Research paper

Underwater explosion test of precompressed emulsion explosives

Fumihiko Sumiya†

NOF Corporation Taketoyo Plant, 61-1 Kita-komatsudani, Taketoyo-cho, Chita-gun, Aichi 470-2379, JAPAN
†Corresponding address: fumihiko_sumiya@nof.co.jp

Received: April 22, 2008 Accepted: August 4, 2008

Abstract

To clarify the detonation properties of precompressed emulsion explosives, the preliminary assessment experiments were performed by applying an underwater explosion test. Underwater explosion test makes it possible to induce dynamic pressure wave into the sample emulsion explosives. The bubble energies of precompressed explosives were measured.

Two types of microballoon were used as a sensitizer for the sample emulsion explosives respectively. Delay period is identified as a time between the time on which dynamic pressure wave is induced and the time on which sample explosive is initiated.

It is concluded that the bubble energy of explosive is decreased as the delay period become longer. And the influence of the type of microballoon used on the bubble energy was observed. It is assumed that the result would be attributed to the difference of the reactivity on explosives.

Keywords: Underwater explosion test, Emulsion explosive, Bubble energy, Dead-pressing, Microballoon.

1. Introduction

Since the invention of emulsion explosives in 1960's, emulsion explosives have been used in all blasting situation, for example, tunneling, mining, quarrying and so on. Emulsion explosives have replaced gelatin dynamite explosives as a cap-sensitive explosive during the last decade because of the occupational safety and health in handling for blasting operators. For a fact, the consumption of the emulsion explosive was about 6 times larger than that of the dynamite explosive in 2007.

And now, a way of the sequential blasting is applied as a common technique for all blasting scene. However this technique can often cause the 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 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. 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)].

If the precompressed explosives can be initiated, it would create a poor energy release due to incomplete reaction and that creates much toxic fumes. The poor energy release will bring down the underachieve fragmentation, and the generation of the toxic fumes will make the working environment worse. These phenomena will be undesirable for safe blasting operations.

It is well known that an explosive energy can be quantitatively evaluated using the underwater explosion test. The results of this test respectively give the shock wave energy and bubble energy on the evaluated explosive. In general, the shock wave energy contributes to chapping the rocks, and the bubble energy will be exhausted for the extension of the cracks and the movement of the crushed rocks [4)].

In the previous paper [5)], we reported the detonability of emulsion explosives precompressed by dynamic pressure. The different types of microballoons 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, which is regarded as characteristics of the shock wave energy, of sample explosives was measured. The result indicated that the decrease of detonation velocity in the explosives sensitized by glass microballoons was larger than that in the explosives sensitized by resin microballoons. It was concluded that the recovery of the detonability occurred rapidly in the sample explosives sensitized by

Table 1 Characteristics of microballoons.

Name	Bulk density (kg cm^{-3})	Average diameter (μm)	Crush strength (MPa)	Structure
g m b	120	65	3.2	Mono Cell
r m b	20	90	—	Mono Cell

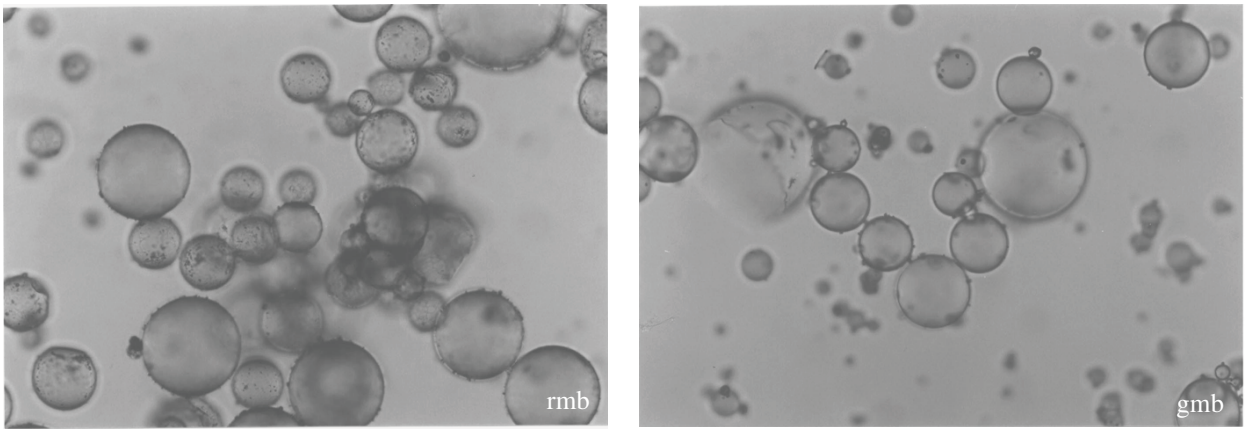

Fig. 1 Photographs of microballoons.

