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Study on Reaction Rate of the Non-Explosive Demolition Agent

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비폭성 파쇄재의 반응률 특성에 관한 연구

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요 약

팽창재와 같은 비폭성 파쇄재는 화약발파와 비교하여 볼 때 진동을 유발하지 않는다는 면에서 인접한 구조물에 영향을 주지 않고 암반을 파괴할 수 있는 장점을 갖고 있다. 비폭성 파괴방법으로 유압식 암석 분할기도 팽창재와 유사한 적용성을 갖고 있으나 힘을 작용시킬 수 있는 천공깊이에 제약을 갖고 있으며 규모가 큰 암반의 파괴 방법으로는 적용한계가 있다. 반면에 팽창재는 천공깊이에 큰 제약을 받지 않으며 천공수에 제한을 받지 않는다는 장점이 있다. 그러나 팽창재의 현장적용시 가장 큰 단점의 하나로 지적되고 있는 것은 파괴력을 나타내기까지의 시간이 오래 걸림으로 작업능률에 문제가 있다는 것이다. 반응시간은 물과 팽창재와의 반응률과 밀접한 관계를 갖고 있으며 본 논문에서는 팽창재의 적용성을 높이기 위하여 실시한 여러 조건하에서 팽창재 반응률 특성에 관한 연구내용을 기술한다. 연구결과를 요약하면 다음과 같다. 1) 팽창재의 반응은 주위온도에 큰 영향을 받는다. 2) 팽창재의 성능을 충분히 발휘하기 위하여는 주위 온도 조건에 따라 천공직경을 적절히 조절하는 것이 필요하다. 3) 낮은 주위 온도 조건에서 팽창재의 반응은 압력이 증가하는 시간이 느리고 따라서 최대 팽창압이 높은 온도 조건에 비해서 낮게 나타난다. 4) 팽창압이 증가하는 시간은 팽창재와 물과의 반응률에 좌우된다.

1. INTRODUCTION

Calcium-oxide has been used as a demolition agent in fracturing rock. An agent has great advantages over an explosive in that it causes no vibration, thus avoiding damage to adjacent structures. But application of the non-explosive demolition agent is a time-consuming job, especially in winter. At an environmental temperature of 0℃, it may take several days for the agent to complete the reaction and crack the rock or concrete. This long time hampers the extensive application of the non-explosive demolition agent. Essentially, this problem is related to the reaction rate of the demolition agent with water.[1,2] The objective of this research is to characterize the reaction rate of the demolition agent under different environmental conditions and to enhance the understanding of the demolition agent.

2. TEMPERATURE CURVE UNDER IDEAL THERMAL INSULATION CONDITION

To measure the reaction rate of an agent, an apparatus has been built. To control the reaction rate,

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the apparatus, under quasi-thermal insulation condition, has been designed to perform the experiment under water. The apparatus consists of four parts : number 1 represents the container ; 2, the mixture ; 3, thermal meter ; and 4, thermal insulation materials. In this experiment, the following testing conditions were used to measure the reaction rate of agents :

1. The mixture mass $m_1 \geq 600$ g
2. $H_1/D \leq 1/2$
3. $H = (1 \sim 2) H_1$

The heat loss ϕ of the apparatus is a function of time and inner and outer differences of temperature. Based on the results of the experiment, heat loss ϕ of the apparatus can be expressed as:

$$\frac{d\Phi(t)}{dt} = L[T_i(t) - T_o(t)] \quad (1)$$

Where $T_i(t)$ and T_o are the temperatures of the inner and outer side of the apparatus, respectively ; L is the heat loss coefficient of the apparatus and equal to 0.0057 cal/(s.℃).

