Experiment and Numerical Simulation of Explosive Safety

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State Key Laboratory of Explosion Science and Technology (Beijing Institute of Technology)

- State Key Laboratory of Explosion Science and Technology (SKLEST) was founded in 1991 and open to public in 1996. It is the unique state key laboratory in the field of explosion science and technology in China.

- The mission of SKLEST is to solve the fundamental research and applied-basic problems of explosion science and technology and social safety

- The research areas are focus on Theory and Applied Technology of Energetic Materials, Detonation and Explosion Technology, Impact Dynamics of Materials and Construction, Damage Theory and Protection Technology, Explosion Safety Theory and Assessment Method.

- There are 2 post doctoral programs, 9 Doctor's degree programs and 13 Master's degree programs in SKLEST..

Introduction

- **To understand the safety of Energetic materials is very important.**

- **Some explosive safety tests, such as Cook-off, SDT , DDT, Shot, Sympathetic detonation, are employed to evaluate the safety of explosive.**

- **But from the most the safety tests, we only know the response of explosives , not understand the details of reaction.**

Introduction

- **The numerical simulation of explosive safety tests can show the details of explosive reaction to give more information to us.**

- **With numerical simulation , we can easily change the stimulation to analyze explosives safety in some extreme condition, which could be conducted difficultly by test.**

- **So it important to use test and numerical simulation together to study the explosive safety.**

In this report, the investigation about Cook-off, DDT and Sympathetic Detonation tests and calculations are being talked

1 Slow Cook-off test of TNT

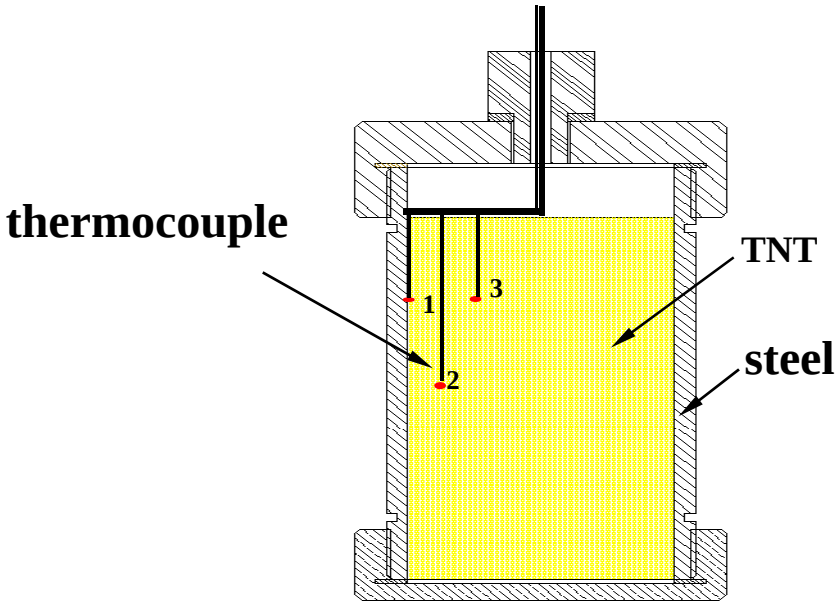
- **TNT explosive has low-melting point and will melt before ignited in slow cook-off test.**

- **The melting of explosive will absorb heat and changes the state of explosive so as to effect on cook-off progress.**

- **So TNT melting have to be considered in cook-off test study for getting the correct results for assessing explosive safety.**

Slow Cook-off test

The Cook-off test setup consists of the bomb, electric heating band, thermocouples, witness plates, temperature recorder etc. The bomb was heated by a cylindrical electrical heater. Three thermocouples were installed in explosive to record the temperature.

