Research paper

A fundamental study on greening of deserts using explosives
— Fragmentation and fertilization effect for sandstone specimen by blasting of ANFO —

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Abstract

As a fundamental study for the development of a blasting technique for the greening of deserts, the detonation velocity of the ANFO, the distribution of the fragment size, and the diffusion amount of nutritional ions were investigated using a 30-cm cubic model of sandstone. Moreover, the behavior was compared with that of granite, which was reported in a previous study. It was observed that the amount of fine fragments increased with an increase in the contact surface area between the ANFO and the sandstone. In comparison with the fragmentation of granite, no significant differences were observed in the particle size of the rock fragments after blasting. The amount of ions in the fragment correlated with the detonation velocity. Thus, the amount of ions for the sandstone, in which a low detonation velocity was observed, was higher than that in the case of granite.

Keywords: Greening, Desert, ANFO, Fertilization, Blasting method.

1. Introduction

Blasting using ANFO is thought to convert rock deserts into fertile soil areas because blasting by ANFO can immediately crush rocks into very small particles with a size less than 2 mm, and the unreacted ammonium nitrate diffuses as a nutritional supplement for various plants. As a result of lab-scale experiments using a 30-cm cubic specimen of granite [1], we have reported that the contact surface area of the ANFO with the rock, the tamping condition, and the detonation velocity influenced the particle size of the rock fragments. Moreover, the amount of ANFO in the blasting could control the nutritional ion contents, for example, NH_4^+ and NO_3^-. The study was carried out only for granite. In a previous study [2], it was suggested that the detonation behavior of ANFO, especially the detonation velocity, was dependent on the physical properties of the materials around the ANFO. Therefore, an investigation of the fragment property of other types of rocks is required in order to develop the blasting technique for various types of rock areas.

In order to investigate the differences among different types of rocks with regard to the detonation velocity, the particle size of the fragments, and the amount of nutritional ions in the fragments, which are caused by differences in the material properties, we conducted lab-scale experiments using a 30-cm cubic specimen of sandstone. Further, the results were compared with those of granite, which were reported in a previous study [1].

2. Experimental

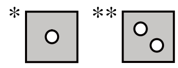
2.1 Samples

The lab-scale experiments were carried out with a 30-cm cubic specimen of Kimachi sandstone and with blast hole diameters of ϕ 38 mm, ϕ 38 mm × 2 holes, and ϕ 58 mm.

The ANFO explosive comprising 94 wt.% of ammonium nitrate and 6 wt.% of No.2 fuel oil (JIS K2204), 30 g of

Table 1 Loading conditions.

No.	Number of blasting holes	Hole diameter (cm)	Amount of ANFO (g)	Contact furaface area (cm^2)
1	1*	38	290	358
2	1*	58	664	546
3	2**	38	599	716



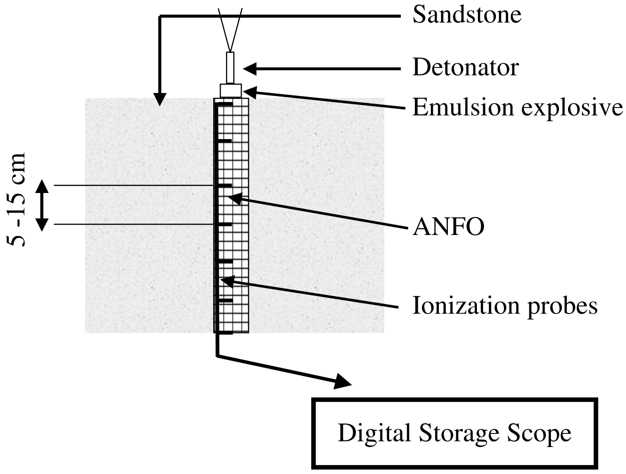


Fig. 1 Experimental assembly.

