Research paper

Study on the simultaneous explosion of fireworks shells by the gap tests in sand
— Judgment on simultaneous explosions and deductions of simultaneous explosion numbers of fireworks shells by pressure and noise measurements —

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Abstract

One of the United Nations Classification Tests, i.e., a 6(b) stack test, was conducted in order to study the classification and its test procedures for fireworks shells. Fireworks shells of 180 mm or larger in diameter are classified as hazard division 1.1 on the classification table. Therefore, the fireworks shells that correspond to such a dangerous division can come under a large handling influence.

The test was conducted by selecting four kinds of samples with different structure, amount of the bursting charge and chemical composition of the star from among the 240 mm color shells (Palm Tree, Butterfly, Brocade Crown and Three color-changing). The inner and external pressure of the shells and the noise generated by the tests were measured to investigate simultaneous explosion, and to deduce the simultaneous explosion number of the shells. The following results were obtained.

1) The acceptor shells caused explosion simultaneously with the donor shell when the inner pressure of the acceptor shells was high.
2) It was possible to deduce effectively the simultaneous explosion number of the shells by measuring the noise.
3) “Butterfly” was classified as hazard division 1.1, and the other shells were classified as 1.3 hazard division candidates.

Keywords: Simultaneous explosion, Fireworks shells, Gap tests in sand, Pressure and noise measurements.

1. Introduction

The hazard division of explosives is judged by the implementation of the tests provided in “Explosives classification tests method of the United Nations recommendation and Manual of Tests and Criteria” (hereafter referred to as “UN Classification Test.”). Although there is a United Nations test series, i.e., the 6(b) stack test, as a classification test method of fireworks, the United Nations Committee of Experts on the Transport of Dangerous Goods is proposing the default table as a method of judging the hazard division of fireworks without testing these classification test methods of fireworks. However, the fireworks shells of 180 mm or larger in diameter are classified as hazard division 1.1 on the classification table. Therefore, the fireworks shells that correspond to such a dangerous division can come under a large handling influence [1].

In this research, the United Nations Classification Tests, the 6(b) stack tests of four kinds of typical color shells of 228 mm in diameter, were conducted to study the default table and test method for fireworks shells. In addition, the inner and external pressure of the shells and the noise generated by the tests were measured to investigate simultaneous explosions, and to deduce the simultaneous explosion number of the shells.

Table 1 Sample specification.

	Serial number		1-1	1-2	2-1	2-2
	Explosives		Sample A	Sample B	Sample C	Sample D
	Number of pieces		Three boxes 12 pieces	Three boxes 12 pieces	Three boxes 12 pieces	Three boxes 12 pieces
	Shell name		Palm tree	Butterfly	Brocade crown	Three color-changing
240 mm color shell – Size and weight	Outside diameter of shell (mm)	A	227	229	228	229
	Inside diameter of shell (mm)	B	210	210	210	210
	Thickness of shell case (mm)	(A-B)/2	8.5	9.5	9.0	9.0
	Total weight of shell (g)	C	4,328	3,622	3,807	3,875
	Weight of shell case (g)	D	1,070	1,070	1,080	1,075
	Total explosive weight of shell (g)	E+F	3,258	2,552	2,727	2,800
	Weight ratio of explosive (-)	(E+F)/C	0.75	0.70	0.72	0.72
	Weight ratio of bursting charge (-)	E/C	0.22	0.34	0.27	0.25
240 mm color shell – Explosive	Weight of bursting charge (g)	E	970	1,225	1,020	970
	Pistil of bursting charge		Cork			
	Total weight of star (g)	F	2,228	1,327	1,707	1,830
	Number of stars (pieces)	G	44	316	322	286
	Weight of star (g/piece)	F/G	52	4.2	5.3	6.4
	Diameter of star (mm)		$48\phi \times 27$ t	17	20	21
	Chemical composition of star		B/P + Ti	B/P + Mg/Al	B/P + Ti	$KClO_4$ divisions
	Chemical composition of bursting charge		$KClO_4$: Charcoal: KNO_3: Starch = 48/26/22/4 (wt.%)			
	Style of packing		Cardboard box (0.487 m × 0.467 m × 0.251 mH = 0.0571 m^3)			
	Manufacture		Abe Industrial fireworks, Ltd.			

2. Experiment

2.1 Explosives

The specification, cross sections and photographs of the sample fireworks shells are shown in Table 1 and Fig. 1 respectively. The amount of bursting charges to cause the explosion sound is about 1 kg, though this differs slightly depending on the kind of shell.

The big stars are encompassed by Japanese paper and arranged along the shell case in the structure of a “Palm Tree” compared with other samples as shown in Fig. 1 (a).

The bursting charge is put in the core in the shell, and the stars are put together to two places and arranged in the structure of a “Butterfly” as shown in Fig. 1 (b).

