Flow Field Simulation and Parametric Design of High-pressure Water Jet Cutting Leather Based on Fluent

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Abstract: This paper studies the flow field simulation process of high-speed water jet cutting leather. Based on the water jet impact model, Fluent is used to analyze different jet pressures, spray distances and nozzles diameter. The effect of the outlet diameter on the jet impact velocity and the impact area is studied. Through the study of three factors, it is found that the jet pressure has the greatest and most direct influence on the jet velocity. Therefore, adjusting the jet pressure is an important means to successfully complete the water jet cutting. The above research has a good guiding for cutting leather.
Keywords: high-speed water jet, fluent; jet pressure, spray distance, nozzle diameter

Introduction

High-pressure water jet technology is an emerging technology developed in recent years [1]. Its principle is to use high-pressure equipment to act on the water body to generate high-pressure water, and then convert the pressure into a highly concentrated water jet flow through the nozzle. This water jet has high speed and huge impact energy so it's can using as cleaning, crushing, and cutting [2].For the application of water jet and flow field simulation research, Qu [3] studied the fluid simulation of high-jet rust removal, and studied the characteristics of high-pressure water jet in the flow field and the force on the target surface through fluid simulation. Finally, the best jet effect is obtained by flow field analysis. Song [4] established a three-dimensional solid model of the water jet from the nozzle outlet hitting the mussels, and used the VOF two-phase turbulence model of the Fluent software to simulate the process of the water jet from the nozzle hitting the mussels, and obtained the corresponding results. The above scholars have carried out a lot of analysis on the research on the water jet flow field, and the application involves many aspects. The main points of the research focus on the nozzle diameter, jet angle, spray distance, etc. There are few simulation studies on jetting leather.

In this paper, the flow field simulation process of high-speed water jet cutting leather is studied. Based on the water jet impact model, the response of nozzle diameter, spray distance, jet pressure to flow field velocity and the field distribution of leather damage stress are studied. The influence of the three on the jet velocity is pointed out, and the distribution of jet pressure, jet velocity and stress at the leather is obtained, and an optimization method for improving the water jet cutting leather is proposed.

1. Water jet flow field simulation settings

This analysis uses the N-S equation as the governing equation and the standard k-ε model as the computational model. In this paper, water is used as the medium to study the jet characteristics of different nozzle structures. The inlet boundary adopts the pressure inlet, and the outlet adopts the pressure outlet set to standard atmospheric pressure. Grid division is required for model calculation.

Mathematical model: The high-pressure water jet is a free jet and can be assumed to be an incompressible viscous fluid. The continuity equation of the incompressible fluid is [5]:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \bullet (\rho_m \vec{v}_m) = 0$$

The momentum equation is:

$$\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \bullet (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla \bullet [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] + \rho_m \vec{g} + \vec{F} + \nabla \bullet (\sum_{k=1}^{n} a_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k})$$

The energy equation is:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(a_k\rho_k E_k)+\nabla\bullet\sum_{k=1}^{n}(a_k\vec{v}_k(\rho_k E_k+p))=\nabla\bullet(k_{eff}\nabla T)+S_E$$

The high-speed water jet works in a state of high turbulence, and the standard model is used in the simulation process, in which the turbulent kinetic energy k and dissipation rate ε equations are:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}[(\mu+\frac{\mu_i}{\sigma_k})\frac{\partial k}{\partial x_i}]+G_k-\rho\varepsilon$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}[(\mu+\frac{u_i}{\sigma_\varepsilon})\frac{\partial\varepsilon}{\partial x_i}]+\frac{C_{1\varepsilon}\varepsilon}{k}G_k-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

G_k is the turbulent kinetic energy caused by the average velocity gradient, $\mu_{\mathrm{i}}=\rho C_\mu\frac{K^2}{\varepsilon}$ is the turbulent viscosity coefficient, the default is constant

$$C_\mu=0.09, C_{1\varepsilon}=1.44 \quad C_{2\varepsilon}=1.92 \quad \sigma_k=1 \quad \sigma_\varepsilon=1.3.$$

2. Simulation results and discussion

The simulation results corresponding to the data in the following table are shown in the appendix. Table 1 shows a total of 27 groups of water jet flow field velocity changes under different loading conditions. The discussion is as follows. The three factors are nozzle diameter, spray distance and jet pressure, and three different conditions are set for each factor. The diameter of the nozzle is 0.2, 0.5, and 1 mm, respectively; spray distance are 1, 2, 4 mm; jet pressure are 100, 200, 300MPa. This paper mainly studies the size of the jet velocity under different conditions.

