Initiation of Sympathetic Detonation between two Separated PETN charges

Desmond Murray[1,*], Ashish Vashishtha[2,*], Donncha Lenihan[1], Dean Callaghan[2], Cathal Nolan[2]
[1] Ordnance School, Irish Defence Forces, Ireland
[2] Institute of Technology, Carlow, Ireland

1 Introduction

The changes in modern battlefield and military operations in recent decades has led to the design and development of insensitive munitions (IM), which can be used with higher degree of effectiveness and flexibility. Additionally, the reduced probability of accidents with IMs, allow them to be suitable for storage, transportation and production in larger quantities. However, the use of IMs necessitates new techniques and methods for explosive ordnance disposal. Conventional munitions disposal (CMD) or disposal of unexploded (failed) ordnance are based on various techniques such as sympathetic detonation (shock induced initiation), shaped charge (directed energy) etc. Sympathetic detonation involves detonating the failed or target munition (acceptor) by detonating a known charge at a nearby location (donor). In the process, the shockwave generated by the donor charge can compress the acceptor charge with high impulse loading to detonate it. In traditional CMD procedures, the amount of donor charge is selected based on user experience. In most cases, this leads to use of higher amount of donor charge than required to ensure the effective disposal. With recent use of IMs, it may be required to repeat the procedure multiple times to have effective disposal of IMs with various donor charges. This study is motivated to understand sympathetic detonation by modelling and simulating it and establishing the models to estimate the required donor charge to dispose of the given munition.

In this study, the experiments are carried out for two separated bare charges of fixed masses, mainly composed of plastic explosive such as Pentaerythritol tetranitrate (PETN). The numerical simulations are carried out for the same and modelling parameters are adjusted to achieve the behaviour of sympathetic detonation similar to the results obtained from experiments. The main objectives of this study are: 1) Model sympathetic detonation of two separated PETN charges using open-source solver blastFOAM, 2) Perform a parametric numerical study to accurately model sympathetic detonating of PETN charges as observed in experiments 3) Develop an understanding of the dynamics of shockwaves, which leads to sympathetic detonation of an acceptor charge, based on different charge sizes and the gap between acceptor and donor.

2 Experimental Findings

The experimental set-up involves keeping the acceptor and donor charges of fixed mass at a fixed distance on a witness plate. Multiple trials are conducted with different masses of bare PETN charges with different gaps, based on previous experiences and simple theoretical models [1–3] The witness plates were inspected post detonation. Figure 1 shows the images of the witness plates used in experiments, which were observed post detonation. Both the aceptor and donor charges were 32 grams of PETN, with

*Joint First Authors, Correspondence to: ashish.vashishtha@itcarlow.ie

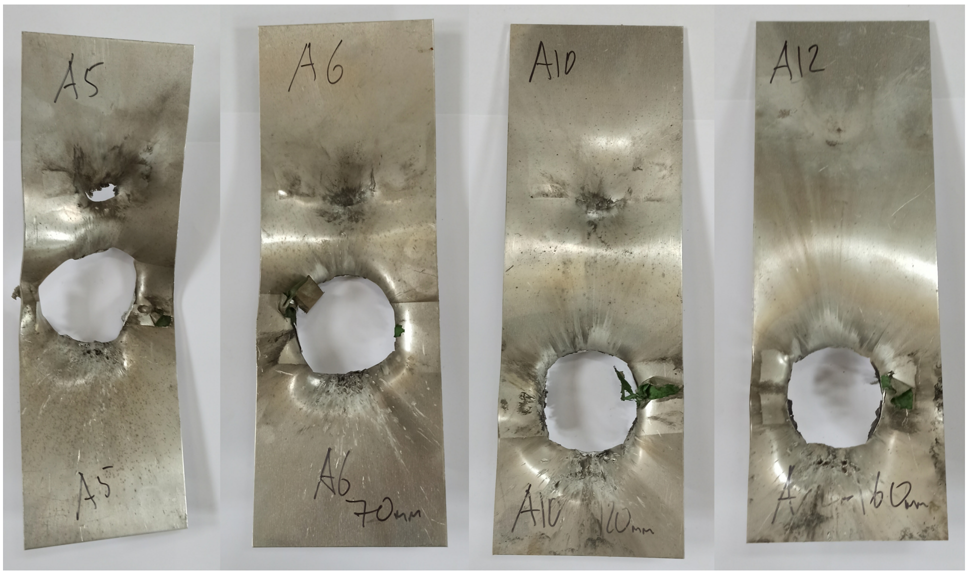


Figure 1: Witness Plate Results with Increasing Gap Distance for 60mm, 70mm, 120mm and 160mm

the donor charge held at increasing gap distances (from left to right). The donor charge was placed on the lower portion of the plate and the acceptor charge was placed on the upper portion of the plate. It can be seen that a spectrum of results were generated. The first witness plate shows two clear holes where the donor and acceptor charges were placed. Observed from left to right it can be seen that the damage to the witness plate, where the acceptor charge was placed, decreases as the gap distance increases, indicating that less of the acceptor charge initiates each time. It was noted also that as gap distance increased more unreacted acceptor charge explosive was recovered from the testing area post trial. This indicates that the reaction of the acceptor charge is likely to be due to the spectrum of detonation, deflagration and no reaction with varying amounts of each reaction as gap distance varies.

