2009 American WJTA Conference and Expo
August 18-20, 2009 ● Houston, Texas
Paper

PULSATION OF ABRASIVE WATER-JET

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ABSTRACT

In order to clarify the unsteady behavior of abrasive water-jets, high-speed observations of abrasive water-jets are conducted using high-speed video. The maximum frame rate of the camera is 190,000 frames per second. The injection pressure is in the range from 100 to 300 MPa, and the abrasive is garnet having a mesh designation of #80. The abrasive mass flow rate is up to 600 g/min. A jet pulsation is observed when the abrasive mass flow rate is relatively large. The jet expands periodically just downstream of the focusing nozzle exit, and humps of the jet develop into large lumps of water droplets. The flow conditions in the abrasive supply tube just upstream of the mixing chamber of the abrasive nozzle head are also observed by high-speed video. Image analyses of the videos show that the pulsation of an abrasive water-jet at a frequency of less than 100 Hz is closely related to the fluctuation of the abrasive supply to the nozzle head.

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1. INTRODUCTION

In the last quarter century, abrasive water jets (AWJs) have been established as a cutting technique for industrial machining. Abrasive water jets can be categorized as abrasive injection jets (AIJs) and abrasive suspension jets (ASJs) based on the generation mechanism and the phase composition.(1) An AIJ consists of solid particles, air, and water and is considered to be a three-phase jet flow. In contrast, an ASJ consists of solid particles and water and it is considered to be a two-phase jet flow.

Abrasive injection jets are widely used for practical applications and the cutting capability of AIJs in air has been investigated extensively.(1) In regard to the flow structure of AIJs, Geskin et al.(2) performed high-speed observations of AIJs and reported that the flow was composed of a jet surrounded by an array of droplets and particles and that the jet was subjected to violent oscillations, both transversal and longitudinal. Himmelreich(3) conducted photographic observations of AIJs and reported that the jet diameter increased significantly as the abrasive mass flow rate increased. Shimizu et al.(4) conducted high-speed observations of AIJs and drilling tests at injection pressures of 50 and 100 MPa. They reported that excessive abrasive flow rate caused violent pulsation of the jet and reduced the drilling capability. Geskin(5) believed that the mechanism of the pulsations of AIJs were such that the pulsations originated as a result of water jet instability and were enhanced by the entrained particles. However, the detailed characteristics of the jet pulsations have not yet been clarified sufficiently.

In the present investigation, high-speed observations of AIJs are conducted at the injection pressure range of from 100 to 300 MPa. The abrasive is #80 garnet, and the abrasive mass flow rate is up to 600 g/min. The flow conditions in an abrasive supply tube just upstream of the mixing chamber of the abrasive nozzle head are also observed by high-speed video. Image analyses of the videos are conducted in order to clarify the relationship between the jet pulsation and the fluctuation of the abrasive supply to the nozzle head.

2. EXPERIMENTAL APPARATUS AND CONDITIONS

Observations of the jets are conducted using the water jet machining system shown in Fig. 1. High-pressure water is supplied from an intensifier pump to an AWJ nozzle head at the injection pressure range of from 100 to 300 MPa. The jet discharges vertically into the catcher tank. The dimensions of the AWJ nozzle head are as follows:

Diameter of the water jet orifice:	0.30 mm
Diameter of the focusing nozzle:	1.0 mm
Length of the focusing nozzle:	76 mm

Abrasive is supplied to the nozzle head by a vibratory feeder through an abrasive supply tube of approximately 4.5 m in length and 5 mm in diameter. The abrasive used in the experiments is garnet having a mesh designation of #80.

Abrasive injection jets are observed using a high-speed video camera, Phantom Ver. 7.2. The maximum frame rate is 190,000 frames per second, and the minimum exposure time is 2 μs.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows a series of photographs of an AIJ issuing from the AWJ nozzle head at an injection pressure p_i of 300 MPa and a time averaged abrasive mass flow rate M_a of 600 g/min. The time interval between frames is 12.29 μs, and the flow direction is downward. Frame numbers are indicated on the top of each photograph. At frame number 1, the jet spreads radially just downstream of the focusing nozzle exit. As time proceeds, the hump of the jet develops into a large lump and moves downstream while growing in the streamwise direction. As the lump leaves the focusing nozzle exit at frame number 10, another hump of the jet appears just downstream of the focusing nozzle exit.

