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Assessment of Abrasive Impact Frequency depending on the Traverse Rate in Waterjet Rock Cutting

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ABSTRACT

Overcoming the high-cost of abrasive is one of the major challenges of abrasive waterjet technology. Therefore, efforts have been made to improve the abrasive efficiency by recycling abrasives or setting optimum parameters. Traverse rate is one of the key performance parameter along with water pressure, but studies on its effect are lacking. In this study, the characteristics of traverse rate were evaluated using the results of rock cutting experiments. The cutting efficiency was evaluated by presenting the relationship between input energy and abrasive impact frequency which is the function of traverse rate. Moreover, an empirical model of cutting efficiency was proposed considering traverse rate. The results of this study can be used in the practical estimation of cutting depth

1. INTRODUCTION

the waterjet use high-pressure and high-velocity water generated by the pump. high-velocity water accelerates the abrasive and remove the target material with the impact energy of the abrasive. abrasive waterjet has higher efficiency with low noise and vibration, so it is used for concrete structure demolition and rock cuttings in the urban area, and interest in decommissioning and dismantling of nuclear facilities increasing (Momber 2012; Oh 2013; Summers 2003). in particular, it is widely used in the maintenance of structures because concrete mass can be removed without damaging

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the internal steel. the main cost of abrasive waterjet technology is the purchase of abrasives. Reducing the cost by up to 60% is the challenge to overcome. therefore, researchers study abrasive recycling (Aydin 2014 Recycling; Babu 2002; Guo 1992), operation parameters (Hashish 1989, Oh 2013). Various abrasive waterjet parameters (standoff distance, traverse rate, water pressure, water flow rate, abrasive flow rate) have been studied to improve cutting efficiency. Traverse rate is the velocity of the abrasive waterjet system. the traverse rate is one of the main variables influencing the efficiency as it determines the amount of time that the cutting target is exposed to the impact energy of the abrasive. traverse rate has a greater effect than standoff distance or abrasive flow rate (Chen 1996) and determines the surface quality as it affects impact frequency and abrasive compactness. the surface roughness is depending on the material properties, but in general, the roughness increases as the traverse rate increases (Hascalik 2007; Ay 2010). In addition, an increase in the traverse rate increases the material removal rate, but the energy dissipating increases, and the cutting efficiency decreases. An increase in the traverse rate makes it possible to increase the multi-pass at the same operating time. When the waterjet system is moved at 8 mm/s, it can be repeated 4 times than at 2 mm/s. Therefore, even with the same input energy, the performance of cutting could be different depending on the traverse rate and the number of overlapped cutting (Wang 2003; Selvam 2017; Oh 2013).

In conclusion, the traverse rate is an important variable that determines cutting performance and efficiency. In this study, the effect of traverse rate was expressed as a function of the energy exposure time and impact frequency. The rock cutting experiments were conducted with a 50 HP high-pressure pump waterjet. The efficiency of the impact energy was expressed by the traverse rate and effective impact range, and an empirical model was proposed to present the effect of the traverse rate, the number of repeated cuttings, and the water flow rate.

2. THEORETICAL BACKGROUND

The traverse rate is a function of the time the cutting object is exposed in the path of effective energy. As shown in Figure 1, $v_{s,1}$, which has a slow traverse rate, has a longer exposure time than $v_{s,2}$ and will show a lot of resistance to cutting energy. The exposure time is proportional to the number of abrasive impacts, thus, the different cutting performances are presented depending on the impact frequency and compactness of abrasive. The relationship between the input energy and the cutting result with the compactness of abrasives can be empirically expressed considering the traverse rate

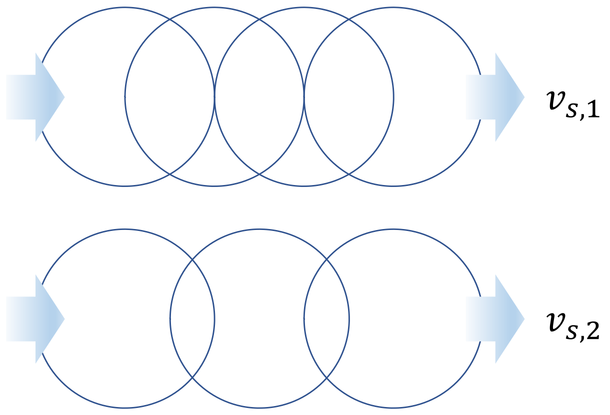


Fig. 1 Conceptual illustration of traverse rate and exposure time

The main energy of abrasive waterjet coms from the accelerated abrasives. In terms of the terminal velocity(v_e) and abrasive flow rate (m_p) with exposure time(t), the kinetic energy of the abrasive waterjet(E_k) can be expressed as:

$$E_k = \frac{1}{2} m_a v_e^2 t, \tag{1}$$

Exposure time is function of the traverse rate(v_s) and diameter of the jet(d_{jet}) depending on the standoff distance, as follows:

$$t = d_{jet}/v_s, \tag{2}$$

Substituting Equation (2) into Equation (1), the effective kinetic energy of abrasive waterjet becomes:

$$E_{ke} = \frac{1}{2} m_a v_e^2 d_{jet} v_s. \tag{3}$$

Assuming that the abrasives are uniformly distributed, the compactness of the abrasive(A) which is the number of the particle in diameter of the jet can be obtained as:

$$A = m_a t/m_p \ = (m_a d_{jet})/(m_p v_s). \tag{4}$$

Where m_p is the mass of the single abrasive particle.

