Initiation of some explosives by irradiation of CO_2 laser

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The continuous wave(CW) CO_2 laser is one of the main laser source for industrial use. Detonation of explosives by means of the CW CO_2 laser has never been reported. Some explosives with and without confinement were irradiated by the CW CO_2 laser. HMX, RDX, PETN, and tetryl were classified as sensitive explosives and TNT, picric acid, and ammonium nitrate were classified as insensitive explosives and Composition B was classified as an intermediate for the CO_2 laser initiation. Some sensitive explosives were confined and their reactions by the laser irradiation were investigated. Temperature profiles of some explosives were also reported.

1. Introduction

The continuous wave CO_2 laser is one of the main laser source for industrial use and is used for welding, cutting, and drilling. Ignition of propellant by the CO_2 laser has been studied by some researchers[1) 2)]. But no results on initiation of confined explosives were reported, to the best of authors' knowledge. We have been studying to find a new energy source to detonate secondary and tertiary explosives directly without a detonator. Initiation of confined explosives by pulsed ruby laser[3)] and microwave[4)] irradiation were reported by the authors. In this study, experiments were carried out to detonate secondary and tertiary explosives with and without confinement by the CW CO_2 laser irradiation.

In the wavelength range of the CO_2 laser, transparent materials such as ZnSe, GaAs, and Ge are too expensive to be used as a disposable window. A relatively inexpensive KBr crystal for infrared spectroscopy was used as a window material and detonation characteristics of some high explosives were observed.

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2. Experimental

2.1 Sample

The explosives used in this study were HMX, RDX, PETN, tetryl, picric acid(PA), ammonium nitrate(AN), and Composition B(Comp. B). The crystalline explosives were ground to 48−100 mesh, then dried by vacuum drying for five hours at 45℃.

2.1.1 Open-mouthed container

Explosive was loaded in an acrylic plastic block which was 20×20㎜ in cross-section and 10㎜ in length with a bore hole of diameter 6㎜ had a 3㎜ thick acrylic plastic plate bottom. The weight of explosive was 0.2 g and it was pressed with a rod of diameter 10 ㎜ at about 15MPa pressure. Sample temperature was measured with a Type-K thermocouple (chromel-alumel : 50μm in diameter) which was pressed to the surface of an explosive. Sample configuration is shown in Fig. 1 (a).

