The response characteristics of warhead fragment impact on shielded H6 explosive

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ABSTRACT

For studying response characteristics resulting from fragmentation warhead fragment impact on shielded H6 explosive. H6 explosive has been shielded with Q235 steel, what was impacted for cuboid tungsten fragments at the velocity range of 2000 m/s~2200 m/s launching from 25 mm ballistic gun, with different quality and length-thick ratio of square, the process of impact response was observed by high-speed photography. The maximum diameter and duration of the fireball as well as destruction of shielded H6 explosive were recorded, then corresponding features of shielded H6 explosive were analyzed accordingly. Furthermore, the mechanism of H6 explosive responses was analyzed based on the theory of explosive impact initiation. Results show that it mainly includes combustion, deflagration and detonation for response features of targets, and it has highest probability for deflagration. Adiabatic shear effect was regarded as the functional mechanism, which could produce different response characteristics. Deflagration reactions could be sparked in which of the situations the quality of fragments was no less than 10 g. what's more, the most violent deflagration reactions could be sparked under the certain condition that the length-thick ratio of fragment was about 1.6.

1. OVERVIEW

It's still the most effective way for the terminal defense that the attacking warhead was penetrated and detonated with high-speed prefabricated fragments[1]. It has been a hotspot in the field of damage technology that the shielded explosive was detonated with fragments. The initiation performance, what's have been derived from fragments detonating shielded explosive, has been related to the factors closely, such as fragmentation, shell, geometric size and material properties of the explosive. In a number of previous studies on the subject, studies mainly focus on the background of composition B explosives both shielded and unshielded. The study mainly deals with the initiation mechanism, initiation threshold and initiation criterion what's have been derived from fragments and jets and the research methods include theoretical analysis, numerical simulation and experiments. So far, the results have been comprehensive and in-depth[2-10]. However, thin targets who's shielded thickness had be not more than 5 mm and thinner relative to fragments size normally have been mainly studied in this field. At present, the thickness of shield for precision-guided munition reaches 10 mm ~ 15 mm [11]. And furthermore, the new generation high energy explosives, such as H6, which's more powerful and safety, is used to replace the B explosive. H6 was more insensitive relative to B explosive and the study on H6 explosives under the condition of fragments impacted has not been reported.

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In this setting, this paper goals to the Response characteristics, which had been resulted from fragmentation warhead fragment impacting on shielded H6 explosive, was studied experimentally. The rule formed from what, response characteristics was affected on fragments design parameters, such as the quality and length-thick ratio. So, it provides some useful references for the design and power evaluation of fragmentation warhead.

2 EXPERIMENTAL DESIGN

2.1 Test samples

The fragment is a cube (size: L×L×H, L means side length, H means thickness) and it had been made of tungsten alloy material. Several different L and H value fragments were tested in the experiment.

The shielded H6 is a 1/4 target model, its maximum outer diameter, inner diameter and height were 500mm, 150mm and 200mm respectively. The thickness of shielding layer and shell which had been made of Q235 steel are all 10 mm. H6 explosives, consisting of 45% RDX, 30% TNT, 20%Al powder and 5% paraffin wax, were packed into the target with a density of 1.7 g/cm^3.

