# NUMERICAL SIMULATION OF HYPERVELOCITY IMPACT ON HONEYCOMB SANDWICH PANELS

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**ABSTRACT**

To understand the process of hypervelocity impact on honeycomb sandwich panels, numerical simulation was carried out by using LS-DYNA hydrocode. The honeycomb panels were impacted by aluminum spheres of diameters ranging from 1mm to 2mm at velocity around 6km/s. Smooth Particle Hydrodynamic method was used coupling with finite element method. The projectile and front face sheet was modeled as SPH particles, while the rear face sheet was modeled as solid elements. Honeycomb cores were modeled as shell elements. It was shown that radial expanding of debris cloud was restricted by honeycomb cells. Additionally, honeycomb cores had considerable channeling and branching effects on debris cloud in the axial path. Further more, the location where projectiles impacted on the front face sheet had a significant influence on the damage of the rear face sheet. Test result that was obtained at Range A was described in this paper. The simulation result agreed well with the test result.

## 1. INTRODUCTION

Honeycomb sandwich panel was widely used on man-made spacecraft as a structure material due to its high strength and low weight. It was typically used as the external wall of spacecraft, providing the primary shielding protection against space debris and meteoroids. The predicted increase in the LEO space debris population (linked to the rise in total satellite mass launched), had meant that the issue of hypervelocity impact on spacecraft honeycomb panels was of increasing concern. Large number of experimental and numerical studies on hypervelocity impact response of honeycomb structure had been performed [1~3]. Most of these studies were focused on the ballistic equation of honeycomb panels. It was realized that honeycomb cores had significant influences on the impact processes in a few papers. In this paper, numerical simulation had been carried out by using LS-DYNA hydrocode to further understand the impact processes.

## 2. NUMERICAL MODEL

Honeycomb sandwich panel was combined of two face sheets and honeycomb cores as shown in Fig.1. Honeycomb cores were made up of several hexagon cells, being adhesively bonded with two face sheets. The size was given in Fig.2. The honeycomb cell was 24.4mm in height and 4mm in side length, with walls of 0.03mm in thickness. The thickness of face sheet varied in different simulation cases, as shown in Table 1.

Smooth Particle Hydrodynamic method has been validated to be a useful numerical method in hypervelocity field. Generally, the projectile and target should be modeled as SPH particles. However, the honeycomb cell walls were too thin so that SPH particles were extremely small. It caused an unacceptable small computational time step and overly large number of particles. Thus, honeycomb cores were modeled as shell elements in this paper. In addition, to reduce the calculation time, the rear face sheet was modeled as solid elements. The shell elements and solid elements were coupled with SPH particles which were employed to mesh the projectile and front face sheet by contacts defined between them.

The projectile and face sheets were modeled as aluminum alloy by using Johnson-Cook material model and Gruneison state equation, which allows for strain rate hardening and thermal softening of the material. Existing well-validated material property parameters for aluminum were used in the simulation.

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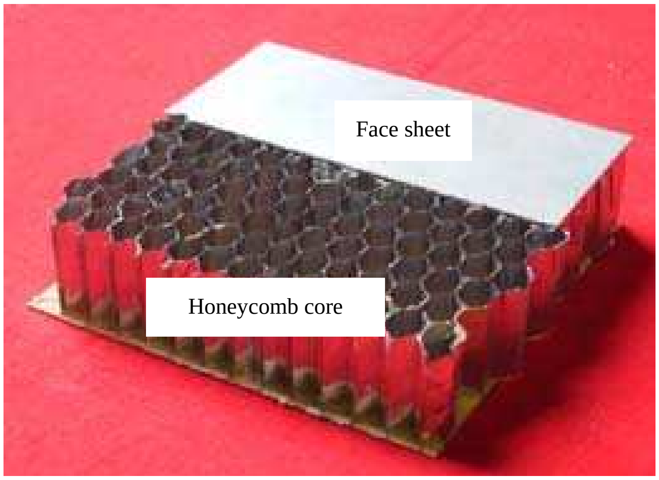



