

Abrasive flow modelling through active parts water jet machine using CFD simulation

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Abstract. This study has the main objective the flow modelling using CFD through active parts waterjet cutting machine, model YCWJ-380-1520. More precisely, the study of flow through the cutting head and estimate the erosion wear caused by abrasion of these parts. The active parts of cutting head are the body of head, high pressure nozzle with jewel and mixing tube made from wolfram carbide. On all these components has previously done measurement in order to create the geometrical model. The most wearing subjected parts water-jet machine are the water nozzle and mixing tube where the erosion wear is accelerated by the high velocity. In the first part of this study is presented the water flow model without regarding the abrasive inlet geometry, using Ansys FLOTRAN CFD. Has been considered three dimensions of water nozzle along with three dimensions of mixing tube in order to evaluate velocity variation at mixing tube outlet and how geometry influences outlet velocity. The second part of this paper is made using CFD software Ansys Fluent regarding a tridimensional geometry and a multiphasic flow. In the framework of flow model is established the abrasive particles velocity, difference of pressure inside tube, contour of streamlines, shear stress on the tube wall in order to accomplish the erosion rate during the process flow. It can be noticed that there are two main streamlines: first at the outlet of water nozzle and second from the inlet of abrasive material. Particles velocity is higher at the contact with water stream and lower at the end of cutting head because the difference of diameters between jewel and mixing tube. The maximum erosion rate is recorded where the shear stress are high values, that means to the interior wall of water nozzle and inlet of mixing tube. Pressure becomes high to the jewel of water nozzle and decreases in value toward at outlet of cutting head.

1. Introduction

The AWJ process is an erosive manufacturing method which causes important damage at active parts of waterjet machines. The aim of this paper is to make an analytical and experimental analysis of water flow throughout active parts of AWJ machine WUXI YCWJ-380-1520 and to estimate the erosion wear on these elements. The flowing model is made with finite element method CFD using Ansys FLUENT. The water jet machine is presented in figure 1 [4], and the cutting head along with the components is shown in figure 2. The geometrical model is accomplished by real measurements on the cutting head elements like: high pressure water nozzle, mixing tube and mixing chamber, considering these elements being the most intensive subjected to wear. The abrasive material used by the AWJ machine is garnet and the dimension of the particle is considered to be between 0.16mm and 0.2mm.





Figure 1. Photo of AWJ Machine WUXI YCWJ-380-X-1520 [4].

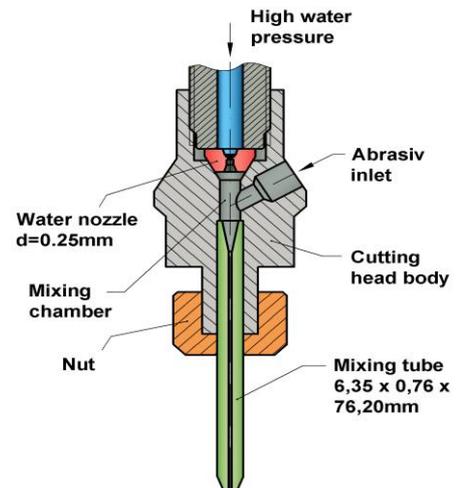


Figure 2. Schematic of Cutting head and the active parts.

In the first part of this study it is made the flowing model using Ansys FLUID 141, only for the liquid part of cutting head without regarding the abrasive inlet orifice. It is made the assumption that the flow throughout the water nozzle is laminar having a parabolic distribution of velocities at the end of the jewel. The first part of the study has the main purpose velocity analysis at the mixing tube outlet, regarding three dimensions of water nozzle along with three other diameters of mixing tubes.

In the second part of this paper it is made a tridimensional CFD analysis using Ansys Fluent upon active parts of cutting machine, regarding the pressure on the water nozzle being 280 MPa and two fluid circuits: one for high velocity water and other for mixing of air and abrasive particles, in order to estimate the erosion wear upon these elements [3].

