Article

Detonability of emulsion explosives precompressed by dynamic pressure

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Abstract

To clarify the detonability and the performance of precompressed emulsion explosives, the detonation velocity was measured. Three types of microballoon or 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. The result indicates that the decrease of detonation velocity in the sample explosives sensitized by glass microballoons was larger than that of detonation velocity in the sample explosives sensitized by resin microballoons or chemical gas bubbles. The detonability of precompressed emulsion explosive was also investigated on the initiation sensitivity test using the weak-strength detonators. 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.

1. Introduction

Since the invention of emulsion explosives in 1960's, emulsion explosives have been used in all blasting situation. Without exception, emulsion explosives have been replacing gelatin dynamite explosives gradually in recent decades, because they have advantages of safety in handling, and they are nitroglycerin-free for blasting operators. Therefore, packaged emulsion explosives are widely used in industrial fields such as tunneling, mining and quarrying.

Sequential blasting is a common technique for blasting in tunneling, mining and quarrying. However it can cause malfunction of the explosives, because the explosive charges in the boreholes will be exposed to the dynamic pressure wave from charges in neighboring boreholes detonating at earlier times on the same delay interval and on the previous interval. It is considered that the interaction of the dynamic pressure wave within the same time interval is caused by the deviation of the ignition time of the electric detonators. Conventional electric detonator has some deviation in the ignition time, and its deviation is usually large for longer delay period. Such a deviation in the delay time may cause dead pressing and shock desensitization, which leads to a detonation failure. Furthermore, if the precompressed explosives can be initiated, it would create poor energy release due to incomplete reaction and that creates much toxic fumes, and wall damage and dangerous deflagrations will be produced. This phenomenon is undesirable for safe blasting operations. Shock desensitization of emulsion explosives have been reported in previous studies[1)~5)].

Emulsion explosives have lower initiation sensitivity compared with dynamites. The detonability of emulsion explosives is lower than that of dynamites during dead pressing. Emulsion explosives consist of emulsion matrix and voids. Microballoons or gas bubbles are used as voids. The voids play an important role as "hot spots" in the initiation of emulsion explosives. Voids in the emulsion explosives have a strong influence on the performance of explosives such as detonation velocity, sensitivity, pressure-resistance and so on. Therefore, the characteristics of the emulsion explosives are significantly affected by the type of voids. Matsuzawa et al.[6)] examined the detonability of emulsion explosives, containing three different kinds of glass microballoons under dynamic pressure in water. They concluded that there was a relationship between the property of voids in the explosive charges and the critical pressure for detonability under dynamic shock loading.

Usually, the ignition delay intervals of the electric detonators are regularly 25 and 250 milliseconds. Matsuzawa et al.[6] examined the detonability of emulsion explosives under these intervals under the assumption that a certain charge might be affected by the detonation of the previous charge. The interaction of the dynamic pressure wave from the detonation in the same delay interval must be considered, because there is a deviation of ignition time with the electric detonators, as previously mentioned.

To clarify the detonability and the performance of the precompressed emulsion explosives, the detonation velocities were measured and the initiation sensitivity was investigated as an index of the explosives performance in the underwater explosion test. The influence of the type of microballoon used on detonability of emulsion explosive was examined in this study.

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. Glass microballoons 1 (designated as gmb 1) and resin microballoons (rmb) have the structure of mono-cell, while glass microballoons 2 (gmb 2) have a multi-cell structure. As a result of the difference in structures, gmb 2 is stronger than gmb 1 against shock pressure. Figure 1 shows the particle size distribution of microballoons used in these experiments. No significant difference was observed.

For the preparation of the other sample explosive, a solution of sodium nitrite ($NaNO_2$) was added to the emulsion matrix as gassing agent and mixed immediately. The chemical gas generated was nitrogen (N_2).