2.2 Test principle and method

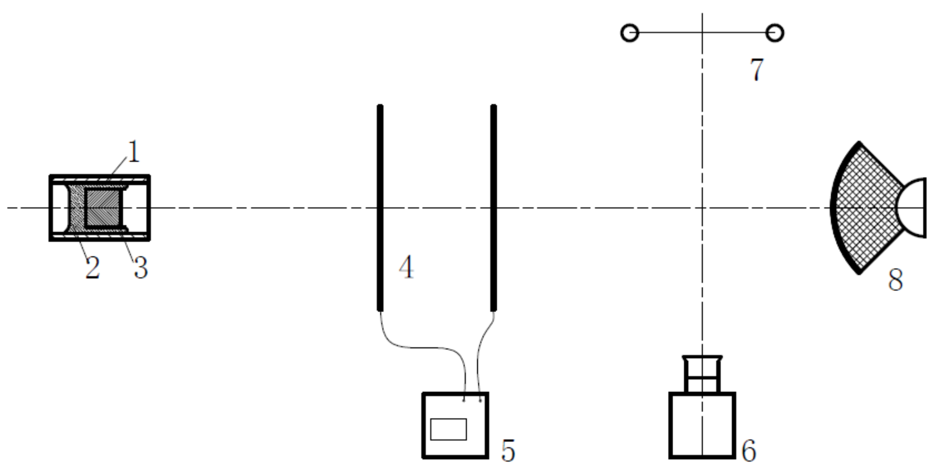

FIG.1 Experimental system; 1-Ballistic gun, 2-Sabot, 3-Fragment, 4-Velocity, measuring device, 5-Chronoscope, 6-High speed cinematography, 7-Surveyor's rod 8-Shield H6 explosive target.

The experimental system had been shown in figure 1 and It was consisting of a ballistic gun, a sabot, fragments, a velocity measurement device, a chronoscope, a high-speed cinematography, a distance surveyor's rod and a shield H6 explosive target. With 30mm cartridge case, the combination of the sabot which had been made of nylon and fragment were launched to the predetermined speed by ballistic gun which had a 25mm caliber. After out of the muzzle, the sabot was separated from fragment. Fragment were launched at the velocity range of 2000 m/s~2200 m/s which had been the initial velocity of fragmentation warhead. connected-disconnected probes, using for speed measurement, were placed at 6 m and 8 m from the gun in order that the instantaneous velocity of fragments could be measured at 7 m. The impact velocity of fragments could be calculated according to experience-curve of external ballistics. The target was placed at 12m from the muzzle. The high-speed cinematography was placed on one side about 11 m away from the muzzle while two posts,1m apart, were placed on the other side. The sampling frequency of high-speed cinematography is 3000 amplitude/s and 5000 amplitude/s and the response characteristics of impact could be observe and recorded.

The explosive reaction rating had been divided into detonation, incomplete detonation, explosion, deflagration and combustion from MIL-STD-2105C and the Judgment of responses had been provided [12]. According to the Judgment from MIL-STD-2105C, the response characteristics, resulted from fragments impacting on shielded H6 explosive, was evaluated comprehensively. meanwhile the maximum diameter and duration of the fireball which had been caused by the impact as well as destruction of shielded H6 explosive were regarded as reference bases for the evaluation. The maximum diameter of fireball was measured according to the proportional measurement and the distance of two posts in the photos obtained by high-speed photography had been used as the reference distance. The duration of the fireball was calculated by the number of frames and frequency of the image which had been recorded by the high-speed cinematography.

3 EXPERIMENTAL RESULTS AND ANALYSIS

A total of 21 tests were completed and the results were counted and shown in table 1.

3.1 Response characteristics

Based on the statistical results and the judgment provided in reference [12], the responses could be divided into combustion, deflagration (or weak explosion, there were judged to be deflagration in this paper) and detonation. The typical destruction state of the targets was shown in figure 2~ figure 5. The response processes of the targets which had been recorded by the high-speed cinematography were shown in figure 6~ figure 8.

When the combustion reaction had been produced, the speciation of the fireballs was the pinnate jet and the maximum diameter of fireball was between 0.6 m~1.2 m. The fireball last for tens of microseconds and then turned into stable combustion that last for tens of minutes. After the combustion reaction, the explosive reaction waste was left in the shield.

When the deflagration reaction had been produced, the speciation of the fireballs was the approximate sphere and the maximum diameter of fireball was between 1.4 m~3.1 m. The fireball last for more than 200 microseconds, what's exceed the maximum sampling time of the high-speed cinematography. The size of fireball was correlated with duration of fireball positively and related to the amount of unreacted explosive inversely. The shield was broken to different degrees torn apart by degrees and then there were unreacted explosive that is sprinkled around.

When the detonation reaction had been produced, the maximum diameter of fireball could reach 13m. A blasted hole which had been formed from the detonation reaction could be observed obviously. The explosive was reacted completely. Judging by the damage to the surrounding trees, it is thought that high speed fragments could be formed from the fragmentation of the shield.