2.1 Different nozzle diameters

The fluid mechanics of the same spray distance, the same pressure, and different nozzle diameters are studied. Three spray distances, the pressure is the same but the nozzle diameter gradually increases, the comparison can be seen in a certain spray distance range. The jet velocity increases with the increase of the nozzle diameter, but when the nozzle diameter is too large, the increasing trend of the jet velocity becomes slower. Observing the stress around the leather, it can be seen that with the change of the jet velocity, the stress on the leather is also different. When the jet velocity increases, the stress on the leather will also increase. The water jet is generally shot in the middle of the leather. When the stress value exceeds the ultimate stress of the leather, the leather is damaged.

2.2 Different pressure levels

Observe the same nozzle diameter, the same spray distance, the flow field velocity under different pressures, the three spray distances, the nozzle diameter is the same but the pressure gradually increases, the comparison can be seen within a certain range, the jet velocity increases with pressure, and the pressure increases faster. Observing the stress around the leather, it can be seen that with the change of the jet velocity, the stress of the leather is also different. The pressure increases, the jet velocity increases, the stress on the leather also increases, and the leather is more prone to damage.

2.3 Different spray distances

Observing the flow field velocity of the same nozzle diameter, the same pressure, and different nozzle diameters, the three spray distances, the pressure is same but the nozzle diameter gradually increases. The jet velocity decreases as the spray distance increases. Observing the stress around the leather, it can be seen that with the change of the jet velocity, the stress of the leather is also different. In the case of other factors remaining unchanged, the spray distance should be minimized.

2.4 Orthogonal experimental design

Through orthogonal experiments, the influence of three factors on the jet velocity under different conditions is studied

(Table 2), and it is pointed out which factor has a greater influence and the optimal conditions. Through the three-factor and three-level orthogonal test, it can be found that the influence of the jet pressure is the largest, followed by the nozzle diame-ter, and the spray distance is the weakest. This shows that as long as the jet pressure is large enough, the leather can be com-pletely destroyed, but excessive jet pressure is also not desirable. First, it is difficult to generate equipment with excessive pressure and it is easy to damage the equipment, and second, the harmful side effects caused by high jet pressure will also change. Although the optimal conditions obtained are 1mm nozzle diameter, 1mm spray distance and 300MPa

Table 1. Water jet data

Number	nozzle diameter /mm	spray distance /mm	jet pressure /MPa	velocity m/s	stress on leather /MPa
A1	0.2	2	100	121	312
A2	0.2	2	200	183	322
A3	0.2	2	300	243	692
B1	0.2	1	100	118	8583
B2	0.2	1	200	166	20015
B3	0.2	1	300	222	25944
C1	0.2	4	100	92.2	12929
C2	0.2	4	200	138	25833
C3	0.2	4	300	202	38873
D1	0.5	2	100	167	20273
D2	0.5	2	200	173	40723
D3	0.5	2	300	212	61434
E1	0.5	1	100	186	56634
E2	0.5	1	200	232	11333
E3	0.5	1	300	299	16983
F1	0.5	4	100	164	47992
F2	0.5	4	200	212	9611
F3	0.5	4	300	243	14382
G1	1	2	100	166	12622
G2	1	2	200	231	24502
G3	1	2	300	249	38041
H1	1	1	100	139	12248
H2	1	1	200	196	24498
H3	1	1	300	241	36741
I1	1	4	100	171	8749
I2	1	4	200	238	24431
I3	1	4	300	288	31467

Table 2. Three-factor and three-level orthogonal table

Number	Factor 1 (nozzle diameter/ mm)	Factor 2 (spray distance / mm)	Factor 3 (pressure /MPa)	Result (jet velocity m/s)
1	0.2	2	100	121
2	0.5	1	100	186
3	1	4	100	171
4	1	1	200	196
5	0.5	2	200	173
6	0.2	4	200	138
7	0.2	1	300	222
8	0.5	4	300	243
9	1	2	300	249
K1	481	543	478	
K2	602	604	507	
K3	616	552	714	
k1	160.33	181	159.33	
k2	200.66	201.33	169	
k3	205.33	184	238	
R	45	20.33	78.66	
		factor level C>A>B		best result A3B2C3

pressure, the jet velocity at this time is already very high, and the generated pressure can completely destroy the leather, resulting in excess performance, so it can be adjusted appropriately.