Figure 3 shows the relationship between the time averaged jet diameter D_{ave} and the standoff distance x measured from the focusing nozzle exit for the injection pressure p_i of 300 MPa. The time averaged jet diameters D_{ave} are obtained from approximately 29,000 high-speed video images. With the increase of the standoff distance x, D_{ave} increases linearly. The jet diameter D_{ave} increases significantly when the abrasive-mass flow rate increases, as reported by Himmelreich(3).

The time variations of the jet boundaries are obtained by the high-speed video for the jets at p_i = 300 MPa. Pixels of the jet high-speed video images at x = 7 mm are arranged in time series. Figures 4(a) through 4(d) are time series images of the jets at time averaged abrasive mass flow rates M_a of 150, 300, 450, and 600 g/min. The width of the black band corresponds to the instantaneous jet diameter. When M_a is relatively small, the jet tends to expand intermittently, as shown Fig. 4(a). With increasing M_a, the jet tends to pulsate periodically, as shown in Fig. 4(b). As M_a increases further, the durations of large jet diameter periods increase, as shown in Figs. 4(c) and 4(d).

Flow conditions in the abrasive supply tube just upstream of the mixing chamber of the AWJ nozzle head are observed by high-speed video. Figure 5 shows an example of instantaneous photographs of the flow in the abrasive supply tube for p_i = 300 MPa and M_a = 300 g/min. Abrasive particles in the tube are observed as black grains. The number density of abrasive particles changes with time. Pixels of the images in the tube 2 mm upstream of the abrasive port, which is indicated by the white line in Fig. 5, are arranged in time series to visualize the time fluctuation of the abrasive supply. Figures 6(a) through 6(d) show time series images of the flow in the abrasive supply tube for p_i = 300 MPa and M_a = 150, 300, 450, and 600 g/min. Black stripes in the images represent dense abrasive supply periods. When M_a = 150 g/min, as shown in Fig. 6(a), the dense abrasive supply period is intermittent, and its frequency is low. With the increase of M_a, the frequency of the dense abrasive supply increases, as shown in Fig. 6(b). With the further increase of M_a, the duration of the dense abrasive supply period is extended, as shown in Figs. 6(c) and 6(d). These tendencies correspond to the time variations of the jet boundaries shown in Fig. 4.

In order to examine the relationship between the jet pulsation and the fluctuation of the abrasive supply to the nozzle head, the averaged gray levels in the radial direction of the jets at different standoff distances x and averaged gray levels of the flow in the abrasive supply tube at 2 mm upstream of the nozzle head, as indicated by the white line in Fig. 5, are obtained from high-speed videos. In the present high-speed videos, a gray level of 0 corresponds to black, and a gray level of 255 corresponds to white. Accordingly, a lower gray level in the radial direction of the jets corresponds to a larger jet diameter, and a lower gray level of the flow in the abrasive supply tube corresponds to a dense abrasive supply. An example of a time series of the averaged gray level in the radial direction of the jet and its power spectrum are shown in Figs. 7 and 8 for a jet in which p_i = 300 MPa and M_a = 300 g/min. The standoff distance x is 7 mm. Figures 9 and 10 show an example of a time series of averaged gray levels of the flow in the abrasive supply tube at 2 mm upstream of the AWJ nozzle head and its power spectrum. Note that the time series of the averaged gray level of the jet shown in Fig. 7 and the time series of the averaged gray levels of the flow in the abrasive supply tube shown in Fig. 9 are not synchronous. The dominant frequencies of the flow in the abrasive supply tube and that of the jet gray level are 21 and 20 Hz, respectively. In the range of 50 to 100 Hz, the jet gray level component of 73 Hz is enlarged, as shown in Fig. 8. The corresponding frequency of the abrasive supply tube gray level is also enlarged. The pulsation of an abrasive water-jet at a frequency of less than 100 Hz is closely related to the fluctuation of the abrasive supply to the nozzle head.