In the underwater explosion test, sample explosives were confined in a plastic film tube with inner diameter of 30 mm and length of 250 mm. The plastic film 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 sample name shows the name of microballoons in 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.[7] and Chaudhri et al.[8] 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 considered that the particle sizes of chemical gases are similar to the other three types of microballoons.

Table 1 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	---

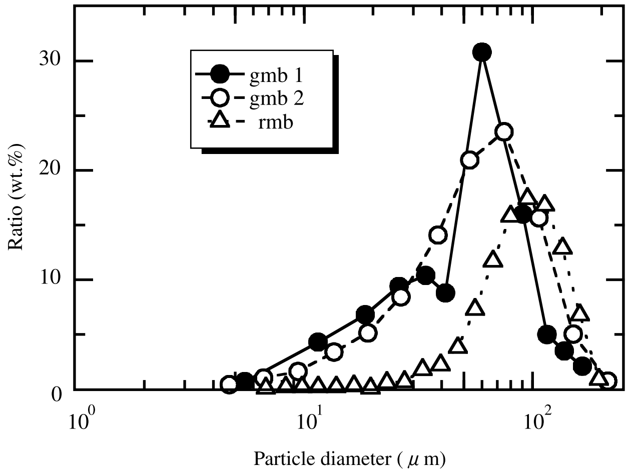

Fig. 1 Particle size distribution of microballoons.

2.2 Experimental arrangement

Detonation velocity measurement test ; The underwater explosion technique was applied as a method for applying dynamic pressure into the sample emulsion explosives. Because water as an intermediate is a homogeneous mater-

Table 2 Performance of sample emulsion explosives.

Sample name	Microballoon or Void	Density (kg m^{-3})	Detonation velocity (m s^{-1}, 20 ℃) (30mm ϕ, Plastic Film Tube)	Sensitivity-Weak Detonator Test (20℃) (30mm ϕ, 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
Base emulsion	------------	1400	No Detonation	More than Class 4

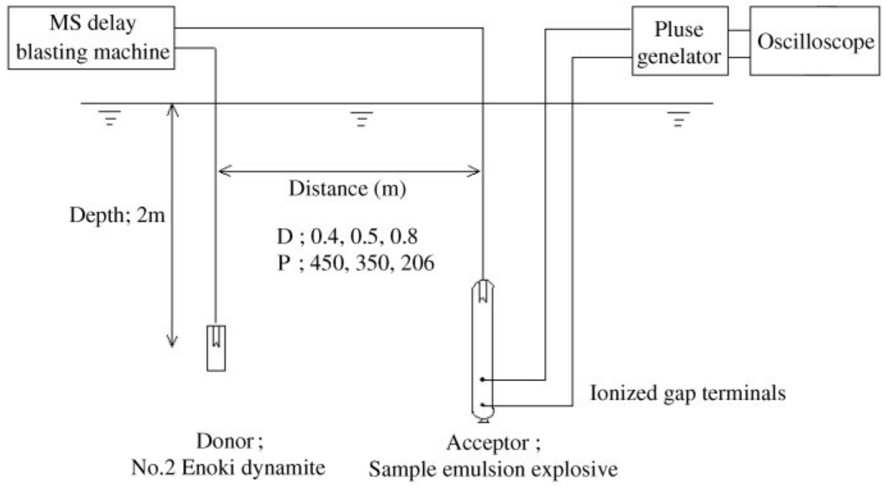

Fig. 2 Experimental arrangement for detonation velocity measurement.

ial and provides consistent pressure transmission conditions, it is considered that pressure attenuates gradually. A shock pressure to compress to sample emulsion explosives was generated by the detonation of dynamite of 40 g as a donor explosive, and applied to the sample emulsion explosives as an accepter. Two ionized gap terminals at the interval distance of 5 cm were installed into the sample explosive to measure the detonation velocity and to confirm the propagation of detonation. Also, the detonability was checked by the existence of remnants. Each ionized gap terminal was connected to the pulse generator. The pulse signals detected by the shorted gaps caused by the detonation propagation were recorded by a digital oscilloscope. The distance between the donor and the accepter was varied to modify the shock pressure applied to the acceptor. The distance taken in this study was 0.4, 0.5 and 0.8 m. Figure 2 shows the experimental arrangement for the measurement of the detonation velocity in the acceptor charge. The pressure values were calculated based on the 'Kirkwood-Bathe Equation'.

