Measurements of Detonation Pressures of Initiating Explosives

Tsugio Sawada*

I. Introduction

Detonation pressure of an initiating explosive is considered to be a predominant factor of sympathetic detonation between adjoining rooms in a detonator plant. Detonation pressure measurement is necessary for designing an explosion-proof construction.

Detonation pressure measurement was carried out by an ion-gap method[1] in which the shock velocities in an explosive and in an inert material in contact with the explosive were measured. The detonation pressure is obtained[2] from the relation of pressure (P)-particle velocity (W) in the inert material. Metaacryl resin was used as the inert material, because its $P-W$ relation is analogous to that of explosives and its acoustic approximation is held in the explosives. Detonation velocity and pressure observed were compared with those calculated from T. Hikita and T. Kihara's formula[3] of detonation characteristics.

II. Experimental

1. Sample

Diazodinitrophenol (DDNP) (granular crystal, bulk density $\Delta=0.62$ and 0.48; needle crystal, bulk density $\Delta=0.38$), mercury fulminate (bulk density $\Delta=1.515$) and tricinate (bulk density $\Delta=1.03$) were used as samples. The sample was loaded part by part in three times to get uniformity of loading density in a polypropylene cylinder (1mm in thickness, 40 mm in inner diameter and 65 mm in length). Loading densities were $\rho_{0x}=0.55\sim1.20$ for DDNP, $\rho_{0x}=1.60\sim2.50$ for mercury fulminate and $\rho_{0x}=1.50\sim2.10$ for tricinate. The polypropylene cylinder charged with was set on an acryl plate (10 mm in thickness, 50 mm in width and 50 mm in length). In the upper part of the cylinder (20 mm in length) was loosely loaded with DDNP (17g for $\Delta=0.62$ DDNP, 13g for $\Delta=0.48$, 9g for $\Delta=0.38$, 13g for mercury fulminate and 13g for tricinate). And the whole charge was fired with a fuse head inserted in the centre of the upper part.

Tricinate was loaded in a wet state (water

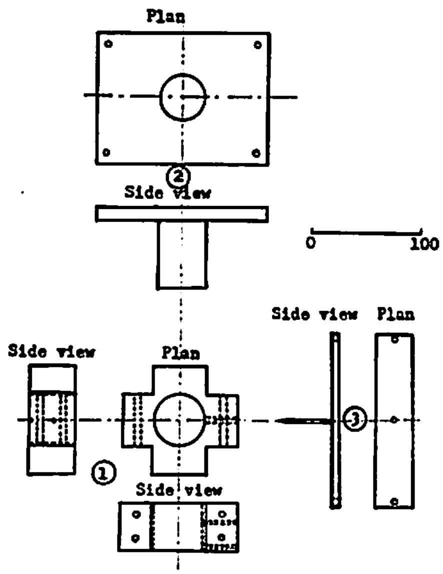

Fig. 1 Brass forming tool of initiating explosive

① : dies ② : plunger electroplated with chromium ③ : boring tool

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content: about 13%), because its friction sensitivity[4] is very high in the dry state and was tested after being completely dried at 50℃ to constant weight for about five days.

The polypropylene cylinder was used to hold the charge, as it retained better geometry than another common plastics.

The forming tool of the explosives was made of brass. It is shown in Fig. 1.

2. Method

An ion gap was two enameled wires twisted together (S. W. G. No. 36, 0.192mm in dia.). Average detonation velocity in 20mm of length of the explosive and average shock velocity in 10mm of thickness of acryl plate was observed with a synchroscope in an external triggering mode. The block diagram is shown in Fig. 2.

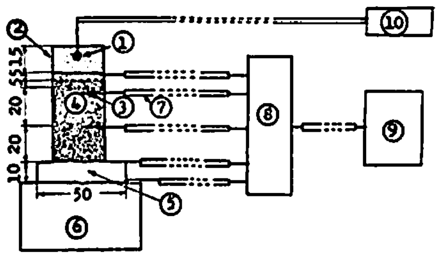


Fig. 2 Block diagram of detonation pressure measurement

① : fuse-head
② : polypropylene cylinder (40 in inner dia., 1 in thickness)
③ : ion gap
④ : initiating explosive
⑤ : metaacryl plate
⑥ : iron anvil
⑦ : coaxial cable
⑧ : pulse shaper
⑨ : C. R. O. ⑩ : exploder