*Figure1. Structure of honeycomb sandwich panel*

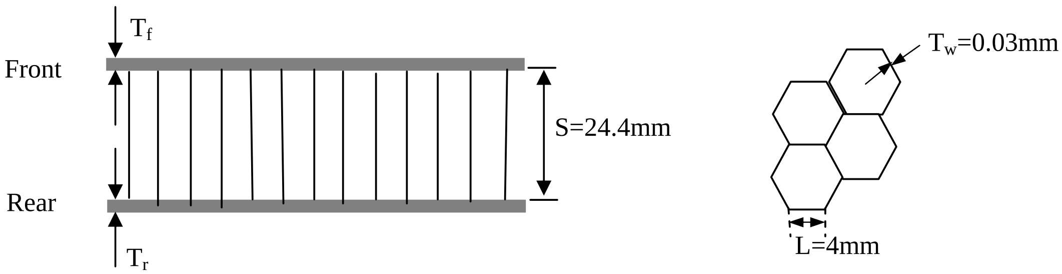



*Figure2. The simulated honeycomb configuration*

*Table 1 Parameters of the simulation*

| NO | Target | Projectile diameter | Impact velocity | Impact point |
|---|---|---|---|---|
| HC-1 | front face: 0.5mm; rear face: 0.3mm; Whipple shield | 1.0mm | 6.0km/s | (0,0) |
| HC-2 | front face: 0.5mm; rear face: 0.3mm; with single cell | 1.0mm | 6.0km/s | (0,0) |
| HC-3 | front face: 0.5mm; rear face: 0.3mm; with 3 cells | 1.0mm | 6.0km/s | (-4,0) |
| HC-4 | front face: 0.8mm; rear face: 0.3mm; with 7 cells | *2.0mm* | 6.0km/s | (0,0) |
| HC-5 | front face: 0.8mm; rear face: 0.3mm; Whipple shield | *2.0mm* | 6.0km/s | (0,0) |
| HC-6 | front face: 0.8mm; rear face: 0.3mm; with 7 cells | 2.0mm | 6.0km/s | (2.5,1.5) |
| HC-7 | front face: 0.3mm; rear face: 0.3mm; with 7 cells | 1.0mm | 6.35km/s | (0,0) |

Simplified Johnson-Cook model was employed to describe the shell elements of cores since its failure mechanism could be easily expressed by using a strain parameter.

Totally 7 cases were calculated, details of which were shown in Table1.

## 3. NUMERICAL RESULTS

### 3.1 Interaction between Cores and Debris Cloud

As we kneed, debris cloud was the most important phenomena in hypervelocity impact. When a projectile impacted a plate, debris cloud which was filled with small particles would form after the penetration hole.

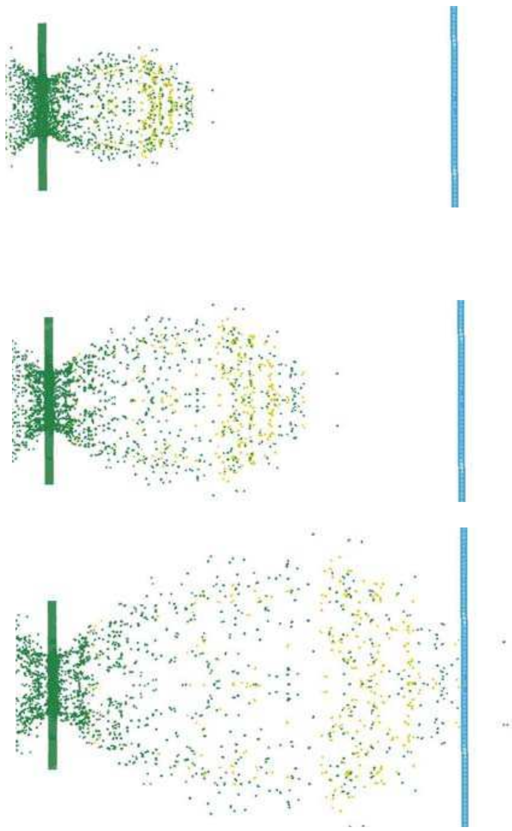


*Figure3. Debris cloud in Whipple Shield (HC-1)*
*(Projectile diameter: 1mm; impact velocity: 6km/s)*