3 Numerical Modelling Approach

In this study, the sympathetic detonation between donor and acceptor charges are modelled and simulated by using open source CFD code blastFoam [4], which is based on the OpenFOAM framework version 7 [5].The unique feature of blastFoam is its capability of using efficient adaptive grid refinement to model various space and time scales in large domains of explosions. In this study AMR is adopted based on local density gradient. The two dimensional, multiphase Euler equations are solved with detonating thermodynamics model, specifying 3^{rd} order Birch-Murnaghan for reactants & Jones Wilkins Lee for explosion product. The approximate HLLC Riemann solver is used to evaluate fluxes based on volume fraction method with van Leer reconstruction method. The explicit 4^{th} order Runge-Kutta method is used for time-integration. The conversion of reactants to product is modelled using reaction progress variable (λ_i) to describe the individual cell activation [4]. The initial energy is defined using unreacted equation of state, and the reaction energy (E_0) is based on time rate of change of the reaction progress variable:

$$\dot{E} = \frac{E_0 \rho_i}{\rho_{0,i}} \frac{d\lambda}{dt} \tag{1}$$

where, ρ_i $\rho_{0,i}$ are local and initial densities of i^{th} phase, respectively.
The phase properties are calculated using:

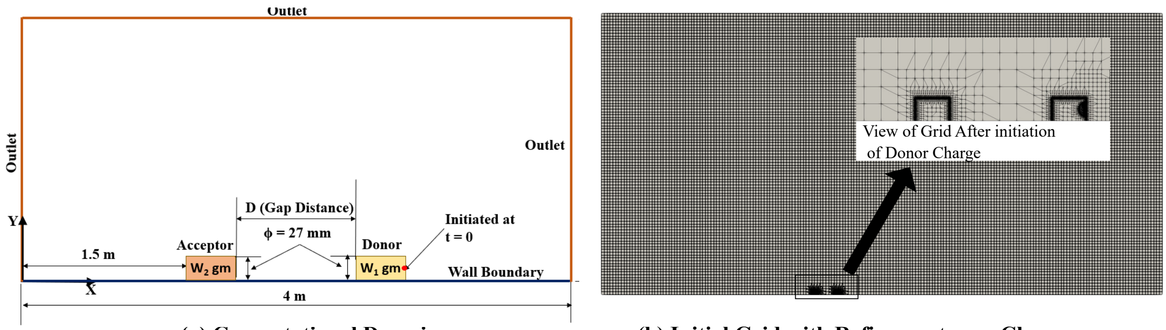
$$x_i = \lambda_i^l x_{r,i} + (1 - \lambda_i^l) x_{u,i} \tag{2}$$

where, $x_{r,i}$ is the reacted phase quantity and $x_{u,i}$ is unreacted phase quantities, and l is the exponent used to blend the unreacted and reacted phase. The transport equation was used for reaction progress variable with source term determined by reaction rate ($\dot{R}_i$), which is determined by the activation model. The activation of donor charge is modelled using a linear activation model using detonation point and constant detonation energy and detonation velocity. The activation of acceptor charge is modelled using pressure based activation model. The reaction rate for acceptor charge is dependent on local pressure and modelled as follows:

$$\dot{R}_i = G_1(1-\lambda)^c \lambda^d p^y \tag{3}$$

where, G_1 is first activation rate, c, d and y are various exponent of choice controlling the reaction rate based on progress variable and local pressure. In this study, these exponents are adjusted and formulated to model sympathetic detonation for PETN as observed in experimental findings.

The two-dimensional computation domain consists of rectangular region with uniform structured grid and the acceptor and donor charges are modelled by defining as initial condition with respect to unreacted phase equation of state of PETN.The gas (air) phase is considered as an ideal gas.



