Chapter 8

Numerical Analysis on the Effect of Abrasive Parameters on Wall Shear Stress and Jet Exit Kinetic Energy

A parametric based numerical analysis is carried out in this chapter by varying abrasive concentration (volume fraction), size of the abrasive particle and abrasive type. The effect of these parameters on the erosion characteristics on the inside wall of the nozzle as well as on useful exit jet force are analysed with respect to output parameters viz., the wall shear stress and exit jet kinetic energy respectively.

8.1 Introduction

In AWJ machining, the capability of machining generally depends on abrasive parameters such as abrasive concentration (volume fraction), size of the abrasive particle and abrasive type. The selection of these parameters depends on the type of work piece being machined and the desired surface finish. Higher abrasive flow rate is always preferred as it leads to higher material removal rates and good kerf characteristics, but it may lead to adverse effects such as clogging of nozzle as well as reduction in jet energy due to inertial effect of mass, as well as inter-particulate collisions. Harder abrasive particles lead to higher material removal rate but they result in higher nozzle wear rate. In this section the effect of abrasive parameters in the flow is investigated on the wall shear stress developed on inside surface of the nozzle as well as exit jet kinetic energy produced by the nozzle and results obtained are discussed. CFD simulations are carried out on the AWJ nozzle (Figure 6.2) using different abrasives at an inlet operating pressure of 40 MPa. It is found from the analysis that garnet abrasive produced better jet kinetic energy for effective machining. Hence, garnet abrasive is selected for further analysis with respect to abrasive concentration and size.
8.2 Effect of the type of abrasive particles on wall shear stress

In AWJ machining abrasive particles which are commonly used are garnet, aluminium oxide and silicon carbide. The choice of suitable abrasive is mainly dependent on mechanical properties of the target materials being machined. The type of abrasive chosen possesses different machining as well as nozzle flow characteristics. The effect of these abrasive particles on wall shear stress is investigated at abrasive volume fraction of 10%, inlet operating pressure is maintained at 40 MPa and the average size of the abrasive particles is taken to be 63 µm. The wall shear stress developed along the length of the nozzle corresponding to different types of abrasive particles is shown in Figure 8.1.

![Graph showing wall shear stress along nozzle length for different types of abrasives]

**Fig 8.1 Wall shear stress along the nozzle length for different types of abrasives**

It is observed from the Figure 8.1 that the highest wall shear stress is developed by garnet abrasives followed by aluminium oxide and silicon carbide abrasive particles. This is due to the effect of mass density of abrasive particles. The garnet abrasive possesses lowest density
of about 2300 kg/m$^3$ among the abrasives being investigated. For abrasives of higher density which are being investigated, there is a proportional loss in flow velocity due to mass inertial effects. This leads to reduction in flow velocity and thus the wall shear stress developed at the inside surface of the nozzle is also reduced.

Fig. 8.2 (a) Distribution of walls shear stress (N/m$^2$) produced by garnet abrasive particles in the flow near critical region of nozzle

Fig. 8.2 (b) Distribution of walls shear stress (N/m$^2$) produced by aluminium oxide abrasive particles in the flow near critical region of nozzle

Fig. 8.2 (c) Distribution of walls shear stress (N/m$^2$) produced by silicon carbide abrasive particles in the flow near critical region of nozzle
In the present analysis, peak value of wall shear stress exhibited by garnet abrasive is 354 kN/m², aluminium oxide abrasive is 326 kN/m² and silicon carbide abrasive is 298 kN/m². The contour plot of peak wall shear stress near critical section of the nozzle corresponding to use of these abrasives is shown in Figure 8.2 (a), 8.2 (b) and 8.2 (c).

8.3 Effect of the type of abrasive particles on jet exit kinetic energy

Analysis is carried out to investigate the magnitude of jet exit kinetic energy produced corresponding to the use of abrasive particles such as garnet, aluminium oxide and silicon carbide. The jet kinetic energy is determined from surface integral of area weighted average velocity at exit of the nozzle. The maximum jet kinetic energy produced by each of the chosen abrasive type at 10% volume fraction and operating pressure of 40 MPa is shown in Figure 8.3. It is observed that the jet energy produced by the use of garnet abrasive particle is higher than the jet energy produced by other abrasive particles of the study.

