Article

Developments and field tests of granular emulsion explosives

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Abstract

Highly improved drilling machines and mucking machines have been used for the underground construction. To have rapid construction, particularly, it is important to shorten the cycle time of blasting operation. At the most tunneling in the present, cartridged emulsion explosives have mostly been used for tunnel blasting in Japan. At the present day, a blasting system of ANFO using a loading machine has been introduced recently for a tunnel blasting. However, ANFO has some problems, such as a useless explosive in wet boreholes, bad blasting fume and producing the ammonia gas due to the decomposition of ammonium nitrate in contact with the sprayed concrete in tunnel.

A blasting system using bulk emulsion explosives with loading machine has been used practically in the world. However, it is difficult to introduce this system to Japanese tunneling because of the Japanese Explosives Control Law. Also, bulk emulsion explosives need complicated loading machine for chemical gassing. Therefore, we, Nippon Kayaku Co., Ltd has developed granular emulsion explosives with the development concept, which has explosive properties of emulsion explosives and handling property similar to ANFO. And the field blasting tests were carried out to confirm actual operations and blasting effects in some tunnels. As a result of the field tests, the loading time of explosives can be reduced. The cycle time of blasting operation is less than that of cartridged explosive products, and blasting fume are much better than that of ANFO.

Keywords: Granular emulsion explosives, Loading machine, ANFO

1. Introduction

In recent years, the mechanization of explosives loading is requested in tunnel construction in Japan. The trials of the long hole blasting have been carried out to extend the length of advance in the tunnel. The blasting system of the ANFO using a loading machine by compressed air has been used for long hole blasting. However, ANFO is poor in waterproof and blasting fumes are bad for environment of tunnel[1]. Therefore, the use of ANFO sometimes restricted. We, explosive engineers cannot recommend the use of ANFO in tunnel blasting.

The bulk emulsions have been used for the underground constructions worldwide[2]. However, loading machine with this system is complex, and it is difficult to introduce this system for small-scale underground construction, because this system requires the technical services by explosives and blasting engineers.

Therefore, the granular emulsion explosives has been developed with the development concept, which has explosive properties like emulsion explosives and easy handling property like ANFO, which can be used by the simple loading machine.

2. Granular emulsion explosives

Granular emulsion explosives consists of oxidizer salts, water, fuels, emulsifiers and glass micro-balloons (GMB). The formulation is shown in Table 1. Granular emulsion explosives is made a small cylinder of diameter 4 mm and length 4 mm by extrusion (Fig. 1). The emulsion explosives have a viscous property generally and tend to stick together. Therefore, the special waxes and resins as fuels have been chosen to harden the granular emulsion explo-

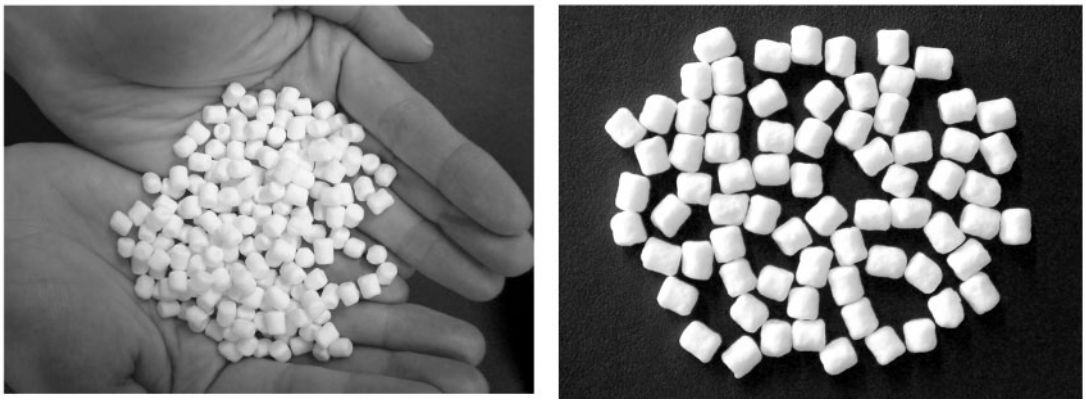

Fig. 1 Granular emulsion explosives (Diameter: 4 mm, Length: 4 mm).