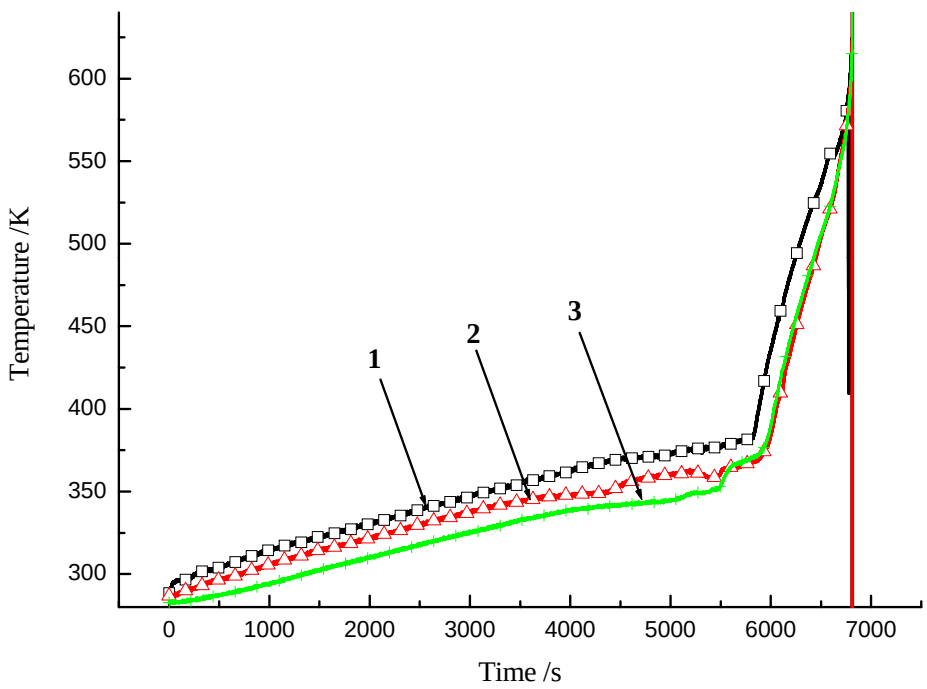


Cook off bomb structure

Photograph of bomb

Results of Cook-off test

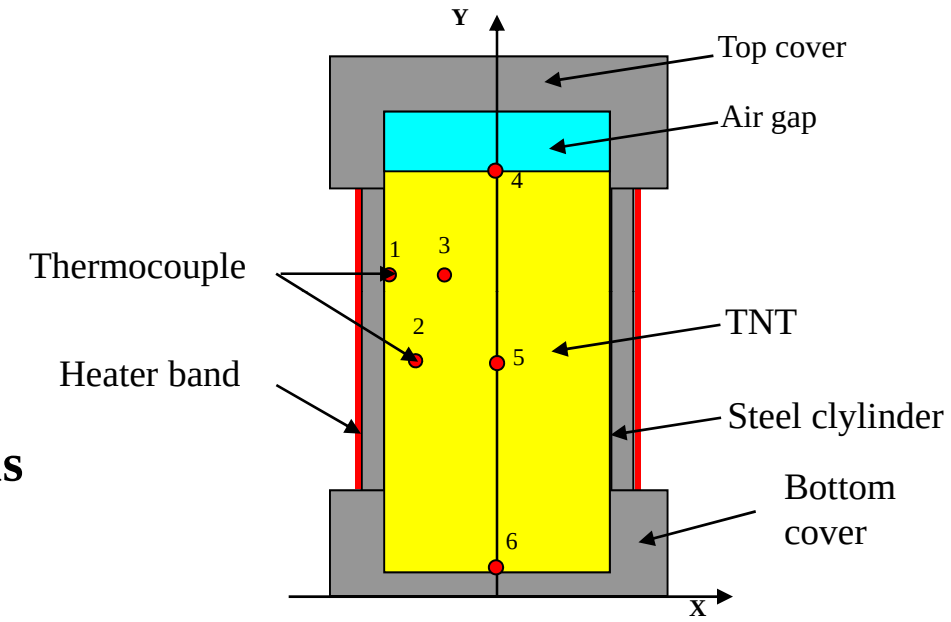
- Two different heating rates is used during the cook-off test. First, the heat rate is 1K/min heat rate.
- After TNT had melted, the heat rate is increased to 13K/min.
- TNT had happened explosion because no steel fragments and were found near the test.



Measured T-t curves for TNT Cook-off test

Numerical simulation of Cook-off test

Two assumptions for model:
1) Only thermal conduction exists in solid explosive and thermal conduction and convection coexist in liquid explosive.
2) The thermal decomposition of explosive abide by Arrhenius rate law.



Calculation model .

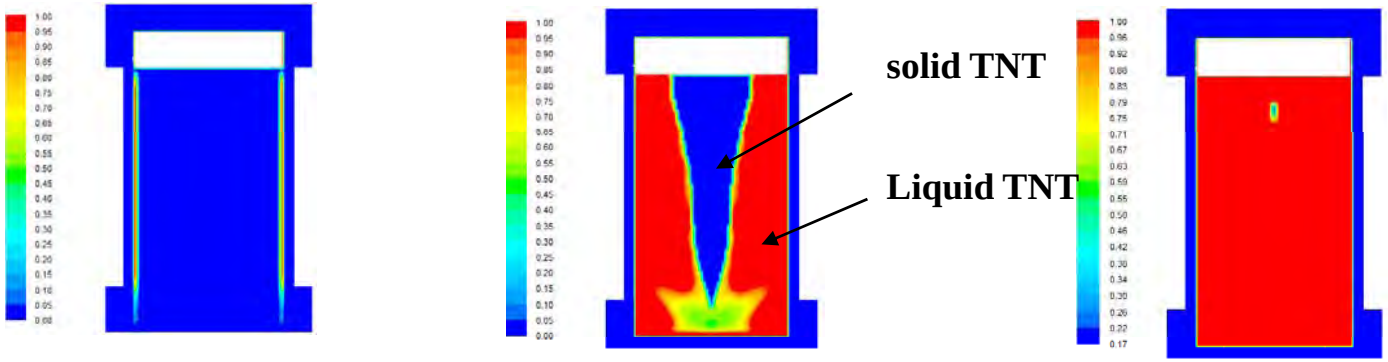
energy equations :

$$\frac{\partial}{\partial t}(\rho H)+\nabla(\rho u_i H)=\lambda\nabla^2 T+S$$

$$H=h+\Delta H \qquad \Delta H=\beta L$$

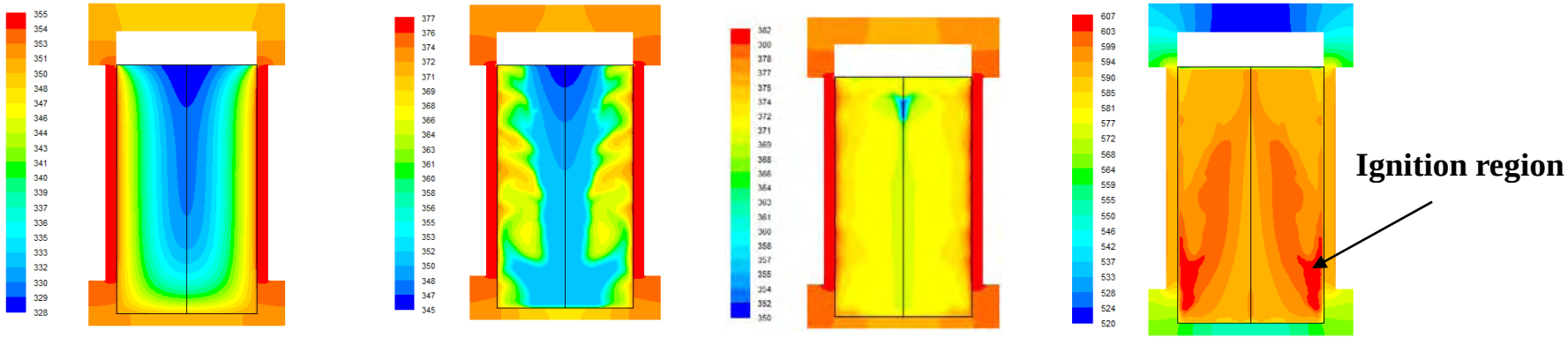
βis the liquid fraction to describe TNT melting .