2.1.2 Sealed container

Some explosives which were classified as sensitive

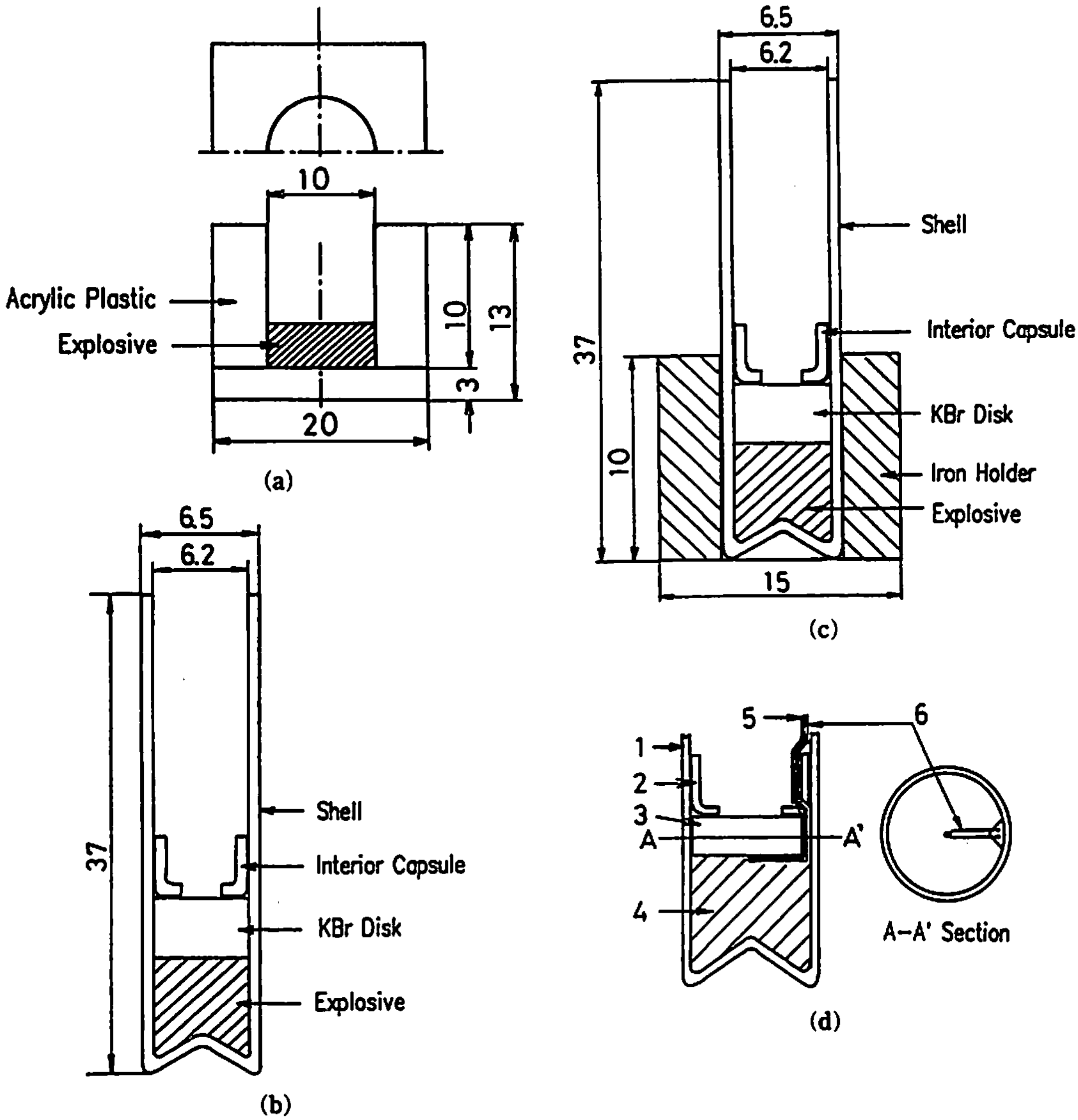

Fig. 1 Cross-sectional view of the containers
(a) Open-mouthed type; (b) Sealed type; (c) Reinforced type; (d) Temperature measuring system for sealed type;
1 : Shell; 2 : Interior capsule; 3 : KBr disk; 4 : Explosive; 5 : Aluminum foil; 6 : Type-K thermocouple

explosives by the open-mouthed container test were tested in sealed containers. The explosive was loaded in a shell for no. 6 detonator, which was used as a container, with 10MPa pressure. A KBr disk of 6mm diameter and about 2mm thick was glued to an interior capsule with a hole of 3.5mm diameter, which was large enough to let the laser beam pass undisturbed. The interior capsule and the shell were sealed with a cap crimper. And at the bottom of the detonator a lead plate (4 × 40 × 40mm) was placed as a witness plate. The weight of explosive was 0.2 g and the loading density was from 1.2 g/cm^3 to 1.5g/cm^3. Sample configuration is shown in Fig. 1 (b).

2.1.3 Sealed container with reinforcement

In some cases, the sealed shell loaded with an explosive was reinforced with an iron holder which was 20 × 20mm in cross-section and 10mm in length with a hole of 6mm diameter. Configuration of the sample

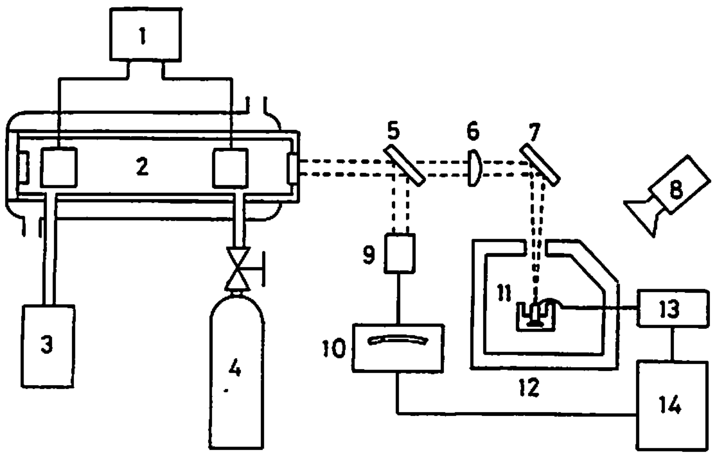

Fig. 2 Schematic diagram of CO_2 laser ignition apparatus.
1 : High voltage power supply; 2 : Laser tube; 3 : Vacuum pump; 4 : Mixed gas cylinder; 5 : Beam splitter; 6 : Ge lens; 7 : Au mirror; 8 : Video camera; 9 : Absorption head; 10 : Power meter; 11 : Sample; 12 : Acrylic plastic protective box; 13 : DC amplifier; 14 : Pen and ink recorder.

holder is shown in Fig. 1 (c).

