PROTECTION OF MANNED SPACECRAFT RADIATOR FROM SPACE DEBRIS

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ABSTRACT

With worsening of the space debris environment, research on the hypervelocity impact phenomena of space debris attracts more and more interests of investigators all over the world. Radiators are the important component parts of the manned spacecraft thermal control subsystem, and under threat of the hypervelocity impact of space debris. In this study, we used numerical simulation and test investigations to research radiator pipes which are impacted by space debris and evaluated their performance of resisting the hypervelocity impact of space debris. The results show that some kinds of radiator pipes have low ballistic limits and should be strengthened in the future.

1 INTRODUCTION

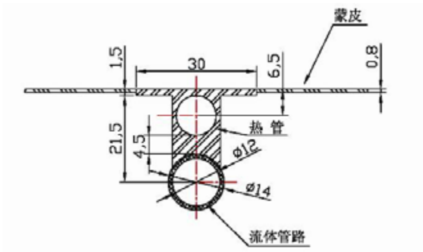
With the increasing of human spaceflight activities, the space debris environment is getting worse. At present, the number of space debris above 1cm is over 700 thousand, and the number of space debris above 1mm is more than 170 million. The average relative velocity of the space debris impacting the spacecraft is 10km/s, which will damage or even destroy the spacecraft, and the deteriorating space debris environment increases the risk of space debris collision.

At present, the methods of hypervelocity impact of space debris are hypervelocity impact test and numerical simulation. Hypervelocity impact test is expensive, and the impact velocity of projectile is limited by the test equipment. Compared with the experimental method, the numerical simulation method has the advantages of flexible implementation, low cost, rich simulation conditions, and can capture the complete evolution process.

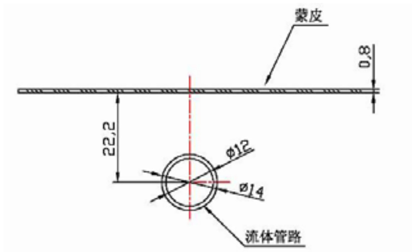
The radiator is an important part of the thermal control system of manned spacecraft, and the probability of collision is very high. Hypervelocity impact of space debris can damage the radiator pipe in different degrees, and even lead to breakdown of pipes, resulting in failure of the thermal control system, so it is necessary to carry out research on hypervelocity impact of space debris against radiator pipes and evaluate pipe resistance capability. In this paper, numerical simulation and test investigations of hypervelocity impact of space debris against radiator pipes are studied.

2 MANNED SPACECRAFT RADIATOR PIPES

Figure 1 shows the configuration of the manned spacecraft radiator pipes. The material of the skin and fluid piping is Al alloy LF21, the material of the heat-pipe wall is Al alloy 6063.



(a) Heat-Pipe Radiator Type I Pipe



(b) Heat-Pipe Radiator Type II Pipe

Figure 1. Manned Spacecraft Radiator Pipe

3 NUMERICAL SIMULATION MODEL

3.1 Failure Criteria and Material Model

Smoothed particle hydrodynamics (SPH) method is a mesh-less method, first proposed by Lucy[1] and Gingold[2] in 1977, which is used in the field of hypervelocity impact numerical simulation [3].

The failure criterion adopted in this paper includes: (a) the pipe is breakdown, or (b) there is a piece of debris in the pipe.

The constitutive equations of Al alloy 6063 and Al alloy LF21 are based on the Steinberg Guinan equations, the state equations are the Shock equations, and the failure criterions are the maximum tensile stress criterions.

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The material of space debris is assumed to be Al alloy 2024, the constitutive equation is Steinberg Guinan equation, the state equation is Shock equation, and the failure criterion is the maximum tensile stress criterion.

3.2 Heat-Pipe Radiator Type I Pipe

The simulation model of the initial time is shown in Figure 2, in which the diameter of the space debris is 6.0mm. The space debris is idealized as a spherical projectile, and the 3D simulation model is simplified as an axial symmetry model. The radiator is simplified to a Whipple shield. The upper wall of the heat-pipe is assumed as the bumper of the Whipple shield, and the upper wall of the heat-pipe and the upper wall of the radiator pipe are assumed as the back wall of the Whipple shield.

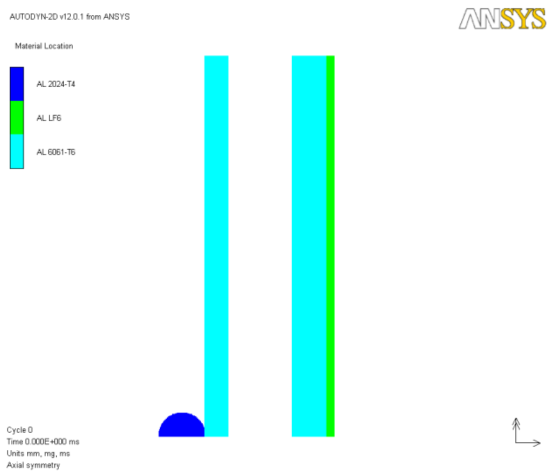


Figure 2. Simulation Model of Heat-Pipe Radiator Type I Pipe

3.3 Heat-Pipe Radiator Type II Pipe

The simulation model of the initial time is shown in Figure 3, in which the diameter of the space debris is 2.0mm. The space debris is idealized as a spherical projectile, and the 3D simulation model is simplified as an axial symmetry model. The radiator is simplified to a Whipple shield. The skin is assumed as the bumper of the Whipple shield, and the upper wall of the radiator pipe is assumed as the back wall of the Whipple shield.