The structures of “Brocade Crown” and “Three color-changing” are quite similar, as shown in Fig. 1(c) and (d). The stars of “Three color-changing” are a change star of the perchlorate series, while the stars of “Brocade Crown” are a black powder series.

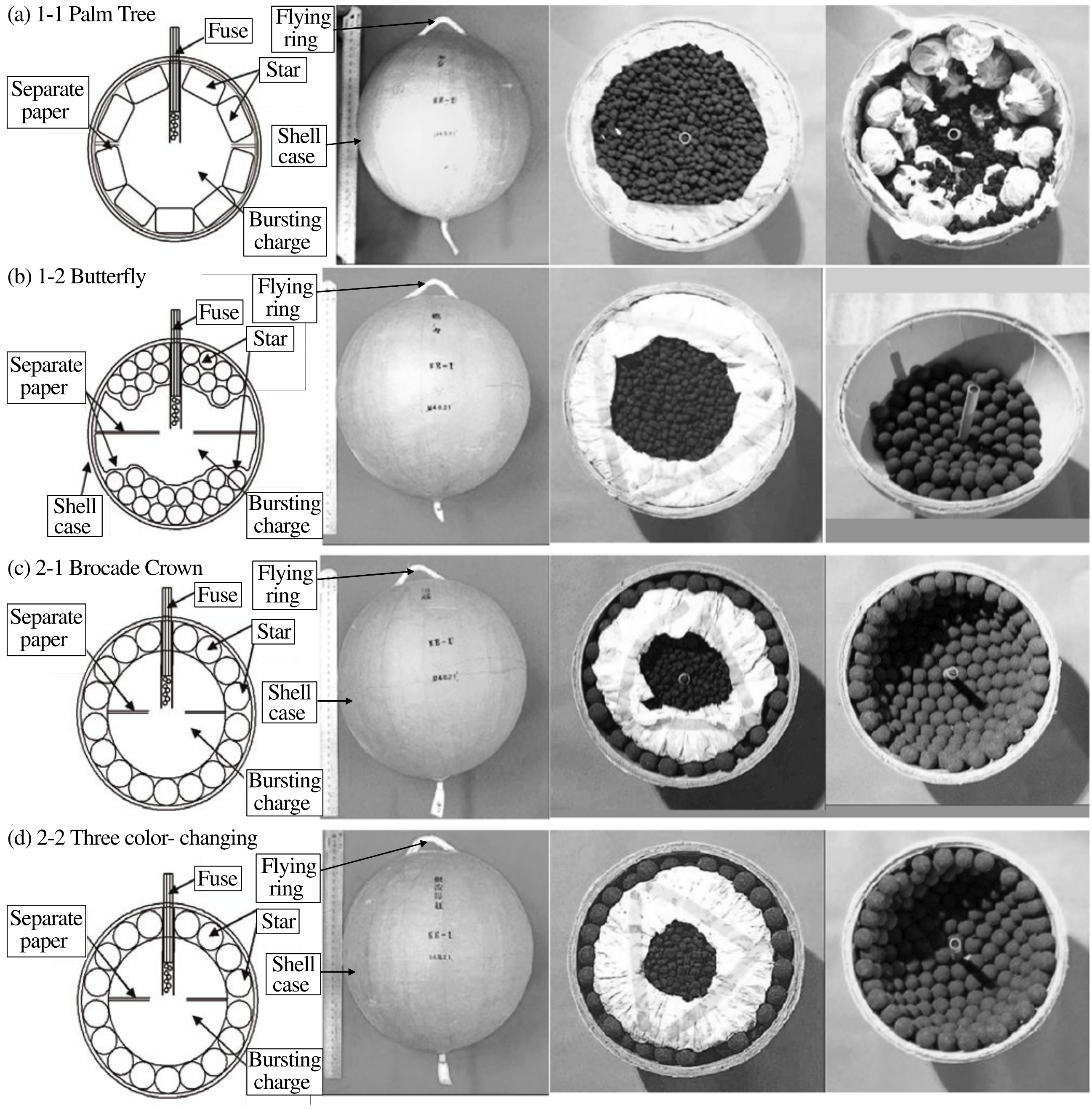

Fig. 1 Cross section and photograph of 240 mm color shell (*Warimono* (spherical) shell).

2.2 Experimental procedure

The installation situation of the samples of the tests is shown in Fig. 2[2]. The tests were conducted while wrapped by the storage of the four 240 mm color shells as the sample in one cardboard box. The three cardboard boxes that wrapped the shells were piled on the witness plate (915 mm × 915 mm × t 2.9 mm), and the packing tape was pasted to prevent sand from entering the space between the cardboard boxes. The quick match (10 m) was installed in the shell put in the box at the center of the three boxes that were piled and set up, and the quick match was passed through the pipe (made of vinyl chloride 70 mm in diameter) and drawn out outside the sand so that it was not pressed with sand.