3. Calculation of detonation pressure

According to Rices, McQueen and Walsh et al.[5], an approximate linear relation between shock velocity and particle velocity is:

$$D_M = C_0 + kW_M \qquad (1)$$

D_M : Shock wave velocity in inert material

C_0 : Sound velocity in inert material, 2,000 m/sec for acryl plate

k : Coefficient, 1.61 for acryl plate

W_M: Particle velocity of free surface

Relation between shock velocity and shock pressure in an inert material is shown as follows:

$$P_M = \rho_{0M} \cdot D_M \cdot W_M \qquad (2)$$

P_M : Shock wave pressure in inert material

ρ_{0M}: Inert material density, 1.19 for acryl plate

Shock impedance in explosive and inert material are given as follows:

$$I_x = (\rho_0 D)_x, \quad I_M = (\rho_0 D)_M \qquad (3)$$

I_x : Shock impedance of explosive

ρ_{0x}: Loading density of explosive

D_x: Detonation velocity

I_M : Shock impedance of inert material

Detonation pressure is found as follows:

$$P_x = \frac{P_M}{ZI_M}(I_x + I_M) \qquad (4)$$

P_x: Equal to detonation pressure P_{CJ}

4. Results

(1) Examples

Typical oscillograms obtained by the ion-gap method are shown in Fig. 3.

As shown in Fig. 3, in the case of a higher loading density, detonation velocity of the first 10 mm, the second 20 mm and the third 20 mm of length of the explosive, and shock velocity in 10mm thickness of acryl plate are securely obtained. Sometimes they are unsuccessful in the case of a lower loading density.

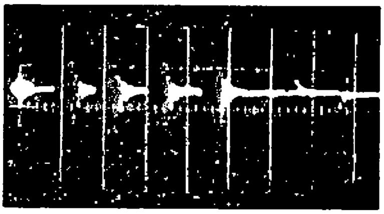
(2) Summary of experimental results

Detonation pressures are summarized in Table 1.

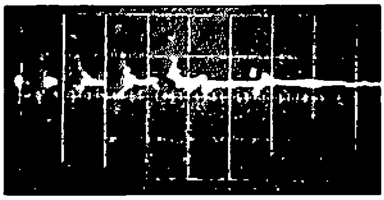
They are calculated from the above formula (1)~(4) in which detonation velocity D_x and shock velocity D_M were observed.

Measurements at the same loading density were repeated four times.

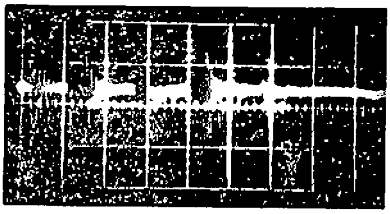
The observed shock velocity in the acryl plate happened to be lower the sound velocity (2,500 m/sec) in a literature[5]. The sound



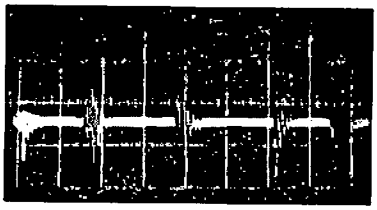
(a) DDNP, $\Delta=0.62$, $\rho_{0x}=1.2$
voltage sensitivity = 1V/cm, sweep velocity = 2 μsec/cm



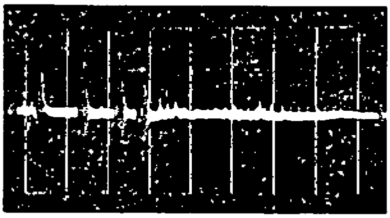
(b) DDNP, $\Delta=0.48$, $\rho_{0x}=1.2$
voltage sensitivity = 1V/cm, sweep velocity = 2μsec/cm



(c) DDNP, $\Delta=0.32$, $\rho_{0x}=1.2$
voltage sensitivity = 1V/cm, sweep velocity = 2μ sec



(d) mercury fulminate, $\Delta=1.515$, $\rho_{0x}=2.5$
voltage sensitivity = 1V/cm, sweep velocity = 2μsec/cm



(e) tricinate, $\Delta=1.037$ $\rho_{0x}=1.5$
voltage sensitivity = 0.5V/cm, sweep velocity = 5μsec/cm

Fig. 3 Typical oscillograms obtained by the ion-gap method

velocity obtained from an experiment described below seems to be reasonable.

(3) Detonation characteristics calculated from T. Hikita and T. Kihara's formula[3)]

Detonation velocity and pressure at various loading densities were obtained by the following decomposition equation. Molecular constants λ_i being proportional to the molecular volume were used the value determined from compressibility data.