Table 2 Performance of sample explosives.

Sample name	Microballoons	Density (kg m^{-3})	Detonation velocity (ms^{-1}, 20°C) (30mmϕ, Plastic Film Tube)	Sensitivity-weak detonator test (20°C) (30mmϕ, Plastic Film Tube)
GMB	g m b	1,150	5,200	Class 0.5
RMB	r m b	1,140	5,330	Class 0.5

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

resin microballoons. However, a long period was needed for the recovery of detonability in the sample explosives sensitized by glass microballoons. It was considered that the deformation of explosive charge caused by dynamic pressure is one of the factors for the decrease of detonation velocity.

In this study, the preliminary assessment experiments were performed by applying an underwater explosion test as previously described to measure the bubble energy of the precompressed explosives. Two types of microballoon were used as a sensitizer for the sample emulsion explosives respectively. And also, the degree of the breakage on emulsion was measured using the dielectric breakdown device after the dynamic pressure was loaded.

2. Experimental

2.1 Sample emulsion explosives

The emulsion matrix used in this study has a density of 1400 kgm^{-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 – 1150 kgm^{-3}. The characteristics of microballoons used in these experiments are summarized in Table 1.

Figure 1 shows the photographs of two microballoons. Glass microballoons (designated as gmb) and resin microballoons (designated as rmb) have also the structure of mono-cell.

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 was sensitized by gmb. The performance of the sample emulsion explosives is summarized in Table 2. It is clear that the performance of two emulsion explosives is just similar.

2.2 Experimental arrangement & devices

2.2.1 Underwater explosion test

An underwater explosion technique was applied as a method to load dynamic pressure into the sample emulsion explosives. Our underwater explosion testing tank is 4 m in diameter and 4 m in depth. A shock wave was generated by the detonation of dynamite explosive of 40 g as a donor explosive, and applied to the sample emulsion explosives as an acceptor. Donor and acceptor explosives were set in testing tank at 2 m in depth and initiated by No. 6 instantaneous electric detonators respectively using MS delay blasting machine.

The reason why the MS delay blasting machine was used as an initiation system was as follows. Katsabanis et al.[6] mentioned that the actual initiation delay of pyrotechnic

