ORIGINAL ARTICLE

Finite Element Analysis and Experimental Study of Atomized Gas Flow Field in Spray Forming

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Abstract: During the spray forming process of die steel, the gas flow field of nozzle atomizer has an important influence on the atomization effect of metal solution and the shape and performance of deposited billet. In this paper, the finite element analysis method was used to study the flow field distribution of the annular slot type restricted nozzle. The results showed that the negative pressure area was formed at the front of the atomizing gas outlet of the nozzle; the negative pressure area was enlarged and the negative pressure value was increased with the increase of the extending position of the liquid guide pipe and the atomizing pressure; when the atomizing pressure was 0.5MPa and the extending position of the liquid guide pipe was 7mm, the negative pressure value of the front of the liquid guide pipe could reach-38650Pa and the gas flow rate could reach 191.4m/s; the back-injection could be effectively avoided by optimizing the appropriate process parameters. And the damage of atomizing nozzle could be reduced.

Keywords: Spray Forming; Atomized Gas; Flow Field Analysis; Finite Element Method

Introduction

Spray forming is an important innovation in the material preparation technology in the 20th century. It breaks through the traditional preparation mode of metal smelting—casting. With its solidification characteristics of high cooling rate and high interface growth rate under high undercooling, it can make the microstructure of the material uniform, refine the crystal grain, eliminate macro segregation of components, reduce brittle phase, and show a series of excellent service properties[1,2] such as high strength, high toughness, high wear resistance and isotropy. By combining injection molding with other advanced manufacturing technologies, near-net forming (precision injection molding) of products (such as molds) can be realized while preparing high-performance materials, which can not only improve product quality and performance, but also greatly shortens the production process of products, shortens the production time and reduces the production cost, so that it has obvious technical advantages[3-6] in the manufacturing process of materials or products.

In the spray forming process, metal atomization is one of the key factors in the whole spray forming process, and the flow field of nozzle atomization gas is directly affected. The size and position of the liquid guide tube, spray height, cooling rate, etc., further affect the morphology, density and structure of the deposited blank. At the same time, it will also affect gas process parameters, such as pore size and air pressure[7-10]. Existing research and author's previous experiments. The result shows that negative pressure will be generated at the front end of the liquid guide tube during atomization. The existence of negative pressure zone is conducive to the outflow of metal solution in the liquid guide tube on the one hand, and on the other hand, the phenomenon of reverse spray will occur, blocking the liquid guide tube[11,12]. Therefore, it is necessary to analyze the flow field of spray forming atomization gas, which provides theoretical analysis basis for determining reasonable spray forming process and provides reference for optimizing nozzle structure.

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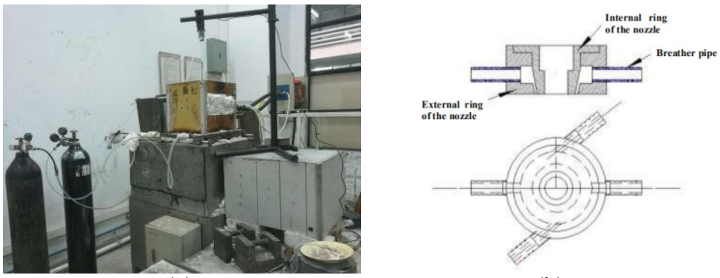
In this paper, starting from the optimization of spray forming process parameters, the Fluent gas dynamics software is used to analyze the atomization gas flow field of the nozzle, and the extension length and atomization pressure of the liquid guide tube are analyzed, and compared with the experimental results, so as to design the nozzle and process optimization provide theoretical and experimental basis.

1. Experimental and analytical process

The spray forming process test was carried out on a self-developed 10kg grade spray forming equipment. The nozzle adopts a circular seam type restriction structure with lateral 4 inlet air intake, as shown in Figure 1. The experimental material is HM1 die steel and the atomizing gas is n 2.



(a) (b)

Figure 1. Self-made 10kg spray forming equipment and nozzle structure diagram. (a) Equipment; (b) Nozzle.