4. CONCLUSIONS

High-speed observations of abrasive water injection jets were conducted at the injection pressure range of from 100 to 300 MPa. The abrasive was #80 garnet, and the abrasive mass-flow rate was up to 600 g/min. The flow conditions in the abrasive supply tube just upstream of the mixing chamber of the abrasive nozzle head were also observed by high-speed video. Image analyses of the videos were conducted in order to clarify the relationship between the jet pulsation and the fluctuation of the abrasive supply to the nozzle head. The findings of primary interest are as follows:

(1) When the abrasive mass-flow rate is relatively small, the jet tends to expand intermittently. With increasing abrasive mass-flow rate, the jet tends to pulsate periodically. As the abrasive mass-flow rate increases further, the durations of large jet diameter periods increase.

(2) The pulsation of the abrasive water-jet at a frequency of less than 100 Hz is closely related to the fluctuation of the abrasive supply to the nozzle head.

5. ACKNOWLEDGEMENTS

The authors would like to thank Mr. O. Saito and Mr. S. Saito for their help in carrying out the image processing of the high-speed videos. The water jet machining system and the high-speed video were installed in 2006 with the support of Nihon University.

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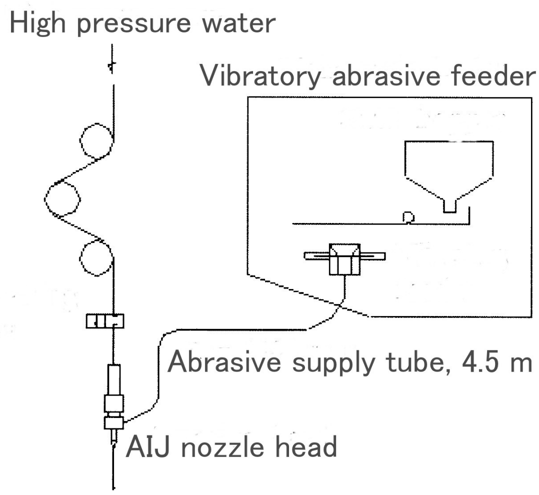


Figure 1: Schematic diagram of the water jet machining system

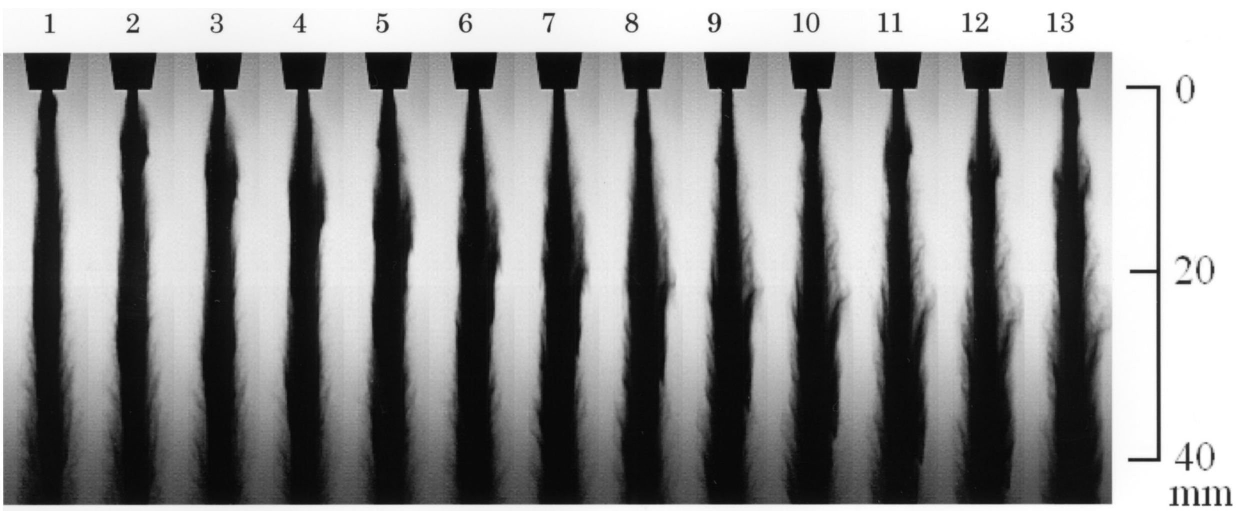


Figure 2: Time series of photographs of AIJ (p_i = 300 MPa and M_a = 600 g/min)

