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NUMERICAL PREDICTION OF THE INITIATION OF CONFINED HETEROGENEOUS EXPLOSIVES BY FRAGMENT PENETRATION

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The paper provides insight into the threshold levels required for the shock initiation process of a fragment impacting a confined explosive. In order to determine this threshold value quantitatively, the approach adopted was to observe the pressure profile amplitude, and the P^2dt criterion of the explosive along the fragment trajectory. The basic model consists of a tungsten fragment hitting a confined (Comp B or Tritonal) high explosive (HE). We first calibrated our numerical simulation routine with a set of test results to estimate the threshold values of shock initiation of the explosives. The thresholds values were then used to predict the shock initiation of other confined explosive configurations. It was shown that fragment impact velocity, impact angle, fragment weight, and fragment shape affect the shock wave pressure initiating from the fragment explosive interface.

INTRODUCTION

The shock initiation of confined explosives, when impacted by bullet or fragments, is of practical interest in numerous instances. For example, if an explosion occurs in a weapon, the possibility of propagation to one or more additional weapons may exist due to blast loadings and also due to fragment penetration. For a given confined explosive, the fragment threshold initiation is a function of the shape and velocity of the fragment, the impact angle, the covering material and its thickness. The threshold level may also change with the type of explosive.

Historically, research has focused on determining threshold levels for shock-to-detonation transition, deflagration-to-detonation transition (SDT & DDT, respectively)

[1, 2], and lower threshold situations, below which no reaction is initiated in the explosive [3].

A number of different explosive initiation models, implemented in continuum mechanics computer hydrocode programs, have been proposed over the years. For example, the Forest Fire [1], the Ignition and Growth [4], and the CTH codes use the “History Variable Reactive Burn” (HVRB) model [5]. These models are all limited by the type of explosive initiation they apply. They are useful for treating problems of shock-to-detonation transition (SDT), (often called shock initiation) or high order detonation (HOD). Models for more complex scenarios involving deflagration-to-detonation transition (DDT), which are a type of low order detonation (LOD), have also been attempted. Most of the initiation models mentioned above are too complicated for numerical implementation, and hence limited to specific experimental arrangements from which a large number of experimentally determined constants are derived.

The effect of the pressure profile on the critical initiation conditions is very well known and appears often in the literature. From experimental results on the initiation of various HE compositions by shock waves generated by mechanical impact from fragments of different materials, it has been shown that the critical initiation parameter depends upon P^2t = const, where P is the shock-wave pressure and t is the shock duration. The P^2t = constant relationship is often used in simple estimates of shock initiation of detonation in explosives [6, 7, 9]. Once this constant is determined for a specific explosive, the relationship between shock pressure and duration continues to hold quite well. In this paper we offered methodology to predict the reaction threshold level based upon numerical results. We numerically "tuned" the P^2t = constant criterion to the threshold initiation values by relying on experimental results of confined explosives (Tritonal, CompB). The resulting threshold values were used as shock initiation values for other tested configurations and characteristics of confined explosives and fragment impact scenarios.

Experimental Results

Several sets of multi layered confined explosive (Tritonal and CompB) targets were used to experimentally verify the ability of the fragments to initiate the explosive bulks. The fragments have different weight and impact velocities varying from 1500 to 3000 m/s. The HE was covered by a steel sheet with thicknesses ranging from 3-20mm. In a few of the experimental tests double steel layers with an air gap in between were used to confine the explosive. Two test configurations are shown in Figure1.

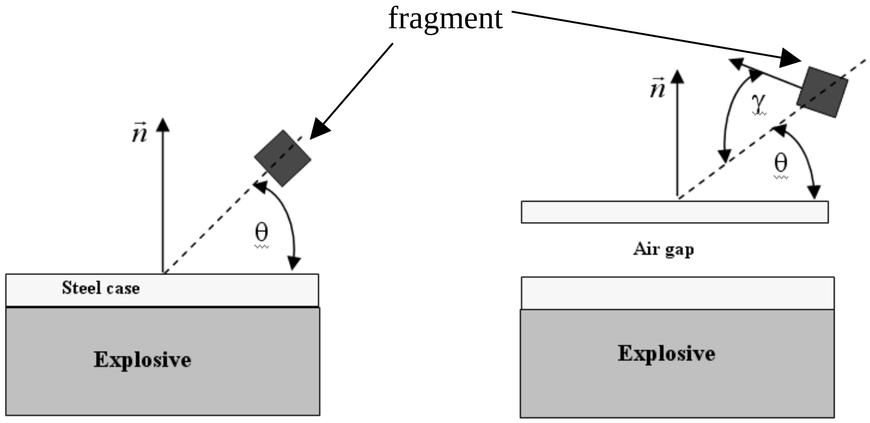


Fig 1a Fig 1b

Figure 1. Two explosive target confinement geometries

Table 1 summarizes the main characteristics of each experiment and the corresponding results for the initiation of the explosive state,

