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APPLICATION OF OVERDRIVEN DETONATION IN HIGH DENSITY EXPLOSIVE TO SHAPED CHARGE

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To increase largely the performance of shaped charge, it is required to generate detonation velocity much higher than CJ velocity or detonation pressure much higher than CJ pressure of existing high explosives. One solution is the application of overdriven detonation phenomena. In this study, the effects of overdriven detonation in tungsten loaded high density explosive on the performance of shaped charge were demonstrated by experiments and numerical simulation. Sample shaped charge was composed of the inner layer tungsten loaded high density PBX and outer layer high velocity PBX. Concentration of tungsten powder in high density PBX was varied from 20 to 60% in mass. The pressure of overdriven detonation in inner layer PBX was measured by PMMA gauge, and was shown to be higher than 50GPa. The experimental results showed that the initial jet velocity and jet penetration velocity in target plates were largely increased by the effects of the overdriven detonation in tungsten loaded high density PBX.

1. INTRODUCTION

In the application of explosives such as material processing, explosion synthesis of new material and generation of high velocity projectile etc., it is requested to generate pressure much higher than CJ pressure of existing high explosives. One solution is the application of the overdriven detonation phenomena.

The overdriven detonation (ODD) was generated by Mach reflection of divergent or plane detonation waves. In this case, propagation of the overdriven detonation was not stationary, and relatively important charge size was necessary. Some experimental results[1] showed that the overdriven detonation was generated by Mach reflection of conical detonation wave and propagated quasi-steadily in co-axial double layer cylindrical charge composed of outer high velocity explosive (HVE) and inner low velocity explosive. In this configuration, steady overdriven detonation was generated using relatively small charge size. The use of high density explosive (HDE) containing tungsten powder as inner low velocity explosive is expected to generate the overdriven detonation with extremely high detonation pressure.

In this study, the effects of the overdriven detonation in tungsten loaded high density explosive on the performance of shaped charge were studied by experiments and numerical simulation.

2. DETONATION CHARACTERISTICS OF HIGH DENSITY EXPLOSIVE

Properties of sample explosives are shown in Table 1.[2] Tungsten powder of mean diameter 1micrometer was added to RDX based PBX (PBX NS-211). Content of tungsten powder in high density explosives (RHW2, RHW4 and RHW6) was 20, 40 and 60% in mass respectively. HMX based PBX (PBX NS-201) was used as high velocity explosive in outer layer of co-axial cylindrical charge. Detonation velocity was measured by optical fiber and ionization probe. Measured detonation velocity is compared with detonation velocity calculated with KHT e.o.s. [3] in Figure 1.

Table 1. Detonation properties of sample explosives

Explosive		PBXNS-201	PBXNS-211	RHW2	RHW4	RHW6
Component [wt.%]	RDX	0	91	72	53	34
	HMX	90	0	0	0	0
	HTPB	10	9	8	7	6
	Tungsten	0	0	20	40	60
Density [kgm^{-3}]		1700	1650	2018	2452	3184
Detonation Velocity [ms^{-1}](1)		8200	8060	7200	6150	4830
Detonation Velocity [ms^{-1}](2)		8112	7999	7252	6135	4834
Detonation Pressure [GPa](2)		28.3	26.4	25.9	22.4	17.1
Detonation Pressure [GPa](3)		28.7	27.5	25.6	24.1	19.5

(1) Measured (Ionization Probe)
(2) Calculated (KHT)
(3) Measured (PMMA Gauge)

It was confirmed that measured and calculated detonation velocity agree very well, and they decrease with the increase of tungsten powder content. To measure detonation pressure, tungsten loaded PBX was confined in PVC tube of 32mm in inner diameter, 38mm in outer diameter and 100mm in length. Detonation pressure of tungsten loaded PBX was obtained using shock velocity in PMMA plate of various thickness attached to butt end of sample charge.