3. EXPERIMENTAL PROGRAM and RESULT

3.1 Experimental setup

The main variable in this study is the traverse rate. The effect of the traverse rate and multi-pass at the same operating time was evaluated. Therefore, traverse feed rate is 4 types of 2, 4, 8, and 16 mm/s, and it was repeated 1, 2, 4, and 8 times, respectively, for applying a state of equal input energy. To review the effect of compactness of the particle, the water flow rates affecting the terminal velocity of the abrasive were set to 30 and 50 mL/s. The abrasive flow rates are 7 and 10 g/s at each water flow rate. These values were measured as the optimum abrasive flow rate by preliminary experiments. The water pressure used in the experiment was 320 MPa, and the distance between the abrasive water jet and the target; The standoff distance(SOD) is 10mm. This SOD is to provide the condition assumed in Equation 4 by minimizing the abrasive dispersion. The experimental cases and details are shown in Table 1. Fig. 3 shows the high-pressure pump, the transfer device and the rock specimen.

Table 1. Experimental cases and conditions

Test case	2	4	8	16
	1	1	1	1
		2	2	2
			4	4
				8
Operational condition	Water pressure (MPa)	320		
	Water flow rate (ml/s)	30, 50		
	Abrasive flow rate (g/s)	7 (for WFR 30), 10 (for WFR 50)		
	Standoff distance (mm)	10		

Granite was used as a target rock. since granite is the most common rock type in Korea, it was selected for field application later. The specimen was very hard with a uniaxial strength of 236 MPa and a tensile strength of 10.2. The abrasive used is a pyrope garnet, the most common commercial abrasive, with a nominal diameter of the particle of 0.18mm. the details of the specimen and abrasive are shown in Tables 2 and 3, respectively.

Table 2. Rock specimen properties

Rock type	UCS (MPa)	Tensile strength (MPa)	Density (kN/m^3)
Granite	236	10.2	26.5

3.2 Experimental result and discussion

Figure 3 shows a side view of a rock specimen cut in the experiment, and Intuitively indicates the depth of cut according to single-pass cut or multi-pass cut. The experimental depth was measured 5 times and expressed as the average value excluding the minimum and maximum values. The experimental results at water flow rates of 30 and 50 mL/s are plotted in Figure 4.