Kirkwood-Bathe Equation ; $P\text{max} = 537(W^{1/3}/R)^{1.13}$ [kg cm^{-2}]
(W=Weight [kg], R = Distance [m])

The pressure values that the acceptors are subjected to at the distance of 0.4, 0.5, 0.8 m are 450, 350, 206 kg cm^{-2} respectively.

Initiation sensitivity test; The underwater explosion technique was also applied. Fundamentally, the configuration of the donor and acceptor explosive was same as that of detonation velocity measurement test. However, the detonator for acceptor employed the weak-strength detonators. The loading explosive weight on their detonators was varied to control the out-put energy. The loading explosive weight for the weak-strength detonators is summarized in Table 3. "Minimum weight of base charge" was defined as the weight of base charge that could initiate the precompressed explosive perfectly on 2 trials. The distance between the donor and the accepter taken in this study was only 0.5 m.

Table 3 Loading explosive weight of weak-strength detonators.

Classification (class)	Base charge (g)	Primary charge (g)
0	0	0.2
0.5	0.05	0.2
1	0.1	0.2
2	0.2	0.2
3	0.3	0.2
4	0.4	0.2

2.3 Initiation system

Pyrotechnic delay detonator was not used in our experiments. Katsabanis et al.[3] mentioned that the actual initiation delay of pyrotechnic delay detonators exhibits scatter when the detonators were subjected to shock pressure. The accuracy of the initiation interval between the donor and the acceptor is absolutely essential for the repeatability of the experimental results. A MS delay blasting machine was used to realize the desired accuracy. This machine uses an AC power supply, and its relief current for ignition is high enough to ignite the fuse head of the detonator immediately. The initiation interval between donor and acceptor charges can be set at a 1 ms interval step-wise. The time accuracy compared with a target time is within 0.1 ms. This is the reason why all instantaneous electric detonators were used in our experiments.

3. Results and discussion

3.1 Detonation velocity Measurement

Figure 3 summarizes the experimental results on the relation between the detonation velocity and the delay time for GMB 1 under respective pressure condition. It is obvious that the detonation velocity in the explosive decreases with increasing pressure. The detonation failure of the explosive GMB 1 was observed within the delay time of 5 ms. That meant the explosives were lain under the compressed condition, therefore, they could not be detonated. The detonation velocity shows the minimum at the delay time of 7 ms, and its value is equal to 80% of the original detonation velocity. It was considered that the density of the explo-

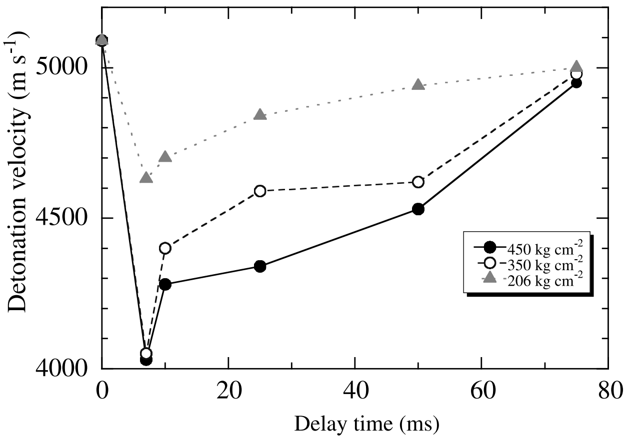

Fig. 3 Detonation velocity under dynamic pressure loading (GMB 1).