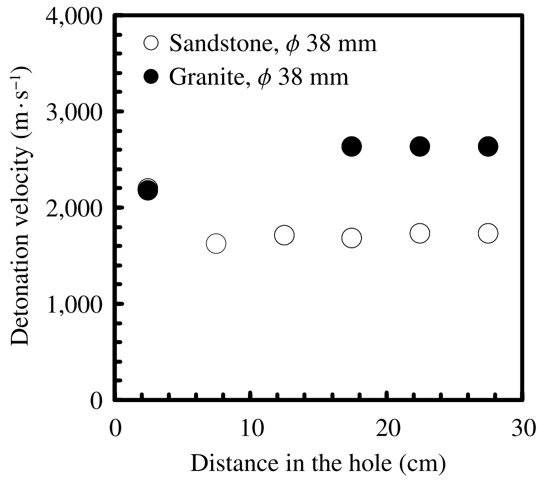


Fig. 2 Detonation velocities in sandstone and granite (ϕ 38 mm).

emulsion explosive as a primer charge, and a No.6 electric detonator for seismic prospecting (NOF Corp.) were charged into the blast hole. The experimental assembly and the loading conditions are shown in Fig.1 and Table1, respectively.

2.2 Measurement of detonation velocity

In order to measure the detonation velocity, ionization probes were attached at 5-cm intervals from the bottom of the blast hole (as shown in Fig.1); the ionization probes for the ϕ 38 mm × 2 holes condition, which has two blast holes, were set at 10 cm or 15 cm intervals in each hole.

The experiments were carried out in a closed-type explosion room (3 m × 3.4 m × 8.4 m) at Tsukuba Center West, AIST. The rock sample with the explosive and the ionization probes was set in the room.

2.3 Particle size distribution

Approximately 3 hours after blasting, all of the rock fragments were collected on metal trays (49 cm × 59 cm). Six JIS standard mesh sieves and a sieve shaker (AS 2000 DIGIT Asone) were used to classify the collected fragments on the basis of their particle size. The fragments were classified into seven groups: less than 0.075 mm, 0.075–0.106 mm, 0.106–0.25 mm, 0.25–0.425 mm, 0.425 –0.85 mm, 0.85–2 mm, and above 2 mm. The weight of each group was measured.

The distribution of particle sizes less than 0.075 mm was analyzed with a particle size distribution analyzer (Multisizer3, Beckman Coulter Corp.). Six mg of rock fragments was used as the sample for the measurement.

2.4 Ion analysis

Ten grams of the fragments with less than 2 mm of particle size and 100 ml of water were shaken for 6 hours with a shaker (Recpro Shaker NR-1, Taitec Co.). The solution was then filtrated and analyzed using ion chromatography (CDD-10Avp, Shimadzu Corp.) with SHIM-PACK IC-CI PEEK for NH_4^+ and SHIM-PACK IC-A3 for NO_3^- and NO_2^-.

3. Results and discussions

In this section, the results on the detonation velocity, particle size distribution, and ion analysis obtained from the experiments using the sandstone specimen are reported. Moreover, the results are compared with those for granite obtained from a previous study [1].

3.1 Detonation velocity

When the experiments were carried out with the sandstones with blast hole diameters of ϕ 38 mm and ϕ 58 mm, a higher detonation velocity was observed in the ϕ 58-mm case. In the case of the sandstone with the ϕ 38-mm blast hole, a detonation velocity of 1700 ms^{-1} was observed at 7.5 cm from the end of the booster, as shown in Fig.2. In the case of the ϕ 58-mm blast hole, the detonation velocity increased until it exceeded 3000 ms^{-1}, as shown in Fig.3. This indicates that a longer distance was required to attain a steady detonation velocity for the ϕ 58-mm condition.