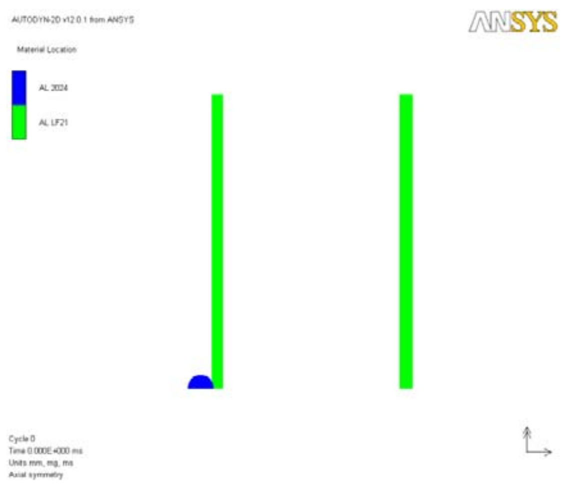


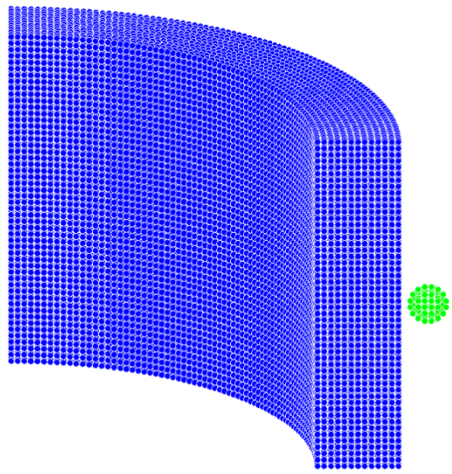
Figure 3. Simulation Model of Heat-Pipe Radiator Type II Pipe

4 ANALYSIS OF THE INFLUENCE OF THE WORKING FLUID ON NUMERICAL SIMULATION RESULTS

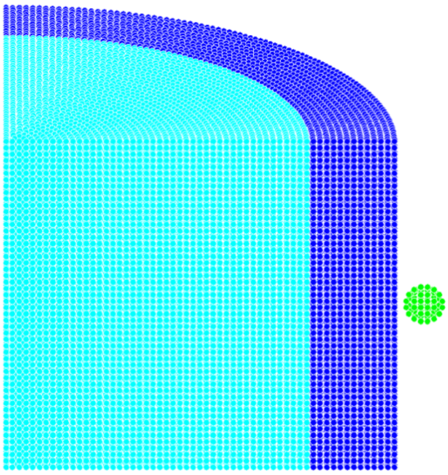
In order to compare the influence of the working fluid on the numerical simulation results, two kinds of working conditions are designed, as shown in figure 4. The outer diameter of the pipe is 18mm, the thickness is 2mm.

Condition A is the impact of the pipe at the speed of 3.0km/s. Condition B is the impact of the pipe at the speed of 8.0km/s.

Select two reference points for comparison of the results. The reference point 2 is the center of the impact point, and the reference point 1 is the back of the reference point 2. The numerical simulation results are given in figure 5 and figure 6.

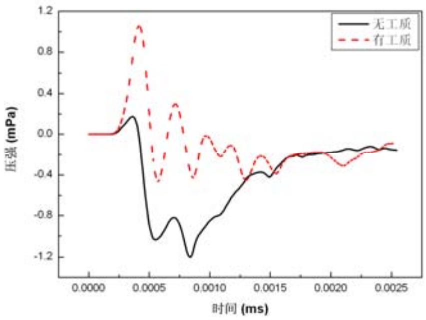


(a) Without Working Fluid

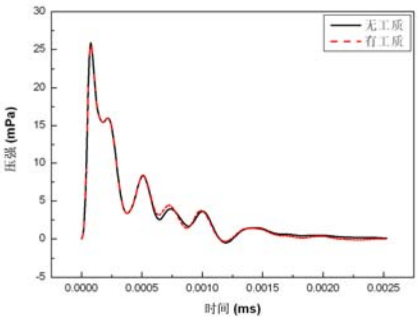


(b) With Working Fluid

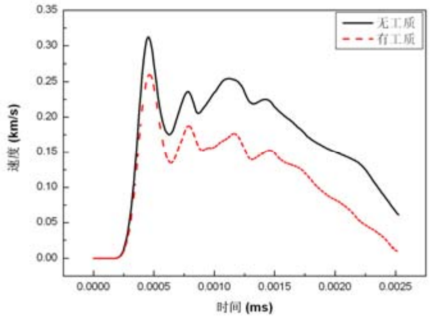
Figure 4. Numerical Simulation Model



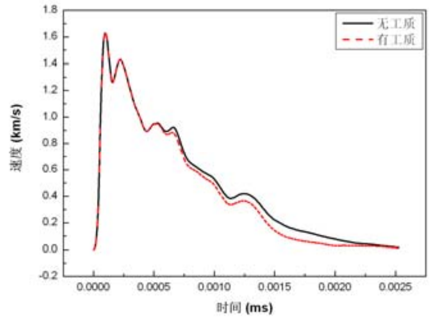
(a) pressure history of Reference point 1



