Initiation of Explosives by Microwave Irradiation

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Initiation of explosives by microwave irradiation has never been reported. In this paper, several explosives were confined in ceramic tubes (hard alumina) and their reactions by microwave irradiation were observed. It was found that dynamite was initiated by microwave irradiation but emulsion explosive was not initiated because evaporated water component's pressure caused openings between glass plugs and the ceramic tube.

PETN, RDX, tetryl, and HMX were able to be initiated at 2. 5kW microwave power levels but PETN, RDX, and tetryl were not initiated at 1. 5kW microwave power levels. The frequency of a CW 5kW microwave power source was 2450±50 MHz.

By mixing additives such as silicon carbide or active carbon, PETN, RDX, and tetryl were initiated at 1. 5kW microwave power levels.

1. Introduction

The microwave region of the electromagnetic spectrum may be defined as the frequency range between 1, 000 MHz and 30, 000 MHz. Microwave techniques are being adopted increasingly in such diverse applications as radio astronomy, long-distance communication, navigation, microwave oven, and the study of physical and chemical properties of matter[1]. The destruction of building materials and rocks by microwave irradiation has become of interest in recent years[2][3][4]. However, initiation of explosives by microwave irradiation has not been reported.

In this report, explosives were confined in a strong ceramic container which was placed in a rectangular waveguide and the reaction by microwave irradiation was observed.

The absorbed power P, which is produced by microwave dielectric heating is given by the following equation[1],

$$P=(5/9)\,f\varepsilon_s \tan\delta E\, 10^{-12}\ \ (\mathrm{W/cm^3}) \qquad (1)$$

where f is frequency (Hz), ε_s is relative permittivity, tan δ is dielectric loss, and E is electric field intensity (V/cm).

In the above equation, if the value of f and E are constant, then P depends on both ε_s and tan δ of the explosive. Because ε_s of water, which has a large dielectric loss, is 80 and ε_s of polyethylene, which has a small dielectric loss, is 2. 3[5], the difference of ε_s in explosives was expected to be about two orders.

On the other hand, the difference of tan δ in explosives might be four to five orders.

Therefore, it was expected that some explosives which have large dielectric losses could be initiated by microwave irradiation while other explosives with small dielectric losses could also be initiated by means of mixing with some materials with large dielectric losses.

2. Experimental

2. 1. Explosives

Explosives used in this paper were dynamite (No. 2 Enoki), emulsion explosive, PETN, RDX, tetryl, and HMX.

Silicon carbide and active carbon were used as

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Table 1 Dielectric loss of explosives and additives

Sample	Dielectric loss ($\tan\delta$)
Emulsion explosive	Not measurable
Dynamite	Not measurable
PETN	3.0×10^{-3}
RDX	6.7×10^{-4}
Ammonium nitrate	6.2×10^{-4}
Tetryl	5.5×10^{-4}
TNT	1.2×10^{-4}
HMX	2.9×10^{-5}
Silicon carbide	Not measurable
Active carbon	Not measurable
Graphite	Not measurable
Charcoal	8.4×10^{-3}

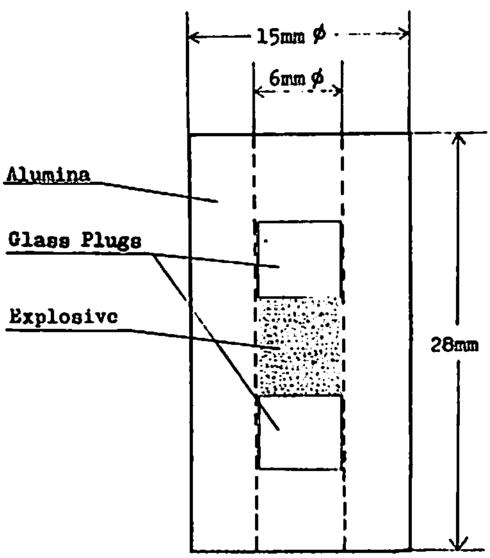

Fig. 1 Sample tube configurations

additives because of their large dielectric losses. These materials' dielectric losses are shown in Table. 1 The dielectric loss was measured by placing the sample in a maximum electric field of a rectangular cavity resonator at room temperature.

The weight of explosives ranged from 0. 2g to 0. 45g and they were confined in hard alumina tubes, as shown in Fig. 1. Alumina's bending strength is 3, 276kgf/cm^2, compression strength is 28, 875kgf/cm^2, and Mohs' scale of hardness is 9[6].

Both ends of the containers were closed by glass plugs (6mm in diameter, 5mm in height) using epoxide resin additive on the insides of container walls.

