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Effect of jet dispersion on the underground excavation in rock using abrasive waterjet

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ABSTRACT

An abrasive waterjet with low noise and vibration characteristics enables effective rock excavation. For deep excavation, it is necessary to insert the waterjet nozzle into pre-drilled holes, which requires ensuring a sufficient excavation width. In this study, we set the standoff distance and focusing tube length as variables that dominantly influence the excavation width. An experimental test was conducted to investigate the dispersion of the jet based on different standoff distances and focusing tube lengths. This research has the potential to enhance the efficiency of rock excavation by enabling accurate estimation and control of the excavation width. Operators can improve productivity and minimize disturbances during excavation operations by optimizing these parameters.

1. INTRODUCTION

In recent years, overcrowding and lack of space in urban centers have become a frequent problem in the world, and underground space development has been actively carried out to solve this problem. On the other hand, excavation of underground rock is essential for the development of underground space in urban centers, but various problems arise during construction. In particular, noise problems in residential areas near the site and stability problems of the surrounding ground and buildings due to vibration are typical. If construction is delayed or stopped due to these problems, it can cause not only structural stability but also economic problems in urban

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centers, so new construction methods are needed to solve them.

On the other hand, waterjet technology, which is known for its low noise and low vibration, can solve the problems that may occur when excavating underground rock in urban areas. So far, various types of water jets have been studied for material removal in drilling and cutting, including plain waterjet (PWJ), which uses only water, and abrasive waterjet (AWJ), which uses a mixture of water and abrasives (Summers 1992, Summers 1995, Karakurt et al. 2012). On the other hand, rock, which is a brittle material, has a relatively large strength compared to ductile materials such as iron, so it is efficient to use AWJ for effective underground rock excavation (Momber and Kovacevic 1998). The rock excavation mechanism of an AWJ is as follows (Fig. 1). A hydraulic pump generates high-pressure water, which is injected into the waterjet nozzle head along a pipe. The high-pressure water passes through an orifice, where it is converted to high-velocity water and mixed with abrasive within a mixing chamber to accelerate the abrasive. The water and abrasive mixture is directed through the focusing tube and blown into the air to remove material. At this time, the standoff distance (SOD) refers to the distance between the end of the focusing tube and the target material.

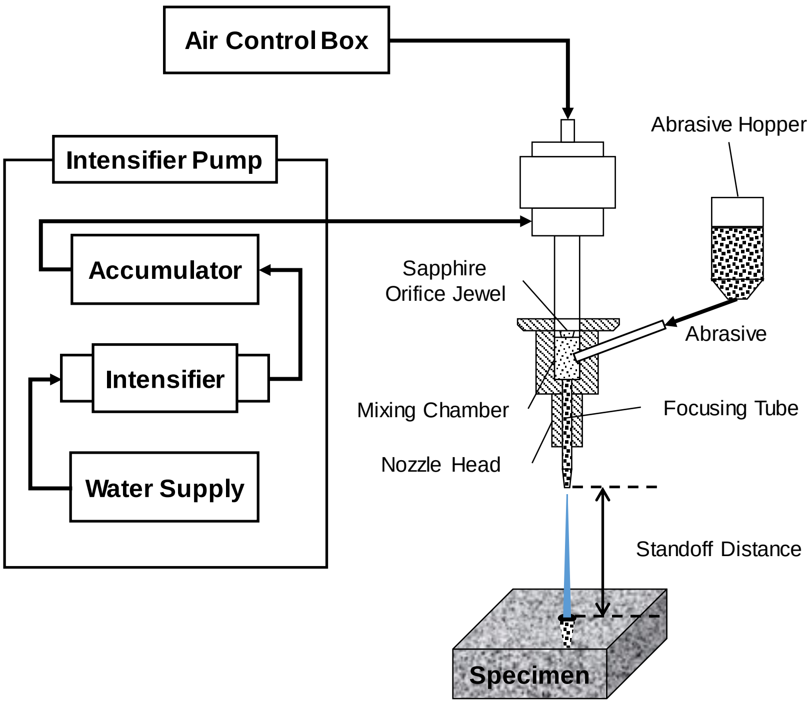

Fig. 1 Schematic of abrasive waterjet system (Hwang et al. 2019)

On the other hand, in order to effectively excavate underground rock with abrasive waterjetting, a large width of excavation must first be made. This is so that the waterjet nozzle head can be inserted into the hole in the partially removed rock for deep excavation. The excavation width is closely related to the jet dispersion and is affected by various parameters such as water pump pressure, abrasive flow rate, focusing tube geometry, and standoff distance (Oh and Cho 2014). In this study, the drilling performance was analyzed experimentally by observing the drilling depth and drilling width as a function of focusing tube length (L_f) and SOD, which are the most closely related among various parameters. In addition, the drilling width was used to analyze the characteristics of jet dispersion as a function of L_f and SOD.

