Research paper

Fertilization of rock areas by blasting with ANFO explosive containing KNO_3 and $(NH_4)_2HPO_4$

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Abstract

Blasting by ammonium nitrate fuel oil (ANFO) is considered to convert rock deserts into rich soil areas because it can break up the rocks and diffuse nitrogenous nutritional ions (NH_4^+, NO_3^-) into the rock fragments. However, various nutritional ions, other than the nitrogenous ones, are required in terms of the fertilization of rock areas. The purpose of this study was to establish a blasting method by using ANFO with fertilizers, KNO_3 and / or $(NH_4)_2HPO_4$, for diffusing nutritional ions into rock fragments. In this study, the hazard evaluation of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ was conducted with the help of sealed cell differential scanning calorimetry (SC-DSC). Further, the diffusion amount of the nutritional ions and the blasting effect of the ANFO with KNO_3 and $(NH_4)_2HPO_4$ were investigated with the help of field experiments. The results of the SC-DSC revealed nearly identical decomposition temperatures and decomposition heats for the ANFO alone and the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$. Thus, it is considered that the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ could be treated as similar to the ANFO alone. The results of the field experiments also revealed the presence of NH_4^+, K^+ and NO_3^- in the rock fragments blasted by the ANFO with KNO_3 and $(NH_4)_2HPO_4$. The content of the nutritional ions in the rock fragments blasted by the ANFO with KNO_3 and $(NH_4)_2HPO_4$ was more than that ions in the rock fragments blasted by the ANFO alone, and it was approximately equal to that found in natural soil. These results may indicate that blasting by the ANFO with KNO_3 and $(NH_4)_2HPO_4$ can control the amount of nitrogenous ions diffused into a rock area.

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

1. Introduction

Ammonium nitrate fuel oil (ANFO) explosive is one of the most widely used industrial explosives because of its low cost and sensitivity.

In previous studies, it was suggested that blasting by the ANFO had the effect of fragmentation of rocks into soil level particles of size less than 2 mm and diffusing nutritional ions such as NH_4^+ and NO_3^- into the rock fragments that are useful to plant growth. [1), 2)] This indicated a possibility of converting rock deserts into green areas with the help of blasting by the ANFO. However, in terms of greening and plant growth, in addition to the nitrogenous ions, various other ions are also essential [3)]. A greater variety of nutritional ions are required to plow rock areas by means of blasting for the purpose of greening since it is difficult to grow trees or plants with the help of just the nutritional ions originally present in the rock fragments [4)]. By means of blasting by ANFO containing certain fertilizer elements, elemental nutritional ions can be diffused into the rock fragments.

In this study, in order to establish a blasting method for diffusing various nutritional ions into rock fragments, the thermal stability and the diffusion behavior of nutritional ions from the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ were investigated. The thermal stability was evaluated by means of sealed cell differential scanning calorimetry (SC-DSC), and the diffusion behavior was investigated by measuring the ion contents in the rock fragments obtained

Table 1 Composition of samples on hazard evaluation with DSC.

	Composition / mg			
	KNO_3	$(NH_4)_2HPO_4$	ANFO	Total
ANFO	–	–	0.65	0.65
ANFO / KNO_3	0.51	–	0.90	1.41
ANFO / $(NH_4)_2HPO_4$	–	0.71	0.77	1.48
ANFO / KNO_3 / $(NH_4)_2HPO_4$	0.45	0.52	1.05	2.02

Table 2 T_{DSC} and Q_{DSC} values of ANFO and ANFO with fertilizer.

	T_{DSC} / °C	Q_{DSC} / kJ · ANFOg^{-1}
ANFO	311	3.5
ANFO / KNO_3	296	4.2
ANFO / $(NH_4)_2HPO_4$	322	4.3
ANFO / KNO_3 / $(NH_4)_2HPO_4$	323	3.1

via a blasting experiment. Following the measurement of the ion contents, measurement by ion chromatography was conducted.

