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Paper

SUBMERGED ABRASIVE SUSPENSION JETS ISSUING FROM SHEATHED NOZZLE WITH VENTILATION

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ABSTRACT

A sheathed nozzle with ventilation for abrasive suspension jets (ASJs) was proposed as a means of extending the effective standoff distance in submerged condition. The effectiveness of the sheathed nozzle with ventilation has been demonstrated by submerged cutting tests. However, detailed flow structure of the jet and the optimum jetting condition issuing from the sheathed nozzle with ventilation in submerged condition have not been clarified sufficiently. In the present investigation, submerged cutting tests of aluminum specimens by the ASJs issuing from sheathed nozzles with ventilation are conducted at the jetting pressure of 30 MPa. The effects of air flow rate and sheath length on the cutting capability of the ASJs are investigated experimentally. High-speed observations of water jets issuing from the sheathed nozzle with ventilation are also conducted by using a transparent acrylic resin sheath. Aspects of air coated water jets in submerged condition and effects of air flow rate on the flow structure in the sheath are clarified through image processing of the high-speed videos.

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1. INTRODUCTION

The drilling and cutting capability of a submerged abrasive suspension jet (ASJ) decreases drastically with increasing the standoff distance and the cavitation number [1, 2]. A sheathed ASJ nozzle with ventilation was proposed as a means of expanding the effective standoff distance under submerged condition and submerged cutting tests were conducted with aluminum specimens at the jetting pressure of 30 MPa[3]. It was demonstrated that the sheathed ASJ nozzle with ventilation is useful for extending the effective standoff distance. However, detailed flow structure of the jet flow and the optimum jetting condition such as sheath length and the ventilation air flow rate have not been clarified sufficiently.

In the present work, submerged cutting tests by ASJs issuing from the sheathed nozzles with ventilation are conducted with aluminum specimens at the jetting pressure of 30 MPa. The cutting capabilities of the ASJs under different sheath lengths and ventilation air flow rates are investigated experimentally. High-speed observations of water jets issuing from the sheathed nozzle with ventilation are also conducted by using a transparent acrylic resin sheath in order to clarify the flow structure. Aspects of air coated water jets in submerged condition and the effect of ventilation air flow rate on the flow structure in the sheath are investigated through image processing of the high-speed videos.

2. EXPERIMENTAL APPARATUS AND METHOD

Experiments are conducted using an ASJ system based on bypass principle [4]. Figure 1 shows the ASJ system used for the experiments. The system consists of a high-pressure pump, abrasive storage tank of approximately 10 L, and abrasive mixture unit. The maximum working pressure of the system is 35 MPa, but submerged cutting tests are conducted at the jetting pressure of 30 MPa. The abrasive used in the experiments is garnet having a mesh designation of #100. The ASJ nozzle head is attached to a robot arm of Motoman HP 20 six axes robot. The depth of water at the nozzle head is approximately 100 mm and the jet discharges horizontally. During the cutting tests, the surface of the water is covered by a plate not to swallow air through the surface of the water. Air is sucked to the sheath via a plastic tube with an inner diameter of 6 mm. The air flow rate is measured by a float type area flow meter attached to the end of the plastic tube. Figure 2 shows a sheathed ASJ nozzle. A sheath with diameter several times that of the nozzle is attached to the nozzle outlet and an air supply port is equipped at the base of the sheath. A conical convergent nozzle followed by a straight passage, nozzle A10 [5], is used for the cutting tests and high-speed observations of the jet. The diameter d and the length of the nozzle straight passage are 1.0 and 9.6 mm, respectively. In the cutting tests, the sheath is fabricated from stainless steel pipe with an inner diameter of 3 mm.