2. Pure waterjet CFD model

2.1. Theoretical and experimental data

The flow modelling through cutting head of AWJ Machine it is made using Ansys FLOTRAN-CFD and element type FLUID 141. For the FLOTRAN CFD elements, the velocities are obtained from the conservation of momentum principle, and the pressure is obtained from the conservation of mass principle. A segregated sequential solver algorithm is used; that is, the matrix system derived from the finite element discretization of the governing equation for each degree of freedom is solved separately. The flow problem is nonlinear and the governing equations are coupled together. The sequential solution of all the governing equations, combined with the update of any temperature or pressure-dependent properties, constitutes a global iteration [6]. In this model has been considered only the water jet flow without regarding the geometry of abrasive tube. For each model has been adopted three dimensions for water nozzle and tree dimensions for mixing tube, according to manufacturer documents [7], as is shown in table 2.

Table 1. Water nozzle and mixing tube dimensions.

Water nozzle diameter, <i>mm</i>	Mixing tube diameter, <i>mm</i>
0.20	0.76
0.25	0.90
0.30	1.02

The water flow generated by WJ machine has been obtained through experimental attempts measuring the water level difference which fills the machine bath into a specified time period. Knowing the surface of machine bath and measuring the water level difference, can be calculated the water volume using equation below.

$$V = A_b \cdot \Delta h = 3.8824 \cdot 12 \cdot 10^{-3} = 4.658 \cdot 10^{-2} \text{ m}^3 \quad (1)$$

where: A_b is the surface of machine bath, $A_b = 3.8824 \text{ m}^2$; Δh – water level difference, $\Delta h = 12 \text{ mm}$.

Knowing the water volume which fills the machine bath in a specified period of time, it can be calculated the water flow using relation (2)

$$Q = V/t = 4.658 \cdot 10^{-2} / 1525 = 3.055 \cdot 10^{-5} \text{ m}^3/\text{s} \quad (2)$$

where: t is the measured time period to fill the machine bath with Δh , $t = 25' 25'' = 1525 \text{ seconds}$.

Making the assumption that the water flow is the same for all water nozzle dimensions and knowing the flowing area for all of them, can be calculated the maximum velocity using equation (3) for each water nozzle diameter [2, 8].

$$v_{max,D} = 2 \cdot v_m = 2 \cdot Q/A_D \quad (3)$$

where: $v_{max,D}$ is the maximum velocity value for each water nozzle diameter; Q is the water flow; A_D is the surface area of water nozzle for each diameter; v_m is the average value of velocity.

Regarding a parabolic distribution of outlet velocity on water nozzle and the flowing is made in opposite direction of Y axis, the physical distribution law of velocity along the symmetry axis of geometrical model is given by a parabolic equation [1]. The equation (4) is used to write loads as input velocity in Ansys CFD model.

$$v_y(x) = v_{max,D}(R^{-2} \cdot x^2 - 1) \quad (4)$$

where: $v_{max,D}$ is the maximum velocity value for each water nozzle diameter; R is the radius of water jewel.

2.2. Experimental results

The experimental results for outlet mixing tube velocity given by Ansys FLOTRAN CFD are depicted in diagrams shown below. The flow analysis it is made considering an incompressible fluid (water) and the reference temperature is 20°C . The velocity vectors generated in this analysis are shown in figure 3.

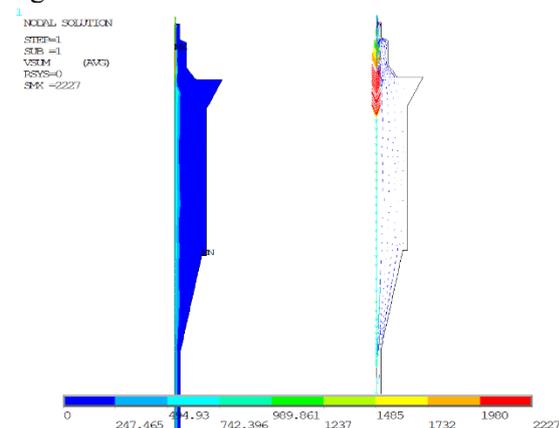


Figure 3. Velocity contour and vectors of flowing model.

