Measurement of Velocity Field of an Abrasive Fan Jet by PIV

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Abstract Water jets issuing from a fan jet nozzle (Fan Jets: FJs) are widely used in cleaning, decontamination of radiological substances, and removal of plasma spray coating and asbestos. The material removal performance of abrasive suspension jets issuing from a fan jet nozzle (Abrasive Fan Jets: AFJs) are much higher than that of FJs. In the present study, flow structure and velocity distribution of AFJs are investigated by using PIV method to clarify the material removal characteristics of AFJs.

Keywords PIV · Water jetting technology · Flow visualization
Abrasive fan jet · Fan jet

1 Introduction

Water jets issuing from a fan jet nozzle (Fan Jets: FJs) are widely used in cleaning, decontamination of radiological substances, and removal of plasma spray coating and asbestos. The material removal performance of abrasive suspension jets issuing from a fan jet nozzle (Abrasive Fan Jets: AFJs) is much higher than that of FJs [1].

There are some reports on AFJ and FJ. Xu and Summers [2] and Shimizu et al. [3] have investigated the flow structure and erosion characteristics of FJs at a high injection pressure. Shimizu et al. [4] have investigated the flow structure of AFJ and FJ. Material removal characteristics of AFJ was related to the standoff distance and the traverse velocity. Particle image velocimetry (PIV) has been used to measure velocity distribuiton of FJs [5–7]. However, the velocity distribuiton of AFJs have not been clarified sufficiently.

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In the present study, the flow structure and velocity distribuiton of AFJs are investigated by using PIV method to clarify the material removal characteristics of AFJs.

2 Experimental Apparsatus

As shown in Fig. 1, the FJ nozzle used in the present experiments has an elliptical outlet hole in a triangular notch on the outlet face. The major and minor axes of the nozzle are 1.37 and 0.72 mm, respectively. The equivalent diameter of nozzle is approximately $d_e = 1$ mm.

Figure 2 shows the experimental PIV system used to measure the velocity distributions of AFJs and FJs. AFJ and FJ are formed using an abrasive suspension jet (ASJ) system. Detailed information of the ASJ system used in this study can be found in a previous study by Shimizu et al. [8]. In the case of AFJ, a high-pressure slurry is generated in the mixing unit of the pressure vessel by discharging high pressure water and stirring up abrasive particles. High-pressure slurry is discharged from the nozzle head. In the cases of FJ, only water are filled in the pressure vessel. The injection pressures P_i are 10 MPa for both cases. Abrasive used in the experiments is garnet having a mesh designation of #220. Abrasive concentration and density of abrasive slurry are calculated from the measured volume and mass of slurry collected using a pipe catcher. Average abrasive concentration is 12.7 wt%. Density of average abrasive slurry is 1,078 kg/m^3 during observation of the AFJ. The velocity distribuitons of the AFJs and the FJs are measured using a high-speed CMOS camera and a laser light sheet system. Tracer particles, such as nylon particles, are not used in these measurements; instead, water droplets, lumps and abrasive particles are used as tracers. Observation area of the high-speed