DDNP: $N_2C_6H_2(NO_2)_2 \rightarrow 2N_2 + H_2O + 4CO + 2C + 174.5$ kcal; H. F. -39.2 kcal

Mercury fulminate: $Hg(ONC)_2 \rightarrow Hg(g) + N_2 + 2CO + 53.4$ kcal; H. F. -63.0 kcal, heat of vaporization Hg -15.2 kcal

Tricinate: $PbO_2C_6H(NO_2)_3 \rightarrow \frac{3}{2}N_2 + \frac{1}{2}H_2O + \frac{3}{2}CO_2 + \frac{9}{2}CO + Pb + 301.3$ kcal; H. F. $+200.3$ kcal

The detonation velocity and pressure of DDNP are far higher than those of mercury fulminate and tricinate.

(4) DDNP

The effects of loading density on detonation velocity and shock velocity of DDNP are shown in Fig. 4.

Differences of the detonation in bulk density ($\Delta=0.62, 0.48, 0.32$) and crystal form (granular, needle) are not found clearly. The detonation velocity greatly increases as the loading density increases and the shock velocity also increases as the loading density increases.

The detonation velocity observed by the ion-gap method accords with the value observed by S. Kinoshita's[6)] streak camera method and the calculated value.

The effect of loading density on detonation

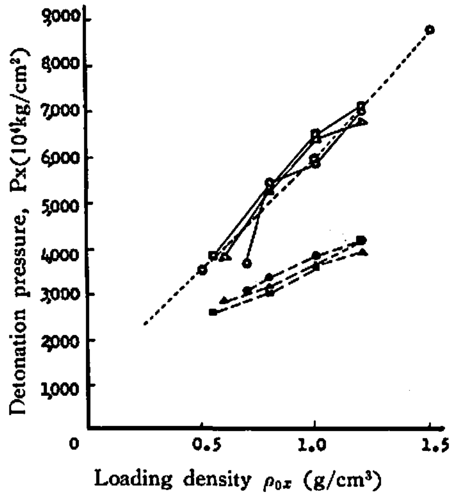


Fig. 4 Loading density effect on detonation velocity and shock velocity

DDNP	Detonation velocity	Shock velocity	Calculated detonation velocity
Granular, Δ=0.62	—○—	···●···	
Granular, Δ=0.48	—△—	···▲···	···○···
Needle, Δ=0.32	—□—	···■···	

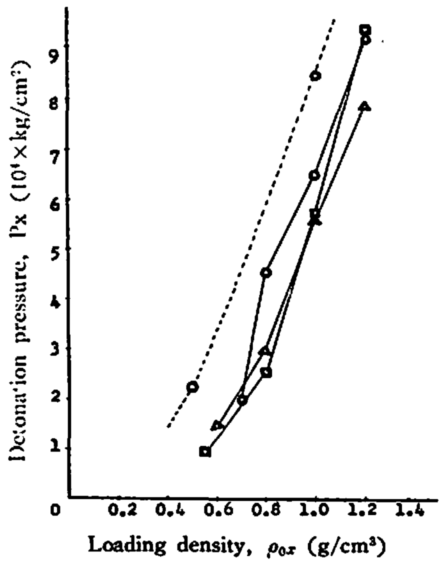


Fig. 5 Loading density effect on detonation pressure

DDNP —○—: granular., Δ=0.62
—△—: granular., Δ=0.48
—□—: needle., Δ=0.32
···○···: calculated detonation pressure

pressure of DDNP is shown in Fig. 5.

The detonation pressure greatly increases as the loading density increases, but the pressure is a little lower than the calculated value.

(5) Mercury fulminate and tricinate

The effects of loading density on detonation velocity and shock velocity of mercury fulminate and tricinate are shown in Fig. 6.

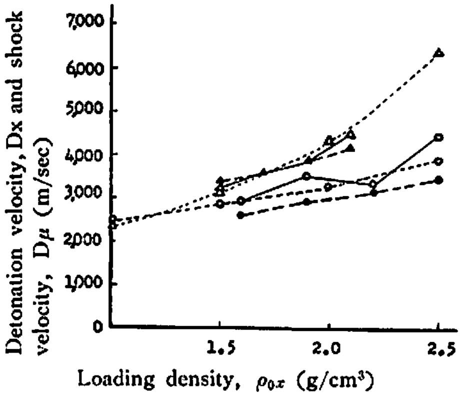


Fig. 6 Loading density effect on detonation velocity and shock velocity

	Detonation velocity	Shock velocity	Calculated detonation velocity
Mercury fulminate	—○—	···●···	···○···
Tricinate	—△—	···▲···	···△···

The detonation velocities of mercury fulminate and tricinate increase as the loading density increses but the velocity increase is not so remarkable as that of DDNP.

