Article

# Study on blasting rock into soil for greening the desert

Kaname Shirotani*†, Katsumi Katoh**, Shiro Kubota**, Yuji Wada**, Yuji Ogata**, Shuzo Fujiwara**, and Mitsuru Arai*

*Institute of Environmental studies, Graduate School of Frontier Sciences, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN

†corresponding author: shirotani@explosion.t.u-tokyo.ac.jp

**National Institute of Advanced Industrial Science and Technology (AIST), 16-1 Onogawa, Tukuba, Ibaraki 305-8569, JAPAN

Received: May 27, 2005 Accepted: September 5, 2005

## Abstract

Greening of desert area is one of the important actions to fix $CO_2$ and mitigate the global warming. However, greening of rock desert, which is the main part of dried area on the earth, is not an easy task, because it takes more than 10,000 years by natural process.

We suppose rock-blasting may expand useful soil area for plants with higher pace. Ammonium nitrate and fuel oil (ANFO) is the most popular explosive for industrial blasting because of its reasonable price and low sensitivity. We thought this explosive might have ability to crush rock into soil level particles (less than 2 mm) immediately and to spread AN as a nutritional element for plants into the particles. In order to obtain an understanding of effectiveness of using explosives to crush rock into soil particle size and spread nutritional ions, particle distribution and content of nitrogen ions, $NH_4^+$, $NO_2^-$, and $NO_3^-$, in products from blasting 30 cm cubic model of granite at various loading conditions were investigated.

As a result, two things were founded. One is that proportion of very fine particles such as less than 0.020 mm, which qualify the balance between the particles and water, could be controlled by loading conditions such as contact surface area between explosive and rock, tamping, and detonation velocity of explosive. Another was that the blasting with ANFO can spread nutritional ions, $NH_4^+$, $NO_2^-$ and $NO_3^-$, into particles. Especially, the contents of $NH_4^+$ and $NO_3^-$, can be controlled by the amount of ANFO whether the blast holes are tamped or not.

***Keywords***: ANFO, Desert, Greening, Blasting, Particle size distribution, Nutritional ions

## 1. Introduction

### 1.1 Background

Blasting by explosives was used for a long time as one of the most efficient method to demolish buildings, constructions, and solid rocks. Recently, application of blasting is extending in various fields.

Greening a desert is one of the effective ways for $CO_2$ sequestration. The natural soil in agricultural sense contains organic materials, microbes, and fine particles. The particles are formed from rock after the long natural refining process, that is, weathering[1]. Therefore, blasting rocks into soil-level particles is thought to help fundamental expansion of the greening area because the appropriate refining of rocks may make the basis of soil.

The purpose of this study is to develop a new greening system of rock desert by the blasting of explosives. In this paper, the relationships between loading conditions of explosives and soil characteristics, particle sizes distributions, and nutritional ions amount have been investigated.

### 1.2 Physical characteristics of the soil

The distribution of particle sizes determines the soil characteristics. Soils can be classified into three groups by their particle sizes. ; sand : 0.02 ~ 2 mm, silt : 0.002 ~ 0.02 mm, clay : ~ 0.002 mm. The adequate soil textures for greening in Japan are shown in Fig. 1[2].

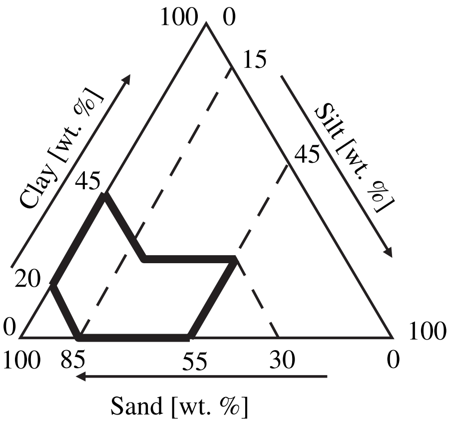



Fig. 1 The adequate proportion of sand, silt, and clay in Japan.

