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EXPERIMENTAL STUDY ON THE REACTION EVOLUTION OF PRESSED EXPLOSIVES IN LONG THICK WALL CYLINDER CONFINEMENT

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Abstract: The non-shock initiation reaction behavior of pressed HMX-based PBXs inside long thick wall steel tube is studied with detailed diagnostics of tube movement on different sampling sites along the tube and its two ends. The multi-stage reaction processes are revealed with transportation of reaction products, e.g. the convective flow of high temperature gaseous products driven by high pressure along the seam between the HE pellets and the inner wall of the confinement tube, the early stage burning of HE pellets on their surface with an induction time delay and uneven pressure growth alone the tube, the late stage violent reaction with rapid expansion and rupture of the tube wall. These processes last nearly 10ms which is much longer than the corresponding detonation duration. The pressure measured by tube wall velocities is much less or about 1GPa for two tested HMX-based PBXs correspondently while the tube wall is accelerated to almost 200m/s during the last 200μs -300μs before the confinement rupture. The observed reaction evolution could not be explained by classic DDT mechanism without consideration of convective flow of reaction products along the seam between tube wall and HE pellets when there is no reaction activated in HE bulk by the ramp wave caused by upper stream non shock initiation reaction.

Introduction

The possibility of deflagration to detonation transition in dense PBXs or solid propellants is under question for long time [1, 2] though there were many reports of experimental observation of DDT behavior in recent years [3, 4]. In the classic 1-dimensional DDT concept of Macek [5], the mass transportation of reaction products from the initial end is not considered (typical 2-D phenomenon), consequently the convective mechanism of combustion front propagation through structure seam or HE cracks might be thoroughly ignored. The high pressure gaseous products convection might be the dominant factor in the reaction propagation and reaction violence evolution beside the stress wave mechanism for reaction initiation of HE in long tubular confinement, and also in any explosive charges under various confinement. In this study, a group of experiments were conducted with heavy steel DDT tube confinement in comparing with the experiments of the same HMX-based PBX in thin wall light confinements [6].

Experimental setup

The experimental setup is shown in figure 1. The steel tube with 20mm thick wall is filled with 8 pieces Φ20mmx48mm +Φ20mmx60mm and 7 pieces Φ20mmx60mm +Φ20mmx20mm of two type pressed PBX pellets and fixed with two strong end caps. The seam between the HE pellets and inner wall surface of steel tube is about 0.05-0.08mm without seal glue. The artificial non-shock initiation is triggered with an electric igniter with 1.5g black powder from one end surface of explosive charge.

High speed photography, strain gauges, pressure gauges, multichannel PDV probes and air blast over-pressure measurements are engaged to diagnose the reaction evolution and tube wall expansion process. No diagnostic bore is drilled through the tube wall so as to avoid early time failure from these defect points of tube wall under long duration extremely high level pressure that may exceeds GPa.

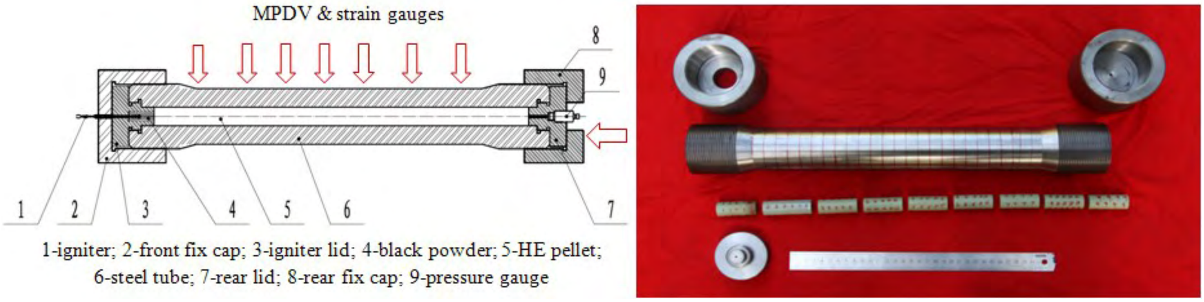

Figure 1. Experimental setup and diagnostic design

Experimental results

A detonation experiment was conducted specially as a metric for reaction violence calibration of non shock initiation reaction process. The high speed frame photography of tube expansion process shows emerge of fracture during early stage tube wall expansion. The velocity profile on 8 selected sites along the tube recorded a maximum radical velocity peak ~400m/s along tube wall as result of the stationary propagation of detonation front with limited acceleration under detonation products push. The detonation propagation process lasted about 50μs. High strain rate shear fracture section on inner side of fracture surface can be seen clearly on the slender recovery fragments.

