Modelling of pulsed laser ignition of energetic materials

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Abstract
Energetic materials are conventionally ignited by the application of heat to the explosive. Now a days lasers are used to trigger chemical reaction in explosives. So the objective of this work is to simulate a numerical model for laser induced heating and ignition of confined energetic material Cyclotrimethylene trinitramine (RDX)**.** The model considers the effect of irradiating a steel plate with long laser pulses and the thermal response of the explosive. Here thermal decomposition of energetic material is modelled along with the heat diffusion of the laser energy in the solid.
Keywords: *Pulsed laser ignition; Explosion; Numerical model*

I. INTRODUCTION

Recently, significant interest has been placed on the use of lasers as an ignition source for large calibre ballistic systems. The ignition of materials through a radiative heating mechanism offers several advantages over other mechanisms. These include 1) incident flux levels and exposure intervals to the propellant surface that can be controlled very precisely, 2) safe and long distance explosion of energetic materials can be done without much requirements. Therefore reliable data for time to ignition and location of ignition are essential for safeguarding the ammunitions.

Many studies has already done in this area using continuous laser beam. So through this project the effect of pulsed laser beam on RDX explosion is studied. The explosion in RDX can occur either by DDT or SDT method. .

II. PROBLEM DESCRIPTION

Here a one dimensional heat flow from a high energy laser source to steel plate and to the RDX is considered. The steel plate is having a length of 10 mm and that of RDX is 41 mm. Five pulses of laser beam of power 200KW/cm^2 is made to fall on the front side of the steel plate in an interval of 49 ms. The ignition of energetic materials is considered through affixing a layer of RDX to the rear side of steel plate.

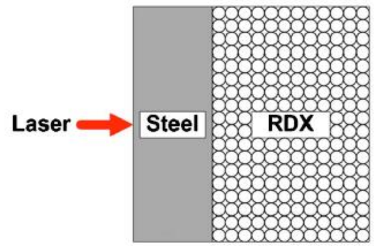

Figure1: Pulse energy transfer to steel with RDX in contact

III. METHODOLOGY

All ignition process and the one dimensional heat transfer analysis was done using a MATLAB programme which uses Forward Time Central Space (FTCS) method to solve the differential equations governing the ignition process. The heat transfer in the steel plate is considered to be one dimensional diffusion equation.

$$\rho_S C_S \, \partial T/\partial X = K_S \, \partial^2 T/\partial^2 X$$

Where ρ_S, C_S and K_S are the density specific heat and conductivity of the steel plate respectively. It is assumed as the conductivity, specific heat are independent of temperature. The heat transfer in RDX is modelled as

$$\rho_e C_e \, \partial T/\partial X = K_e \, \partial^2 T/\partial^2 X \quad + \sum_{i=1}^{N} riqi$$

ρ_e , C_e and Ke are the density ,specific heat and thermal conductivity of RDX. r_i is the reaction rate , qi is the heat of reaction and N is the total number of chemical reaction steps. The laser heating of RDX causes thermal decomposition of RDX followed by a rapid gaseous exothermic reaction. A three step chemical decomposition for RDX is considered. These steps are described by Arrhenius model[3].

The reaction steps is written

$A \rightarrow B \quad r_1 = Z_1 \exp(-E_1/RT)\, \rho_A$, $B \rightarrow C \quad r_2 = Z_2 \exp(-E_2/RT)\, \rho_B$,

$C \rightarrow D \quad r_3 = Z_3 \exp(-E_3/RT)\, \rho^2_D$ and $r_1 + r_2 + r_3 = 0$

Table 1. Kinematic parameters for thermal decomposition of RDX [2]

Reaction step	E (kJ/mol)	Z(S^{-1})	Q (kJ/kg)
A→B	197.2	5.76×10^{19}	-418
B →C	184.338	4.740×10^{17}	1256
C→D	142.8	1.586×10^{15}	5016