![Fig. 8.3 Jet exit kinetic energy produced by different types of abrasives](image-url)
This is due to the fact that, among the type of abrasive particles being investigated, the garnet abrasive particle possesses lowest density followed by aluminium oxide and the silicon carbide abrasive particles. As explained earlier, increase in density of abrasives results in flow losses due to mass inertial effect while transporting the abrasives in the flow. Since the garnet abrasive possesses lowest density among the abrasive particles being investigated, it produces relatively higher jet exit kinetic energy. Hence, increase in the density of abrasive particles lead to corresponding decrease in the jet kinetic energy as depicted in the Figure 8.3. From the present analysis it is found that garnet abrasive produced 7.39 % higher jet kinetic energy compared to silicon carbide abrasives. Hence, in the analysis that follows in the next section regarding the effect of abrasive volume fraction and particle size on wall shear stress and exit jet kinetic energy, garnet is used as the abrasive material.

8.4 Effect of volume fraction of garnet abrasive particle on wall shear stress

The numerical simulations are carried out at abrasive volume fractions of 5, 10 and 15%. The abrasive volume fraction (\(v_f\)) is defined as the volume ratio of abrasive particles to the water in the flow. The wall shear stress developed on inside surface of the nozzle at different abrasive volume fractions is shown in Figure 8.4. It is seen that the wall shear stress increase with reduction in volume fraction of abrasive particles along the length of the AWJ nozzle. Wall shear stress attains a peak value at critical section of nozzle where cross section of the nozzle changes from conical to straight portion and there after remains almost constant along the straight focus section of the nozzle. This pattern of variation remains the same for change in volume fraction of abrasive particles. The peak wall shear stress developed in the nozzle at different volume fraction of abrasives is shown in Figure 8.5. It is seen that, the increase in volume fraction of abrasives in suspension mixture results in decrease in wall shear stress. This is due to the fact that, increase in volume fraction of abrasive particles results in
increased concentration of abrasives in the suspension slurry. Hence, there is increased fluid energy loss in transporting these abrasive particles, leading to a decrease in kinetic energy of the jet resulting in decreased jet exit velocity. In addition, the increase in number of abrasive particles in the flow would also promote inter-particulate collisions in random directions, resulting in increased turbulence in the flow, which further reduce the flow velocity. Due to the above cited reasons, it is found that there is a reduction in wall shear stress along the wall of the nozzle with increased abrasive concentration. The wall shear stress is found to be decreased by 17.45% for abrasive volume fraction of 15% when compared to abrasive volume fraction of 5%. The wall shear stress developed at the critical section of the nozzle with respect to various abrasive volume fractions is shown in Figure 8.6 (a), 8.6 (b) and 8.6 (c).

Fig. 8.4 Effect of volume fraction on wall shear stress along the length of the nozzle
Fig. 8.5 Effect of volume fraction on peak wall shear stress at the critical section of the nozzle at inlet operating pressure 40 MPa

8.6 (a) Distribution of wall shear stress (N/m$^2$) at critical region of nozzle ($v_f = 5\%$)

8.6 (b) Distribution of wall shear stress (N/m$^2$) at critical region of nozzle ($v_f = 10\%$)
8.6 (c) Distribution of wall shear stress (N/m²) at critical region of nozzle (v_f = 15 %)

8.5 Effect of volume fraction of abrasive particles on jet exit kinetic energy

The average jet exit kinetic energy is computed from area-weighted average velocity of surface integral over the control volume at exit of the nozzle. The variation of average exit kinetic energy of the jet corresponding to different volume fractions of abrasive particles is shown in Figure 8.7.

![Figure 8.7](image)

Fig. 8.7 Effect of volume fraction on average exit kinetic energy of the jet
It is observed from the figure that there is a marginal decrease in jet exit kinetic energy with increase in volume fraction of abrasive particles. As explained previously, higher the concentration of abrasive particles in the fluid, higher is the fluid inertial resistance while transporting these abrasive particles that lead to reduction in exit velocity. Hence there is a corresponding decrease in jet kinetic energy with increase in volume fraction of abrasive particles. The jet energy is found to be reduced by 6.01 % and 10.04 % for an increase in abrasive volume fraction by 10 % and 15 % respectively.

