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Rock Cutting Performance between Abrasive Waterjet and Abrasive Suspension Jet System

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ABSTRACT

Rock excavations in urban areas are highly restricted due to the need to control the blasting vibration level and make rapid excavation. Rock excavation using an abrasive waterjet system is now under development for efficiently creating tunnels and underground spaces. There are two types of abrasive waterjet system: the abrasive waterjet system (AWJ, injection type) and the abrasive suspension jet (ASJ) system. This study compares the rock cutting performance of the AWJ and ASJ systems. Appropriate application fields of each waterjet system are recommended and cutting performance characteristics are described. The recommended methods can be effectively used to obtain baseline data for implementing alternative rock excavations for civil engineering applications.

1. INTRODUCTION

Hard rock excavation in urban areas is a significant challenge owing to unacceptable excavation vibration levels and the necessity of rapid excavations. Conventional blasting methods and the use of a tunnel boring machine (TBM) are broadly utilized at present. However, conventional blasting methods cannot prevent the propagation of blasting vibration, while the TBM method is not appropriate for mixed ground conditions or short tunnels. Therefore, the development of a new tunnel

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excavation method is necessary for efficiently constructing tunnels and underground spaces and with fewer restrictions. High pressurized waterjet systems are used in various industries like machining and mining (Summers, 1995). The waterjet system is now being used not only in the machining and mining fields but also in the civil engineering field, especially in tunneling.

Rock cutting using an abrasive waterjet (AWJ) has been in use in recent years. An AWJ system can more efficiently remove the work material than a pure waterjet by using high pressurized water entrained with various types of abrasives, such as garnet, alumina, steel grit, sand, silicon carbide, glass beads, etc. Its system is now an emerging technology not only in the machining or mining field but also in the civil engineering field, especially in tunnelling.

Abrasive is an important process parameters that can differentiate between the cutting performance and system's maintenance costs. Its portion of the total AWJ process cost is now approximately estimated to be up to 60% in the manufacturing or machining fields. Thus, a huge amount of abrasives will inevitably be consumed to construct mega underground structures such as tunnels, shafts, etc. Abrasive particle sizes for commercial purposes of abrasive waterjetting range from 60-mesh to 200-mesh. Abrasive particle sizes under 60-mesh are usually utilized for sand blasting that does not require precise quality of cutting results. The most commonly used abrasive is garnet, which has good cutting performance and is cost efficient (Hashish, 1989; Vasek et al., 1993). Garnet is a silicate mineral that can be synthesized artificially. However, naturally occurring garnet is mostly utilized for industrial purposes because of the complexity of chemical synthesis and the cost of production (Tauber et al., 1958). The Mohs hardness of garnet is typically in the range of 6.5-7.5, and its specific gravity is in the range of 3.1-4.3.

An AWJ system is mainly divided into two typical types. (1) The injection jet type in which high pressurized water passes through the nozzle's orifice in the mixing chamber. Then, pressure in the mixing chamber is diminished according to Bernoulli's principle, and the abrasive will be entrained through the abrasive pipe, which is connected to the mixing chamber. This type of AWJ system is commercially utilized in most machining industries because of the simple unit installation and low maintenance cost. (2) The suspension jet type, in which highly pressurized water and abrasives are pre-mixed in the specially organized mixing unit, and these pre-mixed fluids are supplied through the nozzle. This type has some advantages in eliminating the influence of air. However, it requires the purchase of an additional abrasive mixing unit, which can be easily eroded by pre-mixed fluids. In addition, the unit installation and maintenance costs are more expensive than the injection jet type of AWJ system.

In this study, we introduce the two major commercial abrasive waterjet systems (injection jet type and suspension jet type) and compare their rock cutting performances in traverse cutting conditions and penetration cutting conditions. We made the other waterjet operating parameters as similar as possible.

