Research paper

Study on the shock sensitivity of an emulsion explosive by the sand gap test

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Abstract

The gap test has been widely used as the shock sensitivity test for explosives. Shock sensitivity determined by the gap test is one of the important safety measures for explosives.

A specimen consisting of a vinyl chloride tube and two mortar discs filled with sand was used as the gap material, and an emulsion explosive widely used as a commercial explosive with comparatively high shock sensitivity was used for the donor and acceptor charges. Both charges had a cylindrical shape with the ratio of the length to the diameter (L/D) being set to 1. The thickness of the sand layer between the two mortar discs of a constant thickness was adjusted by changing the height of vinyl chloride tube.

The objective of this study was to obtain basic data on sympathetic detonation experimentally. We studied the shock sensitivity of different amounts of explosives by the gap test method to clarify the scale effects.

The experiments were conducted with four amounts of explosives, i.e., 20 g, 160 g, 1.25 kg and 5 kg, and the relationship between the gap thickness and amount of explosives was determined. The following results were obtained.

1) It was possible to determine the each boundary between sympathetic detonation and non-detonation within the range of 2.5 mm, 5 mm, 10 mm, and 20 mm, where the respective critical gap lengths were 14.2 mm, 33.1 mm 90.4 mm, and 130.4 mm for explosive amount of 20 g, 160 g, 1.25 kg, and 5 kg, respectively.
2) There was found to be a linear relationship between the critical gap length and the amount of explosives on the logarithmic scale.

Keywords: Shock sensitivity, Sympathetic detonation, Sand gap test, Scale effects, Emulsion explosive

1. Introduction

In the assessment of the safety of storage facilities for explosives, it is necessary to investigate the blocking effects of sympathetic detonation by a partition wall. If the sympathetic detonation of the adjoining cell can be obstructed by installing a partition wall in a magazine, the safe distance can be decreased because the explosive amount is considered to be reduced by 1/2. A structure where sand fills in between two concrete or mortar walls can contribute to the strength of the concrete or mortar and the sand can reduce the effects of the shock pressure [1), 2)].

An emulsion explosive with a comparatively high shock sensitivity was chosen from among the multipurpose commercial explosives currently being used and was examined based on the scale rules for the gap test with a gap material to imitate the partition wall structure.

In this study, the gap tests with mortar discs and sand fill (hereafter, referred to as mortar + sand.) were conducted. In order to clarify the scale effects in the shock sensitivity, laboratory experiments with 20 g, 160 g, and 1.25 kg of an emulsion explosive for the donor and accepter charges and field explosion experiments with 5 kg of an emulsion explosive for the donor and accepter charges were carried out.

2. Experiment

2.1 Explosives and assembly

An emulsion explosive was used for the donor and acceptor charges. The composition is shown in Table 1.

A schematic drawing and photographs of a sand gap test

Table 1 Formulation of the emulsion.