Since L is very small, according to the energy conservation law, the temperature curve T_{ci} under ideal thermal insulation conditions can be obtained by adding the temperature change caused by heat loss to T_{ca}, the temperature of mixture measured by the device under quasi-thermal insulation conditions :

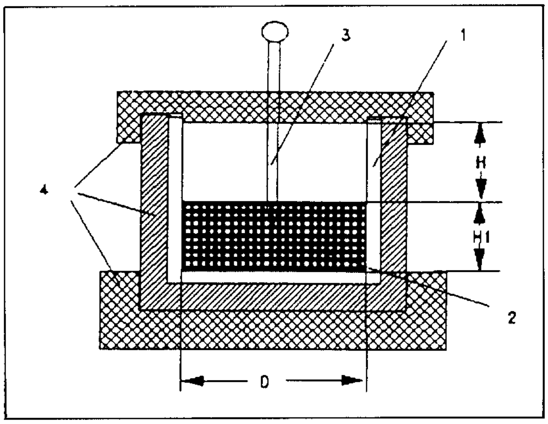

Fig. 1. Ideal temperature measuring apparatus.

$$T_{ci}(t) = T_{ca}(t) + \frac{L}{m_1 c_1} \int_0^t [T_{ca}(t) - T_e] \, dt \quad (2)$$

Where T_e is the environmental temperature, and c_1 is the specific heat capacity of the mixture.

At different environmental temperatures, the temperature curves of the mixture under ideal thermal insulation conditions are shwon in Fig. 2. Fig. 2 shows that the reaction rate of the demolition agent is obviously dependant on the environmental temperature. The reaction rate of the agent at 35℃ is about five times as fast as the reaction rate at 4℃.

3. TEMPERATURE CURVE IN BORE HOLE

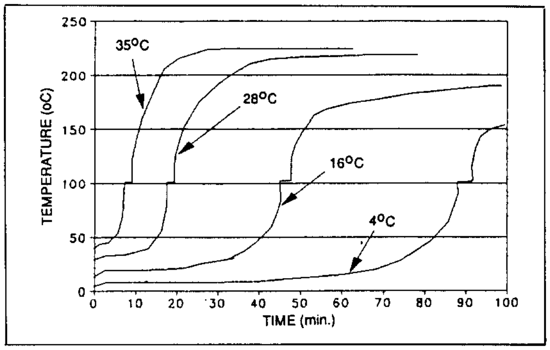

Fig. 2. Temperature of the mixture under ideal insulation condition at different environmental temperature.

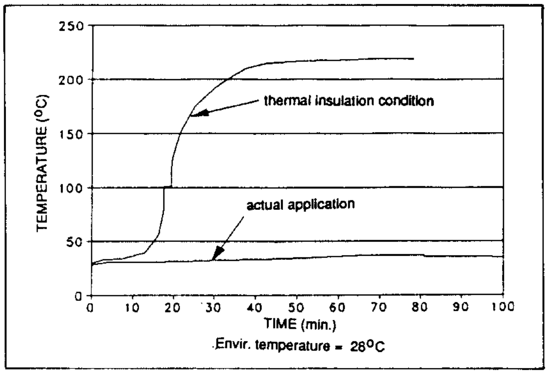

Fig. 3. Measured temperature of the mixture in bore hole (R=1.1 cm and T_o=28℃) and temperature under ideal condition.

The temperature of the mixture of agent and water in bore hole can be known either by measuring directly with a thermal couple, results shown in Fig. 3, or by solving the following equations 4 to 8.

Consider a hole within the rock containing a mixture of the agent. The general equation to describe the heat conduction is as follows :

$$\frac{\partial T(x, y, z, t)}{\partial t} = \frac{k_2}{\rho_2 c_2} \nabla^2 T(x, y, z, t) \quad (3)$$

where, k_2 and c_2 are rock thermal conductivity, and rock specific heat capacity ; ρ_2 is the rock density and T(x, y, z, t) is the temperature in rock.

Because of the axial symmetry of a cylindrical hole located in the center of a large piece of rock, the above equation (3) can be expressed as the equation (4) by using a cylindrical coordination system. Equation (5) represents the initial conditions of the experiment. Equations (6) and (7), which represent hole wall conditions and condition of rock, respectively, describe the boundary conditions of the experimental set-up. The energy conservation equation in temperature and heat form can be expressed as equation (8).

