23RD INTERNATIONAL SYMPOSIUM ON BALLISTICS
TARRAGONA, SPAIN 16-20 APRIL 2007

STUDY ON SHELLED EXPLOSIVE INITIATED BY EXPLOSIVE FORMED PROJECTILE

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EFP(Explosively Formed Projectile) has the characteristic of higher velocity, larger behind armor effect, attack at long distance, It has been used in antiarmor weapon system and antimissile warhead widely, such as terminally sensitive projectile, intelligent mine etc. In recent years EFP has been used to initiate the explosive charge of PGM(Precision Guided Munition) for it's high initiation ability in antimissile warhead. This paper focuses on the critical condition of EFP initiating the shelled explosive. We study the Jacobs-round rules, the Rindner experiential expression and the initiation results of different projectile density of HELD, and a new experiential expression of critical condition has been founded. The new expression include the factors of projectile and shelled explosive, such as nose shape of projectile, material of projectile etc. Corresponding experiment has been carried out to validate the parameter of the expression. A numerical simulation of formation and initiation process of shelled explosive of EFP has been developed based on methods of ALE arithmetic of LS-DYNA. Numerical simulation results calculated from this paper agree well with the results from the expression.

INTRODUCTION

Explosive formed projectile(EFP) is formed from a shallow metal liner, and it has different projectile shapes by varying the thickness and contour angle of the liner. EFP has the velocity of 1600m/s to 2500m/s, and the penetration depth may be 0.6～0.8*D*, in which *D* is the diameter of charge. EFP has the characteristic of higher velocity, larger behind armor effect and can attack in long distance, and it has been used in antiarmor weapon system and antimissile warhead widely, such as terminally sensitive projectile, intelligent mine etc. In recent years EFP has been used to initiate the explosive charge of PGM(Precision Guided Munition) for it's high initiation ability in antimissile warhead.

The problem of initiation process of shelled explosive by EFP has received a great deal of attention for the past few decades. Chick[1] focus on the initiation process of shelled explosive by Cookie-Cutter EFP, and two different diameters Cookie-Cutter EFP were used against the munitions such as MK82, MK84 and FAB etc. Initiation mechanism of shelled explosive by EFP has been discussed by Tang yong[2],and he considered that the explosive with thin shell can be initiated by initial shock waves which produce by EFP impact. The initiation mechanism of shelled explosive and critical condition have been discussed in this paper, and corresponding numerical simulation has been carried out using finite element programme of LS-DYNA.

INITIATION MECHANISM AND THE CRITICAL CONDITION

Consulting the correlative literature information of ignition process of shelled explosive [3, 4], there may be three mechanism of shelled explosive initiated by EFP. The first is hot spot of explosive heated by forward shock waves which produce by high velocity impact, and this case appeared in the condition of thin shell. The second is detonation caused by local warming up of explosive by macro-shear which produced by high velocity impact into the shell. The third is the residual EFP and collapsed fragment of shell initiate the explosive directly.

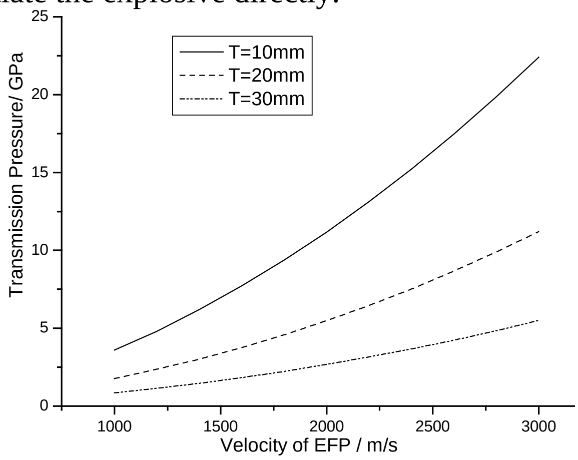


Figure 1. Transmission shock wave intensity of EFP impact into shelled explosive

In the first mechanism, a high speed shock wave has been produced at the moment of EFP impact into the shell, and the peak pressure decreased and wave length increased for friction and rarefaction wave effect. Transmission and reflection appeared at interface of explosive/shell, and a shock wave produced in explosive for the wave impedance of metal shell was higher than that of explosive. Figure 1 is the transmission shock wave intensity of EFP impact into shelled explosive with different thickness *T* of shell based on the theory of the one-dimensional propagation of shock waves[2]. The peak pressure of explosive was far less than initiation threshold pressure of explosive as EFP of 2000m/s impact into shelled explosive when shell thickness is 20mm form the results of Figure 1.

