Research paper

Overdriven detonation in high density explosives containing tungsten powder

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Abstract

Detonation velocity and pressure of high density explosives containing tungsten powder (tungsten concentration 20, 40 and 60 wt.%) were measured and compared with calculated values obtained by KHT e.o.s. Formation of the overdriven detonation was studied using co-axial double layer cylindrical charge composed of outer high velocity explosive and inner low velocity explosive. High density explosive containing tungsten powder was used as inner low velocity explosive. The results of experiments and numerical simulations showed the formation of quasi-steady overdriven detonation by Mach reflection of conical incident detonation. Measured and calculated pressure of the overdriven detonation was more than two times higher than CJ pressure.

Keywords: Overdriven detonation, High density explosive, Numerical simulation, Double layer cylindrical charge, Tungsten powder

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.

Formation of the overdriven detonation has been examined in various experimental and theoretical studies [1)-7)]. The overdriven detonation was generated by Mach reflection of divergent or plane detonation waves. In both cases, propagation of the overdriven detonation was not stationary, and relatively long charge size was necessary to generate the steady state overdriven detonation. Some experimental results [4)-6)] 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 and inner low velocity explosive. In this configuration, steady overdriven detonation was generated using relatively small charge size.

The use of high density explosive containing tungsten powder as inner low velocity explosive is expected to generate the overdriven detonation with extremely high detonation pressure.

In this study, detonation characteristics of high density explosives containing tungsten powder were measured, and formation of the overdriven detonation in inner charge of co-axial double layer charge was studied.

2. Detonation characteristics of high density explosive

Properties of sample explosives are shown in Table 1.

Tungsten powder of mean diameter 1 micrometer was added to RDX based PBX (PBX NS-211). Content of tungsten powder in high density explosives (PBX-W20,

Table 1 Properties of sample explosives.

Explosive		PBX NS-201	PBX NS-211	PBX-W20	PBX-W40	PBX-W60
Component [wt.%]	RDX	—	91	72	53	34
	HMX	90	—	—	—	—
	HTPB	10	9	8	7	6
	Tungsten	—	0	20	40	60
Density [kg m^{-3}]		1700	1650	2018	2452	3184
Detonation velocity [m s^{-1}](1)		8200	8060	7200	6150	4830
Detonation velocity [m s^{-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)		29.2	27.6	26	25.1	20.2
Detonation pressure [GPa](4)		28.7	27.5	25.6	24.1	19.5
Detonation pressure [GPa](5)		—	—	—	25.1	—

(1) Optical Fiber
(2) KHT
(3) Manganin gauge
(4) Velocity measurement
(5) PVDF gauge

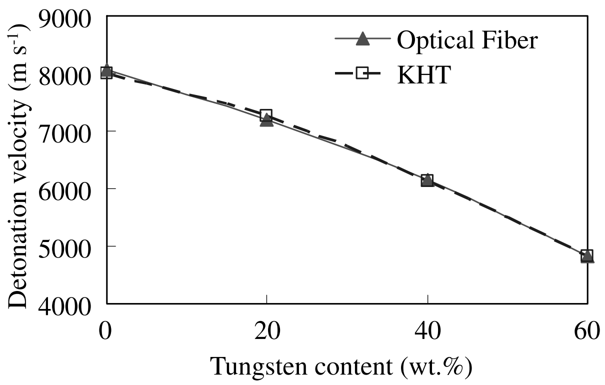

Fig. 1 Detonation velocity vs. tungsten content (wt.%).

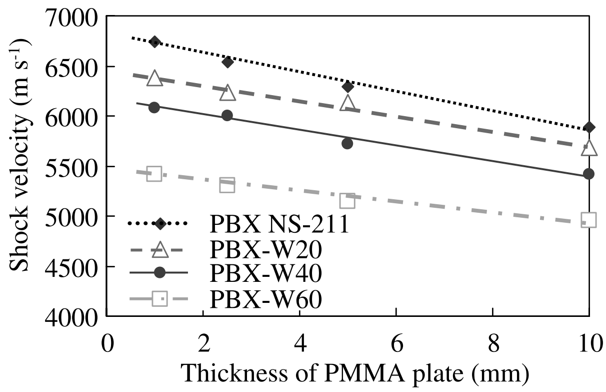

Fig. 2 Shock velocity in PMMA plate.