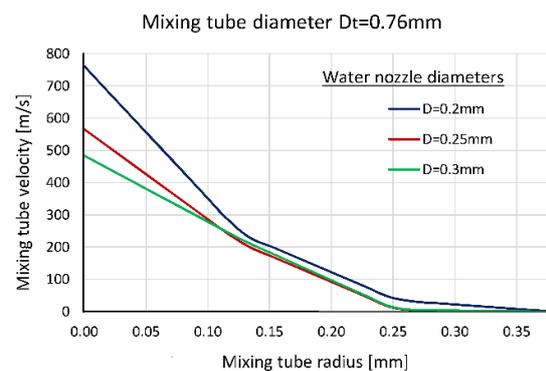


Figure 4. Velocity diagrams for mixing tube diameter 0.76 mm.

On figure 4, can be observed that in the case of 0.76mm in diameter of the mixing tube, the biggest value of outlet velocity can be obtained in the middle of waterjet (symmetry axis of jet) using 0.2 mm diameter of water nozzle and lowest value for the 0.3 mm. Also, can be noticed a slowing down of velocity from jet axis toward the extremity, once with the approach nearby mixing tube wall. The reduction rate becomes maxim using 0.2 mm water nozzle and minimal using 0.3mm of water nozzle jewel. At values of mixing tube radius around 0.11 mm, the outlet velocities obtained for 0.25 mm and 0.3 mm diameters of water nozzle become equal and over that value both water nozzle have approximately the same behaviour.

In the case of 0.9mm mixing tube diameter, as shown in figure 5, the biggest value of the jet axis velocity it is obtained using 0.25 mm water nozzle and the lowest value using 0.3 mm. The outlet velocities of mixing tube are reduced from the jet axis toward the mixing tube wall. On the diagram, it is observed that over 0.07mm of mixing tube radius, the obtained velocity using 0.2mm water nozzle becomes higher rather than using 0.25mm and 0.3mm. Around this very same value of radius, the outlet velocities become equal using both 0.2mm and 0.25mm water nozzle. Can be noticed that, in this case, using a 0.3mm water nozzle can be obtained lower values of outlet velocities in comparison with two others dimension.

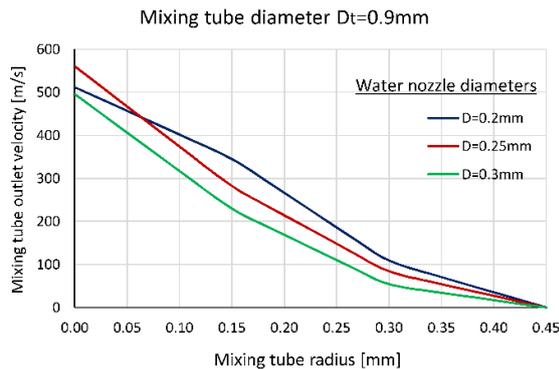


Figure 5. Velocity diagrams for mixing tube diameter 0.9mm.

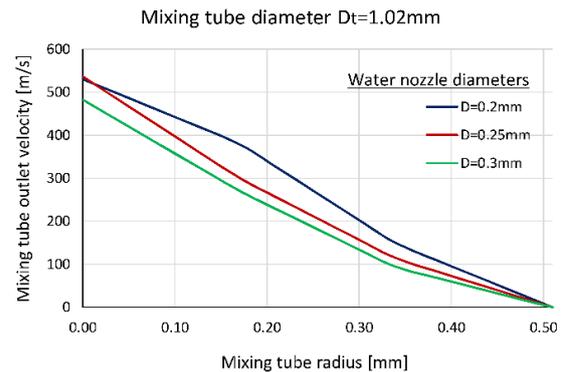


Figure 6. Velocity diagrams for mixing tube diameter 1.02mm.

In the case of 1.02mm mixing tube diameter the highest outlet velocity value in jet axis it is obtained using 0.25mm water jet nozzle (figure 6) and the lowest using 0.3mm. It can be noticed that to 0.03mm towards axis jet on radius, the maximum velocity value can be obtained using 0.2mm water nozzle and the reduction rate is lower in comparison with two other diameters of nozzle. Such in the previous case, lower values of outlet velocities can be obtained using 0.3mm water nozzle rather than using the two other dimensions.

