AIR COATED ABRASIVE SUSPENSION JETS UNDER SUBMERGED CONDITION

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In order to improve cutting capability of a submerged abrasive suspension jet (ASJ), a ventilated sheathed nozzle for producing an air coated ASJ has been developed. Cutting characteristics of air coated ASJs under submerged condition are provided by cutting tests with specimens of aluminium alloy. Unsteady behaviour of the air coated layer around the jet is also investigated by high speed observations of air coated water jets. The cutting capability of air coated ASJs and the unsteady behaviour of the air coated layer of the submerged jets are arranged properly by the cavitation number based on the pressure in the ventilated cavity and Strouhal Number.

KEYWORDS

abrasive suspension jet, submerged cutting, air coated jet, high-speed observation, pulsation

1 INTRODUCTION

Drilling and cutting capability of submerged abrasive suspension jets (ASJs) decreases drastically with the increase of the standoff distance and the cavitation number [Shimizu et al. 2002, Hung et al. 2004]. A sheathed nozzle with ventilation for ASJs [Shimizu et al. 2010] has been developed as a means of extending the effective standoff distance in submerged environments. Figure 1 shows a schematic diagram of an air-coated ASJ issuing from a sheathed nozzle with ventilation under submerged condition. A sheathe 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. Air layer around the ASJ prevents the drastic reduction of the drilling and cutting capability of the submerged ASJ.

Two types of experiments are cunducted in the present investigation i.e., cutting tests by ASJs in air and submerged conditions with specimens of aluminium alloy and high-speed observations of water jets issuing from the sheathed nozzle with ventilation. Since observations of submerged ASJs are difficult because of the muddiness by abrasive particles, observations of air-coated water jets are carried out.

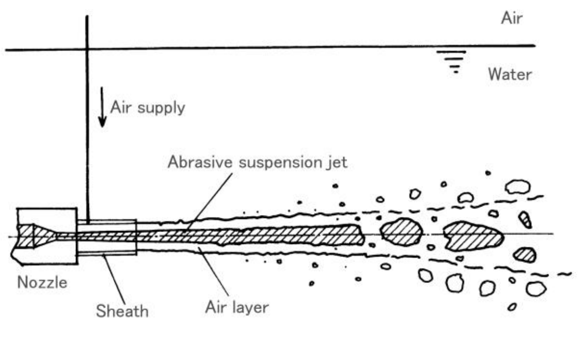

Figure 1. Schematic diagram of an air-coated ASJ issuing from sheathed nozzle with ventilation under submerged condition

2 EXPERIMENTAL APPARATUS AND METHOD

Experiments are conducted using an ASJ system based on bypass principle [Brandt et al. 1995]. Figure 2 shows a circuit diagram of the ASJ system 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. For details of the ASJ system, the reader may refer to Ito et al. [2012]. Abrasive used in the cutting tests is garnet having grain size of between 125 to 250 µm. Approximately 75 w% of the abrasive particles are in the range from 150 to 212 µm.

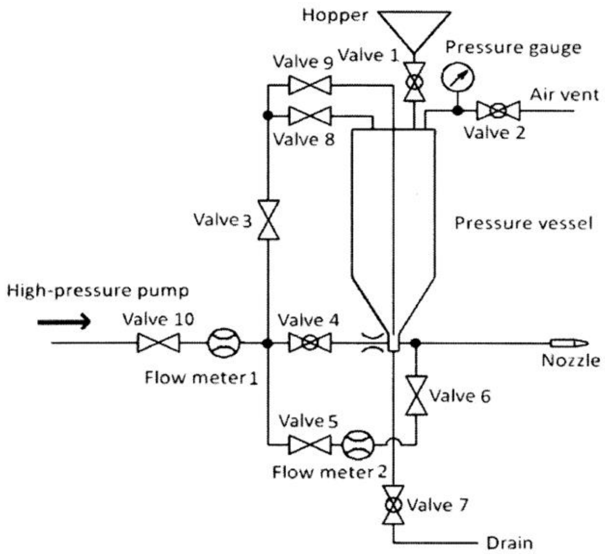

Figure 2. Circuit diagram of ASJ system

Figure 3 shows a water tank for submerged cutting tests. The ASJ nozzle assembly is attached to the arm of Motoman HP20 six axes robot via an extension shaft. The jet impinges vertically to an aluminium test specimen (JIS A5032P). The depth of water at the nozzle exit is approximately 100 mm or 700 mm. Air is sucked to the sheath via a plastic tube with an inner diameter of 6 mm. The air flow rate can be regulated by a valve and is measured by an air flow meter attached to the end of the plastic tube.