The surrounding area of the three cardboard boxes that stored the four 240 mm color shells respectively was covered with sand of a thickness of 1 m or more, and the one piece for the center section of the sample was detonated by the electric ignition with two fuse heads connected with the quick match.

2.3 Measurement

A witness plate made of mild steel was put under the samples in order to judge a large amount of explosion.

The internal pressure of the shells and external pressure of the shell cases in the cardboard boxes with the shells were measured in order to investigate the simultaneous explosion situation. The pressure measurements were carried out to “Butterfly” and “Three color-changing.” The locations of the pressure gauges are shown in Fig. 3. The pressure gauges used are the piezo pressure elements made by PCB Piezotronics Inc, (HM113A22, For measurement

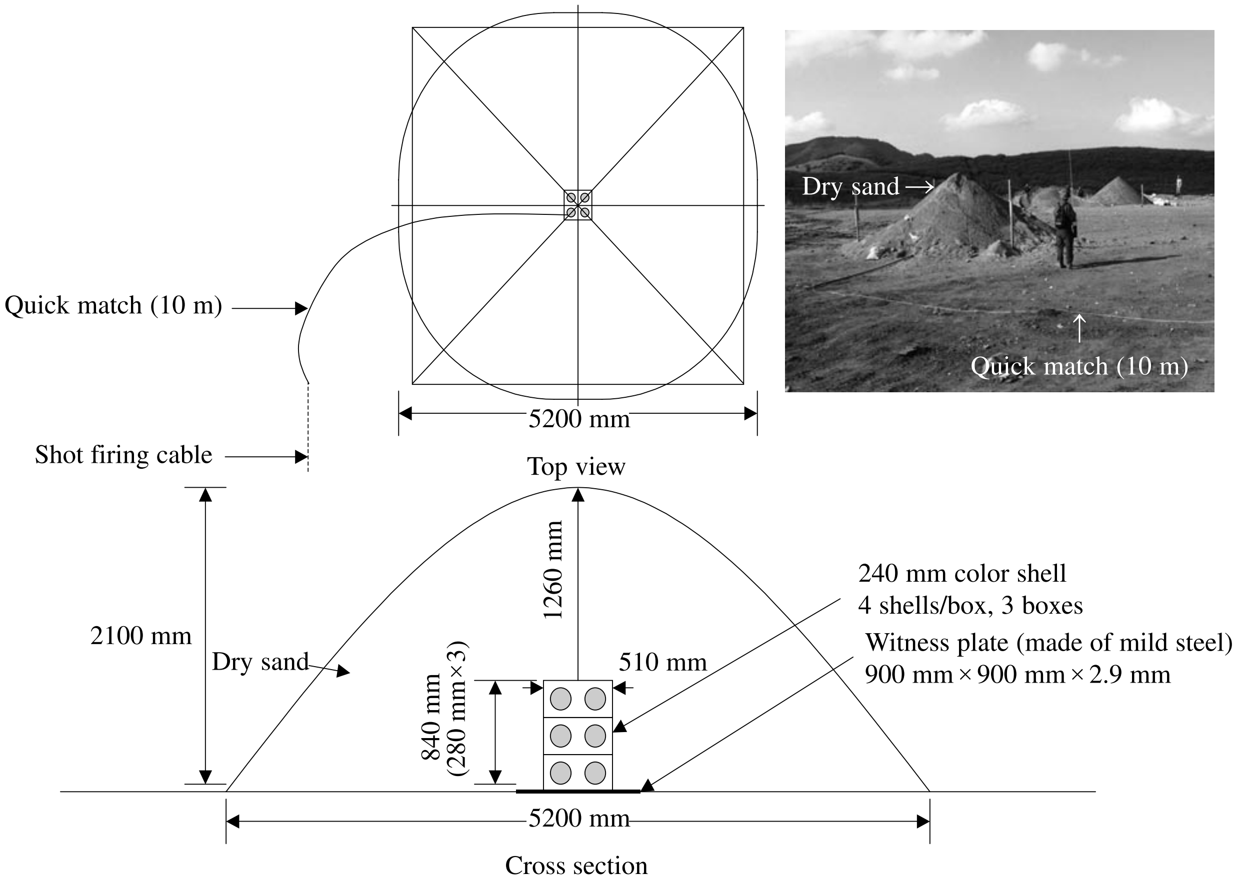

Fig. 2 Experimental setup for the gap test in sand.

