Propagation of Reactive Cracks in Pressed HMX-Based Pbx and Reaction Violence of Explosive System in Thick Wall Confinement

Hu Haibo[1], Li Tao[1], Guo Yingwen[1], Fu Hua[1], Wen Shanggang[2], Qiu Tian[2]
1 Laboratory for Shock Wave and Detonation Physics Research, Institute of Fluid Physics, CAEP
2 Institute of Chemical Materials, CAEP

Mianyang, Sichuan, China

1 Introduction

The dynamic reaction behavior of explosive system with heavy confinement caused by non-shock initiation reaction might be quite different when reaction front penetrates into cracks in explosive bulk [1, 2]. Because of the chocking of reaction products inside explosive cracks, pressurization would become the dominating factor of reaction violence growth while more reaction surface is being created by uneven high reaction pressure inside the cracks of brittle explosive bulk. In comparison the classic 1-D DDT tube, a spherical explosive system with central ignition is specially designed to explore the evolution of non shock initiation reaction in cracks inside explosive [3].

2 Experimental Setup

The basic experimental setup is shown in Fig.1. A Φ110mm pressed PBX sphere with a lead to electric igniter and 1g black powder package is mounted inside 20mm heavy confinement of steel with PMMA window. The second experimental setup is designed for stronger confinement without window for optical observation as shown in Fig.2. Multi PDV, pressure gauges, air blast overpressure gauges and high speed camera are used to diagnose the deformation of confinement structure, the pressure inside confinement and air blast overpressure and the explosive crack system evolution process.

Correspondence to: huhaibo@caep.cn

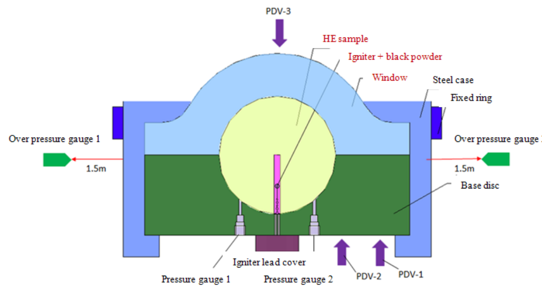

Figure 1. Confinement with optical window and diagnostic arrangement

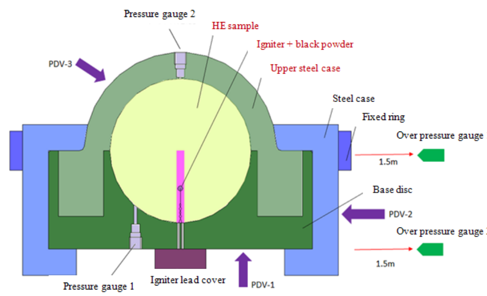

Figure 2. Full steel confinement without optical window and diagnostic arrangement

3 Experimental Results

The full evolution process of reactive crack system after central point ignition was recorded in experiment with PMMA window as shown in Fig.3.

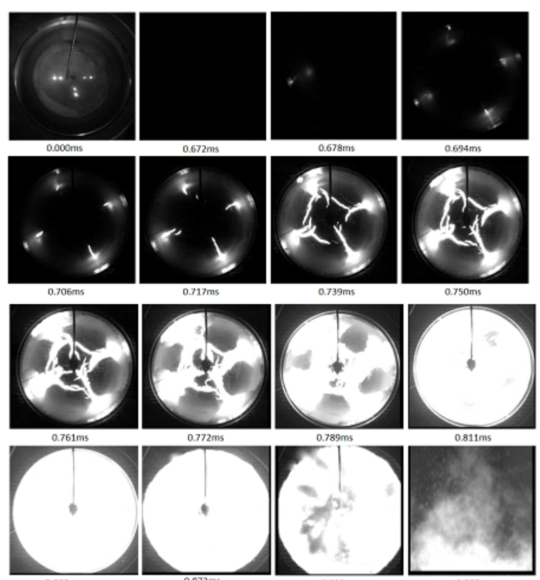

Figure 3. The full evolution process of reactive crack system in experiment with PMMA window

The time sequence of the high speed camera images was defined as the time after the igniter action (~600μs after electric pulse), e.g. the beginning moment of black powder ignition.