Oxidizer	Water	Fuel	GMB*	Others
73.2 %	10.8 %	6.5 %	4.6 %	4.9 %

* Glass micro balloon

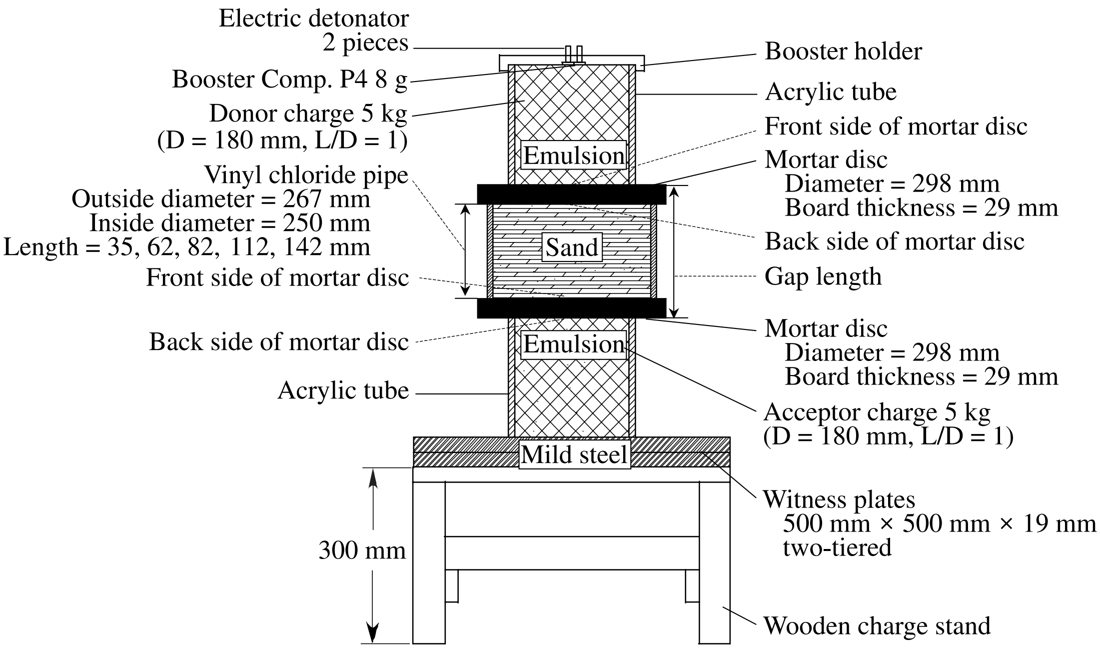
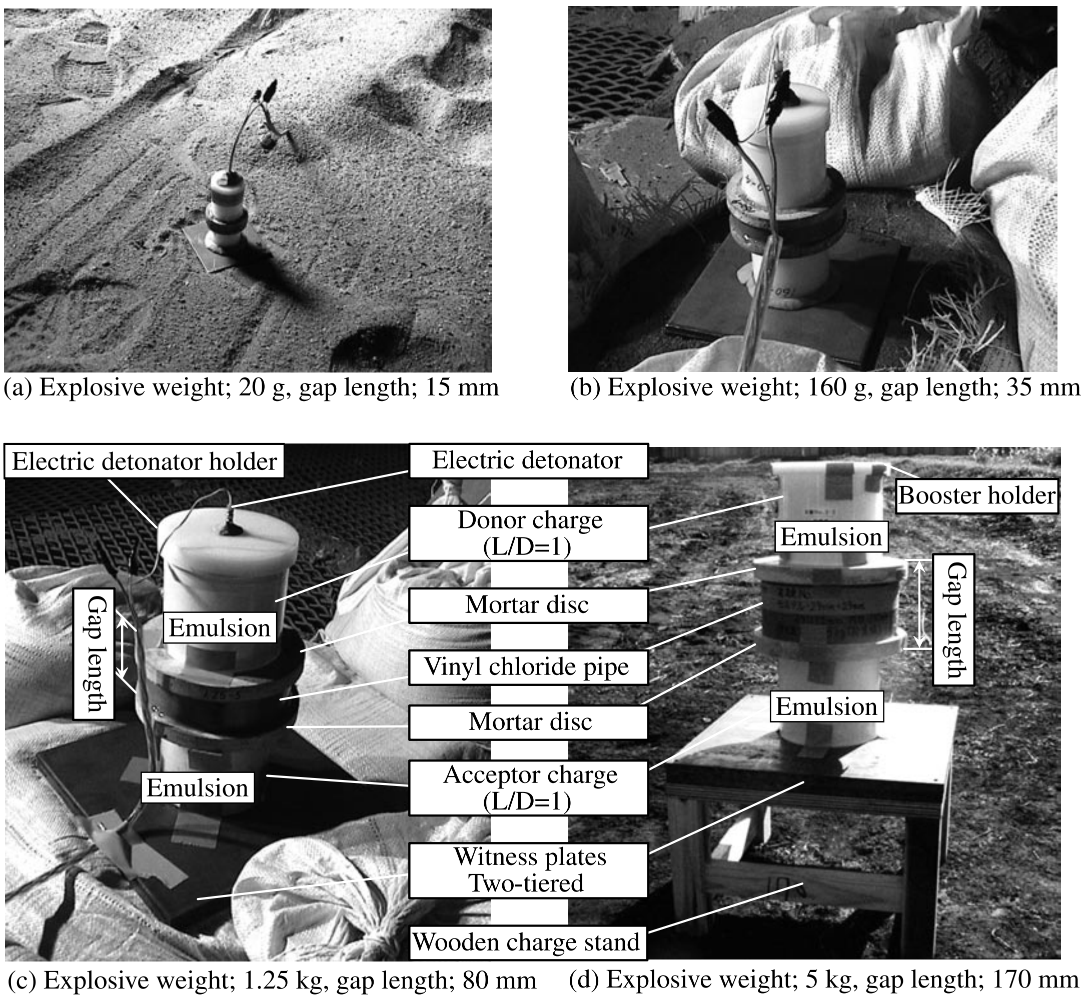


Fig. 1 Experimental setup for the sand gap test in the field explosion experiment.