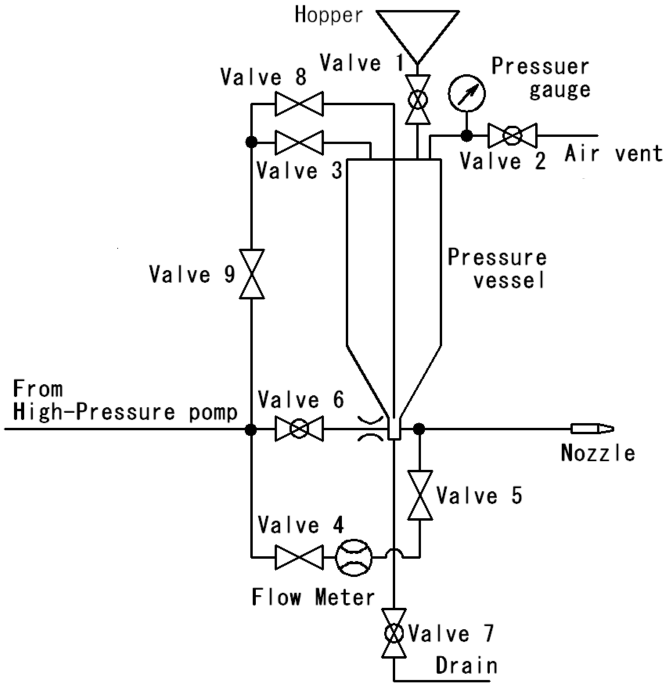

Figure 1. Scheme of ASJ system

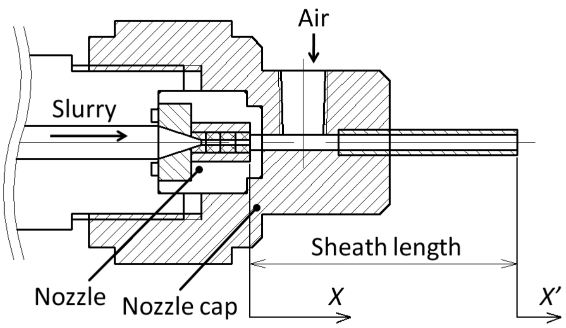

Figure 2. Sheathed ASJ nozzle with ventilation

In order to clarify the flow aspects in the sheath and air coated water jet under submerged condition, observations of the flow are carried out without addition of abrasive. In this case, the jetting pressure is 10 MPa and a sheath made of transparent acrylic resin pipe is used instead of the stainless steel pipe.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

According to the drilling tests by the ASJs [1], the drilling capabilities of ASJs in air are closely related to the flow structure of the jet. In order to clarify the flow structure in air, high speed observations of the ASJs are conducted using high-speed video. Figure 3 shows an example of the flames of the high-speed video. The framing rate is 61538 frame/s and the exposure time is 2 µs. Since the jet is illuminated from behind, the ASJ appears dark in the photograph. The jetting pressure is 30 MPa and the abrasive concentration is approximately 25 wt%. The jet is relatively compact and the continuous core of the jet is maintained in the range of the photographs. The velocities of the irregularity and liquid lumps of the jets are calculated from images of the high-speed video. Figure 4 shows the non-dimensional jet velocity in the range of X/d = 0 to 100. The velocities of the irregularity and liquid lumps of the jets are 0.82 to 0.91 times of the theoretical jet velocity V_{th} calculated by the Bernoulli's equation assuming the loss in the nozzle to be zero. The measured velocities V/V_{th} agree with the previous results [5].

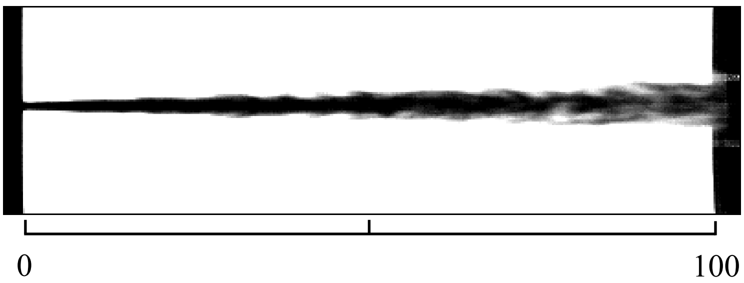

Figure 3. Instantaneous photograph of ASJ issuing from the nozzle A10 (p_i = 30 MPa)

