International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.2 (2016), pp.323-330
http://dx.doi.org/10.14257/ijmue.2016.11.2.31

Numerical Simulation on Crater Characteristics of Different Shape of Projectiles Hypervelocity Impact on Thick Plates

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Abstract

Hypervelocity impact by space debris can cause direct damage to spacecraft internal subsystem, and even lead to catastrophic failure of manned spacecraft. To research the crater characteristics of different shape of projectiles hypervelocity impact on semi infinite thick aluminum alloy plates, Lagrange and SPH (smoothed particle hydrodynamics) coupling method in AUTODYN is used. By analyzing the influence on crater characteristics by different impact velocity of spherical projectile, different ratio between length and diameter and different impact velocity of cylindrical projectile, we obtain the law of crater characteristics of the semi infinite thick plates. The research results have reference value and engineering application of guiding significance to the study of spacecraft space debris shield structure design.

Keywords*: space debris; hypervelocity impact; crater semi-infinite plate; numerical simulation*

1. Introduction

With the increasing of human space activities, space environment is becoming increasingly complex, space debris is one of the main threats to spacecraft. The research of protection to meteoroid and space debris hypervelocity impact receives high attention [1-5], by the hypervelocity impact experiment and numerical simulation researches on the protective performance of spacecraft shield structure, a variety of protective structure are developed, and used for the protection of spacecraft to meteoroid and space debris [6-9]. Because the speed limit and the cost of hypervelocity impact experiment, the numerical simulation is an efficient method to study the properties of protective structure. By using the appropriate material model and numerical simulation method, the results can be agreement very well with the experimental.

2. Numerical Simulation

Because the Lagrange grid method can smooth processing material boundary, and also can tracking the deformation history of the model conveniently, the semi infinite plate model is established by using the Lagrange grid method, while the projectile by SPH method. Due to axial symmetry when the spherical projectile normal impact on semi infinite plate, only half of the projectile and plate is established in order to reduce the amount of calculation. Figure 1 shows the initial geometric model.