Exp Set ID	Explosive Type	Fragment Shape	Impingement Angle θ [Degree]	Velocity [m/s]	Fragment Weight	Explosive initiation status
.1	Comp B	Cubic	10^0	2350	m_1	Penetration
			20^0	2250		LOD
			30^0	2000		Penetration
			30^0	1750		Penetration
.2	Tritonal	Cubic	50^0	2918	m_2	Penetration
			50^0	2890	m_3	LOD
			60^0	2693	m_4	LOD
			70^0	2903	m_1	HOD
.3	Tritonal	Cylindrical	45^0	3070	m_4	LOD
			45^0	2495		LOD
			45^0	3030		HOD

Table1. Characteristics of experimental tests

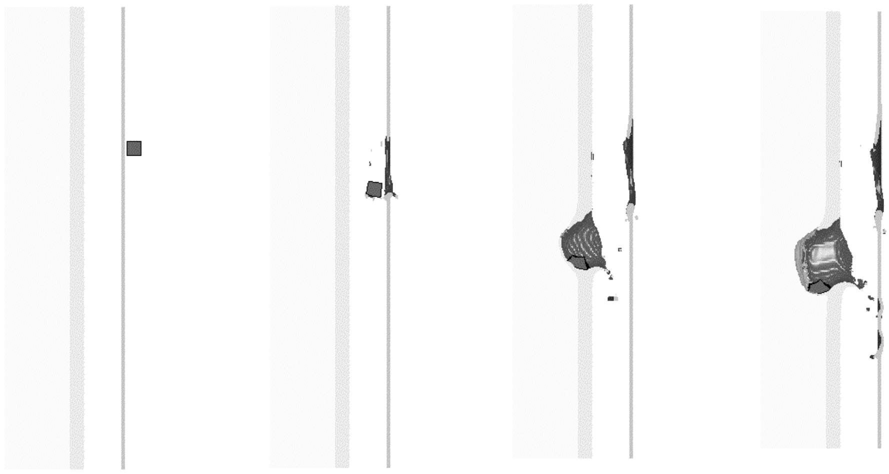
where the initial LOD and HOD are Low Order Detonation and High Order Detonation respectively.

NUMERICAL ANALYSIS - EXPLOSIVE INITIATION CRITERIA

The test results presented in the previous section were used to construct the shock initiation threshold values numerically. The numerical analysis was done using LS-DYNA finite element code. The main aim of the analysis was to study the shock to detonation transition due to a fragment impacting confined explosive target by calculating the pressure history at the explosive. Both Euler-Lagrange and Lagrange-Lagrange approaches were used for this purpose. All of the experimental test configurations and fragment impact conditions were modeled and analyzed by means of numerical simulations. The goal was to utilize this vast data base and the knowledge concerning the explosive initiation status for each of the cases.

The explosive and its encasement of mild steel sheet were modeled using the Johnson Cook Material strength model. The Gruneisen equation of state with cubic particle velocity which defines pressure for shock-compressed material was used.

The shock pressure time history of the bulk explosive around the fragment trajectory motion region was calculated and the P^2t criterion was evaluated in order to determine the explosive initiation threshold level. Figure~~s~~ 2. depicts a fragment penetration process of confined explosive target following the "calibration" stage of the simulation~~s~~ procedure.