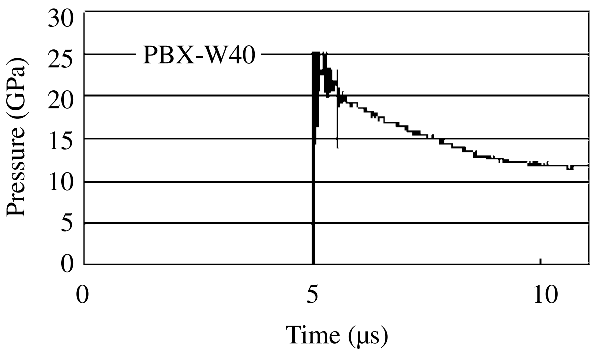

Fig. 3 Pressure profile by PVDF gauge.

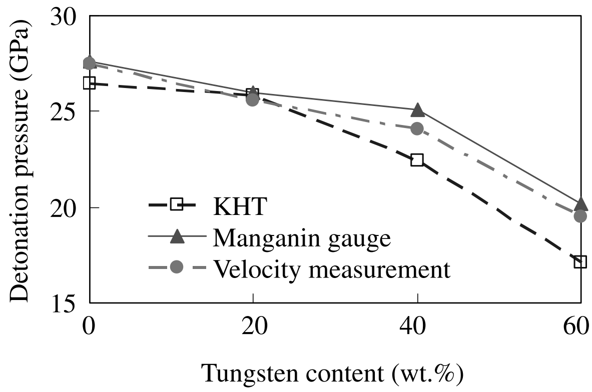

Fig. 4 Detonation pressure vs. tungsten content (wt. %).

W40 and W60) 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. To measure detonation velocity, tungsten loaded PBX was confined in steel tube of 25 mm in inner diameter, 30 mm in outer diameter and 250 mm in length. The sample explosive was initiated by a booster charge composed of Comp. C-4. Detonation velocity was measured by optical fiber and ionization probe. Measured detonation velocity is compared with detonation velocity calculated with KHT e.o.s.[8)] in Fig. 1.

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 32 mm in inner diameter, 38 mm in outer diameter and 100 mm in length. Detonation pressure of tungsten loaded PBX was also obtained using shock velocity in PMMA plates of various thickness attached to butt end

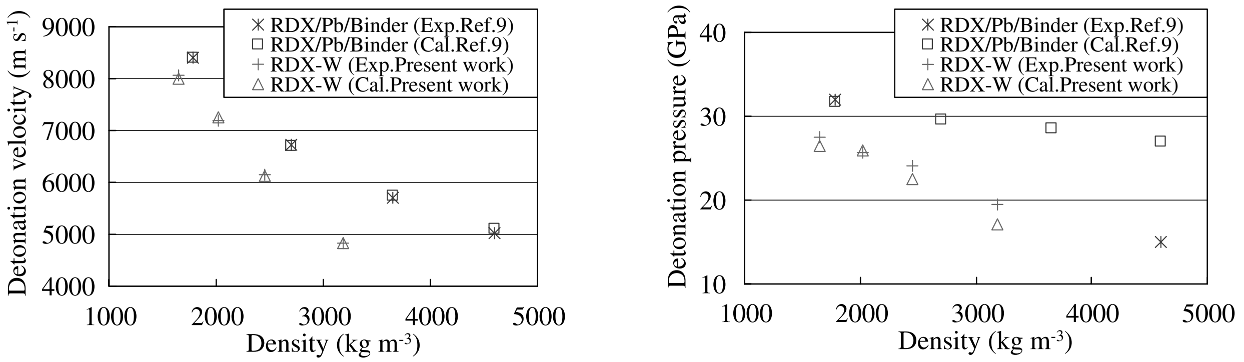

Fig. 5 Detonation properties of metal loaded explosives.