Results of calculation



3500s 5250s 5675s

Liquid fraction distribution in TNT at different time



3500s 5250s 5675s 6791s

Temperature distribution in TNT at different time

2 Fire Cook-off test

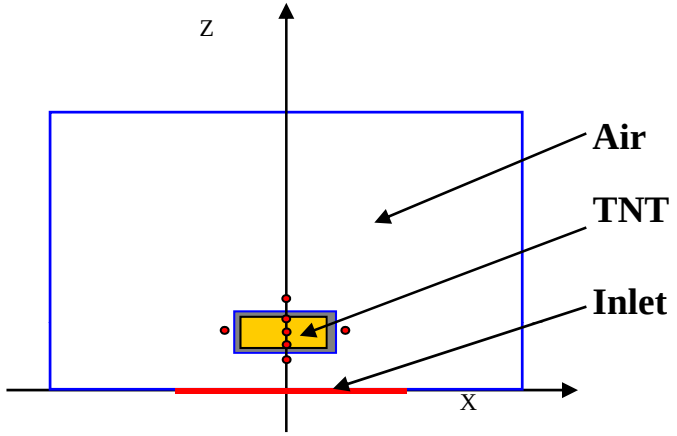
The fire cook-off test consists of the bomb, fuel, thermocouples and witness plates.

The fuel burns to heat the bomb in charged explosives.

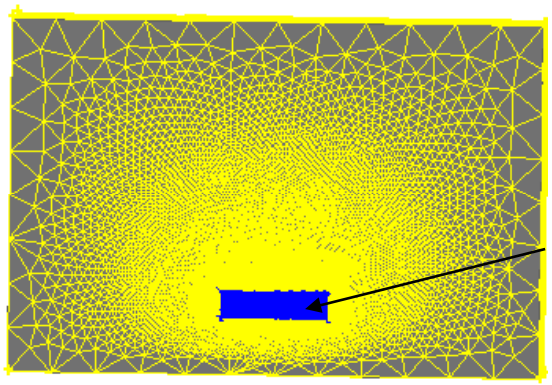
Photograph of Fire Cook-off test

Fire Cook-off test Model

- It is important to describe correctly the heat flux of flame for simulation.
- So the calculation domain includes the bomb and the air around bomb.
- The k-ε turbulent model is employed to describe the flame of fuel.



