Article

Influence of pressure wave propagating in compressed emulsion explosives on detonator

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Abstract

To clarify the dead-pressing phenomena of explosives, the pressure profiles inside emulsion explosives were measured under the laboratory conditions. Two types of glass microballoons, one type of resin microballoon and micro bubbles of chemical gas were used as sensitizer for sample emulsion explosives. The underwater explosion technique was used for loading dynamic pressure into the sample emulsion explosives. Measured pressure profiles were remarkably different depending on the type of microballoons or micro bubbles. The impulse of pressure wave was independent of the type of microballoons or micro bubbles. To elucidate the influence of pressure wave on the detonator in sample explosives, a study on squeezing of the detonator shell was conducted using the similar technique. While the impulse of pressure wave was almost same, a remarkable difference in the degree of deformation was observed depending on the type of microballoons or micro bubbles. Good relationship between the scaled distance and squeeze ratio was observed.

1. Introduction

Emulsion explosives have replaced gelatin dynamite explosives as cap-sensitive explosive during last decades because of the advantages of "nitroglycerin-free" and safety in handling for blasting operators. As the performance of emulsion explosives has been advanced gradually, the amount of consumption of emulsion explosive trebled to that of dynamite explosives in recent year. Therefore, packaged emulsion explosives are widely used in industrial fields such as tunneling, mining and quarrying.

Sequential blasting is a common technique for all blasting scene. However it can cause malfunction of the explosives, because the explosive charges in the boreholes will be exposed to the dynamic pressure waves from charges in neighboring boreholes detonating at earlier times on the same delay interval and on the previous interval. The pressure waves compress and desensitize the unreacted explosives that are expected to detonate at the next sequence, which leads to detonation failure. This phenomenon is undesirable for safe blasting operations. It is well known that emulsion explosives possess the characteristics of desensitization that is called as dead-pressing phenomenon. Desensitization of emulsion explosives by pressure waves have been reported in previous studies[1)~3)]. Also, pressure measurements of detonating charges have been reported by several researchers[4)~6)].

The voids entrained in emulsion matrix play an important role in the initiation of emulsion explosives as "hot spots". The characteristics of the voids affect strongly on the performance of explosives such as sensitivity, detonation velocity, pressure-resistance and so on. Matsuzawa et al.[7)] studied the detonability of emulsion explosives, containing three different kinds of glass microballoons under loading of dynamic pressure in water. They showed the relationship between the strength of glass microballoons in the explosive charges and critical pressure for detonability under dynamic shock loading.

In the previous paper[8)], we reported the detonability of emulsion explosives precompressed by dynamic pressure. Three types of microballoon and micro bubble were used as sensitizers for the sample emulsion explosives. The underwater explosion test was carried out to load dynamic pressure into the sample explosives, and the detonation velocity of sample explosives was measured. The result indicates that the decrease of detonation velocity in the sample explosives sensitized by glass microballoons was larger than that in the sample explosives sensitized by resin microballoons or chemical gas bubbles. It is concluded that the recovery of the detonability occurred rapidly in the sample explosives sensitized by resin microballoons and chemical gas bubbles. However, a long period was needed for the recovery of detonability in the sample explosives sensitized by glass microballoons. It is considered that the deformation of explosive charge caused by dynamic pressure is one of the factors for the decrease of detonation velocity. Dynamic pressure wave transmitted into sample explosives propagates toward the center of the charge. It is deduced that the dynamic pressure affects the detonability of the detonator positioned at the center of the charge.

In this paper, to clarify the dead-pressing phenomenon, the pressure profiles inside emulsion explosives were measured under the laboratory conditions, and the influence of the type of microballoons was examined. The underwater explosion technique was used for loading dynamic pressure into the sample emulsion explosives. To elucidate the influence of pressure wave in sample explosives on the detonator, a study on squeezing of the detonator shell was conducted using the similar technique.

Table 1 Physical characteristics of microballoons.