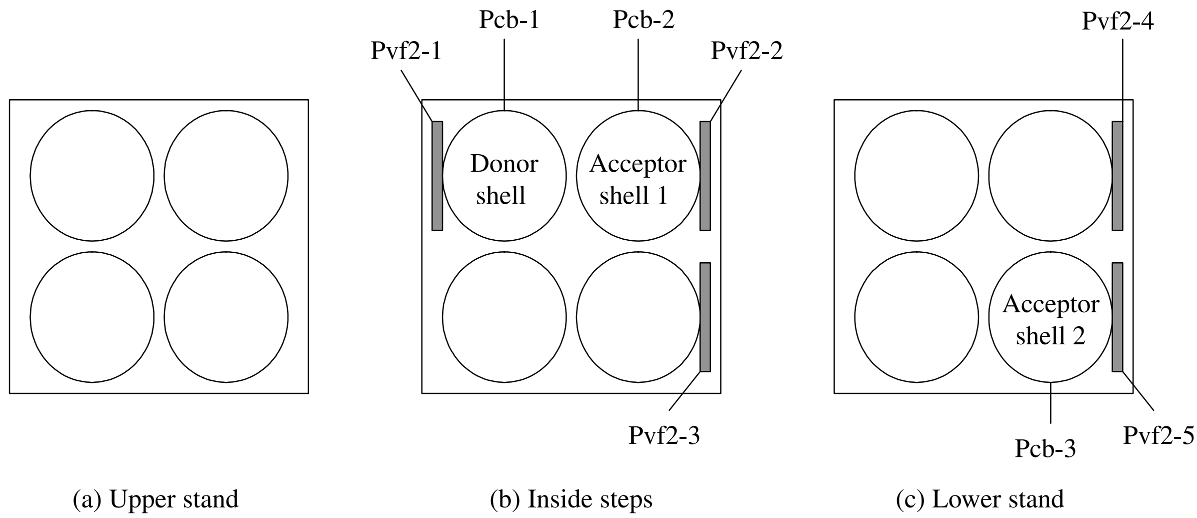

Fig. 3 Mounting position of the pressure sensors.

of the internal pressure of shells) and the piezo film made by DYNASEN INC (Pvf2-11.25-EK, For measurement of the external pressure of shell cases). The time at which a voltage with a constant output of the Pcb-1 pressure sensor was generated (about 0.2 V in the case of this study) corresponds to time-base 0, and other pressure sensors were triggered.

The explosion noises according to the bursts of the shells were measured in order to deduce the simultaneous explosion number of the shells. The low frequency sound level meter (Rion, NA-17) was used for the measurements of the noises. The signals from the low frequency level meter were taken with data recorders (SONY, PC-204, and PC-208). The first sound pressure pulse rise time corresponds to time-base 0.

Table 2 Test result and judgment result on 240 mm color shell.

	Serial number	1-1	1-2	2-1	2-2
Result division	Measurement item	Sample A (Palm Tree)	Sample B (Butterfly)	Sample C (Brocade Crown)	Sample D (Three color-changing)
Sample specification	Total explosive weight (g)	3,258 (75%)	2,552 (70%)	2,727 (72%)	2,800 (72%)
	Weight of bursting charge (g)	970 (22%)	1,225 (34%)	1,020 (27%)	970 (25%)
Test result	Simultaneously reacted shells (pieces)	2/12	9/12	5/12	3/12
	Unreacted shells (pieces)	1/12	0/12	0/12	1/12
Judgment item	Crater	None	None	None	None
	Damage on the witness plates	Fig. 4 (a)	Fig. 4 (b)	Fig. 4 (c)	Fig. 4 (d)
	Shock pressure	Non-measurement	Non-measurement	Non-measurement	Non-measurement
	Scattering of the confining material	Small	Big	Small	Small

Remarks: The number of sample firework shells that explodes at the same time as detonating is called simultaneous numbers of explosions.

