Chapter - 7

Numerical Analysis on the Effect of the Operating Pressure on Wall Shear Stress and Jet Kinetic Energy

A parametric based numerical analysis is carried out in this chapter with the operating parameter being inlet pressure. The effect of this operating parameter on the erosion characteristics of the inside wall of the nozzle as well as useful exit jet force is analysed with respect to output parameters, the wall shear stress and exit jet kinetic energy respectively.

7.1 Introduction

In AWJ machining, the inlet operating pressure of the flow is one of the critical input parameters which will have significant impact on the depth of penetration and kerf geometry produced on the work piece. The effect of this parameter on wall shear stress and exit jet kinetic energy developed by the nozzle is studied by using CFD analysis. The operating conditions used for this part of the analysis are shown in the Table 7.1. The inlet operating pressure is varied to establish its effect on wall shear stress and jet exit kinetic energy. The geometric detail of the nozzle in which numerical simulations are carried out is shown in Figure 6.2. The results obtained are discussed in the following sections.

Table 7.1 Operating conditions for numerical simulation

<table>
<thead>
<tr>
<th>Operating parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of abrasive</td>
<td>2300 kg/m³</td>
</tr>
<tr>
<td>Size of the abrasive</td>
<td>63 µm (#230)</td>
</tr>
<tr>
<td>Abrasive volume fraction</td>
<td>10 %</td>
</tr>
<tr>
<td>Inlet diameter of nozzle</td>
<td>4.0 mm</td>
</tr>
<tr>
<td>Exit diameter of nozzle</td>
<td>1.3 mm</td>
</tr>
</tbody>
</table>
7.2 Effect of inlet pressure on average exit kinetic energy of the jet

The inlet operating pressure is varied from 20, 40, 80, 120, 150 MPa in each numerical simulation. The average exit kinetic energy is computed from surface integral of area-weighted average velocity over the control volume at the exit of the nozzle. The variation of average exit kinetic energy of the jet corresponding to various inlet operating pressures is shown in Figure 7.1. It is observed from figure that the jet exit kinetic energy increases linearly corresponding to inlet operating pressures. This is due to the fact that, the inlet operating pressure energy manifests itself as proportional amount of kinetic energy at the exit of the nozzle with viscous shear stress dissipation representing the loss of energy. The contour plots of steady state velocity distribution of the slurry flow consisting of a mixture of water and abrasive, through the nozzle are shown in Figures 7.2 (a), 7.3 (a) and 7.4 (a). The velocity gradually increases till the critical section is reached in the conical portion of the nozzle, followed by a fully developed velocity profile along the focus tube.

![Graph showing variation of average exit kinetic energy of the jet with inlet operating pressure](image)

Fig. 7.1 Variation of average exit kinetic energy of the jet with inlet operating pressure
Fig. 7.2 (a) Contour plot of jet velocity (m/s) at an inlet operating pressure of 40 MPa

Fig. 7.2 (b) Vector plot of jet velocity (m/s) at an inlet operating pressure of 40 MPa

Fig. 7.2 (c) Velocity distribution of AWJ at an inlet operating pressure of 40 MPa
Fig. 7.3 (a) Contour plot of jet velocity (m/s) at an inlet operating pressure of 80 MPa

Fig. 7.3 (b) Vector plot of jet velocity (m/s) at an inlet operating pressure of 80 MPa

Fig. 7.3 (c) Velocity distribution of AWJ at an inlet operating pressure of 80 MPa
Fig. 7.4 (a) Contour plot of jet velocity (m/s) at an inlet operating pressure of 150 MPa

Fig. 7.4 (b) Vector plot of jet velocity (m/s) at an inlet operating pressure of 150 MPa

Fig. 7.4 (c) Velocity distribution of AWJ at an inlet operating pressure of 150 MPa
Figures 7.2 (b), 7.3 (b) and 7.4 (b) shows the velocity vector plots to capture the nature of flow in the nozzle. It is clearly seen from the vector plots that flow is generally without much flow disturbances but peak values of velocity show a deviation. Figures 7.2 (c), 7.3 (c) and 7.4 (c) represent the plot of the axial velocity at three critical regions viz., (a) upstream section at 10% of the duct length from the critical section, (b) at critical section and (c) at 25% of the duct length downstream from the critical section. The velocity profiles taken across the cross section of the nozzle at the above mentioned three locations shows significant changes near the critical section. The velocity distributions also show flatter profile due to the high velocities representing turbulent flow within the nozzle. At the critical section near the wall it is possible to see an inflection. This is caused due to the sudden change in the velocity at the critical section. It may be observed from the contour plots 7.2 (a), 7.3 (a) and 7.4 (a) that, the maximum velocity or jet kinetic energy is found at the centre of the nozzle and it is reduced to zero at the vicinity of the wall boundary of the nozzle due no slip boundary condition.