	Bulk density (kg m^{-3})	Average diameter (μm)	10% Crush strength (MPa)
gmb 1	120	65	3.2
gmb 2	150	63	8.6
rmb	20	90	---

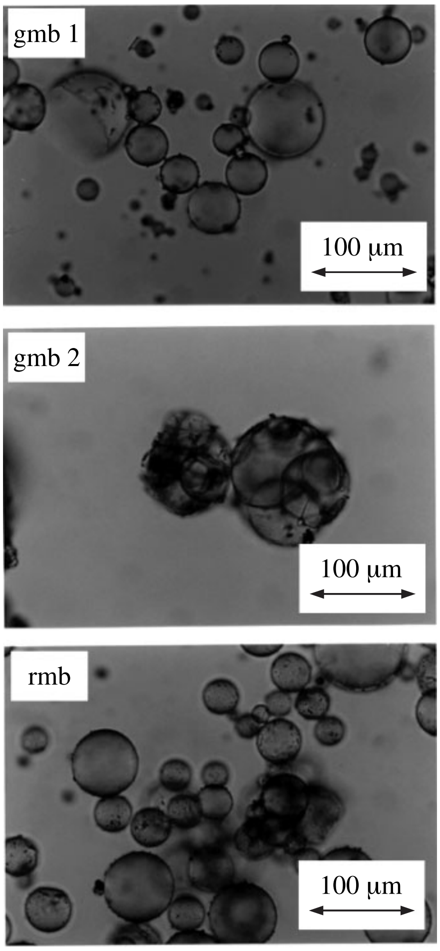

Fig. 1 Photographs of microballoons.

2. Experimental

2.1 Explosives

The emulsion matrix used in this study has a density of 1400 kg m^{-3} with the formulation of ammonium nitrate and sodium nitrate / water / wax and emulsifier = 83.4 / 11.2 / 5.4. A certain amount of inorganic or organic microballoons was added to the emulsion matrix respectively to adjust the initial explosive density of 1140 – 1160 kg m^{-3}. The characteristics of microballoons used in these experiments are summarized in Table 1. Figure 1 shows the photographs of three types of microballoons. Glass microballoons 1 (designated as gmb 1) and resin microballoons (rmb) have mono-cell structure, while glass microballoons 2 (gmb 2) have multi-cell structure. As a result of the difference in structures, gmb 2 is stronger than gmb 1 against shock pressure. Figure 2 shows the particle size distribution of microballoons used in these experiments. No significant difference was observed.

To prepare the sample explosive sensitized by the bubbles chemically generated, a solution of sodium nitrite ($NaNO_2$) was added to the emulsion matrix as gassing agent and mixed immediately. The chemical gas generated is nitrogen (N_2), and entrained into the emulsion matrix.

Sample explosives were confined in plastic film tube whose inner diameter is 30 mm. Diameter of 30 mm was chosen because the cartridged explosives of this size are widely used in domestic market. The plastic film used is very thin and soft. Therefore, the confinement effect of the plastic film tube is considered to be negligible against shock pressure.

In the following, the name of sample explosive shows the type of microballoons added to the emulsion matrix except the difference between capital letter and small letter. For example, the sample explosive GMB 1 was sensitized by gmb 1. 'GAS' refers to the case where the sample explosive was sensitized by chemical gases. The performance of the sample emulsion explosives is summarized in Table 2. It is clear that the performance of four sample emulsion explosives is approximately at the same level. Hattori et al.[9)] and Chaudhri et al.[10)] studied the relation between particle size of microballoons and detonation velocity of the emulsion explosives, and showed a strong dependence of the detonation velocity on the size of microballoons. Therefore, it was

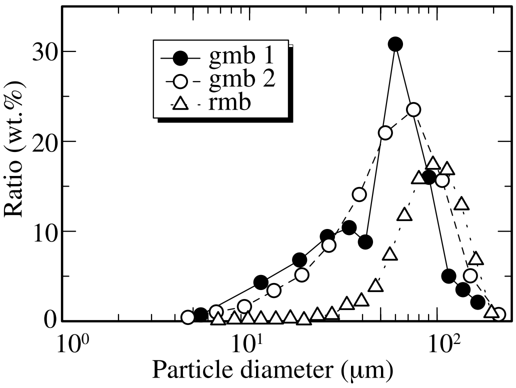

Fig. 2 Particle size distribution of microballoons.

Table 2 Performance of sample emulsion explosives.

Sample name	Microballoon or void	Density ($kg\ m^{-3}$)	Detonation velocity ($m\ s^{-1}$, 20°C) (30mmϕ, Plastic film tube)	Sensitivity-weak detonator test (20°C) (30mmϕ, Plastic film tube)
GMB 1	gmb 1	1150	5200	Class 0.5
GMB 2	gmb 2	1160	5360	Class 0.5
RMB	rmb	1140	5330	Class 0.5
GAS	Chemical gas	1160	5230	Class 0.5
Emulsion	------------	1400	No detonation	More than Class 4

* Sensitivity-weak detonator tests were carried out according to "Japan Explosives Society Standard, ES-32(3)".

considered that the particle sizes of chemical gases are similar to the other three types of microballoons.

Pressure measurement was also performed for the emulsion matrix containing no voids (designated as Emulsion) in the same way.