Table 1 Formulation of granular emulsion explosives.

Composition	Ammonium nitrate	Sodium nitrate	Water	Fuels	Emulsifiers	GMB
Mass (%)	70 – 80	5 – 10	10 – 12	3 – 5	1 – 2	3 – 5

sives and reduce stickiness of explosive surface. Granular emulsion explosives can be loaded into borehole with a loading machine using compressed air.

The explosives properties of granular emulsion explosives, cartridged emulsion explosives and ANFO are shown in Table 2. During loading, granular emulsion explosives are blown out through the hose by compressed air so that they stick together into a continuous column in the boreholes. Figure 2 shows granular emulsion explosives, which was loaded to pipe.

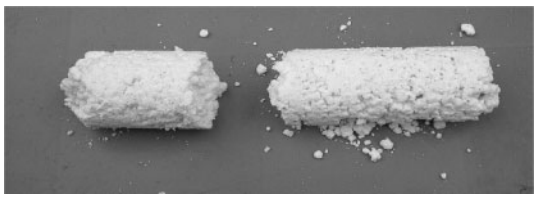

Fig. 2 Granular emulsion explosives loaded to pipe (Loading density: 0.75 g cm^{-3}).

3. Velocity of detonation (VOD of granular emulsion explosives)

The measurements of velocity of detonation (VOD) were conducted in the steel pipes having an inside diameter of 42 mm, a length of 1000 mm, using 50 g primer (cartridged emulsion explosives). The optical fiber method was used VOD measurement at an interval of 100 mm. The loading density of 0.65 g cm^{-3} was poured to a steel pipe. The loading densities of 0.7 to 0.9 g cm^{-3} were loaded to a steel pipe with the charge machine. The relationship between VOD and loading density is shown in Fig. 3.

The loading density of granular emulsion explosives can

Table 2 Explosives properties.

Explosives	Granular emulsion explosives	Cartridged emulsion explosives	ANFO
Density (g cm^{-3})	(Bulk density) 0.6~0.7 (Loading density) 0.7~0.9	1.15~1.23	0.8~0.9
Waterproof performance	Good	Excellent	None
Cap sensitivity	None	Yes	None
VOD (m s^{-1})	3500~4500	5800~6000	2500~3000
Ballistic pendulum (mm)	72~78	78~84	62~68

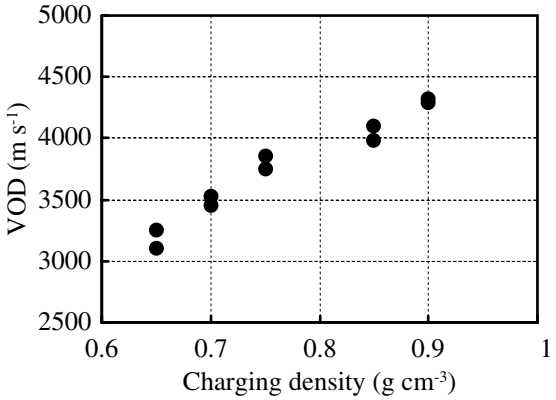

Fig. 3 Relationship between loading density and VOD.

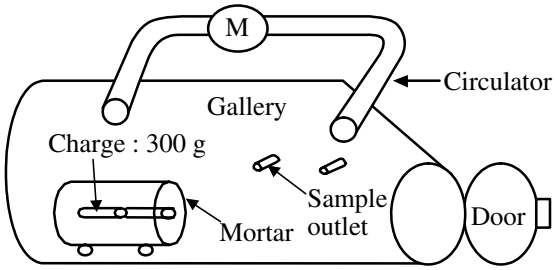

Fig. 4 Test equipment for measuring gaseous products of explosion.