The detonation velocity of mercury fulminate accords with the value mearured by Y. Mizushima's image converter tube method and the calculated value.

The observed detonation velocity of tricinate also accords with the calculated value and is higher than that of mercury fulminate.

The effects of loading density on detonation pressure of mercury fulminate and tricinate are shown in Fig. 7.

The observed detonation pressures of mercury fulminate and tricinate increase as the loading density increases but the pressure increases are not so remarkable as that of DDNP.

The observed detonation pressure of mercury fulminate is lower than that of tricinate and the calculated value.

Table 1-(a) Results of measurement by DDNP

Explosive	Charge (g)	Loading density $\rho_0 x$ (g/cm³)	Detonation velocity D_x (m/sec)		
			Averaged	Deviation	Sample size
DDNP (granular crystal) Δ=0.62	39.56	0.70	3,673.4	324.1	11
	45.22	0.80	5,400.2	1,390.7	12
	56.50	1.00	5,846.1	896.0	12
	67.82	1.20	6,987.5	1,452.5	12
DDNP (granular crystal) Δ=0.48	33.91	0.60	3,761.7	468.6	11
	45.22	0.80	5,276.1	856.4	12
	56.50	1.00	6,390.2	1,191.6	11
	67.82	1.20	6,748.5	1,144.5	11
DDNP (needle crystal) Δ=0.32	31.09	0.55	3,823.3	615.6	12
	45.22	0.80	5,371.8	1,148.0	11
	56.50	1.00	6,427.4	1,738.0	12
	67.82	1.20	7,059.8	1,208.3	12

Table 1-(b) Results of measurement by Mercury fulminate and tricinate

Explosive	Charge (g)	Loading dencity $\rho_0 x$ (g/cm)	Detonation velocity D_x (m/sec)		Shock velocity D_m (m/sec)	
			Observed	Averaged	Observed	Averaged
Mercury fulminate Δ=1.51	90.43	1.60	2,928 2,928	2,928	2,403 2,747	2,575.0
	107.39	1.90	3,436 4,071 3,546 3,000	3,513.2	2.853 2,983 2,983 2,853	2,918.0
	124.30	2.2	3,790 2,794	3,292.2	2,820 3,438	3,129.0
	141.30	2.5	5,000 4,074 4,500 4,277 4,180	4,406.2	3,236 3,448 3,654 3,431 3,315	3,416.8
Tricinate Δ=1.04	84.78	1.5	3,110 3,252 3,252	3,204.8	3,257 3,367 3,584	3,366.8
	96.08	1.7	3,401 3,571 3,766	3,579.7	3,584 - 3,584	3,584.0
	107.39	1.9	3,766 3,976	3,878.3	3,891 3,773	3,832.3
	118.69	2.1	4,474 4,474	4,474.0	1,891 4,484	4,187.7

ion-gap method

Shock velocity Dm (m/sec) Averaged	Deviation	Sample size	Particle velocity Wm (m/sec)	Shock pressure Pm (kg/cm²)	Detonation pressure $P_X = Pcj$ (kg/cm²) Averaged	Deviation	Sample size
3,023.3	161.6	11	635.6	23.569.6	19,616.8	3,898.7	11
3,347.5	227.9	12	836.9	41,784.1	45,106.1	27,282.4	12
3,818.5	381.9	12	1,129.5	55,950.5	64,577.6	25,865.3	12
4,136.8	384.7	12	1,368.5	67,729.6	91,247.6	26,144.3	12
2,810.3	313.4	11	503.3	17,981.7	14,375.5	7,281.3	11
3,154.4	101.4	12	717.0	27.602.3	29,394.3	3,701.4	12
3,629.8	166.1	11	1,012.3	44,822.4	55,604.8	9,711.2	11
3,915.7	189.7	11	1,212.1	58,103.6	77,993.4	8,252.1	11
2,557.7	134.6	11	346.4	10,928.2	9,217.7	3,152.8	11
3,007.1	350.1	11	625.5	23,730.3	25,562.0	10.009.9	11
3,599.4	263.1	12	1,002.7	47,216.1	57,019.1	10,896.3	12
4,147.9	453.7	12	1,334.1	68,928.1	93,445.8	31,050.4	12