2.2 Experimental arrangement

The underwater explosion technique was applied as a method to load dynamic pressure into the sample emulsion explosives. Because water is a homogeneous substance and provides consistent pressure transmission conditions, it is considered that pressure attenuates exponentially. In addition, the homogeneous substance is expected to make possible to gain the high repeatability of experimental results.

2.2.1 Pressure measurements

Figure 3 shows the experimental arrangement for the measurement of pressure waves transmitted in the sample explosives. Pressure profiles were obtained with two tourmaline gauges (PCB model-138A10). One was inserted into the center of the sample emulsion explosives to measure the transmitted pressure, and the other was used to trigger and to measure the shock pressure applied to the sample emulsion explosives. Shock wave was generated by the detonation of 40 g of dynamite as donor explosive. The distance between donor explosive and tourmaline gauges was 50 or 80 cm. The pressure profiles measured by tourmaline gauges were recorded by a digital oscilloscope through a charge amplifier. Two trials of pressure measurement were conducted to calculate the average value. In the case of test at the distance of 50 cm, applied pressure reached to the level of 16.6 MPa. And in the case of test at the distance of 80 cm, applied pressure level was 10.5 MPa.

2.2.2 Deformation test for detonator shell

This test was conducted to clarify the influence of the pressure wave on the detonator deformation. Fig. 4 shows the experimental arrangement used to observe the deformation of detonator shell in sample explosives. Shock pressure was generated by the detonation of dynamite of 40 g as donor explosive, and applied to the sample emulsion explosives as accepter. Dummy detonator that contains no charges was employed for this test. Detonator shell was made of copper with the length of 37 mm, the inner diameter of 6.2 mm and the wall thickness of 0.2 mm.

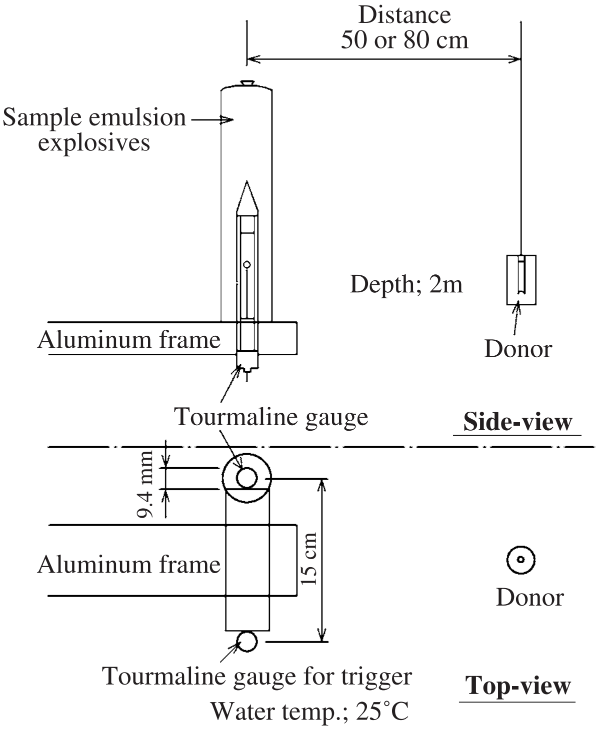

Fig. 3 Experimental arrangement for pressure measurement.

Dummy detonator was inserted into the center of the sample emulsion explosives to be exposed to a transmitted pressure wave. After the deformation test, the dummy detonator was visually checked study the degree of the shell deformation. The squeeze ratio defined by the following equation (1) was evaluated.

$$\text{Squeeze Ratio (\%)} = [(\text{Initial shell volume} - \text{Shell volume after deformation}) / (\text{Initial shell volume} - \text{Shell volume after fully deformed})] \times 100 \quad (1)$$

Fully-deformed shell was formed by pressing shell by hammer. Shell volume was measured by submerging the shell into water. And the increasing amount of volume was converted into shell volume.

Average of squeeze ratio was derived from the results of five trials. The distance between the donor and accepter was varied to modify shock pressure applied to the acceptor. The distance taken in this study was 50 and 100 cm.

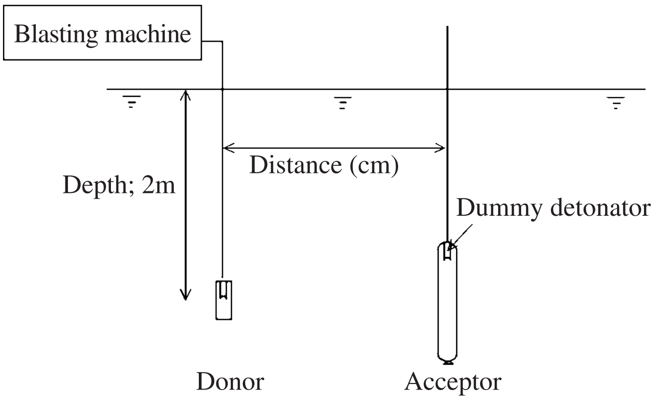

Fig. 4 Experimental arrangement for deformation test.