2. Experimental

2.1 Samples

The ANFO explosive was prepared by mixing 94 wt% of ammonium nitrate and 6 wt% of No.2 fuel oil (JIS K2204).

2.2 Thermal stability of ANFO with KNO_3 and / or $(NH_4)_2HPO_4$

The hazard evaluation of the ANFO with KNO_3 (Wako Pure Chemical Industries, Ltd., 99.0 %) and / or $(NH_4)_2HPO_4$ (Wako Pure Chemical Industries, Ltd., 95.0 %) was conducted using the SC-DSC (Mac. Science Corp., DSC3100S). The composition of the samples is summarized in Table 1. The ANFO alone was used as the control sample.

The sample was scanned from 50 °C to 500 °C at a heating rate of 10 K / min in a gold- rolled container. The thermal stability was evaluated by comparing the decomposition temperature (T_{DSC}) and the heat amount (Q_{DSC}) of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ and the ANFO alone. T_{DSC} was defined as the intersection of a tangent on the maximum inclination point of the heat flow and the baseline of the heat flow, and Q_{DSC} was defined as the integration value of the exothermic peak.

2.3 Diffusion behavior of the nutritional ions

2.3.1 Blasting experiment

Blasting by the ANFO and ANFO with KNO_3 and $(NH_4)_2HPO_4$ was conducted on a solid sandstone area of a quarry at Tsukada Tohkan Corp. Blasting holes with a diameter of 64 mm and depth of 500 mm were drilled on the flat rock area. In these holes, 210 g of the ANFO with 50 g of KNO_3 and 15 g of $(NH_4)_2HPO_4$ as a fertilizer, 50 g of emulsion explosive as a booster, and No.6 electric detonator (NOF Co.) were loaded. The 210 g of ANFO alone was used as the control sample, and according to the Hauser's equation, this sample can create a crater of 1 m diameter. The average value of granite and sand stone, 1.70 kg / m^3, was used as the drag coefficient in the Hauser's equation. [5), 6)] These holes were tamped with clay or cement after loading, and the holes were covered with a "TATAMI," a blasting mat, and a defense sheet in order to confine the fragments within the crater. The loading aspect is shown in Fig. 1.

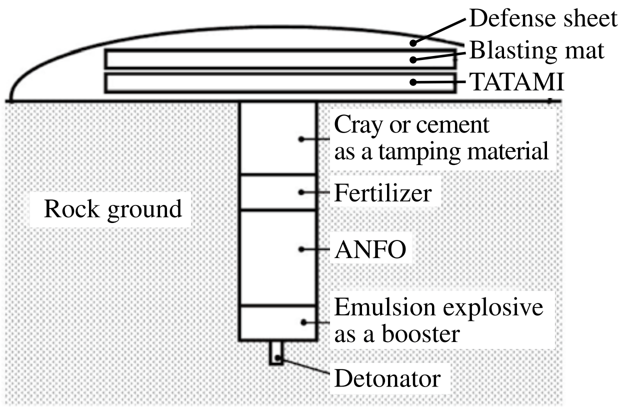

Fig. 1 The loading aspect of ANFO and fertilizer.

2.3.2 Measurement of the ion contents

After blasting, 10 g of fragments were extracted taken from the crater. The fragments were mixed with 100 ml of water and shaken for 6 h with the help of a shaker (Taitec Corp., Recpro Shaker NR-1). The solution was filtrated and the content of NH_4^-, NO_2^-, and NO_3^- ions in this solution was measured by using ion chromatography (Shimadzu Corp., CDD-10Avp).