The analysis of the atomization gas flow field of the nozzle adopts CFD software of Fluent company. According to the structure of the nozzle used in the experiment, the analysis model is the model is simplified. Considering the conical distribution characteristics of the nozzle and atomizing gas flow field, the atomizing gas flow field is analyzed by taking the axial centerline plane of the nozzle. According to the experimental results, when analyzing the atomization gas flow field, the gas flow inside the nozzle is not considered, and therefore, a physical model for analyzing the atomization gas flow field is established, as shown in Figure 2, in which the abscissa is the center line of the liquid guide tube and the positive direction is the gas flow direction. In Figure 2, the cone angle of the nozzle gas outlet is 27 and the width of the outlet annular gap is 2 mm. The atomization field central surface area 100 mm×100 mm is taken for analysis to study the atomization gas flow field at the nozzle outlet and the front end of the liquid guide pipe. Flow field analysis adopts quadrilateral grid with 2mm side length. The atomizing gas is nitrogen. Considering the flow rate and pressure of the atomizing gas, the flow field separation temperature is 300 K, i.e. the influence of solution on the temperature of the atomizing gas flow field is not considered, which is consistent with the high cooling rate characteristic of spray forming. The surface roughness of the nozzle is 0.4.

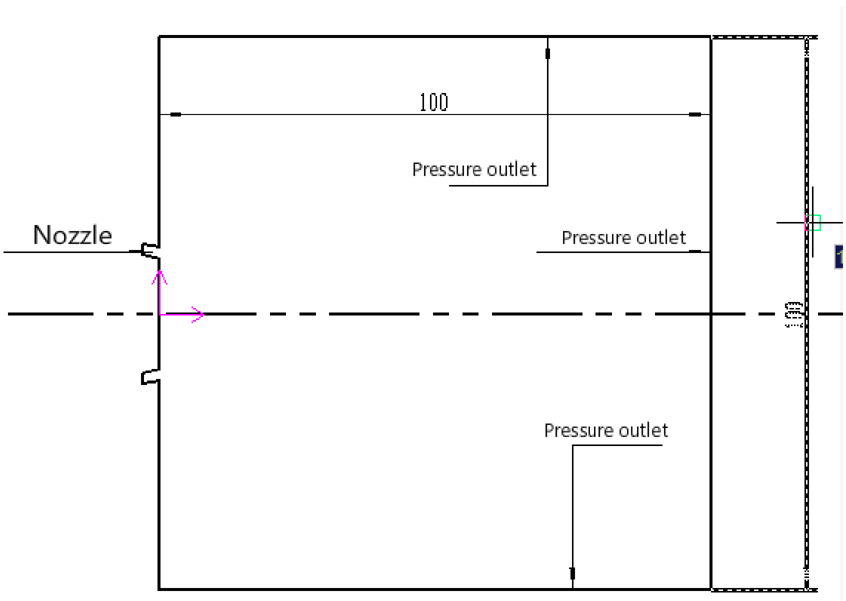


Figure 2. Physical model of flow field analysis for nozzle atomized gas.

2. Results and discussions

2.1 Flow field characteristics of atomized gas from nozzle

Figure 3 shows the nozzle outlet pressure of 0.5 MPa and the equivalent 75 line diagram of the pressure distribution of the atomizing gas flow field in the nozzle without a central liquid guide pipe. As can be seen from the figure, at the outlet of the nozzle annular gap, the atomizing gas pressure is relatively high, about 0.35 MPa; This is because the atomizing gas immediately diffuses around the nozzle after it is sprayed from the nozzle atomizing chamber through the nozzle annular gap, and the pressure drops sharply. At the same time, because the nozzle annular seam has a certain cone angle, under the action of high-speed jet air flow, a certain negative pressure area will be formed in the central area of the annular seam outlet, and its negative pressure value can reach -0.09 MPa. The existence of the negative pressure region will produce an extraction effect on the metal solution in the liquid guide tube when the outlet of the liquid guide tube in the center of the nozzle is located in the region, thus contributing to the outflow of the metal solution in the liquid guide tube; However, when the catheter flows when the diameter of the 80 outlet flow is small, the negative pressure region produces a radial attraction effect on the metal solution, i.e., reverse spray phenomenon. At this time, the metal solution will diffuse outward along the end of the liquid guide tube, while the surface temperature of the liquid guide tube is low, causing the metal solution to solidify and adhere to the outlet of the liquid guide tube, thus causing the liquid guide tube to be easily blocked. It can be seen from this that the diameter and extension position of the nozzle annular gap and the central liquid guide pipe are within a certain range, which is helpful for the smooth outflow of the metal solution in the spray forming process.

