Article

Field-blasting tests of high-performance ANFO

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ANFO is the most useful industrial explosive in mining and quarries. The main reasons are its lower cost and easier mixing compared with the other explosives. Furthermore, ANFO has good characteristics in handling such that it can be filled in multiwall bags or flexible containers and be suited for bulk loading with pneumatic loading equipment.

Recently, several field-blasting tests of high-performance ANFO [ANFO (H)] have been carried out. ANFO (H) has the improved detonation properties and the rather low density of 0.70 – 0.80 $g \cdot cm^{-3}$ compared with conventional ANFO (0.80 – 0.90 $g \cdot cm^{-3}$). The results of these field-blasting tests showed that ANFO (H) made it possible to decrease the specific charge without affecting the fragmentation, the displacement of the blasted rock and the breakage in the toe [1]. Furthermore, the field-blasting tests of more improved high-performance ANFO [ANFO (SH)] have been carried out. ANFO (SH) also keeps the advantages of ANFO, and has the more excellent explosion performance and the lower bulk density (0.60 – 0.70 $g \cdot cm^{-3}$) than ANFO (H). Although fears were entertained that problems caused by the significant reduction of the charge would occur in the tests, e.g. a toe-problem, the results indicated that ANFO (SH) would be available for field use.

1. Introduction

It is well known that AN prills of small particle size increases the density and detonation velocity of ANFO [2),3),4)]. If this type of ANFO is used in blasting under the condition for conventional ANFO, the charge weight per hole will be excessive resulting in possibility of fly rock and inefficient utilization of charge [5)]. In order to avoid the above-mentioned problems, it would be necessary to take the appropriate method of blasting, e.g. deck charge blasting.

These circumstances and good use of energy considered, ANFO (H) and ANFO (SH), which have higher power of explosion and lower density than conventional ANFO, would be useful. Actually, ANFO (H) has already been put into practical use and got high estimation because of the economical and efficient blasting with it.

2. Explosives properties

Main characteristics of three types of ANFO used in the field tests are shown in Table 1. ANFO (H) and (SH) have safety characteristics no better than conventional ANFO has. The detonation properties of them are improved by heightening the reactivity between ammonium nitrate and fuel oil in comparison with the one of conventional ANFO. The significant improvement of the static effect may be expected in particular because the ballistic pendulum value of ANFO (H) and (SH), which

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Table 1 Explosives properties

Explosives	ANFO	ANFO (H)	ANFO (SH)
Bulk density ($g \cdot cm^{-3}$)	0.80～0.90	0.70～0.80	0.60～0.70
VOD ($m \cdot s^{-1}$)	2500～3000	3000～3500	3300～3800
Ballistic pendulum (mm)	45～55	60～70	70～80
Cap sensitivity	None	None	None
Impact sensitivity (cm)	50<	50<	50<
Friction sensitivity (N)	353 <	353 <	353 <

expresses the volume of the gas produced by the detonation, is increased by 30 % and 50 %, respectively. In addition, although the bulk densities of them are reduced by more than 10 – 20 %, the detonation velocities are increased by 20 – 30 %. That will result in showing the excellent dynamic effect.

The measurements of explosives properties are as follows.

Detonation velocity test conforms to Japan Explosives Society Standard ES-41 (1)[6]: The VOD (Velocity of Detonation)measurement is conducted in a steel pipe having an inside diameter of 35 mm, a length of 230 mm and a thickness of 3.5 mm. It is initiated by 40 g primer (pentolite) with the No.6 detonator.

Ballistic pendulum test conforms to Japan Explosives Society Standard ES-45 [7]: The test consists of placing the explosives in a cardboard tube with 30 mm inside diameter and 5 mm thickness. Initiation is made with the No.8 detonator.

Cap sensitivity test conforms to Japan Explosives Society Standard ES-32 (2)[8]: The test consists of placing the explosives in a 60 mm outside diameter by 130 mm long PVC tube. The No.6 detonator is fully embedded in the center of the explosives.

Drop hammer test according to Japan Explosives Society Standard ES-21 (1)[9] is conducted to measure the impact sensitivity.