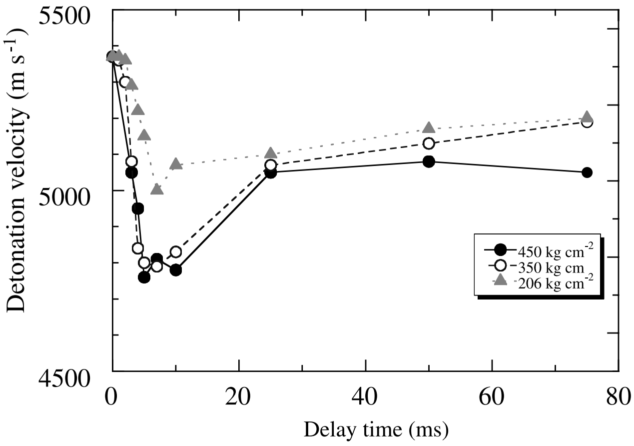

Fig. 4 Detonation velocity under dynamic pressure loading (RMB).

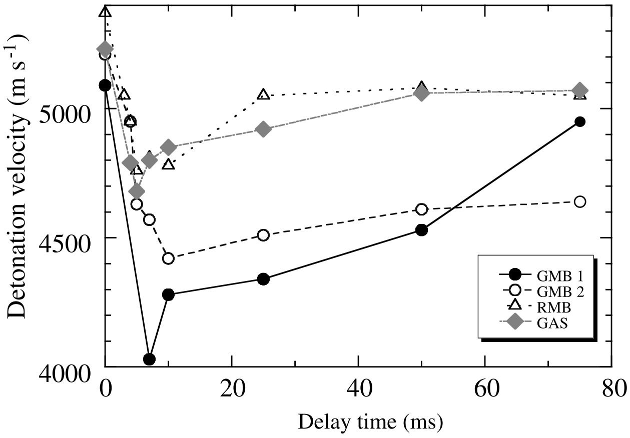

Fig. 5 Detonation velocity under dynamic pressure loading (450 kg cm^{-2}).

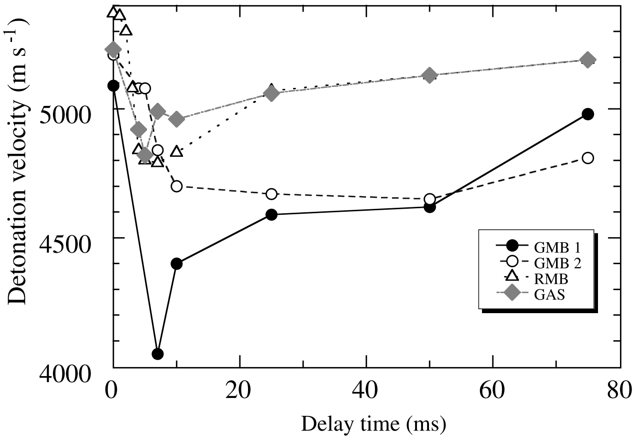

Fig. 6 Detonation velocity under dynamic pressure loading (350 kg cm^{-2}).

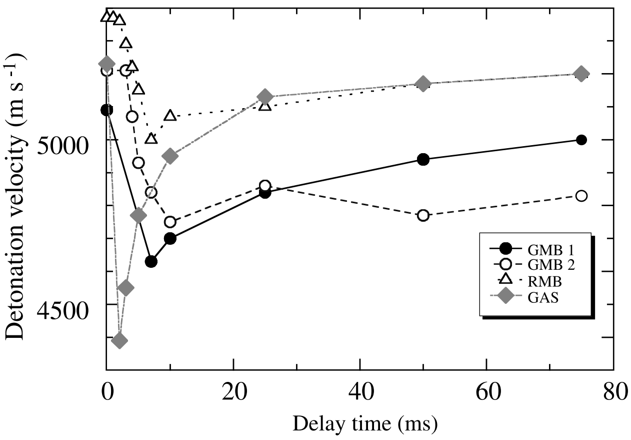

Fig. 7 Detonation velocity under dynamic pressure loading (206 kg cm^{-2}).

sive was increased by compression. At the delay time longer than 75 ms, GMB 1 can recover its detonation velocity value equal to 95% of the original detonation velocity.