At the same time, it can be seen from Figure 3 that there is a positive pressure and negative pressure interface in the atomizing gas flow field, where the metal dissolves liquid will be crushed under the action of airflow to form small droplets.

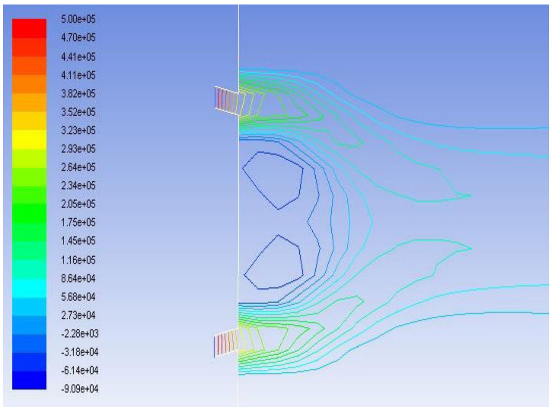


Figure 3. The contour map of pressure distribution for atomized gas flow field of nozzle.

Under the condition of 90, the pressure change of atomizing gas along the nozzle axis is shown in Figure 4. As can be seen from Figure 4, along the central axis, at a position about 6mm from the nozzle outlet, the negative pressure value reaches the maximum. as the gas injection distance increases, it changes into positive pressure and the pressure value increases rapidly. when the distance exceeds 30mm, the pressure value starts to decrease slowly again.

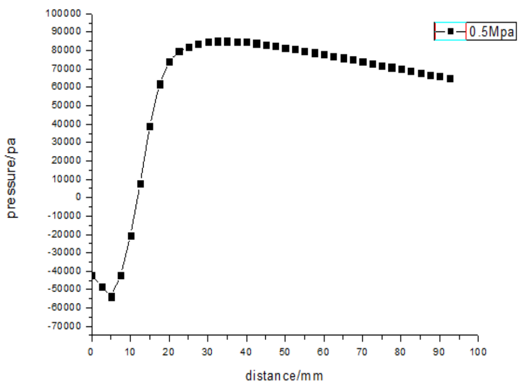


Figure 4. The pressure curve of atomized gas at the center axis of nozzle.