Temperature of the sample was measured with a Teflon coated Type-K thermocouple (80μm in diameter, Omega Engineering, Inc., TT-K-40) and a bead of the thermocouple was inserted between a KBr disk and an explosive. Configuration of the sample is shown in Fig. 1 (d).

2.2 Apparatus

A schematic of the apparatus is depicted in Fig. 2.

The power source was a continuous wave 25W CO_2 laser. The irradiation power was controlled by changing the flow rate of mixed gas (CO_2:10%, N_2:20%, and He:70%). The laser beam was divided by means of a ZnSe beamsplitter into a monitor beam and an incident beam. The incident beam was focused on a sample surface by a Ge lens (f=1000mm). The power of the monitor beam was measured by a power meter (Laser Precision Corp., PKP-545). The incident power was measured by a power meter (Coherent Radiation Laboratories, Model 201) which was placed at where the sample was placed. The incident power on an explosive surface was estimated by measuring the monitor beam power. The relationship between the incident power and the monitor beam power is expressed as follows:

$$I_i = 8.718 \times I_m \qquad (1)$$

where I_i is the incident laser beam power (W), I_m is the monitor beam power (W). A coefficient of correlation r was found to be 0.9915. The monitor beam power and temperature were recorded on a pen and ink recorder (Rikadenki, R-60). The irradiation beam was stopped by a shield placed on the protective box's opening and the shield was removed for the ignition of explosive, after the monitor beam power reached at a prescribed power. The ignition time was measured by a VCR (National NV-150) and a video camera (National Vz−C70, 30frames/s). The ignition time is the time difference between the shield removing time and the time when explosion light appears on a video tape.

The transmittance of a KBr disk, τ_{KBr} was expressed as

$$\tau_{KBr} = (I_{KBr}/I_{mh}) \times 100 \ (\%) \qquad (2)$$

where I_{mh} is the monitor beam power passed through a hole (W) and I_{KBr} is the transmittance power passed through a KBr disk (W).

3. Results and Discussion

3.1 Open-mouthed container

3.1.1 Ignition time

The ignition times of eight kinds of explosives placed in an acrylic plastic container are shown in Fig. 3.

All explosives tested burned by laser irradiation and no explosion was observed. The explosives tested were classified into three groups, based on the igni-

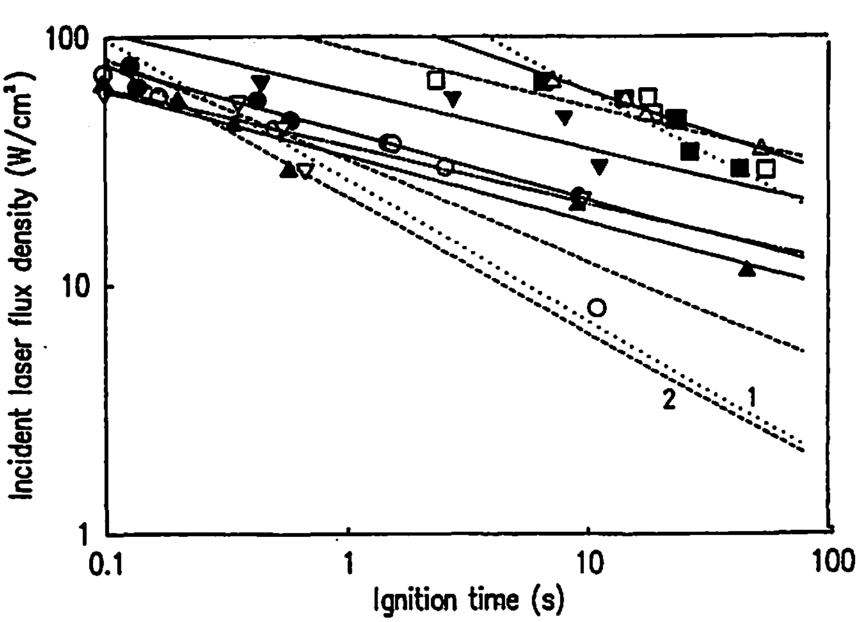

Fig. 3 Relation between incident laser flux density and ignition time

HMX	---o-----	RDX	—●—	PETN	—▲—
Tetryl	—▽—	TNT	····■····	Picric acid	—△—
AN	---□----	Comp. B	—▼—		
TNT [5]	··········	HMX [5]	----------		