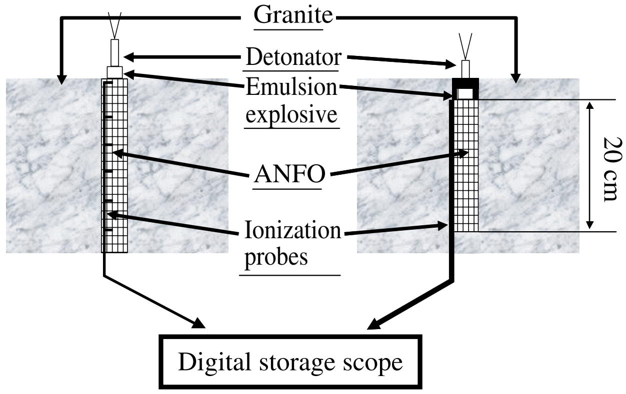



Fig. 2 Experimental set-up of detonation velocity measurement of ANFO using ionization proves.

### 1.3 Chemical characteristics of the soil

The soil must have some nutrient elements for plant to grow up. The elements consumed in growing process are called essential nutrients. They are classified into nine groups: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Especially, nitrogen, phosphorus, and potassium are essential macronutrients[1]. Carbon, hydrogen and nitrogen are supplied from air or water in the soil. On the other hand, other elements are absorbed into plants body through their roots as the inorganic ions in water of soil.

In the blasting, some kinds of inorganic ions in the explosives may be supplied. In this study, the application of blasting for making nutritious soil was also evaluated.

## 2. Experimental

### 2.1 Rock samples

It has been known that 15 % of the surface of earth is consisted of granite[3]. The lab-scale experiments were carried out with 30 cm cubic model of Inada granite. Explosives were loaded into samples in nine patterns. They are shown in Fig. 2 and Table 1.

### 2.2 Explosives

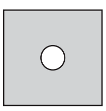
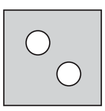
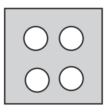
ANFO explosive was used in this study, which consists of 94 wt.% of ammonium nitrate (AN) and 6 wt. % of No. 2 fuel oil (JIS K2204)(FO). ANFO expected to spread the nutritional ions into rock particles at explosion as the effect of its non-ideal detonation[4]. ANFO are initiated with 30 g of emulsion explosive as a booster and No. 6 electric detonator for seismic prospecting (NOF Co.) in each loading conditions as shown in Fig. 2 and Table 1. Emulsion explosive and composition C4 were used in order to evaluate the influence of detonation velocity.

### 2.3 Measurement

In order to measure the detonation velocity, ionization probes were set at each 5 cm from the bottom of the blast hole as shown in Fig. 2.

Table1 Loading conditions in this study.

| Condition number | Explosives | The number of blasting hole | Tamping | Hole diameter [cm] | Amount of explosive [g] | Contact surface area [cm$^2$] |
|---|---|---|---|---|---|---|
| 1 | ANFO | 1 *1 | Penetrated | 29 | 160 | 273 |
| 2 | ANFO | 1 *1 | Penetrated | 38 | 287 | 358 |
| 3 | ANFO | 2 *2 | Penetrated | 38 | 573 | 716 |
| 4 | ANFO | 1 *1 | Penetrated | 58 | 634 | 546 |
| 5 | ANFO | 4 *3 | Penetrated | 38 | 1000 | 1432 |
| 6 | ANFO | 1 *1 | Tamped | 38 | 200 | 250 |
| 7 | ANFO | 1 *1 | Tamped | 58 | 450 | 391 |
| 8 | Emulsion explosive | 1 *1 | Tamped | 38 | 240 | 250 |
| 9 | Composition C4 | 1 *1 | Tamped | 38 | 260 | 250 |

*1  *2  *3 

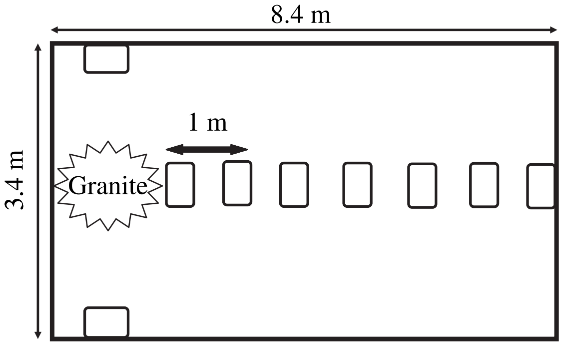



Fig. 3 Experimental set-up of trays to collect fragments from the blasting rock.