High-speed observations of air coated water jets under submerged condition are carried out by using a water tank shown in Figure 4. The jet discharges horizontally and the depth of water at the nozzle head is approximately 210 mm. During the flow observations, the surface of water is covered by a plate so as not to take in air through the surface of the water.

Figure 5 shows a sheathed ASJ nozzle assembly for cutting tests. The diameter d_{sheath} and length L_{sheath} of the sheath are 3 mm and 16 mm, respectively. An air supply port is equipped at the base of the sheath. A conical convergent nozzle followed by a straight passage, nozzle A10 [Shimizu 1996], is used in the experiments. The diameter *d* and the length of the nozzle straight passage are 1.0 mm and 9.6 mm, respectively. In the case of the sheathed ASJ nozzle assembly, the pressure in the sheath P_{sheath} is measured by a pressure hole located 7 mm from the exit of the sheath. In the case of the sheathed water jet nozzle assembly, d_{sheath} and L_{sheath} are 3 mm and 46 mm, respectively. The location of the pressure hole is 9 mm from the exit of the sheath. The distances measured from the nozzle exit and from the sheath exit are denoted *X* and *X'*, respectively.

The distances *X* and *X'* are related as follows:

$$x = x' + Lsheath \quad (1)$$

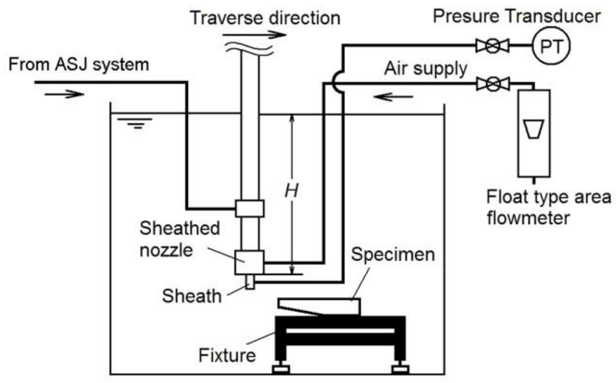

Figure 3. Water tank and setup for submerged cutting tests logo

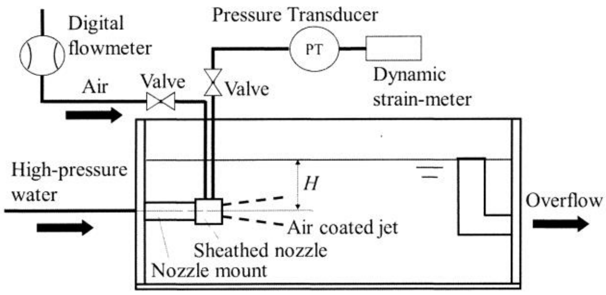

Figure 4. Water tank for high-speed observations of air coated water jets

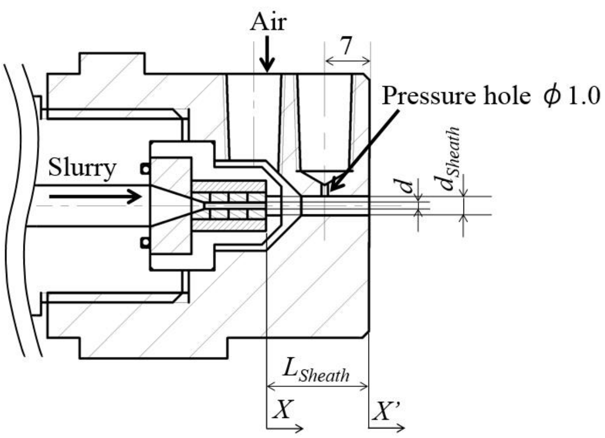

Figure 5. Sheathed ASJ nozzle assembly

3 EXPERIMENTAL RESULTS AND DISCUSSION

Relative cutting depth and cavitation number based on the cavity pressure around the jet are introduced [Shimizu et al. 2015] to understand the cutting capability of ASJs issuing from a sheathed nozzle with ventilation. The relative cutting depth is defined by $h_{submerged}$ /$h_{In\text{-}air}$, where $h_{submerged}$ and $h_{In\text{-}air}$ are the cutting depths