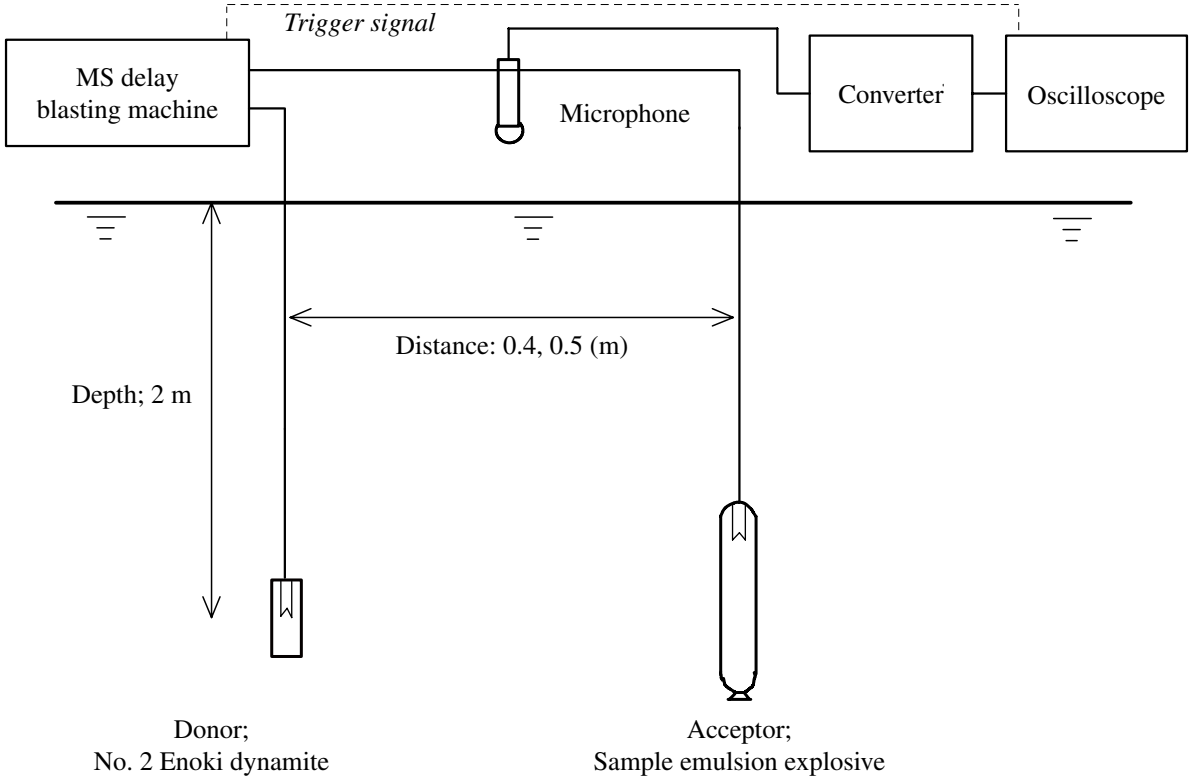

Fig. 2 Experimental arrangement for underwater explosion test.

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 these experiments. 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 can be set at a 1 ms interval step-wise. The time accuracy compared with a target time is within 0.1 ms. Therefore, the instantaneous electric detonators were used instead of pyrotechnic delay detonators. The delay times were set at 250 ms or 1000 ms.

The distance between the donor and acceptor was varied to modify the shock pressure level applied to the acceptor. The distance was 0.4 and 0.5 m. Figure 2 shows the experimental arrangement for underwater explosion test.

Bubble pulse generated from the bubble oscillation was detected by dynamic microphone, which was set at the distance of 0.5 m above the water surface. The bubble pulse was recorded by digital storage oscilloscope (sampling time was 0.2 ms). This oscilloscope was synchronized to the trigger signal from MS delay blasting machine. A bubble period was decrypted from the profile of bubble pulse. Bubble energy (E_b) was determined according to the following equation [7), 8)].

$$E_b = 6.84 \cdot 10^{7/2} \cdot P_0^{5/2} \cdot T_b^3 \cdot W^{-1} \quad (MJkg^{-1}) \qquad (1)$$

where P_0 is the total hydrodynamic pressure at explosive depth (MPa), T_b is the bubble period (s), W is the explosive weight (kg).

Bubble energy on the intact explosives was also determined so as to compare with the experimental results.

However, the values obtained from this study must be regarded as the preliminary figures, because the above equation (1) will be satisfied only when the infinitely large testing tank is used [9)].

2.2.2 Status of emulsion

The degree of the breakage on emulsion was estimated after the dynamic pressure was loaded. Experimental arrangement was applied as a similar way of the above-mentioned underwater explosion test. The sample explosives as an acceptor were just the same as the previous ones. Both donor and acceptor explosives were set in testing tank at same depth. The acceptor that the electric detonator was not inserted into, was immediately recovered from its tank after the donor was initiated by No. 6 electric detonator. After then, this acceptor exposed to the dynamic pressure was evaluated using the dielectric breakdown device regarding the degree of the breakage of emulsion.

In general, the voltage at normal level can not flow through an emulsion because of the insulation performance of emulsion. However, if the voltage will be boosted gradually, the threshold voltage can pass through an emulsion by an occurrence of a dielectric breakdown phenomenon. An oxidizing agent is dissolved in the droplet as a discontinuous phase of emulsion. The solution of an oxidizing agent is easy to conduct electricity as an electrolyte. There is the tendency that the dielectric breakdown phenomenon occurs more easily with the enlargement of

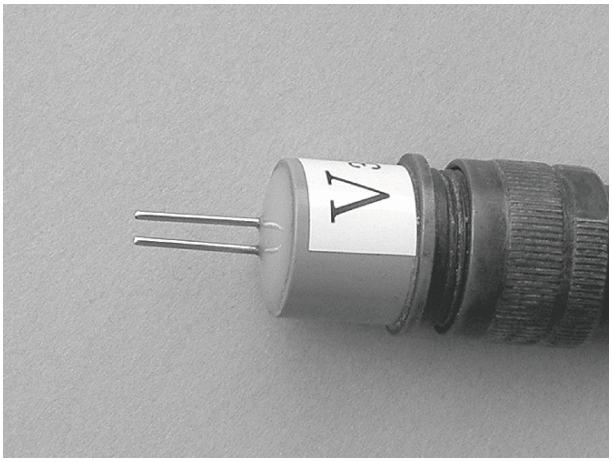

Fig. 3 Photograph of detective terminal.

the droplet. The breakage of emulsion structure means the enlargement of the droplet by the droplet's coalescence and the crystallization of the oxidizing agent. Therefore, the degree of the breakage on emulsion can be evaluated by the measurement of its dielectric breakdown voltage. The dielectric breakdown device made it possible to put this fundamental principle to practical use.