Comparison between the sandstone and granite indicates that the detonation velocity in the case of the former was lesser than that in the case of the latter, as shown in Figs. 2 and 3. This difference in the detonation velocity results

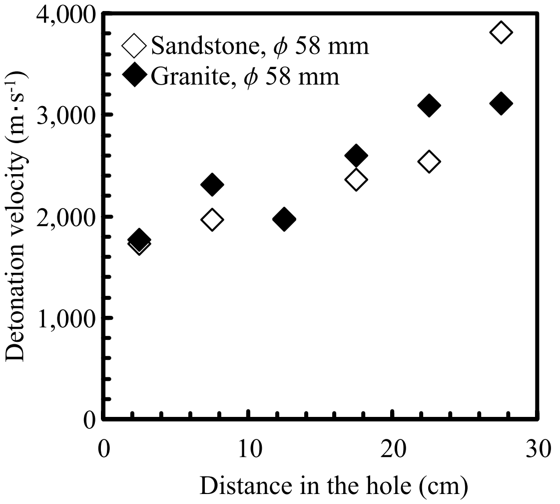


Fig. 3 Detonation velocities in sandstone and granite (ϕ 58 mm).

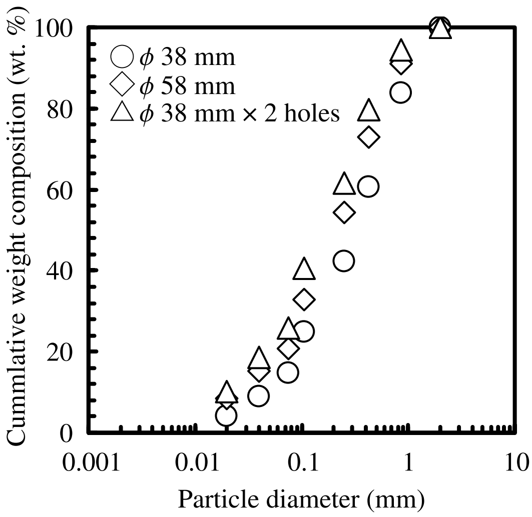


Fig. 4 Cumulative weight composition against particle diameter for sandstone.

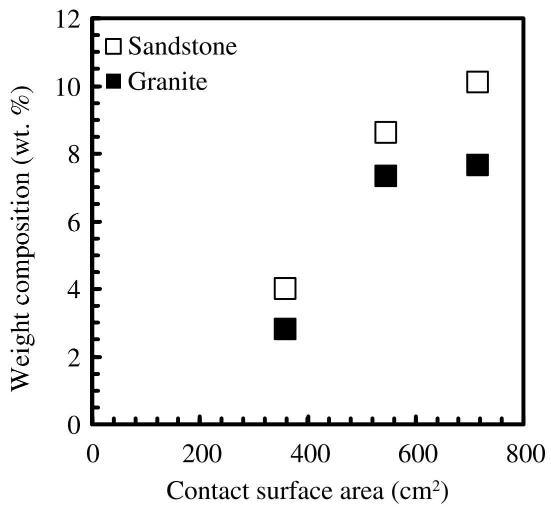


Fig. 5 Relationship between contact surface area and weight composition of the fragments with a size less than 0.020 mm.

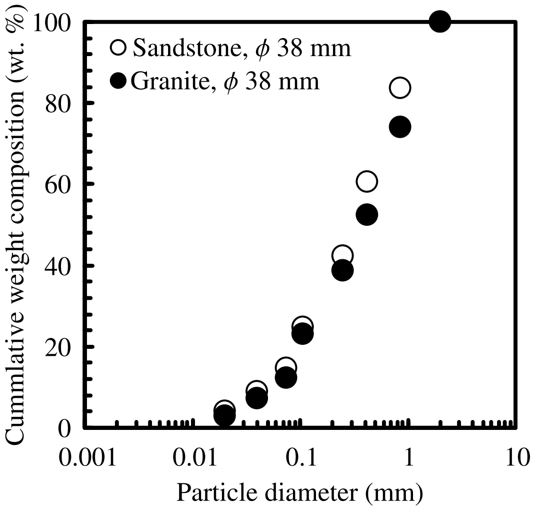


Fig. 6 Comparison between sandstone and granite (ϕ 38 mm) with regard to the cumulative weight curves of the fragments.

from the rock property. In a previous study, it was reported that the pressure wave reflected from the surface of the blast hole contributed to the detonation velocity of the ANFO [2]. The sandstone has a higher transmissive character for pressure waves because its acoustic impedance is 5.038 GPa sm^{-1}, which is lower than the value of 10.75 GPa sm^{-1} for granite. Therefore, it was observed that the detonation velocity in the sandstone was lower than that in granite.