(b) pressure history of Reference point 2

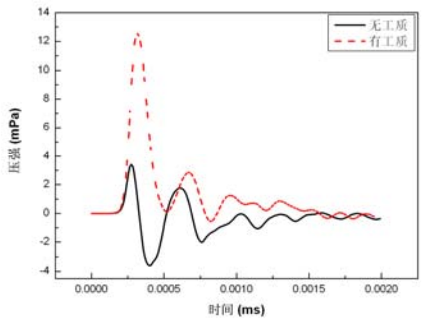


(c) velocity history of Reference point 1

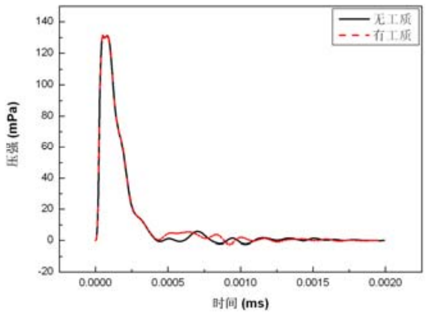


(d) velocity history of Reference point 2

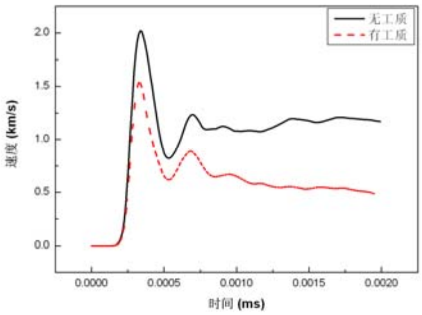
Figure 5. Numerical Simulation Results of Condition A



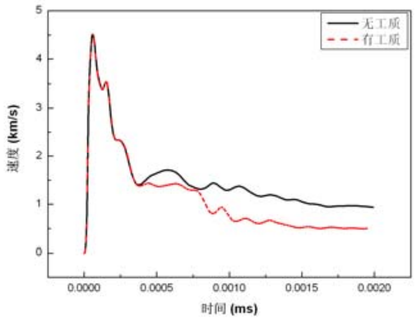
(a) pressure history of Reference point 1



(b) pressure history of Reference point 2



(c) velocity history of Reference point 1



(d) velocity history of Reference point 2

Figure 6. Numerical Simulation Results of Condition B

The impact pressure history curve and the velocity history curve are similar at the reference point 2, but are significantly different from the reference point 1.

This is obviously caused by the different reflection of the shock wave at the interface of different materials.

In the case of absence of working fluid, the pressure at the reference point 1 becomes the negative pressure after the shock wave, which is the main cause of the back of the material; In the case of existence of working fluid, the negative pressure value is low, the material is not easy to penetrate.

The results of numerical simulation show that the presence of the working fluid can enhance the impact resistance of the pipe.

5 Numerical Simulation Results

The velocity of the space debris impacting on the pipe is 3.0km/s and 7.0km/s, and the numerical simulation results of the damage of the pipes are obtained.

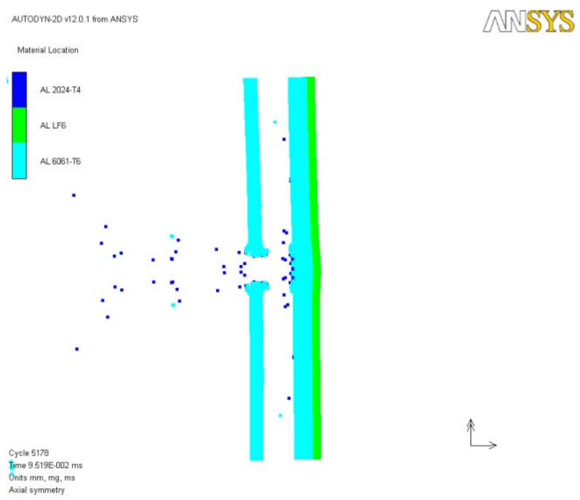
5.1 Heat-Pipe Radiator Type I Pipe

The numerical simulation results are listed in table 1.