The dielectric breakdown device consists of the main two parts. One is the main body that can supply its gradient of power voltage with constant electric current : 1 mA. The maximum supply voltage can reach approximately 1100 V. Another is the detective terminal with two thin parallel needles of 20 mm in length. The distance between needles is 3 mm. Figure 3 shows the photograph of the detective terminal.

Both main parts are connected by the parallel wires.

For the purpose of measuring its broken voltage of emulsion, the parallel needles are inserted to the previous-mentioned sample emulsion explosive, and the measuring button is pushed to start boosting power voltage. This voltage rises automatically up to reach the threshold voltage. The threshold voltage will be shown on the display panel of main body.

The measurements of the broken voltage were carried out at 5 points per one emulsion stick. An average value was obtained from two sticks under same experimental condition.

3. Results and discussion

3.1 Underwater explosion test

The bubble periods obtained from the experiments of the intact explosive employed were 130.90 and 131.35 ms respectively. These values can be converted to 2.18 and 2.20 $MJkg^{-1}$ as bubble energies by the calculations of equation (1). The average value of these bubble energies gives 2.19 $MJkg^{-1}$. This value will be identified as a reference : E_{bref}.

The 12 experiments were conducted under various conditions. Table 3 summarizes the obtained bubble periods : T_b , the calculated bubble energies : E_b, the "Average E_b" and the "Relative E_b ratio". The "Relative E_b ratio" is meant the ratio of "Average E_b" to reference : E_{bref}.

Roughly speaking, it can be seen from Table 3 that E_b values of sample explosive : RMB are larger than those of sample explosive : GMB under same conditions. It is deduced that the sample : GMB would be deteriorated by the collapse of gmb. That is to say, the characteristics of gmb indicate a plastic behavior. And each balloon size must be different as shown in its particle distribution. Hence, it is considered the strength of each balloon against shock pressure has a variation. As a result, a part of them collapses its structure permanently when the pressure is applied.

Matsuzawa et al. [10] examined the detonability of emulsion explosives, containing three different kinds of glass microballoons under dynamic pressure in water. They concluded that the collapse of gmb would be started at the time of 80 ms after the shock pressure is loaded.

In contrast, an elastic behavior will be observed for rmb. The rmb can recover its shape rapidly after the pressure is released. It is considered that the difference of E_b values under same conditions is attributed to this original physical property.

From the viewpoint of the delay time, E_b values from the experiments with longer delay time are smaller than those from the experiments with short delay time. It is assumed that these results would be ascribable to the crystallization of the oxidizing agent in emulsion. So, the reactivity as an explosive would decrease. In addition, the data scatter can be seen on the results, for example, on "Experimental No.s 3 & 4".

The after fume in bubbles generated by the detonation of precompressed acceptor often gave a bad smell and yellowish color. It is considered that this phenomenon is attributed to the incomplete reaction in detonation. Also, it is assumed the recovery of explosives is not perfect, and the performance of the explosive is below that of the intact explosives. In other words, the explosive malfunctions due to shock pressure. Katsabanis et al. [11] investigated after fumes in their experiment. The fumes were analyzed using a gas chromatography. They concluded that 'toxicity of fumes was not always higher in the case of malfunction. It appears that toxic fumes are not a necessary result after malfunction of explosive charges'. In my study, a bad smell and yellowish-colored fume could not be always observed at all experiments.

3.2 Status of emulsion

The dielectric breakdown voltage for the intact emulsion explosive read the maximum voltage, that is, 1100 V. The breaking-down tests of emulsion were conducted at the distance between donor and acceptor of 0.5 or 0.8 m. When the precompressed explosives were recovered, it was observed by the sense with my palm that the explosive was warm. It is deduced that the exothermal reaction by the partial crystallization of the oxidizing agent in emulsion might happen.

The breakdown voltages were measured at the portion of its surface and its inside respectively for each sample. Relative ratio is identified as the ratio of the gained values to the maximum voltage. Figure 4 shows the bar graph of each relative ratio.

Table 3 Summary of underwater explosion test.