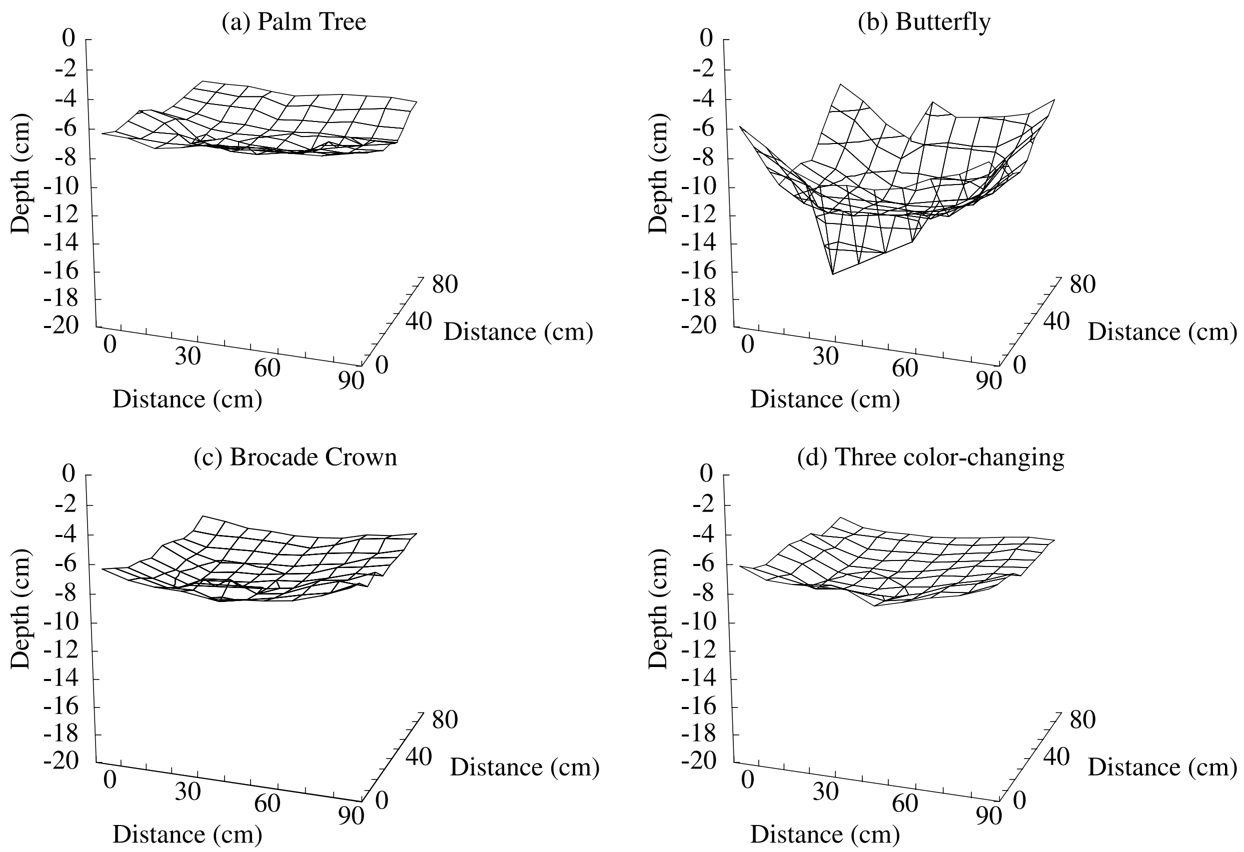

Fig. 4 Distortion situation on the witness plates.