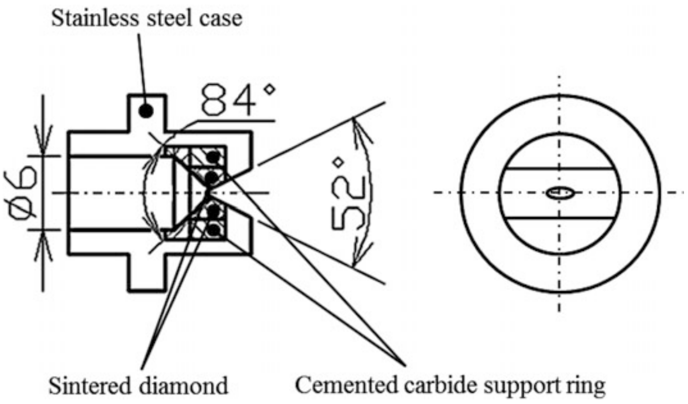

Fig. 1 Fan jet nozzle

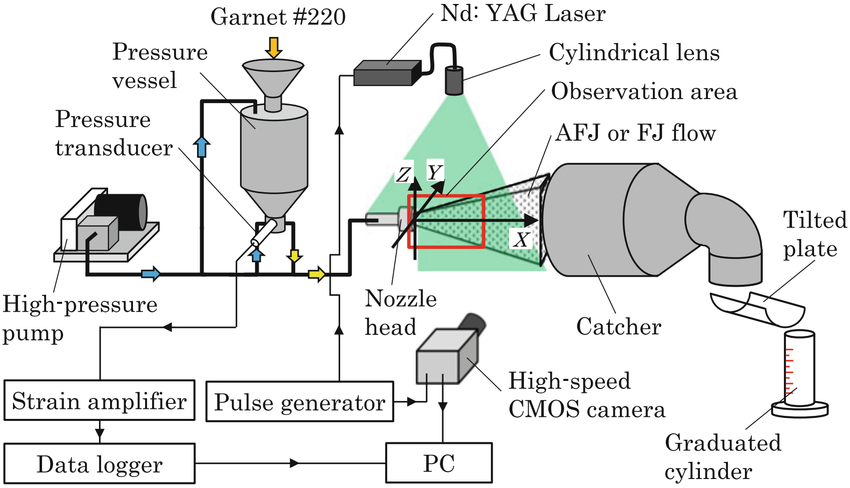

Fig. 2 Experimental setup

CMOS camera is in the region the near nozzle head (image area: 108 mm × 108 mm).

Origin of the coordinate system is on the nozzle outlet plane and *X*-, *Y*-, *Z*-axis are taken on the jet center axis, the nozzle minor axis, and the major axis, respectively. The instantaneous velocity component of *X*, *Y* and the *Z*-direction is designated by u, v, w respectively. A laser light sheet with a thickness of approximately 2 mm is used to illuminate the jet cross-section vertical to the *XY*-plane along the *X*-axis.

3 Results and Discussion

3.1 Instantaneous Visualization and Velocity Distributions

Figure 3 shows the instantaneous images and velocity distributions of (a) AFJ and (b) FJ. Irregular reticulated structures are observed from nozzle exit to the region further downstream of AFJ and FJ. In the case of AFJ, the reticulated pattern appears to be dominated by the *Z*-directional structures. In the case of FJ, the irregular reticulated structure pattern appears to be dominated by the *X*-directional structures. The magnitude of instantaneous velocity is defined by $V = (u^2 + w^2)^{1/2}$. The velocity vectors of AFJ and FJ are nearly constant in *Z*-direction.

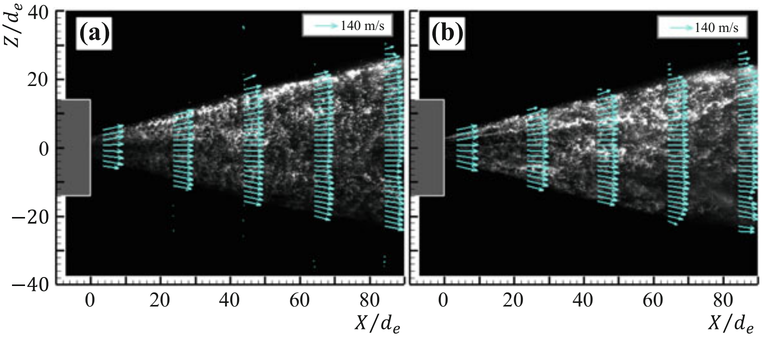

Fig. 3 Instantaneous visualization images and velocity distribuitons: **a** AFJ, **b** FJ

3.2 Time Average Velocity and Velocity Fluctuation Distribuitons

Figure 4a, b show the time-averaged velocity and the root-mean-square of velocity fluctuation distribuitons normalized by the theoretical jet velocity V_{th} at different locations along the X/d_e-axis. The theoretical issuing velocity V_{th} is calculated by Bernoulli's equation using injection pressure and the fluid density (water or abrasive slurry). The theoretical jet velocity V_{th} of the AFJ and the FJ are 137 m/s and 141 m/s respectively. The time average velocity distributions are obtained in the upper side of the AFJ and the FJ ($Z/d_e = 0–40$) because liquid droplets and abrasive particles are clearly observed at this area.