There are several evolution stages that can be defined from these images. Stage I -the early stage evolution of crack inside explosive bulk before the cracks are visible on surface. Stage II -the crack system evolution after the crack breaking through to surface with 4 fold symmetric crack pattern. Stage III -the mild violence evolution after the flame covered the surface with a sustaining low growing rate~ 100μs under the yield strength of confinement, in this case the yield strength of PMMA window before the confinement movement stage and a rapid burst during the confinement wall movement stage in about 10μs up to over GPa. Stage IV-the deformation and rupture of confinement after the equivalent reaction pressure is high enough to drive the case to move to the final rupture of confinement.

The detailed evolution of 4 fold symmetric crack pattern is shown in Fig.4. The formation and evolution of such a crack mode is deduced to be related with outer layer confinement configuration.

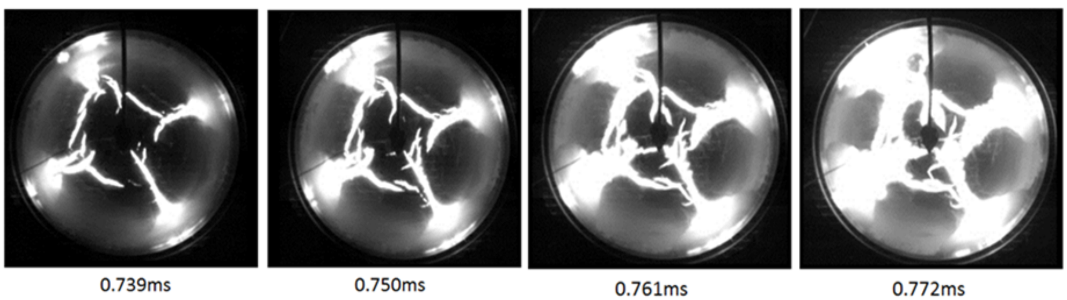

Figure 4. The crack propagation at the early half of Stage II (20mm steel wall with PMMA window)

The deformation velocity of confinement structure and the pressure measured inside confinement case is presented in Fig.5 with the corresponding label in comparison with visual images. The PMMA window (PDV3) was pushed to move around 0.7μs early than the steel structure (PDV1&PDV2) because of the lower strength of the PMMA window. The emergence of cracks on explosive surface is almost in the same time. This indicates the stress level caused by the reaction inside explosive cracks and has been balanced with confinement structure. The pressure gauge mounted on basic disc recorded the rapid growth of gaseous pressure up to GPa level in a short duration of 10μs which corresponds the pressure burst moment before 0.85μs (Stage III).

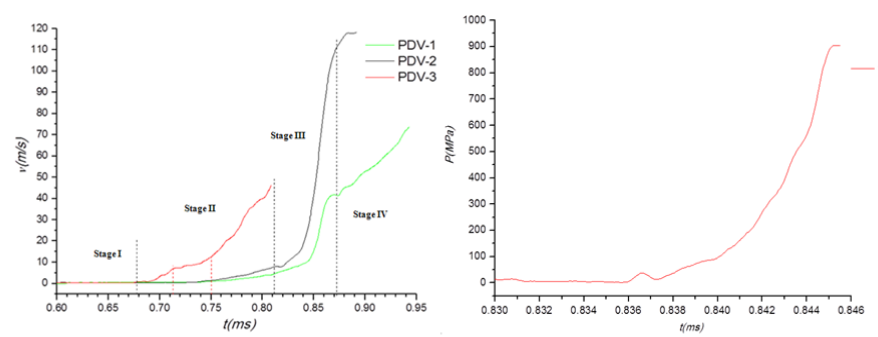

Figure 5. The pressure inside confinement and velocity profiles in experiment without window

In the second experiment without window, the pressure gauges recorded more details of early stage reaction evolution. The pressure and velocity histories showed a sustaining low pressure <200MPa with growing period about 100µs and a rapid reaction burst event inside confinement. In the end of Stage IV pressure has grown over GPa and the velocity of thick steel wall has been accelerated to 500m/s rapidly during 20µs -40µs. The velocity profile recorded by probe PDV3 reflected the equivalent pressure inside confinement more directly than the signals from gaseous pressure gauges.

