

Study on Propagation and Distribution Characteristics of Explosion Shock Wave Loading on Two Kinds of Explosives inside Cylindrical Device

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Abstract. In order to investigate propagation and distribution characteristics of the explosion shock wave loading of thermobaric explosive and TNT inside cylindrical device, internal explosion experiment of these two explosives are carried out in cylindrical device, propagation characteristics of shock wave are analyzed, distribution characteristics of overpressure and positive pressure impulse of the shock wave about two explosives of same mass are compared on wall and cover in the cylindrical device. The results show that superposition effect is characteristic of the shock wave in cylindrical device, and the superposition effect increases gradually with increase of the distance from explosion center; The superposition effect of thermobaric explosive is more obvious than TNT; The average value of positive pressure impulse of the shock wave on thermobaric explosive increases by 20.3% compared with TNT, this growth is about twice the average value of overpressure peak, and positive pressure impulse of the two explosives tends to increase firstly and then decrease with increase of the distance from explosion center, the rule on thermobaric explosive is more obvious than TNT.

1. Introduction

Because the ship cabin is closed space, propagation and attenuation law of explosion shock wave in the cabin is very different from that of free field. The explosion shock wave reflect many times in the cabin, the process is very complex, and it is difficult to describe accurately by theory [1], so most of the researchs are carried out through the internal explosion experiment. The difference between the internal explosion shock wave and the free field shock wave is studied by the model experiment [2]. The explosion shock wave will reflect many times in the cabin because of the sealing effect of the cabin. The flow field in the cabin is more complicated than the explosion in free field, and the damage effect is stronger [3]. The failure mode of the stiffened plate in the structure of the target ship and the free field is compared, and explosion shock loading in the closed space is far more complicated than free field due to the influence of the cabin structure [4-7]. The explosion loading characteristics and the convergence of the shock wave in the corner of the cabin are analyzed by the experimental study of the internal explosion in the cabin [8]. The shock wave may be superimposed after the reflection of the cabin, and the shock wave may form a large shock wave at the center of the cabin [9].

In the relevant researches, most of researches are applied to TNT. With development of weapons and equipments, application of thermobaric explosive about anti-ship missiles is more and more



extensive. Because of the detonation reaction and post-combustion effect, energy output structure of thermobaric explosive is very different from TNT. In internal explosion environment, post-combustion effect is stronger, the energy output structure is more different than TNT, and the quasi-static pressure is obvious. Therefore, the internal explosion effect of the thermobaric explosive cannot be simply based on the characterization method of the ideal detonation explosive.

Because the ship cabin is a square structure, there are a lot of corners inside, the distribution characteristics of explosion shock wave loading in the cabin are very complicated, and the influence factors are too numerous to be studied further directly. The author will simplify the cabin into a cylinder, reducing the influence factors. The propagation and distribution characteristics of the shock wave loading in the cylinder will be obtained. On this basis, study on explosion shock wave in the square cabin will be carried out later.

In this paper, the internal explosion experiments of TNT and thermobaric explosive will be carried out in the cylindrical device. The propagation characteristics of explosive shock wave in cylindrical device are studied, and the distribution characteristics of shock wave loading of two explosives are compared and analyzed. It is of great significance to the study on the damage effect of the anti-ship warhead to ship cabin.

2. Experiment

2.1. Experiment Device

The schematic diagram of the cylindrical device is shown in Fig. 1. The cylinder is a seamless steel pipe, with inner diameter of $\varnothing 800\text{mm}$, thickness of 12 mm, and length of 1670mm. Two flanges are installed on the left side of the steel pipe, and a thin plate of Q235 is sandwiched between the two flanges. The cover is installed on the right side of the steel pipe, forming a sealing structure, and the mounting hole of the sensor is reserved on the wall and cover of the cylinder. The length of the support rod is determined according to the height of the explosive to ensure that the detonation is in the center of the cylinder.