t=0µs t=21µs t=72µs t=98µs

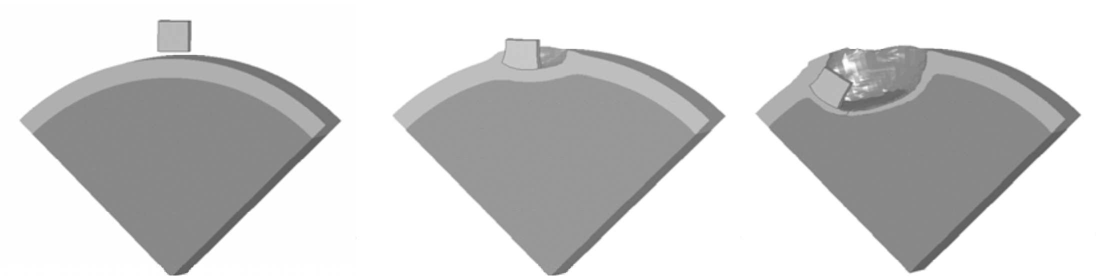
Figure 2. Numerical simulation results of fragment penetration
(Experimental set ID 2 (Tritonal explosive))

As was previously mentioned, all of the experimental configurations and fragment impacts conditions were modeled and analyzed by means of numerical simulations, which were calibrated and tuned with the experimental results. From simulations figure 5, which graphically depicts the non dimensional initiation threshold criterion for each of the explosives was generated.

IMPLEMENTATION EXAMPLE

The implementation problem consists of a cylindrically shaped explosive confined within a steel case. The aim of the simulation was to examine the possibility of shock initiation due to fragment impact, by calculating the pressure history at the explosive and approximating the P^2t criteria. The simulation used the same algorithm and code structure as the one used for the "calibration" phase. The numerical results of the simulation are shown in figures 3 and 4 respectively. The numerical results are graphically presented on a limit sector of a slice of the encased target located on the plane of fragment motion.

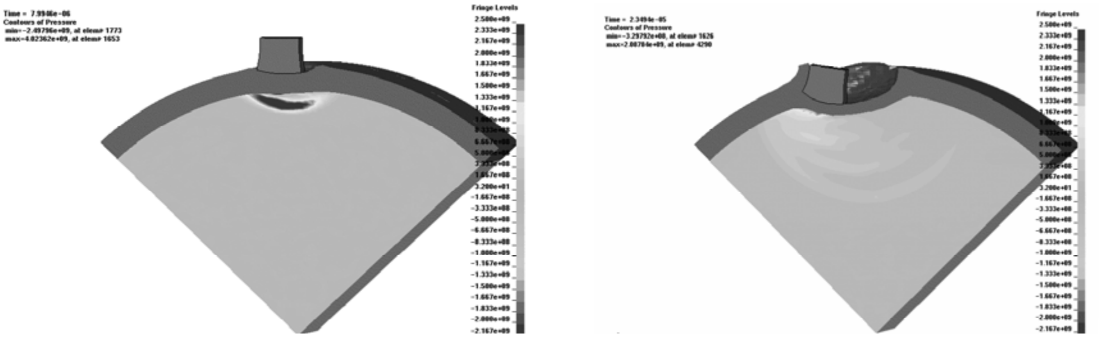
Figure 3. shows three different time frames of the fragments as it impacts and penetrates the confined HE's steel case. From this figure one can see the large erosion of the steel casing at (50µs).



Time=0.0 Time=15µs Time=50µs

Figure 3. Fragment impact and penetration (weight =20gr, impact velocity=1500m/s, impact angle=45^0) into confined HE (tritonal) enclosed within a steel case

Figure 4 depicts contours of pressure amplitude of the un-ignited explosive for the case shown in figure 3. A shock response is obtained in the explosive material by the fragment impacting during the early stage (8µs) of the fragment motion. The largest pressure at the explosive is achieved a few millimeters ahead of the front fragment interface due to the transmitted shock wave which is propagated from the steel case to the explosive having lower acoustic impedance. As may be seen, the maximal pressure value at the explosive bulk is in the range of 2.5-2.7 [GPa], and must lead to the possibility of an HOD process.



Time=8µs Time=25µs

Figure 4. Pressure contours at the un-ignited bulk explosive during fragment impact (weight =20gr, impact velocity=1500m/s, impact angle=45^0) at confined tritonal explosive covered by cylindrical steel case at two times 8µs and 25µs respectively.