2. EXPERIMENTAL PROGRAM

Underground excavation tests using AWJ system were conducted on granite frequently found in construction sites. Abrasive material used garnet which consists of tiny particles (i.e., 0.00018 mm) and has high hardness ranging from 7.5 to 8.5 on the Mohs scale. The specification of the intensifier-type hydraulic pump used in the experiment is summarized in Table 1. In addition, this experiment was performed on the same granite specimen while changing three L_f (i.e., 76.2, 101.6, and 152.4 mm) and four SOD (i.e., 50, 100, 150, and 200 mm). The details of the parameters applied to the experiment are summarized in Table 2.

Table 1 Specifications of hydraulic pump

Pump type	Power [HP]	Max. water pressure [MPa]	Max. water flow rate [ml/s]
Intensifier pump	50	412	100

Table 2 Experiment cases and details

Water pump pressure [MPa]	320
Orifice diameter [mm]	0.33
Water flow rate [ml/s]	50.01
Abrasive flow rate [g/s]	5.6
Focusing tube diameter [mm]	1.02
Focusing tube length [mm]	76.2, 101.6, 152.4
Standoff distance [mm]	50, 100, 150, 200

The effective jet radius is defined as the radius of the erosion zone and is affected by the focusing tube shape parameter and standoff distance (Oh and Cho 2016). In this study, analysis was performed by applying the effective jet radius to the excavation width (W), which is the result of the excavation experiment (Fig. 2). The excavation width is defined as a function of focusing tube geometry and standoff distance (Eq. 1).

$$W = D_f + 2 \cdot SOD \cdot tan\frac{\alpha}{2}, \tag{1}$$

where W is excavation width, D_f is the focusing tube diameter, and SOD is the standoff distance, and α is the jet dispersion angle.

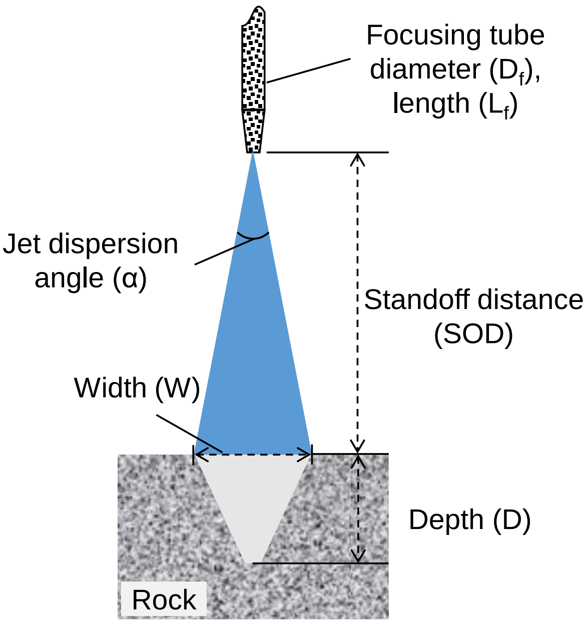

Fig. 2 Concept of jet dispersion for underground excavation with abrasive waterjet