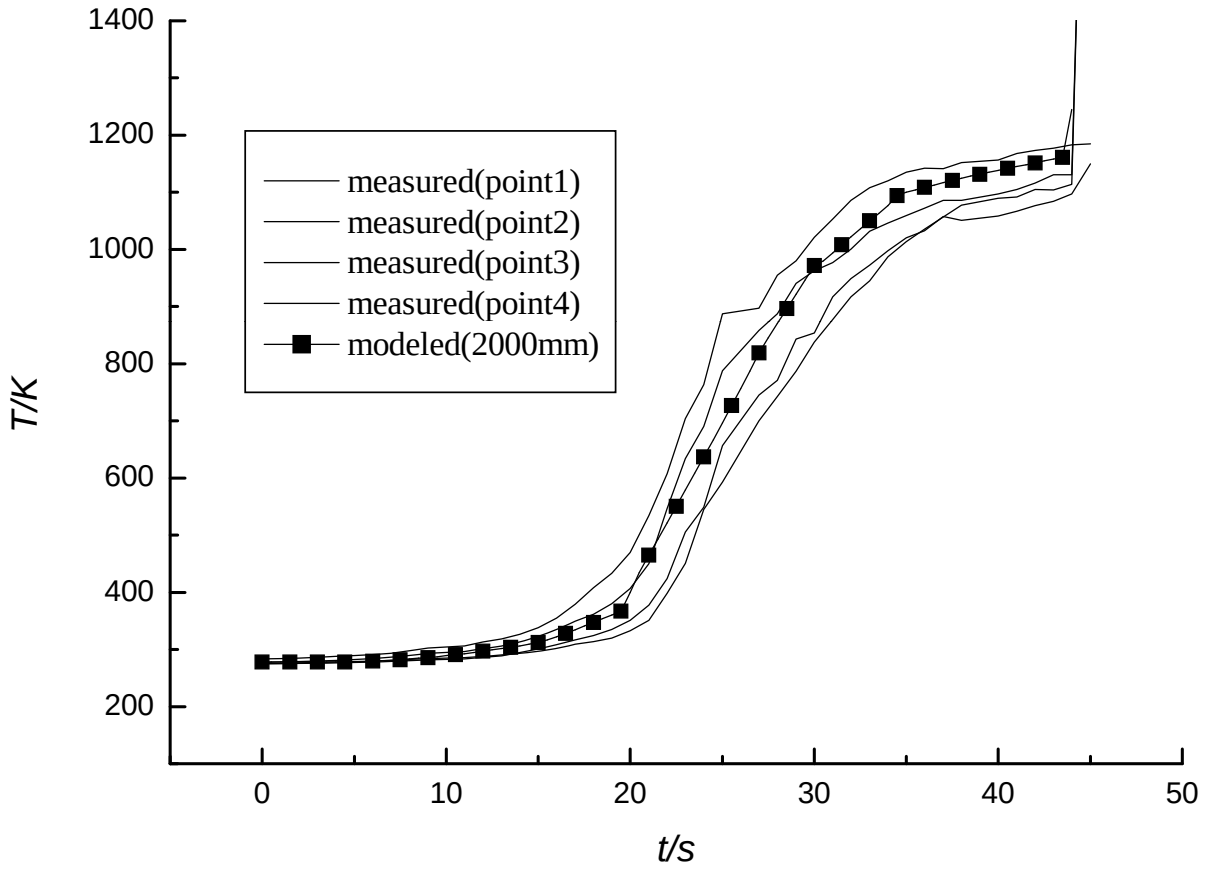
Calculation model



Calculation grid

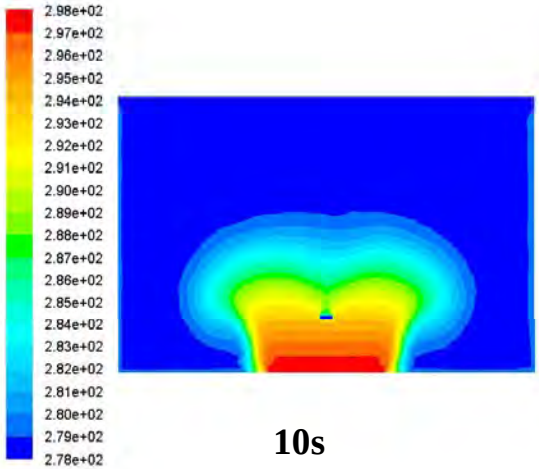
Fire Cook-off test Model

The flame heat flux was achieved by adjusting mass flux of the combustion gases according to the measured data.

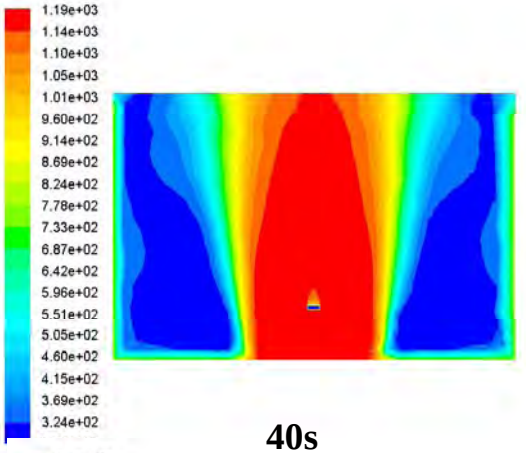


Comparision of measured and modeled temperature vs. time of external flame

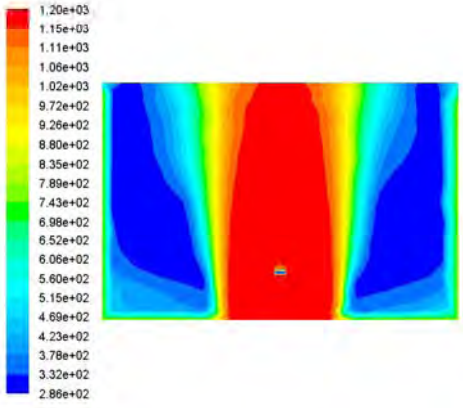
Results of Calculation



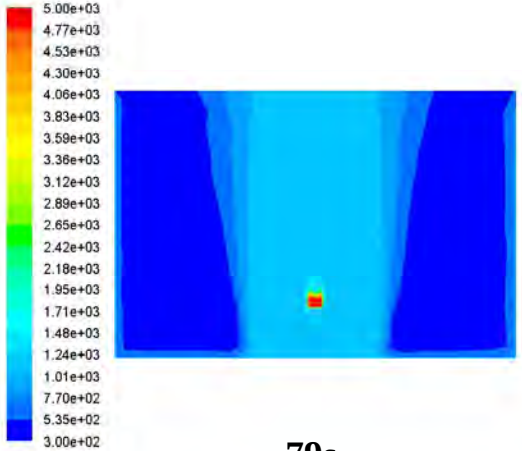
10s



40s



78s



79s

Temperature distributions at different times

3 Explosive DDT Test

- From the cook-off tests and calculations, we can know the time , temperature and position of explosive ignition, but can not know the reaction violent degree of explosives.

- The reaction violent degrees are related to both the explosive kind and constraint conditions of charges.

- The DDT (deflation to detonation transition) tests are employed to study the reaction violent degree of explosives.

DDT Test

Explosives are almost in high density to be used. Therefore to study the DDT behaviors of explosives in high density is more important.