3.2 Particle size distribution

When the fragment sizes were measured after the blasting, the ratio of the amount of fragments with a size less than 2 mm to the total amount of collected fragments was more than 90 wt.% in each loading condition. These results show that blasting can effectively crush the sandstone into soil-sized particles.

With regard to the distribution of the fragments less than 2 mm, the fine fragments increased for the ϕ 38 mm × 2 holes condition in comparison with the ϕ 58-mm condition, as shown in Fig.4. The contact surface area for the ϕ 38 mm × 2 holes condition is larger than that for the ϕ 58-mm condition, whereas the ANFO amount and detonation velocity are lower for the former condition. This may indicate that the fine fragments less than 2 mm in size were generated mainly from the contact surface area between the ANFO and the sandstone. This consideration is supported by the mechanism of Kaneko et al. that suggests that rocks suffer from some cracks generated by the compressive fracture near the contact surface and subsequently the generated gases stimulate the progress of the cracks by entering them [3]. From this, it is apparent that not only the detonation velocity and the ANFO amount but also the contact surface area was conducive to the effect of fragmentation. Additionally, even in the case of the distribution of fragments less than 0.020 mm, the particle size depended on the contact surface area, as shown in Fig.5. Therefore, during the actual blasting for greening, it is necessary to perform the blasting under the condition of a large contact surface area.

Table 2 Nutritional ion content of the fragments.

	Condition	NO_3^- (wt.%)	NO_2^- (wt.%)	NH_4^+ (wt.%)
Sandstone	ϕ 38 mm	0.0659–0.126	0.0126–0.0168	0.0682–0.0861
	ϕ 38 mm × 2 holes	0.104 –0.167	0.0342–0.0406	0.0999–0.126
	ϕ 58 mm	0.0346–0.0994	0.0188–0.0369	0.0568–0.0806
Granite	ϕ 38 mm	0.0029–0.0216	0.0004–0.0016	0.0005–0.0035
	ϕ 38 mm × 2 holes	0.0305–0.0567	0.0005–0.0026	0.0051–0.0116
	ϕ 58 mm	0.0210–0.0960	0.0000–0.0016	0.0049–0.0217

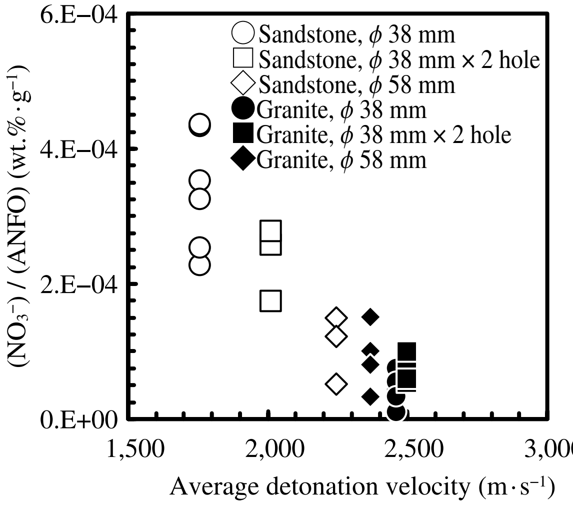


Fig. 7 Relationship between amount of NO_3^- per gram of ANFO and detonation velocity (NO_3^-).

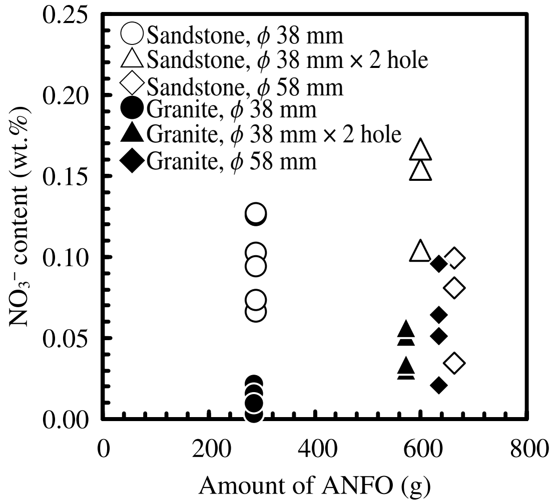


Fig. 8 Relationship between amounts of NO_3^- and ANFO (NO_3^-).