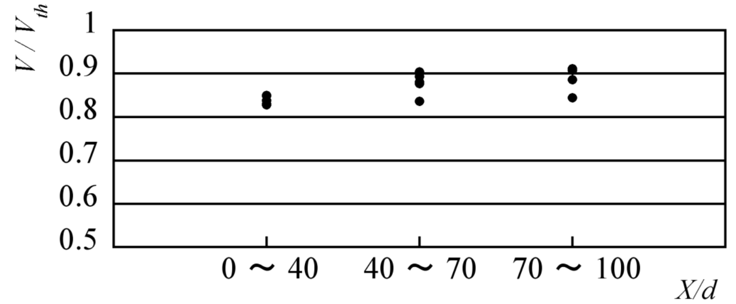

Figure 4. Non-dimensional velocity V/V_{th} versus distance from nozzle exit X/d

The entrainment of air into the sheathed ASJ nozzle is an important process for the formation of the air coated ASJ in submerged condition. Gaseous phase around the ASJ prevents the deceleration of abrasive particles and drastic decrease in the cutting capability of the submerged ASJ. Figure 5 shows the measured maximum air flow rate $Q_{air\,max}$ as a function of the sheath length L_{sheath} for the air supply hose of approximately 4 m in length. The measured air flow rate $Q_{air\ max}$ increases with the increase of L_{sheath} but is constant irrespective of L_{sheath} in the region of $L_{sheath}/d > 30$. On inspection of the sheath after jetting, damage of the inner surface of the sheath by the impingement of abrasive particles is observed in the cases of $L_{sheath}/d \geq 50$. The ASJ issuing from the nozzle A10 is relatively compact but the diameter of the jet increases linearly with the increase of X/d as shown in Figure 2. The ASJ expands fully out to the sheath inner diameter in the sheath when $L_{sheath}/d \geq 50$.

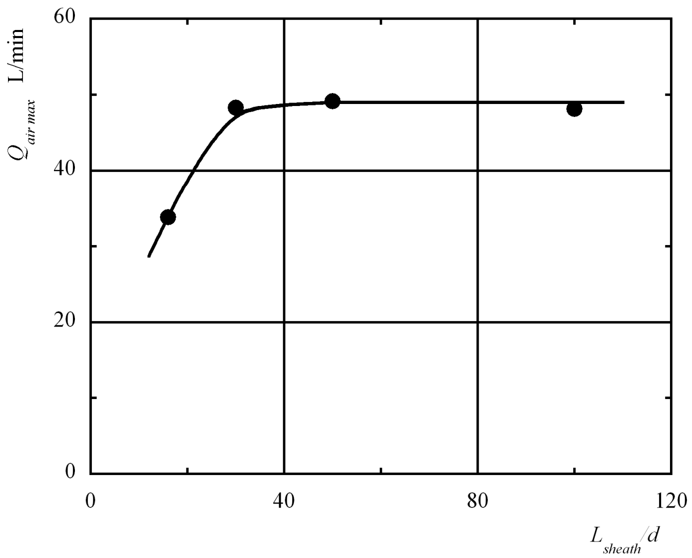

Figure 5. Maximum air flow rate $Q_{air\ max}$ versus non-dimensional sheath length L_{sheath}/d

Submerged cutting tests are conducted with specimens of aluminum plate at the jetting pressure p_i of 30 MPa and the nozzle traverse speed V_t of 2 mm/s. The abrasive concentrations of the ASJ and the air supply rate Q_{air} during the cutting tests are 25±3 wt% and 34 L/min, respectively. The relationships between the non-dimensional depth of kerf h/d and the non-dimensional distance X'/d for the non-dimensional sheath length of L_{sheath}/d = 16, 30 and 50 are shown in Figure 6. When $L_{sheath}/d = 50$, the depth of kerf in the range of $X'/d < 20$ is almost constant irrespective of X'/d and depth of kerf decreases linearly with the increase of X'/d in the region of $X'/d > 20$. In the cases of L_{sheath}/d = 16 and 30, the depth of kerf decreases linearly with the increase of X'/d. Since the ASJ expands fully out to the sheath inner diameter in the sheath when $L_{sheath}/d \geq 50$, the sheath restrains radial expansion of the jet and carries out as a focusing action. Accordingly, the depth of kerf for $L_{sheath}/d = 50$ is almost constant irrespective to X'/d in the region just downstream of the sheath exit. The depth of kerf by the longer sheathed nozzle becomes smaller than that by the shorter sheathed nozzle. In the extent of our experiments, shorter sheath is preferable for submerged cutting by the sheathed ASJ nozzle with ventilation.

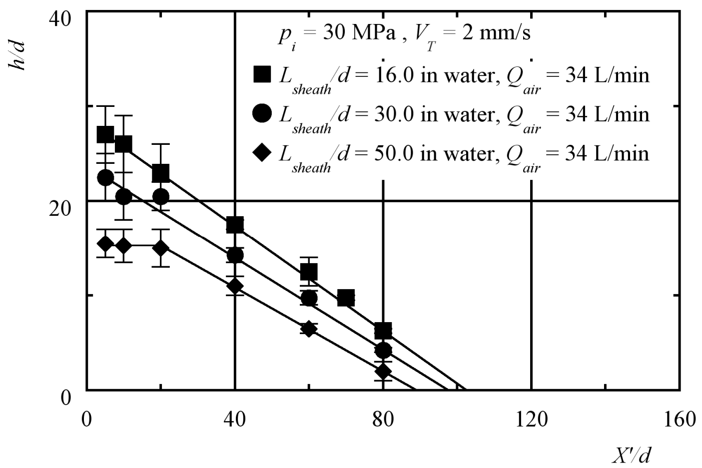

Figure 6. Variations of depth of kerf *h/d* with distance from sheath exit *X'/d* for L_{sheath}/d = 16, 30 and 50