Table 3 Components of blasting fumes.

Explosives	Granular emulsion explosives	Cartridged emulsion Explosives	ANFO
Component (L/kg)			
NO_X	1	2	6
CO	2	4	23
CO_2	87	120	115

be specified from 0.7 to 0.9 g cm^{-3} by varying the air pressure of loading machine. The VOD changes to the range of 3,500 - 4,500 m s^{-1} depending on the loading density.

4. Blasting fumes of granular emulsion explosives

The test procedure of blasting fumes can be described as follows. It is based on the method described in the Bureau of Mines Bulletin 346 and has been somewhat modified by Nippon Kayaku. Explosives of 300 g are bottom-primed with 30 g primer (cartridged emulsion explosives) and are loaded into borehole (diameter: 45 mm, length: 1 m) of steel cannon without tamping material.

The cannon is placed in a steel gallery of 35 m^3 in volume. After the explosives are fired, the door of gallery is closed and a blower circulates the gas in the gallery immediately. Carbon monoxide (CO) and nitrogen oxide (NO_x) are measured using the gas detector (Drager Safety AG & Co.KgaA). Test equipment is shown in Fig. 4. Gaseous products obtained from explosion of granular emulsion explosives, cartriged emulsion explosives and ANFO are shown in Table 3. Each component of gaseous products is represented by dimension (L/kg), which used the following equation.

$$(\text{L/kg}) = \frac{35000 \times 10^{-6}}{0.300} \times (\text{ppm})$$

Granular emulsion explosives have less generating of NO_x and CO than ANFO and cartriged emulsion explosives. Granular emulsion explosives are better explosives for work environment of underground constructions.

5. Loading machine of granular emulsion explosives

The loading machine of granular emulsion explosives has been developed for underground construction with concept of simple mechanism. The loading machine is shown in Fig. 5. Granular emulsion explosives are blown through the loading hose of 30 m to bore holes by compressed air. The pressure of compressed air can be changed easily to vary the loading density of granular emulsion explosives.

Fig. 5 Loading machine of granular emulsion explosives.

Table 4 Results of the field test No. 1.

Explosives type	Granular emulsion explosives	Cartriged emulsion explosives
Number of boreholes	97 (89 %)	109 (100 %)
Total charge of explosives (kg)	53 (113 %)	47 (100 %)
Loading time of explosives (min)	24 (65 %)	37 (100 %)

The loading machine and compressor are placed on the deck of a truck.

Four kinds of loading weight can be inputted into control panel, and a choice of loading weight is operated by wireless remote controller at the face. Since loading weight can be set per 200 g unit, it is possible to charge with the optimum loading weight. The loading machine has two loading hoses which can independently controlled, and the loading rate is 25 kg/minute.

6. Field test No. 1

The field test No. 1 of granular emulsion explosives was carried out in a highway tunnel. Cartridged emulsion explosives have been used exclusively in this tunnel. The explosives property and handling property of granular emulsion explosives were confirmed in this field test as compared to cartridged emulsion explosives. Granular emulsion explosives were loaded at a loading density of 0.75 g cm^{-3}.

The face area was 60 m^2, and the rock type was a granodiorite. The boreholes were 45 mm in diameter and drilled to a depth of 1.2 m. The test blasting used granular emulsion explosive was carried out 6 times, and the blasting used cartriged emulsion explosives was carried out 6 times. The results of field tests No. 1 are shown in Table 4. The average of 6 times is shown in results.

The numbers of borehole were reduced about 10 %, and the loading quantity of explosives was increased about 10 % as compared to cartridged emulsion explosives. If a depth of boreholes becomes longer, the number of boreholes will be able to be reduced further.