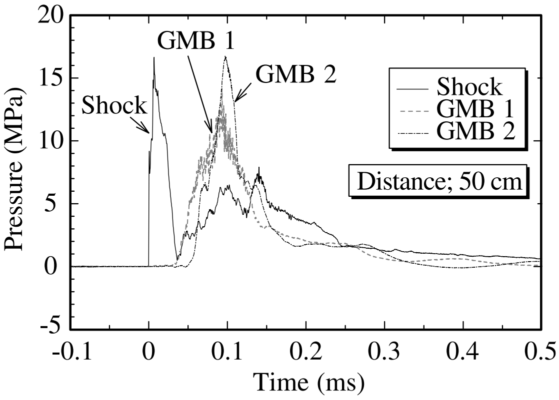

Fig. 5 Pressure profiles of shock and in GMB 1 and GMB 2.

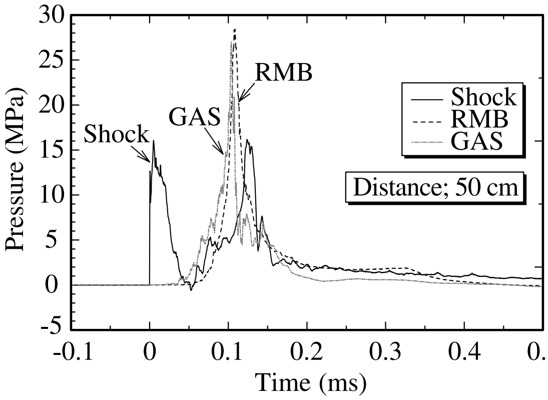

Fig. 6 Pressure profiles of shock and in RMB and GAS.

3. Results and discussion

3.1 Pressure profiles

Figure 5 shows the pressure profiles of shock wave loaded to the sample explosives and pressure profiles inside GMB 1 and GMB 2 which were positioned at the distance of 50 cm from donor explosive. Applied pressure was as high as about 16 MPa. It shows clearly that pressure profiles in GMB 1 and GMB 2 are broad compared to that of the incident shock wave. However, the peak pressure levels of three profiles are almost the same. Figure 6 shows the pressure profiles of the shock wave applied to the sample explosives and those observed in the explosives RMB and GAS at the distance of 50 cm. It shows that the peak pressure level of RMB or GAS is higher than that of the incident shock wave. Two tests to detect the pressure profiles shown in Fig. 5 and in Fig. 6 were carried out under the same condition. However, the difference between two profiles of shock wave is observed by comparison. Electrical trouble, for example, by electrical leakage or by triboelectric noise and mistaken preparation, for example, the unstable positioning of pressure gage are suspected as the factor affecting.

Tanaka et al.[11] evaluated the shock propagation property in dummy slurry explosives containing gas bubbles or glass microballoons using drop hammer test equipment. It was concluded that in case relatively strong shock was loaded, elastic behavior was observed for the explosives containing gas bubbles, and plastic behavior was observed for the explosives containing glass microballoons. Because resin microballoons is considered to give similar elastic behavior as gas bubbles, it is deduced that similar profiles would be obtained for GAS and RMB in this study. It is also concluded that plastic behavior was attributed to the collapse of glass microballoons. As shown in Fig. 1, gmb 1 has mono-cell structure, while gmb 2 has multi-cell structure. And as shown in Table 1, the value of crush strength for gmb 2 is higher than that for gmb 1. This means that gmb 2 is stronger than gmb 1 against pressure. From this viewpoint, the difference of two pressure profiles in GMB 1 and GMB 2 is due to the difference in structure strength.

Mohanty et al.[12] measured pressure wave profiles in several kinds of explosives. The transmitted pressure profile in water-gel explosive sensitized by entrained air-bubbles indicated sharp peak. Pressure profile indicated in their investigation showed similar pressure profile observed in the sample explosive of GAS. On the other hand, the pressure profile in the emulsion explosive containing glass microballoons had its broad peak. Their results are also in accordance with our results for the sample explosive sensitized by gmbs. They concluded that the 'noise' features on pressure profile in the case of the emulsion explosive containing glass microballoons are attributed to violent crushing of the microballoons. This conclusion agrees well with that by Tanaka above-mentioned.