Figure 7 shows the relationships between non-dimensional depth of kerf *h/d* and air supply rate Q_{air} for non-dimensional distance *X'/d* = 10 and 40. Jetting pressure and non-dimensional sheath length L_{sheath}/d are 30 MPa and 16, respectively. When *X'/d* = 10, the depth of kerf increases linearly with increasing of Q_{air} in the region of Q_{air} < 6 L/min, but is almost constant irrespective of Q_{air} in the range of Q_{air} > 6 L/min. When *X'/d* = 40, *h/d* is much smaller than that of *X'/d* =10 and increases linearly with Q_{air} in the region of Q_{air} < 20 L/min. The cutting capabilities of the submerged ASJs in the region of relatively small *X'/d* can be improved remarkably by the ventilation of small air supply rate. In the case of larger *X'/d*, larger amount of air supply is necessary to improve the cutting capability. However, excessive air supply rate does not improve the cutting capability of the submerged ASJ.

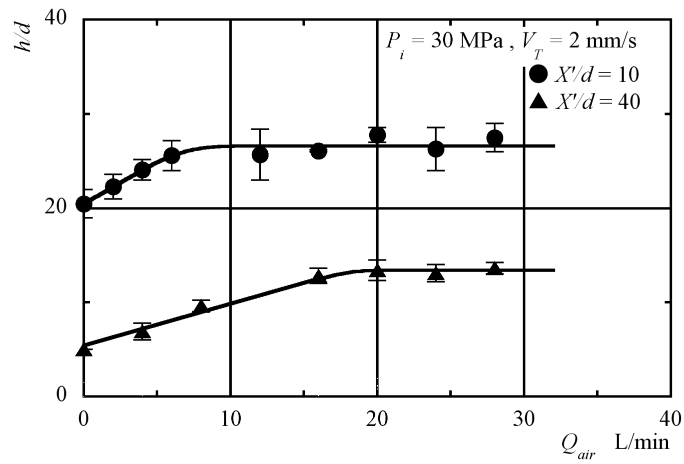

Figure 7. Variations of depth of kerf *h/d* with air flow rate Q_{air} when *X'/d* = 10 and 40

In order to observe the effects of air flow rate on the aspects of the flow in and out of the sheath, high-speed observations are conducted by using a transparent acrylic resin sheath. Experiments are conducted at the jetting pressure of 10 MPa without addition of abrasive. Transparent acrylic resin sheath with an inner diameter of 3 mm and L_{sheath}/d = 50 is attached to the nozzle A10. Figure 7 shows time series photographs of the flows in the vicinity of the sheath exit at the air supply rate Q_{air} = 0, 6, 14 and 22 L/min. The time interval between the frames is 1 ms. Since the flows are illuminated from behind, water droplets and bubbles appear to be black. Under these experimental conditions, the continuous core of the water jet is maintained in the sheath and the diameter of the water jet at the sheath exit is smaller than the sheath inner diameter. When the Q_{air} is relatively small, the backward flow occurs along the inner wall of the sheath, and it interferes with jet flow in the sheath. Meanwhile, the backward flows rarely appear in the sheath for the case of larger air flow rate. When Q_{air} = 0, the jet expands fully out to the sheath inner diameter in the region near the sheath exit and a bubbly mixture zone is formed. A cavitation cloud extending from the bubbly mixture zone appears to be continuous near the sheath exit but separates and develops into lumps of cavitation clouds. For detailed behaviors of bubbly mixture zone in the sheath and cavitation clouds, the reader may refer to Reference 6. When Q_{air} = 22 L/min, the core of the water jet is clearly observed in the region downstream of the sheath exit. This flow condition is considered to prevent the drastic reduction of the cutting capability.