8.6 Effect of abrasive particle size on wall shear stress  
Numerical simulations are carried out to study the effect of abrasive particle size on jet exit kinetic energy and wall shear stress exerted on inside surface of the nozzle. In AWJ machining, the average size of the abrasive particles is expressed in mesh number which is determined by standard Taylor sieve analysis method. In the present numerical analysis, the size of the abrasive particle is varied at mesh size of 50, 60, 80, 140 and 230. In this numerical simulation to evaluate the effect of abrasive particle size on wall shear stress, the inlet operating pressure, density of abrasive particle, abrasive volume fraction and nozzle dimensions are fixed at suitable level as shown in the Table 8.1. The equivalent size of abrasive particles in microns is given in Table 8.2.

<table>
<thead>
<tr>
<th>Table 8.1 Operating conditions used for numerical simulations</th>
</tr>
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<tbody>
<tr>
<td>Operating parameters</td>
</tr>
<tr>
<td>Density of abrasive</td>
</tr>
<tr>
<td>Inlet operating pressure</td>
</tr>
<tr>
<td>Abrasive volume fraction</td>
</tr>
<tr>
<td>Inlet diameter of nozzle</td>
</tr>
<tr>
<td>Exit diameter of nozzle</td>
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</tbody>
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Table 8.2 Conversion chart for mesh number to microns

<table>
<thead>
<tr>
<th>Mesh number (µm)</th>
<th>50</th>
<th>60</th>
<th>80</th>
<th>140</th>
<th>230</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size in µm</td>
<td>297</td>
<td>250</td>
<td>177</td>
<td>105</td>
<td>63</td>
</tr>
</tbody>
</table>

The wall shear stress developed for abrasive particles of different sizes in the flow along the length of the nozzle is shown in Figure 8.8. It is observed from the figure that there is almost no variation in wall shear stress distribution for the abrasive particles of finer diameter chosen. The inertial effect of mass of the abrasive particles on the through flow is insignificant and hence do not contribute to any significant changes in the velocity of the AWJ. For the coarser abrasive particles of size 297 µm, a perceptible inertial effect of the abrasive particles can be foreseen as shown in Figure 8.8. The inertia of the flowing abrasive particles causes lowering of the velocity of the flow field and hence contributing to a decreased wall shear stress. However, the velocity drop is less than 1.8%.

Fig. 8.8 Wall shear stress developed by abrasive particles of various sizes along the length of the AWJ nozzle
The peak wall shear stress produced near the critical section of the nozzle for different abrasive particle sizes is shown in Figure 8.9 (a), 8.9 (b) and 8.9 (c).

8.9 (a) Distribution of wall shear stress (N/m²) near critical section of the nozzle at abrasive size of 297 µm

8.9 (b) Distribution of wall shear stress (N/m²) near critical section of the nozzle at abrasive size of 177 µm

8.9 (c) Distribution of wall shear stress (N/m²) near critical section of the nozzle at abrasive size of 63 µm
8.7 Effect of abrasive particle size on average exit kinetic energy of the jet

Figure 8.10 shows the distribution of the jet kinetic energy produced in AWJ by garnet abrasive particles of different sizes. The size of the abrasive particles is varied as shown in Table 8.2 and the operating pressure is maintained constant at 40 MPa in all numerical simulations. It is observed from the Figure 8.10 that, the effect of abrasive size on jet kinetic energy is not significant. Within the chosen range of abrasive particles sizes, the variation in the jet kinetic energy is observed to be lesser than 1.79%. However, it is seen that an increase in the size of abrasive particle leads to marginal decrease in the jet kinetic energy. This is due to the increase in loss of kinetic energy while transporting the abrasive particles of higher size. The contour plots of velocity distribution of AWJ with the use of abrasive particles of different sizes are shown in Figure 8.11 (a), 8.11 (b) and 8.11 (c).

![Graph showing variation of average exit kinetic energy of the jet with abrasive size](image)

**Fig. 8.10 Variation of average exit kinetic energy of the jet with abrasive size**
8.11 (a) Velocity profiles (m/s) of AWJ at particle size of 297 µm

8.11 (b) Velocity profiles (m/s) of AWJ at particle size of 177 µm

8.11 (c) Velocity profiles (m/s) of AWJ at particle size of 63 µm
8.8 Conclusions

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

• For the same operating parameters, increase in the abrasive volume fraction (concentration) results in significant decrease in the wall shear stress as well as the jet exit kinetic energy.

• Increase in the abrasive particle size results in marginal decrease in the wall shear stress and jet exit kinetic energy.

• Increase in abrasive density results in decrease in wall shear stress and reduction in jet exit kinetic energy.

• Numerical simulation indicates that garnet abrasives produce better jet exit kinetic energy than aluminium oxide and silicon carbide.