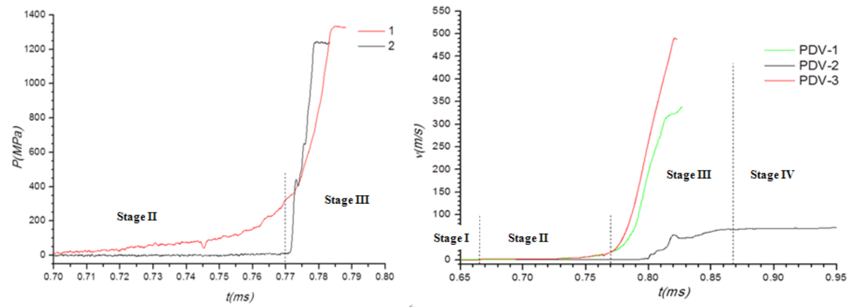

Figure 6. The pressure inside confinement and velocity profiles in experiment without window

The recovery fragments of the full steel confinement parts are presented in Fig.7.

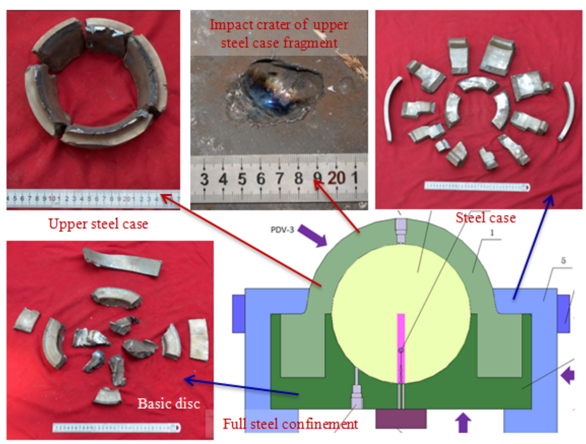

Figure 7. The recovery fragments of the full steel confinement in second experiment

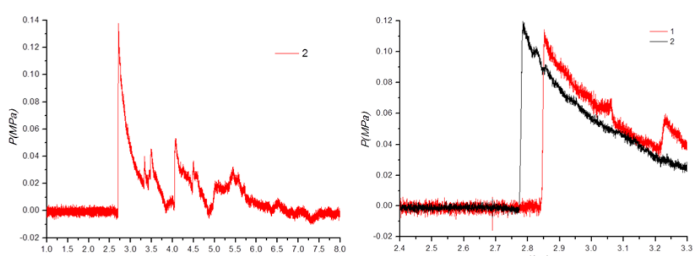

Figure 8. The air blast overpressure measure in the experiment with and without window

4 Discussion

The focus of these experiments is the evolution of cracks driven by the reaction products pressure inside explosive bulk. The first trigger is given by the artificial non-shock initiation with the help of electric igniter and 1g black powder which is going to produce ~100MPa in the center after ignition [4].

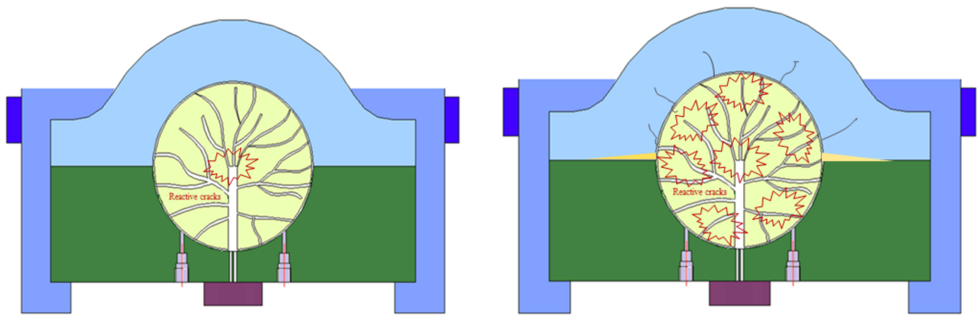

Figure 9. The early and late stage evolution of reactive cracks inside explosive bulk under confinement

The combustion of 1g black powder in the given confinement condition is evaluated as 600μs during which the cracks might be initiated around the end of ignition lead channel. The influence of confinement on initial crack formation is needed to be evaluated because the stress field in the central part could be balanced if the crack were not formed promptly and the damage and fracture behavior of explosive might be influenced strongly by confinement hoop stress.

