hole of the second plate, the larger craters are mainly formed by the pieces of fragments that breaked off from the tip of petals. These craters' diameter is obviously greater than the one of mono-plate test, and the shape is irregular.

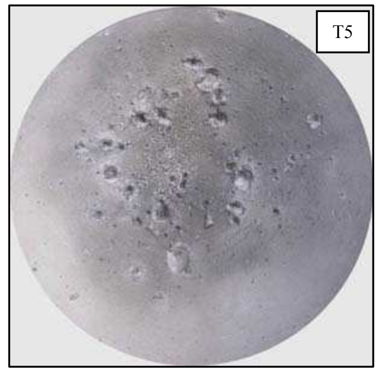


Figure6. Post-test olefin plate of multi-plate

3.3. Fragments scale and mass distribution

The fragments size is divide into following 8 intervals: >5mm, 4mm-5mm, 3mm-4mm, 2mm-3mm, 1mm-2mm, 0.8mm-1mm, 0.6mm-0.8mm and <0.6mm, The mass of fragments of each group is measured separately, and then the average mass and mass proportion of the fragments in each group is calculated. Here the total mass of fragments that smaller than a certain scale is defined as *residual mass*[6]. The relationship between residual mass percentage and fragments size is shown in Fig. 7. As fragments size is reduced, the residual mass percentage is reduced correspondingly. Five curves for different projectiles and targets configurations (i.e. 1.44mm mono-plate, 2.42mm mono-plate and 3×1.44mm multi-plate) divide into three groups obviously, it is indicated that the mass distribution of fragments is more influenced by projectile and target configuration than the impact velocity.

The relationship between fragments mass percentage in every 1mm interval and fragments size of mono-plate test is shown in Fig. 8. For the fragment whose size is larger than 1mm, its mass distribution is relatively more average, while the mass obviously increases for the size smaller than 1mm, approximately account for 50%- 74% of retrieved mass. It is indicated that large fragment produces less in mono-plate test than in multi-plate test.

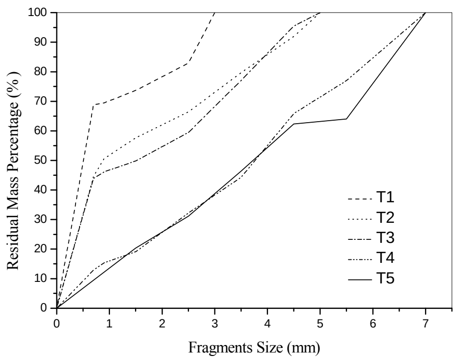


Figure7. Residual mass percentage vs debris sizes

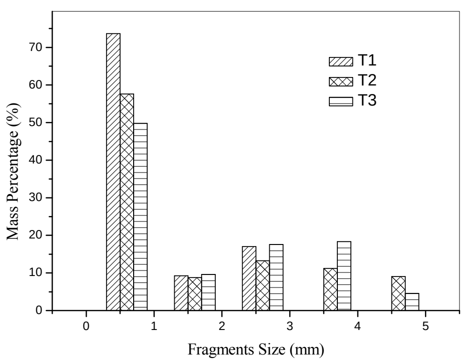


Figure8. Debris mass percentage in each size range of mono-plate test

The relationship between fragments mass percentage in every 1mm interval and fragments size of multi-plate test is shown in Fig. 9. Its distribution is more even than that of the mono-plate test, the fragments mass of the size smaller than 1mm approximately account for 20% of retrieved mass. This is due to the second and third plate have produced certain amount of large size fragments in penetration and tearing process, and make the mass proportion of large size increase accordingly.

Fig. 10a presents the fragments quantity statistics curves for mono-plate test, while the target thickness in T1 test is probably 1.65 times than that of T2. The fragments quantity presents the power law to increase with the decrease of fragments size from the figure, and when the projectile and target size increases, fragments quantity of all different size increases correspondingly.

Fig. 10b presents the fragments quantity statistics curves at 4.4km/s and 5.8km/s as the projectile and target size haven't change in two tests. Because the impact velocity of T3 is higher than T2, it is more serious to cause the breakup of projectile and target material, and the fragments quantity increases more distinctly with its size reduced than T2. The quantity of large fragments that the average size is greater than 2.5mm does not change much in two tests, prove the quantity of small fragments is more sensitive to impact velocity.

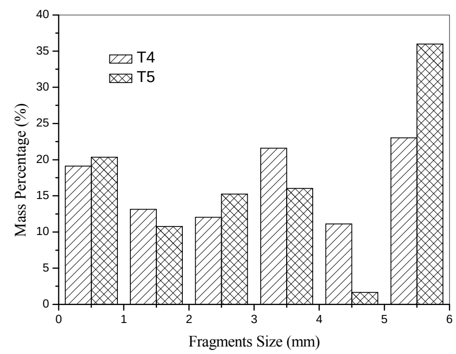


Figure9. Debris mass percentage of each size range of multi-plate test

The fragments quantity statistics curves under 4.0km/s and 5.7km/s of multi-plate tests are shown in Fig. 10c. Its changing law is similar to mono-plate test result in Fig. 10b.