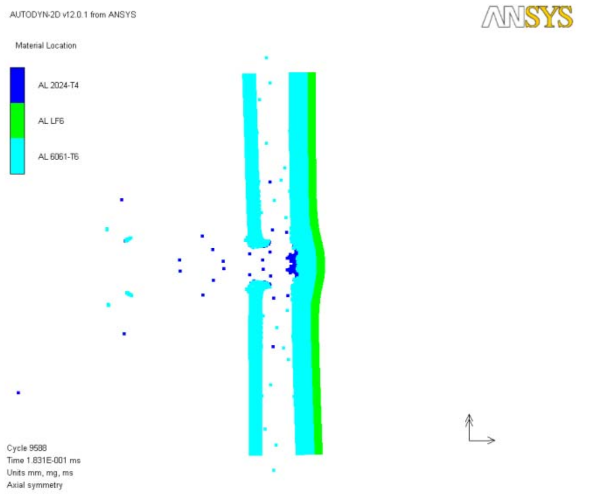
Table 1. Simulation Results of Heat-Pipe Radiator Type I Pipe

Projectile Impact Velocity	Simulation Results				
3.0km/s	Projectile Diameter (mm)	4.0	5.0	5.2	5.4
	Whether Penetration	No	No	No	Yes
7.0km/s	Projectile Diameter (mm)	3.6	3.8	4.0	5.0
	Whether Penetration	No	No	Yes	Yes

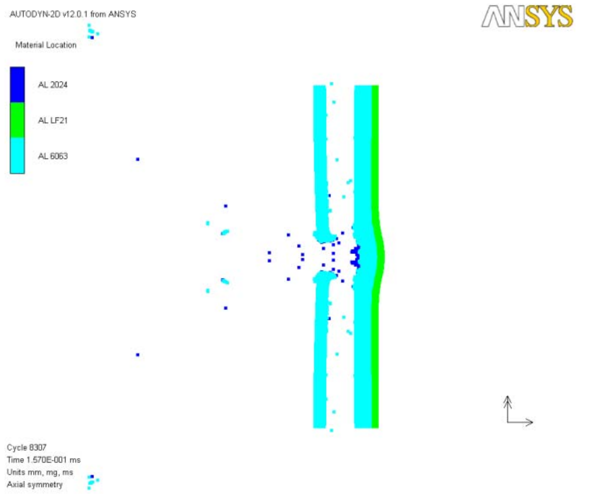
The numerical simulation results of the damage of the pipes are shown in figure 7.



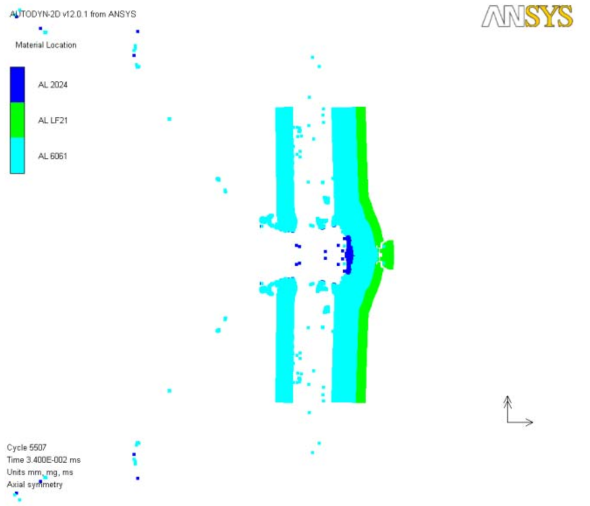
(a) Impact Velocity 3.0km/s, Projectile Diameter 4.0mm



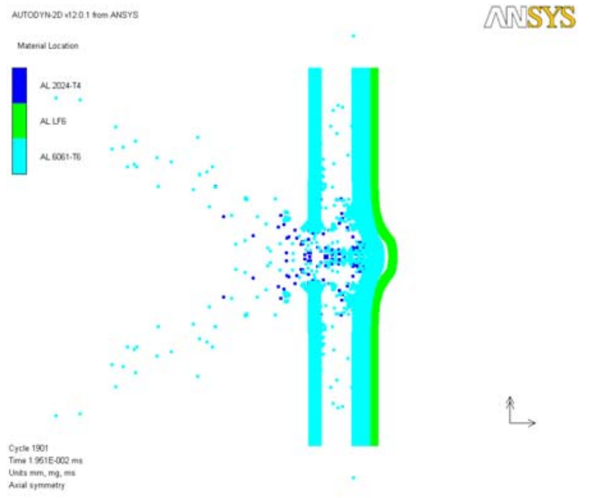
(b) Impact Velocity 3.0km/s, Projectile Diameter 5.0mm



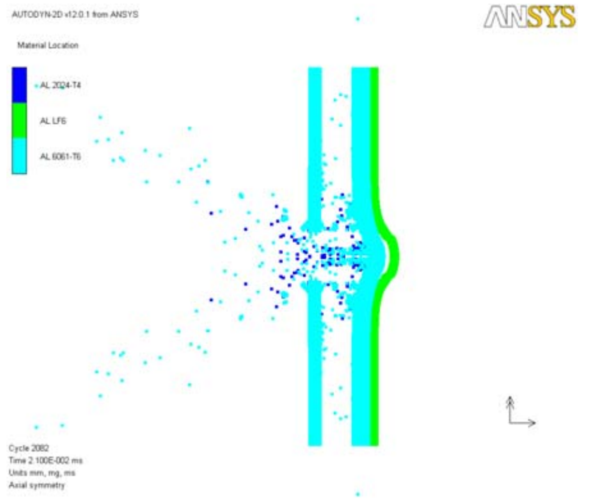
(c) Impact Velocity 3.0km/s, Projectile Diameter 5.2mm