It is interesting to evaluate the 'Delay time' and 'Rise time' of the pressure profiles defined as follows. 'Delay time' is defined as the interval between the arrival time of incident shock loaded and start of pressure rises in sample explosive and 'Rise time' is defined as the interval between start of pressure rises and pressure peak. It can be seen from Figs. 5 and 6 that 'Delay time' of GMB 1 or GMB 2 is smaller than that of RMB or GAS. It means that the pressure wave in GMB 1 or GMB 2 propagates faster than that in RMB or GAS. On the other hand, 'Rise time' in RMB or GAS is smaller than that in GMB 1 or GMB 2. Results are summarized in Table 3.

As mentioned above, elastic behavior was observed for the explosives containing rmb and gas bubbles, and plastic

Table 3 Propagation velocity of pressure wave in sample explosives.

Distance (cm)	Sample explosive Name	Time (μs) Delay	Time (μs) Rise	Propagation velocity (ms^{-1}, 11mm/Delay time)
50	GMB 1	40.8	52.4	270
	GMB 2	59.2	38.0	186
	RMB	80.8	28.0	136
	GAS	60.6	43.4	182
	Emulsion	22.1	6.4	498
80	GMB 1	43.5	85.2	253
	GMB 2	61.2	61.6	180
	RMB	79.0	41.4	139
	GAS	74.4	27.8	148
	Emulsion	26.6	8.4	414

behavior was observed for the explosives containing gmbs. Another way of saying, the explosives containing rmb and gas bubbles possess the characteristics of easy- absorbability for pressure wave, while the explosives containing gmbs possess the characteristics of rigidity against pressure. It is deduced that the difference of the physical characteristics exerts a strong influence on the propagation mode of pressure wave in sample explosives.

Pressure measurement test was also carried out under the condition that the distance between donor explosive and the pressure gauges was 80 cm. The results were similar to that at the distance of 50 cm, while the peak pressure was lower. Figure 7 shows the pressure profiles inside all sample explosives respectively at the distance of 80 cm.

3.2 Amplification of peak pressure

The amplification of peak pressure induced in five sample explosives was evaluated as the ratio of peak pressure reached and the pressure applied. The results are summarized in Table 4.

The values of peak pressure amplification can be divided into 2 groups. For the group of GMB 1, GMB 2 and Emulsion, the amplification level of peak pressure is in the range of 0.8 - 1.3. For the group of RMB and GAS, the amplification level of peak pressure is in the range of 1.6 - 2.1. To estimate the pressure wave concentration inside the explosives charged in borehole, numerical simulation using DYNA2D program has been carried out by Nie[13]. The properties of sample emulsion explosive were used for the calculation. On his calculation, when the pressure wave with its

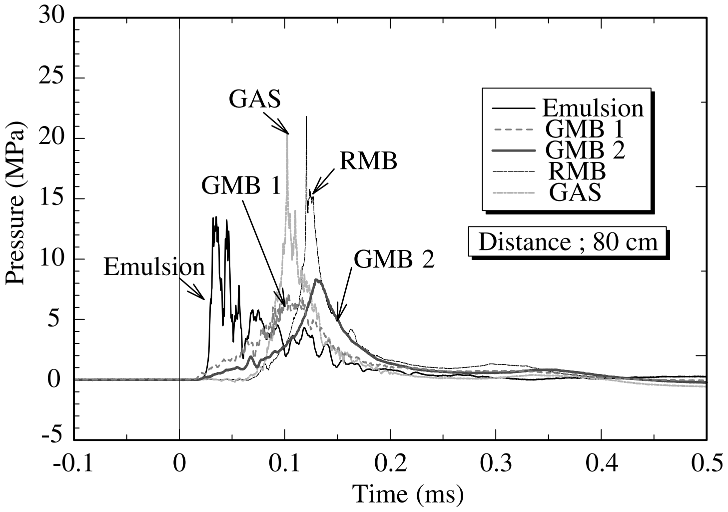

Fig. 7 Pressure profiles inside all sample explosives.

Table 4 Amplification of peak pressure.

Test condition (distance)	Applied shock wave pressure (MPa)	Peak pressure (MPa) Ratio				
		GMB1	GMB2	RMB	GAS	Emulsion
50 cm	16.6	14.3	16.8	28.6	27.1	20.1
		0.86	**1.01**	**1.72**	**1.63**	**1.21**
80 cm	10.5	8.6	8.9	21.8	20.50	13.3
		0.82	**0.85**	**2.08**	**1.95**	**1.27**

Table 5 Amplification of impulse.