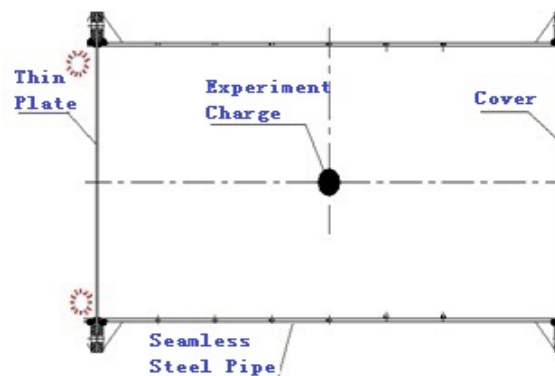


Figure 1. The schematic diagram of the cylindrical device.

2.2. Experiment Charge

The experiment charges are TNT and WY (thermobaric explosive), the mass of explosive is 80g and the ratio of length to diameter is 1. TNT is a fused cast column with a density of 1.58g/cm^3 ; WY is a pressurized pharmaceutical column and is mainly composed of aluminum powder, ammonium perchlorate (AP), RDX and plastic binder, with density of 1.81 g/cm^3 . The detonator is C4 explosive, and NO. 8 industrial electric detonator is installed at the terminal center of the explosive to initiate the explosion.

2.3. Experiment System of Shock Wave Pressure

The shock wave pressure is measured by ICP high-frequency response pressure sensor with range of 6.9MPa and 34MPa. As shown in Fig. 2, the pressure sensor are arranged with four measuring positions on the wall and the cover respectively, and the distances from explosion center are shown in Table 1.

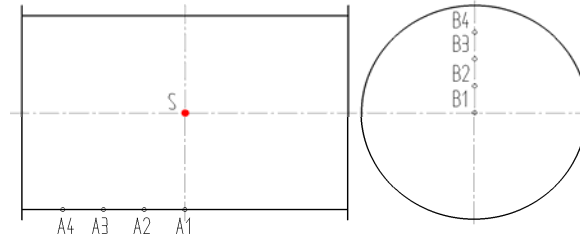


Figure 2. Layout on measuring positions of overpressure.

Table 1. Distances between detonation and measuring positions.

Measuring position	A1	A2	A3	A4	B1	B2	B3	B4
Distance from explosion center/m	0.40	0.45	0.57	0.72	0.80	0.82	0.90	1.00

3. Experiment results and analysis

3.1. Analysis of the Propagation Characteristics of Explosion Shock Wave in Cylindrical Device

The overpressure curves of 80g TNT and WY in the cylindrical device are shown in Fig. 3 and Fig. 4 respectively. It can be seen that in the same measuring position, the shock waveform generated by two explosives is basically identical.

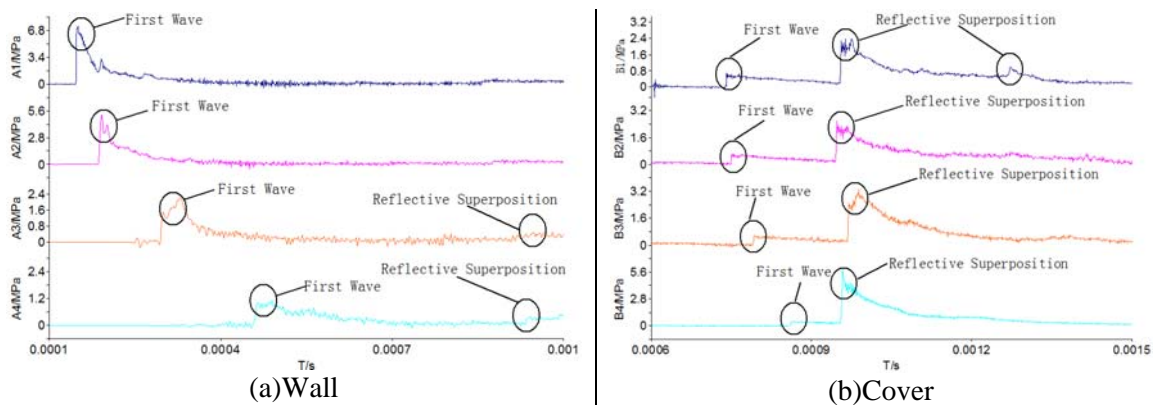


Figure 3. The overpressure curve of explosion shock wave on 80g TNT.

