Research paper

Expansion agent utilizing thermite reaction

Yusuke Kaji*†, Tomoya Ishikawa*, and Hideaki Sugihara*

*Kayaku Japan Co., Ltd. 2300 ooaza-kori sanyo onoda, Yamaguchi-ken, 757−8686 JAPAN
Phone: +81−836−72−0959
†Corresponding author: yusuke.kaji@kayakujapan.co.jp

Received: November 3, 2017 Accepted: November 2, 2018

Abstract

Crushing method utilizing thermite reaction has been known in Japan. This system is not defined as explosives in the Japanese Explosives Control Law, so it is used as non-explosives. Now, Kayaku Japan Co., Ltd. manufactures and sells utilizing thermite reaction agent "ROCKRACK®". USA DDT test was experimented. As a result, ROCKRACK® was not detonated. In this time, ROCKRACK® was used for two patterns sinking crush, and we confirmed satisfactory crush. From these crush tests, it was found that diameter of crushed stone of ROCKRACK® was larger than that of explosives, and ROCKRACK® could be used in deck charge under appropriate conditions.

Keywords: non-explosive, ROCKRACK®, thermite reaction, bedrock, fragmentation

1. Introduction

Crushing agent using thermite reaction has been used in Japan[1),2)]. This agent is not defined as explosives in Japanese Explosives Control Law because thermite composite is not defined as explosives. Therefore, it is used as non-explosives. Moreover, this agent has less burning velocity than explosives. Therefore this agent don't generate shock wave and has low vibration comparison to explosives.

Now, Kayaku Japan Co., Ltd. manufactures and sells multistage crushing agent "ROCKRACK®" and that initiator (Figures 1, 2).

The initiator of ROCKRACK® utilize thermite reaction. Hence this initiator is not defined as explosives too. The characteristics of ROCKRACK®[3)] and that initiator are shown in Tables 1, 2.

The delay time of electronic delay initiator is programmable (between 100 and 10,000 milliseconds) by yourself on site.

In this time, we will introduce examples of use of ROCKRACK®.

2. Theoretical

The agent of ROCKRACK® is composed of aluminium, copper (Ⅱ) oxide and sulfate. The mechanism of generation of pressure has two steps. The first step is thermite reaction with aluminum and copper (Ⅱ) oxide (scheme 1).

$$3\,CuO + 2\,Al \rightarrow 3\,Cu + Al_2O_3 \quad \text{(scheme 1)}$$

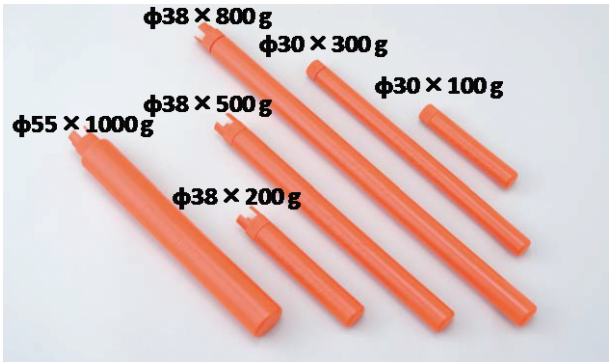


Figure 1 ROCKRACK®.

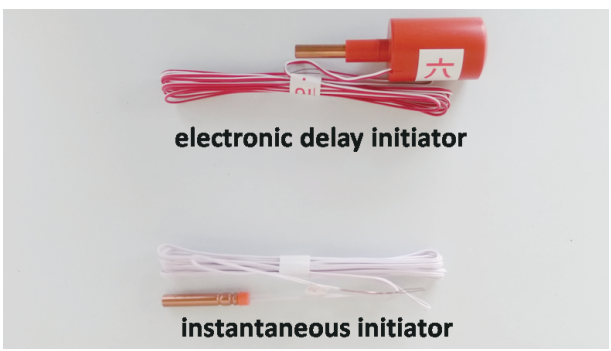


Figure 2 Initiator of ROCKRACK®.

Table 1 Characteristics of ROCKRACK®.

Specific gravity	1.25~1.45
Gas volume [L·kg^{-1}]	379
Water resistant in cartridge [MPa]	0.05
Burning velocity [m·s^{-1}]	100~300

Table 2 Characteristics of Initiator.

Type	Electric initiator / Electronic delay initiator
Water resistant [MPa]	0.1
Static electricity characteristic [pF·kV]	2000·8 over

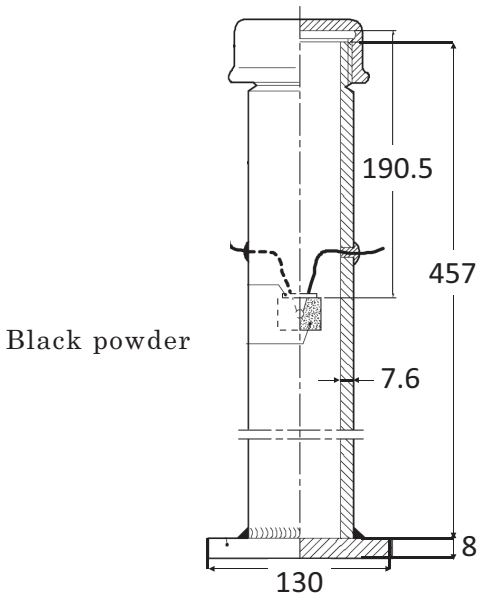


Figure 3 Inner of pipe [mm].