Test condition (distance)	Applied shock wave impulse (MPa·ms)	Impulse (MPa·ms) Ratio				
		GMB 1	GMB 2	RMB	GAS	Emulsion
50 cm	1.63	1.56	1.53	1.66	1.56	1.71
		0.96	**0.94**	**1.02**	**0.96**	**1.05**
80 cm	1.05	0.95	0.90	0.99	0.90	1.02
		0.90	**0.86**	**0.94**	**0.86**	**0.97**

level of 14 MPa was applied, the pressure level at the center of explosive was derived to be the order of 21 – 22 MPa. Therefore, he concluded that pressure in the center of explosive charge was concentrated to give the pressure of 1.5 – 1.6 times higher than the pressure applied. There is no information about the microballoons used in his calculation. However, judging from the value of peak pressure amplification derived from his calculation, air bubbles were considered to be applied as a sensitizer on his calculation.

Additional tests were conducted to investigate the influence of diameter for explosive charge on peak pressure level showed. Two sample explosives of GMB 1 and RMB with its charge diameter of 50 mm were used. The test condition was that distance between donor explosive and pressure gauges was 50 cm.

The result of additional tests indicated that the value of peak pressure amplification for GMB 1 with charge diameter of 50 mm was in the same range of the case with charge diameter of 30 mm. However, the value of peak pressure amplification for RMB with charge diameter of 50 mm was obtained as the value of 3.65. In other words, the enlargement of charge diameter for GMB 1 gave no influence on the enhancement of the amplification of peak pressure, however the enlargement of charge diameter for RMB gave a great influence on the enhancement of the amplification of peak pressure.

In the previous section, the difference of propagation mode of pressure wave in sample explosives was described depending on the difference of the explosives characteristics. It is deduced that this difference of enhancement of amplification is attributed to the difference of propagation mode of pressure wave. It is concluded that the diameter for explosive charge gives an influence on peak pressure at the center of charge where detonator is positioned.

3.3 Amplification of impulse

The pressure impulse was calculated for five sample explosives by integrating pressure curve between time 0 and 0.5 ms. For example, the value of pressure impulse for shock wave at the distance of 50 cm was calculated to be 1.63 MPa·ms. The amplification of the impulse induced in five sample explosives was evaluated as the ratio of the impulse in the sample explosives and impulse for shock wave. The results are summarized in Table 5.

The impulse ratios are maintained constant approximately. It is considered that pressure energy induced in sample explosives is transmitted to the center of the explosives without loosing significant energy.

Above-mentioned additional tests using sample explosives with charge diameter of 50 mm were also conducted to evaluate the influence of diameter of explosive charge on amplification of impulse. The result indicated that the impulse ratios were maintained constant approximately too. It is concluded that the diameter of explosive charge gives no influence on amplification of impulse.

3.4 Deformation of detonator shell

Figures 8, 9 and 10 show photographs of detonator shells deformed in each test at the distance of 50, 60 and 80 cm respectively.

No deformation was observed in the case of "Emulsion" at the distance of 50 cm. No deformation occurred in the

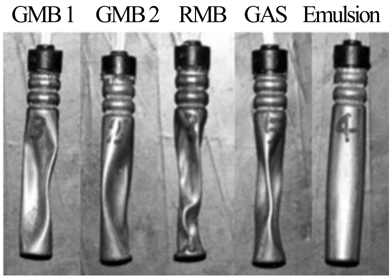

Fig. 8 Deformation of detonator shell (Distance : 50 cm).

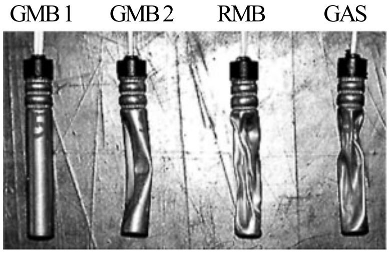

Fig. 9 Deformation of detonator shell (Distance : 60 cm).

Fig. 10 Deformation of detonator shell (Distance : 80 cm).

case of "GMB 1" at the distance of 60 cm. No deformation occurred in the cases of "GMB 1", "GMB 2", but slight deformation was observed in the case of "GAS" at the distance of 80 cm.

The degree of deformation was the largest for the detonator in "RMB" among the all samples, and the smallest for the detonator in "Emulsion". The degree of deformation for the detonators is determined as the following order ;
RMB > GAS > GMB 2 > GMB 1 > Emulsion

While the impulse of pressure is almost same, a remarkable difference in the degree of deformation was observed.