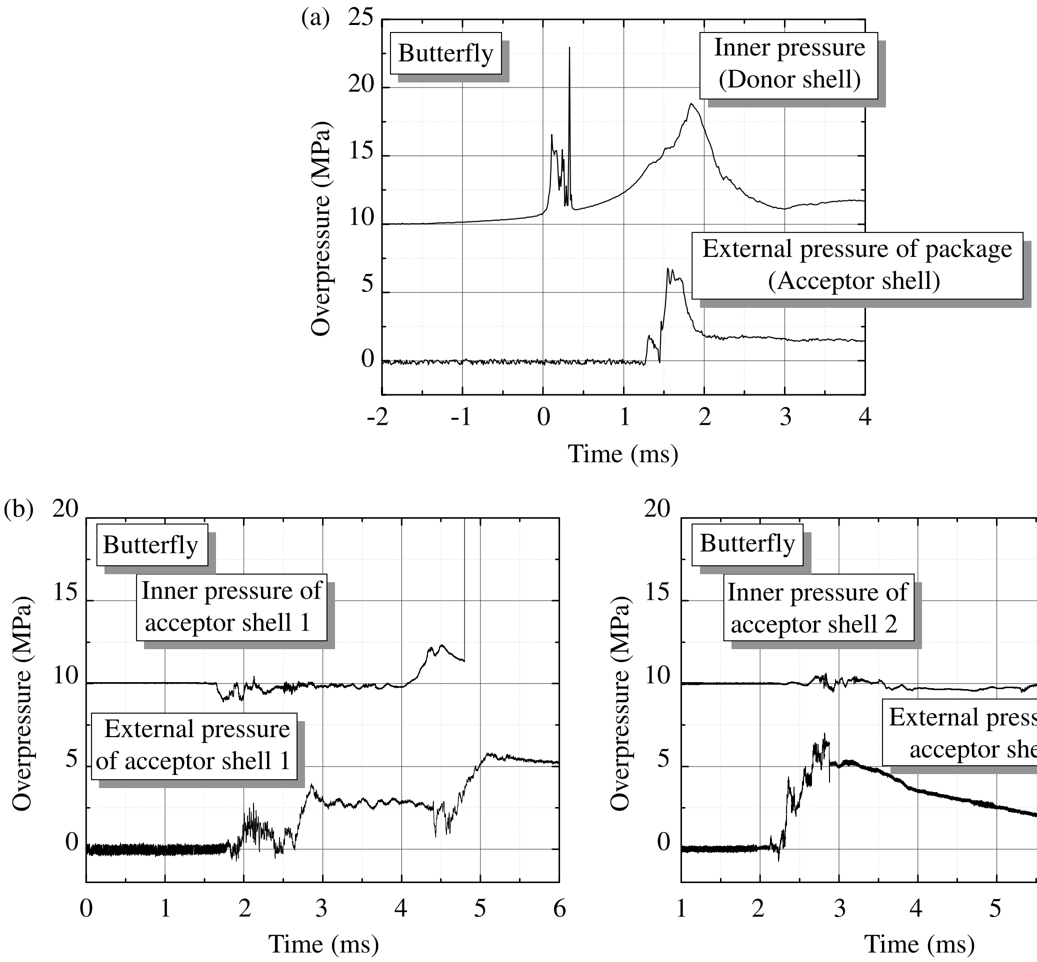

Fig. 5 Pressure change of the 240 mm color shell (Butterfly).

3. Results and Discussion

The results are shown in Table 2.

3.1 Distortion situations on the witness plates

Figure 4 shows distortion situations on the witness plates made of mild steel collected after the tests. The amounts of distortions are shown by the distance from a temporary base level to the surface of the witness plates.

A large distortion was admitted for "Butterfly" as shown in Fig. 4(b), and the amounts of the distortion were 5.7 cm-16.0 cm.

The amounts of the distortions were small as shown in Fig. 4(a), (c), and (d) excluding "Butterfly," and the amounts of the distortion were 5.9 cm-8.6 cm.

3.2 Measurement results of the pressures

Figure 5 shows the measurement results of the pressure of "Butterfly," and Fig. 6 shows the measurement results of the pressure of "Three color-changing."

The external pressure rose and the inclination in the internal pressure rise became gradual after 1.2 or 1.3 ms in the pressure curve of each donor shell. Thus, the shoulder parts correspond in the internal pressure waveforms at the burst time of the donor shells [3].

The maximum internal pressure of the donor shell was 8.8 MPa, and the half bandwidth of the peak was 0.8 ms in "Butterfly" as shown in Fig. 5(a). The internal pressure rise of acceptor shell 1 was confirmed as shown in Fig. 5(b). Therefore, it is presumed that the simultaneous explosion of acceptor shell 1 occurred. On the other hand, hardly any internal pressure rise of acceptor shell 2 was confirmed as shown in Fig. 5(c). Therefore, it is though the simultaneous explosion of acceptor shell 2 did not occur.

The maximum internal pressure of the donor shell was 7.5 MPa, and the half bandwidth of the peak was 0.9 ms in "Three color-changing" as shown in Fig. 6(a). Although "Three color-changing" was almost equal to "Butterfly" in the duration of the internal pressure of the donor shells, and the internal pressure of the donor shell was slightly the lower of the two, hardly any internal pressure rise of accepter shell 1 and 2 were confirmed as shown in Fig. 6(a) and 6(b). Therefore, it is thought that both accepter shell 1 and 2 did not react, and did not undergo simultaneous explosion.

3.3 Measurement results of the noises

Figure 7 shows the sound pressure waveforms obtained at the position 200 m away from the point where the samples were set up.

All pulses confirmed delaying more than five seconds show explosion on the ground, and the number of exploding shells is understood according to the number of pulses shown in Fig. 7[4].