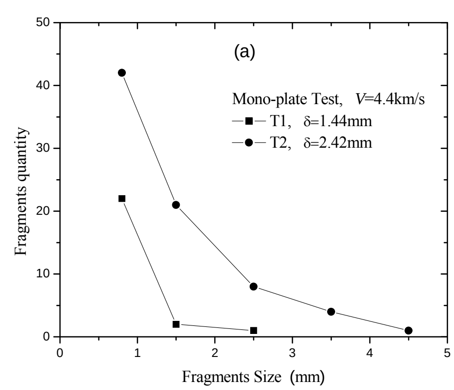


Figure10. Debris number vs debris average size

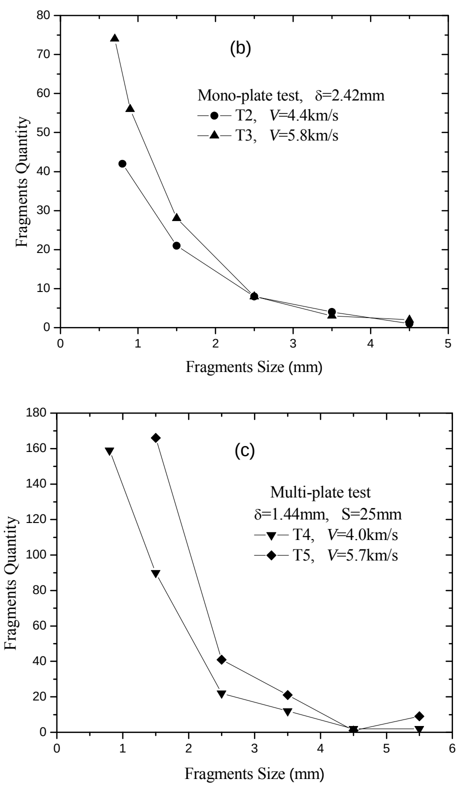


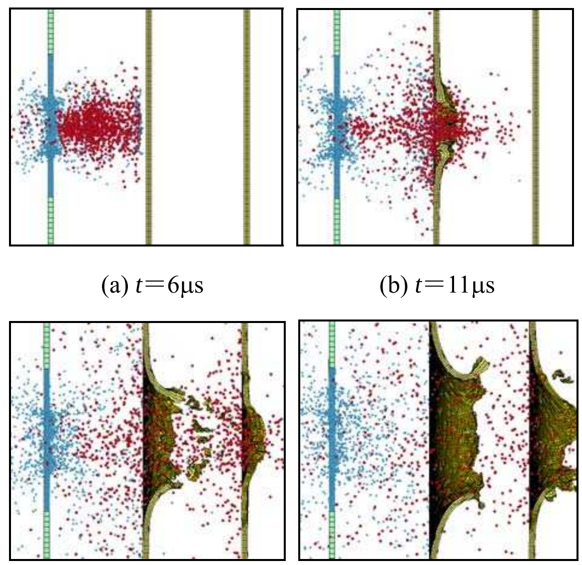
Figure10. Debris number vs debris average size

4. NUMERICAL SIMULATION AND ANALYSIS

A SPH method combine with finite element arithmetic is used to simulate the multi-plate test on LS-DYNA platform. The typical simulation result of T2 is shown in Fig.11. It can be observed from the picture that the cylindrical Lexan projectile is totally broken up when impact have happened for 6μs, form a fluffy debris cloud. The primary part of debris cloud is composed of Lexan material, and there is a flat part on front debris, which is composed of the first aluminium plate material.

Debris cloud has penetrated second plate when impact happened 11μs, form a large hole in the plate center, with a lot of small perforation around. The center area begin dented under the impact load at this moment, but has not presented obvious pull-away and rolled up phenomenon yet.

When impact time develop to 24μs, debris cloud which traverse through the second plate in center hole has perforated the third plate, but produce less damage in the third plate as a result of fragments' quantity and kinetic energy drops a lot. At this moment, the petal edge material of second plate present the break off phenomenon under the effects of perforation and shock load, form a ring region of large fragments. These fragments fly in the impact direction at velocity about 100m/s. When impact time develop to 24μs, no distinct change will present in damage shape and characteristic in the plates, the edge of centre bore of the second plate demonstrates the final characteristic rolled up outwards at this moment, and the third plate has the rolling up tendency, but the degree is smaller than the second plate, this limitation is caused by absence of crackle model in finite element simulation.



(a) t=6μs (b) t=11μs

(c) t=24μs (d) t=50μs

Fig.11 Numerical simulation result of the cylindrical projectile impact the multi-plate target

Compared with test result, simulation result can describe the whole process of impact, get some quantitative data, and is consistent with test result on mainly characteristic of damage.

5. CONCLUSION

Under the test conditions, the projectile's extensive breakup happens when impacting the first plate, form the initial cloud. When the initial debris cloud impact the subsequent target plates, it will produce intense shock load on a larger area, make the target plates perforated, torn and rolled up.

It is conclude that, the larger the projectile and targets scale is, or the higher impact velocity occurs, the more fragments be in quantity. The data presented confirm a power-law debris fragments population, and the quantity of small fragments is more sensitive to impact velocity than that of large fragments.

As for multi-plates target, the second and third plate can produce breaking off phenomenon on petal tip, generates certain amount of large size fragments at about 100m/s.

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