### 2.4 Experimental method

Experiments were carried out in the closed type explosion pit (3 m × 3.4 m × 8.4 m) at AIST. The sample with ionization proves and the explosive was set in the pit as shown in Fig. 3. The resulted fragments were accumulated for approximately three hours after the blasting on metal trays (49 cm × 59 cm). The arrangement of trays was also shown in Fig. 3.

### 2.5 Analysis

#### 2.5.1 Particle size distribution

Six sieves less than 2 mm of JIS standard mesh and sieve shaker (AS 2000 DIGIT Asone) were used to classify sample particles by their size (diameter). The particles were classified into seven groups: less than 0.075, 0.075 - 0.106, 0.106 - 0.25, 0.25 - 0.425, 0.425 - 0.85, 0.85 - 2, over 2 mm. Weights of each particle group were measured.

The distribution of particle size less than 0.075 mm was analyzed with particle size distribution analyzer Multisizer 3 (Beckman Coulter Co.). Measurements were conducted with 6 mg of fragments and 200 ml of the solution prepared with Isoton (Beckman Coulter Co.) and 1.5 wt. % of potassium phosphate tribasic.

#### 2.5.2 Ion analysis

The 10 g of fragments and 100 ml of water was shaken for six hours with shaker (Recpro Shaker NR-1, Taitec Co.). And the solution was filtrated and conducted with ion chromatography (CDD-10Avp, Shimadzu Corp.) with SHIM-PACK IC-CI PEEK for cation and SHIM-PACK IC-A3 for anion. $NH_4^+$, $NO_2^-$, and $NO_3^-$ were quantified.

## 3. Result and discussion

### 3.1 Detonation velocity

The steady state detonation velocities varied from 2,300 m $s^{-1}$ to 3,100 m $s^{-1}$ were obtained for ANFO. They might be influenced by the hole diameter[5]. The steady state detonation velocity of tamped conditions 6 and 7 accelerated by 20 cm from start point in the hole as same as these of penetrated conditions 2 and 4 as shown in Figs. 4 and 5. These results indicated that tamping had no significant effect on the detonation velocity in these conditions.

The steady state detonation velocities of emulsion explosive and composition C4 were about 5,200 m $s^{-1}$ and 7,200 m $s^{-1}$.

### 3.2 Particle size distribution

Proportion of the particles of less than 2 mm increased from approximately 50 wt. % to 90 wt. % and the shape of weight cumulative curves shifted up with the increasing of contact surface area between the explosive and the rock as shown in Fig. 6. These results might indicate that the particles from blasting rocks become suitable for growth of plants because of the improvement of water retentivity and the decline of hydraulic conductivity.

Proportion of the particles of less than 0.020 mm increased from 2.8 wt. % to 11.1 wt. % with increase of the contact surface area as shown in Fig. 7. This might suggest that the fine particles such as 0.020 mm were generated mainly from the neighborhood of the contact surface of the explosive and the rock[5, 6]. It was suggested that changing contact surface area might control the particle size of blasting rocks.