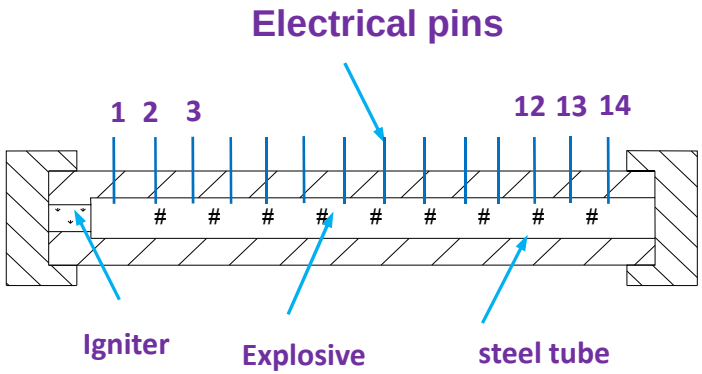
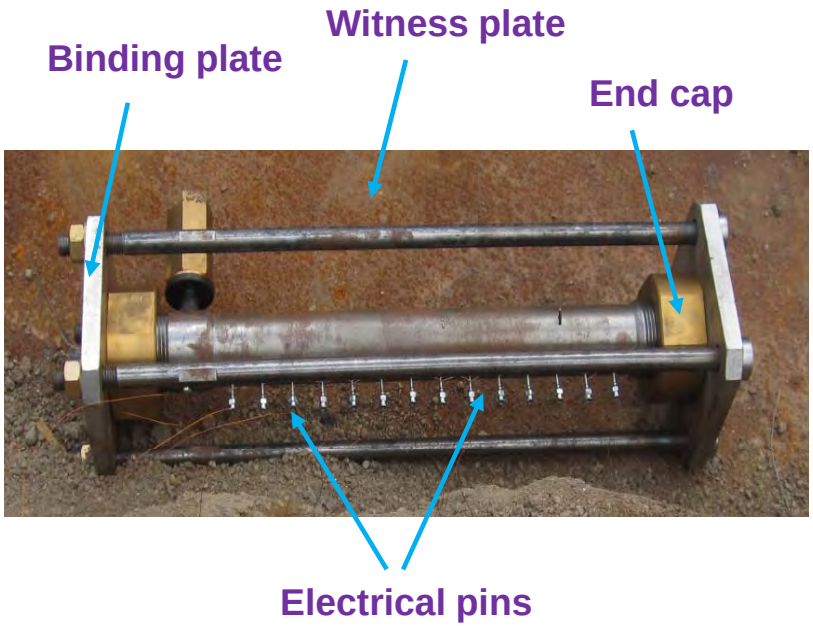


Diagram of DDT test



Photos of DDT test

Results of Test

- **The different thick tubes are used for changing the constraint condition of explosives in DDT tests.**

- **The reaction violent degree is estimated by the tube fragments and reaction wave velocity.**

Some fragments of DDT test photo

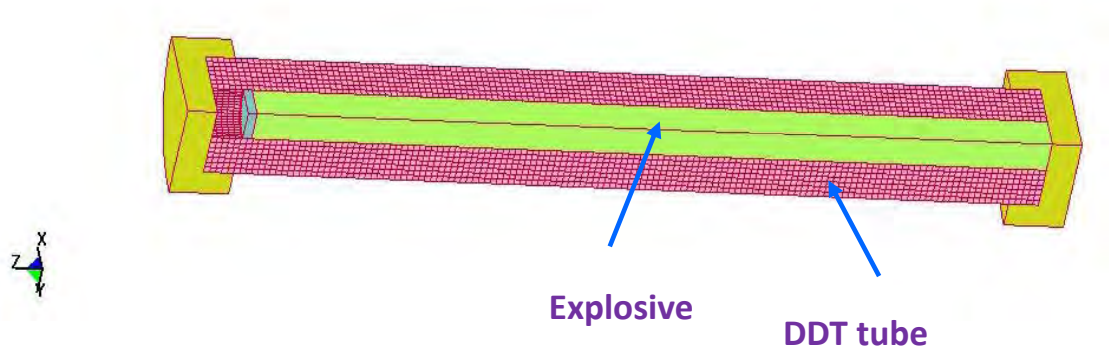
Calculation Model of DDT

- **A reactive model is used to describe reaction of explosive in high density:**

$$\frac{dF}{dt} = a(1-F)^c(F+F_i)^d(p+p_i)^y + b(1-F)^e F^g p^z$$

$0<F<F_{a\max}$ $\qquad$ $F_{b\min}<F<1$

- **The reactive speeds depend on the pressures.**

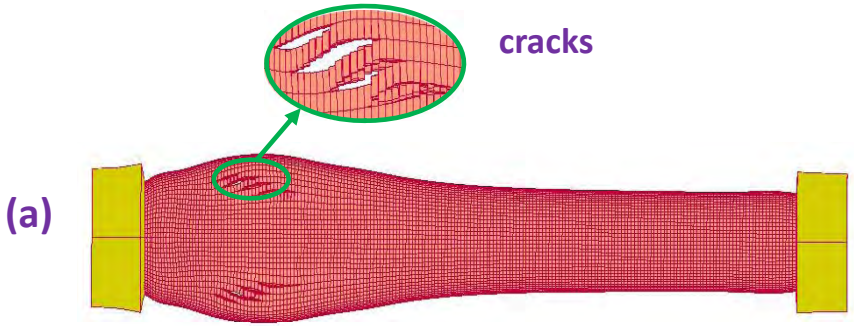


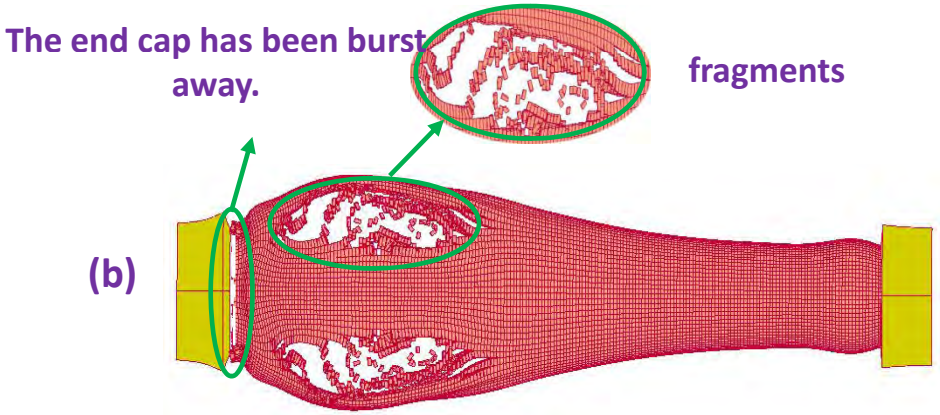
Calculation Model

How to calculate tube rupture

- **The methods of separating elements and random invalidation strain are used to simulate the tube rupture.**
- **As tube expands, the strain of tube elements will grow. As it get to its failure value. the nodes of element will separate from another elements to produce the cracks in tube.**
- **The failure strains are set randomly within a certain range, So the cracks and rupture of tube are produced randomly, which is much closer to actual condition.**