Friction test according to Japan Explosives Society Standard ES-22 [10] is conducted to measure the friction sensitivity.

3. Field test condition and assessment

The field tests of ANFO (H) were carried out under the same blasting condition as each one normally used in two quarries (Table 2). In case of the condition A of which the rock type was limestone, the test faces were arranged alternately as shown in Fig.1 in order to eliminate differences in the geology of the rock or the shape of face, that influence the result of the blast, and evaluate the performance of ANFO and ANFO (H) relatively. The following factors were evaluated:

- Degree of fragmentation
- Mucking situation
- Breakage in toe

In addition, the ground vibrations and the air waves were measured when the field test was carried out in the condition B of which the rock type was sandstone. The measuring of them was

Table 2 Field test conditions

Condition	A	B
Rock type	Limestone	Sandstone (hard)
Blasting type	Bench*	Bench*
Bench height (m)	8.0	18.0
Hole depth (m)	9.5	9.0
Hole diameter (mm)	95	65
Spacing (m)	4.8	2.5
Burden (m)	3.6	3.0
Stemming (m)	3.6	3.7
Number of holes	10	5
Detonators	DSD #1	DSD #1-5

* : Vertical blastholes

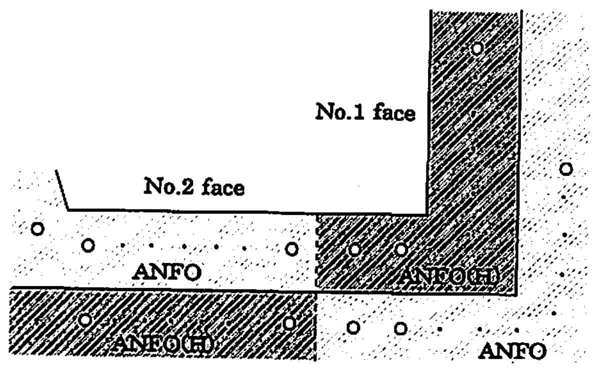


Fig. 1 Arrangement of field test faces

Table 3 Results of bench blasting with ANFO (H) and conventional ANFO under the condition of A

Explosives	ANFO	ANFO (H)	ANFO	ANFO (H)
Face No.	1	1	2	2
Charge per hole (kg)	35.0	31.5	35.0	31.5
Specific charge ($kg \cdot m^{-3}$)	0.253	0.228	0.253	0.228
Degree of fragmentation Number of boulders (1m≦) Fragmentation size(1m≦)	 40 0.84 m	 40 0.98 m	 24 1.02 m	 18 0.88 m
Mucking situation	Breaker was utilized to crush boulders as usual.	Boulders were broken during the excavation.	Breaker was utilized to crush boulders as usual.	Boulders were broken during the excavation.
Breakage in toe	No stumps.	No stumps.	No stumps.	No stumps.

Table 4 Results of bench blasting with ANFO (H) and conventional ANFO under the condition of B

Explosives	ANFO	ANFO (H)
Charge per hole (kg)	15.0	13.5
Total charge (kg)	75.0	67.5
Specific charge ($kg \cdot m^{-3}$)	0.22	0.20
Number of boulders (1m≦)	8	8
Ground vibrations (dB)	45	46
Air waves (dB)	99	99
Note	As usual.	Reduced overhang compared with usual.

done at a distance of 500 m from the blasting site.

The field tests of ANFO (SH) were also carried out under the condition A at the faces arranged alternately so that the performance of ANFO (SH) could be evaluated in comparison with ANFO (H).

4. Test results

The results of the test of ANFO (H) in the condition A are shown in Table 3. The specific charge of ANFO (H) with low density was decreased by about 10 % because there were no differences between the blasting with ANFO and ANFO (H) with respect to the burden, the spacing, the hole depth and the stemming. The rock of the face No.1 was dark brown, full of faults and incompetent zones. On the other hand, the rock of the face No.2 was white, relatively competent. When the blasts with ANFO (H) are compared to that with ANFO at the same faces, it can be found out that ANFO (H) has the same or higher explosion performance with the charge reduced by 10 %. In the blast with ANFO (H) at the face No.2, while the designed amount of blasted rock was 3,270 t, the blasted rock of 4,100 t was obtained. Although we were particularly afraid that a toe-problem would occur because of the decrease of the specific charge, there ware no stumps in the bottom part. In these results, ANFO (H) showed no negative effect of its low density in the blast.