(a) Computational Domain **(b) Initial Grid with Refinement near Charges**

Figure 2: (a) Computational Domain (b) Initial Grid with Adaptive Grid Refinement

Figure 2 shows the computational domain with two separated cylindrical PETN charges of mass ($W_1 = W_2 =$) 32 gm. and diameter of 27 mm. The left charge is named acceptor and the right charge is named as donor charge. The acceptor and donor charges are separated by the gap distance (D), which is considered to be 120 mm for the preliminary study. Although the donor and acceptor consists of the same explosives, both are modelled through different phases along wth same thermodynamics properties, so that reaction progress related to the individual charge can be traced with time. The donor charge is initiated with linear activation at the center of the donor charge cylinder at $t = 0$ s. The donor charge explodes and the shock wave is generated with its initiation and consumes the donor charge. Depends on the gap distance and local strength of donor charge shock wave, which reaches acceptor charge, it may also detonate or consumed through partial detonation, which was analyzed through reaction progress parameter of acceptor charge.

4 Results and Discussions

4.1 Theoretical Model:

A simple theoretical model is developed which calculates the expected impulse at the acceptor charge based off donor charge mass and air gap distance using scaled distance theory. These model assumed that two explosions can be expected to give identical blast waves at distances which are proportional to the cube root of the respective energy release. This impulse figure was then compared to a theoretical threshold for initiation. This model was modified semi-empirically using the difference between pressure readings recorded during practical experimentation and the simple theoretical model which calculates pressure at the gauge location. Figure 3 shows the calculated theoretical impulse, with the theoretical initiation threshold. The results observed in experiments with respect to the witness plates denoted by the background colour in the figure identifying various initiation modes. It can be seen that

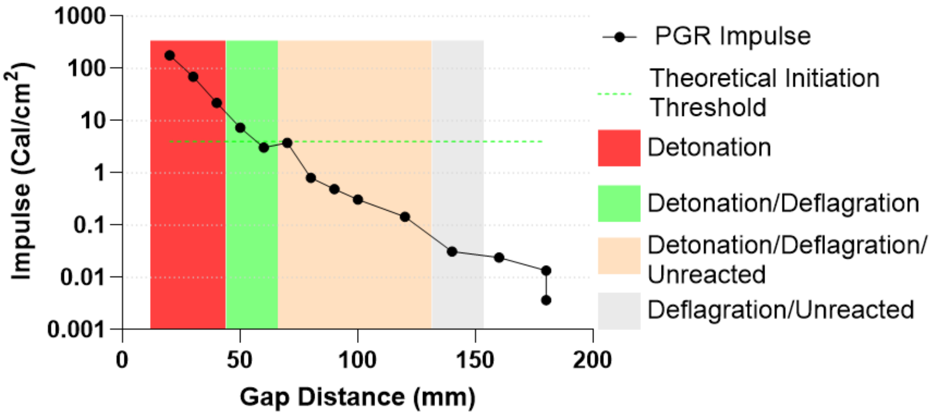


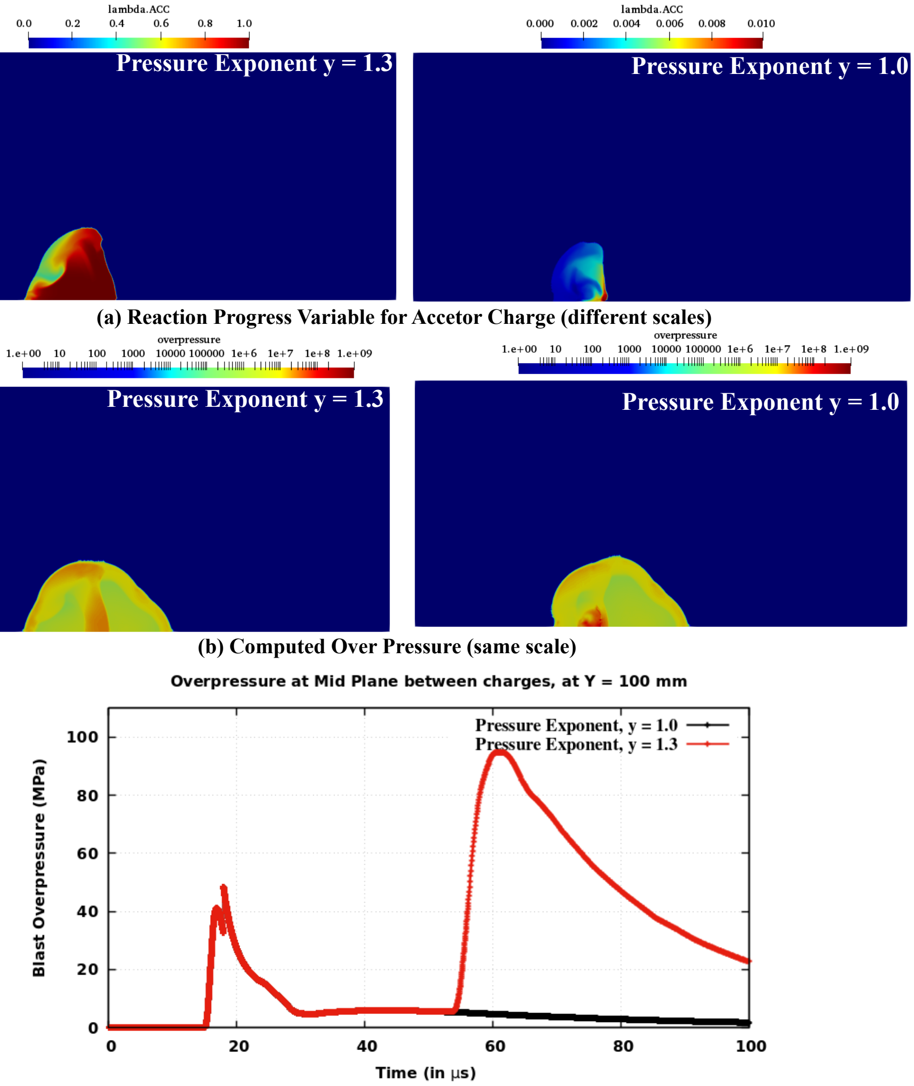
Figure 3: Results from Experimental Observations and Semi-emperical Theoretical model