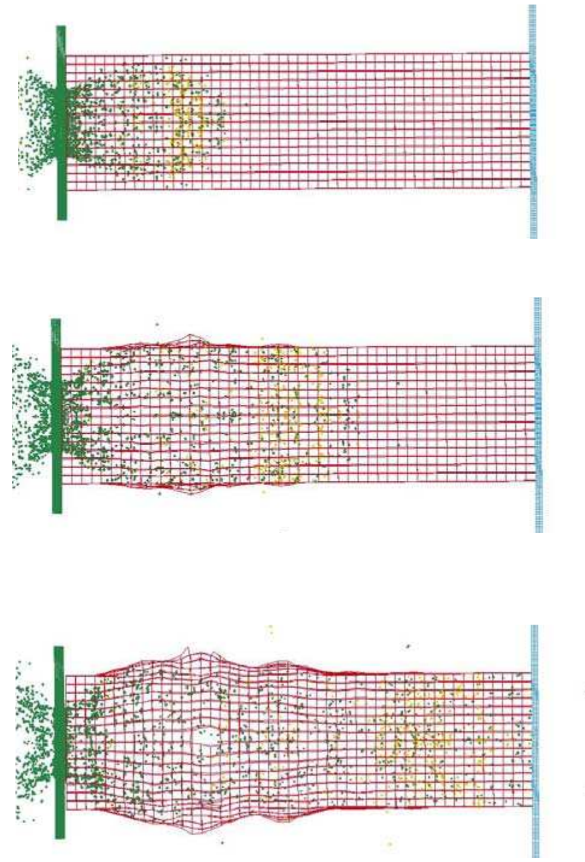


*Figure4. Debris cloud in single cell (HC-2)*
*(Projectile diameter: 1mm; impact velocity: 6km/s)*

It could move along the incident trajectory and expanded in radial. Structures behind would be damaged by debris cloud because of its large energy. HC-1 simulated a projectile of 1mm diameter impacted a double wall target that was commonly named “Whipple Shield” at 6km/s. Fig 3 showed the process that debris cloud formed and expanded in HC-1. As shown in this figure, projectile fragmented during penetrating the front wall. Debris cloud formed at impact point and expanded in radial path as it moved along the ballistic trajectory.

However, the honeycomb cell disturbed the development of debris cloud, as shown in Fig.4. HC-2 simulated a 1mm projectile impacted a target that was composed of two face sheets and single honeycomb cell at 6km/s. The radial expanding of debris cloud was restricted by cell walls. Although some particles with high radial speed penetrated the cell wall, particles with low radial speed were blocked off and rebounded. Thus, much more particles were gathered in axial path than that in Whipple Shield. It seemed that honeycomb cell had a channeling effect on debris cloud in the axial path.

HC-4 simulated a 2mm sphere impacted a target that was composed of two face sheets and seven honeycomb cells. Fig.5 showed the debris cloud in bottom view. Inner cell walls held up a majority of debris, then outside cell walls held up some of the remained debris. It could be concluded that debris cloud would be blocked off by honeycomb cell walls layer upon layer, gathered in several circle fields. At the same time, the honeycomb cells were damaged by debris cloud as shown in Fig.6.