2.2 Experimental apparatus

The experimental arrangements are shown in Fig. 2. The power souce was a continuous wave 5 kW magnetron and its frequency was 2450 ± 50 MHz. The incident power P_0 was measured by a power meter connected to a directional coupler.

Since the power divider can divide microwave power arbitrarily into either a sample chamber or a microwave water load, the incident power to the sample chamber was easily varied from 75W to 2. 5 kW.

The circulator is a device which couples only in one direction; the arrow in Fig. 2 shows the coupling direction. The circulater made microwaves propagate to the sample chamber and reflected microwaves from the chamber wall propagate to the microwave water load. Water is well known as a good microwave absorbent. The microwave water load was used as a device to absorb unnecessary microwaves.

The directional coupler separates the incident microwave from the reflected microwave and the incident microwave power was measured by the power meter.

The sample chamber was made of 3mm thick mild steel plates with many 2mm holes. The sample chamber was coupled with the waveguide. And a 5mm polyethylene plate, which has a small dielectric loss, was inserted between them to protect the waveguide from explosion fragments.

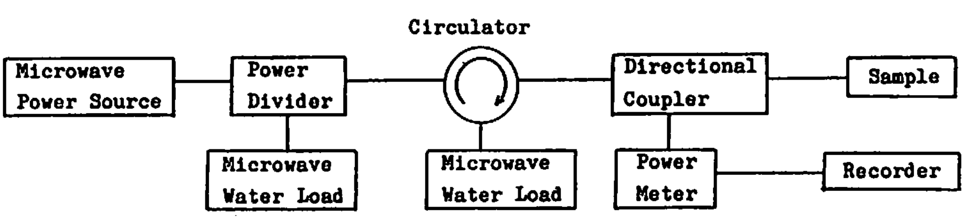

Fig. 2 Block diagram of experimental apparatus

A hard alumina tube which contained explosive was placed in the sample chamber at the point of maximum intensity in the electric field. The position of the maximum intensity is one-fourth of a guide wavelength from the short circuit of the sample chamber, as shown in Fig. 3.

2.3 Judgement criteria of explosion

Explosion and no explosion judgment criteria are shown in Table 2. The sample tube was completely shattered in explosion, broken into several fragments in half-explosion, and held its original shape in no-explosion.

3. Results

The experimental results of some explosives with large dielectric loss are shown in Table 3. Dynamite was initiated and emulsion explosive was not initiated at 1.5kW microwave power levels.

PETN, RDX, tetryl and their mixture with silicon carbide or active carbon were irradiated by 1.5kW microwave and the results are shown in Table 4. PETN, RDX, and tetryl were not initiated. But their mixtures with silicon carbide or active carbon were intiated at 1.5kW microwave power levels.

The results of 2.5kW microwave irradiation on PETN, RDX, tetryl, HMX, and their mixtures with silicon carbide or active carbon are shown in Table 5. PETN, RDX, tetryl, and HMX were initiated without additives at 2.5kW microwave power levels.

4. Discussion

To initiate explosives by microwave irradiation, explosives had to be confined in sample tubes till the temperature of the explosives exceeded their ignition temperature. A larger microwave power

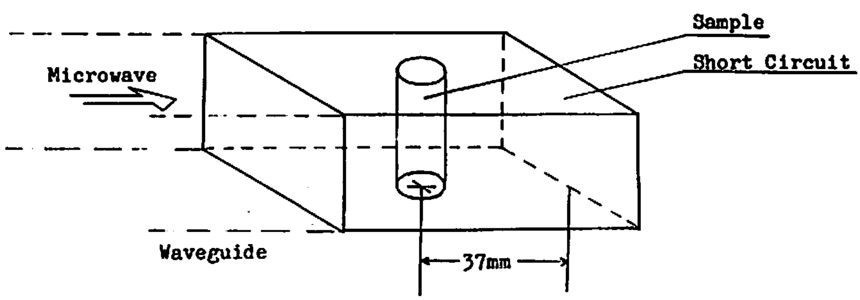

Fig. 3 Sample chamber configurations

Table 2 Explosion judgment criteria

Judgment	Criteria
Explosion (○)	Sample tube was shattered into small pieces and little of explosive was left unreacted.
Half-explosion (△)	Sample tube was broken into several pieces and some part of explosive was left unreacted.
No-explosion (×)	Sample tube held its original shape and some part of explosive burned ostside of the tube or smoke was observed.