under submerged condition and in air at the same cutting conditions, i.e., standoff distance *X* from the nozzle exit, jetting pressure, traverse speed, abrasive concentration, target material, and so on. The relative cutting depth is considered to depend on solely the condition around the jet. The flow aspect around a submerged jet is express by the cavitation number σ_c based on the cavity pressure P_c around the jet.

$$\sigma_c = (P_d - P_c)/(P_i - P_d) \quad (2)$$

where P_d and P_i are the ambient pressure around the jet and the jetting pressure, respectively. Since P_c is considered to be almost the same with the pressure in the sheath P_{sheath}, σ_c can be calculated by Eq. (3).

$$\sigma_c = (P_d - P_{sheath})/(P_i - P_d) \quad (3)$$

Variations of relative cutting depth $h_{submerged}$ / $h_{In\text{-}air}$ with the cavitation number σ_c is shown in Figure 6 [Shimizu et al. 2015]. The jetting pressure P_i is 30 MPa or 20 MPa, the water depth *H* at the nozzle exit is 100 mm or 700 mm, the nozzle traverse speed is 2 mm/s, and the non-dimensional standoff distance *X/d* = 26 or 56. The relative cutting depth $h_{submerged}$ / $h_{In\text{-}air}$ is arranged effectually with σ_c, i.e., the relationship between $h_{submerged}$ / $h_{In\text{-}air}$ and σ_c only depends on *X/d* irrespective of the water depth (the ambient pressure around the jet) and the jetting pressure. In the case of *X/d* = 26 which means the non-dimensional distance from the sheath exit *X'/d* = 10, the relative cutting depth $h_{submerged}$ / $h_{In\text{-}air}$ takes approximately 1 at σ_c = 0.0005 and decreases with the increase of σ_c. In the case of *X/d* = 56 (*X'/d* = 40), $h_{submerged}$ / $h_{In\text{-}air}$ takes approximately 0.8 at σ_c = 0.0005 and decreases more drastically with the increase of σ_c.

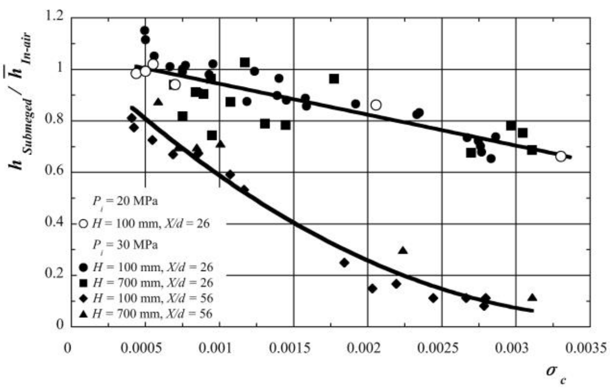

Figure 6. Variations of relative cutting depth $h_{submerged}$/h_{In}-air with cavitation number σ_c [Shimizu et al. 2010], (L_{sheath} = 16 mm and abrasive concentration of 23 wt%)