tion time. HMX, RDX, PETN, and tetryl were classified as sensitive explosives. TNT, picric acid, and AN were classified as insensitive explosives. Comp. B was classified as an intermediate. The relation between the ignition time(s), t and the laser flux density(W/cm²), I_0 is expressed as the following expression[1) 2) 5)]

$$t = aI_0^{-\mu} \qquad (3)$$

Where a and μ are constant. Harrach[5)] reported that μ for PETN, HMX, and TNT are 1.81, 1.83, and 1.745, respectively. The results for HMX and TNT by Harrach are also shown in Fig. 3. Compared with Harrach's work, sensitivities of PETN, RDX, and HMX are similar but TNT is less sensitive in our work. This is probably caused by the fact that his work covers higher incident laser flux density than our work and he used pulse laser.

Incident laser flux densities for producing an ignition in five seconds are shown in Table 1. Infrared absorbance in Table 1 is the absorbance of 0.1mmol explosive at 10.6μm. The ignition energy(J), E_i was obtained by the following equation.

$$E_i = I_i \times t \qquad (4)$$

The order of increasing incident laser flux density for producing an ignition in 5s are almost the same as the sequence of explosives ordered according to increasing ignition points[6)] except HMX. HMX's lowest incident laser flux density in 5s is explained by the fact that HMX has the highest infrared absorbance at 10.6μm among the explosives tested.

3.1.2 Effect of additives

The effect of additives was studied. Five per cent graphite or active carbon by weight was added into RDX, PETN, or TNT and the ignition time was measured. Effect of additives on the ignition of RDX in an open-mouthed container is shown in Fig. 4.

The ignition times of PETN and TNT were also shortened by addition of graphite or active carbon. Active carbon is slightly effective than graphite. The effects of active carbon on the ignition time of HMX, RDX, and PETN are summarized inTable 2. The ignition of RDX and HMX became unstable when the con-

Table 1 Experimental results for open-mouthed container

Explosives	Incident laser flux density for producing an ignition in 5s (W/cm²)	Incident laser beam power for producing an ignition in 5s (W)	Ignition energy for producing an ignition in 5s (J)	Average surface temperature at ignition (℃)	Ignition point[8] (ignition delay period:5s) (℃)	Infrared absorbance of 0.1mmole explosive at 10.6μm (%)
HMX	16.4	4.6	23.2	343	335	39.5
PETN	21.3	6.0	30.1	218	225	18.5
Tetryl	24.7	7.0	34.9	305	257	8.5
RDX	26.4	7.5	37.3	380	260	24.0
Comp. B	41.4	11.7	58.5	-	278	17.0
AN	61.4	17.4	86.8	-	325	3.0
PA	76.9	21.7	108.7	-	322	10.0
TNT	86.6	24.5	122.4	-	475	6.0

AN:ammonium nitrate;PA:picric acid;-:no experiment

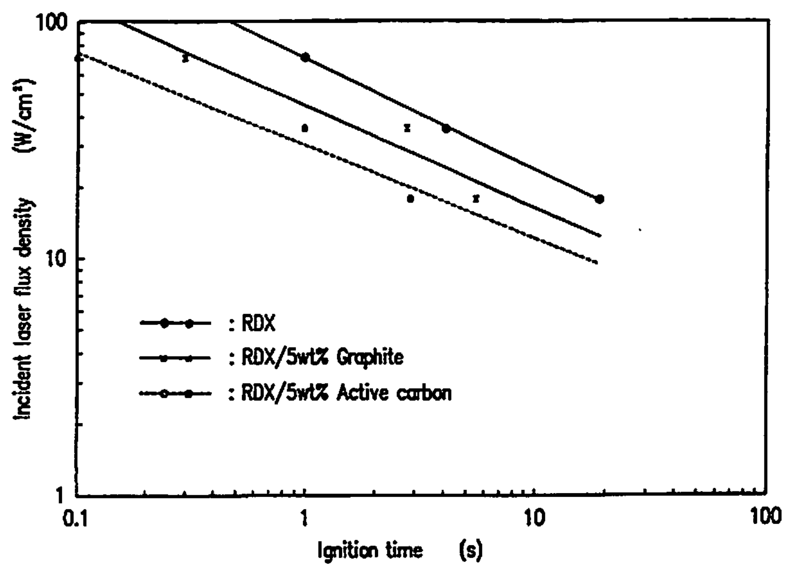

Fig. 4 Effect of additives on ignition of RDX

centration of active carbon exceeded 12.5wt%. PETN did not ignite when the concentration was 30 wt% of active carbon. It suggests that active carbon works as a diluent rather than a CO_2 laser absorbent above a certain concentration.