Where the subscripts A, B, C and D represents RDX, H2C=N-NO2, C represents (CH2O+N2O) or (HCN+HNO2) and D represents the final gaseous products. The species conservation equations[1] are

$$\partial Y_A / \partial t = -r_1 \qquad \partial Y_B / \partial t = r_1 - r_2 \qquad \partial Y_C / \partial t = r_2 - r_3$$

$$\partial Y_D / \partial t = -r_4 \quad \text{and} \quad Y_i = \rho_i / \rho_e$$

The following boundary conditions are used in this problem. On the front side of the steel five pulsed laser beam of power 200 KW/cm^2 is given in intervals along with it a convectional heat loss from the steel surface to the ambient air at 300 K is also considered. On the rear side of the RDX again a convectional boundary is given. The energy balance equation applied at the front face and rear face are

$$q_{radiation} - q_{convection} - q_{conduction} = 0$$

$$q_{convection} - q_{conduction} = 0$$

IV. RESULTS AND DISCUSSION

In this work a RDX confined steel vessel is exposed to five pulses of laser and the results are shown below.

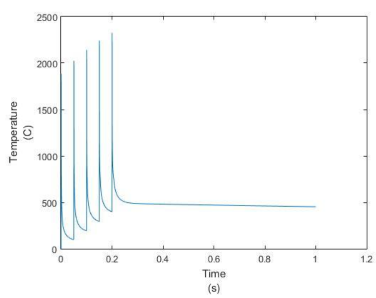

Figure2: The temperature profile of steel - front surface

The maximum temperature obtained at the front side of the steel is around 2300 K then it is reduced and again reached higher temperature this is because of the laser pulses. After a certain time it starts to decrease this is because of the convection losses of the temperature to the surrounding atmosphere as well as conduction to the steel rear end. The temperature in the rear end of steel is increasing with time.In usual constant heat flux conditions the graph adopt a linear profile but here it have a slight curvy nature this is due to the irradiation of laser beams in intervals or in pulses.

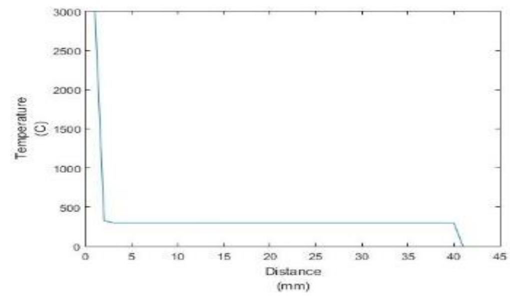

Figure3: The temperature profile of RDX during explosion

When the interface temperature reaches around 460 ^{0}C the reaction starts and it suddenly shoots to 3000 ^{0}C after explosion. At this region of RDX the concentration of final gaseous products become unity and that of RDX is zero which shows that the reaction as completed at this point where as in the other region the reaction is still going on which is evident from the figure 4 that the concentration of RDX at other points is almost near to unity.

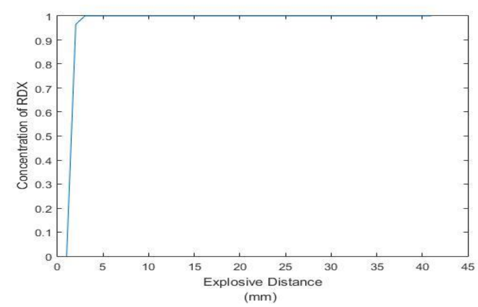

Figure4 Concentration of RDX with distance after explosion

V. CONCLUSION

The location of ignition and the temperature after explosion of the RDX material confined in a steel container when ignited using laser pulses are found out using a MATLAB programme. The results obtained matches with the theoretical datas. The temperature after explosion is 3000 ^{0}C and it occurs at the steel explosive interface.

REFERENCES

1. Modelling of high energy laser ignition of energetic material by Kyung-cheol Lee, Ki-hong Kim,and Jack J. Yoh

2. Experimental and Numerical Investigations of thermal Ignition of a Phase changing energetic material by M. Deepu and Priyanka Shukla

3. A Comprehensive Analysis of Laser-Induced Ignition of RDX Monopropellant by Y.-C. Liauj.

Acknowledgements

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