In our additional experiment, the detonation failure of GMB 1 was observed again at the delay time of 1000 ms under 350 kg cm^{-2} pressure. Liu et al.[9] investigated the desensitization characteristics of emulsion explosive sensitized with microballoons in terms of blast hole spacing and delay time under actual rock blasting conditions. They mentioned that the distinction between the desensitization zone and the normal detonation zone could be conducted at a threshold value of spacing. Their result is different from what has been observed by us. It is deduced that precompressed emulsion explosives would be deteriorated by the crystallization of the oxidizing agent, and by the collapse of glass micro balloons attributed to their plastic behavior in our additional experiment at the delay time of 1000 ms.

Figure 4 summarizes the experimental results on the relation between the detonation velocity and the delay time for RMB under respective pressure condition. It is obvious that the detonation velocity of the explosive decreases with increasing the pressure applied. However, the magnitude of decreasing detonation velocity is low compared with the case of GMB 1. The detonation velocity shows its minimum at the delay time of 5 ms, and its value is equal to 90% of the original detonation velocity. The detonation velocity at the delay time of 5 ms is lower than that at the delay time of 2 ms. It was deduced that the explosives were on the process of compression during this period. No detonation failure of RMB was observed except under 450 kg cm^{-2} condition.

It is considered that elastic behavior will be observed for the explosives containing resin microballoons. This characteristic is attributed to that a resin microballoon can recover its shape rapidly after the pressure is released. This is reason why the explosives containing resin microballoons can regain its detonation velocity rapidly. That status is as same as the status for chemical gas bubbles. In contrast, on a glass microballoon, a part of them collapses its structure permanently when the pressure is applied.

Some researchers[10)~12)] have investigated the temporary desensitization and the recovery of the detonability with emulsion explosives. Huidobro et al.[11)] determined that the behavior of various water based explosives was affected under dynamic pressure conditions using different initiation energies. The recovery of the detonability in the emulsion explosives was observed in a short delay time.

Figures 5-7 summarize the experimental results on the relation between the detonation velocity and the delay time for all the sample explosives under pressure condition respectively. It is shown that it is difficult to affect the performance of RMB by a pressure wave.

It is shown that the degree of the decrease on the detonation velocity for explosives of GMB 1 and GMB 2 is different. As mentioned previously, gmb 1 have a structure of mono-cell, while gmb 2 have a multi-cell structure. So gmb 2 is stronger than gmb 1 against shock pressure. It is easily deduced gmb 1 is more fragile than gmb 2, when the pressure is applied. It is concluded that the strength of microballoons gives an influence on the difference of the results between GMB 1 and GMB 2.

Furthermore, in our additional experiment, the relation between the detonation velocity and the density of emulsion explosives was studied. The detonation velocity of emulsion explosives with initial density of 1230 – 1250 kg m^{-3} indicated the approximate same value as the minimum detonation velocity under 350 kg cm^{-2} condition.

3.2 Time interval of detonation failure

Table 4 shows the time intervals of the detonation failure on all the sample explosives. As mentioned previously, RMB is expected to give better performance due to the higher pressure resistance. Nie[12)] conducted the computer simulation on the recovery of detonability using N_2 bubbles. The computer simulation indicated that the dead pressing and the detonability recovery are very rapid processes, that is, approximately 2 ms was required for the dead pressing and 50 ns for the detonability recovery. Our results on GAS indicate that the time intervals of the detonation failure are within 1 and 3 ms. Gas bubbles can be shrunk and expanded rapidly. Therefore, gas bubbles make it possible that the time intervals of the detonation failure are shortened.