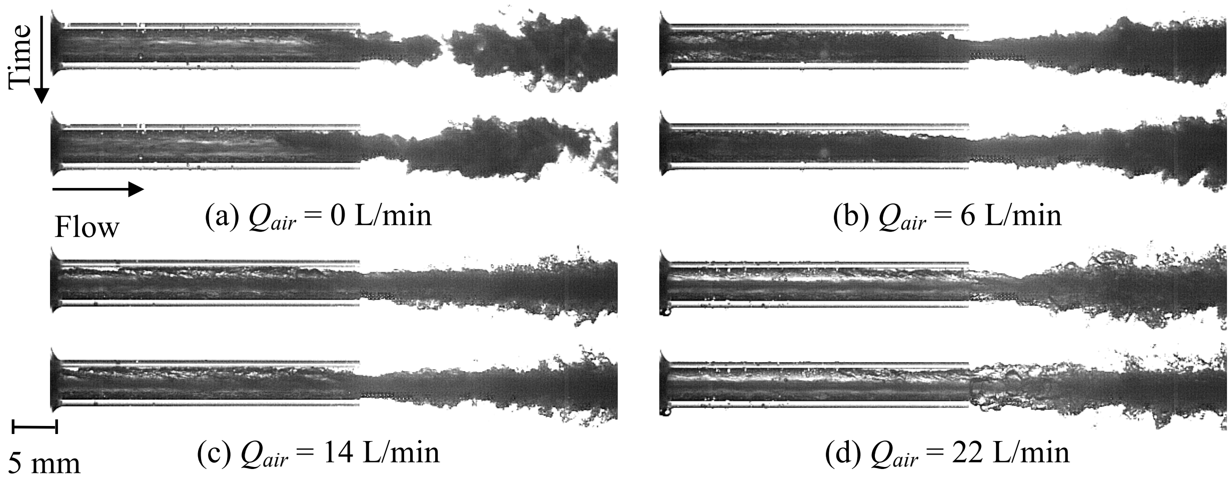

Figure 8. Instantaneous of photographs of jets issuing from the sheathed nozzle under different ventilation flow (p_i = 10 MPa, $L_{sheath/d}$ = 50)

In order to clarify the qualitative characteristics of the flow discharged from the sheathed nozzle, the image analyses are conducted. Figure 9 shows a time variations of the radial width of bubbly clouds for analysis time of 20 ms. Pixels of the high speed video images on X'/d = 5 arranged in time series to visualize the time variations of cavitating or air-coated zone. The width of the black band corresponds to the instantaneous diameter of the air coated zone. The diameter of the air coated zone varies with time. When Q_{air} is relatively small, the diameter of the air coated zone fluctuates irregularly at high frequency. With increasing Q_{air}, the air coated zone tends to pulsate periodically. The frequency of the pulsation of the air coated jet decrease with the increase of Q_{air} as shown in Figure 10.

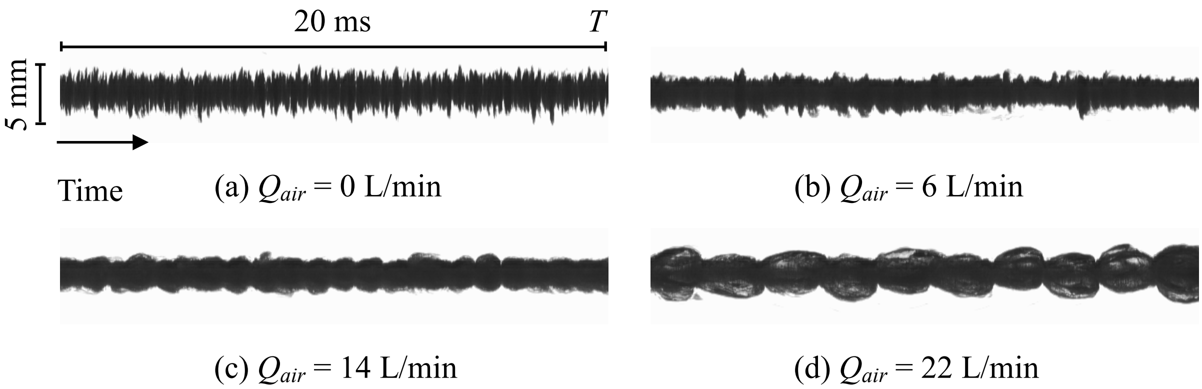

Figure 9. Image analyses of jets discharging from the sheath (p_i = 10 MPa, X'/d = 5)