The blasting test of ANFO (H) in the condition B was also carried out with the lower specific charge than the one of ANFO and evaluated by comparing with the result when blasting with ANFO (Table 4). The degree of fragmentation and the displacement of the rock were good and there was also no difference between the mucking situations after the blasting operations with two explosives. Furthermore, there were no significant differences between the values of the ground vibrations and the air waves from the blasts with two explosives. This result also indicated that the effect of ANFO (H) in the blast would be equivalent to the one of ANFO in spite of the decreased specific charge. The vibration level can be converted into the vibration velocity in accordance with the following equation:

Table 5 Results of bench blasting with ANFO (SH) and ANFO (H) under the condition of A

Explosives	ANFO (SH)	ANFO (H)	ANFO (SH)	ANFO (H)
Face No. (Fig.1)	1	1	2	2
The geology of the rock	Fissured. Dark brown.	Fissured. Dark brown.	Comparatively homogeneous. White.	Comparatively homogeneous. White.
Charge per hole (kg)	28.0	31.5	28.0	31.5
Specific charge ($kg \cdot m^{-3}$)	0.203	0.228	0.203	0.228
Degree of fragmentation and movement	Fine. The designed amount of blasted rock (3,700 t) was obtained.	Fine. Enough displacement.	Fine. Enough displacement.	Fine. Enough displacement.
Mucking situation	As usual. There was no difference in shovel productivity compared with ANFO (H).	As usual.	As usual. There was no difference in shovel productivity compared with ANFO (H).	As usual.
Breakage in toe	No stumps.	No stumps.	No stumps.	No stumps.

$$VL = 20 \log V + A$$

where VL is the vibration level, V is the vibration velocity, and A is a constant. When each vibration level is compared as the vibration velocity, it is suggested that ANFO (H) has high explosion performance, as follows:

$$V_{(H)} / V_{(J)} = 10^{(VL(H) - VL(J))/20} = 1.12$$

where small (H) and (J) stand for ANFO (H) and conventional ANFO respectively.

The results of the tests of ANFO (SH) in the condition A are shown in Table 5. The blasting operations with even lower specific charge were made attempt in the field tests of ANFO (SH). The specific charge was deceased by approx. 10 % and 20 % in comparison with ANFO (H) and conventional ANFO, respectively. The blasting results of ANFO (SH) were good as well as that of ANFO (H) at both faces, which were geologically different as shown in Fig.2 and 3 (a). From Fig.3 (b) and (c), it is known that the forward movement of the entire rock mass and the rock fragmentation were satisfactory. There was no problem with respect to the breakage in the bottom part in spite of the significant reduction of the charge (Fig.4).

Fig. 2 The cross section of No.1 and 2 faces (The difference in the geology of the rock)

The field test results mentioned above may be inferred from the values of the detonation pressure, which are related to the explosives density and the detonation velocity as follows:

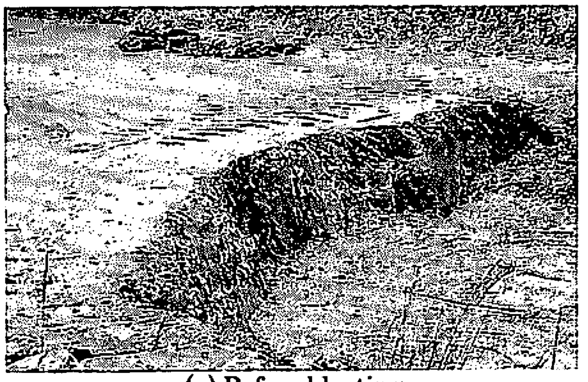
$$P \fallingdotseq 1/4 \cdot \rho D^2$$

where P is the detonation pressure, ρ is the initial explosive density, and D is the detonation velocity. From the above equation and the explosives properties shown in Table 1, the detonation pressure of each explosive can be calculated as follows:

ANFO : $\rho = 0.85 \times 10^3 (kg \cdot m^{-3})$, $D = 2750 (m \cdot s^{-1})$
$P \fallingdotseq 1.61$ (GPa)

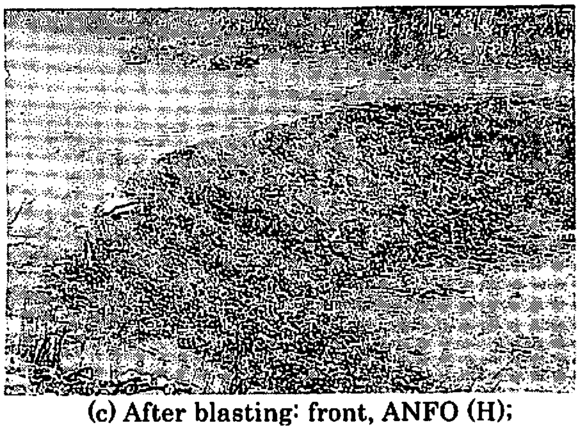
ANFO(H) : $\rho = 0.75 \times 10^3 (kg \cdot m^{-3})$, $D = 3250 (m \cdot s^{-1})$
$P \fallingdotseq 1.98$ (GPa)

ANFO(SH): $\rho = 0.65 \times 10^3 (kg \cdot m^{-3})$, $D = 3550 (m \cdot s^{-1})$
$P \fallingdotseq 2.05$ (GPa)



(a) Before blasting

(b) During blasting



(c) After blasting: front, ANFO (H); behind, ANFO (SH)

Fig. 3 Field-blasting test of ANFO (SH)

5. Conclusion

Based on a series of the field tests, we can draw the following conclusions:

- It is obvious that there is an interrelation between the detonation characteristics of explosives and the field test results.
- The use of ANFO (H) and (SH) makes it possible to give the specific charge about 10 % and 20 % lower than the one of conventional ANFO, respectively.
- These high-performance ANFO can give full effect (good fragmentation, displacement of the blasted rock, and breakage in the bottom part) in spite of the decrease of the specific charge.
- They have the same handling characteristics as conventional ANFO and there is not any problem of caking.

The field tests of ANFO (H) had been extended over a long period before ANFO (H) was put into practical use. Due to the saving in cost of explosives, ANFO (H) has been highly regarded. It can be expected that ANFO (SH) will be welcomed by the user of explosives as well as ANFO (H).

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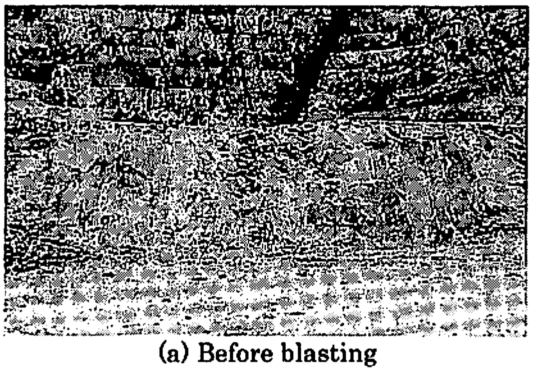
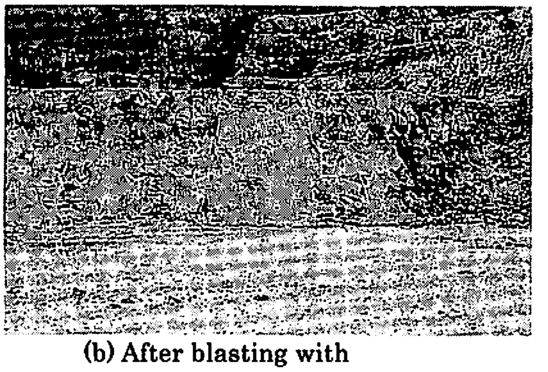


(a) Before blasting



(b) After blasting with ANFO (SH) and mucking

Fig. 4 The cross section of No.2 face

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