Experimental No.	Sample emulsion explosives	Experimental conditions		Bubble period T_b (ms)	Bubble energy E_b ($MJkg^{-1}$)	Average E_b ($MJkg^{-1}$)	Relative E_b ratio E_{bref} = 100 (%)
		Distance (m)	Delay time (ms)				
1	GMB	0.4	250	122.57	1.79	1.78	81
2				122.30	1.77		
3		0.4	1,000	118.95	1.63	1.68	77
4				121.25	1.73		
5		0.5	1,000	124.30	1.86	1.89	87
6				125.67	1.93		
7	RMB	0.4	250	124.15	1.86	1.86	85
8				124.50	1.87		
9		0.4	1,000	123.35	1.82	1.79	82
10				122.10	1.77		
11		0.5	1,000	126.70	1.97	1.99	91
12				127.30	2.00		

* E_{bref} = 2.19 ($MJkg^{-1}$)

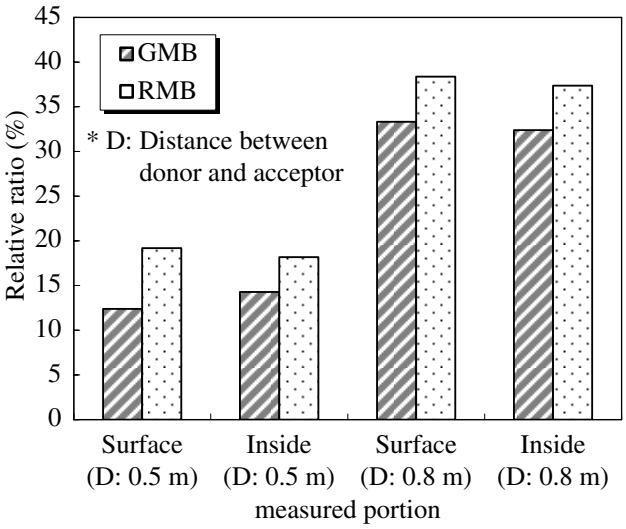

Fig. 4 Relative ration of breakdown voltage.

In case that the distance between donor and acceptor was smaller, the obtained relative ratio would be small. It is deduced that the degree of the breakage on emulsion must be higher.

Significant difference of ratio between GMB and RMB is not observed. And also, significant difference of ratio between two measured portions is not observed. The reason of these results can be considered that the breakage on emulsion must be on the advanced stage.

Regarding this evaluation method, it would be very difficult to elucidate the time course of the breakage on emulsion.

4. Conclusion

From this investigation, it is concluded that the bubble energy of the precompressed explosive becomes smaller with the lengthening of the period after the shock pressure is applied to its explosive. It is assumed that this result would be attributed to the breakage of emulsion and the collapse of microballoons.

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) Edition of Jpn. Explos. Soc., "HAPPA KOUGAKU HANDBOOK", p.124 (2001), KYORITSU SHUPPAN.
5) F. Sumiya, Y. Hirosaki, and Y. Kato, Sci. and Tech. Energetic Materials, Vol.65, pp.88-93 (2004).
6) 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.
7) G. Bjarnholt, and R. Holmberg, Proc. of 6th Symposium (International) on Detonation, pp.540-550 (1976), Coronado.
8) K. Tanaka, M. Yoshida, K. Yoneda, and Y. Mizushima, Kogyo Kayaku (Sci. and Tech. Energetic Materials), Vol.42, pp.239-247 (1981).
9) Edition of Jpn. Explos. Soc., "ENERGY BUSSHITSU HANDBOOK", p.237 (1999), KYORITSU SHUPPAN.
10) T. Matsuzawa, M. Murakami, Y. Ikeda, and K. Yamamoto, Kogyo Kayaku (Sci. and Tech. Energetic Materials), Vol.43, pp.317-322 (1982).
11) P.D. Katsabanis and A. Ghorbani, Proc. of the 21st Annual Conference on Explosives and Blasting Technique, pp.356-368 (1995), Nashville.

加圧されたエマルション爆薬の水中爆力試験

角谷文彦†

トンネル, 鉱山, 採石場などの発破工法として段発発破工法が通常採用されている。この工法においては爆薬包が順次起爆されるため, 点火順序が後の爆薬包は, 先の爆薬の爆轟による衝撃波が印加された状態で起爆されることとなる。衝撃波で加圧された爆薬は本来の性能を発揮せず, 時として不発となる場合がある。

今回, 水中爆力試験において, 通常の段発発破工法における秒時間隔で加圧された爆薬の静的効果を評価するため, バブルエネルギーを測定した。

爆薬の性能に大きな影響を及ぼす気泡剤において, ２種の材質の異なる気泡剤を使用した。どちらの気泡剤を使用した場合も秒時間隔が長くなるほどバブルエネルギーは低下したが, 気泡剤の違いによりエネルギー低下の程度は異なった。しかし衝撃波印加によるエマルションの破壊状態は２種の気泡剤により大きく異なることはなかったから, エネルギーの差違は気泡剤の種類に起因することが判明した。

日油㈱・武豊工場　〒470-2379　愛知県知多郡武豊町北小松谷61-1
†Corresponding address: fumihiko_sumiya@nof.co.jp