The aforementioned numerical simulation was executed several times using the same geometric structure for the explosive target but incorporating different fragment impact conditions. The fragments have wide ranges of impact angle, impact velocity and fragment weight values. The P^2t value was calculated for all of the simulated impacts in order determine the possibility of explosive initiation type for each of the cases. The calculated P^2t values were compared to the threshold initiation values generated at the simulation "calibration" stage, which was initially based upon the experimental results. The initiation threshold~~s~~ values generated by the experimentally “calibrated” simulations are presented as a non-dimensional parameter in figure 5.

Figure 5. depicts the threshold ratios ($P^2t_{CompB} / P^2t_{tritonal}$) for shock initiation detonation for the three sets of experiments. In addition to the experimental results, the simulation results from the implementation example stage are described by straight solid lines for specific fragment weight and three different impact angles.

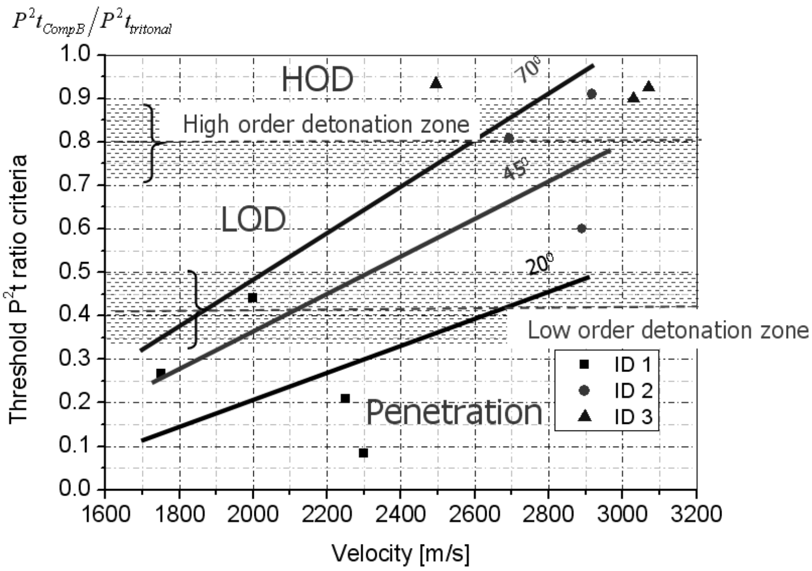


Figure 5. The initiation threshold ratio (P^2t_{CompB} / $P^2t_{tritonal}$) values vs. impact velocity at various fragments weights and impact angles for Tritonal and Comp B high explosive (HE).

Two horizontal dashed lines are crossing the ordinate (y - axis) of figure 5. These lines represent the ratio threshold values of shock initiation criteria for two kinds of shock intensities:

a). A shock detonation transition or (HOD) process is demonstrated by the upper initiation line

b). A Low order detonation (LOD) which can be accompanied by a certain amount of deflagration is shown by the lower line.

The threshold initiation ratio values are not unique and uncertain zones corresponding to different fragments impact scenarios exist. These varying fragment impact strike incidents may cause the same explosive initiation results shown in figure 5 and thus one can conclude that a vast collection of experimental trials should be used to lower the range of the uncertain zone for both types of initiation criteria (HOD,LOD).

The region beneath the LOD zone describes a condition at which only penetration of the fragment occurs at the explosive medium. For example if the history of the pressure development (i.e. experimental or simulation results) falls below the LOD lower uncertainty limit, then the initiation process will have zero probability of taking place.

SUMMARY

The paper provided some insight into the threshold level for the shock initiation process by a fragment impacting an encased explosive. Several shock initiation criteria based on the idea of some minimum stimulus are necessary to begin the process that eventually leads to detonation. In the present study, the threshold values for shock initiation were well described by the P^2t criterion, which is currently the most useful one in a quantitative sense and is macroscopic in nature.

It was demonstrated that the two parameters relationship (viz. pressure and duration), which defines the initiation boundary limit for two types of explosives (Tritonal and Comp B) for a variety of fragment~~s~~ weights and shapes, has wide applicability even to complex impact scenario involving heavily confined explosive targets. The numerical simulations were preformed using the hydrodynamic codes and were based upon and calibrated against available experimental results. The influence of fragment shapes and weight, impact angle orientation, and explosive confinement, on the shock initiation process was studied. A comparison of numerical simulation results with experimental data show close agreement and encourages further study of minimal stimulus initiation criteria. It was realized that the criterion is easy to use and simple for application apply to engineering problems.

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