Equations (4) to (8) are derived to consider the mode of a single hole of heat source in infinite rock/concrete, since both rock and concrete are non-conductors of heat. In most cases, the space between two bore holes is about 40 cm or larger, thus the thermal effects between two holes can be ignored from the stand point of heat conduction.

$$\frac{\partial T(r, t)}{\partial t} = \frac{k_2}{\rho_2 c_2} \left[\frac{\partial^2 T(r, t)}{\partial r^2} + \frac{1}{r}\frac{\partial T(r, t)}{\partial r}\right] \quad (4)$$

$$T(r, 0) = T_o \quad (5)$$

$$T(R, t) = T_{ch}(t) \quad (6)$$

$$T(\infty, t) = T_o \quad (7)$$

$$[T_{ch}(t) - T_o] + \frac{2\rho_2 c_2}{k_2 \rho_1 c_1} \int_R^\infty [T(r, t) - T_o]\, r dr = \int_o^t \frac{Q(\tau)}{c_1}\, d\tau \quad (8)$$

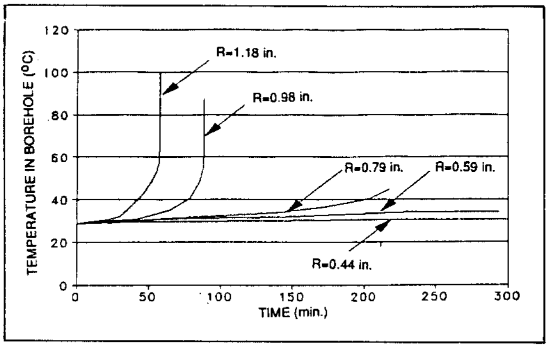

Fig. 4. Temperature of the mixture in different size of bore holes (T_o=28℃).

where ρ_1 is the density of mixture, $T_{ch}(t)$ is the temperature of the mixture in bore hole, $Q(\tau)$ is the heat generating rate of the mixture and can be expressed, from the temperature curve under ideal insulation condition, as a function of $Q(\tau) = Bc_1 T_{ch}^{\alpha}(\tau)$, B is the coefficient and $\alpha > 1$.

Since it is impossible to get the exact solutions of equations (4) through (8), numerical solutions can be obtained by changing the above equations into forms of differential equations and by using a computer.

One of the useful solutions resulting from equations (4) through (8) is that the temperature of the mixture in different sizes of bore holes, shown in Fig. 4, and other conditions are the same. Fig. 4 shows that, at the environmental temperature of 28℃, if a 6 cm diameter hole is used, the demolition agent will blow out from the hole ; for a 5 cm diameter hole, the agent might blow out ; and for the hole with a diameter of less than 4 cm, the agent will not blow out. In theoretical analysis, hole size of 3.8 to 4.4 cm may be recommended for use. At higher environmental temperatures, such as 38℃, even using a bore hole of 4 cm, equations (4) to (8) reveal that the agent still will probably blow out of the hole. On the other hand, at a lower environmental temperature of 4℃, even using a bore hole with a diameter larger than recommended size, equations (4) to (8) demonstrate that the agent might not blow out of the hole.

Another important use of equations (4) through (8) is to show, from the solutions, how the reaction rate of the demolition agent with water in bore hole is dependent on different environmental temperatures and can be explicitly known. Under ideal thermal insulation conditions, it is known that, as above mentioned, the reaction rate of the agent at 35℃ is about five times as fast as the reaction rate at 4℃. From the solution of equation (4) to (8), it is known that the reaction rate of the agent in bore hole at 35℃ is about twenty eight times as quick as the reaction rate at 4℃. This means that, in bore hole case, the reaction rate of the demolition agent is more closely related and more dependent on the environmental temperature than the case of ideal thermal insulation conditions. At a 4℃ environment, about ninety six hours are required for the agent to complete its reaction with water. This is one of the main reasons why using the non-explosive in winter is a time consuming job. The amount of time which is needed for demolition agent to complete its reaction at different environmental temperatures is shown in Fig. 5.

4. EXPANSIVE PRESSURE CURVE

The expansive pressure curves were obtained by using metal pipe 28 mm in diameter and 300 mm long (Fig. 5). The demolition agent was placed inside of the pipe ; the pipe was then placed in the environmental chamber to simulate the temperature. At this time, the expansion rate of the pipe was measured to detect the internal pressure of the agent. The curing time, which is needed for the demolition agent to reach the maximum expansion pressure, is listed in Table 1.