(a) Explosive weight; 20 g, gap length; 15 mm

(b) Explosive weight; 160 g, gap length; 35 mm

(c) Explosive weight; 1.25 kg, gap length; 80 mm

(d) Explosive weight; 5 kg, gap length; 170 mm

Fig. 2 Photographs of sand gap test devices.

Table 2 Sizes of each part of the test devices.

Explosive weight	Acrylic tube		Mortar disc		Vinyl chloride pipe		Witness plate (mm)
	Diameter (mm)	Length (mm)	Diameter (mm)	Thickness (mm)	Outside diameter (mm)	Outside diameter (mm)	
5 kg + 5 kg	180.0	180.0	298	29.0	267	250	500×500×19
1.25 kg + 1.25 kg	113.0	113.0	188	17.5	165	146	320×320×12
160 g + 160 g	57.0	57.0	95	9.0	89	83	160×160× 6
20 g + 20 g	28.5	28.5	48	4.5	48	40	80× 80× 3

Table 3 Gap material specification.

	Mortar disc	Sand for partition wall
Material	Water : Cement : Aggregate	Soma sand
Mixing (% by weight)	10:30:60	100
Apparent density ($g \cdot cm^{-3}$)	2.15 – 2.30	1.52
Compressive strength ($N \cdot mm^{-2}$)	53.2 – 60.3	—
Tensile strength ($N \cdot mm^{-2}$)	3.4 – 6.1	—
Grain size (mm)	0.15 – 2.5	0.425 – 1.7
Remarks	—	Natural silica sand Standard sample of strength test etc. on cement

Table 4 Particle size distribution of the sand for the partition wall.

Grain size (mm)	0.425	0.600	0.850	1.180	1.700
Passage percent (by wt.)	0-3 %	10-15 %	55-72 %	15-25 %	0-5 %

device are shown in Fig. 1 and Fig. 2, respectively, and the sizes of the devices are shown in Table 2. The donor and acceptor charges were set up respectively at the top and bottom of the gap material, and the lower side of the acceptor charge was set on a witness plate that could touch it.

An emulsion explosive added into an acrylic resin was used and its density was adjusted to 1.10-1.15 $g \cdot cm^{-3}$ [3]. The ratio of the length to the diameter (L/D) was set to 1. A booster holder made of polyethylene with Composition P4 (hereafter, referred to as Comp. P4) booster was set on the emulsion cylinder. In the field explosion experiments, the emulsion explosive serving as the donor charge was detonated by two electric detonators. In the laboratory scale experiments, Comp. P4 was not used, and the donor charge was detonated by one electric detonator.