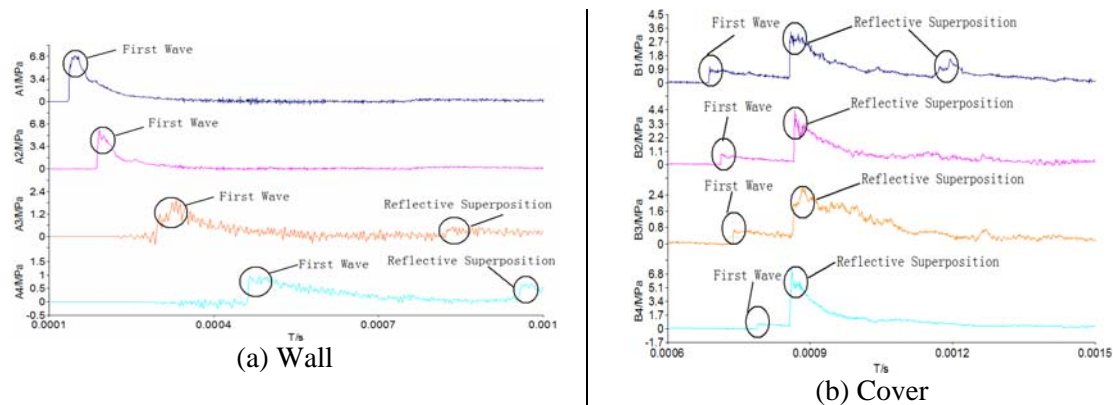


Figure 4. The overpressure curve of explosion shock wave on 80g WY.

Table 2. The arrival times of the first shock wave peak of two explosives.

Charge	The arrival time of the first shock wave peak /ms							
	A1	A2	A3	A4	B1	B2	B3	B4
TNT	0.146	0.187	0.294	0.453	0.741	0.749	0.791	0.860
WY	0.135	0.187	0.293	0.461	0.709	0.712	0.737	0.788

The arrival times of the first shock wave peak of two explosives are shown in Table 2. The relationship between the peaks of the first wave and the second wave and the distance from explosion center are shown in Fig. 5.

It can be seen from Table 2 that the arrival times of the first wave peak of the two explosives increases with increase of the distance from explosion center, and it can be seen from Fig.5 that the first wave peak decreases with increase of the distance from explosion center, which corresponds to the attenuation law of the shock wave. Therefore, the first wave can be judged to be the formation of the explosion shock wave directly to the measuring positions, the subsequent wave peak is that the shock wave is reflected by the wall or the cover then propagated to the measuring positions to be superimposed. Comparing the peak value of the second wave between TNT and WY, with increase of the distance from explosion center, the superposition effect of the shock wave on the wall or the cover is significantly enhanced, and shock wave peak is significantly increased after superposition. (Inhomogeneity of WY charge causes the second shock wave peak in B3 to be small, so it is not marked in Fig. 5.)

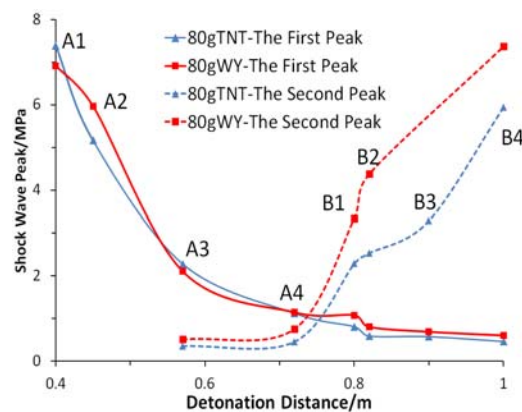


Figure 5. Relationship between shock wave peak of two explosives and distance from explosion center.

