Effect of atomization pressure on the flow field distribution of TC4 alloy powder prepared by EIGA

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Abstract. By means of the electrode induction melt inert gas atomization (EIGA) equipment designed and developed by ourselves, TC4 alloy powder were prepared. In the process of atomization, the pressure plays a decisive role in the morphology and particle size of the powder. In this paper, the effect of atomization pressure on the distribution of fluid structure was studied by computational fluid dynamics (CFD). The results show that with the increase of atomization pressure, the shape of the recirculation zone is expanded and then compressed. When the gas pressure is 2MPa, the suction pressure $\Delta P$ is 0.498MPa, thus forming a positive pressure zone. So it is easy to liquid droplets dripping up, resulting in clogging the nozzle, which has been confirmed in the experiment.

1. Introduction

With its significant advantages of high efficiency, high speed and being suitable for processing complex parts, additive manufacture (3D printing) has become the focus of rapid prototyping technology at home and abroad [1,2]. In recent years, the hotspot of 3D printing technology research and development has gradually shifted to the metal material 3D printing technology where the metal material printing equipment has gradually been applied. For the metal additive manufacture, the powder is a dominant material which has a great influence on the final product; meanwhile, powder is the bottleneck of restricting the development of the entire metal 3D printing. The amount of titanium and its alloys can represent a country’s aerospace level. The working temperature of TC4 alloy can reach 400°C, widely applied in the field of aerospace, mainly in the preparation of engine fan, compressor disk, blade aircraft structural beam and other important tensional components. However, the local TC4 powder have not reached the standard, China mainly relies on importing 3D printing powder. At present, the preparation of 3D printing titanium alloy powder mainly depends on mechanical polishing, chemical vapor deposition and atomization [3]. As liquid metal doesn’t contact with the crucible and directly flows into the atomization zone, the induction Electrode Inert Gas Atomization (EIGA) powder has the following advantages, including high purity, good performance, a high degree of sphere, narrow particle size distribution and high-cooling rate and little environmental pollution. Therefore, EIGA has become the main method of preparing atomized powder of titanium alloy. TC4 titanium alloy powder has been prepared by the self-designed rotating electrode induction melting gas atomization equipment.

In this paper, the software Fluent 6.3 was adopted to simulate the flow field of rotating electrode vacuum atomization in different pressure. The basic characteristics of the gas flow field of the rotating
electrode were explored by the simulation of the vacuum atomization flow field of the rotating electrode vacuum atomization.

2. Experiment methods

The atomization nozzle preparation of the TC4 powder experiment is designed of the ring-type HPGA aerosolized nozzle [3-5]. In order to establish an aerosolized hydrodynamic model consistent with the actual situation and higher computational efficiency, it is easier to obtain accurate convergence solution and improve the simulation results and efficiency [6]. The following calculation requirements are designed:

1. The air flowing inside the nozzle is set to transient flow.
2. In the process of single-phase simulation of two-dimensional atomized gas, the gas flow field in the atomization model is arranged in the symmetric distribution, which can be optimized and the calculation time is reduced.
3. The atomization medium interacts with the melt, and the process involves mass transfer, momentum transfer and energy transfer, and the flow type is turbulent flow.
4. Ignoring atomization medium and droplet gravity.

Since this experiment is an aerosol preparation of 3D printing titanium alloy powder experiments, in addition to the gas flow involved in the basic continuous equations and equations of motion, as well as droplets and high-speed air contact energy exchange energy equation.

Continuous equation:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0
\]  

Motion equation (Navier-Stokes equation):

\[
\frac{\partial}{\partial t} (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left( \mu \frac{\partial u_i}{\partial x_j} - \tau_{ij} \right) + s_i
\]  

Energy equation:

\[
\frac{\partial}{\partial t} (\rho T) + \frac{\partial}{\partial x_j} (\rho u_j T) = \frac{\partial}{\partial x_j} \left( K \frac{\partial T}{\partial x_j} - \rho u_j T \right) + s_T
\]  

Where \( \rho \) is the density; \( u_i \) and \( u_j \) are the velocity components of \( X_i \) and \( X_j \) directions respectively; \( \mu \) is the dynamic viscosity; \( \tau_{ij} \) is the convex tensor; \( s_i \) is the generalized source term of the dynamic equation; \( T \) is the temperature; \( K \) is the thermal conductivity of the gas rate; \( c \) is the specific heat capacity of the gas; \( s_T \) is the viscous dissipation term.

The flow of atomized gas belongs to turbulent flow, but there are many kinds of models corresponding to turbulent flow, such as one-equation model, two-equation model and Reynolds stress model and large eddy simulation. This test selects the standard k-ε model.

The flow field structure of the annulus HPGA aerosolized nozzle was simulated by "Fluent Version 6.3" hydrodynamic software. First of all, the use of Fluent commonly used pre-processing software Gambit2.4.6 on the nozzle and its fog chamber within the flow field model. When atomization, the distribution of the air flow field is symmetrical distribution of the central line of the nozzle, so taking half of the flow field as a calculation area. The boundary conditions are as follows: the inlet of the nozzle is imported by pressure, the outlet of the atomization chamber is far from the pressure, the center line of the flow field is set as the symmetry surface, and the other sides are all wall type and the wall type is...
non-slip adiabatic wall. The grid is divided by the division of triangular non-structural network. The calculated area after dividing the grid is shown in Fig. 1.