3.2 Sealed container

3.2.1 Ignition time

Each explosive placed in an open-mouthed container only burned. Some explosives classified as sensitive explosives placed in a sealed container exploded. Explosion assessment criteria are shown in Table 3.

Table 2 Effects of active carbon on ignition time for open-mouthed container (s)

AC wt%	HMX			RDX			PETN	
0.0	0.14	-	-	0.13	-	-	0.07	-
5.0	0.14	-	-	0.17	-	-	0.04	-
10.0	0.13	-	-	0.17	-	-	0.06	0.05
12.5	○	○	-	○	-	-	-	-
15.0	2.00	2.31	1.90	○	3.39	-	0.02	-
17.5	2.05	2.24	○	○	○	○	-	-
20.0	0.94	-	-	○	4.20	○	0.03	0.03
22.5	-	-	-	3.11	○	○	-	-
25.0	0.80	-	-	○	-	-	0.02	-
30.0	0.43	-	-	○	-	-	○	-

Incident laser flux density:61.5W/cm² ; AC:active carbon:○:no ignition:-:no expriment

Table 3 Explosion assessment criteria

Judgment		Assessment Criteria
Explosion	(×)	Lead plate(4mm thick) was perforated and test sample completely disappeared.
Half-explosion	(△1)	Lead plate was concaved but not perforated and some of the explosive left.
	(△2)	Lead plate was little concaved and large part of the explosive left.
No-explosion	(○)	Chemical reaction was observed on the surface of explosive but did not explode.

Incident laser flux density at the surface of an explosive in a sealed container, I'_0 was obtained by the following equation.

$$I'_0 = I_0 \times (I_{KBr}/I_{mh}) \quad (5)$$

The ignition times of some explosives are shown in Table 4.

PETN, HMX, tetryl, and RDX which burned in an open-mouthed container showed half explosion. Their lowest incident laser flux densities were as follows; 32.0, 32.6, 32.6, and 36.0W/cm². However, TNT, PA, AN, and Comp. B did not explode up to ca. 50W/cm².

3.2.2 The effect of irradiation area

The effects of window diameter on explosion of some explosives are shown in Table 5.

Table 4 Experimental results of some explosives confined in sealed container

Explosives Run No.	Incident laser flux density (W/cm^2)	Moniter beam power (W)	Incident beam power (W)	KBr disk transmittance (%)	Judgment	Ignition time (s)	Ignition energy (J)
HMX-1	33.0	2.20	19.2	48.6	△2	5.97	55.6
HMX-2	46.3	2.06	18.0	72.9	△1	2.31	30.2
HMX-3	50.3	1.83	16.0	89.1	○	–	–
HMX-4	31.9	1.42	12.4	72.9	△2	6.86	61.9
RDX-1	48.3	2.00	17.4	78.3	△2	5.05	41.6
RDX-2	41.6	1.85	16.1	72.9	△2	10.11	118.9
RDX-3	36.0	1.80	15.7	64.8	△2	11.41	116.0
RDX-4	39.6	1.40	12.2	91.8	△2	4.30	48.2
PETN-1	50.6	2.25	19.6	72.9	△2	0.90	12.9
PETN-2	32.6	1.70	14.8	62.1	△2	4.00	36.8
PETN-3	59.9	2.40	20.9	81.0	△1	5.02	85.1
PETN-4	35.0	1.50	13.1	75.6	△2	1.06	10.5
Tetryl-1	54.4	2.00	17.4	88.2	△1	3.93	60.4
Tetryl-2	32.6	1.40	12.2	75.6	△2	10.62	98.0
Tetryl-3	35.1	1.62	14.1	70.2	△2	5.02	49.8
Tetryl-4	38.7	1.72	15.0	72.9	○	–	–
TNT-1	40.7	2.10	18.3	62.8	○	–	–
TNT-2	49.7	1.85	16.1	87.2	○	–	–
TNT-3	33.8	1.60	14.0	68.6	○	–	–
TNT-4	31.2	1.40	12.2	72.2	○	–	–
PA -1	34.9	1.40	12.2	80.8	○	–	–
PA -2	41.2	1.62	14.1	82.4	○	–	–
PA -3	49.3	2.10	18.3	76.2	○	–	–
PA -4	48.9	2.20	19.2	72.1	○	–	–
AN -1	27.6	1.38	12.0	64.8	○	–	–
AN -2	39.4	1.62	14.1	78.8	○	–	–
AN -3	50.0	1.96	17.1	82.8	○	–	–
AN -4	43.8	2.21	19.3	64.2	○	–	–
Comp. B-1	36.1	1.38	12.0	84.8	○	–	–
Comp. B-2	43.0	1.70	14.8	82.1	○	–	–
Comp. B-3	43.3	1.93	16.8	72.8	○	–	–
Comp. B-4	54.7	2.25	19.6	78.9	○	–	–