As mentioned before, the relative cutting depth $h_{submerged}$/$h_{In\text{-}air}$ is considered to depend on solely the condition around the jet, i.e. $h_{submerged}$ /$h_{In\text{-}air}$ ≈ 1 when submerged ASJs impinge on a target under the similar condition of ASJs in air. In order to understand the cutting capability of air coated ASJs, behavior of air coated layer must be clarified. Since observations of submerged ASJs are difficult because of the muddiness, high-speed observations are conducted for air-coated water jets. The air suction characteristic of a sheathed nozzle for a water jet is different from that for an ASJ. Spread of the jet in the speath influences very much on the suction chracteritics of air. Breakup of a water jet is different from that of an ASJ even if the same nozzle is used at the same injection pressure. In the present report, a sheath of L_{sheath} = 46 mm and d_{sheath} = 3 mm is used for the observations of air coated water jets under submerged condition. Figure 7 shows variations of the pressure in the sheath and the suction air flow rate for ASJs issuing from a sheath of L_{sheath} = 16 mm and water jets issuing from a sheath of L_{sheath} = 46 mm at the jetting pressure of 30 MPa. Since air suction characteristics for both cases are almost the same, behavbior of the air coated layer of ASJs issuing from the sheath of L_{sheath} = 16 can be simulated by the air coated layer of the water jets issuing fron the sheath of L_{sheath} = 46.

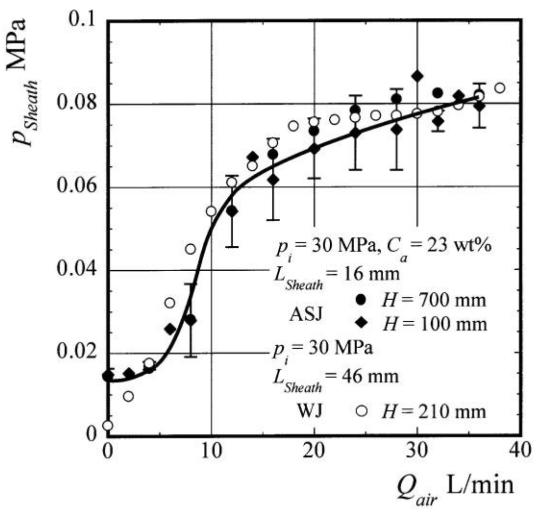

Figure 7. Variations of sheath pressure and suction air flow rate

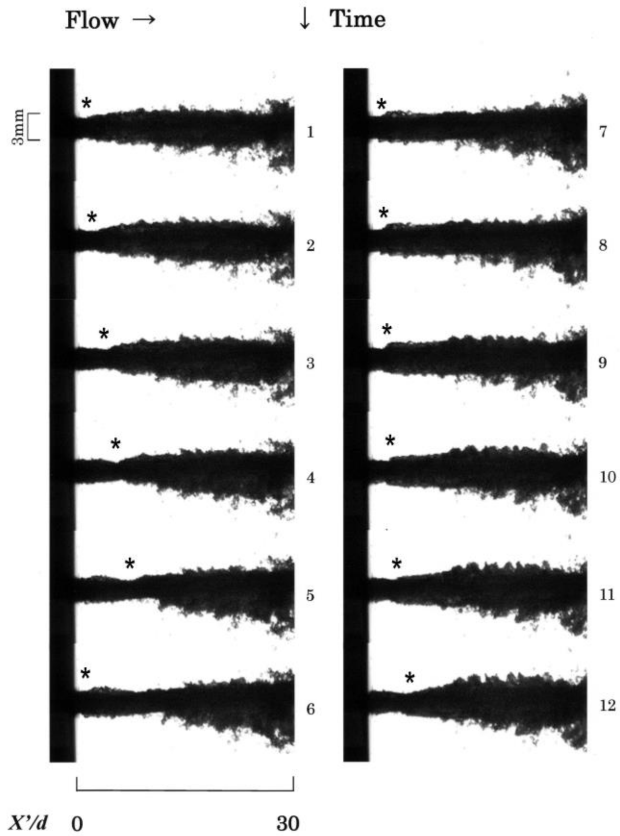

Figure 8. High speed video images of air coated water jet. (P_i = 30 MPa, Q_{air} = 38 L/min)

Figure 8 shows a series of successive images of the air coated water jet issuing from the sheathe nozzle of L_{sheath}/d = 46. The jetting pressure P_i is 30 MPa and the suction air flow rate Q_{air} is 36 L/min. Time interval between the images is 0.17 ms. Air coated layer appears to be black since the jet is illuminated from behind. In the image No.1, air coated layer shrinks just downstream of the sheath. The shrunken portion of the air coated layer indicated by asterisk moves downstream with time. In the image No.6, next shrunken portion appears just downstream of the sheath.