ISSN: 1975-0080 IJMUE

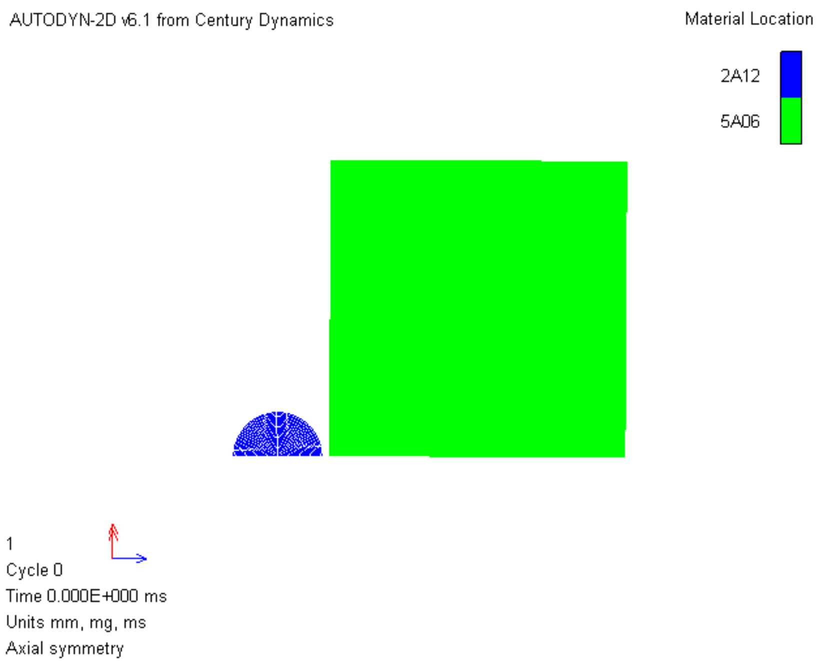


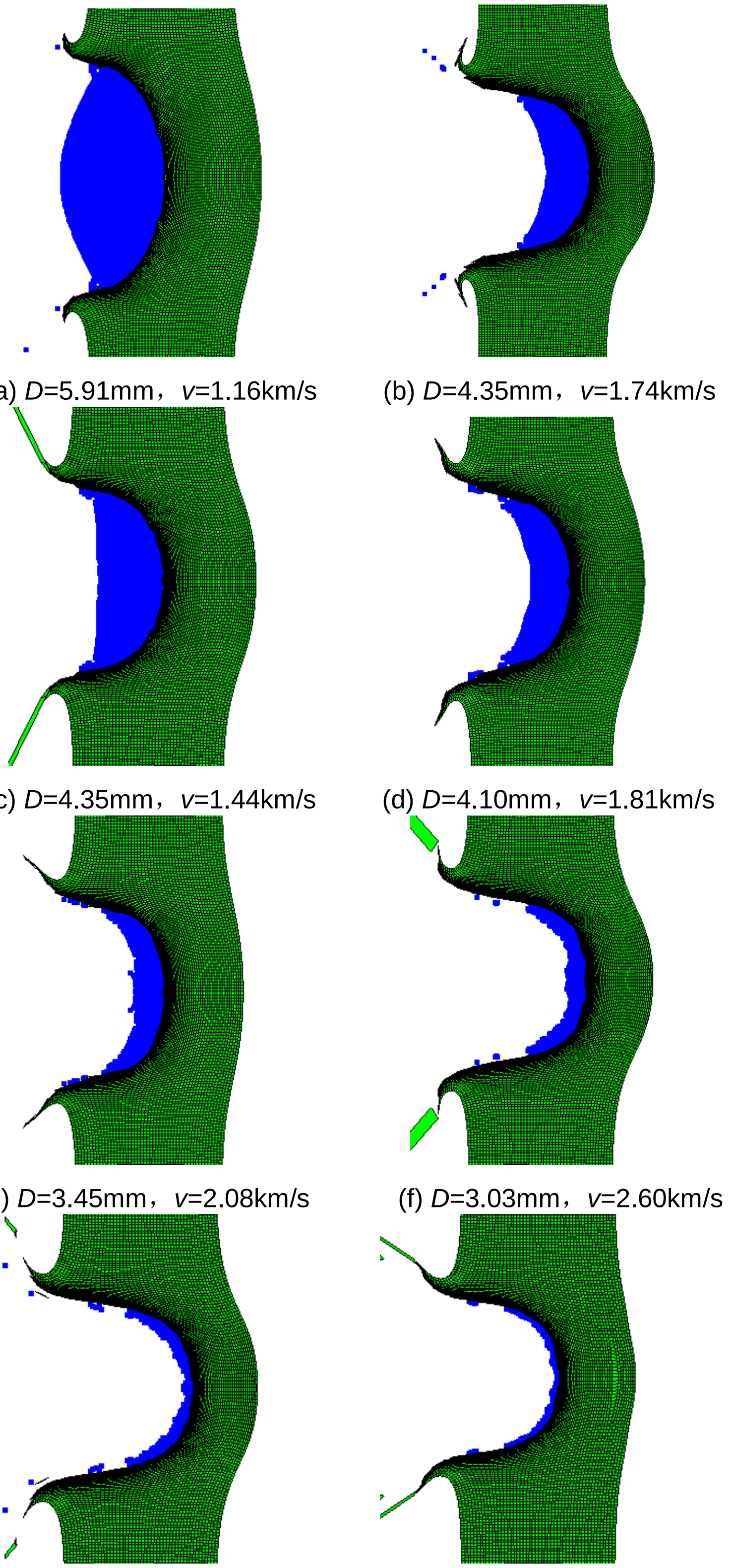
Figure 1. Initial Geometric Model

In order to verifies the validity of the numerical model, take the experimental data from reference [11] to compared with. 10 experimental conditions in reference [11] are selected to simulate. The material of spherical projectile is 2A12 aluminum alloy, the velocity of the projectiles is between 0.96km/s and 5.39km/s, the diameter of the projectiles is from 2mm to 6mm, the impact angle is 0 degrees. The material of the target plate is 5A06 aluminum alloy , the plate thickness is 5mm, with the size of 120mm × 120mm, target plate are fixed on the target frame with four edges. The parameters of experimental conditions are shown in Table 1.