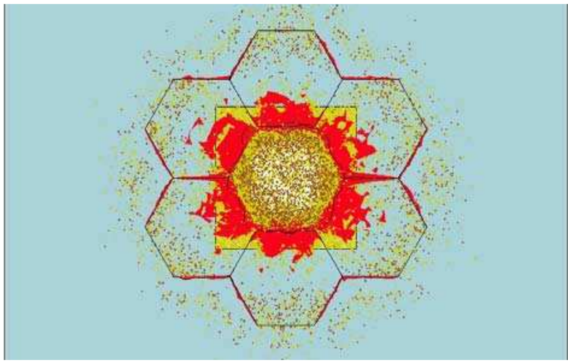


*Figure5. Debris cloud in HC-4*
*(Projectile diameter: 2mm; impact velocity: 6km/s)*

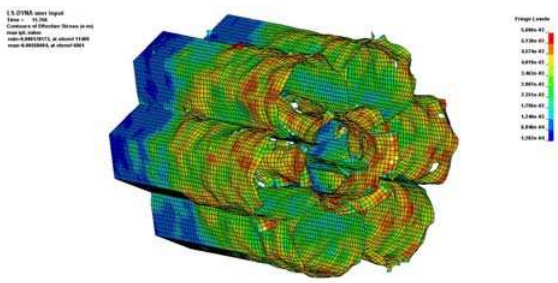


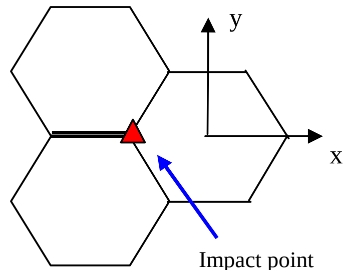
*Figure6.Damage of honeycomb cores in HC-4*

Thus, interaction between honeycomb cores and debris cloud been summarized as follow: honeycomb cells would be penetrated and damaged by debris cloud because of its large energy, at the same time, honeycomb cells could restrict the radial expanding of debris cloud, having considerable channeling and branching effects on debris cloud in axial path.

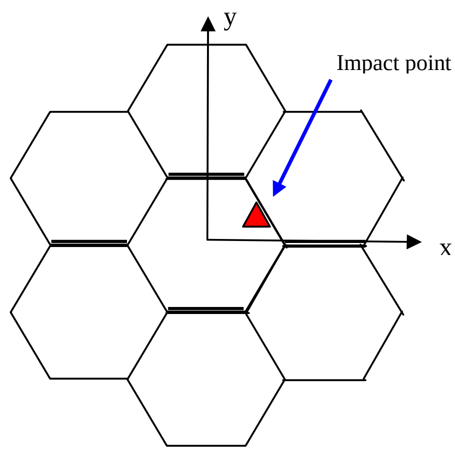
**3.2 Discussion on the impact location**

Simulations in previous paragraphs were all assumed that the projection of impact point on the cross section of cell was in the center of hexagon. However, the impact point often varied on the front face. So, it was necessary to take into account the influence of impact location.

Based on this consideration, two cases HC-3 and HC-6 were carried out. The impact location was described by using (x, y) coordinate in mm unit in the cross section of honeycomb cell. Fig.7 showed the impact points of the two simulations, (x, y) values could be found in Table1.