Without reinforcement; Window diameter: 3.5 mm ; PA: picric acid; AN: ammonium nitrate

With reinforcement, the ignition time of RDX decreased with increasing the window diameter. The incident laser flux density at 5mm window diameter was four times stronger than that at 2.5mm diameter and the ignition time was expected to be one forth but it was about half in this experiment. Without rein-

Table 5 Effects of irradiation area and reinforcement on explosion of some explosives

Explosives Run No.	Incident laser flux density (W/cm²)	Moniter beam power (W)	Incident beam power (W)	KBr disk transmittance (%)	Window diameter (mm)	Reinforcement	Judgment	Ignition time (s)	Ignition energy (J)
RDX-1	47.0	1.93	16.8	79.0	2.5	Yes	×	2.67	35.5
RDX-2	33.7	1.92	16.7	57.0	2.5	No	△2	2.67	25.5
RDX-3	38.7	1.82	15.9	69.0	3.5	Yes	△2	2.47	27.0
RDX-4	47.1	1.96	17.1	78.0	3.5	No	△2	1.60	21.3
RDX-5	33.3	1.94	16.9	55.6	5.0	Yes	×	1.47	13.8
RDX-6	48.2	1.92	16.7	81.4	5.0	No	△2	3.09	42.1
HMX-1	27.7	1.70	14.8	52.9	2.5	Yes	×	–	–
HMX-2	37.6	2.00	17.4	60.9	2.5	No	△2	–	–
HMX-3	30.8	1.70	14.8	58.8	3.5	Yes	×	–	–
HMX-4	38.8	1.90	16.6	66.3	3.5	No	△2	–	–
HMX-5	35.1	1.70	14.8	66.9	5.0	Yes	×	–	–
HMX-6	42.5	1.92	16.7	71.8	5.0	No	△2	–	–
PETN-1	34.6	1.90	16.6	59.0	2.5	Yes	○	–	–
PETN-2	26.2	1.60	14.0	53.1	2.5	No	△2	–	–
PETN-3	41.1	1.60	14.0	83.2	3.5	Yes	×	–	–
PETN-4	44.4	1.95	17.0	73.9	3.5	No	△2	–	–
PETN-5	44.8	1.86	16.2	78.1	5.0	Yes	△1	–	–
PETN-6	36.7	1.70	14.8	70.0	5.0	No	○	–	–

forcement, the effect of window diameter was not clear. In this study, the window diameters adopted were either 3 or 3.5mm by considering the 5mm window diameter may weaken the KBr disk.

3.2.3 Effect of reinforcement

The effect of an iron holder on the sealed container for RDX, HMX, and PETN is shown in Table 5.

With an iron holder, 6 out of 9 samples exploded. Without an iron holder none of 9 samples exploded.

Without an iron holder, the following phenomenon was observed in 8 out of 9 samples; the shell was broken by the force of combustion gas and unreacted sample was scattered before the explosion.

3.2.4 Effect of additive

Effects of active carbon on explosion of some explosives in a sealed container with reinforcement are shown in Table 6. Addition of active carbon generally shortened the ignition time, but weakened the detonation strength which was judged by the damage of the lead plate. HMX, RDX, and PETN perforated a lead plate without active carbon but their active carbon mixture could not perforate a lead plate. It implied that the mixtures were not suitable for a cap's charge. Generally the absorbances of explosives at 10.6μm were high without additives, the effect of active carbon was relatively small.