TAB 1 The test results

ordinal number	quality of fragment /g	size of fragment /mm	thickness of shield /mm	impact velocity /m·s^{-1}	maximum diameter of fireball/m	duration of fireball /ms	response of target
1	6	7×7×7	10	2169	0.9	22	combustion
2	6	7×7×7	10	2108	0.8	32	combustion
3	8	7.7×7.7×7.7	10	2131	1.2	80	combustion
4	8	7.7×7.7×7.7	10	2050	1.0	80	combustion
5	8	7.7×7.7×7.7	10	2160	1.4	> 200	deflagration
6	8	7.7×7.7×7.7	10	2107	1.6	> 200	deflagration
7	8	7.7×7.7×7.7	10	2127	1.1	32	combustion
8	8	7.7×7.7×7.7	10	2169	2.3	> 200	deflagration
9	10	8.3×8.3×8.3	10	2170	2.3	> 200	deflagration
10	10	8.3×8.3×8.3	10	2130	2.0	> 200	deflagration
11	10	8.3×8.3×8.3	10	2193	-	-	deflagration
12	10	8.3×8.3×8.3	10	2198	2.4	> 200	deflagration
13	10	8.3×8.3×8.3	10	2138	1.7	> 200	deflagration
14	10	8.3×8.3×8.3	10	2033	2.4	> 200	deflagration
15	10	8.3×8.3×8.3	10	2026	13	> 80	detonation
16	10	9×9×7.1	10	1998	1.6	> 200	deflagration
17	10	9.7×9.7×6.1	10	2018	2.6	> 200	deflagration
18	10	10.3×10.3×5.4	10	2082	2.5	> 200	deflagration
19	10	13.5×10.5×4	10	2070	1.0	45	combustion
20	12	8.8×8.8×8.8	10	2109	3.1	> 200	deflagration
21	12	8.8×8.8×8.8	10	2100	2.8	> 200	deflagration

FIG. 2 detonation of target (results of test for number 15)

FIG. 3 deflagration of target
(results of test for number 14)

FIG. 4 combustion of target
(results of test for number 3)

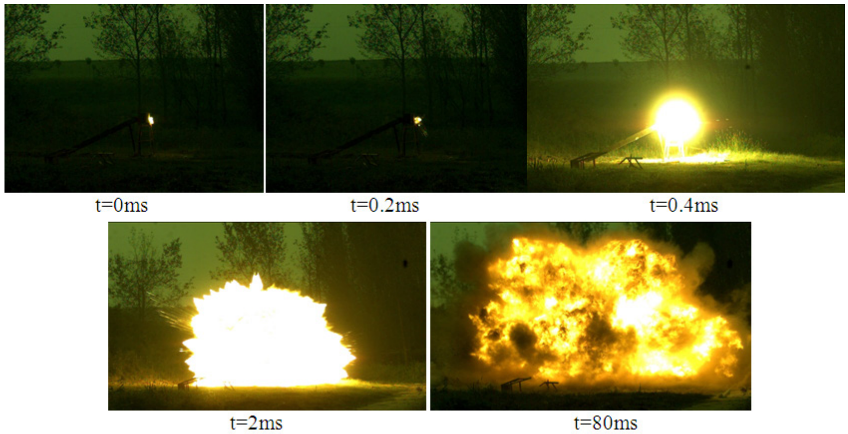

FIG. 5 detonation processes of target (results of test for number 15)

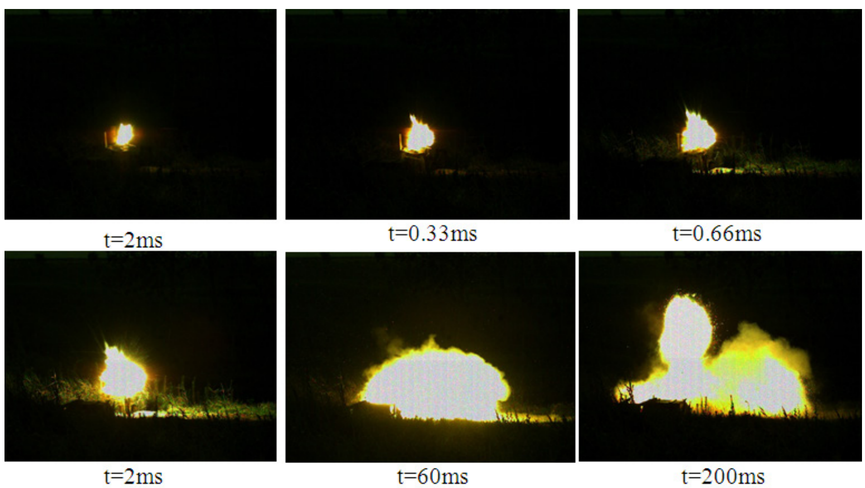

FIG.6 deflagration processes of target (results of test for number 14)