Table 3 Reaction of explosives by microwave irradiation

Explosive	No additive	With silicon carbide
Emulsion explosive	×	×
Dynamite	○	○

1.5kW microwave power levels

Table 4 Reaction of explosives by microwave irradiation

Explosive	PETN		RDX		Tetryl	
Additive / Additivi content (%)	SiC	AC	SiC	AC	SiC	AC
0	×		×		×	
10	○	○	○	○	△	△
20	○	○	△	○	△	△
30	○	○	○	○	○	△
40	○	○	△	○		
50	×	○	×	○		
60		○	×	×		
70		×	×	×		

1.5kW microwave power levels
SiC, silicon carbide; AC, active carbon

Table 5 Reaction of explosives by microwave irradiation

Explosive	PETN		RDX		Tetryl		HMX	
Additive / Additive content (%)	SiC	AC	SiC	AC	SiC	AC	SiC	AC
0	○		○		○		○	
10	○	○	○	○	×	○	○	○
20	○	○	○	○	○	○	×	×
30	○	○	○	○	×	○	×	△
40	○	○	○	○	×	×	×	○
50	○	△	△	○	×	×	×	×
60	○	○	○	×	×	×	×	×
70	○	×	×	×			×	×

2.5kW microwave power levels
SiC, silicon carbide; AC, active carbon

and stronger container would be preferable when initiating explosives.

The strength of a container depends on the strength of a tube as well as the strength of plugs. Although the strength of the container might vary with the adhesive conditions, the initiation results of explosives were consistent except in a few cases.

Because of its large dielectric loss, dynamite exploded with or without the additives when the incident power was 0.9kW. The reason for dynamite's large dielectric loss was not clear.

Eventhough emulsion explosive has a large dielectric loss, it was not initiated with or without the additives. The reason for no-explosion of emulsion explosive was that water in the explosive was evaporated by microwave heating and the steam's high pressure broke the seal and the explosive eventually leaked out of the opening and burned outside the container. C・H・N・O explosives were initiated without the additives at 2.5kW microwave power levels but they were not initiated without the additives at 1.5kW microwave power levels. Mixing the additives, especially active carbon, with C・H・N・O explosives lowered the critical initiation energy of them.

The order of the initiation sensitivity by microwave irradiation was PETN, RDX, tetryl, and HMX and that was the same order of their dielectric loss.

Table 6 Reflectivity and the power absorbed

Sample	Reflectivity	P'/P_0
Emulsion explosive	0.86	0.26
Dynamite	0.95	0.10
PETN with 5% SiC	0.96	0.08
Sample tube	0.95	0.10

P', power absorbed by a sample;
P_0, incident power

The reflectivity of hard alumina tubes and some explosives which were confined in the hard alumina tubes are shown in Table 6. The reflectivity of emulsion explosive was lower than that of the hard alumina tubes. This indicated that emulsion explosive was easily heated by microwave irradiation because of its water component. On the contrary, because PETN with 5% silicon carbide had large reflectivity, it would be difficult to raise its tempera ture by microwave irradiation.

P', the power absorbed by sample, is given by the following equation,

$$P' = P_0 (1 - |\Gamma|^2) \quad (2)$$

where P_0 is incident power and Γ is voltage reflectivity.

From 8% to 26% of irradiation power was absorbed by the samples, as shown in Table 6. The strength of the hard alumina tube was enough to make some explosives explode but the reflectivity of samples seemed too large. Methods of lowering the reflectivity will be sought. The microwave initiation of the secondary explosives without additives would be useful for safer underwater explosions than the conventional methods.

5. Conclusion

Initiating six explosives, with or without additives such as silicon carbide and active carbon, by microwave irradiation was investigated.

The main conclusions are as follows.

(1) Explosives were able to be initiated by microwave irradiation.

(2) Dynamite, which has a large dielectric loss, was easily initiated but emulsion explosive, which also has a large dielectric loss, was not initiated by microwave irradiation because the water in emulsion explosive was evaporated by microwave heating and the generated steam pressure broke the seal of the container.

(3) C•H•N•O explosives such as PETN, RDX, tetryl, and HMX were initiated at 2.5kW microwave power levels. PETN, RDX, and tetryl were not initiated without additives, such as silicon carbide or active carbon, but they were initiated with the additives at 1.5kW microwave power levels. In C•H•N•O explosives, the order of initiation sensitivity was the same as that of their dielectric loss.

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マイクロ波による火薬類の起爆

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現在のところマイクロ波を照射して火薬類を起爆したという報告はない。そこで，硬質アルミナ管に密閉した火薬類に対して，マイクロ波を照射し，その起爆状況を観察した。ダイナマイトはマイクロ波に対して非常に鋭感であった。エマルション爆薬は加熱中に水分の蒸発により密閉が破されるので爆発しなかった。PETM, RDX, テトリル，HMX などの C・H・N・O 系化合火薬類は，電力が小さいと不爆であるが，電力が大きいと起爆できた。電力が小さくても炭化けい素，活性炭など誘電損失の大きい物質を添加すれば起爆できた。

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