In order to clarify the qualitative characteristics of the air coated layer discharged from the sheath, pixels of the high speed video images at X'/d = 5 are arranged in time series for 20 ms. Results of the image analysis are shown in Figure 9 for various suction air rate Q_{air}. The width of the black band corresponds to the instantaneous diameter of the air coated layer at X'/d = 5. In the case of Q_{air} = 0 L/min, the diameter of cavitating layer around the jet fluctuates irregularly with high frequency. With increasing Q_{air}, the air coated layer tends to pulsate periodically with lower frequency.

Dominant frequencies f of the air coated layer pulsation are obtained from frequency analysis. As for the air coated layer pulsation, the experimental results are correlated by introducing Strouhal Number St and σ_c, The Strouhal number St is defined by Eq. (4).

$$St = f \cdot d_{sheath} / V_{th} \qquad (4)$$

where V_{th} is the theoretical jet velocity calculated by Bernoulli's theorem. Figure 10 shows the relationship between 1 / St and the cavitation number σ_c. Most of 1/St for dominant frequencies are in the region between the dotted lines and mainly follow along the solid line.

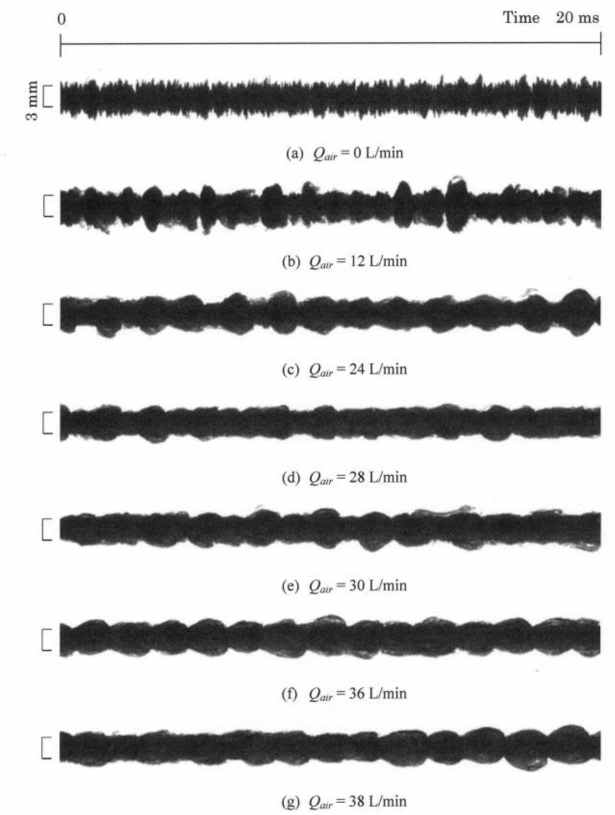

Figure 9. Time variations of air coated layer diameter at X'/d = 5.