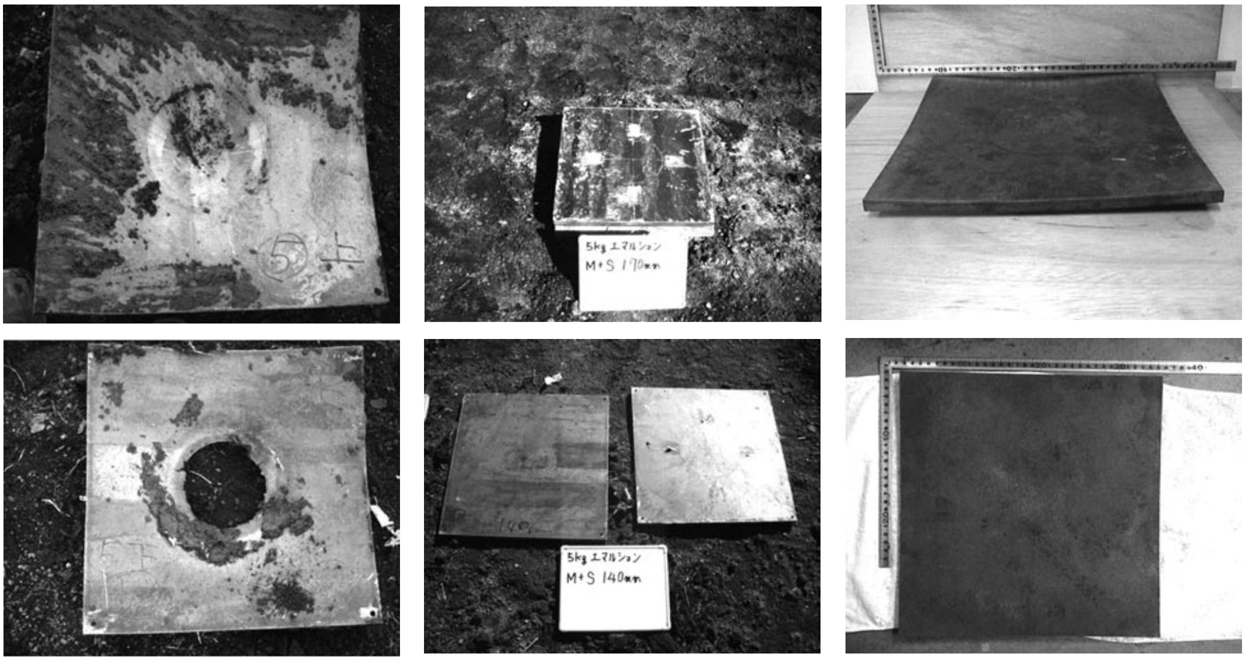
2.2 Gap material

The components of mortar are more uniform than those of concrete and the reproducibility of the experiments could also be expected to be better using mortar than concrete. Therefore, in this study, mortar was used as the gap material. It was decided to make the diameter of the mortar discs 1.66 times that of the explosive in accordance with the Japan Explosives Society standard [4]. Natural silica sand was used as the sand for the partition wall.

The gap material for the partition wall was produced by loading sand in between the two constant thickness mortar discs. The sand was supported using a vinyl chloride tube. The loading density of the sand was adjusted to 1.6 $g \cdot cm^{-3}$. The thickness of the sand layer was adjusted using vinyl chloride tubes of various lengths. The total gap length was therefore defined by adding the thickness of the two mortar discs to the length of the vinyl chloride tube filled with sand.

The specifications of each gap material are tabulated in Table 3. There was a difference in surface roughness on the front side and the back side of the mortar disc. One side of the disc was polished to fine-tune the thickness and to smooth its surface, and the aggregate section was exposed. On the other hand, small holes due to bubbles were apparent, but hardly any aggregate was visible on the other side (unpolished). In this study, the polished side was made the back side of mortar disc, and the other side was made the front side of mortar disc.

The particle size distribution of the sand for the partition wall is tabulated in Table 4. The foreign object such as clay was removed from the mined original sand by washing in clear water. In addition, the particle size has been adjusted by sifting out to 0.425-1.7 mm though it was considerably all of a size at this point.



(a) Detonated
Explosive weight; 5 kg
Gap length; 120 mm
Under side of acceptor charge (above)
On ground side (below)

(b) Not-detonated
Explosive weight; 5 kg
Gap length; 170 mm (above)
Gap length; 140 mm (below)

(c) Detonated incompletely
Explosive weight; 1.25 kg
Gap length; 90 mm
Under side of acceptor charge (above)
On ground side (below)

Fig. 3 Damage on the witness plates collected after the explosion experiments.

3. Results and discussion

3.1 Damage states of the witness plates

Figure 3 shows photographs of witness plates made of mild steel collected after the explosion experiments.

The judged result of Fig. 3(a) depicts the detonation of the accepter charge. The witness plate just under the acceptor charge was greatly distorted, and a hole was opened to it on the ground side. In addition, no remaining unexploded explosive was discovered on the witness plate under the acceptor charge or in its vicinity.

The judged result of Fig. 3(b) depicts non-detonation of the accepter charge. Neither of the two witness plates piled up were distorted. In addition, remaining unexploded explosives were discovered on the witness plate under the acceptor charge and in its vicinity.