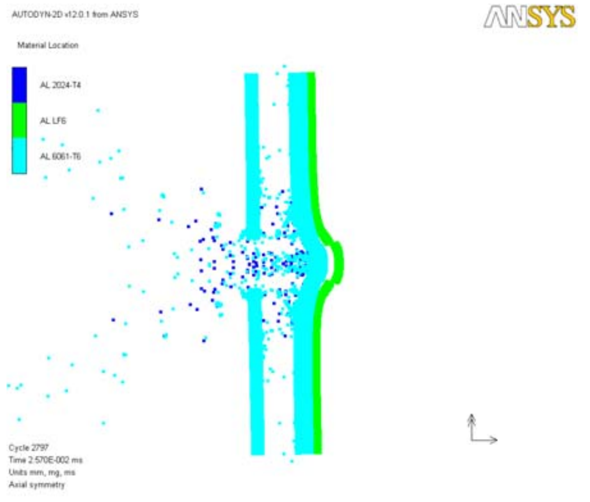
(d) Impact Velocity 3.0km/s, Projectile Diameter 5.4mm



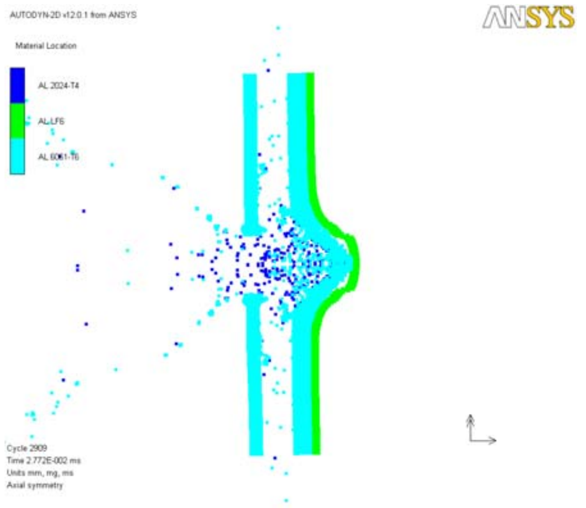
(e) Impact Velocity 7.0km/s, Projectile Diameter 3.6mm



(f) Impact Velocity 7.0km/s, Projectile Diameter 3.8mm



(g) Impact Velocity 7.0km/s, Projectile Diameter 4.0mm



(h) Impact Velocity 7.0km/s, Projectile Diameter 5.0mm

Figure 7. The Damage of Heat-Pipe Radiator Type I Pipes

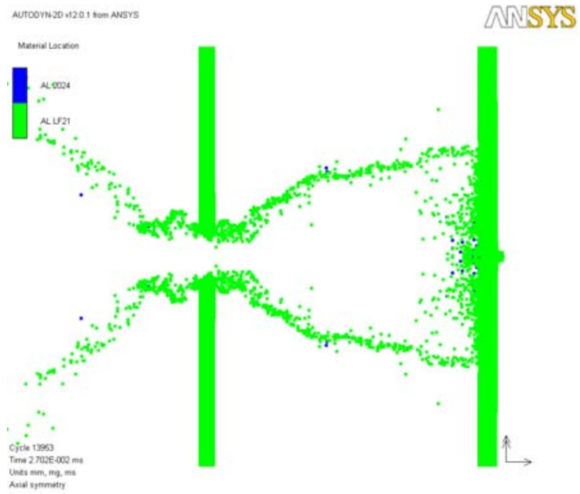
5.2 Heat-Pipe Radiator Type II Pipe

The numerical simulation results are listed in table 2.

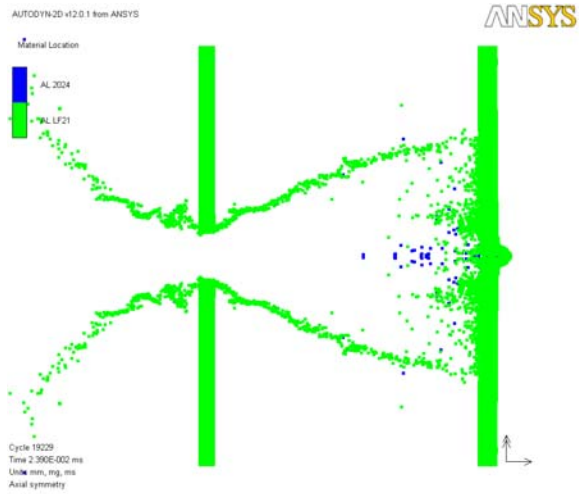
Table 2. Simulation Results of Heat-Pipe Radiator Type II Pipe