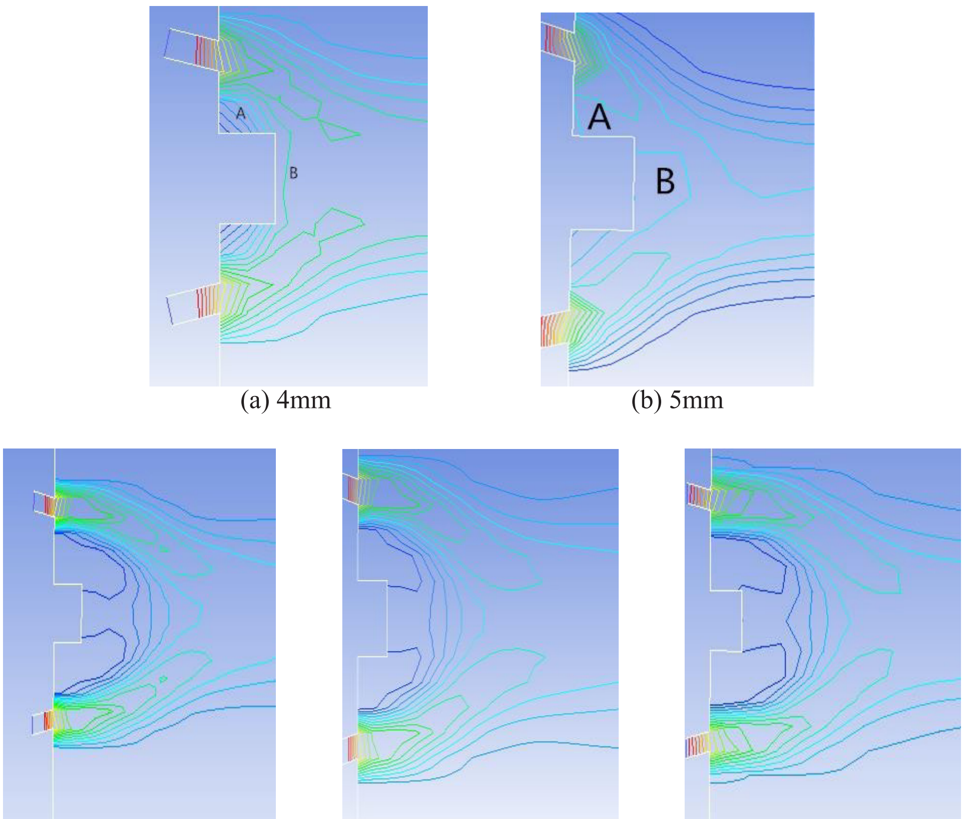
Therefore, from the analysis results in Figures 3 and 4, it can be seen that the nozzle structure used in the experiment, under the condition of atomization pressure of 0.5 MPa, the central liquid guide pipe extends 4-8 mm, which is beneficial to the flow of metal solution, and can avoid the phenomenon of reverse spraying. In order to optimize the spray forming process parameters, it is to deposit the metal solution to obtain a greater cooling rate, and the liquid guide pipe is extended as the main component below.

100 and atomization pressure were analyzed.

2.2 Influence of liquid guide pipe extension position on nozzle atomization gas flow field

Figure 5 shows the pressure distribution diagram of atomizing gas flow field at different extension positions of the liquid guide tube under the condition of the size and structure of the liquid guide tube used in the experiment. As can be seen from the figure, with the change of the extension position of the liquid guide tube, that is, the distance between the outlet of the liquid guide tube and the outlet of the nozzle changes, the shape of the negative pressure area and the maximum negative pressure value will change. When the extension positions of the liquid guide pipe are 4 mm and 5 mm (Figures 5a and b), because the air outlet hole is too close to the liquid guide pipe, the air flow speed is too fast, and the gas cannot fill the a position, negative pressure is generated, which is not conducive to the stable flow of the gas ejected from the outlet of the atomizer and the stable state of the air pressure field, seriously losses the kinetic energy of the gas, and reduces the crushing efficiency. In addition, eddy current is generated in the atomizing gas flow field, thus affecting the stable flight of the atomized metal solution and seriously causing tiny metal droplets to adhere to the outlet of the upper atomizer and blocking the atomizer; B indicates positive pressure. In this area and beyond, the molten metal will fly forward and atomize under the action of high-speed airflow. When the extension position of the liquid guide tube is 6 mm, 7 mm and 8 mm (Figure 5c, d and e), the negative pressure area expands and the negative pressure value increases, and the gas flow field distribution is more uniform.

Therefore, according to the analysis result of Figure 5, when the extension position of the liquid guide tube is 7 mm and 8 mm, the negative pressure value in the negative pressure area is larger, and the gas flow field is stable and evenly distributed.



(a) 4mm (b) 5mm

(c) 6 mm (d) 7 mm (e) 8 mm

Figure 5. The distribution of atomized gas pressure field at different extension positions of liquid guide tube.