3. RESULTS AND DISCUSSION

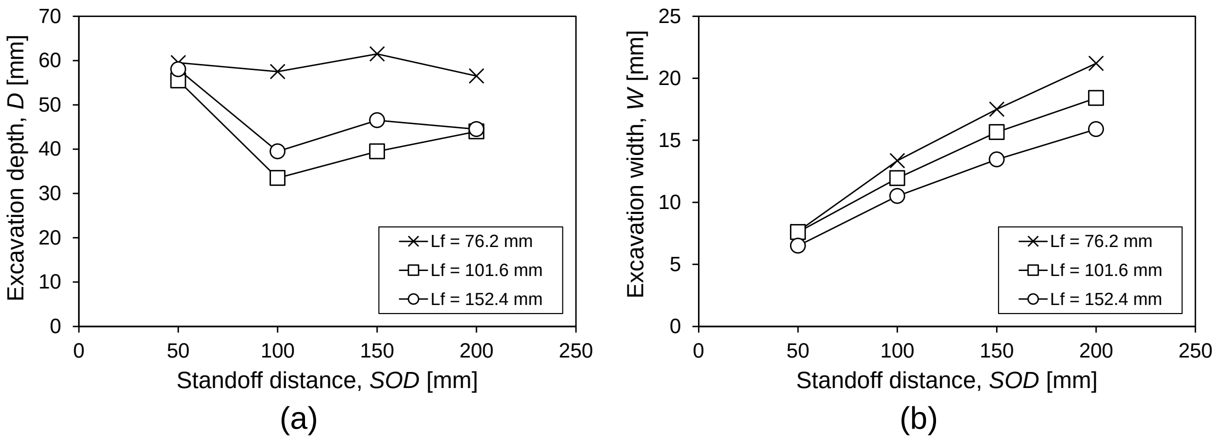

Fig. 3 Rock excavation performance of abrasive waterjet: (a) excavation depth and (b) excavation width with abrasive flow rate of 5.6 g/s

Fig. 3 shows the results of rock excavation performance as a function of SOD and L_f. For the excavation depth, it tended to increase and then decrease as the SOD increased (Fig. 3(a)). For L_f of 76.2 mm, the excavation depth was relatively effective as the SOD increased. This is because as the length of the focusing tube increases, the duration of collision and friction between the abrasive and the wall is relatively longer, resulting in energy loss of the abrasive. In addition, the smallest excavation depth was achieved when the SOD was 100 mm. Fig. 3(b) shows the results for the excavation width, which tends to increase with increasing SOD for all L_f cases. This is because as L_f increases, the straightness of the jet increases, making the jet relatively less spread out.

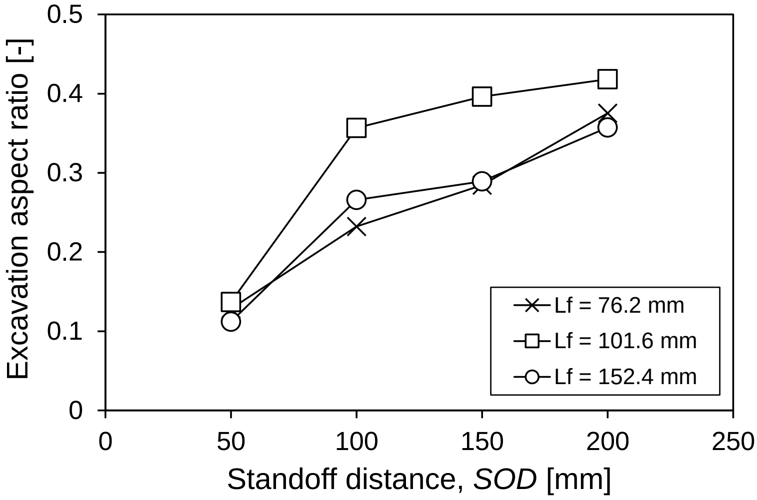

Fig. 4 Effect of standoff distance and focusing tube length on the excavation aspect ratio

Fig. 4 also shows the results of the excavation aspect ratio as a function of SOD and L_f. The excavation aspect ratio was defined as the ratio of excavation width to excavation depth. For all L_f cases, the excavation aspect ratio increased as the SOD increased. In particular, the L_f of 101.6 mm had the largest excavation aspect ratio and was analyzed to enable efficient underground excavation. This shows that there is an optimal L_f and SOD for effective excavation when the same energy is input. Therefore, it is necessary to apply the optimal L_f and SOD to derive effective performance for underground excavation using AWJ system.

4. CONCLUSIONS

In this study, experimental test of abrasive waterjet system was performed considering focusing tube length and standoff distance. The results are summarized as follows.

- As the standoff distance increased, the excavation depth tended to decrease and then increase.

- As the focusing tube length increased, the straightness of the jet increased and the jet became less dispersed.

- When the focusing tube length was 101.6 mm, an effective excavation aspect ratio was obtained, and it is judged that efficient underground excavation is possible.

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