The judged result of Fig. 3(c) depicts incomplete detonation of the accepter charge. Their distortion was obviously less than in the case of sympathetic detonation, and no hole was opened to either witness plate. However, no remaining unexploded explosives were discovered on the witness plate under the acceptor charge and in its vicinity. The reaction appears to be an incomplete detonation, though the acceptor charge reacted in this case. It was difficult to categorize the damage to the witness plates either as a sympathetic detonation or non-detonation, and the result was judged to be an incomplete detonation. In that sense, the gap length in the result judged to be an incomplete detonation is thought to be very close to the critical gap length.

If the shortest thickness in gap length judged to be a non-detonation is assumed to be L_n, and the longest thickness in gap length judged to be a sympathetic detonation is assumed to be L_d, the critical gap length (L_c) is expressed as

$$L_c = \sqrt{L_n \times L_d}\ .$$

In addition, the length judged to be an incomplete detonation is assumed to be the critical gap length in this study.

3.2 Effect of the weight of the explosive on the shock sensibility

The scale effects on the shock sensitivity of an emulsion explosive are indicated in Table 5. When 15.4 mm thick gap material was used, the result was judged to be non-detonation, though a sympathetic detonation occurred upon using 13.1 mm gap material in the laboratory experiments with 20 g of the explosive. It was then predicted that the accepter charge would be judged a non-detonation under the condition where 30.6 mm gap material is used in a laboratory experiment separately executed with a 160 g explosive corresponding to eight times 20 g in weight (double the scale). However, a sympathetic detonation actually occurred in that condition, and the accepter charge was judged a non-detonation upon using 35.6 mm gap material. Sympathetic detonation occurred despite the use of 70.3 mm gap material, and the accepter charge was judged a non-detonation when 101.4 mm gap material was used in laboratory experiments with 1.25 kg explosive corresponding to eight times 160 g in weight (double the scale). The peculiar effect of the scale on the explosion phenomena

Table 5 The scale effect on the shock sensitivity of the emulsion explosive.

Explosive weight	Thickness of sand layer (mm)	Thickness of mortar disc (mm)		Gap length (mm)	Judge*
		Put on the top	Put on the bottom		
5 kg + 5 kg	35.0	29.6	29.6	94.1	○
	62.0	29.3	29.2	120.4	○
	81.9	29.1	29.4	140.4	×
	110.9	29.4	29.3	169.6	×
	141.5	29.1	29.4	200.0	×
1.25 kg + 1.25 kg	34.9	17.7	17.7	70.3	○
	44.7	17.6	17.7	80.0	○
	55.0	17.8	17.7	90.4	△
	64.7	18.3	18.4	101.4	×
160 g + 160 g	11.6	9.7	9.3	30.6	○
	17.1	9.6	9.0	35.6	×
	21.6	9.8	10.2	41.6	×
20 g + 20 g	0	4.9	4.8	9.7	○
	3.5	4.9	4.6	13.1	○
	5.7	5.0	4.7	15.4	×
	11.0	4.7	4.6	20.3	×

Explosive weight	L_n (mm)	L_d (mm)	L_c (mm)
5 kg + 5 kg	140.4	120.4	130.4
1.25 kg + 1.25 kg	101.4	80.0	90.4
160 g + 160 g	35.6	30.6	33.1
20 g + 20 g	15.4	13.1	14.2

* ○; Detonated, ×; Not-detonated, △; Detonated incompletely

of explosives is enumerated as a reason for the results obtained in these experiments.

In the field explosion experiments with a 5 kg explosive, five lengths of gap material, 94.1 mm, 120.4 mm, 140.4 mm, 169.6 mm, and 200.0 mm were used as a result of the preliminary experiments. The acceptor charges were judged a non- detonation when 140.4 mm or thicker gap material was used, though sympathetic detonation occurred when 120.4 mm or thinner gap material was used.

It was possible to delimit the boundary between sympathetic detonation and non-detonation within a range of 2.5 mm – 20 mm through experiments with 20 g – 5 kg emulsion explosive. Moreover, the relationship between the weight of the explosive and the critical gap length exhibited a straight line in the log - log plot, as shown in Fig. 4. The power law between the gap length and the weight of the explosive was approved.