Figures 4,5,6 point out that the maximum outlet velocities values are obtained using 0.76mm mixing tube diameter (about 761.52 m/s) and 0.2mm water nozzle, 565.86 m/s using 0.25mm water nozzle and 483.76 m/s using 0.3mm water nozzle diameter. At 0.9mm mixing tube diameter the highest velocity is 560.26 m/s obtained with 0.25mm water nozzle and in case of 1.02mm mixing tube diameter, the highest velocity value (536.22 m/s) is obtained using 0.25mm water nozzle.

3. Erosion CFD model of active parts

The erosive flow through active elements AWJ Machine WUXI YCWI-380-1520 has been made using Ansys Workbench – Fluid flow (Fluent) and 3D model of geometry [5]. The materials considered in the framework of simulation is solid-aluminum for body elements and anthracite particles like abrasive material (these materials are provided by Workbench Library). The analysis has been made considering an isothermal model and the reference temperature is ambient (20°C). The erosive CFD model is accomplished regarding them. The real material of mixing tube is tungsten carbide (WC), abrasive material used is garnet, ruby jewel for water nozzle and the other elements are made from stainless-steel. There are two circuits of flow: first circuit is pure water at 280MPa and the second is mixed air and abrasion particles. It is considered that particles are spherical with 180 μm diameter and total flow rate is $5 \cdot 10^{-7}$ kg/m. The fraction of air on abrasive inlet is 0.85.

In figure 7 can be observed the streamlines created by the high pressure of waterjet along the cutting head. It is noticed that the maximum fluid velocity is about 751.2 m/s and appears throughout the waterjet ruby jewel of 0.25mm diameter, this velocity is created by the jewel implicitly and the high pressure of water (280MPa). The velocity value throughout the mixing tube is about 187.8 m/s, this decreasing appears because the flowing section increases from the 0.25mm to 0.76mm diameter of

mixing tube. It can be noticed a vortex created by the turbulences which appear in the region of abrasive material inlet. This vortex is created because the water strives to go outside through the higher diameter of abrasive inlet. Finally, some of the waterjet streamlines are directed through the mixing tube orifice and others are striking the wall of mixing chamber.

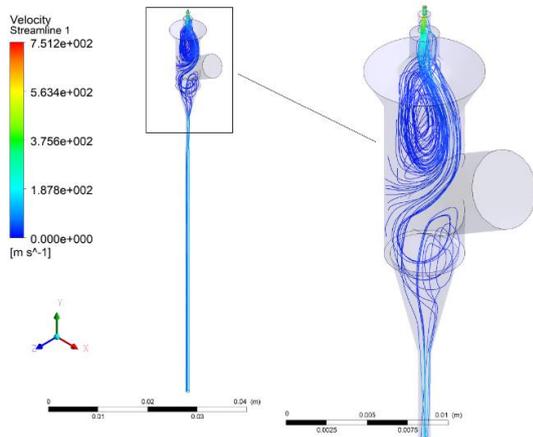


Figure 7. Waterjet streamline provided by 280MPa.

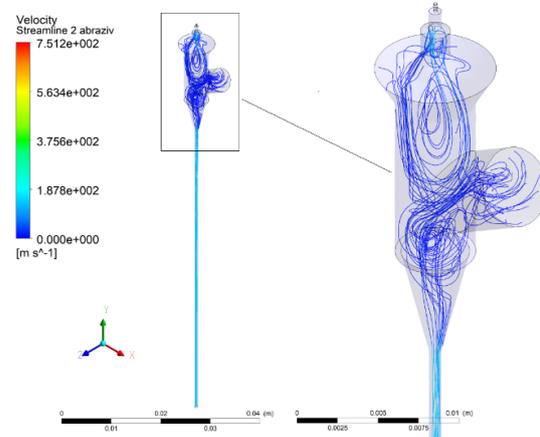


Figure 8. Abrasive particles track generated during 0.337seconds.

There is another fluid circuit created by air which carry away abrasive particles, as is shown in figure 8. The abrasive particles are carried out and trained by the high velocity waterjet up to the value of 187.8 m/s throughout the mixing tube. Also, can be observed some turbulences, mainly on the cone region of mixing tube and to the vortex created by the high velocity waterjet.