Because of the second mechanism, the precondition of macro-shear initiation is the shear layer must appear, little heat exchange and heat can cumulate in shear layer. Aperture occurred whether the explosive be pressed or cast-loaded, and the aperture will prevent the produce of heat insulation in shear layer. So there has little case of macro-shear initiation of shelled explosive.

Summarizing the above conclusion, shelled explosive initiated by residual EFP and collapsed fragment in mass condition, or three initiation mechanism will concurrence.

Whether the initiation mode of shelled explosive is one mechanism or concurrence, the ignition of shelled explosive can come down to initiation critical condition form macroscopical initiation mechanism. Consulting the correlative literature information, Jacobs-Roslund formula can describe the initiation critical condition all-around, but it's a linear variation formula and can not consider influence of the material and dimension of projectile. The new initiation critical condition should be based on the following principle.

(1) The initiation threshold speed of different projectile nose shaped should approach consistently when it has large shell thickness, because the rarefaction wave affect weakly in large shell thickness.

(2) Curve of initiation threshold speed with *T*/*D* ratio should be protruded upwards based on numerical simulation results[5,6,7], that is to say the initiation threshold speed increased slowly when *T/D* ratio increased.

(3) The formula can describe initiation critical condition of bare explosive when the thickness of shell is zero.

Consult the papers of Rinder[8] and Held[9], a new initiation critical condition formula as following has been founded base on above principle.

$$v_{cr} = k^{e^{-T/d}} \sqrt{\frac{I_{cr}}{d}} \left(1 + \sqrt{\frac{\rho_e}{\rho_p}}\right) \sqrt{\frac{1+\alpha T/d}{e^{\beta T/d}}} \left(\frac{L}{d}\right)^{-\gamma} \tag{1}$$

where k is the coefficient which considered the nose shaped of projectile, I_{cr} is initiation critical condition of bare explosive, and I_{cr} =23mm^3/μs^2 for Comp B, ρ_e is the density of explosive, ρ_p is the density of projectile, α、β、γ is the coefficient which considered the material of projectile and shell, L , d is the length and diameter of projectile, and T is the shell thickness.

The first part of the formula is the correct item which considered the nose shaped of projectile, the second part is the initiation critical condition of bare explosive by projectile, the third part is the correct item of shell thickness, diameter and material of projectile, and the fourth part is the item of *L/d* ratio.

EXPERIMENTAL VERIFICATION

Shelled explosive initiation experiments by four type of EFP have been carried out to calibrate the coefficient of $k\ \alpha\ \beta\ \gamma$, and the diameter of EFP charge varying 50mm to 60mm. The aim of different charge parameters is to get EFP of different velocity and *L/d* ratio. X ray photography experiment has been carried out to get different parameters of EFP. The range of velocity of EFP varying 1500m/s to 2000m/s, and that of *L/D* ration varying 1.76 to 3.76 form Table 1, and four type excellent EFP have been get for our next initiation experiment.

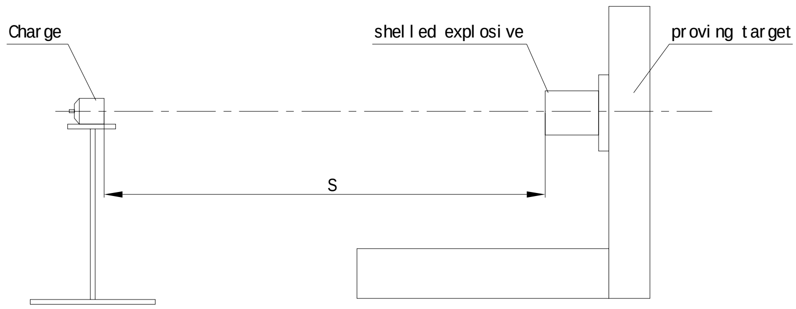


Figure 2. Sketch map of experimental layout

Table 1. Parameter of EFP

Type	time/ μs	EFP velocity/ m/s	EFP diameter/ mm	EFP length/ mm	*L/D*
1	300	1507	17.49	30.75	1.758
2	300	1838	13.29	50.08	3.768
3	300	1915	15.56	46.00	2.956
4	300	2030	13.40	42.60	3.179