3. Results and discussions

3.1 Hazard evaluation

The thermal analysis using the SC-DSC revealed that the T_{DSC} and Q_{DSC} values of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ were approximately equal to those of the ANFO alone. The thermodiagrams of the ANFO alone, ANFO / KNO_3, ANFO / $(NH_4)_2HPO_4$, and ANFO / KNO_3 / $(NH_4)_2HPO_4$ are presented in Fig. 2, and their T_{DSC} and

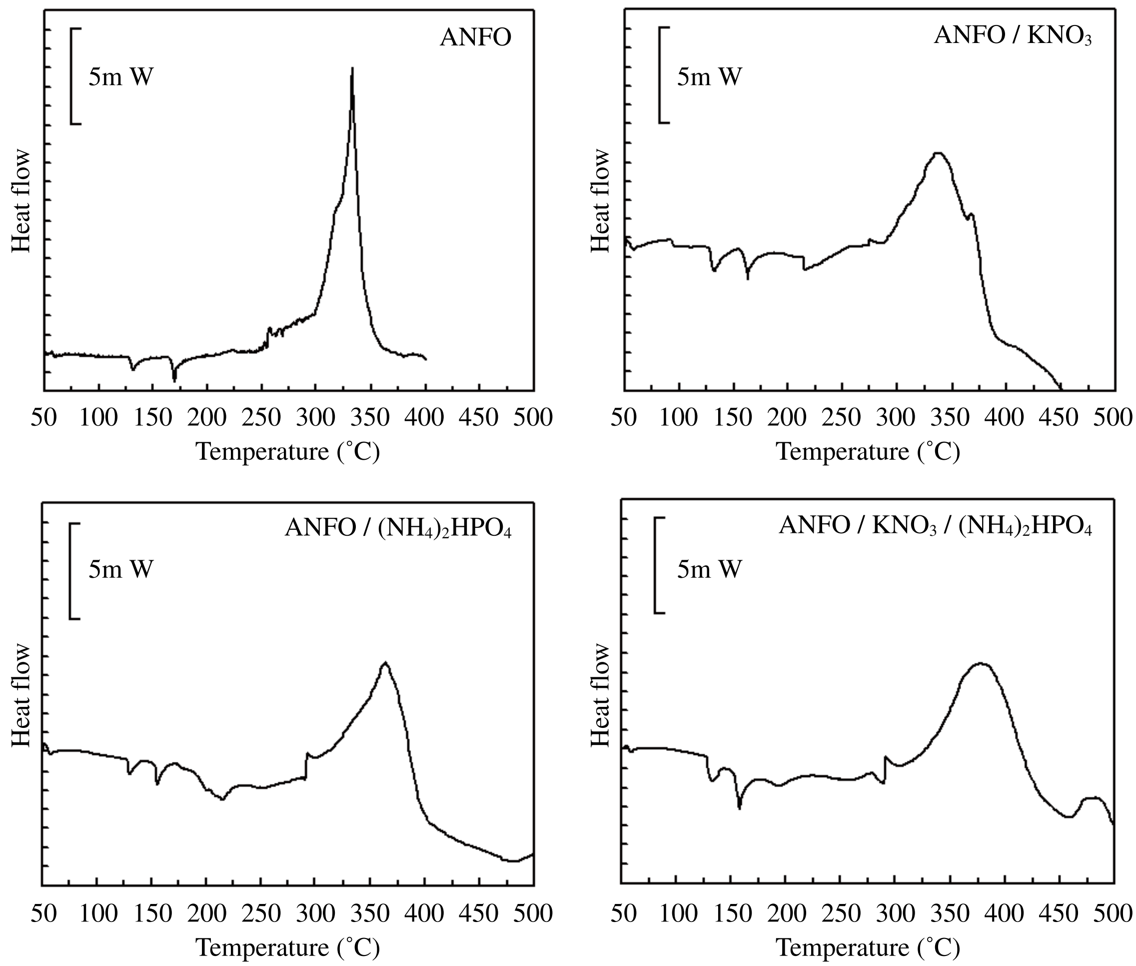

Fig. 2 The thermal behaviors of ANFO and ANFO with the fertilizer.