The erosion wear produced by the abrasive particles in the interval of 0.337 seconds with their specific features presented previously, is estimated to be around $2.34 \cdot 10^{-5} \text{ kg/m}^2$, as is depicted in figure 9 and can be noticed that there are two regions with maximum value of DPM erosion. The first zone is located on the mixing chamber surface and the mixing tube, right on the entrance of abrasive particles into cutting head and the maximum value of erosion wear is estimated to be around $2.11 \cdot 10^{-5} \text{ kg/m}^2$. The second zone is located on the surface of water nozzle, having a maximum value of erosion wear about $2.34 \cdot 10^{-5} \text{ kg/m}^2$ and it is created by the turbulences of waterjet. In practice, it is proved that these two zones are most intensively subjected to erosion wear.

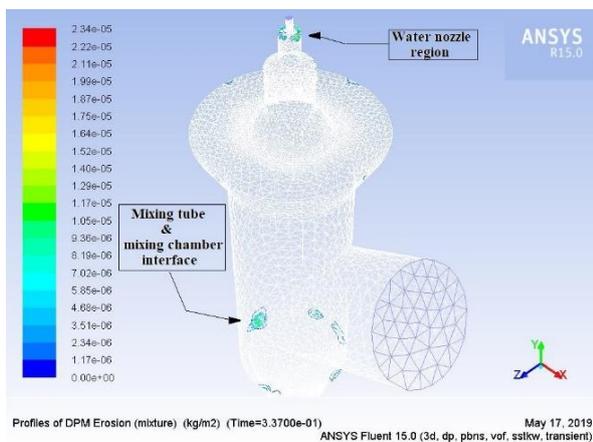


Figure 9. Main regions of maximum DPM erosion on CFD simulation.

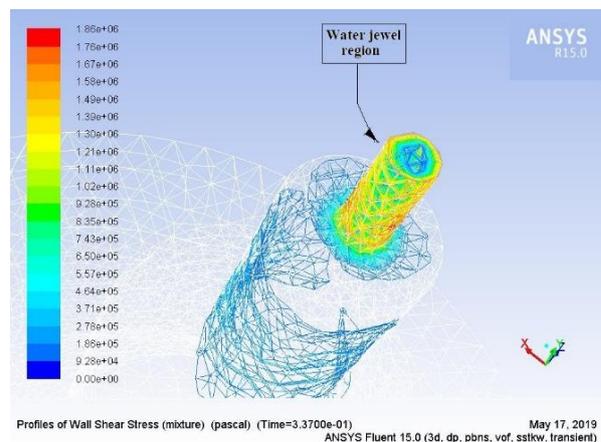


Figure 10. Main regions of shear stress.

In figure 10 presents variation of wall shear stress along the active parts of cutting head. It can be observed that the maximum value is recorded to be 1.86 MPa and it is located on the wall of water

nozzle jewel. That is the reason why this part is made from hard materials like sapphire, ruby and diamond.

4. Conclusions

Regarding a laminar flow along water nozzle and a parabolic distribution law of velocity as input data of Ansys boundary conditions, it is estimated that using 0.76mm mixing tube along with 0.2mm water nozzle drives to the highest value of outlet velocity placed in jet axis of mixing tube.

According to real investigation and calculate Reynolds number it is observed a turbulent flow along water nozzle, because the real value of Re is estimated to be around 155000. Subsequent studies will be done regarding a turbulent flow upon water nozzle and a logarithmic distribution law of velocities along ruby nozzle.

Using a 280 MPa water pressure upon 0.25mm diameter water jewel orifice can be obtained a maximum fluid velocity of 751.2 m/s on water nozzle and 187.8 m/s on mixing tube. These values have been obtained assuming an isothermal flow analysis.

According to initial boundary conditions of active parts and properties and material of abrasive particles, it is estimated that the maximum value of erosion wear of active elements is about $2.34 \cdot 10^{-5}$ kg/m² made in interval of 0.337seconds.

The maximum value of wall shear stress is calculated to be 1.86 MPa and located on water jewel wall. Knowing these wall shear stress can be estimated the erosion rate using analytical and empirical equations given by various researchers.

For more accurate investigation of erosion behavior upon active parts of AWJ Machine WUXI YCWJ-380-1520 studies will be continued in order to take in consideration the real material of water nozzle and mixing tube. Also, will be made experimental investigation to establish influence of real shape of abrasive particles and considering a running program period longer than 0.337seconds.

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