Suzuki et al.[14] described the threshold pressure for the deformation of detonator shell under static pressure. Based on their theory, the threshold static pressure for the deformation of similar-typed detonator employed in our experiments, can be estimated to be approximately 16 MPa. And also, the threshold dynamic peak pressure, which gives the deformation of detonator shell, could be concluded to be approximately 50 MPa by our other underwater explosion tests. However, the pressure level obtained in this study for the deformation of detonator is lower than the above threshold dynamic pressure level. Therefore, another factor must be considered besides the peak pressure level that gives an influence on the deformation of shell. It is considered the duration of pressure applied to the shell is one of those factors. As discussed in section 3.3, the impulses for five sample explosives are same. Therefore, it is deduced that the impulse calculated from the pressure over a certain value gives an influence on the deformation of shell.

3.5 Evaluation of squeeze ratio

After the deformation test, the detonator shell was recovered to measure its volume. The squeeze ratio was calculated based on the equation (1). Five values for squeeze ratio under the same condition were averaged. Figure 11 shows such average values for each sample under the several experimental conditions.

It is obvious that the squeeze ratio of "RMB" is the largest in all samples, and the ratio of "Emulsion" is the smallest. When the ratios of "RMB" obtained from the distance of 50 and 60 cm are compared, the difference is small. This indicates that the ratio obtained from the distance of 60 cm is given the almost maximum value, so it can't be expected that larger value, which exceed the value obtained from the condition of 60 cm distance, will be gained.

The relationship between the scaled distance and the squeeze ratio is indicated in Fig. 12. The data of "RMB" obtained from the distance of 50 cm is deleted due to the above-mentioned reason. Good relationship between the scaled distance and squeeze ratio is observed. As discussed in section 3.4, the occurrence of the deformation is considered to be depending on the interaction with many factors. However, from the viewpoint of one kind of explosive, we reach the tentative conclusion that the squeeze ratio can be related to peak pressure level.

The real detonator can be initiated by the dynamic pressure of 80 MPa in underwater explosion test. At the distance of 50 cm in this experiment, the real detonator wasn't deformed and initiated by incident pressure wave from donor explosive. And also, all sample explosives didn't cause the sympathetic detonation under the same condition. However, from our other research that the combination of the real detonator and the sample explosive "RMB", has a potential to be initiated under the same condition. The process to detonation is considered to be as the followings. At first, the compression of primer charge, or the ignition of fuse head in detonator occurs which was caused by the shell squeezed. As a result of that, the detonator will be initiated, and the explosive will be detonated.

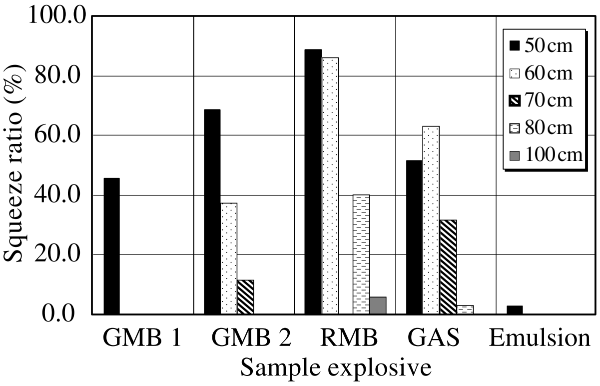

Fig. 11 Average of squeeze ratio (n = 5).

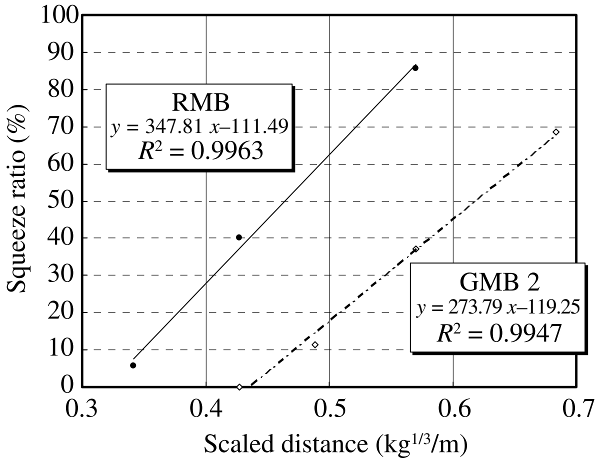

Fig. 12 Relationships between scaled distance and squeeze ratio.