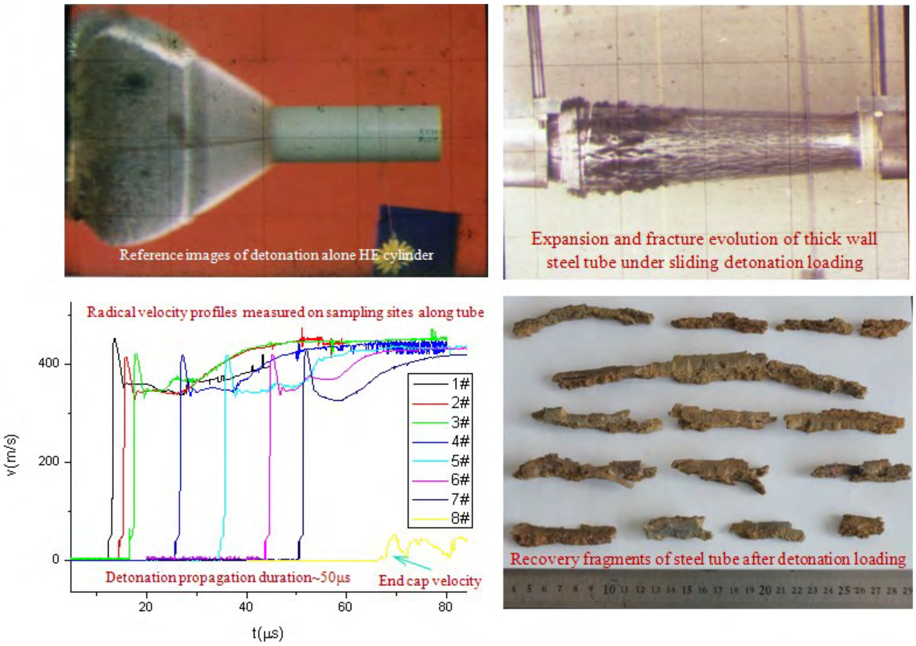

Figure 2. The detonation calibration experiment results and process parameters

In non-shock initiation experiments, the tube expansion process were observed to begin with a time delay of 6ms-8ms after initiation while the trigger time of electric igniter and black powder system is evaluated about 3ms. So the reaction propagation and violence evolution process before the reaction pressure to reach the yield strength of tube takes another 3ms-5ms.

The violent reaction after the reaction pressure exceeded the yield stress of tube lasted only 200μs - 300μs before the tube rupture. The accelerations of tube wall in both experiments are nearly constant < 1m/μs on all section along the tube and the pressure jumps measured on diagnostic sites 1-7 showed random time sequence. So did the flame leakages from the multipoint rupture along the tube. It might be caused by uneven laminar combustion on HE pellet radical and end surfaces in the long duration low pressure reaction process, and maybe the chocking effect of gaseous products in the seam raised the local reaction pressure. The late stage reaction pressures can be evaluated by the tube wall velocity as ~600MPa and ~1GPa along the whole tube in the two experiments correspondently. There is no upstream and downstream relationship for reaction front propagation and reaction intensity growth.

The HE mass consumed evaluated by air blast overpressure in these experiments is about ten time more than that in experiment with light confinement[6], and the fragments velocity has reached half of the detonation driven velocity after a long duration relative stable acceleration process before rupture. On some fracture surface of the tube wall the un-reacted explosive smear could be found.