On the tamped condition, the proportion of the particle of

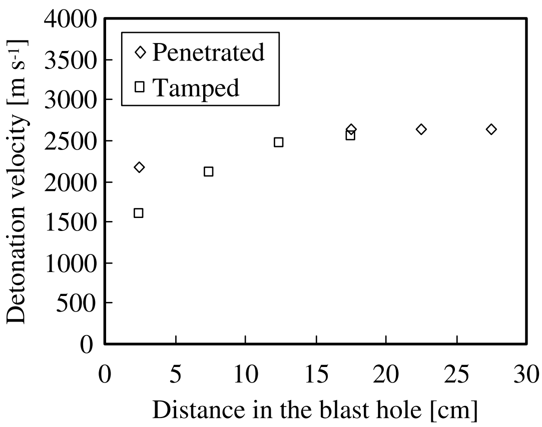



Fig. 4 Detonation velocities in the blast hole (38 mm $\phi$ penetrated / tamped).

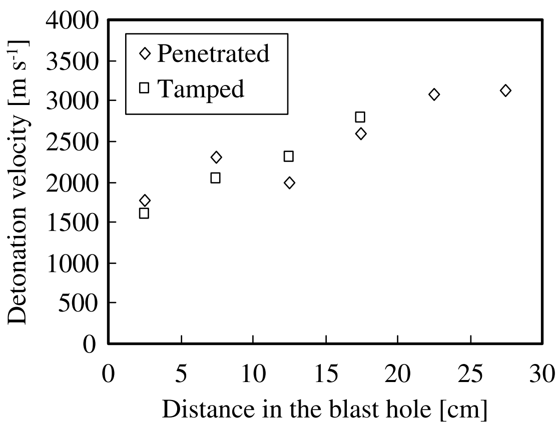



Fig. 5 Detonation velocities in the blast hole (58 mm $\phi$ penetrated / tamped).

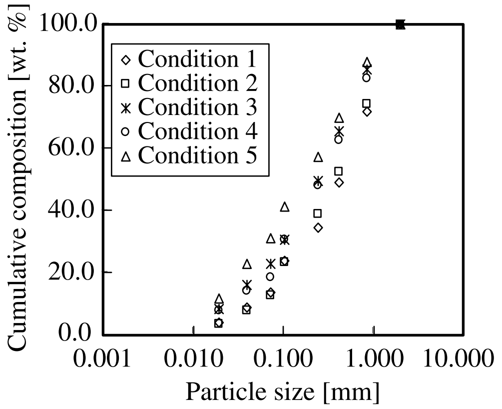



Fig. 6 Weight cumulative curves of particles of condition 1 - 5.

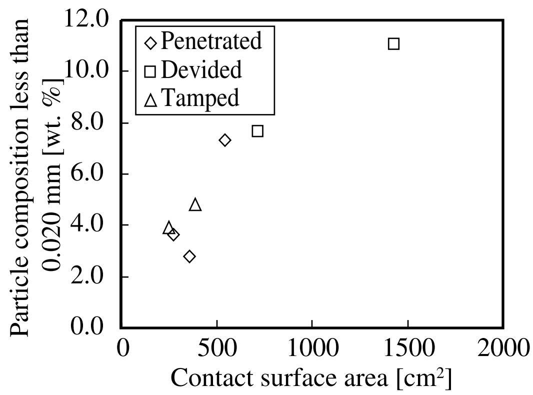



Fig. 7 Interrelation between contact surface area and particle compositions less than 0.020 mm.

less than 2 mm was increased. As shown in Fig. 8, the particle distribution of tamped conditions 6 and 7 were similar to those of penetrated conditions 2 and 4 despite their amount of ANFO were 2 / 3 of penetrated condition. It might be considered that pressure of the released gases contributed to the rock fragmentation.

Blasting by emulsion explosive and composition C4 improved the rock fragmentation. As shown in Fig. 9, the proportion of particles less than 0.020 mm increased from 3.9 wt. % with ANFO to 4.5 wt. % with emulsion explosive and to 7.8 wt. % with composition C4 and the shape of cumulated curve shifted up as the detonation velocity got higher.