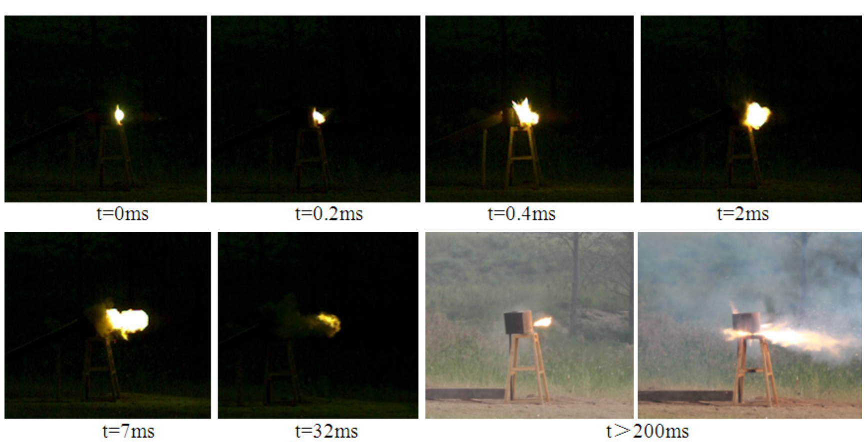

FIG.7 combustion processes of target (results of test for number 14)

3.2 Analysis of response mechanism

At present, detonation reaction mechanism of what fragments impact on shielded explosive is considered of shockwave detonation and adiabatic shear detonation primarily [13]. In addition to the explosives, the detonation mechanism of the explosive is also related to the thickness of the shield. It is generally believed that when the shield is thinner, the shockwave detonation is the main control mechanism of explosive detonation. In particular, the shockwave can be generated in the shield after the rupture of the shell When the shield is thinner, the shockwave is generated in the shield after fragments impacting. A transmission shockwave will be send into the explosive, when the shockwave propagates through the shield to the shield-explosive interface. If the transmission shockwave intensity reaches a certain intensity, it can directly detonate the explosive.

However, in which of the situations that the shield is thicker, the shockwave is attenuated in the shield dramatically, so that the shock wave intensity is not enough to detonate the explosive. However, the shield is washed out of a block with a similar size to the sectional area of the fragment in the terminal process for fragments penetrating the target. The shear can be formed from the wash in the explosive which can be detonated also when the shear zone reaches a certain temperature. Secondly, the hotspot can be produced around speed penetration trajectory while the explosive had been penetrated with the thrust block and the residual fragment at a certain speed and explosive detonation can also be initiated if certain conditions had been met.

With regards to the former of the above two detonation mechanisms, the shockwave pressure of the actual incoming explosive can be analyzed through theoretical analysis on the assumed condition that the impact of the fragments is flattened and the effect from rarefaction waves is not considered. the analysis model was shown in figure 8. The calculation method of shock wave pressure p_e transmitted into the explosive was shown in formula (1).

The significance of each parameter in formula (1) can be seen in the literature [9]. With MATLAB software, it could be calculated that the impact pressure transmitted into the explosive was 12.9GPa ~ 14.8GPa when the explosive which had been shielded with 10mm shielding layer was impacted with the fragment at 2000m/s~2200m/s speed. The pressure is higher than 11.53Gpa, the detonation pressure of H6 explosive, which had been obtained from the plane wave baffle test by the author. However, the detonation reaction of shielded H6 explosives could not be triggered reliably in the tests. The main reason was analyzed that the effect of rarefaction waves could not be ignored in the situations that the shield is thicker. The pressure value which had been transmitted into the explosive practically could be reduced so that the detonation reaction of shielded H6 explosives could not be triggered reliably. The criterion of the long rod projectile impacting on shielded explosives had been analyzed in literatures [2] and [8]. It is not applicable to the criterion since the size of the fragment is less than the thickness of the shield.