![Grid of gas atomization](image)

**Fig. 1 Grid of gas atomization**

The atomization gas is argon and its properties are shown in Table 1.

| **Table 1 Argon properties in gas atomization** |
|-----------------------------------------------|
| Gas type and properties                       | Argon |
| Density(kg·m⁻¹)                               | 1.6228 |
| Specific heat capacity(J·kg⁻¹·K⁻¹)            | 520.64 |
| Thermal conductivity(W·m⁻¹·K⁻¹)               | 0.0158 |
| Viscosity(kg·m⁻¹·s⁻¹)                         | 2.125×10⁻⁵ |
| Temperature(K)                                | 273.11 |

3. Results and discussion

3.1 *Velocity distribution of atomized flow field under different pressure conditions*

Figure 2 shows the velocity distribution in the atomized flow field of a ring-type HPGA nozzle under different pressure conditions. When gas pressure is 2MPa, the total pressure is relatively low, so the gas pressure inside the nozzle and gas velocity of the gas tank is relatively low, the shock and expansion of the waves are relatively small, and the entire flow field is very small. The recirculation zone shows a thin and short look. And the area formed by the stagnation is almost inverted. When the gas pressure increases to 4MPa, the gas pressure inside the nozzle and the gas pressure in the atomization chamber are increased, and the expansion wave and shock wave at the outlet are all more intense, and the gas velocity at the exit edge in the flow field area also increases significantly, the area of the recirculation zone increased significantly, the stagnation area is no longer concentrated and the state of separation. When the pressure increases to 6MPa, the gas velocity increases, resulting the expansion wave further increasing, while the hysteresis region shape has almost no change. When the air pressure increases to 8MPa, the area of recirculation zone is reduced by the compression, the stagnation area is reduced.
3.2 Pressure distribution of atomized flow field under different pressure conditions

Figure 3 shows the pressure distribution in the atomized flow field of the ring-type HPGA nozzle under different pressure conditions. When the gas pressure is 2MPa, the overall pressure of the gas flow field is small, the pressure distribution in the recirculation zone is stable at about 1.11MPa, and the pressure around the recirculation zone is mainly 0.612MPa, so the suction pressure $\Delta P$ is 0.498MPa. The suction pressure is positive, and the formation of this positive pressure region can be interpreted as: the air flow of two air holes in the nozzle, when the impact is at a certain angle (60° in this experiment) for horizontal and vertical components. The two horizontal components of the air flow have the same size and the opposite direction, which are collision at the impact point, because its density and pressure are greater than the surrounding ambient gas, part of the gas moves along the axis of the nozzle. When the molecular packing of air current is larger than that of air jet flow, thus forming a positive pressure zone [7]. So it is easy to liquid droplets dripping up, resulting in the phenomenon of clogging the nozzle, which has also been confirmed in the experiment. While the stagnation pressure remains almost unchanged.
When the gas pressure increases to 4MPa, the overall pressure of the gas flow field can be improved, especially in the gas outlet, the pressure has significantly improved and the emergence of a significant expansion area, the pressure of recirculation zone is almost stable, and the pressure within the reflux area has also received a certain degree of increase. The suction pressure corresponding to the recirculation zone can be calculated from the figure. This negative pressure zone is formed by the entrainment of the airflow. When the catheter is near the focal point of the axial jet, the downward flow of the nozzle strong suction action sucks away the gas near the catheter, but it hasn’t enough time for gas to be added, thus forming a negative pressure zone [7]. The presence of the negative pressure zone allows the metal droplets to be drawn into the atomization zone to accelerate the flow rate of the metal droplets, which facilitates the atomization process. Compared to 2MPa, the stagnation pressure has slightly increased. When the gas pressure increases to 6MPa, the expansion area is further expanded, the area of the recirculation zone and the pressure in the recirculation zone increases, and the suction pressure in the recirculation zone remains negative. After calculating the pressure difference of the negative pressure zone with range from -2.44~ -1.83MPa (6MPa has the maximum absolute of pressure difference), the pressure change on the negative pressure area is not significant, stagnation pressure decreases slightly. When the gas pressure continues to increase to 8 MPa, the expansion zone hardly
changes, the area of the recirculation zone is significantly expanded, the suction pressure remains negative and the stagnation pressure decreases.

4. Conclusion

(1) With the increase of atomization pressure, the shape of the recirculation zone first appears short thin state, then compressed and expanded. The area formed by the stagnation is similar to that of the inverted cone after separation and compression, but finally returns to the approximation inverted cone state and the area decreased.

(2) When the gas pressure is 2MPa, the suction pressure $\Delta P$ is 0.498MPa, thus forming a positive pressure zone. So it is easy to liquid droplets dripping up, resulting in clogging the nozzle, which has been confirmed in the experiment.

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References
[1]. Visser C W, Pohl R, Sun C, et al. Toward 3D printing of pure metals by laser-induced forward transfer, Advanced Materials, 2015, 27(27): 4087-4092.
[2]. Singh R, Verma M. Investigations for deducing wall thickness of aluminium shell casting using three dimensional printing, Journal of Achievements in Materials & Manufacturing Engineering, 2008, 31(2): 565-569.
[3]. Mullis A M, Bigg T D, Adkins N J. Structure and phase-composition of Ti-doped gas atomized Raney-type Ni catalyst precursor alloys, Intermetallics, 2015, 67:63-68.
[4]. Miller S A. Close-coupled gas atomization of metal alloy, In: Kaysser W A, Huppman J W, eds. Horizons of powder metallurgy. Freiberg, Germany: Verlag Schmidt GMBH, 1986. 29-32.
[5]. Strauss J T. Hotter gas increases atomization efficiency, MPR, 1999, 4(11): 24-28.
[6]. Senecal P K, Schmidt D P, Nouar I, et al. Modeling high-speed viscous liquid sheet atomization, Int. J. Multiphase Flow, 1999, 25: 1073-1097.
[7]. Chen Ping, Liu Fu-ping. Improvement of the atomizer used for producing metal powder, Metal Materials and Metallurgy Engineering, 2009, 37(4): 46-49.