Figure 6 shows the relationship curve between atomization gas flow velocity and distance along the axis of the liquid guide tube when the liquid guide tube positions are 7 mm and 8 mm. As can be seen from the figure, the air flow velocities at the 7 mm and 8 mm positions at the outlet of the liquid guide pipe are 191.4 m/s and 168.8 m/s, respectively. This is because the atomized nitrogen gas is accelerated within a certain distance after it is ejected from the air hole. After the speed reaches the maximum value, the speed starts to decrease again under the influence of the ambient air flow and the external normal atmospheric pressure. At the same time, the nozzle is of a circular slit structure, and the ejected gas flows converge after a certain distance. Under the above simulation condition, the gas flow velocity in the convergence region 7 mm from the liquid guide tube is larger than that in the 8mm region from the liquid guide tube, and the velocity generated by the kinetic energy of the gas in the convergence region is offset by the partial velocity in the horizontal direction, so that the kinetic energy 7 mm from the liquid guide tube is larger than that of the 8 mm from the liquid guide tube, and the velocity drops rapidly. As the injection distance continues to increase, the speed of the two approaches the same. Therefore, judging from the atomization effect on the metal solution, the 7 mm extension position of the liquid guide tube will be better than 8 mm.

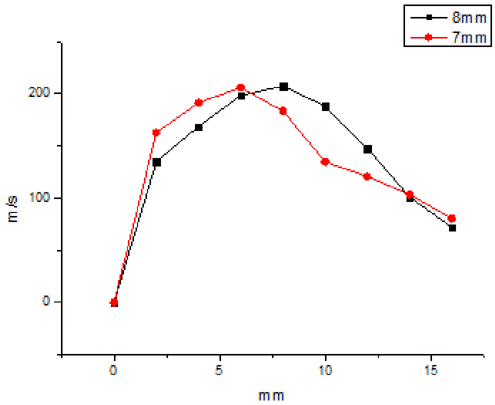
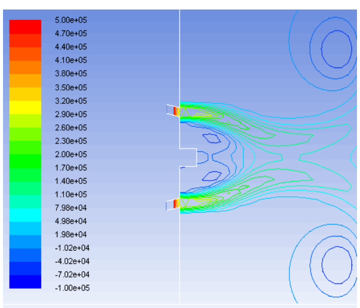


Figure 6. The relationship of air flow speed and distance at the front of liquid guide pipe.

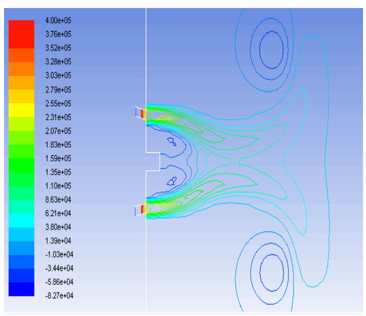
2.3 Effect of atomization pressure on gas flow field of nozzle atomization

According to the above analysis results, the extension position 7 mm of the liquid guide tube is drawn up, and the influence of atomization pressure on the flow field of atomizing gas in the nozzle is analyzed, as shown in Figure 7. As can be seen from the figure, when the atomization pressure is 0.4MPa, the maximum distance depth of the negative pressure area at the front end of the nozzle can reach 10 mm; And with the increase of atomization pressure, the maximum negative pressure value in the negative pressure area increases, reaching a maximum of -85,000 Pa. The negative pressure area increases with the increase of atomization pressure, mainly because the higher the atomization pressure is, the greater the gas flow rate at the outlet of the nozzle annular gap is under a certain nozzle structure, resulting in the farther the gas jet distance is, the larger the negative pressure area is. While the negative pressure area will cause the metal liquid to splash around the outlet of the upward liquid guide pipe and even adhere to the atomizing nozzle, causing the atomizing nozzle to be damaged. This phenomenon occurred during the experiment.

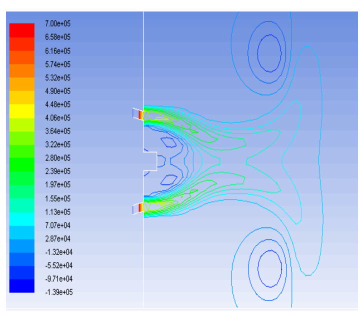
In addition, it can be seen from Figure 7 that the atomization pressure changes, but the pressure distribution state of the atomization gas flow field is almost the same, which indicates that the atomization pressure only affects the size of the negative pressure area, the negative pressure value and the gas flow rate.