If L is gap length and W is weight of the explosive (20 g ≦ W ≦ 5 kg), the approximation is expressed as

$$L = AW^{b}.$$

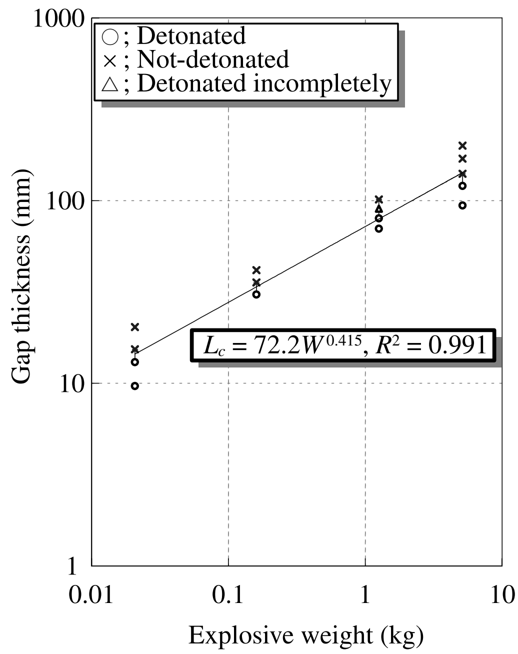


Fig. 4 Variation of the shock sensitivity of the emulsion explosive with the weight of explosive.

and, L_n, L_d and L_c are expressed as

$$L_n = 78.9W^{0.417}, R^2 = 0.988.$$

$$L_d = 65.9W^{0.412}, R^2 = 0.995.$$

$$L_c = 72.2W^{0.415}, R^2 = 0.991.$$

The coefficients of determination (R^2) shows the accuracy of the predictive value to the actual data by an approximate curve, and the accuracy of the approximated curve rises as this value approaches one[5].

It is suggested that this scale rule enabled the extrapolation presumed from these experiments.

4. Conclusions

Sand gap tests with four amounts of explosives, i.e., 20 g, 160 g, 1.25 kg, and 5 kg were conducted by using mortar + sand for the gap material, and using emulsion explosive for the donor and accepter charges, to clarify the relationship between gap thickness and sympathetic detonation and the effects of the amount of the explosive on shock sensitivity. The results obtained are as follows:

1) It was possible to determine the boundary of each sympathetic detonation and non-detonation within the range of 2.5 mm, 5 mm, 10 mm, and 20 mm, and the respective critical gap lengths were 14.2 mm, 33.1 mm, 90.4 mm, and 130.4 mm for explosive amount of 20 g, 160 g, 1.25 kg, and 5 kg, respectively.
2) There was found to be a linear relationship between the amount of explosive and the critical gap length in the log - log plot in the range of 20 g - 5 kg of explosives. It is suggested that this scale rule enabled the presumed extrapolation.
3) It is necessary to improve the certainty of the scale rule by collecting as large an amount of experimental data as possible on explosives in the future to deduce the relationship between gap thickness and sympathetic detonation and the effects of the amount of explosive on shock sensitivity in relation to the amount of explosive of a real scale.

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砂を緩衝材として用いたエマルション爆薬のギャップ試験

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ギャップ試験は爆薬の衝撃起爆感度試験として広く行われている。ギャップ試験によって決定される衝撃起爆感度は，爆薬の重要な安全対策の１つである。

ギャップ材は，砂を装填した塩ビ管を２枚のモルタル円板で挟むことによって製作し，励爆薬，受爆薬には比較的衝撃感度の高い産業爆薬として広く使用されているエマルション爆薬を用いた。爆薬試料はいずれも直円柱状で，その高さと直径の比 (L/D) は，1 とした。一定の厚さの２枚のモルタル円板で挟まれた砂の層の厚さは，塩ビ管の高さを変化させて調整した。

本研究では，殉爆に関する基礎データを実験的に取得し，衝撃起爆感度の薬量効果に関して検討するため種々の薬量のギャップ試験を行った。

20 g，160 g，1.25 kg 及び 5 kg の 4 種類の薬量で実験を行い，ギャップ材厚さと薬量の関係を求め，以下の結果を得た。

1）殉爆，不爆の境目は薬量 20 g，160 g，1.25 kg 及び 5 kg に対し，各々 2.5 mm，5 mm，10 mm 及び 20 mm の範囲で詰めることができ，限界ギャップ長は，各々 14.2 mm，33.1 mm，90.4 mm 及び 130.4 mm であった。
2）薬量と限界ギャップ長の間には，両対数目盛りで直線関係のあることがわかった。

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