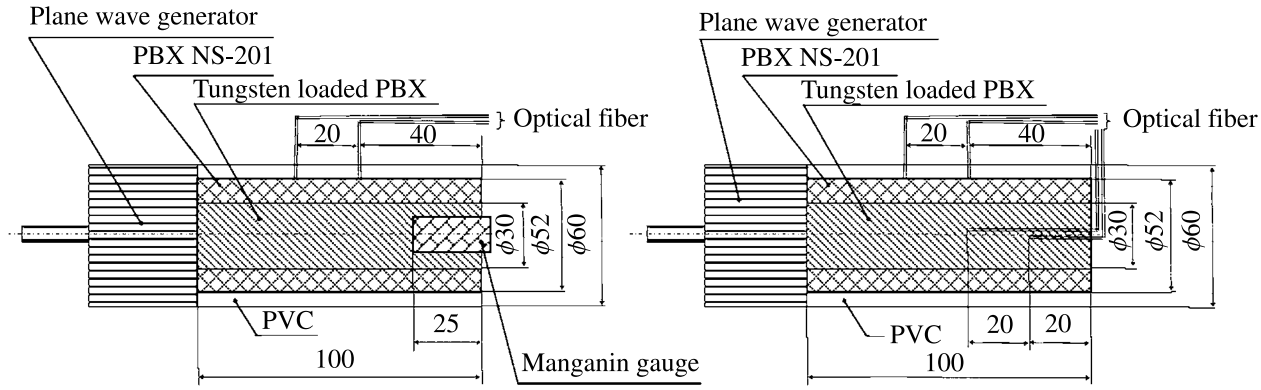

Fig. 6 Experimental devices to measure detonation velocity (right) and detonation pressure (left).

of sample charge. The relation between measured shock velocity in PMMA and thickness of PMMA plate is presented in Fig. 2. The shock velocity in PMMA which has approximately no thickness was extrapolated from Fig. 2. By substituting the velocity into the Hugoniot relation of PMMA, the pressure in PMMA was estimated as the detonation pressure.

Typical pressure profile of tungsten loaded PBX measured by PVDF pressure gauge is shown in Fig. 3.

Measured detonation pressure is compared with detonation pressure calculated with KHT e.o.s. in Fig. 4.

In the case of tungsten content 20 wt.%, good agreement was obtained between measured and calculated detonation pressure. Measured detonation pressure was about 3 GPa higher than calculated detonation pressure in the case of tungsten content 40 and 60 wt.%. An extensive study was undertaken at Los Alamos N.L. to investigate how explosive performance was affected when both inert and non-inert components were added[9]. The results of this study showed that BKW calculations reasonably estimate the detonation velocity, but overestimate the CJ pressure by 10 GPa for RDX/Pb/binder mixtures and HMX/W/binder mixtures. The explosive detonation velocity was ideal, whereas CJ pressure was obviously non-ideal. To study the observed non-ideal behavior of inert metal loaded explosives, Mader et al.[10] performed three-dimensional calculations of a detonation interaction with a matrix of metal particles using reactive hydrodynamic code 3DE with Forest Fire burn model. The results of their numerical simulations demonstrated that the non-ideal behavior of inert metal loaded explosives could be attributed to the failure of some of the individual detonation wavelets as they pass between inert metal particles and subsequent decomposition of the partially decomposed explosive behind the detonation front. The results of numerical simulations explained the observed weak detonation behavior in HMX/W/binder mixture. The effect of particle size and content of metal component was also modeled qualitatively. The experimental and calculated detonation properties of tungsten loaded PBX are compared with those of RDX/Pb/binder mixtures in Fig. 5.

In our study, the discrepancy between the measured and calculated pressure is less than 3 GPa, and measured pressure profile does not show weak detonation behavior, which is due to small volume ratio of tungsten powder in our experiments (less than 11 vol. %). The discrepancy between measured and calculated pressure is expected to increase with increasing tungsten content according to the results of numerical simulations by Mader et al.[10].

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 are presented in Fig. 6.

Diameter of inner charge was 30 mm and diameter of

Table 2 Properties of the overdriven detonation.

Explosive	PBXNS-201	PBX-W20	PBX-W40	PBX-W60
Detonation velocity [m s-1](1)	8206	8197	8163	8134
Detonation velocity [m s-1](2)	8112	8112	8112	8112
Detonation pressure [GPa](3)	—	58.6	—	—
Detonation pressure [GPa](4)	—	59.7	66.9	64.3
Detonation pressure [GPa](5)	—	58.3	73.5	105.6

(1) Optical Fiber
(2) Hydrodynamic code
(3) Manganin gauge
(4) Velocity measurement
(5) PVDF gauge

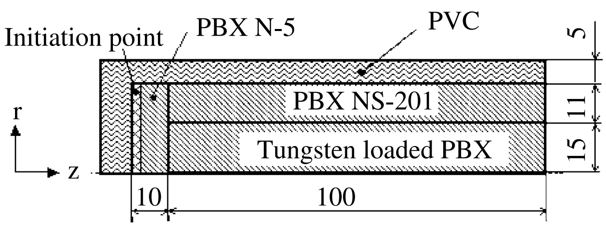

Fig. 7 Numerical simulation model.