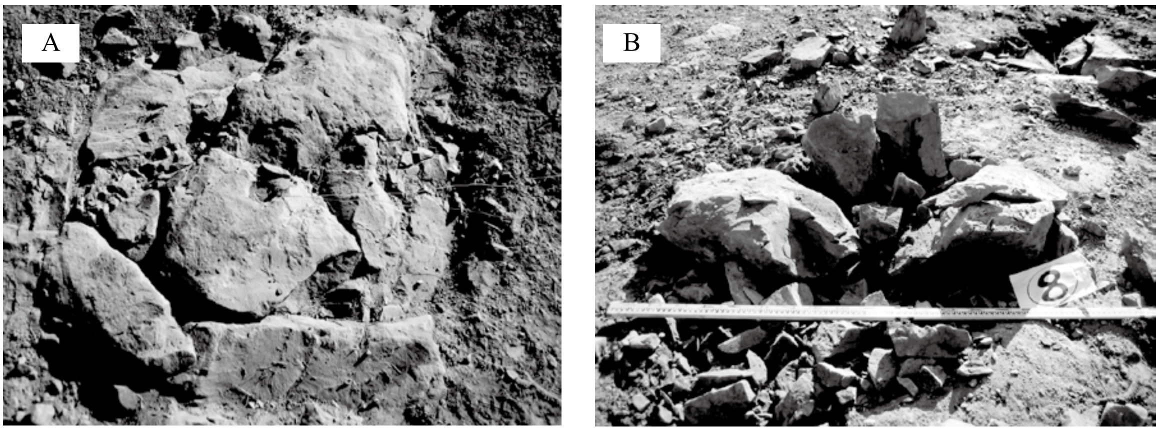

Fig. 3 The crater before and after blasting. A: before, B: after

Q_{DSC} values are summarized in Table 2. The thermodiagrams of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ indicate its complicated thermal behavior in comparison with that of the ANFO alone. However, the addition of a fertilizer considerably destabilized the ANFO because all the T_{DSC} values were approximately equal to 300°C. Moreover, the Q_{DSC} values of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ were approximately equal to, while those of ANFO / KNO_3, ANFO / $(NH_4)_2HPO_4$ were slightly higher than those of the ANFO alone. These results indicate that the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ is relatively stable, and it can be treated as similar to the ANFO.

3.2 Blasting effect

When the blasting experiment was conducted in the field under each condition, a crater was observed after blasting by the ANFO alone or the ANFO with KNO_3 and $(NH_4)_2HPO_4$, as shown in Fig. 3. However, the surface area of the crater was quite different, even under identical experimental conditions. For instance, craters with surface areas of 5.7 m^2 and 8.8 m^2 were observed for two blastings with the ANFO alone, under the identical condition. This indicates that the cracks originally present in the rocks in the experimental field caused this difference in the surface area.

Table 3 Ion contents in the rock fragments.

	NH_4^+ / mg · $100g^{-1}$	K^+ / mg · $100g^{-1}$	NO_3^- / mg · $100g^{-1}$
ANFO alone tamped by clay	0.91	4.17	1.79
ANFO / the fertilizer tamped by clay	1.23	13.12	8.66
ANFO alone tamped by cement	1.33	1.14	1.99
ANFO / the fertilizer tamped by cement	6.78	47.42	92.82
Rock fragments near the experiment field	0.59	1.16	0.83
Natural soil near the AIST	1.73	9.66	5.16

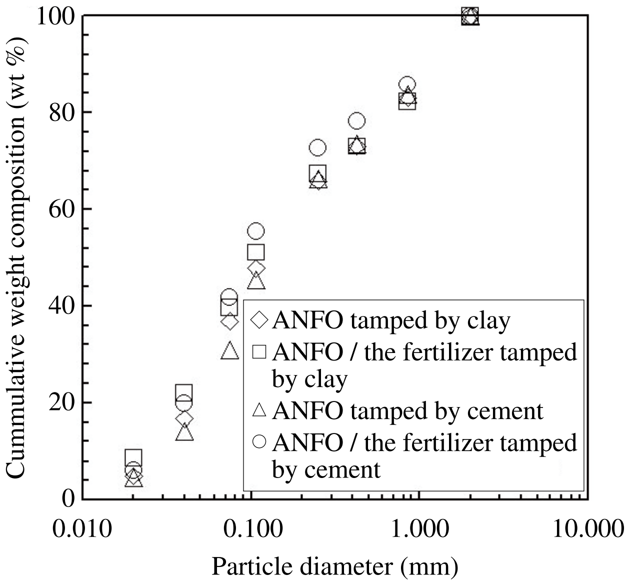

Fig. 4 The weight cumulative curves of less than 2 mm size particles at the bottom of the crater.