In the case of explosive in an open-mouthed container, the explosive vaporized and revealed fresh surface during irradiation. It was probable that an explosive containing additive absorbed more laser light than the pure explosive and shortened the ignition time. But in the sealed container, explosive melted and even some parts vaporized and the vaporized ex plosive absorbed laser and the effect of additive became less effective. In the case of the ruby laser initiation of explosives, addition of active carbon decreased ignition energies remarkably because at the ruby laser wavelength absorbance of explosives were relatively small[7]. And the ignition time was in the order of μs which was much shorter than those of the

Table 6 Effects of active carbon on ignition time of some explosives confined in sealed container

Explosives Run No.	Incident laser flux density (W/cm^2)	Moniter beam power (W)	Incident beam power (W)	KBr disk transmittance (%)	AC content (wt%)	Judgment	Ignition time (s)	Ignition energy (J)
HMX-1	41.5	1.59	13.9	84.6	20	△2	4.12	48.3
HMX-2	39.9	1.65	14.4	78.5	20	△2	10.04	113.4
HMX-3	43.2	1.67	14.6	83.9	15	△2	3.96	48.4
HMX-4	36.7	1.66	14.5	71.7	15	△2	11.12	115.4
HMX-5	34.2	1.67	14.6	66.4	10	○	–	–
HMX-6	35.3	1.67	14.6	68.5	10	△2	3.23	32.2
HMX-7	34.7	1.67	14.6	67.4	5	△1	12.01	117.9
HMX-8	36.5	1.67	14.6	70.8	5	△2	5.03	51.9
HMX-9	40.5	1.70	14.8	77.3	0	×	14.00	160.4
RDX-1	39.3	1.64	14.3	77.7	20	△2	2.47	27.4
RDX-2	35.6	1.64	14.3	70.3	20	△2	2.42	24.3
RDX-3	36.7	1.70	14.8	70.0	15	△1	2.70	28.0
RDX-4	38.5	1.70	14.8	73.4	15	△2	1.47	16.0
RDX-5	38.0	1.70	14.8	72.6	10	△1	11.04	18.8
RDX-6	36.9	1.70	14.8	70.3	10	△2	2.30	24.0
RDX-7	36.7	1.70	14.8	70.0	5	△1	3.54	36.7
RDX-8	37.1	1.70	14.8	70.8	5	△2	6.91	72.5
RDX-9	47.4	1.94	16.9	79.2	0	×	4.90	65.6
PETN- 1	45.8	1.80	15.7	82.5	30	△2	3.76	48.7
PETN- 2	43.3	1.80	15.7	78.0	30	○	–	–
PETN- 3	38.7	1.60	14.0	78.4	25	△2	4.58	50.1
PETN- 4	43.3	1.75	15.3	80.2	25	○	–	–
PETN- 5	45.0	1.75	15.3	83.4	20	△2	–	–
PETN- 6	45.1	1.75	15.3	83.6	20	△2	18.18	231.9
PETN- 7	41.2	1.75	15.3	76.4	15	△2	1.74	20.3
PETN- 8	44.7	1.74	15.2	83.4	15	△1	1.72	21.8
PETN- 9	44.5	1.75	15.3	82.4	10	×	1.53	19.2
PETN-10	42.2	1.74	15.2	78.6	10	×	1.30	15.5
PETN-11	37.9	1.54	13.4	79.8	5	△1	1.11	11.9
PETN-12	43.2	1.68	14.7	83.4	5	×	12.33	150.6
PETN-13	47.0	1.88	16.4	81.0	0	×	58.02	770.3
Tetryl-1	39.2	1.78	15.5	71.4	20	△2	1.01	11.2
Tetryl-2	44.4	1.70	14.8	84.7	20	△2	1.14	14.3
Tetryl-3	51.6	2.10	18.3	79.7	15	△2	0.57	8.3
Tetryl-4	–	–	–	80.4	15	○	–	–
Tetryl-5	44.3	1.89	16.5	76.0	10	△2	19.75	247.3
Tetryl-6	40.5	1.50	13.1	87.6	10	△2	–	–
Tetryl-7	46.9	1.82	15.9	83.5	5	○	–	–
Tetryl-8	45.6	1.77	15.4	83.5	5	○	–	–
Tetryl-9	36.0	1.64	14.3	71.2	0	△2	26.52	269.8

With reinforcement; Window diameter: 3 mm ; - : no result; AC: active carbon

CO_2 laser irradiation, the absorbed energy by the vaporized explosive may much smaller in the case of ruby laser irradiation.