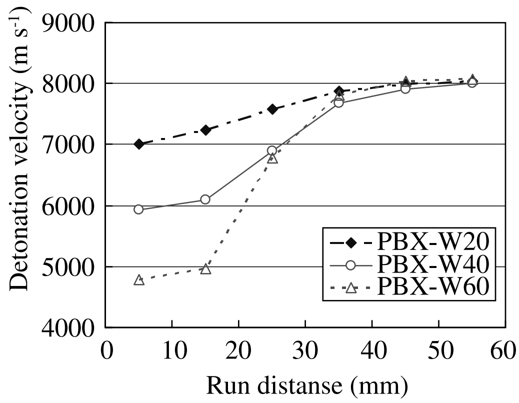

Fig. 8 Variation of the overdriven detonation velocity with run distance.

outer charge was 52 mm. Length of sample charge was 100 mm. Sample co-axial double layer cylindrical charge was initiated by a plane wave generator. 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.

Detonation pressure of the overdriven detonation was measured by manganin gauge. Detonation pressure of the overdriven detonation was also obtained by means of measurements of shock velocity in PMMA plate of 2 mm thick. Manganin gauge and PMMA plate were set 25 mm 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 8200 m s^{-1}. 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. Muller[4] performed direct observation of formation of the overdriven detonation by Mach reflection of conical incident detonation wave using flash x-ray radiography, and demonstrated that Mach reflection was produced within a short run distance. 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.

Numerical simulation using two-dimensional hydrodynamic code [11] 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 7 shows numerical simulation model for co-axial double layer cylindrical charge.

Variation of velocity of the overdriven detonation in tungsten loaded PBX with run distance is presented in Fig. 8.

Velocity of the overdriven detonation in tungsten loaded PBX attains velocity of outer high velocity PBX within the run distance of 50 mm. Time history of calculated pressure profile in tungsten loaded PBX is shown in Fig. 9.

Pressure of the overdriven detonation increases very rapidly with run the distance and attains its stationary value within the run distance of 50-70 mm. In the case of tungsten content 20 wt.%, measured pressure of the overdriven detonation agrees well with calculated pressure.

Measured pressure of the overdriven detonation is about 7 GPa and 41 GPa lower than calculated pressure respectively in the case of tungsten content 40 and 60 wt.%. Calculated pressure contours of co-axial double layer cylindrical charge are shown in Fig. 10.

Mach reflection of incident detonation wave is produced around charge axis. Shape of Mach disc has curvature and size of Mach disc decreases with the increase of the ratio of the overdriven detonation velocity to CJ velocity as shown in the results of previous studies [5), 6)]. Discrepancy between the measured and calculated overdriven detonation pressure is due to the decrease of Mach disc size with the increase of the ratio of the overdriven detonaion veloc-