In addition, the observed response time for targets detonation or detonation was approximately millisecond by the high-speed cinematography and this time scale is larger than the detonation time scale which has been deemed as tens of microseconds [7]. Through simulation, the local hotspot could be produced by the combined action which had been composed of the shear heat and impact shear heat. the shear heat had been resulted from the washing process for the fragment impacting on the shielded and the impact shear heat, resulting from that explosive had been impact with the thrust block and the residual fragments after the washing process. After absorbs heat, the phase transition of TNT for the explosive in the place of the hotspot was that ignition and combustion had been observed firstly and then deflagration or detonation could been transformed from combustion if the number of hotspots or the speed of combustion met certain conditions.

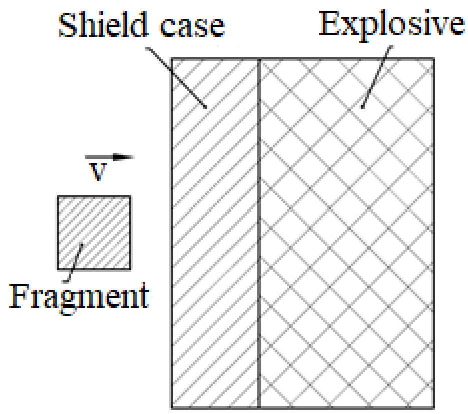

FIG.8. schematic diagram for the fragment impact on the shielded explosive

$$\begin{cases} p_f = \rho_f\left(C_f + S_f u_f\right)u_f \\ p_s = \rho_s(C_s + S_s u_s)u_s \\ p_f = p_s \\ u_f = v_0 - u_t \\ p_s' = p_t \cdot e^{\alpha x} \\ p_t' = \rho_t[C_t + S_t(2u_t' - u_e)](2u_t' - u_e) \\ p_e = \rho_e(C_e + S_e u_e)u_e \end{cases} \quad (1)$$

3.3 Effect of fragment quality on target response

when the quality of the fragments was 6g, the main response of targets was combustion. While the quality of the fragments reached 8g, deflagration and combustion could be observed. The main response of targets was deflagration and the individual response was detonation (such as test 15) if the quality of the fragments was 10g and 12g. The analysis suggests that the cause of detonation was mainly due to the inhomogeneity of the charge, or to that the minute charge defects could make the hotspots more easily.

For further study that the correlation between the reaction intensity of the target and the quality of the fragments. The maximum size of the fireball which had been produced by the response of targets was regarded as the parameter of the reaction intensity. The correlation between the maximum size of the fireball and the quality of the cuboidal fragments was calculated and shown in figure 9. The response was deflagration or more powerful if the quality of the fragments is greater than 10g. The quality of the fragments had positive effect on the size of the fireball and negative effect on the quality and particle size of unreacted explosive.

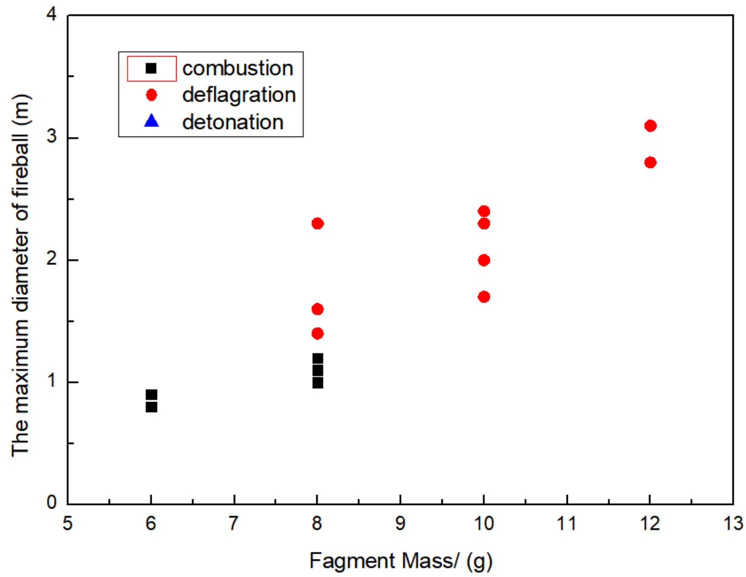

FIG.9. The correlation between the maximum size of the fireball and the quality of the fragments