From Fig. 5 and Table 1, it can be determined that the increment rate of expansive pressure of the demolition agent and the time needed for the agent to reach the maximum expansion pressure are also basically dependent on the environmental temperature. Reaction rate of the agent observed at lower environmental temperatures has not only shown the pressure increase rate to be much slower, but also the magnitude of the corresponding peak expansion pressure to be much less than that found at a higher environmental temperature. The results of this experiment indicated that the application of the demolition agent in winter is inefficient and also uneconomical, another concern.

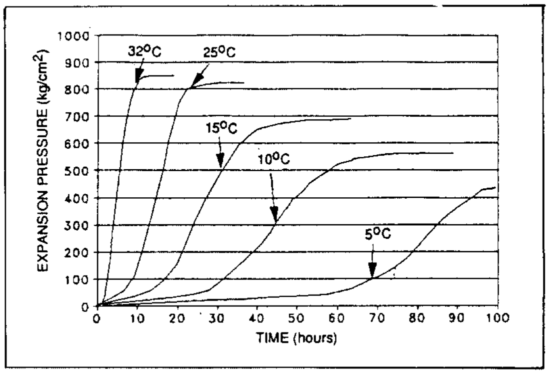

Fig. 5. Expansion pressure and environmental temperature.

Table 1. Time needed to reach maximum expansion pressure.

Environ. Temperature(℃)	5	10	15	20	25	30	35
Time(hours)	102	64	42	28	18	8	4

5. ANALYSIS

Basically, the increment rate of expansion pressure is dependent on the reaction rate of the demolition agent with water. Therfore, factors which affect the reaction rate of the agent, such as composition, grain size, types of admixtures, environmental temperature, and etc., must be carefully considered for better results.

Comparing the temperature curve under the ideal thermal insulation conditions of Fig. 2 to the expansive pressure curve of Fig. 5, it has been observed that the time is needed to complete the reaction at thermal insulation condition is much shorter than the time which is needed to reach the maximum expansion pressure for actual application. For example, at 35℃, it only takes about 20 minutes to complete the reaction at thermal insulation condition, but it takes about four hours to touch the maximum expansion pressure for actual application case. Then what is the explanation for so much time difference found for the two conditions ?

At thermal insulation condition, nearly all heat is used to increase the temperature of the reactants, agent and water, so as to cause the mixture temperature to reach as far as 220℃. It is discovered from the thermal insulation reaction test that the reaction rate is critically dependent on the reactant's temperature, which can be expressed as follows :

$$-\frac{d\,(CaO)}{dt} \propto T^{\alpha}_{ch} \tag{9}$$

This relationship makes the reaction goes extremely fast at relatively higher temperatures and, subsequently, makes that the reactant's temperature also increases extremely fast, and so on. Thus, the reaction is completed in a very short time.

On actual application, most of heat generated by the reaction is absorbed by the rock, concrete, and other surrounding media, and only a small portion of heat is used/consumed to increase the temperature of mixture. The mixture temperature grows very slowly, and the mixture reaction performance is very slow, especially in winter. Therefore, it requires a longer time to complete the reaction and to reach the maximum expansion pressure.

6. CONCLUSION

1. The reaction rate of the demolition agent is obviously dependent upon the environmental temperature.

2. At different environmental temperatures, a different size of bore hole must be considered.

3. Reaction rate of the agent, at lower environmental temperature, demonstrates not only the pressure increase rate to be slower, but also the magnitude of the corresponding peak expansion pressure to be much less than the one at higher environmental temperatures.

4. The increment rate of expansion pressure is dependent upon the reaction rate of the demolition agent with water.

REFERENCES

1) Y. Yamazaki, 1986, "The mechanism of Expansive Pressure Development with The Hydration of CaO", Congr. Int. Quim. Cimento, An. J., 8th, Brazil, pp. 395-400.

2) S. Kasama, S. Suzuki, and K. Sato, 1986, "Hydration Rate of Quick Lime", Trans. ISIJ, vol. 26, P.B355.