Table 1. Parameters of Experimental Conditions [11]

No.	the diameter of the projectiles *D*(mm)	velocity of the projectiles *v*(km/s)	plate thickness *t*(mm)
01	5.91	1.16	5
02	4.35	1.74	5
03	4.35	1.44	5
04	4.10	1.81	5
05	3.45	2.08	5
06	3.03	2.60	5
07	2.74	3.05	5
08	2.00	3.98	5

Figure 2 shows when the diameter of the projectile is 5.91mm, the impact velocity is 1.61km/s and the diameter of the projectile is 4.35mm, the impact velocity is 1.74km/s, the numerical simulation results of the crater shape.



(a) D=5.91mm，v=1.16km/s (b) D=4.35mm，v=1.74km/s

(c) D=4.35mm，v=1.44km/s (d) D=4.10mm，v=1.81km/s

(e) D=3.45mm，v=2.08km/s (f) D=3.03mm，v=2.60km/s

(g) D=2.74mm，v=3.05km/s (h) D=2.00mm，v=3.98km/s

Figure 2. Numerical Simulation Results

Table 2 gives the results of numerical simulation and the experimental results from reference. The crater diameter, depth of crater and bulge height were compared. Can be seen from Table 2, the error of numerical simulation results and experimental results is not more than 10%. Thus, in the range of allowable error, numerical simulation results and experimental results are the same, which verifies the validity of the numerical model.

Table 2. Comparison between Numerical Simulation Results and Experimental Results [11]

No.	depth of crater (mm)			crater diameter (mm)			bulge height (mm)		
	Exp.	Sim.	error (%)	Exp.	Sim.	error (%)	Exp.	Sim.	Error (%)
01	2.7	2.51	7.0	8.30	8.28	0.2	2.18	1.97	9.6
02	5.08	4.86	4.3	7.28	7.06	3.0	2.80	2.73	2.5
03	4.52	4.36	3.5	7.34	6.88	6.3	2.56	2.48	3.1
04	3.28	3.37	2.7	7.82	7.28	6.9	2.08	2.15	3.3
05	2.58	2.72	5.4	6.12	6.26	2.3	1.48	1.51	2.0
06	4.82	4.68	2.9	6.42	6.24	2.8	2.06	1.96	4.9
07	4.60	4.88	6.1	6.36	6.54	2.8	1.96	2.05	4.6
08	3.46	3.12	9.8	5.78	5.58	3.5	1.14	1.07	6.1

3. Analysis of the Numerical Simulation Results

3.1. Effect of Velocity of Spherical Projectile on the Crater Characteristics

The crater characteristics is researched by select 12 groups of spherical projectiles with diameter is 6mm and the impact velocity is between 1km/s and 12km/s. The Shock state model is used if the impact velocity of the projectile is between 1km/s and 7km/s, if the impact velocity is over 7km/s or even higher, the projectile would be vaporized or liquefied, then the Tillotson state model should be chosen. Figure 3 and Figure 4 show the variation curve of the diameter and depth of crater with the velocity of spherical projectiles.