It can be seen from the above that the pressure of 100MPa far exceeds the demand, and the performance is seriously wasted. Therefore, it is considered to appropriately reduce the pressure and study the flow field phenomenon of the water jet. Taking the water jet model with a nozzle diameter of 1 mm and a spray distance of 4 mm as an example, the distribution of the jet flow field with the jet pressures of 1, 5, 10, and 20 MPa and the stress effect on the leather were analyzed. Through linear regression analysis, we obtained the relationship between the jet pressure and the jet velocity was studied to study the damage to the leather.

The relationship between the jet pressure and the jet velocity is satisfied $y = 145.2x^{0.1119}$ (Figure 1. It can be seen that there is a power function relationship between the jet pressure and the velocity, that is, the jet pressure increases and the jet velocity also increases. Similarly, when the jet velocity increases, the stress also increases. When the pressure is greater than 10MPa, the failure stress of the material has been exceeded, and the requirements have been met. The curves of jet velocity, jet pressure and stress at the leather are shown in Figure 2.

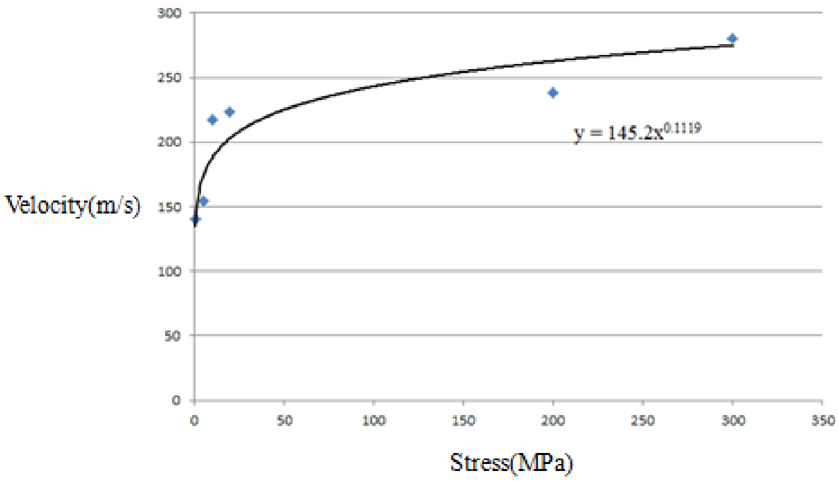

Figure 1. The relationship between jet pressure and velocity

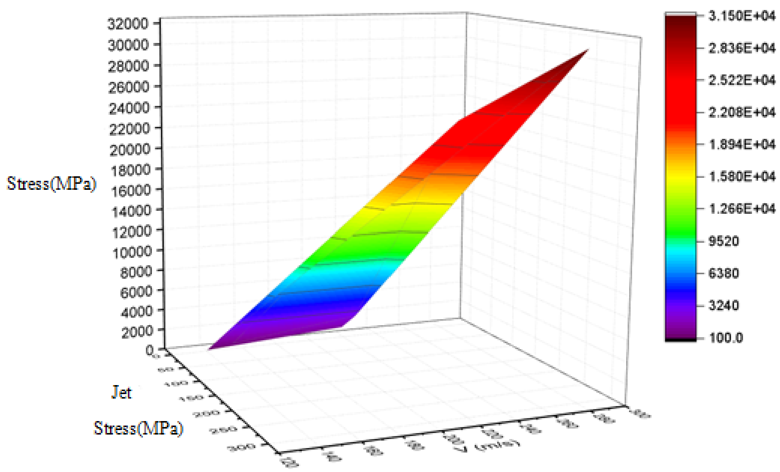

Figure 2. Curve of jet velocity, jet stress and stress on leather

3. Conclusion

Based on Fluent, this paper studies the flow field simulation of water jet on leather. Through three factors and flow field simulation, the flow field velocity changes under different conditions are obtained. Through the orthogonal factor analysis, it is concluded that the jet pressure is the most important factor affecting the jet velocity, and the jet velocity will increase with the increase of the nozzle diameter, but the increase rate will be slower; the jet velocity will increase with the spray distance. When cutting leather, as long as the jet velocity reaches a certain range and the surface pressure exceeds the damage stress of the leather, the cutting condition can be achieved. Through the analysis, it is concluded that the jet pressure has the greatest influence on the jet velocity, so the above conditions are properly corrected, and the optimal jet parameters can be obtained by changing the jet pressure.

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