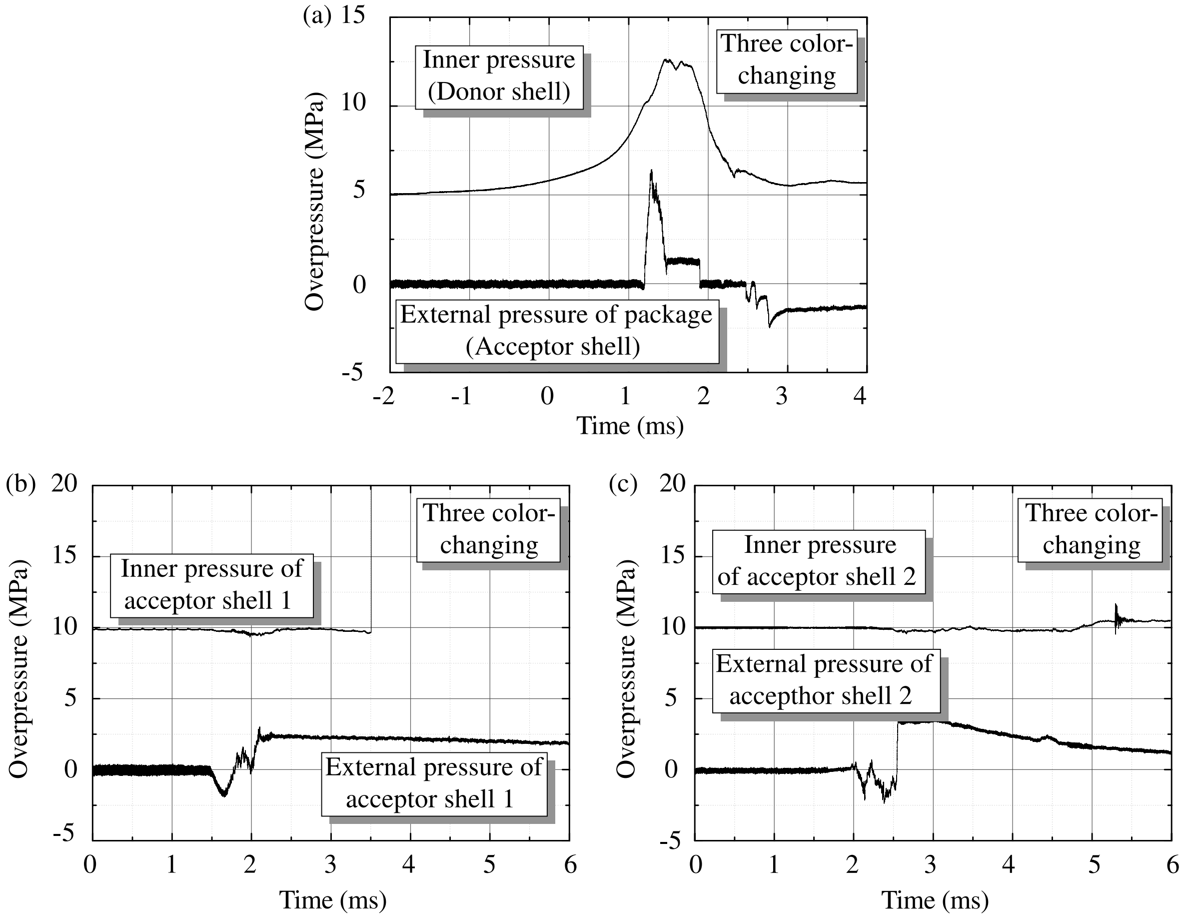

Fig. 6 Pressure change of the 240 mm color shell (Three color-changing).