In summary, superposition of multiple waveforms is characteristic of explosion shock wave in the cylindrical device. Attenuation of shock wave causes the first overpressure peak to decrease with increase of the distance from explosion center, superposition effect of the shock wave increases with increase of the distance from explosion center after reflection of the wall or the cover.

3.2. Analysis of the Distribution Characteristics in Cylindrical Device

3.2.1. Comparison and Analysis of Overpressure Peak. The relationship between the maximum peak and the distance from explosion center of two explosives is shown in Fig.6. The mean value of the maximum overpressure peak of WY is over TNT by 11.9%. In the wall, the distance from explosion center is relatively small, and the direct action of the shock wave plays a leading role. Therefore, the overpressure peak generally declines with increase of the detonation distance. While, on the cover, the distance from explosion center is relatively large, the direct effect of the shock wave is not dominant, and the superimposed effect of the shockwave after reflection is significantly enhanced, resulting in the growth trend of overpressure peak.

It can be seen from Fig.5 that the first peak and the second wave peak of the two explosives are basically consistent with the distance from explosion center. However, with increase of the distance from explosion center, the first peak value of the WY decreases more slowly than TNT, and the superposition effect of shock wave after reflection is more obvious than TNT.

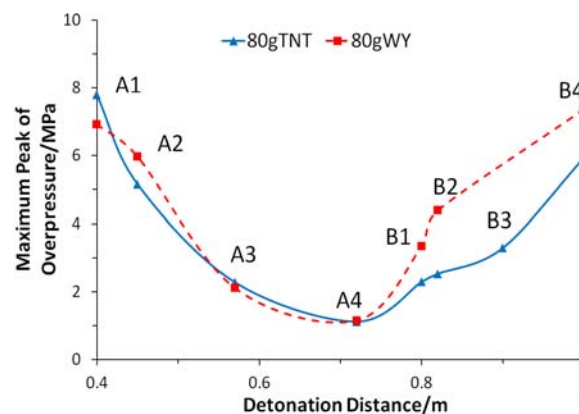


Figure 6. Relationship between the maximum overpressure peak of two explosives and the distance from explosion center.

The first wave peak measured on the cover is superimposed by the second wave peak, its pulse width cannot be fully displayed, so only the waveforms at the four measuring positions on the wall are compared, as shown in Table 3.

Table 3. Comparison on pulse width of the first shock wave on the wall.

Measuring positions	Distance from explosion center /m	TNT/ ms	WY/ ms
A1	0.40	0.237	0.262
A2	0.45	0.265	0.313
A3	0.57	0.326	0.358
A4	0.72	0.346	0.395

The pulse width of the first wave of WY is larger than TNT, due to the energy released by the post-combustion reaction of the aluminium powder extends the duration of the shock wave overpressure, making the shock attenuation slow.

After comprehensive comparison of the peak value and pulse width of shock wave, destructive force of WY is stronger than TNT in closed spaces.

3.2.2. Comparison and Analysis of Distribution Characteristics of Shock Wave Impulse. The curves of transient pressure and positive pressure time corresponding to linear elastic system are shown in Fig.7. The points on the curve indicate positive pressure time of the different shock wave, which can be obtained by comparing the self-oscillation period of the elastic system. For example, positive pressure time in position A corresponds to $1/5$ of the system's self-oscillation period. When the positive pressure time of the shock wave is less than $1/5$ of the self-oscillation period of the elastic system, the structural response depends only on the impulse, not the overpressure; When the positive pressure time is twice as long as the self-oscillation period of the elastic system, the structural response depends on the peak pressure, not the impulse; When the positive pressure time is in the intermediate state of both cases, the structural response is sensitive to impulse and peak pressure.