### 3.3 Ion analysis

In particles blasted by ANFO, 0.4 - 210 mg / 100 g of $NH_4^+$, untraceable - 6.2 mg / 100 g of $NO_2^-$, and 1.7 - 762 mg / 100 g of $NO_3^-$ were detected. As shown in Figs. 10 and 11, the contents of $NH_4^+$ and $NO_3^-$ increased with the increase of amount of ANFO despite that of $NO_2^-$ was untraceable. The effect of tamping had been considered to decline the value of diffused ions because the tamping had been expected to improve the reactivity of explosives with high pressure and temperature[6]. However the contents of $NH_4^+$ and $NO_3^-$ on tamped conditions were almost equal to these of penetrated conditions.

## 4. Conclusions

The relationships between loading conditions and soil characteristics, particle size distribution and nutritional ions amount were investigated. Following conclusions can be made.

(a) The proportion of particle sizes less than 2 mm and 0.020 mm increased with increase of contact surface area between explosive and rock. The contact surface area closely related with the distributions of particle sizes less than 0.020 mm. This result might indicate the rock fragmentation could be controlled by changing the contact surface to create the soil level particles.

(b) The rock fragmentations on tamped conditions were similar to those of penetrated conditions despite the amount of ANFO was about 2 / 3.

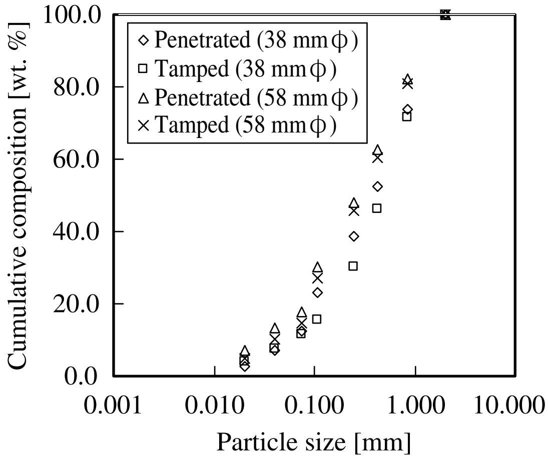



Fig. 8 Weight cumulative curves of particles of condition 2, 4, 6 and 7.

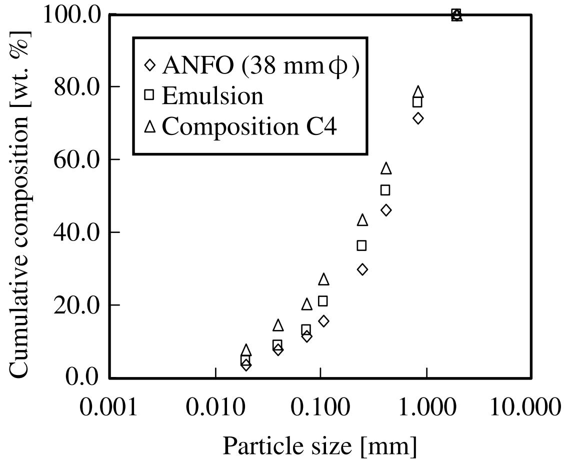



Fig. 9 Weight cumulative curves of particles of condition 2, 8 and 9.

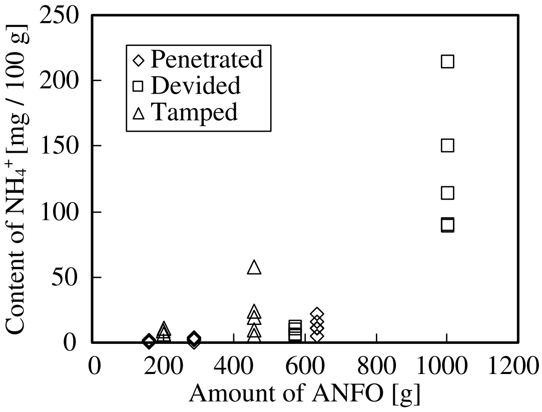



Fig.10 Interrelation between amount of ANFO and content of ion ($NH_4^+$)