After the blasting, large rocks were found on the surface and fine fragments were found at the bottom of each crater. The same result was observed in the case of blasting by the ANFO alone. Therefore, a further effective blasting method is required in order to create finer rock fragments that are equivalent to natural soil.

When rock fragments with size less than 2 mm were picked from the crater and investigated, the cumulative weight against the fragment size was almost equal for each condition, as shown in Fig. 4. These results indicate that KNO_3 and $(NH_4)_2HPO_4$ did not influence the blasting effect of the ANFO, and the blasting effect of the ANFO with KNO_3 and $(NH_4)_2HPO_4$ is similar to that of the ANFO alone.

3.3 Measurement of the nutritional ions

When the amount of nutritional ions diffused by the blasting were measured, the content of nutritional ions detected in the rock fragments blasted by the ANFO with KNO_3 and $(NH_4)_2HPO_4$ was found to be higher in comparison with that detected in the rock fragments blasted by the ANFO alone, as summarized in Table 3. The level of ion contents in the rock fragments after blasting by the ANFO alone did not attain the level of contents in natural soil, although it was more than that before the blasting. On the other hand, in the case of the ANFO with KNO_3 and $(NH_4)_2HPO_4$, the ion content was higher than that in the case of the ANFO alone and equivalent or of a higher value than natural soil. In addition, when cement was used as the tamping material, four times the NH_4^+ ions, five times the K^+ ions, and eighteen times the NO_3^- ions found in natural soil were observed.

4. Conclusion

The thermal behaviors of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ and the diffusion amount of nutritional ions after blasting by ANFO / KNO_3 and $(NH_4)_2HPO_4$ were investigated in order to establish a blasting method for diffusing various nutritional ions into rock fragments. The following conclusions were derived from the obtained results.

1) The decomposition temperatures and the decomposition heat of the ANFO with KNO_3 and / or $(NH_4)_2HPO_4$ were approximately equal to those of the ANFO alone.
2) Blasting by the ANFO with KNO_3 and $(NH_4)_2HPO_4$ increased the amount of nutritional ions in the rock fragments, and these amounts surpassed those of natural soil.
3) Blasting by the ANFO with KNO_3 and $(NH_4)_2HPO_4$ fragmented the rocks similar to the ANFO alone. However, a further effective blasting method is required in order to create finer rock fragments that are equivalent to natural soil because pebbles or larger rocks were found in the crater.

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発破による岩石地帯の施肥効果に関する研究

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ANFOによる発破は，破砕後の岩石粒子中に窒素分イオン（NH_4^+, NO_3^-）を供給することができる。この特徴を利用し，発破後の環境を緑化用地域として活用するには，粉砕後の岩石に窒素分以外の栄養素を加える必要がある。本研究では,岩石粒子中の栄養素を付加する発破法を確立することを目的として，KNO_3と$(NH_4)_2HPO_4$を加えたANFOについて，SC-DSCによる危険性評価および施肥効果の実地試験を行った。ANFO単独と肥料成分を混合した系の発熱開始温度および発熱量を比較すると、肥料成分を混合させたANFOの発熱開始温度と発熱量は，ANFO単独の値に近かった。実地試験では，漏斗孔の底部に残存する細粒からNH_4^+, K^+, NO_3^-が検出された。その量はANFO単独の実験結果および自然土中の含有量よりも多く，肥料分の添加により栄養素を付加できる可能性が示唆された。

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