2. EXPERIMENTAL SETUP

As the abrasive for this experiment, we used small garnet particles, and their abrasive properties are shown in Table. 1. The granite specimens were prepared (quarried from the Hwang-Deung region in Korea) with the physical properties of the specimen as follows: dry density 26.66 kN/m3, porosity 0.68%, absorption ratio 0.25%, and uniaxial compressive strength 208.5 MPa. The dimensions were as follows: thickness 300 mm, width 300 mm, and length 300 mm.

Table 1. Abrasive properties

Component	Hardness (Mohs scale)	Specific gravity	Particle size
$Mg_3Al_2Si_3O_{12}$ (Pyrope garnet)	6.5~7.5	3.1~4.3	30~200 mesh

(1) AWJ system (Injection jet type):

A waterjet using a single nozzle system was implemented by high water pressure with certain water flow rates and traverse speed. For this test we used a diesel plunger pump that generates a high water flow rate. The pump's power was 600 HP and the maximum water flow rate was approximately 80 l/min at 250 MPa. For the orifice and focusing nozzle parts, a sapphire orifice (inner diameters of 0.89 mm) was utilized in this test; the water flow rate reached 18.78 l/min/ea at 250 MPa, and the focusing nozzle inner diameter was 2.29 mm. Waterjet nozzle traverse system can be operated at the same standoff distance conditions (10 mm for a single nozzle system) for a given traverse speed. Water pipes supplied the high pressurized water and abrasive pipes entrained the abrasives inside the nozzle mixing chamber using induced suction pressures (e.g., abrasive injection type).

Fig. 1. Components of the AWJ system.

(2) ASJ system (Suspension jet type):

The major components of the ASJ system were a waterjet pump, an abrasive mixing unit (AMU), a flexible high-pressure hose, and a dedicated cutting nozzle. This ASJ system also used a single nozzle system and maintained similar test conditions (water pressure, water flow rate, abrasive feed rate, traverse speed, stand-off distance) as the AWJ system. A high-pressurized waterjet pump had an operating pressure of

200 MPa and a water flow rate of 17.56 l/min/ea. The focusing nozzle inner diameter was 2.5 mm and the waterjet nozzle traverse system was operated at the same standoff distance conditions (10 mm for a sinlge nozzle system) for a given traverse speed.

The AMU receives the high-pressurized water from the waterjet pump and receives the abrasives from the abrasive hopper. The high-pressurized water and abrasives are mixed inside the AMU chamber (storage capacity of 80 kg of abrasives in a 40 L AMU chamber). This AMU product, which was supplied by ANT, mixes water and abrasives under the operating pressure in a weight-proportion of 90% water and 10% abrasive.

(a) Cutting manipulation system

(b) Abrasive Mixing Unit

Fig. 2. Components of the ASJ system.

3. RESULTS & ANALYSIS

3.1 Cutting performance

The cutting performance results of the AWJ and ASJ systems are shown in Fig. 3. Fig. 4 demonstrates that the AWJ system has better cutting performance than the ASJ system on traverse cutting, while the cutting ability of the ASJ system has about 60% of the cutting ability of the AWJ system (cutting depth basis). This phenomenon is estimated to occur by the air proportion difference of each abrasive waterjet system. Mostly the AWJ system contains a higher proportion of air than the ASJ system, and the jet stream (high-pressurized water and abrasive) is more distributed by air on comparatively large areas. Therefore, improving the cutting performance in traverse cutting conditions by distributing the jet stream is needed for rock cutting.

Fig. 3. Overall cutting performance (left: AWJ system, right: ASJ system)