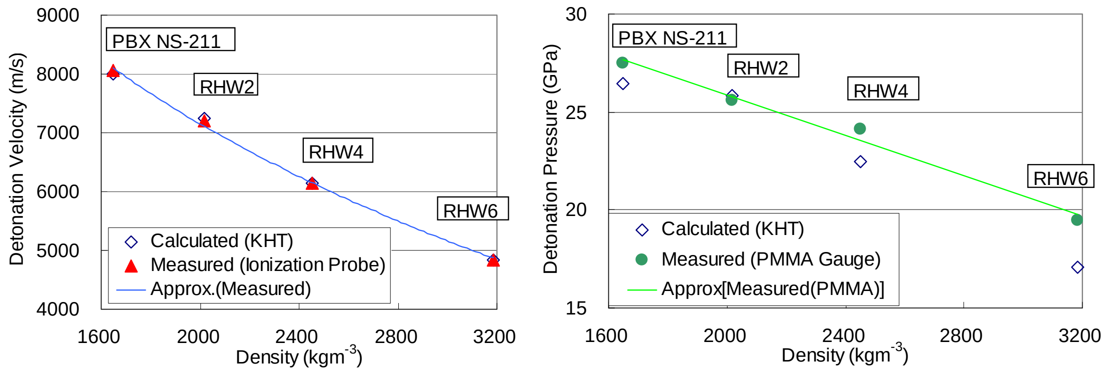

Figure 1. Detonation properties of sample explosives

In the case of tungsten content 20 wt.%, good agreement was obtained between measured and calculated detonation pressure. Measured detonation pressure was about 3GPa higher than calculated detonation pressure in the case of tungsten content 40 and 60 wt.%.

3. OVERDRIVEN DETONATION IN HIGH DENSITY EXPLOSIVES

Experimental devices to measure detonation velocity and pressure of the overdriven detonation in co-axial double layer cylindrical charge were presented in Figure 2.

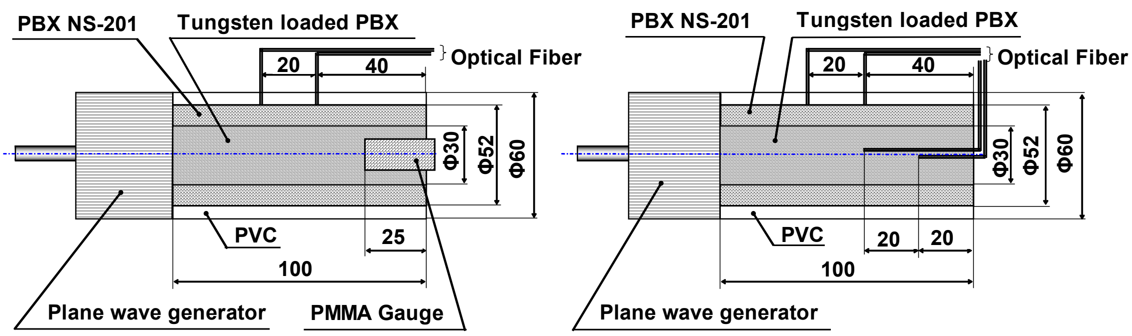

Figure 2. Experimental devices to measure detonation velocity (right) and detonation pressure (left)

Diameter of inner charge was 30mm and diameter of outer charge was 52mm. Length of sample charge was 100mm. Detonation velocity of the overdriven detonation was measured using optical fibers which were inserted parallel with charge axis to avoid the influence of detonation wave of outer layer and conical incident detonation wave. PMMA pressure gauge was set 25mm inside from the end of sample charge to avoid the influence of detonation wave of outer layer and conical incident detonation wave.

Measured detonation velocities of both outer high velocity PBX and inner tungsten loaded PBX were about 8200m/s. Detonation velocity of inner tungsten loaded PBX was increased to the same velocity of outer high velocity PBX which indicated the formation of the overdriven detonation in inner tungsten loaded PBX. Measured pressure of the overdriven detonation in tungsten loaded PBX was more than two times higher than its CJ pressure. Measured velocity and pressure of the overdriven detonation in tungsten loaded PBX are summarized in Table 2.

Table 2. Properties of Sample Explosives

	PBXNS-201	RHW2	RHW4	RHW6
Detonation Velocity [ms^{-1}](1)	8206	8197	8163	8163
Detonation Pressure [GPa](2)	——	59.7	66.9	66.9
Detonation Pressure [GPa](3)	——	58.3	73.5	105.6

(1) Measured (Optical Fiber)
(2) Measured (PMMA Gauge)
(3) Calculated (KHT)

Numerical simulation using two-dimensional hydrodynamic code [4] was performed to study the formation of the overdriven detonation by Mach reflection of conical incident detonation wave in co-axial double layer cylindrical charge. Figure 3 shows numerical simulation model for co-axial double layer cylindrical charge.

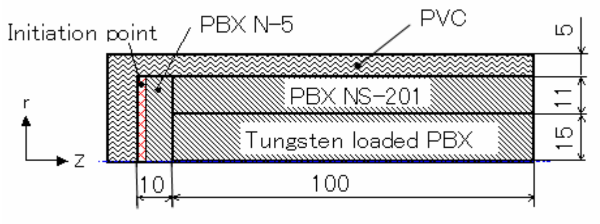

Figure 3. Numerical simulation model

Variation of velocity of the overdriven detonation in tungsten loaded PBX with run distance is presented in figure 4. Velocity of the overdriven detonation in tungsten loaded PBX attains velocity of outer high velocity PBX within run distance of 50mm. Pressure of the overdriven detonation increases very rapidly with run distance and attains its stationary value about run distance of 50mm.