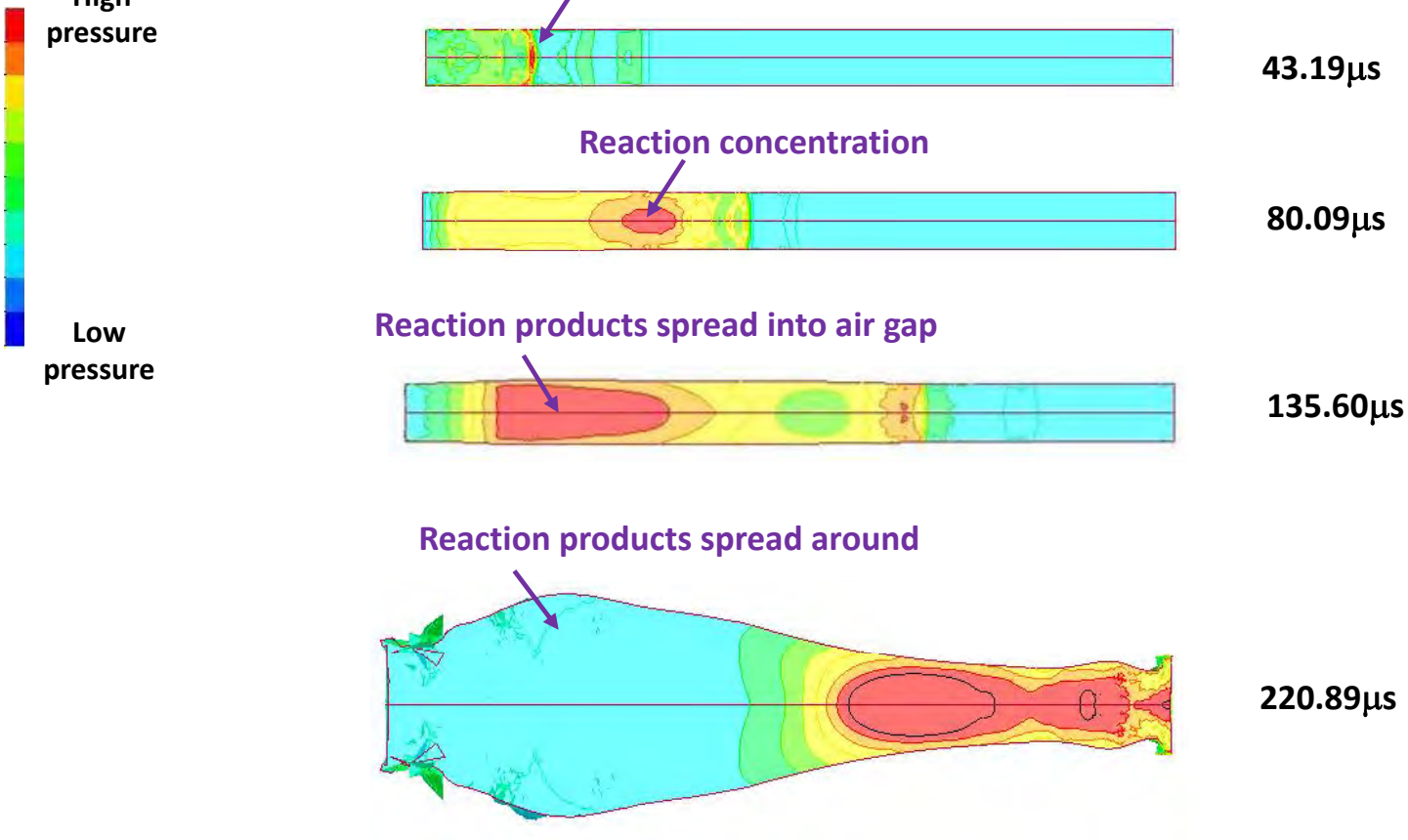
Tube rupture





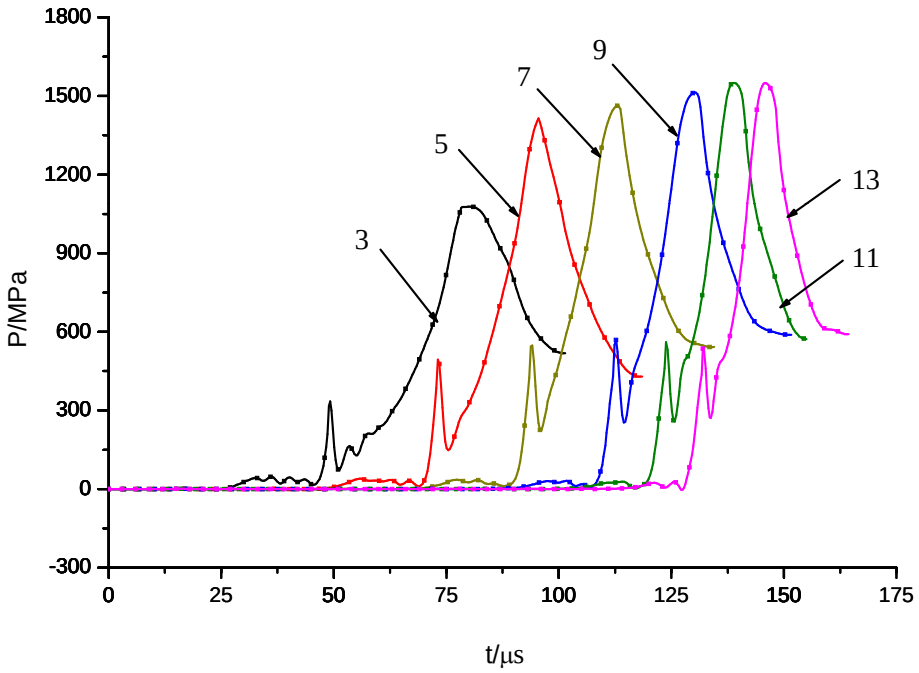
DDT tube deformation

Pressure increasing

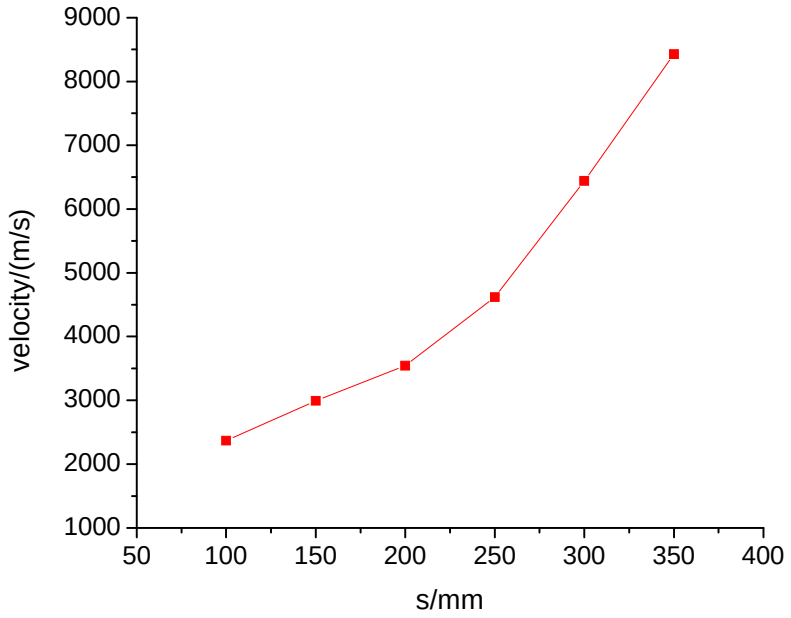


Pressure distribution of explosive at different times

Reaction wave velocity



Pressure versus time curves in explosive



Reaction waves velocity versus spread distance