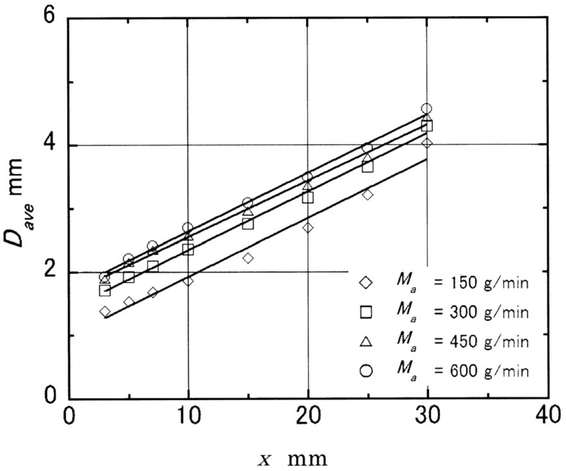
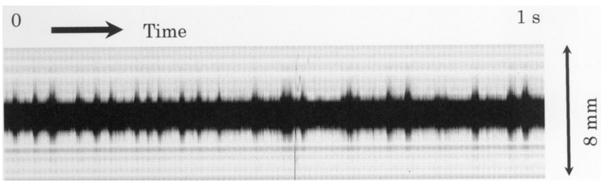
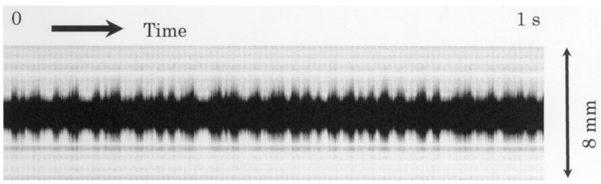


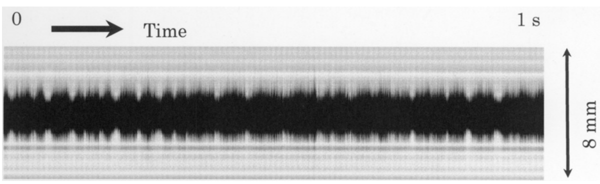
Figure 3: Variation of time averaged jet diameter with standoff distance (p_i = 300 MPa)



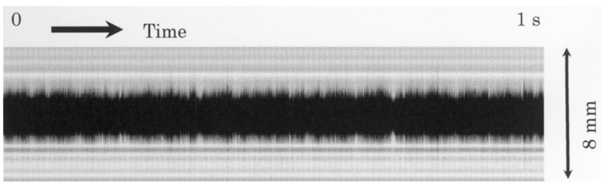
(a) M_a = 150 g/min



(b) M_a = 300 g/min



(c) M_a = 450 g/min



(d) M_a = 600 g/min

Figure 4: Time series image of the jet boundary at x = 7 mm and p_i = 300 MPa

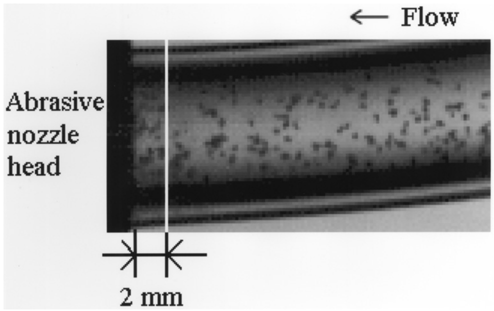


Figure 5: Flow in the abrasive supply tube (p_i = 300 MPa and M_a = 300 g/min)