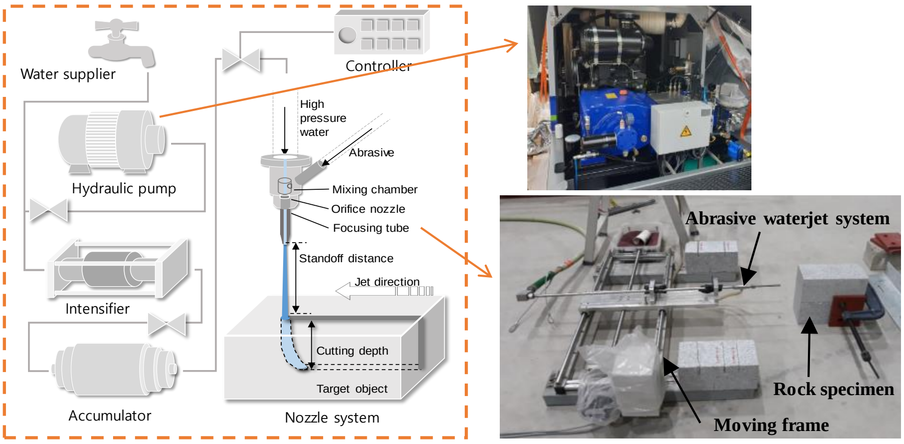


Fig. 2 Experimental setup for abrasive waterjet rock cutting

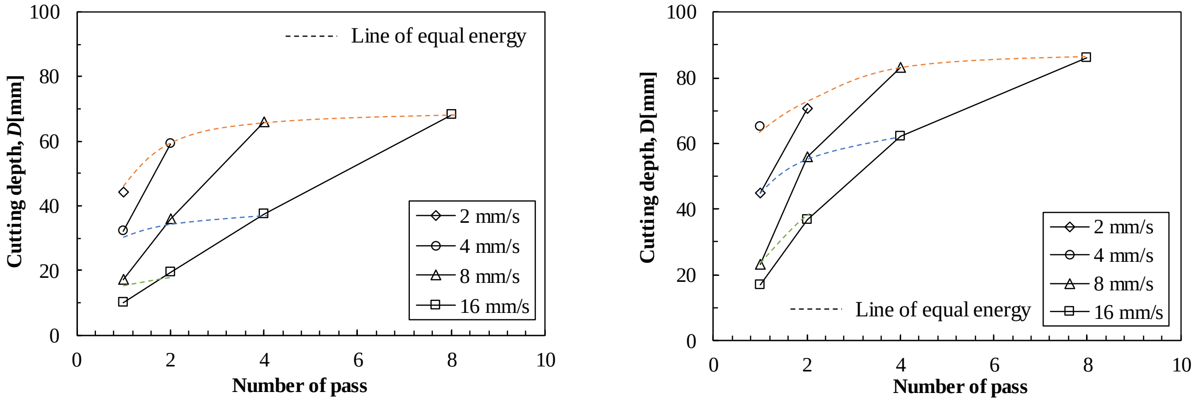
Table 3. Abrasive properties

Abrasive type	Particle size (mm)	Mohs hardness (HM)	Specific gravity
Pyrope garnet	0.18	7.1	3.78

Fig. 3 Cutting result on the rock depending on the traverse rate

The slower traverse rate performs better at single-pass cutting. Multi-pass cutting shows the same results, and the performance cutting depth increases more as the cuts overlapped. the combination of traverse rate and multi-pass allows the comparison of cutting performance at the same input energy. Multi-pass cutting improves cutting performance by 40% compared to single-pass cutting. As the water flow rate increases, the momentum accelerating the abrasive increases, and the total energy increases. As shown in Fig. 4(b), with an increase of 60% of the water flow, the cutting performance increased by 30%, and the effect of traverse rate can be confirmed. Thus, it can be seen that the multi-pass cutting is efficient at the same input energy during the same operation time. This can be demonstrated by the improved impact efficiency of abrasives. the abrasives collide themselves before and after impact with the target, resulting in energy loss. The energy loss can be reduced by reducing the compactness of abrasive at a high traverse rate.

In order to evaluate the effect of traverse rate on cutting efficiency, the relationship between rock cutting results and input energy was expressed with the compactness of abrasive. The dispersion degree and density of the abrasives can represent the interference between the abrasives, and the energy loss due to the interference of the abrasives were presented in an experimental value. It can be seen that the traverse rate greatly affects the energy exposure time and efficiency of the abrasive particle impact. This effect was expressed as an exponential model with R^2 of 0.97 from the empirical model. Using this model, the cutting performance can be predicted depending on the traverse rate and energy parameters.



(a) Water flow rate of 30 mL/s and abrasive flow rate of 7 g/s (b) Water flow rate of 50 mL/s and abrasive flow rate of 10 g/s

Fig. 4 Result of cutting experiment

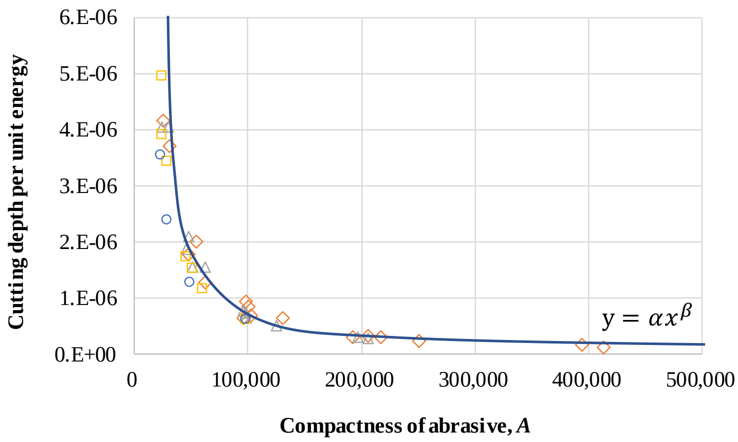


Fig. 5 Rock cutting model considering traverse rate and cutting efficiency

5. CONCLUSIONS

In this study, we assessed the cutting performance and efficiency depending on the traverse rate in abrasive waterjet rock cutting. The effects of traverse rate were summarized through literature review, and an empirical model was proposed after the experiment as an approach to evaluate the energy efficiency of abrasives. The result of this study and the considerations are as follows.

- In single-pass cutting, a slower traverse rate increases the depth of cut since the target is exposed to cutting energy for more time. On the other hand, in multi-pass cutting, an increase in depth of cut due to overlapping cutting can be expected.

- As a result of evaluating the cutting efficiency depending on the traverse rate, the efficiency was greater in a multi-pass cutting single cutting. The abrasives interference with each other before and after they collide with the target, causing energy loss. The faster traverse rate lowers the compactness of abrasives and reduces the chance of collision between the abrasives, thereby improving energy efficiency.

- Traverse rate significantly affects the energy loss of the abrasive as well as the exposure time. The empirical model was proposed from the abrasive compactness and the relationship between the cutting result. This model can be used to predict cutting performance according to traverse rate and input energy. For efficient rock cutting, it is necessary to investigate the abrasive dispersion affected by SOD and waterjet system components.

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