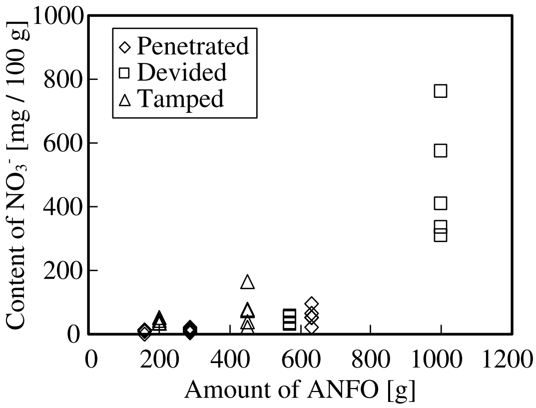



Fig.11 Interrelation between amount of ANFO and content of ion ($NO_3^-$)

(c) The rock fragmentations with explosives with higher detonation velocity seemed to be improved in terms of particle size.

(d) The blasting with ANFO can spread nutritional ions, $NH_4^+$, $NO_2^-$ and $NO_3^-$, into particles. Especially, the contents of $NH_4^+$ and $NO_3^-$ can be controlled by the amount of ANFO whether the blast holes are tamped or not.

## References

1) T. Matsunaka, "Dojyogaku no Kiso" (2004), Nobunkyo (in Japanese).
2) S. Asami, "Daigaku Tekisuto Dojyo Chirigaku", p. 231 (2001), Kokon Shoin (in Japanese).
3) H. Ikeda, "THE WORLD OF GRANITE LAND FORMS", p. 17 (1998), Kokon Shoin (in Japanese).
4) A. Miyake, K. Takahara, T. Ogawa, Y. Ogata, and H. Arai, Kayaku Gakkaishi, Vol. 63, No. 5, p. 279 - 282 (2002).
5) Kayaku Gakkai Happa senmonbukai, "Happa Kougaku Hand book" (2001), Kyoritsu Shuppan (in Japanese).
6) K. Kaneko, Y. Matsunaga, and M. Yamamoto, Kayaku Gakkaishi, Vol. 56, No. 5, p. 207 - 215 (1995) (in Japanese).

# 砂漠緑化のための発破による岩石の土壌化に関する研究

城谷 要*†，加藤勝美**，久保田士郎**，和田有司**，
緒方雄二**，藤原修三**，新井 充*

植林による緑化は，地球温暖化問題の原因の一つである二酸化炭素の固定に繋がり，地球規模で進められるべき手段である。しかし，地球上の乾燥地帯は，大部分が岩石砂漠地帯で占められており，その緑化は，岩石の風化という長期的なプロセスを待たねばならず，非常に困難である。

そこで，風化に代わり緑化に適した土壌地帯をより速く創出する手段として発破に着目した。硝安油剤系爆薬(ANFO)は，硝酸アンモニウム(AN)と軽油(FO)からなる爆薬で安価かつ低感度であることから最もよく使用されている産業用爆薬である。この爆薬ならば岩石を土壌の構成粒子(2 mm以下)まで瞬間的に破砕し，なおかつ粒子中に栄養素となるANを拡散できると考えられる。本研究では，岩石の土壌構成粒子への破砕および栄養素の拡散における発破の有効性について理解するため，30 cm立方のモデル花崗岩を使用して，爆薬の装薬条件と破砕後の粒子の粒度分布と粒子中の$NH_4^+$，$NO_2^-$，$NO_3^-$の含有量について調査した。

結果として，水との関係に重要な 0.020 mm 以下の微小な粒子の割合は，爆薬と岩石との接触面積，穿孔の閉塞，そして爆薬の爆速などによって制御できる可能性が示された。また，ANFOを使用することにより栄養素である$NH_4^+$，$NO_2^-$，$NO_3^-$を粒子中に拡散することができ，特に$NH_4^+$と$NO_3^-$の拡散量を，閉塞の有無に関わらずANFOの装薬量で制御できる可能性があることもわかった。

*東京大学大学院新領域創成科学研究科環境学専攻 〒113-0033 東京都文京区本郷7-3-1
†corresponding author: shirotani@explosion.t.u-tokyo.ac.jp

**産業技術総合研究所 〒305-8569 茨城県つくば市小野川16-1