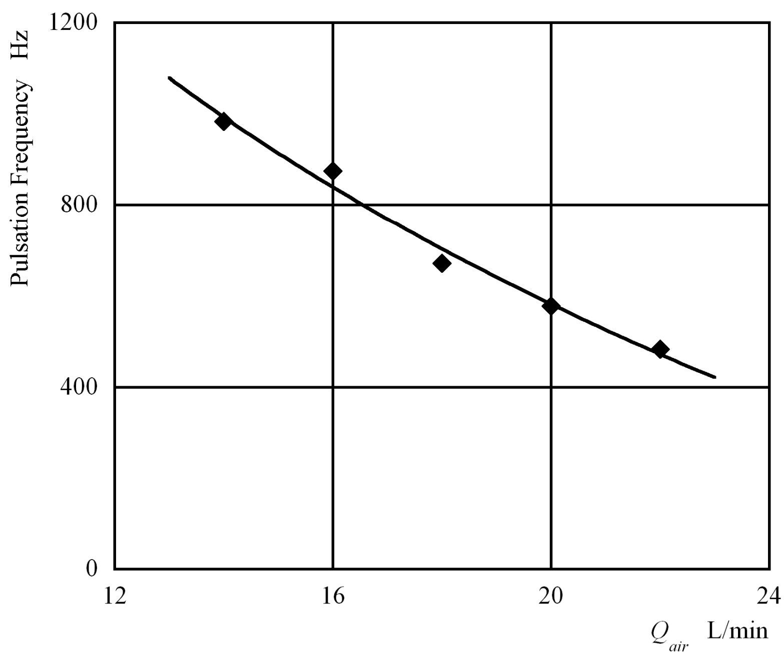

Figure 10. Variation of pulsation frequency with the ventilation flow rate Q_{air} (p_i = 10 MPa, X'/d = 5)

4. CONCLUSIONS

Submerged cutting tests of aluminum specimens by the ASJs issuing from sheathed nozzles with ventilation are conducted at the jetting pressure of 30 MPa. The effects of ventilation air flow rate and sheath length on the cutting capability of the ASJs are investigated experimentally. High-speed observations of water jets issuing from the sheathed nozzle with ventilation are also performed to clarify the flow aspects of the air coated water jet under submerged condition. Main specific points of interests are as follows:

(1) Within the range of the present experiments, a shorter sheath is preferable for submerged cutting by the sheathed nozzle with ventilation.

(2) The cutting capabilities of submerged ASJs in region of relatively small X'/d can be improved remarkably with the ventilation of a small air flow rate. In the case of larger X'/d, a larger amount of air supply is necessary to improve the cutting capability. However, an excessive air supply does not enhance the cutting capability of the submerged ASJ further.

(3) When the air supply is relatively small, a backward flow is formed along the sheath wall and the backward flow interferes with the main jet in the sheath.

(4) The air coated jet under submerged condition tends to pulsate. The frequency of the jet pulsation decreases with the increase of the air supply.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

(1) S. Shimizu and T. Nishiyama, T. Shimura and T. Omote, Drilling capability of submerged abrasive water suspension jet, Water Jetting, BHR Group, 2002, pp.509-520

(2) T. N. Hung, H. Louis, D. Peter and T. Senne, Submerged application of abrasive water suspension jets (AWSJs), Water Jetting, BHR Group, 2004, pp.205-216

(3) S. Shimizu, M. Skuma, K. Hitomi and G. Peng, Submerged cutting byabrasive suspension jet issuing from sheathed nozzle with ventilation, Water Jetting, BHR Group, 2010, pp.435-441

(4) C. Brandt, H. Louis, G. Meier and G. Tebbing, Fields of application for abrasive water suspension jets of pressure from 15 to 200 MPa, Proc. 8^{th} American Water Jet

Conference, 1995, Paper 15, pp.207-217
(5) S. Shimizu, Effects of nozzle shape on structure and drilling capability of premixed abrasive water jets, Jetting Technology, BHR Froup, 1996, pp.13-26
(6) H. Ito, T. Aoyama, G. Peng and S. Shimizu, Observations of cavitating jets issuing from a sheathed nozzle, Water Jetting Technology for LOHAS, International Academic Printing Co. Ltd, 2009, pp.97-100

7. NOMENCLATURE

d : inner diameter of the nozzle
h : depth of kerf
L_{sheath} : sheath length
p_i : injection pressure
Q_{air} : air flow rate
$Q_{air\ max}$: maximum air flow rate
V : velocity of jet
V_t : traverse speed of the nozzle
V_{th} : theoretical jet velocity calculated by the Bernoulli's equation
X : distance measured from nozzle exit
X' : distance measured from sheath exit