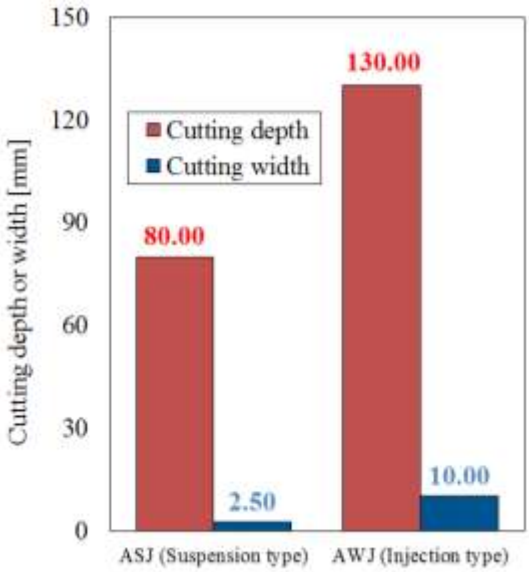

Fig. 4. Cutting performance comparisons

3.2 Penetration performance

Penetration performance results of the AWJ and ASJ system are shown in Fig. 5. Fig. 6 reveals that the ASJ system has an overwhelmingly better cutting performance than the AWJ system on penetration tests. The penetration ability of the AWJ system is about 6.3% of the penetration ability of the ASJ system. This phenomenon is also estimated to occur by the air proportion difference of each abrasive waterjet system. The jet stream concentration will decrease when the air proportion is increasing. That is, the degree of jet stream concentration will be much higher in the ASJ system and this high jet stream concentration dramatically improves the penetration rate of the rock cutting. Therefore, for improving the cutting performance in penetration testing conditions, concentrating the jet stream is necessary for rock cutting.

Fig. 5. Penetration performance (left: AWJ system, right: ASJ system)

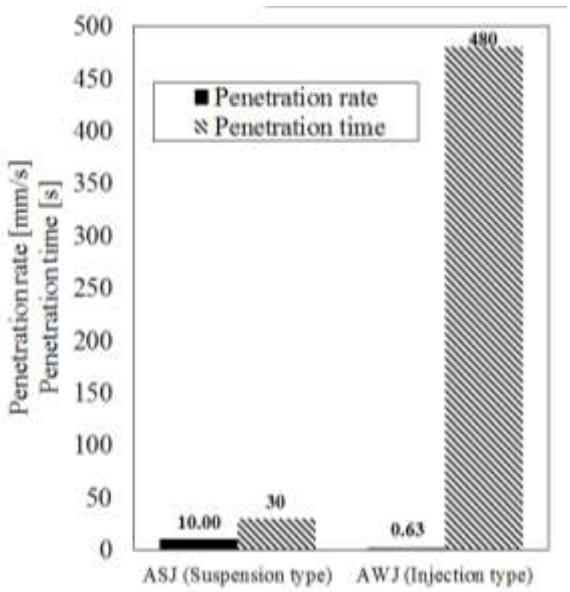

Fig. 6. Penetration performance comparisons

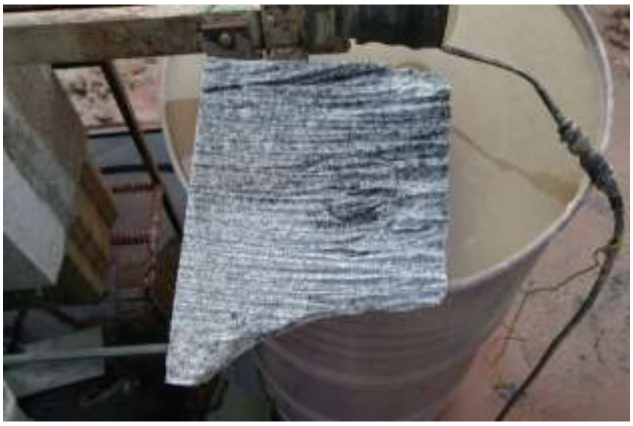

Fig. 7. Cross-section view of a granite specimen (using ASJ system)

3. CONCLUSIONS

In this study, we compared the two major commercial abrasive waterjet systems for rock cutting performance with traverse cutting conditions and penetration cutting conditions. The AWJ system demonstrated higher traverse cutting ability, while the ASJ system had a higher penetration cutting ability. Therefore, the AWJ system will be appropriate for large area cutting such as cut-slope excavation or tunnel excavation with traverse cutting. The ASJ system will be more accurate for small area cutting, such as pipe cutting in chemical plants or pressure vessel cutting in nuclear power plants with penetration cutting.

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