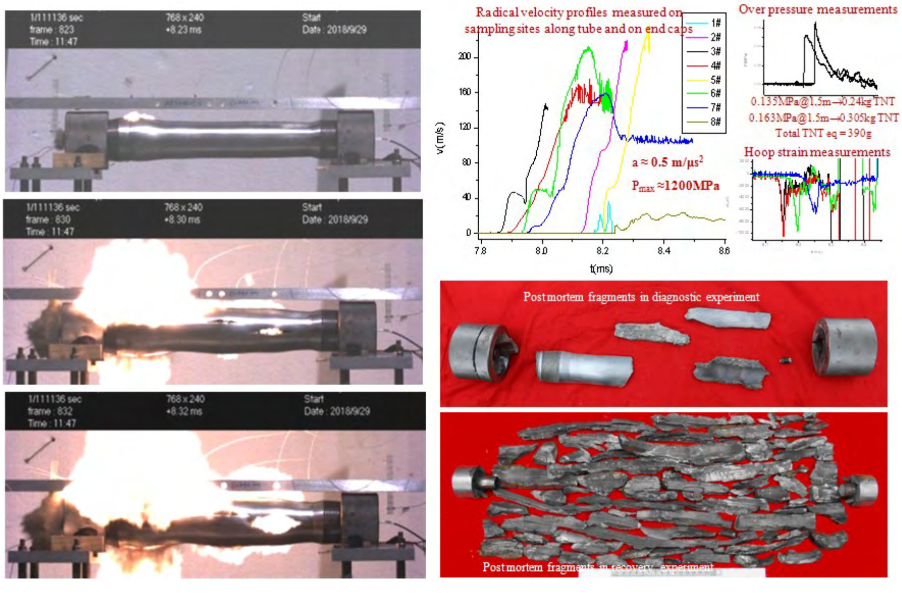

Figure 3. The reaction evolution of non-shock initiation behavior and recovery fragments for PBX1

Discussion

The stress wave caused by early stage reaction on initiation end, especially with the ramp front and limited amplitude could not transform into a shock wave with adequate strength to initiate detonation in HE bulk, while the 100MPa level high pressure reaction products include the gaseous products of igniter system in initiation section at early stage do penetrate into the seam between tube wall and HE pellets transporting downstream alone the tube. In early experiments, the shorting or eliminating signals in time range of several hundreds μs were recorded with help of ionized gauge and optical fiber probe mounted through tube wall. The action of these gauges might be caused by convective flow of upper stream high temperature gaseous products with limited amplitude of several MPa on front and gradually growing up to tens of MPa before the surface of HE downstream along the seam is ignited by the hot convective gaseous products[7]. These kinds of processes do happen and dominant the reaction evolution in the so called DDT tube experiment for dense PBXs. In numerical simulations, the convection phenomena and laminar deflagration on explosive pellets or crack surface should be properly taken into account instead of any type of stress induced bulk reaction model.

The non-shock initiation reaction propagation via convection of early stage reaction products is strongly dependent on the details of explosive pellets packing state inside confinement. But the reaction violence is more likely dependent on the properties of explosive, e.g. the reaction propagation rate under high pressure and the brittleness of explosive and the confinement strength. In such case, the real concern should not be the DDT tendency for pressed PBX, but a HEVR with serious lethality.

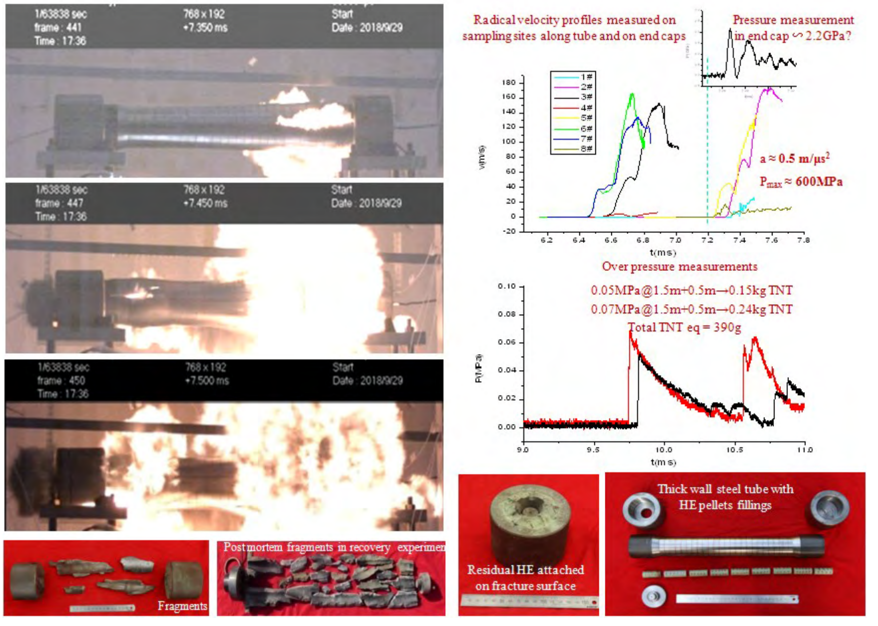

Figure 4. The reaction evolution of non-shock initiation behavior and recovery fragments for PBX2

Acknowledgments

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