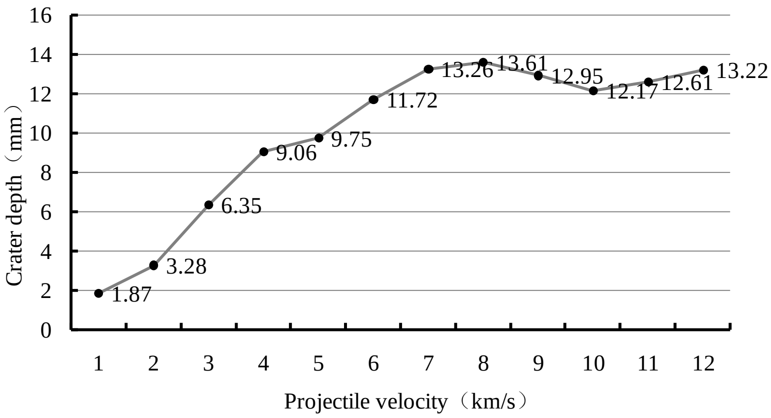


Figure 3. Crater Depth

From Figure 3 and Figure 4, we can seen that the velocity of projectile is one of the main factors which affecting the depth and diameter of the crater. Figure 3 shows if the projectile velocity is between 1km/s and 8km/s or if it is between 10km/s and 12km/s, the crater depth increases with increasing of the velocity of the projectile, but if the velocity is between 8km/s and 10km/s, the crater depth decreases with increasing of the velocity of the projectile. Figure 4 shows the diameter of the crater has the same law with the depth of the crater.

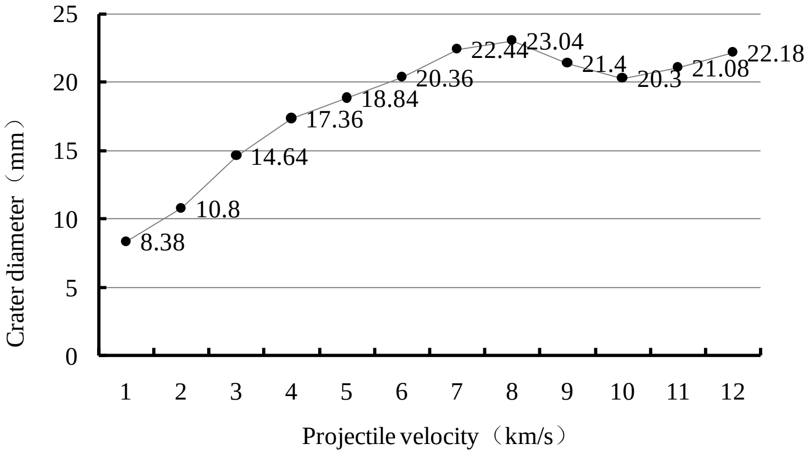


Figure 4. Crater Diameter

In summary, for the spherical projectile, if the projectile diameter is a constant, the law of damage on the thick plate by the projectile is changed with increasing impact velocity. If the projectile velocity is between 1km/s and 8km/s and if it is between 10km/s and 12km/s, the damage of projectile on the plate increases with increasing impact velocity, if the projectile velocity is between 8km/s and 10km/s, the damage of projectile on the plate decreases with increasing impact velocity.

3.2. Effect of Velocity of Cylindrical Projectile on the Crater Characteristics

To research the effect of velocity of cylindrical projectile on the crater characteristics, select 12 group of cylindrical projectiles with the ratio of length to diameter is 5(L=15.325mm, D=3.065mm) and impact velocity from 1km/s to 12km/s. Figure 5 and Figure 6 show the variation curve of the diameter and depth of crater with the velocity of cylindrical projectiles.