4. Conclusions

The following conclusions were obtained in this study ;

- The pressure profile in the sample explosives sensitized by rmb or chemical gas was sharp, but that in the sample explosives sensitized by gmb was broad.
- The peak pressure level in the sample explosives sensitized by rmb or chemical gas was twice as high as that in the sample explosives sensitized by gmb.
- The impulse was independent of the type of microballoons or microbubbles. And the impulse ratios are maintained constant approximately.
- The deformation degree of the detonator was determined as the following order ;

RMB > GAS > GMB 2 > GMB 1 > Emulsion
- Relationship between the scaled distance and the squeeze ratio was very good.

Occurrence of dead-pressing phenomenon is not always attributed to the performance of explosives. Detonator is required to ignite on time, and to release the energy enough to initiate an explosive. In our previous paper, we reported that the explosive sensitized by rmb has an advantage of that the recovery of the detonability occurs rapidly. However, the result of this research indicates the explosive sensitized by rmb gives the bad effect on the deformation of the detonator shell. In the worst case, the deformed detonator will ignite on unexpected time, and release too poor energy to initiate an explosive. From this point of view, the blasting malfunction including dead-pressing phenomenon must be considered from both phases of explosive and detonator.

References

1) S. Nie, Proc. of the 4th International Symposium on Rock Fragmentation by Blasting, pp.409-412 (1993), Vienna.
2) Q. Liu, Proc. of the 10th Symposium on Explosives and Blasting Research, pp. 51-62 (1994), Austin.
3) J.J. Mullay, C.J. McGinley, G.W. Anderson, C.J. Keefer, and J.F. VanNorman, Proc. of the 10th Symposium on Explosives and Blasting Research, pp.75-89 (1994), Austin.
4) P.D. Katsabanis, C. Yeung, G. Fitz, and R. Heater, Proc. of the 10th Symposium on Explosives and Blasting Research, pp.63-74 (1994), Austin.
5) M.S. Wieland, Proc. of the 11th Symposium on Explosives and Blasting Research, pp. 62-75 (1995), Nashville.
6) Q. Liu, P. Tidman, D. Tunaley, and J. Mullay, Proc. of the 11th Symposium on Explosives and Blasting Research, pp. 26-37 (1995), Nashville.
7) T. Matsuzawa, M. Murakami, Y. Ikeda, and K. Yamamoto, J. Ind. Explos. Soc. Japan (Kogyo Kayaku), Vol.43, pp. 317-322 (1982) (in Japanese).
8) F. Sumiya, Y. Hirosaki, and Y. Kato, Science and Technology of Energetic Materials, Vol. 65, pp. 88-93 (2004).
9) K. Hattori, Y. Fukatsu, and H. Sakai, J. Ind. Explos. Soc. Japan (Kogyo Kayaku), Vol. 43, pp. 295-301 (1982) (in Japanese).
10) M.M. Chaudhri, L.A. Almgren, and A. Persson, Proc. of 10th Symposium (International) on Detonation, pp.741-748 (1993), Boston.
11) M. Tanaka, A. Suzuki, A. Aoki, T. Abe, T. Ogawa and I. Fukuyama, J. Ind. Explos. Soc. Japan (Kogyo Kayaku), Vol.46, pp.368-375 (1985) (in Japanese).
12) B. Mohanty and R. Deshaies, Proc. of the 8th Symposium on Explosives and Blasting Research, pp. 19-23 (1992), Orlando.
13) S. Nie, Doctoral Thesis 1016, Division of Soil and Rock Mechanics., Departments of Civil and Environmental Engineering, Royal Institute of Technology (KTH), Stockholm., pp. 3-17 (1997).
14) T. Suzuki, M. Hamazaki and N. Izawa, J. Ind. Explos. Soc. Japan (Kogyo Kayaku), Vol. 28, pp. 194-199 (1967) (in Japanese).

加圧されたエマルション爆薬内を伝播する圧力波の雷管への影響

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使用される気泡剤の種類，物性でエマルション爆薬の諸性能は大きく影響を受けることが知られている。エマルション爆薬の死圧現象を解明するために，爆薬に印加された圧力波の爆薬内での伝播状況に関して検討した。種々の異なる気泡剤を使用したエマルション爆薬を用いて水中衝撃圧試験により圧力波を印加して，爆薬内部に挿入された圧力ゲージにてその圧力波形を検知した。気泡剤の違いにより，圧力波形に顕著な違いが見られたが，波形より算出した力積値は気泡剤の種類によらずほぼ一定であった。また，爆薬中心部に添装薬を装薬していない模擬雷管を挿入し爆薬内を伝播した圧力波による雷管管体の変形に関して検討を行ったところ，使用される気泡剤の違いにより管体変形の度合いが大きく異なることが判明した。この変形度合いは，圧力波の換算距離と良好な相関を示した。

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