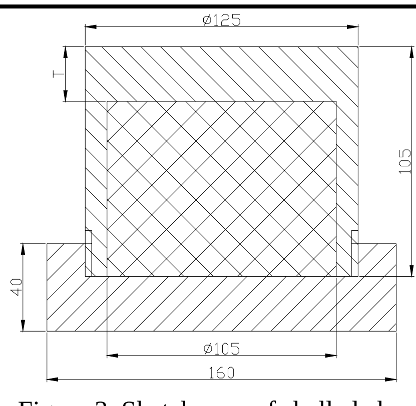


Figure 3. Sketch map of shelled charge

Figure 2 show the sketch map of experimental layout, and the distance(stand-off distance) varies 5m to 8m. The size of the shelled explosive been shown in Figure 3, the material of shell is medium carbon steel, and explosive is cast loading military Comp B of which density is 1.63 g/cm^3. The diameter of shelled explosive is large enough to avoid rarefaction wave effect.

Initiation experiment has been carried out with different thickness shell using above four types of EFP, and three results of detonation, reaction and deflagration appeared. Results of detonation and no reaction have been considered to provide credible criterion of initiation. Table.2 show Initiation experiment results, and Figure 4 show the fragment from initiation case and shell of no reaction case.

Table 2. Initiation result of experiment with four type EFP

NO.	Type	T /mm	Result
1	1	20	Detonation
2	1	30	No reaction
3	2	30	Detonation
4	2	35	No reaction
5	3	35	Detonation
6	3	40	No reaction
7	4	35	Detonation
8	4	38	No reaction

Fitting arithmetic of arbitrary function has been used to determining the value of coefficient base on the experiment results, and the results is k =0.4, α=0.1509, β=-0.2053, γ=0.2552 for EFP of OFHC. Table 3 show the contrast of the result form Experiment and new formula and the results agree well.

Fragment form initiation case   Picture of shell of no reaction case

Figure 4. Photograph of initiation result of experiment by EFP

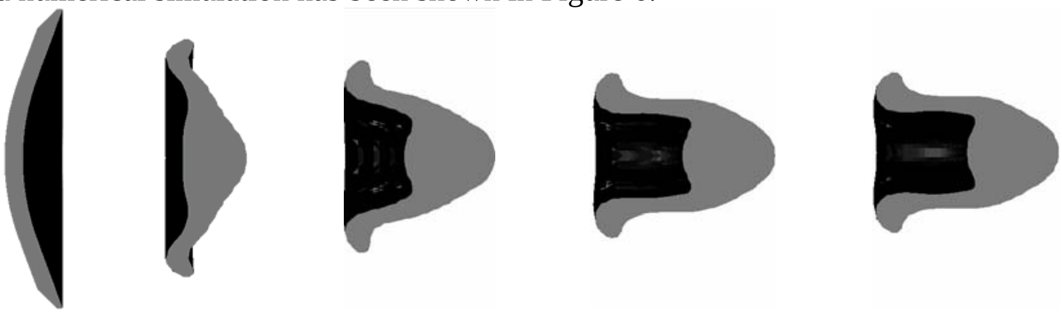
Table 3. Contrast the result form experiment and new formula

NO.	EFP Parameter			Experiment result / mm		Result form formula /mm
	d/mm	L/mm	V/ m/s	Initiation	No reaction	
1	17.49	30.75	1507	20	30	26.6
2	13.29	50.08	1838	30	35	31.7
3	15.56	46.00	1915	35	40	41.0
4	13.40	42.60	2030	35	38	35.5

NUMERICAL SIMULATION

In this paper, the focus is on the process of formation and initiation of shelled explosive of EFP. A EFP is generated when a sufficiently strong compression wave focuses on the tip of a metal liner. The present work did not intend to analyze the complex mechanisms of the explosion, which trigger the EFP formation. The finite element model was set up by using ANSYS, and ALE arithmetic and Multi-material couple technique have been used in the simulation process.

The picture of formation process of EFP with numerical simulation has been get, and it is a rearward fold liner formation. Figure 5 show this process. Table 4 show the parameter of EFP with experiment and numerical simulation, and photography of X ray and numerical simulation has been shown in Figure 6.