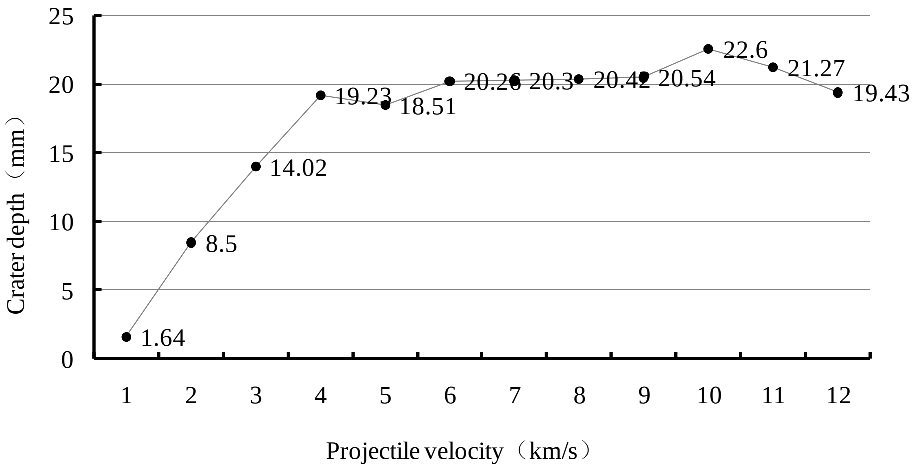


Figure 5. Crater Depth

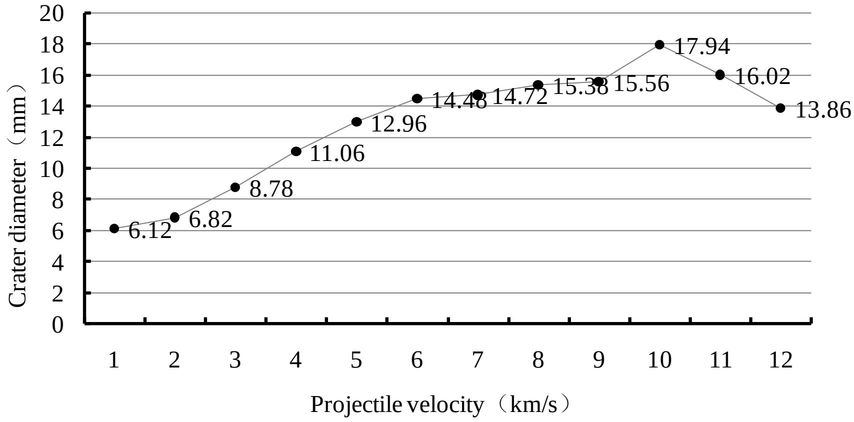


Figure 6. Crater Diameter

Figure 5 shows if the projectile velocity is between 1km/s and 4km/s or if it is between 5km/s and 10km/s, the crater depth increases with increasing of the velocity of the projectile, if the velocity is between 4km/s and 5km/s or if it is between 10km/s and 12km/s, the crater depth decreases with increasing of the velocity of the projectile. Figure 6 shows if the projectile velocity is between 1km/s and 10km/s, the crater diameter increases with increasing of the velocity of the projectile, if the velocity is between 10km/s and 12km/s, the crater diameter decreases with increasing of the velocity of the projectile.

In summary, for the cylindrical projectile, if the ratio of length to diameter is a constant, if the projectile velocity is less than 10km/s, the damage of projectile on the plate increases with increasing impact velocity, if the projectile velocity is more than 10km/s, the damage of projectile on the plate decreases with increasing impact velocity.

3.3. Effect of the Ratio of Length to Diameter of Cylindrical Projectile on the Crater Characteristics

To research the effect of the ratio of length to diameter of cylindrical projectile on the crater characteristics, select 12 group of cylindrical projectiles with the same mass and same impact velocity (3km/s), and the ratio of length to diameter is between 0.1 and 12. Figure 7 and Figure 8 show the variation curve of the diameter and depth of crater with the ratio of length to diameter of cylindrical projectiles.