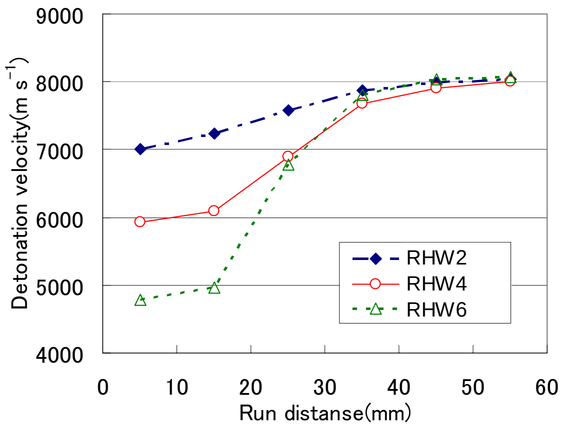

Figure 4. Variation of the overdriven detonation velocity with run distance

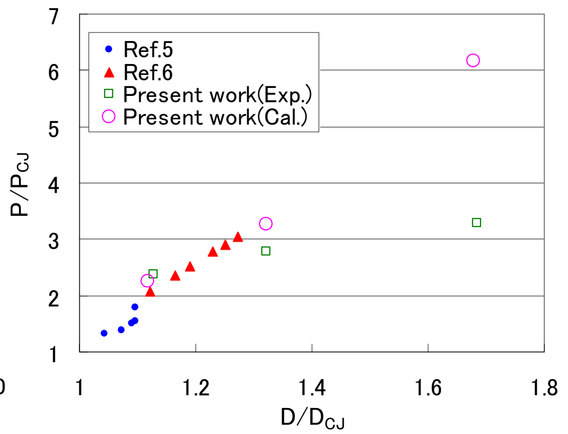

Figure 5. Relation between pressure and velocity of the overdriven detonation for various explosives

In the case of tungsten content 20wt.%, measured pressure of the overdriven detonation agrees well with calculated pressure. Measured pressure of the overdriven detonation is about 7 and 41GPa lower than calculated pressure respectively in the case of tungsten content 40 and 60wt.%. Mach reflection of incident detonation wave is produced around charge axis.

Discrepancy between the measured and calculated overdriven detonation pressure is due to the decrease of Mach disc size with the increase of the ration of the overdriven detonation velocity to CJ velocity. In Figure 5, the variation of the ratio of the overdriven detonation pressure to CJ pressure with the ration of the overdriven detonation velocity to CJ velocity for tungsten loaded PBX are compared with the results of previous works.[5], [6] It is suggested that the use of high density explosives has great advantage to generate higher pressure when CJ pressure is the same level.

4. APPLICATION OF OVERDRIVEN DETONATION TO SHAPED CHARGE

Two types of shaped charges were used in the experiments. One type was conventional shaped charge (Normal type) and the other was composed of the inner layer tungsten loaded high density PBX and outer layer high velocity PBX (Co-axial double layer cylindrical charge type) (Figure 6). Initial jet velocity and jet penetration velocity in target plates were measured. The results of measurements of initial jet velocity show that jet velocity is largely increased by the effects of the overdriven detonation in tungsten loaded high density PBX (Figure 7). Numerical simulation using two-dimensional hydrodynamic code was performed to study the formation of the overdriven detonation by Mach reflection of conical incident detonation wave in co-axial double layer cylindrical charge and collapsed a liner to form a jet. Figure 8 shows numerical simulation model for the sample shaped charge with co-axial double layer cylindrical charge.