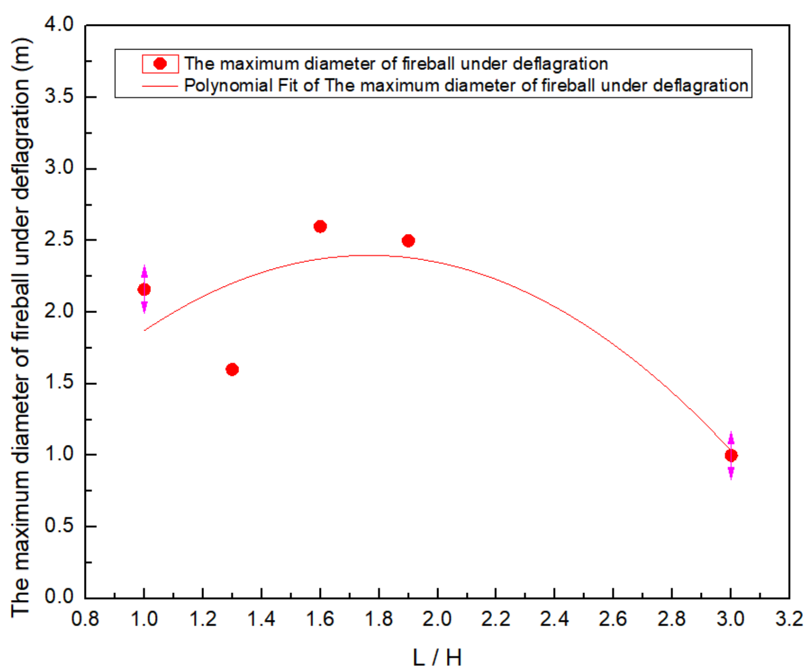

FIG.10. The correlation between the maximum size of the fireball and the parameter of the fragments, with the quality of 10g.

3.4 Effect of fragment length-thick ratio on target response

The size of the contact surface of the fragment and the target plate was defined as the length and the size of perpendicular to target plate as the thickness of the fragment [14]. The correlation between the maximum size of the fireball and the length-thick ratio of the fragments, with the quality of 10g, was calculated and shown in figure 10. With the increase of the length-thick ratio, the size of the deflagration fireball increased at first then decreased, and the response is turned into combustion by deflagration. Analyze the reasons, if the length-thick ratio was not more than 1.6, there was a positive correlation between the increase in the length-thick ratio and the size of the thrust block which had been produced by the fragment penetration. The size of the deflagration fireball was increased by the increase of the sheared zone of the explosives and the quantity of initial hotspot. However, if the length-thick ratio was more than 1.6, the penetration resistance is increased, by which the quality and speed of the remaining penetration of the fragment were reduced at the end of the penetration. The size of the deflagration fireball was reduced by the decrease of sheared zone of the explosives and the quantity of initial hotspot. The response was turned into combustion if the ratio of length-thick reached 3.

4 CONCLUSIONS

(1) The responses, impacted with the fragment at 2000 m/s~2200 m/s speed for H6 explosives with 10mm shielding layer mainly includes combustion, deflagration and detonation, and it has highest probability for deflagration. The initiation mechanism of the targets has been analyzed. The local hotspot could be produced by the combined action which had been composed of the shear heat and impact shear heat. the shear heat had been resulted from the washing process for the fragment impacting on the shielded and the impact shear heat, resulting from that explosive had been impact with the thrust block and the residual fragments after the washing process. Thus, combustion, deflagration turned into by combustion or detonation reactions were triggered.

(2) H6 explosives with 10mm steel shielded to be the targets, Deflagration reactions could be sparked in which of the situations that the quality of fragments was no less than 10g. If the quality of the fragments was certain, the reaction intensity of the target was affected by the size of the fragments. what's more, the most violent deflagration reactions could be triggered under the certain condition that the length-thick ratio of fragment was about 1.6.

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