Projectile Impact Velocity	Simulation Results			
3.0km/s	Projectile Diameter (mm)	0.6	0.7	0.8
	Whether Penetration	No	No	Yes
7.0km/s	Projectile Diameter (mm)	0.7	0.8	1.0
	Whether Penetration	No	Yes	Yes

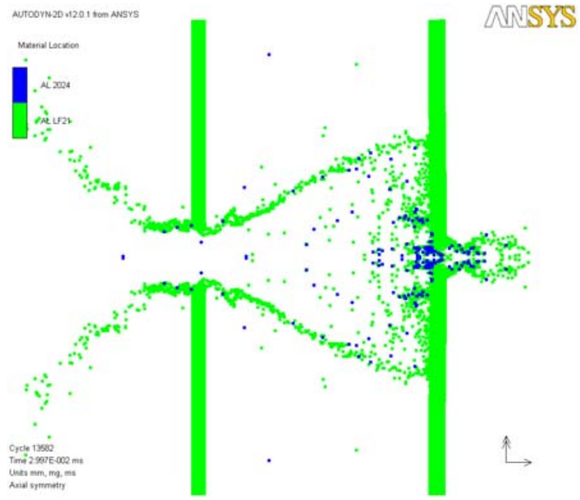
The numerical simulation results of the damage of the pipes are shown in figure 8.



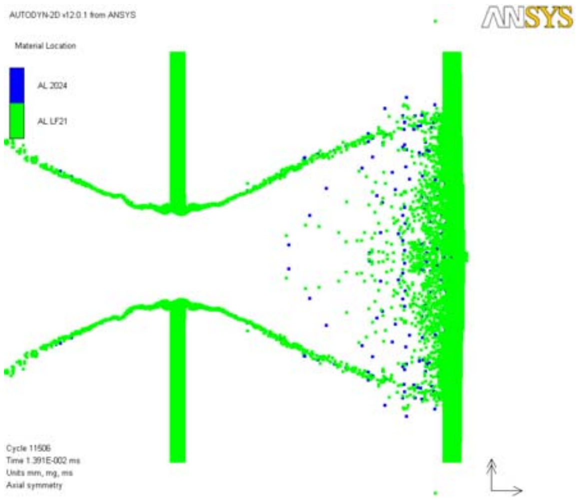
(a) Impact Velocity 3.0km/s, Projectile Diameter 0.6mm



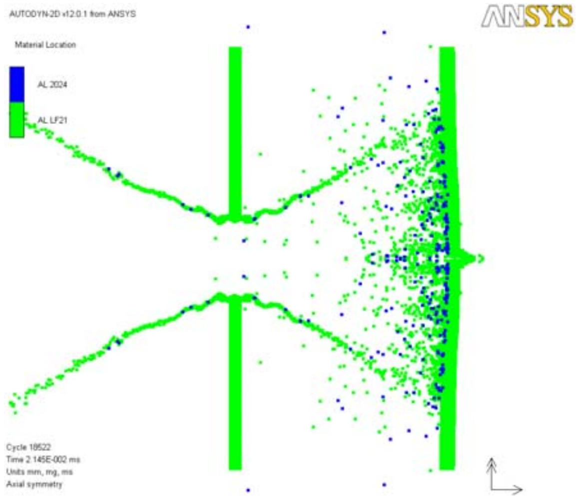
(b) Impact Velocity 3.0km/s, Projectile Diameter 0.7mm



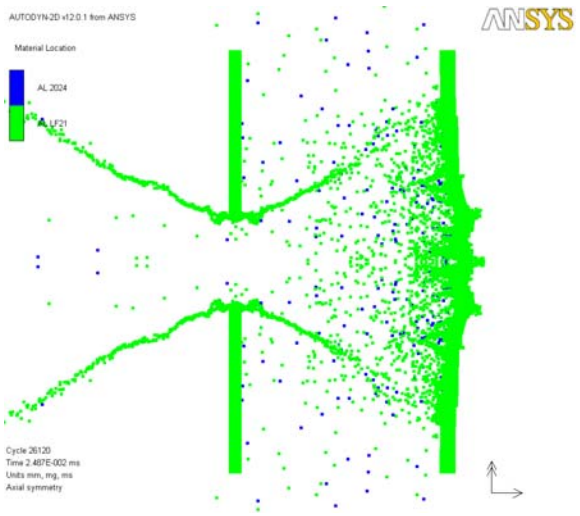
(c) Impact Velocity 3.0km/s, Projectile Diameter 0.8mm



(d) Impact Velocity 7.0km/s, Projectile Diameter 0.7mm



(e) Impact Velocity 7.0km/s, Projectile Diameter 0.8mm



(f) Impact Velocity 7.0km/s, Projectile Diameter 1.0mm

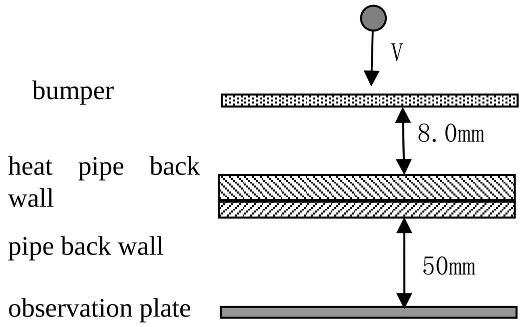
Figure 8. The Damage of Heat-Pipe Radiator Type II

Pipes

6 TEST INVESTIGATIONS

The configuration of the specimen is shown in Figure 9 (a), which is composed of bumper, heat pipe back wall, pipe back wall and observation plate.