4 Sympathetic detonation test

- **The calculation methods of separating elements and random invalidation strain in DDT calculation are used to the simulation of Sympathetic detonation test also .**
- **But the SDT model is used for the explosives.**

Sympathetic detonation study

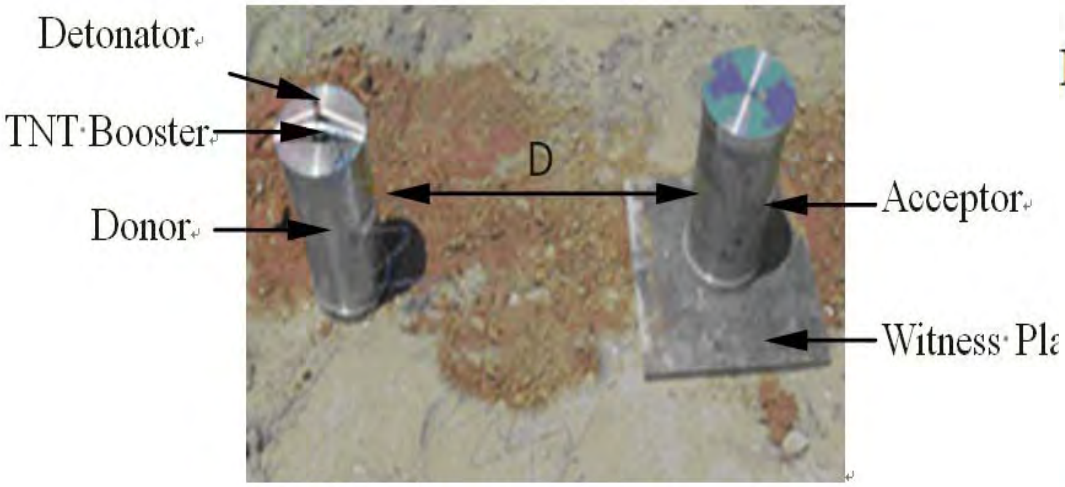
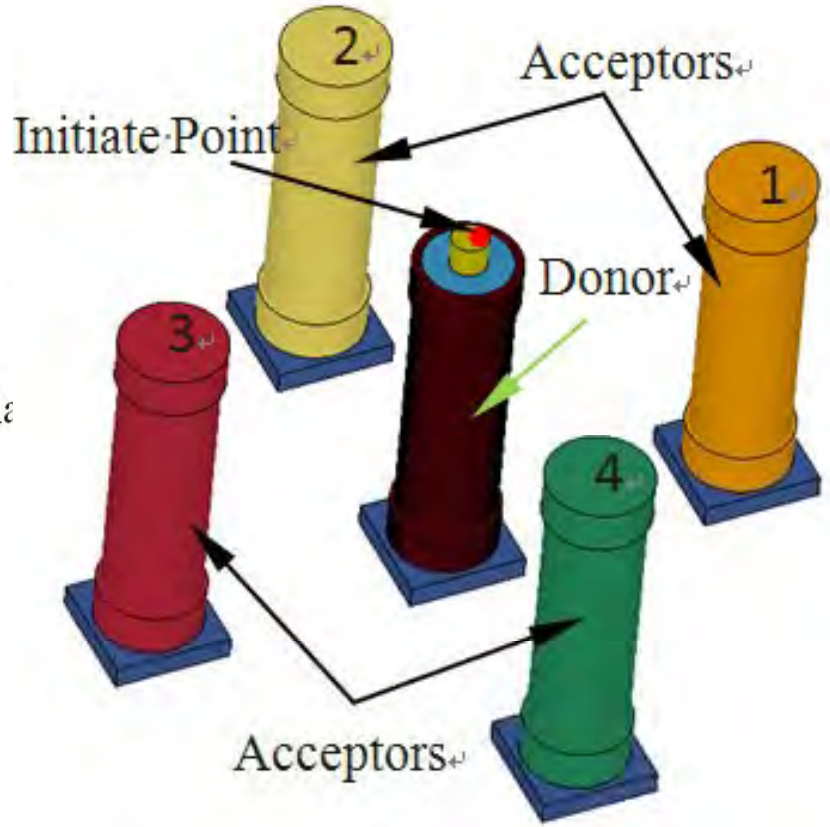