Further, the net energy dissipated due to wall shear stress corresponding to various inlet operating pressure conditions is shown in Figure 7.5. It is seen from the figure that the viscous shear force dissipation is also proportional to various inlet operating pressure conditions. In addition, abrasive particles moving with the flow causes severe wall shear, which leads to erosion of inside surface of the nozzle resulting in decreased jet kinetic energy, there by affecting the performance of the nozzle for effective machining.

The net energy dissipated due to viscous shear is defined as,

\[
\text{Net energy dissipated due to viscous shear} = \text{Area weighted average of Inlet Operating Pressure Energy} - \text{Area weighted average of Jet Exit Kinetic Energy}
\]
Effect of inlet operating pressure on wall shear stress

Numerical simulations are carried out to study the effect of operating pressure on wall shear stress. The inlet pressure is varied from 20 - 150 MPa corresponding to the parameters which are maintained constant in the analysis as given in the Table 7.1. The variation of wall shear stress developed along the length of the nozzle corresponding to various inlet operating pressure conditions is shown in Figure 7.6. An interesting variation in wall shear stress occurs with a peak occurring at the critical section corresponding to the change in shape of the duct i.e., from conical to straight section. The interesting variation in wall shear stress as shown in Figure 7.6 can be explained as follows. It is well known that local wall shear stress is proportional to local Reynolds number of the flow or in other words, the corresponding velocity of flow. Thus, within conical portion of nozzle velocity increases rapidly with decrease in diameter and hence wall shear stress spikes up as shown in the graph.
As the fluid flow is yet to develop in the short conical tube, when the flow velocity changes rapidly at the critical section as explained, it is found from the graph that wall shear stress shows sharp fall. This is due the loss of flow energy due to sudden contraction. However, as the fluid moves further downstream into a well-developed flow field along the focus tube, the wall shear stress do not show much variation and remain almost constant as shown in the Figure 7.6. But at higher inlet operating pressures and hence correspondingly at higher kinetic energy conversions along the flow paths, higher wall shear stress would develop all along the wall corresponding to higher velocities. Hence there is higher level of wall shear stress at higher operating pressure, and conversely at lower operating pressure, wall shear stress will also be lower.

Fig. 7.6 Distribution of wall shear stress corresponding to various inlet operating pressures
Figures 7.7 (a), 7.7 (b) and 7.7 (c) show the contour graph of the distribution of wall shear stress at a critical portion of the nozzle for various operating pressures. As explained in Figure 7.6, it is seen that there is a sudden peak in wall shear stress near the critical section.

### 7.7 (a) Distribution of wall shear stress (N/m$^2$) near the critical section of the nozzle at an inlet operating pressure of 40 MPa

### 7.7 (b) Distribution of wall shear stress (N/m$^2$) near the critical section of the nozzle at an inlet operating pressure of 80 MPa

### 7.7 (c) Distribution of wall shear stress (N/m$^2$) near the critical section of the nozzle at an inlet operating pressure of 150 MPa
Fig. 7.8 (a) Distribution of total pressure near critical section of the AWJ nozzle at an inlet operating pressure of 40 MPa

Fig. 7.8 (b) Distribution of total pressure near critical section of the AWJ nozzle at an inlet operating pressure of 80 MPa

Fig. 7.8 (c) Distribution of total pressure near critical section of the AWJ nozzle at an inlet operating pressure of 150 MPa
Figure 7.8 (a), 7.8 (b) and 7.8 (c) shows the contour plots of total pressure change in the nozzle. As may be expected the total pressure drop is maximum for the higher operating pressure as shown in Figure 7.9. Generally, the total pressure change represents the fluid energy loss along the nozzle. It can be inferred from Figure 7.9 that a higher total pressure drop at a higher inlet operating pressure condition is due to a higher wall shear stress at a higher operating pressure as explained earlier.

7.9 Pressure drop across the AWJ nozzle at different operating pressures
7.4 Conclusions

From the results and discussions based on CFD simulation of the effect of operating pressure on wall shear stress and jet kinetic energy produced by AWJ nozzle, the following conclusions are deduced.

• Increase in inlet operating pressure results in significant increase in the wall shear stress. The wall shear stress approach peak values corresponding to the sudden change in the flow passage geometry at the critical section of the nozzle and it remains almost constant in the focus tube of AWJ nozzle.

• Increase in the inlet operating pressure results in linear increase in the average exit kinetic energy of jet.

• The net energy dissipated due to wall shear stress is also linearly proportion to the inlet operating pressure.