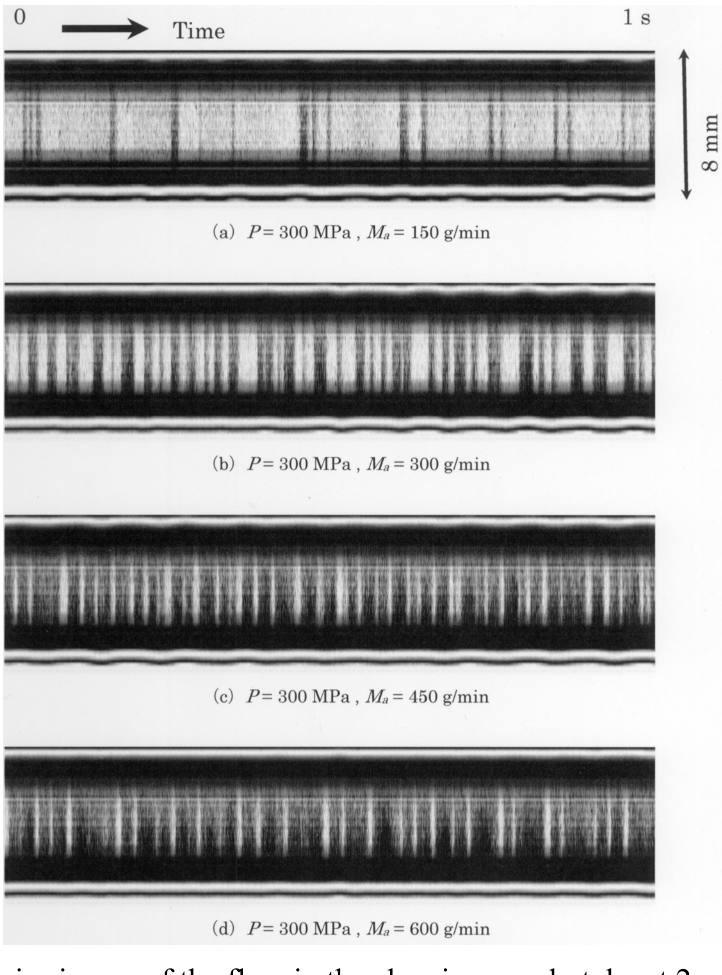


Figure 6: Time series image of the flow in the abrasive supply tube at 2 mm upstream of the abrasive port (p_i = 300 MPa)

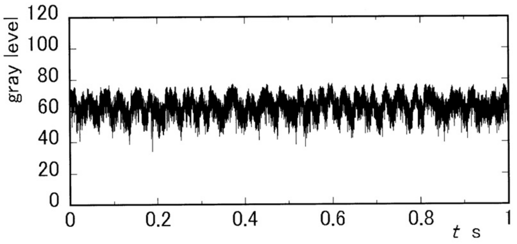


Figure 7: Time variation of the jet gray level at 7 mm downstream of the focusing nozzle exit (p_i = 300 MPa and M_a = 300 g/min)

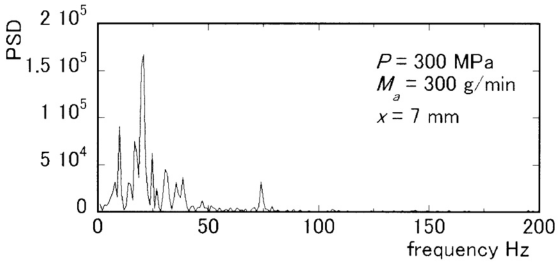


Figure 8: Power spectrum of the jet gray level at 7 mm downstream of the focusing nozzle exit (p_i = 300 MPa and M_a = 300 g/min)

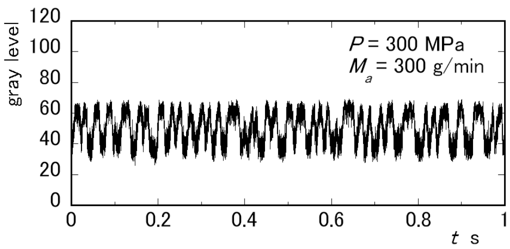


Figure 9: Time variation of the gray level in the abrasive supply tube at 2 mm upstream of the abrasive port (p_i = 300 MPa and M_a = 300 g/min)

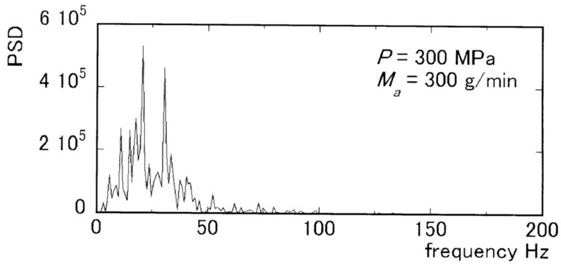


Figure 10: Power spectrum of the gray level in the abrasive supply tube at 2 mm upstream of the abrasive port (p_i = 300 MPa and M_a = 300 g/min)