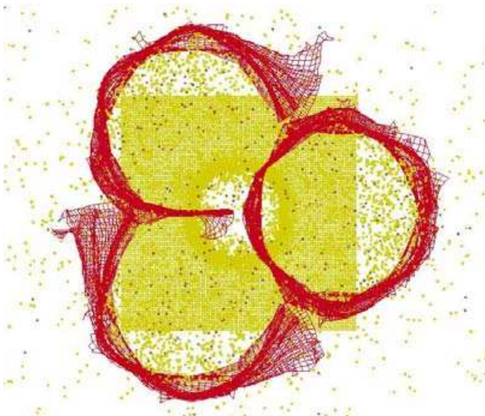

*(a) HC-3*



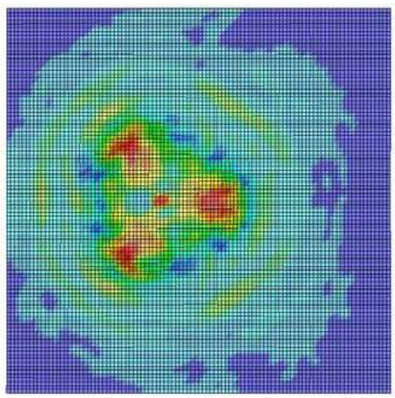

*(b) HC-6*

*Figure7.Impact points of HC-3and HC-6*

HC-3 modeled a projectile of 1mm diameter impacted at the location where three cells joint together at 6km/s. The majority of debris was divided by the cell walls into three parts that were separately within the three cells. The three parts of debris caused three corresponding zones with high stress level on the rear face sheet, which make the rear face bulged (Fig. 8). Compared with the case HC-3, the rear face sheet was ruptured with a cleft of 8.5mm×7.3mm in the case HC-2(Fig. 9), which had the same projectile diameter and impact velocity. The impact location that was in the center of hexagon, caused most debris blocked within the single cell so that the rear face sheet suffered much more shock energy than that in HC-3.



*(a)*



*(b)*

*Figure8.Debris cloud and rear face damage in HC-3*
*(Projectile diameter:1mm; impact velocity: 6km/s)*

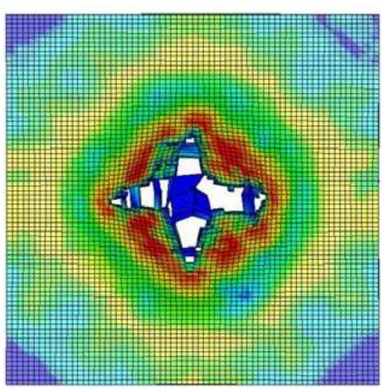
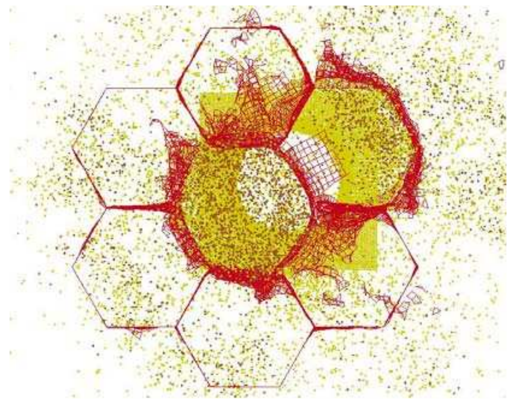
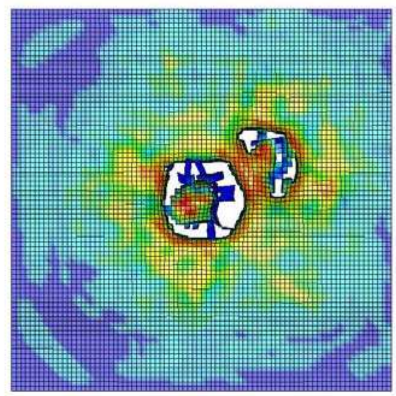


*Figure9.Rear face damage in HC-2*
*(Projectile diameter: 1mm; impact velocity: 6km/s)*



*(a)*



*(b)*

*Figure10.Debris cloud and rear face damage in HC-6*
*(Projectile diameter: 2mm; impact velocity: 6km/s)*

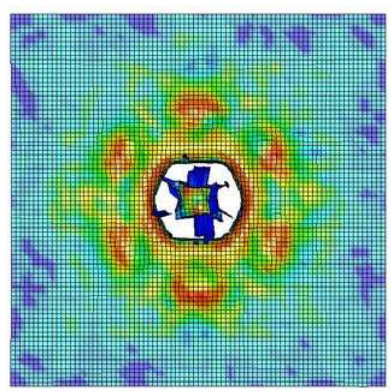


*Figure11.Rear face damage in HC-4*
*(Projectile diameter: 2mm; impact velocity: 6km/s)*