The cracks emerged on surface after the combustion of black powder had finished. The gaseous products of the ignition system might play the dominating role in the early stage crack formation and propagation because that the burning of crack surfaces has a induction time for heating up by the temperature of reaction products of ignition system and reacted explosive. The crack propagation is not necessary driven by the gaseous products of explosive and the newly formed crack surfaces are still to be ignited. For the new formed crack surface, the ignition delay after connective mass has reached might be tens of μs or even more than hundreds of μs [2, 5]. What we see on the high speed camera images as the spreading of flame does not mean ignition of the crack surface, it might the only the hot gaseous products that penetrated into the crack [5]. The final rapid burst of reaction violence comes somehow later after the flame had covered the outside surface for some time.

In the central ignition reaction evolution process, the most sensitive factor in violence growth is the speed of reaction surface increase [6, 7]. The final burst of reaction violence in tens of μs in these central ignition experiments indicates the difference of violence growing mode in comparison with the classic DDT tube with the same PBX. There might be a catastrophic fragmentation process happened inside the bulk some time before the final burst so as to attract enough crack surface into the final moment reaction. When the crack or fragmentation process is absent, as in the classic thick wall DDT tube experiment, the final stage reaction shows a more stable pressure (~GPa level) long duration (~200μs) reaction character before the tube rupture [8].

The heavy confinement created the condition for the growth of reaction violence into a HEVR reaction, especially because of the fragmentation of explosive bulk driven by the reactive cracks, but the rapid failure of the confinement under GPa level inner pressure limited the growth of final stage violent reaction and the total mass consumed in such reaction is only ~20% TNT equivalent in comparison with detonation event in both experiments [3, 4]. The classic DDT concept [9] is not necessary to be considered as dominating mechanism for non-shock initiation reaction of pressed PBX in heavy confinement even in the late stage violent reaction evolution before confinement rupture.

Acknowledgments

This work is supported by the Science & Technology Foundation of CAEP under Grant No.2014A0201008.

References

[1] Jackson, S. I., “Deflagration Phenomena in Energetic Materials: An Overview ” in Non-Shock Initiation of Explosives, Shock Wave Science and Technology Reference Library, edited by B. W. Asay, pp. 245-292, Vol. 5, Springer-Verlag, 2010.

[2]Jackson, S. I., Hill, L. G., Berghout, H. L., Son, S. F. and Asay, B. W., "Runaway Reaction in a Solid Explosive Containing a Single Crack" Proceedings of the International Detonation Symposium, pp. 646-655, 2006.

[3] Guo Yingwen, Experimental Study on Mechanism Dominating the Reaction Violence Evolution for Pressed PBX, Thesis of Master Degree, China Academy of Engineering Physics, 2017.

[4] Haibo HU, Yingwen GUO, Tao LI, Reactive Behavior of Explosive Billets in Deflagration Tube of Varied Confinements, AIP Conference Proceedings, SCCM2017, 2017

[5]Hailin Shang, Jie Yang, Tao Li, Hua Fu, Haibo Hu, Convective Burning in Confined Explosive Cracks of HMX-Based PBX under Non-Shock Initiation, 16th International Detonation Symposium, 2018

[6] Holmes, Matthew David, Parker, Gary Robert Jr. , Heatwole, Eric Mann etc., Center-Ignited Spherical-Mass Explosion (CISME); FY 2018 Report, LA-UR-18-29651

[7] Holmes, Matthew David, Parker, Gary Robert Jr., Broilo, Robert M., Heatwole, Eric Mann, Fracture Effects on Explosive Response (FEER); FY2018 Report, LA-UR-18-29694

[8] Hu Haibo, Li Tao, Wen Shanggang, Qiu Tian, Fu Hua, Shang Hailin, Experimental Study on the Reaction Evolution of Pressed Explosives in Long Thick Wall Cylinder Confinement, International conference XXI Khariton’s topical scientific readings, Russia, 2019

[9] Macek, A.: Transition from deflagration to detonation in cast explosives. J. Chem. Phys. 31(1), 162–167 (1959)