0μs 30μs 60μs 90μs 120μs

Figure 5. Formation process of EFP with numerical simulation

Table 4. Result with Experiment and Numerical simulation of EFP(120μs)

	L / mm	D / mm	V / m/s	L/D
Numerical simulation	44.9	20.4	1609.2	2.2
Experiment	46.8	19.5	1530.6	2.4

Numerical simulation result(120μs) Experiment result(120μs)

Figure 6. Result of EFP with Numerical simulation and experiment

The formation process of EFP cost longer time than that of shaped charge jet. The penetration process started after the formation process achieved completely, and so the stand-off of EFP is 200mm in the simulation model based on experience. The initiation results of different shell thickness by EFP have been carried out. The peak pressure of explosive exceed 20GPa when the shelled explosive ignited, and the peak pressure is impact pressure when no reaction. Figure 7 show the result, and the initiation result by numerical simulation is shown in Figure 8.

Table 5. Result of initiation experiment by EFP

NO.	T / mm	Result
1	10	Initiation
2	15	Initiation
3	20	No reaction

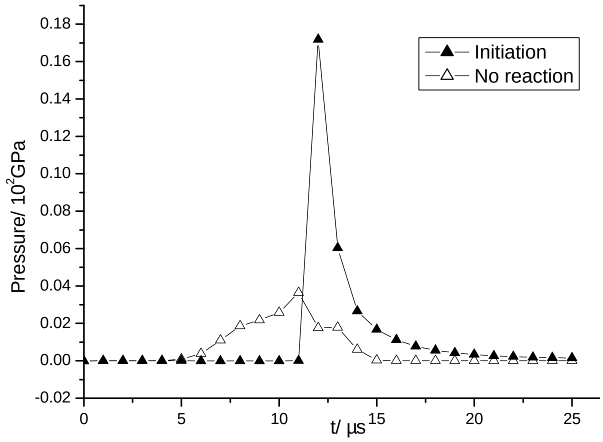
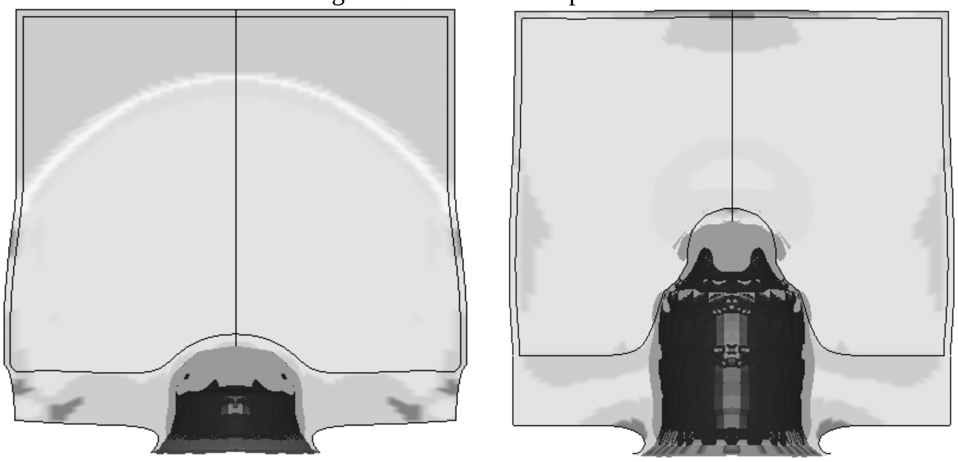


Figure 7. Pressure of Explosive



Initiation No reaction

Figure 8. Picture of initiation result of numerical simulation (160µs)

SUMMARY AND CONCLUSIONS

The critical condition of EFP initiating the shelled explosive has been discussed in this paper. We study the Jacobs-round rules, the Rindner experiential expression and the initiation result of different projectile density of HELD, and a new experiential expression of critical condition has been founded. The new expression includes the factors of projectile and shelled explosive, such as nose shape of projectile, material of projectile etc. Corresponding experiment has been carried out to validate the parameter of the expression. A numerical simulation of the formation process and the initiation process of shelled explosive of EFP has been developed based on methods of ALE arithmetic of LS-DYNA. Numerical simulation results calculated from this paper agree well with the results from the expression.

ACKNOWLEDGENENT

The author would like to thank Prof Gu Wenbing for his support and encouragement, the test team headed by Prof Chen Huiwu(NJUST) and Tang yong, and Ou yangchun for their experimental assistance.

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