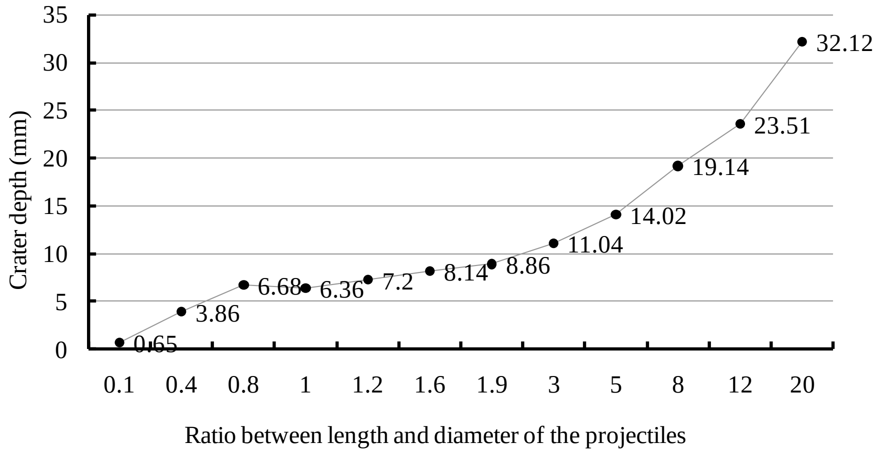


Figure 7. Crater Depth

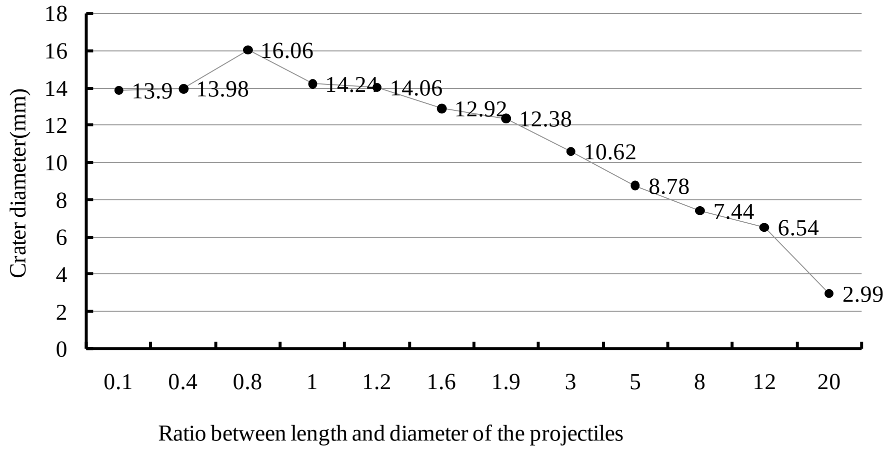


Figure 8. Crater Diameter

Figure 7 shows the crater depth increases with increasing of the ratio of length to diameter of the projectile. Figure 8 shows if the ratio of length to diameter of the projectile is between 0.1 and 0.8, the crater diameter increases with increasing of the ratio of length to diameter of the projectile, if the ratio of length to diameter of the projectile is between 1 and 20, the crater diameter decreases with increasing of the ratio of length to diameter of the projectile.

In summary, for the cylindrical projectile, if the mass and impact velocity of the projectile are constants, the crater depth increases with increasing of the ratio of length to diameter of the projectile, thus, the damage of projectile on the plate increases with increasing ratio of length to diameter.

4. Conclusions

Numerical simulations by AUTODYN have been performed for the impact of spherical and cylindrical projectiles on the semi infinite aluminum alloy plate to investigate the crater characteristics with Lagrange and SPH coupling method applied. The validity of the numerical model is verified by compared with the experimental results. Effect of the velocity of spherical projectile, the velocity and the ratio of length to diameter of cylindrical projectile with the same mass on the crater characteristics is studied by the numerical model. The results show:

(1) For the spherical projectile, if the projectile diameter is a constant, the law of damage on the thick plate by the projectile is changed with increasing impact velocity. If the projectile velocity is between 1km/s and 8km/s and if it is between 10km/s and 12km/s, the damage of projectile on the plate increases with increasing impact velocity, if the projectile velocity is between 8km/s and 10km/s, the damage of projectile on the plate decreases with increasing impact velocity.

(2) For the cylindrical projectile, if the ratio of length to diameter is a constant, and if the projectile velocity is less than 10km/s, the damage of projectile on the plate increases with increasing impact velocity, if the projectile velocity is more than 10km/s, the damage of projectile on the plate decreases with increasing impact velocity. If the mass and impact velocity of the projectile are constants, the crater depth increases with increasing of the ratio of length to diameter of the projectile, thus, the damage of projectile on the plate increases with increasing ratio of length to diameter.

Acknowledgement

This work is supported by National Natural Science Foundation of China (11202070). Young Talent Training Program of Heilongjiang University of Science and Technology (Q20130208).

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