Figure 9 (b) gives the assembled specimen.



(a) Configuration of The Specimen

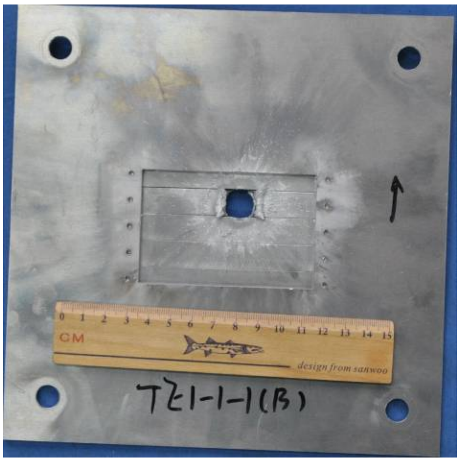
(b) Assembled Specimen

Figure 9. Test Specimen

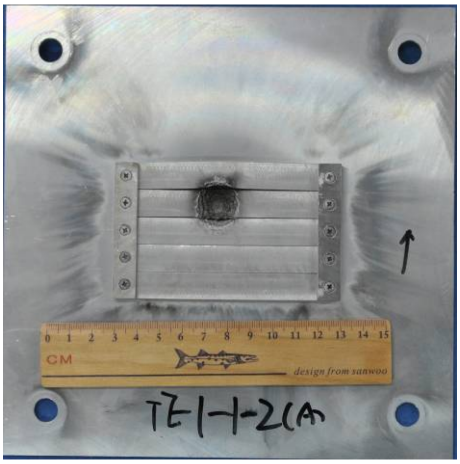
7 TEST RESULTS

The test results of the specimens are shown in figures 10-12.

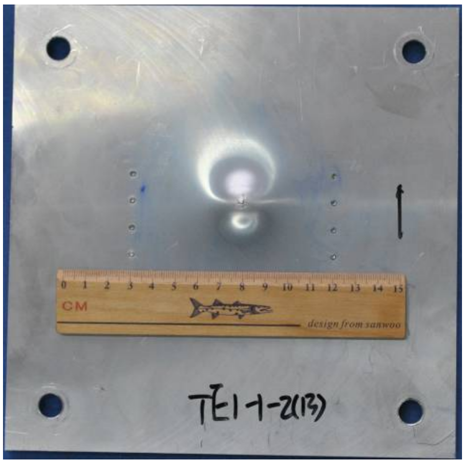
(a) Frontal Damage of Heat Pipe Back Wall



(b) Back Damage of Heat Pipe Back Wall

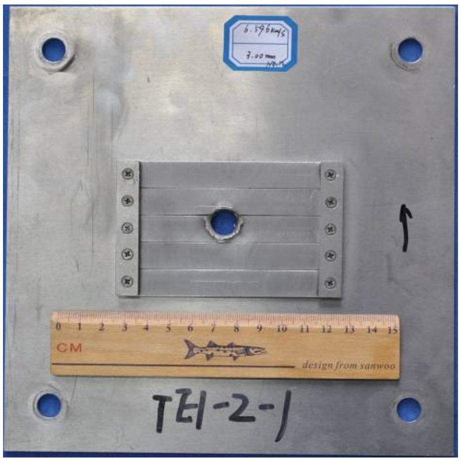


(c) Frontal Damage of Pipe Back Wall

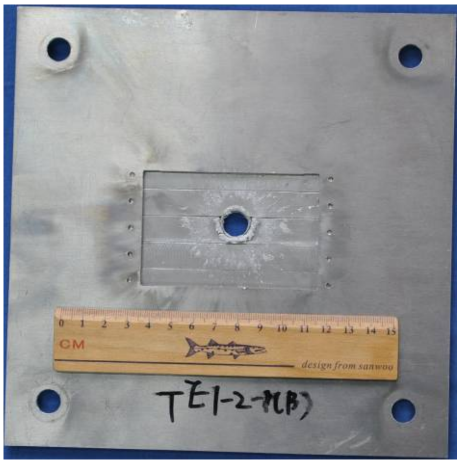


(d) Back Damage of Pipe Back Wall

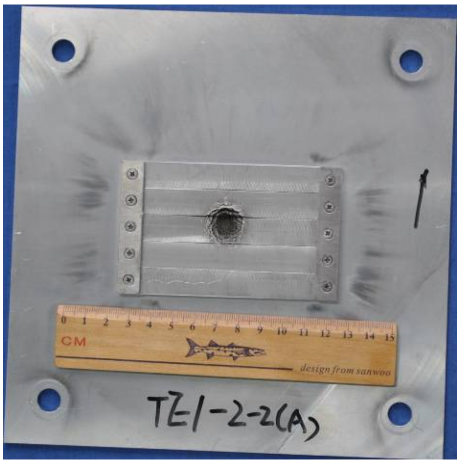
Figure 10. The Damage of Specimen (Impact Velocity 6.6km/s, Projectile Diameter 3.5mm)