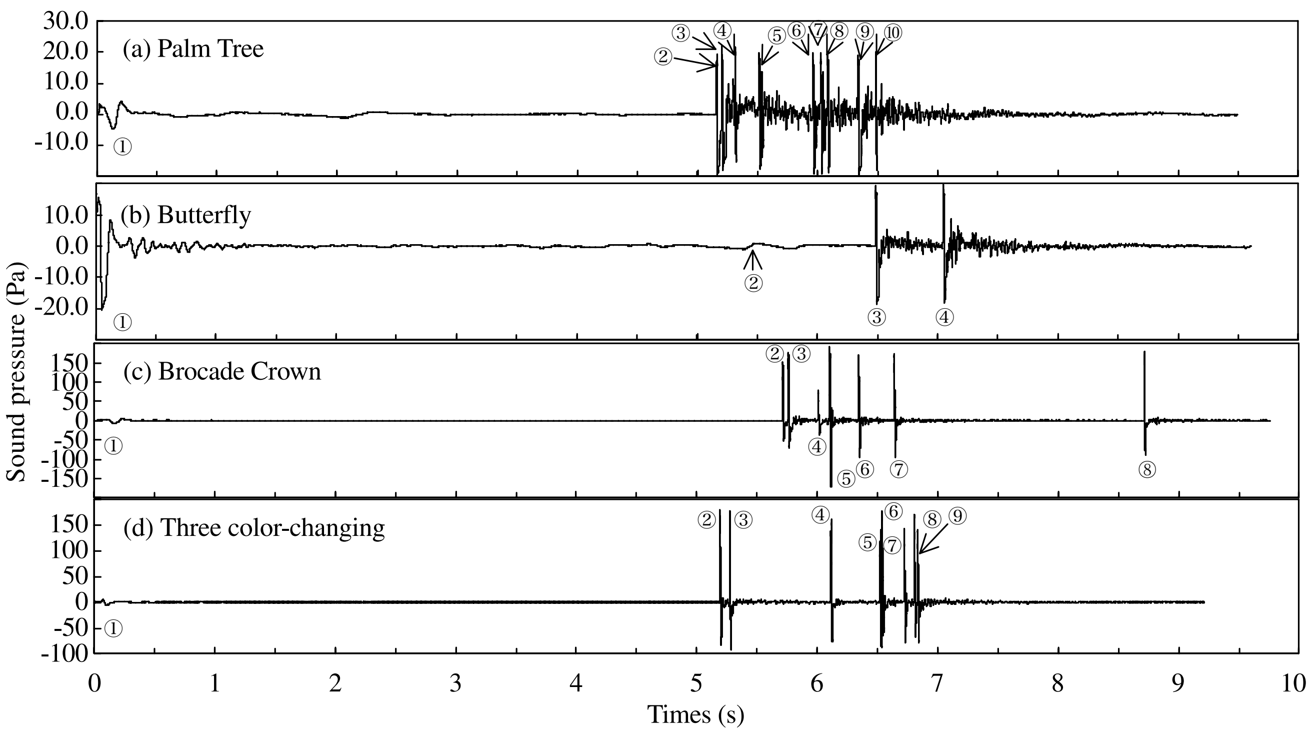

Fig. 7 Sound pressure waveforms of the explosion noise obtained by the gap tests in sand of the 240 mm color shells.

If the number of exploding shells on the ground is assumed to be N_G, and the number of misfire shells is assumed to be N_M, the number of the accepter shells that exploded at the same time as the initiating the donor shell (N_s) is expressed as

$$N_s = 12 - (N_G + N_M).$$

Ten explosion noises were generated in “Palm Tree” as shown in Fig. 7(a). Nine pulses of the ten show N_G. N_M was one. Therefore,

$$N_s = 12 - (9 + 1) = 2 \text{ pieces.}$$

Four explosion noises were generated in “Butterfly” as shown in Fig. 7(b). Three pulses of the four show N_G. There was no misfire shell. Therefore,

$$N_s = 12 - (3 + 0) = 9 \text{ pieces.}$$

Eight explosion noises were generated in “Brocade Crown” as shown in Fig. 7(c). Seven pulses of the eight show N_G. There was no misfire shell. Therefore,

$$N_s = 12 - (7 + 0) = 5 \text{ pieces.}$$

Nine explosion noises were generated in “Three color-changing” as shown in Fig. 7(d). Eight pulses of the nine show N_G. N_M was one. Therefore,

$$N_s = 12 - (8 + 1) = 3 \text{ pieces.}$$

Both chemical compositions of the stars of “Palm Tree” and “Brocade Crown” are B/P+Ti. Each N_s was 2 and 5, where the respective amounts of bursting charge were 970 g (22 %) and 1,020 g (27 %) for the shell name of “Palm Tree” and “Brocade Crown,” respectively. On the other hand, the structures of “Brocade Crown” and “Three color-changing” are quite similar. Each N_s was 5 and 3, where the respective amounts of bursting charge were 1,020 g (27 %) and 970 g (25 %) for the shell name of “Brocade Crown” and “Three color-changing,” respectively. Therefore, N_s is expected to be dependent on the amount of bursting charge if the chemical composition of stars or the structure of fireworks shells is the same [5].

“Butterfly” was judged as hazard division 1.1 from the above-mentioned results, and the other shells were judged as 1.3-hazard division candidates because three tests provided for the United Nations recommendation were not conducted [6].

4. Conclusions

The United Nations Classification Tests, i.e., the 6(b) tests, were conducted to study the default table and test method for fireworks shells. The inner and external pressure of the shells was measured to investigate the simultaneous explosion, and the noise generated by the tests was measured to deduce the simultaneous explosion number of the shells. The results obtained are as follows:

1) The acceptor shells caused the explosion simultaneously with the donor shell when the inner pressure of the acceptor shells was high.
2) It was possible to deduce effectively the simultaneous explosion number of the shells by measuring the noise.
3) “Butterfly” was classified as hazard division 1.1, and the other shells were classified as 1.3 hazard division candidates.

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砂中殉爆実験による煙火玉の同時爆発に関する研究
－圧力測定による煙火玉の殉爆判定と騒音測定による煙火玉の殉爆個数の推定－

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煙火分類のデフォルト表，及び試験方法を検討するために，国連試験 6(b) 積み重ね試験を行った。この分類表では，玉の直径が 180 mm 以上の煙火玉は危険区分 1.1 として分類されるため，これらに該当する煙火玉の取扱いは多大な影響を受ける可能性が高い。本研究では，8 号煙火玉の中から構造，割薬量，星の組成の異なる 4 種類の試料 (椰子，蝶々，錦冠及び銀波先緑紅) を選定した。殉爆状況を調査し，その殉爆個数を推定するために，玉内外圧の計測，発生した騒音の計測を行い，以下の結果を得た。

1）受爆玉の内圧が高い状態の時に受爆玉の同時爆発が起きた。

2）煙火玉の殉爆個数を推定するには騒音の計測が有効であることがわかった。

3)「蝶々」は危険区分 1.1，その他は危険区分 1.3 候補とした。

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