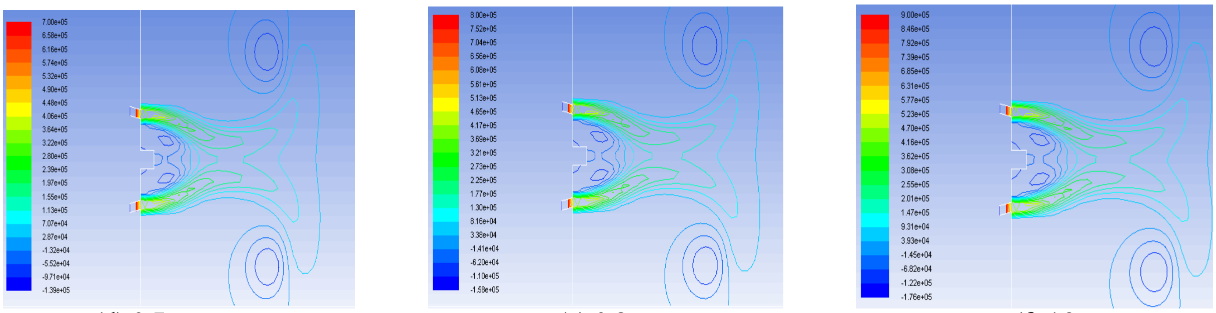
(a) 0.4MPa



(b) 0.5MPa



(c) 0.6MPa



(d) 0.7mpa (e) 0.8mpa (f) (.9mpa

Figure 7. The pressure field of atomized gas under different gas pressures.

2.4 Experimental verification

According to the above simulation results, the HM1 hot work die steel spray forming process verification experiment was carried out. When the temperature of the metal solution is 1550 ℃, the spray deposition height is 140 mm and the extension position of the liquid guide tube is 7mm, spray forming experiments are carried out at the atomization pressure of 0.6 MPa and 0.7 MPa, respectively. Figure 8 shows the morphology of the nozzle outlet under two atomization pressure conditions. As can be seen from the figure, when the atomization pressure is 0.6 MPa, there is basically no metal adhesion at the nozzle atomization gas outlet (Figure 8a), while when the atomization pressure is 0.7 MPa, the metal adhesion at the nozzle outlet obviously increases (Figure 8b), and there is a tendency to block the outlet of the liquid guide pipe, i.e., reverse spray phenomenon occurs. This is consistent with the above analysis results. When the extension position of the liquid guide tube is fixed, the pressure of atomizing gas increases, causing the negative pressure area to increase, thus causing the metal solution to spray back. Therefore, in the process of experiment, various technological parameters of spray forming should be optimized and matched according to different experimental conditions.

(a) 0.6MPa (b) 0.7MPa

Figure 8. The adhesion at nozzle outlet under different atomization pressures.

3. Conclusion

In this paper, Fluent gas dynamics software is used to analyze the flow field of nozzle atomization gas in the process of spray forming, and experimental verification is carried out. The main conclusions are as follows:

(1) For the annular gap type restricted nozzle used in the experiment, a negative pressure area will be formed at the nozzle outlet. The existence of negative pressure zone is not only conducive to the outflow of metal solution in the liquid guide tube, but also causes the phenomenon of reverse spraying.

(2) As the extension position of the catheter increases, the negative pressure area expands and the negative pressure value increases. When the air pressure is 0.5 MPa and the extension position of the liquid guide tube is 7 mm, the negative pressure value at the front end of the liquid guide tube can reach -38650 Pa and the gas flow rate can reach 191.4 m/s.

(3) With the increase of atomization pressure, the pressure distribution state of atomization gas flow field basically does not change, but the negative pressure area and negative pressure value will increase. When the atomization

pressure is 0.9 MPa, the negative pressure value can reach a maximum of -85,000 Pa.

(4) The experimental results show that the occurrence of the phenomenon of reverse spray can be effectively avoided and the damage of the atomizing nozzle can be reduced by appropriate extension position of the liquid guide tube and atomizing pressure.

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