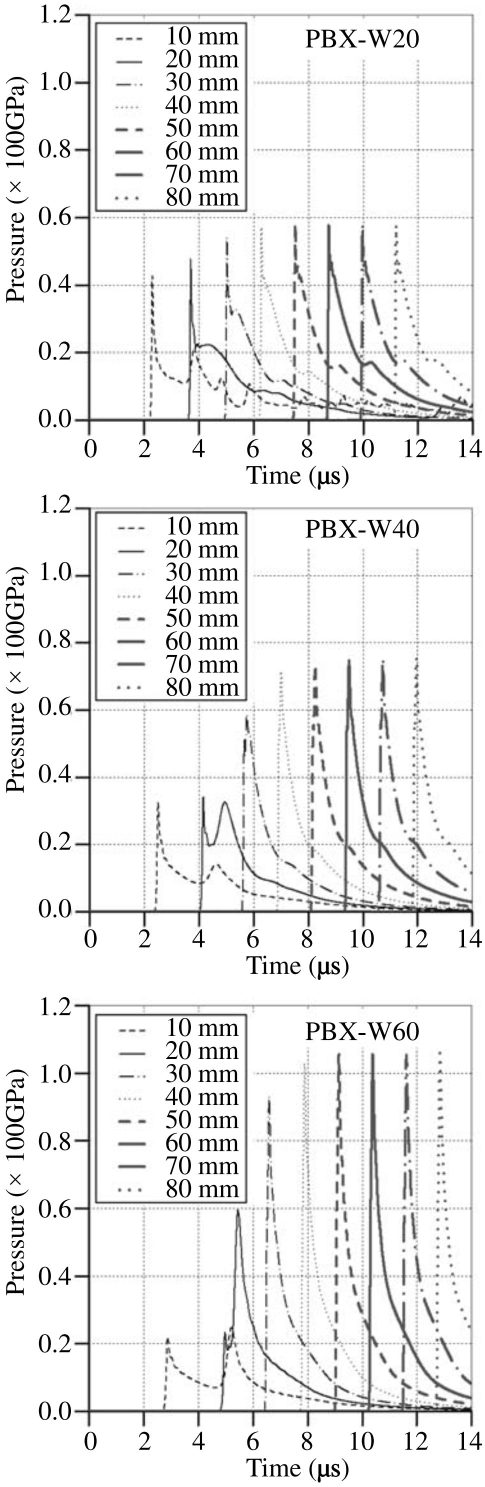

Fig. 9 Time history of calculated pressure profiles in samples.

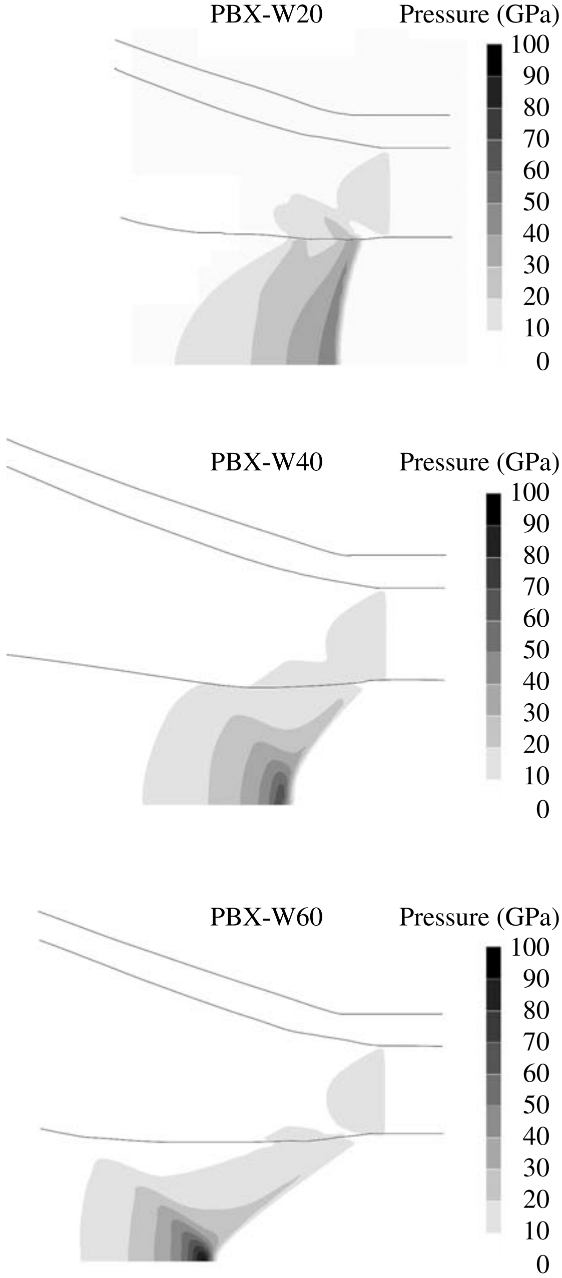

Fig. 10 Calculated pressure contours of the overdriven detonation.