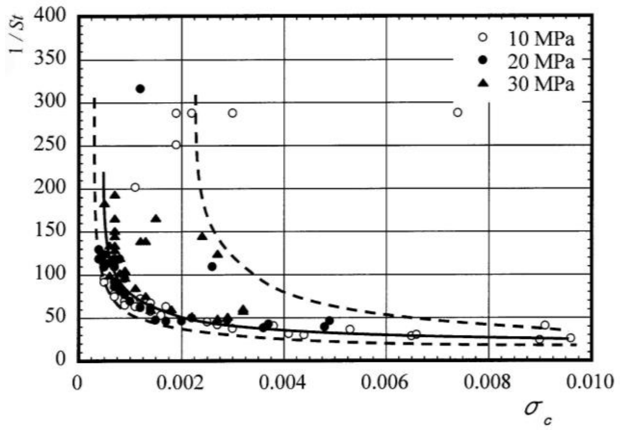

Figure 10. Relationship between *1/St* and σ_c

A continuous length of air coated layer just downstream of the sheath exit is considered to correspond to the product of the traveling velocity of air-water interface V_{cavi} and the period of the pulsation 1/*f*. Non-dimensional traveling velocities of air-water interface V_{cavi} / V_{th} in the region downstream of the sheath exit are obtained by the high speed videos and are in the range from 0.07 to 0.1. According to Figure 10, 1/*St* is approximately 100 in the case of σ_c = 0.0005. From these information, the continuous length of air coated layer just downstream of the sheath exit is estimated to be 20 to 30 mm. The estimated continuous length of air coated layer at σ_c = 0.0005 corresponds to the submerged cutting results shown in Figure 6, i.e. the relative cutting depth $h_{submerged}$ / $h_{In\text{-}air}$ = 1 for *X/d* = 26 (*X'* = 10 mm) but $h_{submerged}$ / $h_{In\text{-}air}$ = 0.8 for *X/d* = 56 (*X'* = 40 mm).

4 CONCLUSIONS

Cutting tests by ASJs in air and submerged conditions are conducted with specimens of aluminium alloy. High-speed observations of water jets issuing from the sheathed nozzle with ventilation are also conducted to clarify the unsteady behaviour of the air coated jets under submerged condition. The main conclusions are as follows :

(1) The cutting capability of air coated ASJs is arranged properly by introducing the relative cutting depth $h_{submerged}$ / $h_{In\text{-}air}$ and the cavitation number σ_c based on the cavity pressure i.e., $h_{submerged}$ / $h_{In\text{-}air}$ depends only on *X/d* and σ_c.

(2) Air coated layer tends to pulsate periodically with lower frequency when the air supply rate Q_{air} increases. Continuous length of air coated layer of the submerged ASJs can be estimated by the observations of air coated water jets just downstrem of the sheath exit.

REFERENCES

[BRANDT 1995] Brandt, C., Louis, H., Meier, G. And Tebbing, G. Fields Of Application For Abrasive Water Suspension Jets Of Pressure From 15 To 200 Mpa. In: Proceedings Of 8th American Water Jet Conference, Paper 15, 1995, Pp 207-217.

[Hung 2004] Hung, T.N., Louis, H., Peter, D. and Senne, T. Submerged application of abrasive water suspension jets (AWSJs). In: International Conference on Water Jetting 17, BHR Group, Mainz, Germany, September 2004, pp 205-216. ISBN 1-85598-0592

[Ito 2012] Ito, H., Peng, G. and Shimizu, S. Characteritics of experimental ASJ system. Journal of Jet Flow Engineering, 2012, Vol. 29, No. 1, pp 4-11, in Japanese.

[Shimizu 1996] Shimizu, S. 1996. Effect of nozzle shape on structure and drilling capability of premixed abrasive water jets. In: International Conference on Jetting Technology 13, BHR Group, 1996, pp 13-26. ISBN 1-86058-0114

[Shimizu 2002] Shimizu, S., Nishiyama, T., Shimura, T. and Omote, T. Drilling capability of submerged abrasive water suspension jet. In: International Conference on Water Jetting 16, BHR Group, Aix-en-Provence, France, October 2002, pp 509-520. ISBN 1-85598-0428

[Shimizu 2010] Shimizu, S., Sakuma, M., Hitomi, K. and Peng, G. Submerged cutting by abrasive suspension jet issuing from sheathed nozzle with ventilation. In: International Conference on Water Jetting 20, BHR Group, Graz, Austria, October 2010, pp 435-441. ISBN 9781-85598-1225

[Shimizu 2015] Shimizu, S., Nishikata, H., Peng, G., Oguma, Y. Submerged cutting characteristics of abrasive suspension jet. Transaction of the JAME, 2015, Vol. 81, No. 831, pp 15-00361. ISSN 2187-9761, in Japanese.

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