(a) Before test

(b) After test

Figure 4 Pipe state.

This reaction generate high temperature (2000~3000 ℃). The second step is thermal decomposition of crystal water of sulfate and this reaction generate high vapor pressure.

3. Experimental

3.1 USA DDT test

It is known from previous study that burning velocity of ROCKRACK® is under 300 m·s^{-1} [4]. However, some studies indicate that burning velocity of thermite composite of aluminium and copper (Ⅱ) oxide is over 340 m·s^{-1} [5,6]. Because it exceeds the velocity of sound, there is a possibility of generating shock wave. Hence, we investigated the possibility from Deflagration to Detonation Transition.

This test is defined by United Nations Recommendations on the Transport of Dangerous Goods[7]. The experimental arrangement is shown in Figure 3.

Sample is loaded in carbon steel pipe with inside diameter 74 mm and capped at one end with a 3000 pound forged steel pipe cap. The other end is welded square mild steel witness plate. An igniter consisting of 5.0 g black powder is located at the center of the sample.

The result is considered "detonation" if there is a hole on witness plate. If there is no hole on witness plate then result is considered "deflagration". Test was conducted at 3 times. ROCKRACK® was loaded about 3 kg in the pipe.

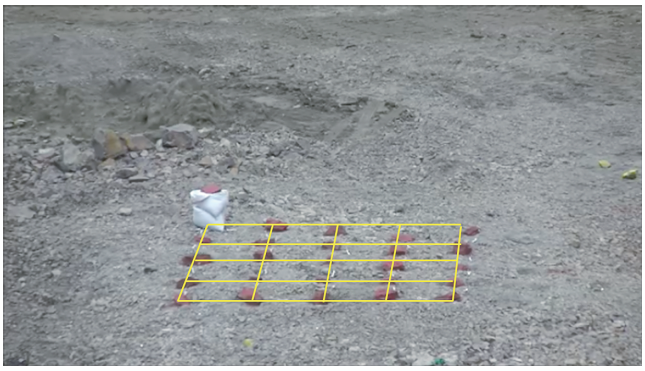
Figure 4 shows the pipes before ignition and after ignition.

Top cap and witness had come off in all tests. However there was no hole on witness in all tests. In this result, it was found that ROCKRACK® did not detonate.

3.2 Sinking crash

Crushing specifications and crushing patterns are expressed in Table 3 and Figure 5.

Using cartridges were $\phi 30 \times 300$ g (length is 450 mm, diameter is 30 mm, net weight is 300 g) and one cartridge was loaded per a hole. In order to reduce decoupling index, borehole diameter was 32 mm. However 32 mm was too



(a) Before crush

(b) After crush

Figure 6 Face state (1).

Table 3 Crushing express (1).

Hardness	Hard rock
Advance [m]	0.9
Length [m]	1.0
Spacing [m]	0.6
Charge [kg/hole]	0.3
Stemming [m]	0.55 (gravel)
Specific charge [kg·m^{-3}]	0.926

Table 4 Crushing express (2).

Hardness	Medium-hard rock
Advance [m]	3.0
Length [m]	3.2
Spacing [m]	0.9
Charge [kg/hole]	2.0
Stemming [m]	1.4 (gravel)
Specific charge [kg·m^{-3}]	0.82

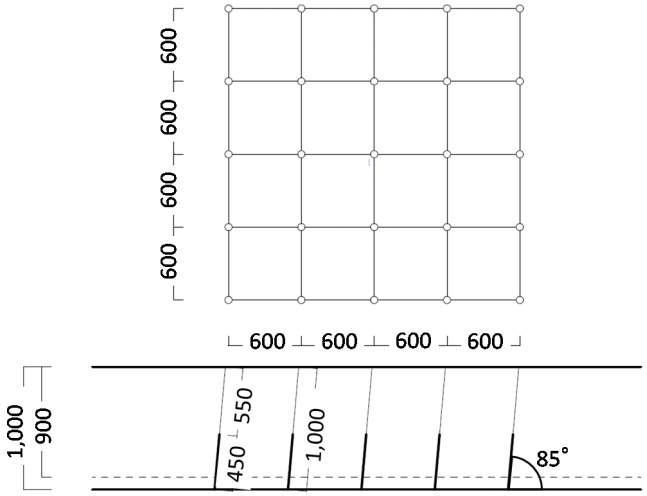


Figure 5 Crushing pattern (1).