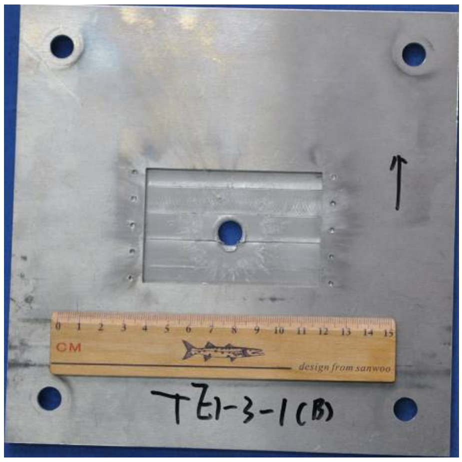
(a) Frontal Damage of Heat Pipe Back Wall



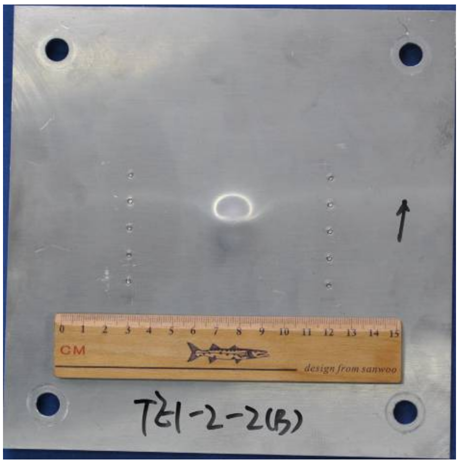
(b) Back Damage of Heat Pipe Back Wall



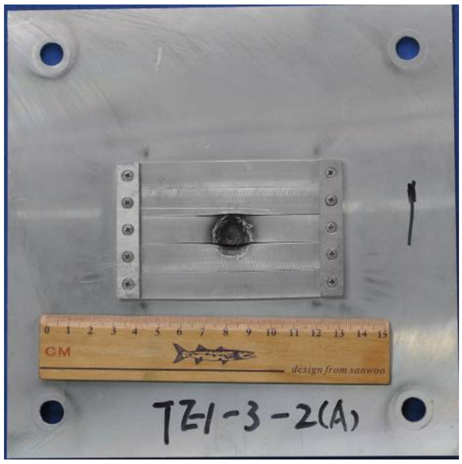
(c) Frontal Damage of Pipe Back Wall



(b) Back Damage of Heat Pipe Back Wall

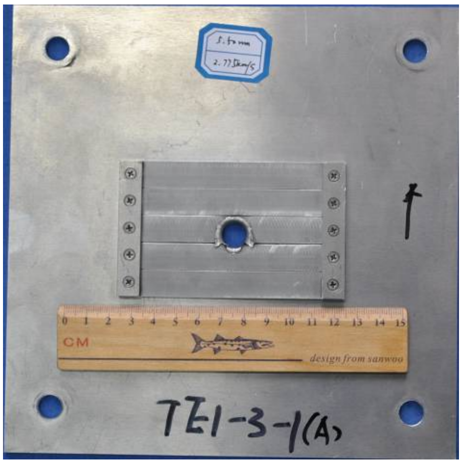


(d) Back Damage of Pipe Back Wall

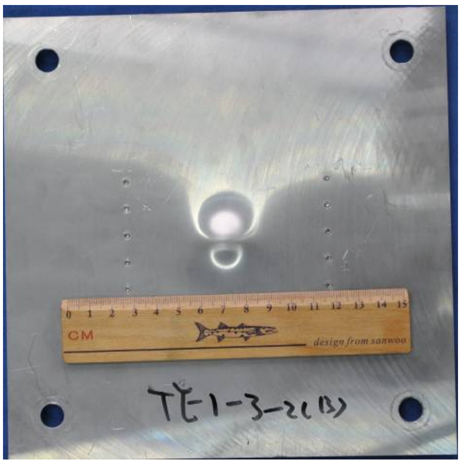


(c) Frontal Damage of Pipe Back Wall

Figure 11. The Damage of Specimen (Impact Velocity 6.6km/s, Projectile Diameter 3.0mm)



(a) Frontal Damage of Heat Pipe Back Wall



(d) Back Damage of Pipe Back Wall

Figure 12. The Damage of Specimen (Impact Velocity 2.7km/s, Projectile Diameter 5.5mm)

8 CONCLUSION

The ballistic limit value of heat pipe radiator type I pipe is higher, and the heat pipe plays a better role in protection.

The maximum tensile limit of aluminum alloy LF21 is relatively low, which leads to the lower ballistic limit value of the heat pipe radiator type II pipe.

The existence of the working fluid can enhance the impact resistance of the pipe.

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