ion-gap method

Particle velocity Wm (m/sec) Observed	Averaged	Shock pressure Pm (kg/cm²) Observed	Averaged	Detonation pressure $P_X = Pcj$ (kg/cm²) Observed	Averaged
250.3	357.1	7,303.8	11,390.1	9,634.7	14,227.6
463.9		15,476.3		18,820.5	
529.8	570.1	18,354.5	20,234.9	26,824.2	29,650.1
610.5		22,115.4		35,152.2	
610.5		22,115.4		32,045.0	
529.8		18,354.5		24,584.9	
509.3	701.2	17,440,2	27,364.5	30,386.5	38,503.6
893.1		37,286.8		46,686.6	
767.7	879.9	30,145.8	36,658.9	63,874.8	67,686.4
899.3		37,655.3		65,562.6	
1,027.3		45,584.4		81,761.0	
888.8		37,029.7		67,002.6	
816.7		32,875.1		59,981.4	
780.7	848.4	30,876.1	34,855.7	34,016.0	30,123.7
780.7		30,876.1		34,864.5	
983.8		42,814.9		21,490.5	
183.8	983.8	42,814.9	42,814.9	50,429.8	52,010,9
-		-		-	
983.8		42,814.9		53,592.0	
1,174.5	1,137.9	55,487.9	52,969.7	70,613.9	69,140.4
1,101.2		50,451.5		67,666.9	
1,174.5	1,358.7	55,487.9	69,745.6	84,035.7	99,994.7
1,542.8		84,003.2		115,953.6	

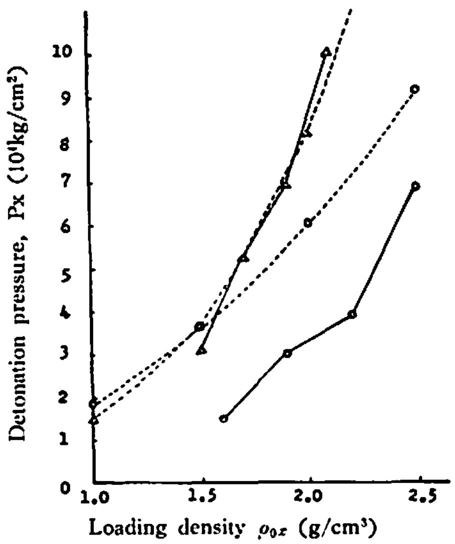


Fig. 7 Loading density, effect on detonation pressure

	Detonation pressure	Calculated detonation pressure
Mercury fulminate	—○—	···○···
Tricinate	—△—	···△···

III. Conclusions

1. The detonation velocity and pressure of DDNP remarkably depend upon the loading density and are higher than those of mercury fulminate and tricinate.

2. The effects of bulk density and crystal form of DDNP on the detonation velocity and pressure are not distinguished.

3. The detonation velocity and pressure of mercury fulminate are lower than those of tricinate.

4. The detonation velocity accords with the calculated value but the detonation pressure is a little lower than the calculated value.

IV. Considerations on sound velocity in metaacrylate

According to Rice, McQueen and Walsh et al., the sound velocity in metaacrylate is given as Co=2,500 m/sec at the density ρ_{0M} =2g/cm³. As mentioned above, the shock velocity occasionally happened to be lower than this value. A discussion concerning the velocity is given below.

1. Calculation of sound velocity

(1) Assuming the Poisson's ratio to be zero and the Young's modulus to be 3×10^4 kg/cm²[8], the sound velocity (Longitudinal elastic wave velocity) in an acryl bar is given by the following:

$$C_0=(E/\rho)^{1/2}$$

E: Young's modulus, 3×10^4 kg/cm²

ρ: density of metaacrylate, 1.19 g/cm³ (observed value)

$\therefore\ C_0 \fallingdotseq 1,570$ m/sec

(2) When the Poisson's ratio is 0.35[8], the sound velocity in an acryl plate is given by the following:

$$C_0=\{E/\nu[(1-\nu)(1-\nu)(1-2\nu)]\}^{1/2}$$

ν: poisson's ratio, 0.35

$\therefore\ C_0 \fallingdotseq 1,990$ m/sec

2. Observed value of sound velocity in metaacrylate

(1) Measurement

The block diagram of sound velocity measurement is shown in Fig. 8. Two pieces of aluminium foil (1mm in thickness) were cemented on the both flat ends of an acryl bar. One end subjected to a shock was connected to a synchroscope through a pulse shaper with a coaxial cable.