3.3 Temperature profile

Typical temperature profiles of HMX, RDX, PETN, and tetryl are shown in Fig. 5. A temperature

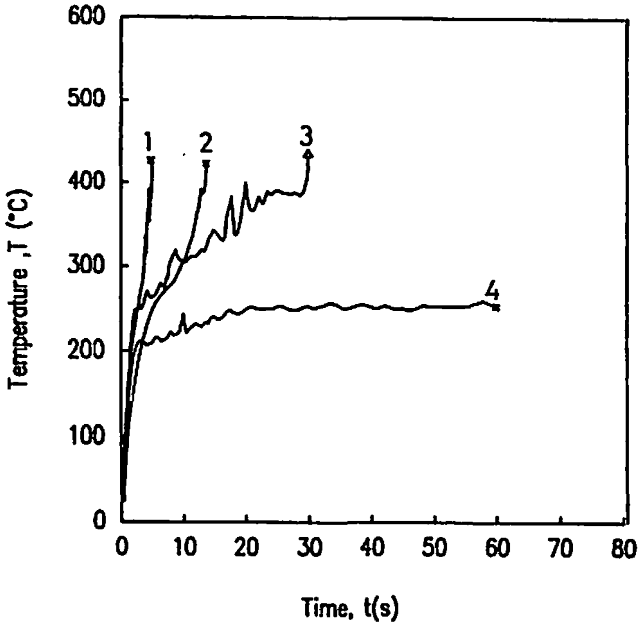

Fig. 5 Typical temperature-time histories of some explosives
1 : RDX; 2 : HMX; 3 : Tetryl; 4 : PETN

Table 7 Ignition temprature and ignition energy of some explosives confined in sealed container

Explosives	Ignition temperature (CO_2 laser) (℃)	Ignition energy CO_2 laser (J)	ruby laser[3] (J)	microwave[4] (kJ)
RDX	425	65.6	0.99-1.2	3.33
HMX	420	160.4	>0.99	3.78
Tetryl	432	269.8	0.39-1.0	2.16
PETN	240	770.3	0.84-0.85	2.72

at which further measurement of temperature became impossible due to the sharp increase of sample temperature was defined as an ignition temperature. The ignition temperatures are shown in Table 7. HMX, RDX, PETN, and tetryl exploded above their m.p's. The temperature profiles of HMX and RDX showed a sharp increase near their m.p.'s. For tetryl and PETN, their m.p.'s were not recognized probably because their temperature rises were too fast to be recorded on the pen and ink recorder. The ignition time of PETN was unexpectedly long. The temperature profile of PETN showed the temperature reached to the ignition temperature (225℃) in a few seconds but did not explode till 60s later.

The ignition temperatures observed were generally higher than the ignition points[6]. Because the thermocouple was placed under the KBr disk, it measured the temperature of the melted explosive which absorbs laser beam and the upper part would show higher temperature than the lower part of explosive due to poor thermal conductivity of explosives.

3.4 Comparison of other heating procedure

Table 7 shows the ignition energies for ruby laser[3] and microwave[4] irradiation.

The ignition energies of some explosives by the CO_2 laser irradiation were 66 to 770 J which located between ruby laser and microwave ignition energies.

The mechanism of explosion of explosives by ruby laser would be caused by shock wave of Q-switch pulse laser and only a very thin surface area was heated. In CO_2 laser, irradiated laser beam heated explosive and it exploded when sample temperature reached its ignition temperature. A thermocouple embedded in a few mm under the surface of an explosive detected no significant temperature rise when a CO_2 laser was irradiated. It indicated that CO_2 laser penetration was not very deep and the melting of explosive was limited on a surface area. In microwave heating, in general, melting of a whole explosive was observed. The ignition energy would depend on the volume of explosives to be heated.

4. Conclusions

Continuous wave CO_2 laser ignition was carried out on HMX, RDX, PETN, tetryl, TNT, PA, AN, and Comp. B and the following conclusions were obtained:

(1) HMX, RDX, PETN, and tetryl were exploded when they were confined in a sealed container with a KBr window.

(2) The explosives tested were separated in three groups after increasing ignition time, the shortest group included HMX, RDX, PETN, and tetryl and the longest group included TNT, PA, AN, and Comp. B was an intermediate.

(3) The ignition time became shorter when the sealed container was inserted in an iron holder.

(4) The ignition temperatures of HMX, RDX, tetryl were higher than their ignition points required to cause ignition in 5s.

(5) Addition of active carbon shortened the ignition time in the case of open-mouthed container.

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CO_2レーザによる爆薬の起爆

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工業加工用に広く用いられている連続波CO_2レーザにより，起爆薬を用いずに，爆薬を直接起爆することを試みた．開放式容器ではいずれの爆薬も爆轟はしなかった．着火時間から判定すると，CO_2レーザに鋭感なものはHMX，RDX，PETN，テトリルで，TNT，ピクリン酸，硝酸アンモニウムは鈍感，コンポジションBはその中間であった．鋭感な4種の爆薬については，密閉容器に入れて，レーザを照射し爆轟の有無を調べた．

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