Although 2 workers loaded for granular emulsion explosives and 5 workers loaded for cartriged emulsion explosives, the loading time of granular emulsion explosives was estimated to reduce about 35 %. So the safety for workers near the face will be improved by shortening staytime at the faces.

7. Field test No. 2

The field test No. 2 of granular emulsion explosives was carried out in a tunnel for underground construction. ANFO have been used exclusively in this tunnel, and small quantity of cartriged emulsion explosives have been used for toe holes in which water existed. The explosive properties and blasting fumes of granular emulsion explosives were confirmed in this field test as compared to ANFO. Granular emulsion explosives were loaded at a loading density of 0.75 g cm^{-3}.

The 59.4 m^2 faces were drilled out with 128 boreholes, and the rock type was granite. The boreholes were 45 mm in diameter and drilled to a depth of 4.0 m. The test blasting used granular emulsion explosive was carried out 3 times, and the blasting used ANFO was carried out 3 times.

Carbon monoxide (CO) and nitrogen oxide (NO_x) were measured using the gas detector (Drager Safety AG & Co. KgaA) at 85 m point from the face shortly after blasting. The results of field tests No. 2 are shown in Table 5. The average of 3 times is shown in results.

The loading weight of granular emulsion explosives was reduced about 12 % as compared with that of ANFO. Since the loading density of granular emulsion explosives was smaller than that of ANFO, the loading weight was reduced in the case where it is set as the same length of explosive column. Although the loading weights of granular emulsion explosives were reduced, similar fragmentation were obtained as compared to ANFO. Granular emulsion explosives were loaded to toe holes in which water existed, and the fragmentations of toe were good.

As a result of blasting fumes measurement, there was less poisonous gas than ANFO. It was confirmed that the blasting fumes of granular emulsion explosives were excellent and it is good for work environment.

Table 5 Results of the field test No. 2.

Explosives type		Granular emulsion explosives	ANFO
Total loading weight of explosives (kg)		409 (88 %)	463 (100 %)
Blasting fumes	NO_x (ppm)	10 (25 %)	40 (100 %)
	CO (ppm)	120 (48 %)	250 (100 %)

8. Conclusion

Granular emulsion explosives developed have high explosive properties, waterproof and good blasting fumes. Granular emulsion explosives can be loaded by simple loading machine using compressed air. The loading density of granular emulsion explosives can be specified from 0.7 to 0.9 g cm^{-3} by varying the air pressure, and the VOD can be changed to the range of 3500 - 4500 m s^{-1} depending on the loading density.

As a result of field tests, the number of boreholes per face and explosives loading time were reduced as compared to cartridged emulsion explosives. Therefore, cycle time was shortened and the safety of operation at face was also improved. The specific charge was reduced and the blasting fumes (NO_x, CO) were excellent as compared to ANFO.

Reference

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粒状エマルション爆薬の開発及び実用試験

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トンネル掘進発破や砕石場のベンチ発破においては，爆薬装填作業の機械化の要望がある。この課題に対して，世界的には流動性をもつエマルション爆薬をモーノポンプ等で装薬するバルクエマルション爆薬が普及している。しかし，良好な爆轟性能，耐水性，後ガス等の長所を持つ反面，高粘性の物性であるために周囲への付着等のハンドリング面，また正確な火薬の数量管理が難しいといった短所がある。また，ANFO爆薬は簡便なエアーローダーでの装填は可能であるが，耐水性がなく様々な作業環境に対応できないといった問題がある。そこで，「含水爆薬並みの威力，耐水性，後ガス，及びANFO爆薬並みの機械装填性，ハンドリング性を併せ持つ爆薬」を開発コンセプトに，粒状エマルション爆薬を開発した。さらに，粒状エマルション爆薬の現場での実用評価試験を実施した結果，含水爆薬と比較し，孔数の削減及び装薬時間の短縮，また，ANFO爆薬と比較し，薬量の削減及び後ガスの良好性が確認できた。

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