Table 4 Time intervals of detonation failure.

Sample explosive	Dynamic pressure (kg cm^{-2}) 450	350	206
GMB 1	~ 5	~ 5	~ 5
GMB 2	~ 3	~ 3	~ 2
RMB	~ 2	---	---
GAS	~ 3	~ 2	~ 1

unit : ms

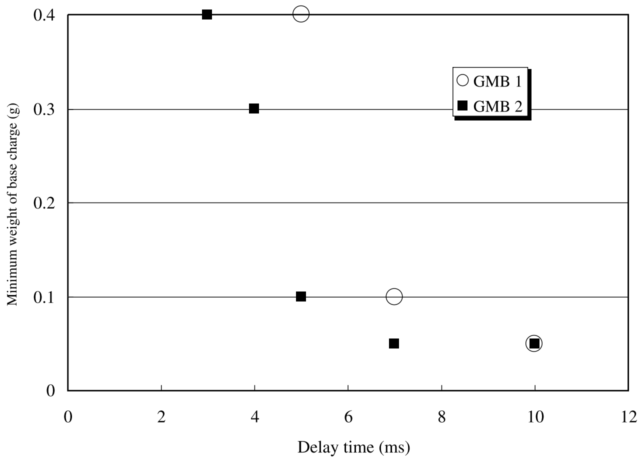

Fig. 8 Relation between delay time and minimum weight of base charge (GMB 1 & GMB 2).

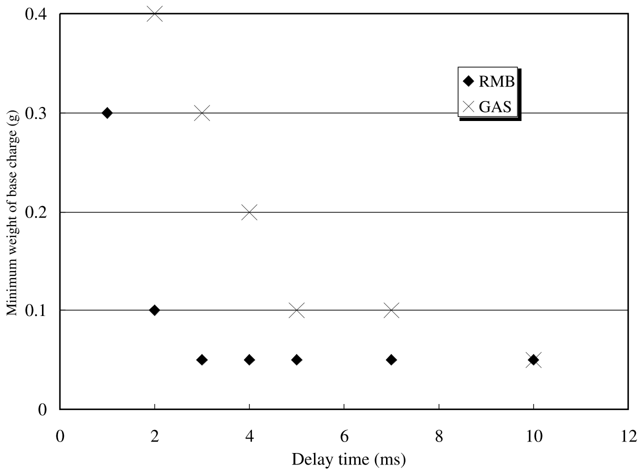

Fig. 9 Relation between delay time and minimum weight of base charge (RMB & GAS).

3.3 Initiation sensitivity

Figure 8 summarizes the experimental results on the relation between the delay time and the minimum weight of base charge to initiate GMB 1 and GMB 2. GMB 1 gave the minimum detonation velocity at the delay time of 7 ms. However, it is obvious that the initiation sensitivity of explosive at that time is as same as that of explosive on initial condition. It can be concluded that the result indicates the similar situation for GMB 2 at the delay time of 10 ms.

Figure 9 summarizes the experimental results on the relation between the delay time and the minimum weight of base charge to initiate RMB and GAS. It is concluded that the recovery of the initiation sensitivity occurred rapidly on RMB.

It was confirmed on additional experiments that all sample explosives could recover its initial initiation sensitivity at the delay time of 25 ms.

4. Conclusion

The following conclusions were obtained in this study ;

- The detonation velocity of precompressed emulsion explosives was low compared with that of uncompressed emulsion explosives in all pressure conditions.
- The decrease of detonation velocity in the sample explosives sensitized by glass microballoons was larger than that sensitized by resin microballoons or chemical gas bubble.
- The recovery of detonability occurred rapidly in the sample explosives sensitized by resin microballoons and chemical gas bubble. However, a long period was needed for the recovery of detonability in the sample explosives sensitized by glass microballoons.

In conclusion the type of microballoon and micro bubble significantly influences the detonability of precompressed emulsion explosives.

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