Generally the non-dimensional time averaged velocity distributions $\bar{u}/V_{th}$ and $\bar{w}/V_{th}$ of the AFJ are almost the same as the those of FJ. In the central part of the jets, the time averaged velocities $\bar{u}/V_{th}$ remain nearly constant with varying Z/d_e. The time averaged velocities $\bar{w}/V_{th}$ are largest at the outer edge of the jets and reach maximums of approximately 0.2. The non-dimensional velocity fluctuation distributions u_{rms}/V_{th} and w_{rms}/V_{th} of the AFJ are almost the same as the those of FJ. The velocity fluctuation distributions u_{rms}/V_{th} and w_{rms}/V_{th} near the outer edge of the jet are large, but are small in the central part of the jets.

It is known that velocity fluctuation also differs when the flow structure is different. However, instantaneous visualization image of AFJ and FJ in the Fig. 3 show completely different flow structures mutually. In the past research, fractal analysis was used to evaluate flow structure of FJ [9]. Fractal analysis quantitatively evaluates flow structure. Evaluation of the flow structure of AFJ and FJ by this fractal analysis will be the future subjects.

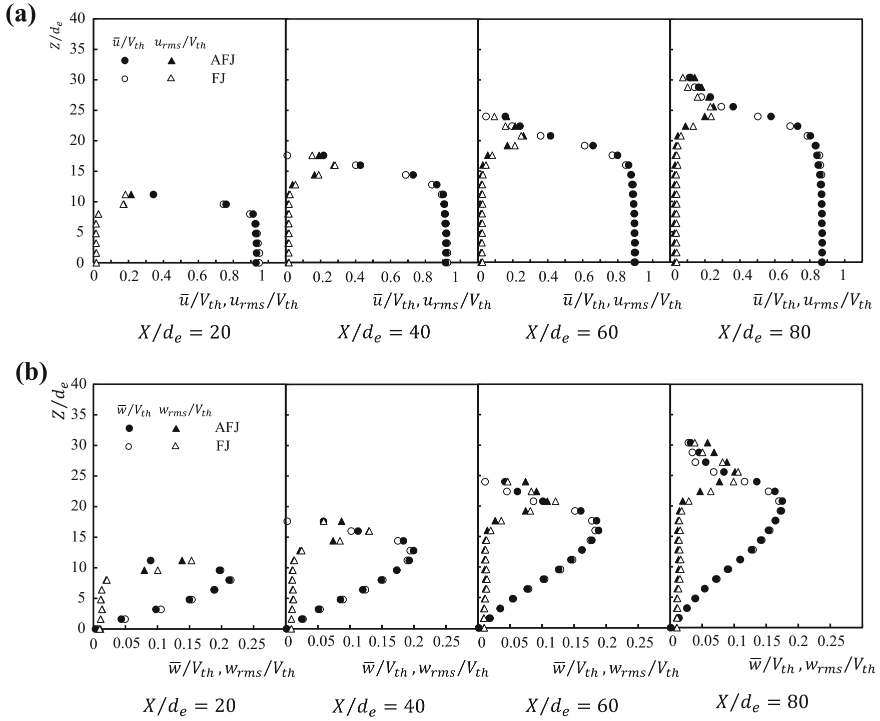

Fig. 4 Distribuitons of dimensionless time averaged velocity components and velocity fluctuation: **a** $\bar{u}/V_{th}$, u_{rms}/V_{th} and **b** $\bar{w}/V_{th}$, w_{rms}/V_{th} at different standoffs

4 Conclusions

In this study, flow structure and velocity distribuiton of an AFJ have been investigated using PIV method to clarify the material removal characteristics of AFJ. The main conclusions are given as follows.

1. The flow patterns of AFJ and FJ are different. Particularly, in the case of AFJ, irregular reticulated structures are observed at the nozzle exit.
2. The normalized velocity ($\bar{u}/V_{th}$ and $\bar{w}/V_{th}$) and velocity fluctuation (u_{rms}/V_{th} and w_{rms}/V_{th}) of AFJ shows almost the same as those of FJ.

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