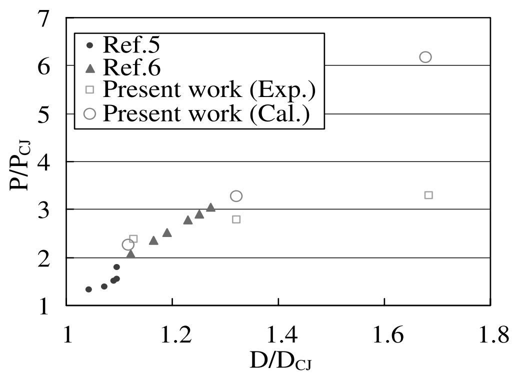

Fig. 11 Relation between pressure and velocity of the overdriven detonation for various explosives.

ity to CJ velocity. In Fig. 11, the variation of the ratio of the overdriven detonation pressure to CJ pressure with the ratio 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. Conclusions

Detonation velocity and pressure of high density explosives containing tungsten powder were measured and compared with calculated values obtained using KHT e.o.s. Measured detonation velocity agreed well with calculated velocity. In the case of tungsten content 20 wt.%, measured pressure agrees with calculated pressure. Measured detonation pressure was about 3 GPa higher than calculated detonation pressure in the case of tungsten content 40 and 60 wt.%. The discrepancy between measured and calculated detonation pressure is estimated to increase with increasing tungsten content.

Formation of the overdriven detonation was studied using co-axial double layer cylindrical charge composed outer high velocity explosive and inner tungsten loaded high density explosive. Velocity and pressure of the overdriven detonation were measured. Numerical calculation by two-dimensional hydrodynamic code was performed to simulate the formation of the overdriven detonation by Mach reflection of conical incident detonation wave in co-axial cylindrical charge. Comparison between the results of measurements and numerical simulation confirmed the formation of quasi-steady overdriven detonation. It was shown that the overdriven detonation pressure of tungsten loaded explosives was more than two times higher than CJ pressure.

It was confirmed that co-axial double layer cylindrical charge was very effective to produce steady overdriven detonation with relatively small charge size. It was also shown that the use of high density explosive containing tungsten powder as inner charge of co-axial cylindrical charge had possibility to generate ultra high pressure.

References

1) B. B. Dunn, "Mach Reflection of Detonation Waves in Condensed High Explosives I", Vol. 4, p. 918 (1961), Physics Fluids.
2) J. P. Argous, C. Peyre, and J. Thouvenin, 4th Detonation Symposium, pp. 135-141 (1965), White Oak, MD.
3) B. D. Lambourn and P. W. Wright, 4th Detonation Symposium, pp. 142-152 (1965), White Oak, MD.
4) F. Muller, Propellants and Explosives, 3, 115 (1978).
5) M. Sellam, H. N. Presles, C. Brochet, and R. Cheret, 8th Detonation Symposium, pp. 425-430 (1985), Albuquerque, NM.
6) J. Souletis and J. Groux, 8th Detonation Symposium, pp. 431-439 (1985), Albuquerque, NM.
7) K. Tanaka, S. Fujiwara, M. Sellam, H. N. Presles, C. Brochet and R. Cheret, 4th Conference of APS Topical Group on Shock Waves in Condensed Matter, pp. 515-518 (1987), Monterey, CA.
8) K. Tanaka, 8th Detonation Symposium, pp. 548-557 (1985), Albuquerque, NM.
9) C. L. Mader, "Numerical Modeling of Explosives and Propellants", p. 64 (1998), CRC Press.
10) C. L. Mader, J. D. Kershner, and G. H. Pimbley, J. Energetic Materials, 1, 293 (1983).
11) Century Dynamics Inc., AUTODYN (Interactive Non-Linear Dynamic Analysis Software) Users Manual Revision 3.0 (1997).

タングステン粉混入高密度爆薬の過剰爆轟に関する研究

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タングステン粉を 20，40，60 %混入した RDX 系高密度 PBX を試作し，爆速及び爆轟圧力を実測した。この結果と KHT による計算値を比較したところ両者はほぼ一致した。過剰爆轟状態を調査するため，試作した高密度 PBX を内側，HMX を使用した高爆速 PBX を外側に填薬した２重円筒爆薬を試料として，定常状態の爆速及び爆轟圧力を実験により実測すると共に Hydro-code による数値シミュレーションを実施した。この結果，中心軸上にマッハディスクが発生し，中心部の爆轟圧力は，高密度 PBX の CJ 圧力の２倍以上になることが判明した。

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