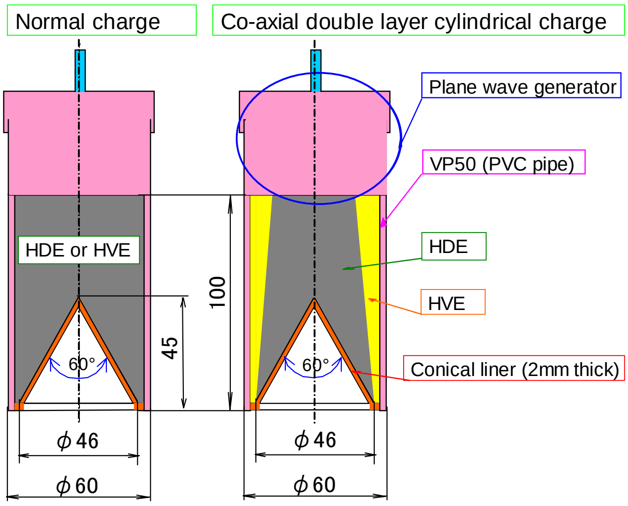

Figure 6. Sample shaped charges

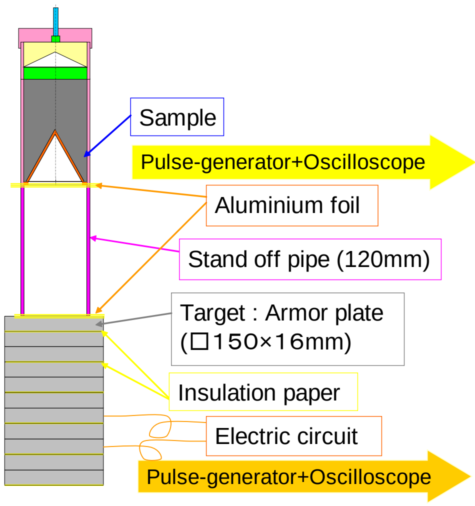

Figure 7. Experimental setup for the jet velocity measurement

The numerical simulation used eulerian processor (upper side) and material models same as experiment (lower side). The results of measurements and numerical simulation show that jet velocity of co-axial double layer type charge is much higher than that of normal type charges in Figure 9.

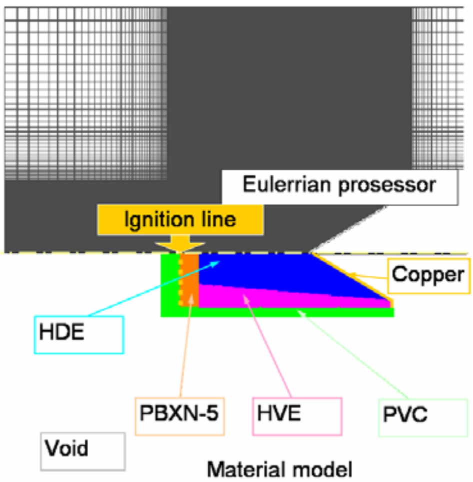

Figure 8. Numerical simulation model

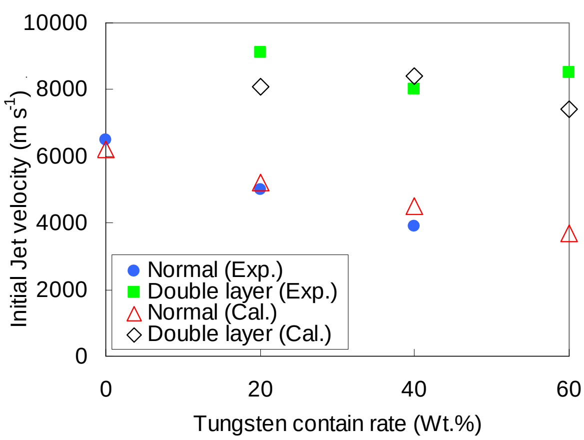

Figure 9. Initial jet velocity vs. Tungsten concentration

The results of measurements show that jet penetration velocity in target plates is largely increased by the effects of the overdriven detonation in tungsten loaded high density PBX (Figure 10).