the calculated impulse crosses the theoretical threshold for initiation at approximately the same location where the witness plate results indicate that full sympathetic detonation stopped occurring.

4.2 Numerical Results:

In the preliminary study, the two sets of numerical simulations are performed for 32 gm of acceptor and donor charges separated by a gap distance of 120 mm with two different pressure exponents in Equation 3 as $y = 1.0$ and 1.3. The pressure exponent governs the reaction rate and progress variable for acceptor charge. The choice of values of pressure exponent y = 1.3 and 1.0 are adopted to distinguish and model two sympathetic detonation modes: 1) initiation of acceptor charge 2) Compression of acceptor charge, but partial transition of reactants of acceptor charge to products. The computations are stopped at $t = 0.1$ ms.

Figure 4a shows the contours of the reaction progress variable of acceptor charge ($\lambda_{Acceptor}$) at time t = 0.1 ms. In the case, where the pressure exponent is $y = 1.3$, the sympathetic detonation occurs and the maximum values of $\lambda_{Acceptor}$ reaches 1.0 as seen in Fig. 4a. In the large spatial region, the acceptor charge converted to reaction products. Corresponding overpressure contours are shown in the left image of Figure 4b. In case of a pressure exponent $y = 1.0$, the reaction progress variable of acceptor charge ($\lambda_{Acceptor}$) reaches a maximum of 0.010, which reflects almost no initiation or a substantially small mass of acceptor charge converts to reaction products. The corresponding overpressure contours in the right image of Fig. 4b, shows a compressed state of acceptor charge, but it has not completely detonated and released the detonation energy. Furthermore, the time history of blast overpressure for two pressure exponents, at location $Y = 100mm$ on the mid-plane between the acceptor and donor charges has been plotted in Fig. 4c. The first peak in the time-history reflects the arrival of a primary shock from the donor charge for both pressure exponents. At time $t = 58\ \mu s$ the overpressure plot shows a second peak



(c) Time History of Blast Overpressure at a Midplane point

Figure 4: Results from Experimental Observations and Semi-emperical Theoretical model

for pressure exponent $y = 1.3$. The reason for a second higher peak is due to shock induced sympathetic detonation of the acceptor charge, which leads to formation of stronger shock with interaction of donor and acceptor shockwave. For pressure exponent $y = 1.0$, the overpressure remains relatively constant. The acceptor charge doesn't detonate or initiate for pressure exponent $y = 1.0$, which was reflected in the overpressure time history as plateau.

4.3 Full Paper Content:

In the full paper, further parametric study will be performed using numerical simulations to determine the various exponents to model the sympathetic detonations for the PETN separated charges as observed in experimental tests. Also, the analysis of various factors such as effects of preliminary shock and reflected shock on sympathetic detonation will be performed along with the pressure history at different locations. After validation of the numerical models using experimental data, it is expected that the outcome of the study can be extrapolated to determine the required donor charge mass for sympathetic detonation of given a acceptor charge.

References

[1] Lee JHS. (1977). Initiation of gaseous detonation. Ann. Rev. Phys. Chem. 28: 75.

[2] Cooper, P. (1996) Explosives Engineering. Albuquerque: Wiley-VCH.

[3] Kinney, G. F. and Graham, K. J. (1985) Explosive Shock in Air. Second Edi. New York: Springer Science+Business Media New York.

[4] blastFoam (2020): A solver for compressible multi-fluid flow with application to high-explosive detonation, Synthetik Applied Technologies, LLC., Available at https://github. com/synthetik-technologies/blastfoam

[5] Weller H. G., Tabor G.,Jasak H., Fureby C. (1998), A tensorial approach to computational continuum mechanics using object-oriented techniques, Computers in Physics, vol. 12, no. 6.