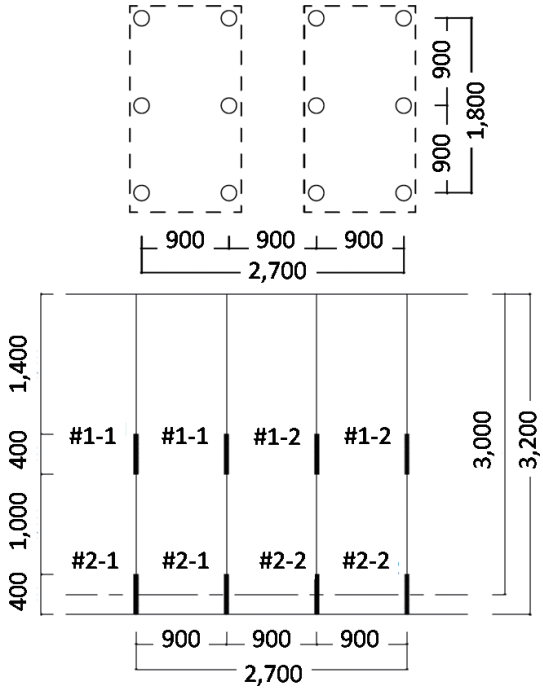


Figure 7 Crushing pattern (2).

small and leading wire was broken. The borehole diameter was appropriate to be not less than 34 mm. In this crushing test, instantaneous electric initiators were used.

Figure 6 shows the faces before crush and after crush.

After crushing, face was dug by excavator. In this result, advance was 0.9 m and sinking crushing was completely successful. As a result of USA DDT test, ROCKRACK® did not generate shock wave. Hence performance of ROCKRACK® was lower than explosives. Diameter of crushed stone of ROCKRACK® was mainly 0.5 to 1.0 meter which was comparatively larger than that of explosives. However ROCKRACK® is differ vastly from Non Explosive Demolition Agent (Pressure generation by calcium oxide-based expansive cements) because vapor pressure is instantaneously emitted in ROCKRACK®. For the reason, it is necessary for using ROCKRACK® to protect from fly rock.

3.3 3 m sinking crash

Crushing specifications and crushing patterns are expressed in Table 4 and Figure 7.

In order to confirm that influence of adjacent cartridges, we tried deck charge in this crush. Gravel that was used as stemming was stemmed in intermediate and upper part of deck charge. Using cartridges were $\phi 55 \times 1000$ g (length is 400 mm, diameter is 55 mm, net weight is 1000 g) and two cartridges were loaded per a hole. In order not to break leading wire, borehole diameter was 65 mm. In this crush, electronic delay initiators were used. Delay time was 25 ms between #1-1 and #1-2, #2-1 and #2-2. 25 ms is

(a) Before crush (b) After crush

Figure 8 Face state (2).

most common selection of delay intervals for the millisecond delay devices[8]. Delay time was 250 ms between #1-1 and #2-1, #1-2 and #2-2, in order to ignite #2 cartridge after burning end of #1 cartridge.

Figure 8 shows the faces before crush and after crush.

After crushing, face was dug by excavator. In this result, advance was 3.0 m and sinking crushing was completely successful. In this crush, deck length was 1000 mm. ROCKRACK® has possibility of decreasing the burning velocity if specific gravity increase by pressed. In this case, end face combustion occurs in cartridge. Therefore it have to be careful of deck length. In case of wet boreholes that are confirmed visually presence of water, high water pressure generates and there is a possibility of entering water in another cartridge. For these reasons, we recommend ejecting water.

4. Results and discussion

In USA DDT test, we confirmed that ROCKRACK® doesn't generate shock wave. Past studies[5),6)] used nano meter scale aluminium and copper (Ⅱ) oxide, however ROCKRACK® used those of micro meter. Interfacial contact of micro scale mixture is lower than nano scale mixture, hence burning velocity was not over the velocity of sound in even carbon steel pipe.

We found that ROCKRACK® could be used for crush bedrock in two patterns. Moreover we confirmed that ROCKRACK® doesn't generate shock wave and crushed bedrock with only vapor pressure. As a result, crushed stone size of ROCKRACK® was comparatively larger than that of explosives. However stone size was enough to excavate by backhoe.

5. Conclusion

We found out that ROCKRACK® could be used instead of explosives. Further complex crushing tests for example tunneling, shaft sinking and so on are needed in order to expand the application of ROCKRACK®.

References

1) K. Murata, M. Kawano, T. Yabuki, and Y. Fujigaki, Proc, Annual Meeting, Japan Explosives Society, 65–66 (2012).
2) Y. Mizohata and R. Fujiwara, Construction Meeting, 33–40 (2015).
3) ROCKRACK® catalog 2017-G-3(K), Kayaku Japan Co., Ltd. (2017).
4) Y. Kaji, T. Ishikawa, K. Yoshihara, and H. Sugihara, Proc. MMIJ Fall Meeting, 1308-15-08 (2017).
5) D. G. Piercey and T. M. Klapotke, Central European Journal of Energetic Materials, 7, 115–129 (2010).
6) M. R. Weismiller, J. Y. Malchi, R. A. Yetter, and T. J. Foley, Proc. Combustion Institute, 32, 1895–1903 (2009).
7) United Nations, "Recommendations on the Transport of Dangerous goods / Manual of Tests and Criteria", Second revised edition (1995)
8) International Society of Explosives Engineers, "Blasters' handbook" 17th ed., p.131, International Society of Explosives Engineers, Cleveland (1998).