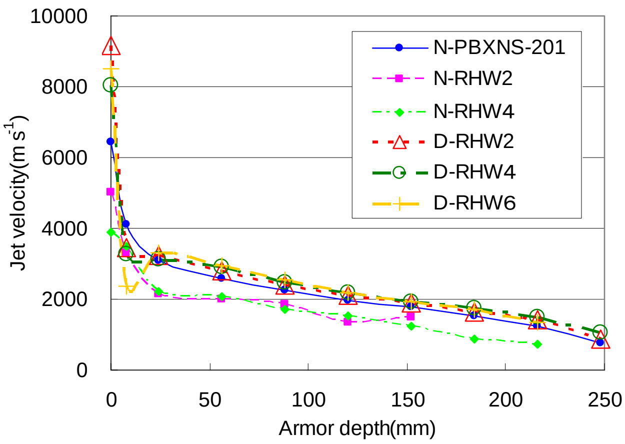

Figure10. Jet penetration velocity in target plates

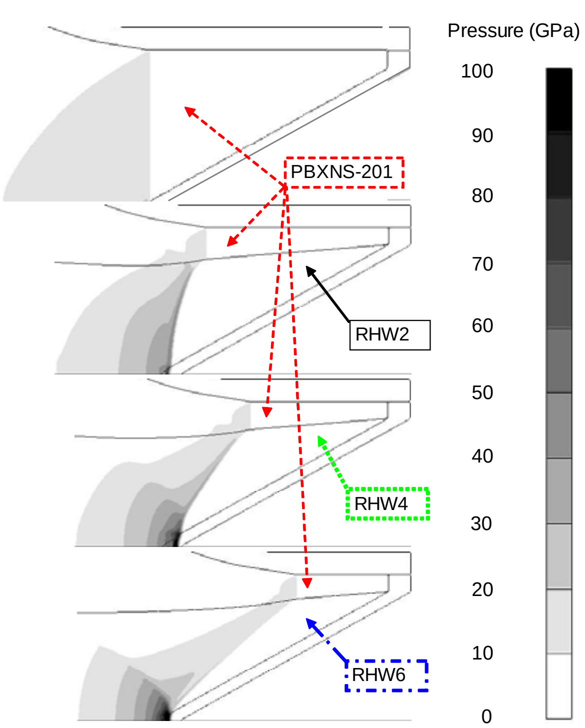

Figure 11. Calculated pressure contours when detonation front reached the top of liner

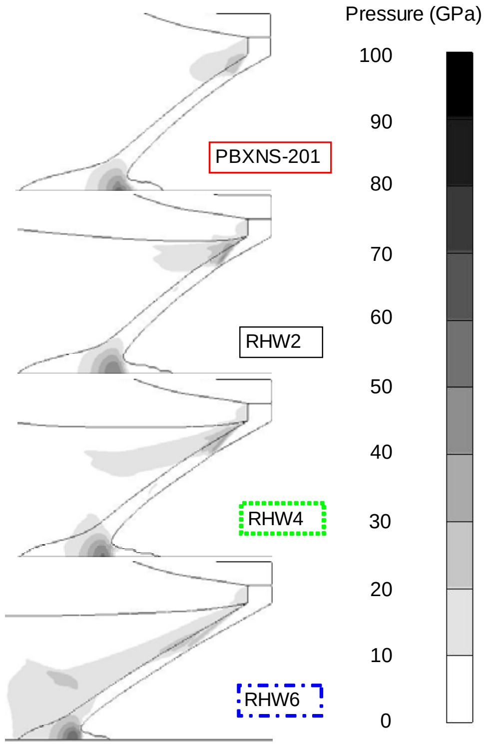

Figure 12. Calculated pressure contours when detonation front reached the end of explosive

Figure 11 shows the calculated pressure contours of samples when detonation front reached the top of liner, and Figure 12 shows those when detonation front reached the end of charge.

CONCLUSIONS

Detonation velocity and pressure of high density explosives containing tungsten powder were measured and compared with calculated values, and those had good agreement. The overdriven detonation pressure of tungsten loaded explosives was more than two times higher than CJ pressure. Velocity and pressure of the overdriven detonation in tungsten loaded PBX attain velocity of outer high velocity PBX within run distance of 50mm. In the case of shaped charge, before the detonation front reach the top of liner, the overdriven detonation had attained steady state. The results of measurements and numerical simulation show that jet velocity of co-axial double layer type charge is much higher than that of normal type charges. However, measured and calculated jet velocity showed that the result of tungsten content 20wt.% is higher than 60wt.%. And the results of measurements show that jet penetration velocity in target plates is also similar result.

REFERENCES

[1] K. Tanaka, S. Fujiwara, M. Sellam, H. N.Presles, C. Brochet, and R. Cheret, Calculation of Overdriven Detonation In Nitromethane, Proceedings of the 4th Conference of APS Topical Group on Shock Waves in Condensed Matter, 515-518 (1987)
[2] H. Kato, K. Murata, T. Hamada, S. Itoh and Y. Kato, Overdriven detonation in high density explosives containing tungsten powder, Science and Technology of Energetic Materials, Vol.67, No.5, 153-158, (2006)
[3] K. Tanaka, Detonation Properties of High Explosives Calculated by Revised Kihara-Hikita Equation of State, Proceedings of the 8th Detonation Symposium, 548-557 (1985)
[4] Century Dynamics Inc., AUTODYN (Interactive Non-Linear Dynamic Analysis Software) Explosive Initiation User Manual Revision 4.3 (2003)
[5] M. Sellam, H. N. Presles, C. Brochet, and R. Cheret, Characterization of Strong Detonation Waves in Nitromethane, Proceedings of the 8th Detonation Symposium, 425-430 (1985)
[6] J. Souletis, and J. Groux, Continuous Observation of Mach Bridge and Mach Phenomena, Proceedings of the 8th Detonation Symposium, 431-439 (1985)