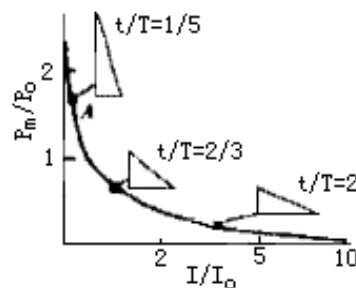


Figure 7. Relationship between pressure pulse and peak pressure and impulse.

The first order frequency of the steel plate is 16.5Hz, so the positive pressure time is in the intermediate state of both cases, and the structural response is sensitive to impulse and overpressure. It is necessary to further analyse the distribution characteristics of positive pressure impulse of the two kinds of explosives in the same period.

The relationship between positive pressure impulse of shock wave of these two explosives and the distance from explosion center is shown in Fig. 8. The positive pressure impulses of the shock wave of WY are higher than TNT both on the wall and the cover, average value of impulse of WY increased by 20.3% than TNT, this increase is about twice as much as the average of the shock wave peak. The reason is that the secondary release of energy during the combustion process can obviously increase the pressure after the shock wave in the cylindrical device, thus increasing the impulse on the wall and the cover. Therefore, the damage effect of WY is better than TNT for the targets according to overpressure - impulse damage criterion in closed space.

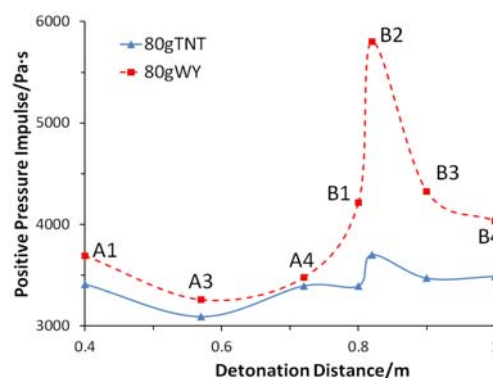


Figure 8. The relationship between positive pressure impulse of shock wave and the distance from explosion center.

With increase of the distance from explosion center, the impulse increases firstly and then decreases, and the regularity of WY is more obvious than TNT. It can be seen from that overpressure curves in the measuring position B2 in Fig. 5 and Fig. 6: although the overpressure peak in this position is not the largest, there are a lot of reflection waves in the posterior segment of the waveform, and the quasi-static pressure value is relatively large, so the impulse in the measuring position B2 is the largest. Although the overpressure peak is very large, there is no obvious reflection shock wave, and the quasi-static pressure is small, so the impulse is small in the measuring position A1. The overpressure peak is also very large, and there is also a relatively obvious reflection shock wave, but impulse of the measuring position is relatively small in the measuring position B4. That may be caused by the structure of the cylindrical device. This position is close to the joint of the cover and the cylinder, after the explosion, the pre-tightening bolt will loosen, and the pressure inside the structure is greater than external pressure, resulting in the leakage of the joint, so that the quasi-static pressure in the measuring position B4 is relatively small, thus unable to form a relatively large impulse.

4. Conclusion

By analyzing internal explosion experiment results of the same mass of TNT and WY in the cylindrical device, the propagation and distribution characteristics of the explosion shock wave loading on WY and TNT in cylindrical device are compared, and the following conclusions are drawn:

(1) The superposition of multiple waveforms is the characteristic of explosion shock wave in cylindrical device. With increase of the distance from explosion center, the attenuation of the shock wave causes the first wave to decrease, overpressure peak after superposition significantly increase and the superposition effect significantly enhance;

(2) With increase of the distance from explosion center, the attenuation effect of the first shock wave of WY is less than TNT, and the superposition effect of the shock wave is more obvious than TNT; The pulse width of the first shock wave of WY is larger than TNT, and the shock wave attenuation is slower than TNT, which is more destructive in closed space;

(3) Due to the second release of energy during the post-combustion, positive pressure impulse of the shock wave of WY is higher than TNT on the wall and the cover, and increase of impulse is about twice as much as overpressure; With increase of the distance from explosion center, impulse increases firstly and then decreases, and the regularity of WY is more obvious than TNT, and impulse value of WY is more conducive to damage targets than TNT.

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