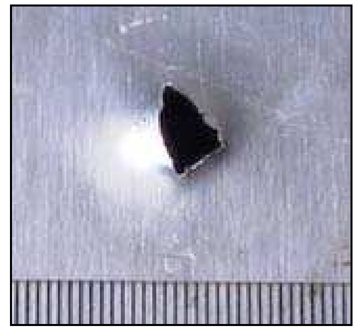
In the case HC-6, the impact point was near the interface of two cells. The projectile was 2mm in diameter with velocity of 6km/s. The interface wall was destroyed; at the same time, debris cloud was separated into two main parts within the two adjacent cells. Thus, the rear face sheet was penetrated, brought two perforation holes, as shown in Fig.10. Comparatively, the case HC-4 which had the same projectile parameter but different impact point formed only one perforation hole and several bulges on the rear face sheet (Fig.11).

Obviously, the impact location had a significant influence on the damage of the rear face sheet. Different impact points caused different damages. The energy density on the rear face was dominant during the process that the rear face sheet was damaged. If the kinetic energy of projectile was large enough, debris cloud could perforate the rear face whether it was branched or not, as in cases HC-4 and HC-6. Thus, debris divided into two or more parts could produce more severe damage than debris restricted in single honeycomb cell. If the kinetic energy of projectile was lower, debris restricted in single cell could cause perforation on rear face, while debris divided could cause some little deformation, as in cases HC-2 and HC-3.

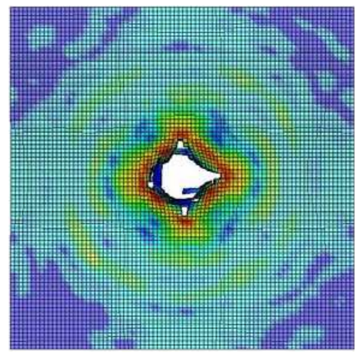
## 4. VALIDATION OF NUMERICAL RESULT

Validation of the numerical result was performed using previous test result. The test was carried out at Range A [4] in Hypervelocity Ballistic Range Laboratory of HAI, which could driver a projectile ranging in 0.5mm to 5.5mm diameter up to 7.4km/s. The tested target was composed of two faces sheets with 0.3mm thickness and honeycomb cores which were combined of many hexagon cells with 4mm side length , as target in HC-7. The 1.0mm aluminum sphere was launched to impact the target at 6.35km/s.

Fig. 12 compared the rear face damage of simulation result in HC-7 and the test result. It was shown that the perforation hole of rear face in HC-7 was similar to the hole of tested target in shape and size. With the same impact condition, perforation size in simulation HC-7 was about 8.2mm×8.1mm, and perforation size in the test was about 8.5mm×5.5mm. Simulation result agreed well with the test result. It was validated that the numerical model could realistically simulate actual impact.



*(a) Test result*



*(b) Numerical result*

*Figure12.Rear face damage in Test and HC-7*

*(Projectile diameter: 1mm; impact velocity: 6.35km/s)*

## 5. CONCLUSION

Hydrocode simulation had been performed to explore the process of hypervelocity impact on honeycomb sandwich panels. Lagrange elements and Shell elements were used coupled with SPH particles. Simulation results showed that the honeycomb cores had restricting, channeling and branching effects on the debris cloud. Furthermore, the influence of impact location was discussed. It could be found that damage of rear face sheet varied significantly with the impact point.

However, some actual factors which would influence the hypervelocity impact performance of honeycomb structure, for example, the adhesive between cores and face sheet, were not taken account for simplification of simulation. So, simulation work would be performed further, and more factors would be considered.

## 6. REFERENCES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