A sound wave traveled through the bar was catched with a piezotite (10 mm in dia.,

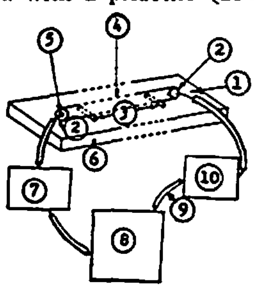


Fig. 8 Block diagram of sound velocity measurement

①: hammer
②: aluminium foil (1 in thickness)
③: gum rod
④: acryl bar
⑤: piezotite bar (10 in dia., 2 in thickness)
⑥: sponge plate (30×500×100)
⑦: impedance converter
⑧: C.R.O.
⑨: coaxial cable
⑩: pulse shaper

2mm in thickness) cemented on the opposite end and was recorded with the synchroscope. As samples, acryl bars of 10~90 mm in length and 10~30mm in diameter were used.

(2) Example of measurement

An example of measurement is shown in Fig. 9.

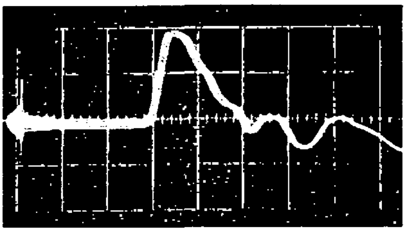


Fig. 9 Oscillogram showing the travelling time of elastic (sound) wave through acryl bar
Acryl bar 10 mm in dia., 30 in length, voltage sensitivity 0.05V/cm, sweep velocity 50μsec, sound velocity 2129 m/sec.

Table 2 Sound velocity in metaacrylate

Acryl bar (mm)		Sound velosity at about 25°C (m/sec)	
Diameter	Length	Observed value	Average value
10	10	1,733.1 1,733.1 1,733.1	1,733.1
	20	1,802.0 1,778.0 1,802.0	1,794.0
	30	2,218.9 2,162.1 2,128.9 2,098.4 2,218.9	2,203.7
	50	2,016.1 2,016.1 1,976.2	2,002.7
	70	1,971.8 1,971.8 1,971.8 1,971.8 1,971.8	1,971.8
	90	1,982.3 1,982.3 1,982.3 1,982.3 2,222.2	2,030.3
20	19.9	2,010.1 2,010.1 2,010.1 2,010.1	2,010.1
30	19.8	1,978.0 1,978.0 1,978.0	1,978.0

(3) Results

Results are summarized in Table 2.

(4) Conclusions

From the observed, the souned velocity in metaacrylate was used as $C_0=2,000$ m/sec, also with referring to the calculated value.

Acknowledgements

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起爆薬の爆轟圧力測定に関する研究

沢　田　継　男

火工品工場における，危険工室の設計に関する研究の一環として，耐爆資料を得るため，および工室間の火薬類の殉爆の主要因と考えられる，起爆薬類の爆轟圧力測定を行なつた。

測定方法は，イオンーギャップ法により，爆薬の爆速と爆轟圧を受ける不活性物質中のショック速度を測定し，

圧力 (P)-粒子速度 (W) の関係より間接的に爆轟圧力を算出した。

不活性物質としては，P-W 特性が爆薬と大差なく，音響学的近似がよく成立するといわれているメタアクリル樹脂を選んだ。メタアクリル樹脂の比重 $\rho_{OM}=1.19$ とし，音速 (C_0) は，計算結果を参考にし，実験的に求めた $C_0 \fallingdotseq 2,000$m/sec. を用いた。

起爆薬としては，DDNP (粒状，仮比重 $\Delta=0.62$ 0.48; 針状，Δ=,.32). 雷こう，トリシネートを選び，3者を夫々装塡比重 ρ_{Ox}=0.55～1.20, 1.60～2.50, 1.50～2.10 に圧搾して，これらの爆速，爆轟圧力に及ぼす影響を求めた。一方疋田，一木原氏の爆轟特性計算方式により求めた値と比較した。

その結果，

DDNP の爆速，爆轟圧力は，生成時の仮比重，結晶形による差異は顕著ではないが，装塡比重に著しく依存し，雷こう，トリシネートよりも大である。

雷こうの爆速，爆轟圧力はトリシネートよりも小である。

爆速は何れも計算値とよく一致するが，爆轟圧力は計算値よりも若干小となつた。