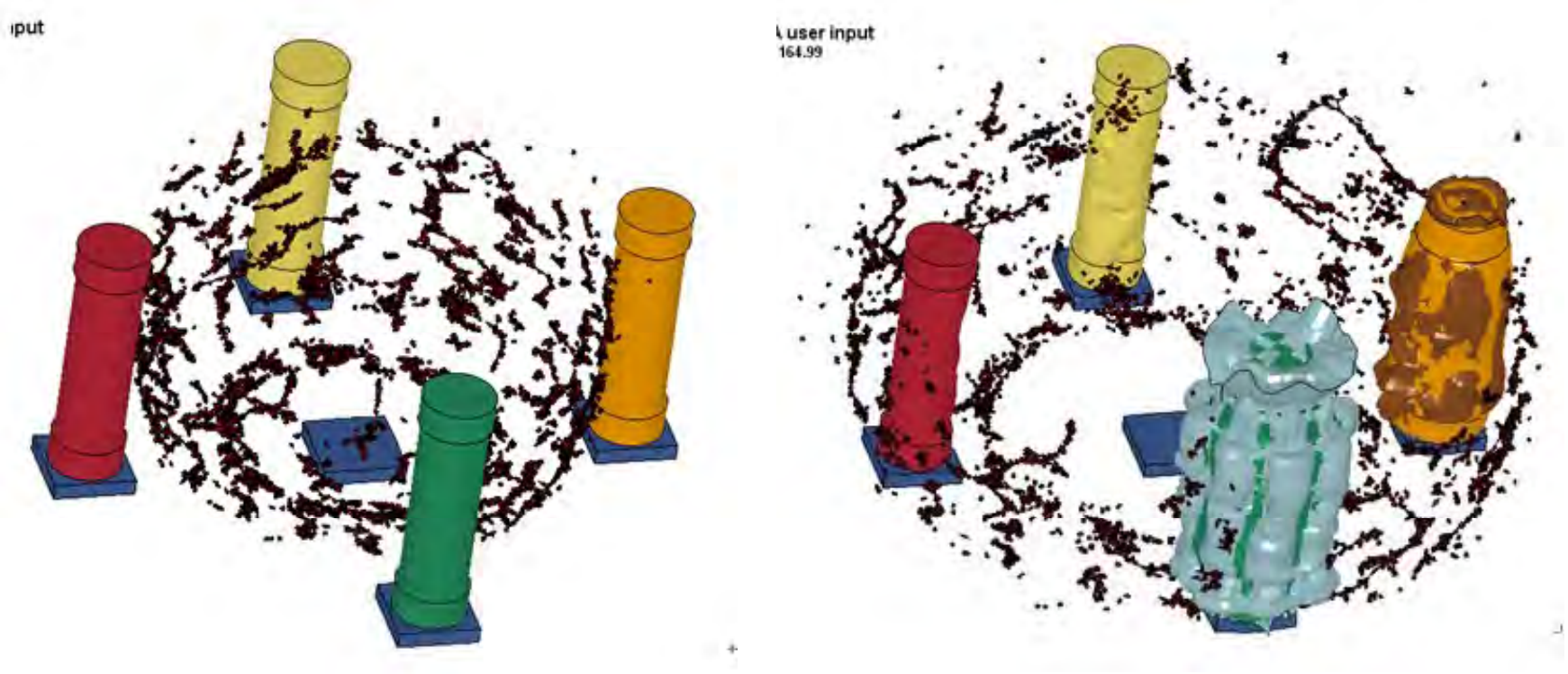
Photo of sympathetic detonation test



Model of sympathetic detonation test

Calculation results of sympathetic detonation

Because the different fragments of donor had been produced randomly, the acceptors at the same distance also detonated randomly.



(a) 135μs (b) 165μs

Calculated deformation at different time

Conclusion

- **For the explosive safety test numerical simulation , the key point are how to set up the reaction model.**
- **For some safety tests, such as cook-off , SDT, DDT and Sympathetic detonation, the calculation models had been done.**
- **But for another tests, such as low velocity impact, drop and XDT, it is still the difficult to set up the correct model. We are working to do them.**

Thanks !