A comparison between the sandstone and granite shows that the distribution of fragments less than 2 mm in size was almost identical for both, as shown in Fig.6. By a simple consideration, it is expected that the fragmentation effect in sandstone should be less than that in granite because the detonation velocity in the former is higher than that in the latter and the contact surface areas are almost identical. However, the experimental results disagreed with this exception. The reason is considered to be the following: since the sandstone has a lower value of dynamic elastic modulus, that fragmentation effect is apparently observed even for a lower detonation velocity.

3.3 Ion analysis

When the amount of nutritional ions—NO_3^-, NO_2^-, and NH_4^+—contained in the fragments of the sandstone was measured, 0.0346–0.167 wt.% of NO_3^-, 0.0126–0.0406 wt.% of NO_2^-, and 0.0568–0.126 wt.% of NH_4^+ were obtained.

Compared to the loading conditions of the sandstone, larger amounts of ions were observed in the ϕ 38 mm and ϕ 38 mm × 2 holes conditions as compared to the ϕ 58-mm condition, as summarized in Table 2. Moreover, in comparison to granite, the amount of ions in the sandstone was larger. These results indicate that the reactivity of ANFO contributed to the generation of nutritional ions because the amount of nutritional ions that diffused from the ANFO into the fragments correlated with the detonation velocities. As an example, the relationship between the amount of NO_3^- per gram of ANFO and the detonation velocity is shown in Fig. 7. Therefore, a larger amount of unreacted ANFO is thought to diffuse in the generated gas for a lower detonation velocity. Further, the previous studies showed a similar result in that a larger amount of unreacted ANFO was released in the gas generated under a lower detonation velocity [4) 5)].

We had previously reported that the amount of nutritional ions increased with the amount of ANFO [1)]. However, as shown in Fig. 8, this tendency was not observed for the sandstone. Because the amount of ions is closely related to the detonation velocity, it did not increase even if the amount of ANFO increases.

4. Conclusion

The blasting of a 30-cm cubic model of sandstone was carried out. After the blasting, the detonation velocity, fragment property, and ion content were observed in the fragments. Moreover, these characteristics were compared with those of granite. The following conclusions were derived from the obtained results.

- The contact surface area between the ANFO and the sandstone contributed to the generation of fine particles less than 2 mm in size. The amount of fine fragments increased with the contact surface area. This behavior was similar to that in the case of granite.
- No significant differences were observed in the particle size distribution of rock fragments between the sandstone and granite.

· The amount of nutritional ions in the fragments after blasting increased for a low detonation velocity. Thus, the amount of ions in the sandstone, in which a low detonation velocity was observed, was larger than that in the case of granite.

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爆発現象を利用した砂漠の緑化に関する基礎的研究, ANFOによる砂岩供試体の破砕効果および施肥効果

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装薬時のANFO周囲の素材強度や込物の程度によって，ANFOの爆ごう挙動，特に爆速が変化することが知られており，岩石の物性によって，ANFOを使用した発破による岩石の破砕効果や栄養素イオンの拡散効果が変化する可能性がある。よって，本研究では，30 cm立方モデル岩石に直径38 mm, 38 mm 2ヵ所, 58 mmの発破孔を明けた条件で発破実験を行い，砂岩と花崗岩での岩石破砕効果および栄養素拡散効果の相違について調査した。その結果，花崗岩と比較して砂岩中でのANFOの爆速は低く，破砕効果の低下が予想されたが，岩石物性により破砕効果に大きな変化は見られなかった。一方，砂岩粒子中の窒素分含有量は，花崗岩よりも高かった。

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