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Analysis of spray particles entrance of Right-angle cold spray nozzle based on CFD

Tan Kun[1]

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Abstract: *Cold spray technology is a solid-state deposition technology, and the nozzle is an important part of the cold spray system. This article proposes a right-angle nozzle. The characteristic of this nozzle is that it can change the flow direction of the gas flow inside the nozzle to realize spraying on the surface of special parts; the acceleration of particles by the right-angle nozzle with different particle entrances is studied. The results show that the outlet center velocity of the right-angle nozzle with a circular throat section is greater, the viscous boundary layer effect is better, and the effective circulation area is larger; the maximum airflow velocity near the outlet of the right-angle nozzle at the particle entrance A is 663.4m/s; it can also effectively avoid the deposition of particles inside the right-angle nozzle, thereby reducing the loss of kinetic energy during the acceleration of particles in the right-angle nozzle; the research on the structure of the new right-angle cold spray nozzle can provide reference for the nozzle of cold spray technology Opinion.*

Keywords: *cold spray, right-angle nozzle, particle entrance, velocity.*

1. Introduction

Cold spray technology is a solid-state deposition technology that began in the 1980s [1]. Its working principle is: the particles are accelerated to supersonic speed in the nozzle [2, 3], and deposit with the surface of the substrate. During the deposition, a large number of particles undergo plastic deformation, and finally a new coating is formed on the surface of the substrate, and particles/substrate and the particles/particles the connection are mainly through mechanical bite [4, 5]. The nozzle is an important part of the cold spray system; as shown in Fig. 1, cold spray nozzles can be divided into: conical (*a*) and bell-shaped (*b*) [6]; cold spray nozzles are mainly composed of three types it consists of: convergence section, throat and expansion section. As can be seen from Figure 1, the curvatures of the constriction section and the throat of the cone-shaped and bell-shaped nozzles are different. Research shows that when the curvature radii of the convergence section and the throat are not the same. When it is large, the energy loss of accelerating the medium and particles in the nozzle is minimal. The converging section, expansion section and throat of the conical cold spray nozzle are connected smoothly at three parts, while the connection curvature of the three parts of the bell-shaped cold spray nozzle changes greatly. From the perspective of structure and processing, the conical nozzle is selected. The management is more reasonable.

As shown in Fig. 2, the cross-sectional shape of the nozzle can be divided into: circular (*a*) and rectangular (*b*) [7]. At present, the widely recognized nozzle cross-section is circular. Its advantages are: mature technology and simple structure; rectangular nozzle is not common. This type of nozzle is mainly used for spraying rotating body specimens. Among them, rectangular nozzle the disadvantage of the nozzle is that the gas flow field in the nozzle is unevenly distributed, and turbulence easily occurs at the edges and corners, which will hinder the acceleration of particles and cause particles to accumulate inside the nozzle. Fig. 3 shows the velocity cloud diagrams of a circular nozzle (*a*) and a rectangular nozzle (*b*) with throat cross sections; it can be seen from the fig. 3 that the velocity in the central area of the circular nozzle is greater than that of the rectangular nozzle. Moreover, the viscous boundary layer effect is better than that of a rectangular nozzle, and the effective

✉ *Tan Kun*
tankun09@126.com

[1] *National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine*

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flow area is large. Summarizing the above advantages, this article chooses a nozzle with a circular throat section.

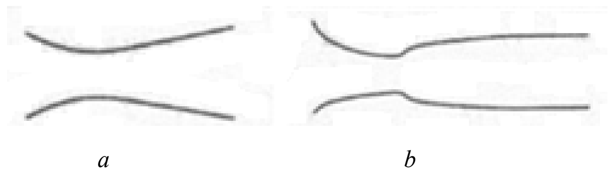

Fig. 1. (*a*): Cone-shaped nozzle; (*b*): Bell-shaped nozzle

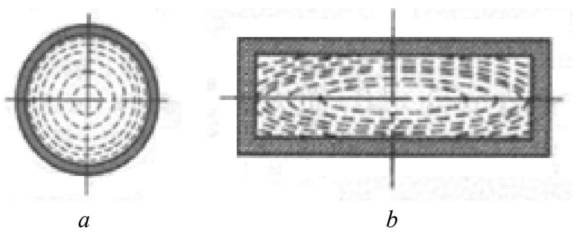

Fig. 2. (*a*): The throat has a circular cross-section; (*b*): The throat has a rectangular cross-section

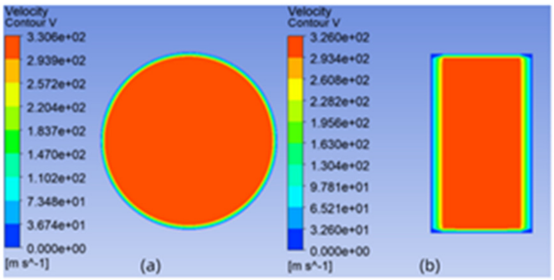

Fig. 3. Throat gas velocity diagram of circular nozzle (*a*) and rectangular nozzle (*b*)

This article proposes a right-angle cold spray nozzle, as shown in Fig. 4; the characteristic of this nozzle is that it can change the direction of the air flow inside the nozzle to spray special parts. The parameters of the right-angle cold spray nozzle are shown in Table 1. The right-angle turning radius of the throat is $R = 5$ mm.

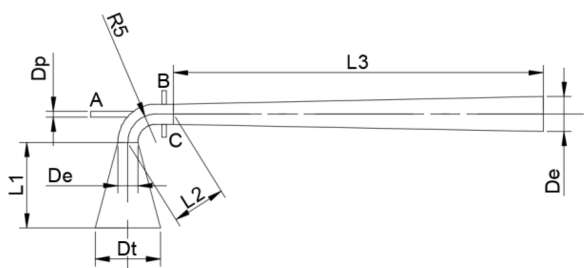

Fig. 4. Parameters of right-angle cold spray nozzle

Table 1. The design parameters of the right-angle cold spray nozzle are as follows

Parameter	D_t	D_i	D_e	D_p	L_1	L_2	L_3
Value/mm	3.5	11.5	6.06	1	15	6.9	65

Five types of particles are accelerated in a right-angle cold spray nozzle at different particle entrances. The *A*, *B*, and *C* entrances of particle injection are shown in Fig. 4; the pressure inlet is 1.2 Mpa, the gas temperature is 500K, and the acceleration gas is nitrogen, the spray particles are: Al (25um), Al6061 (20um), Cu (20um), Ni (20um) and Zn (20um).

2 Simulation results and analysis

2.1 Analysis of the airflow field inside the right-angle nozzle

Fig. 5 shows the velocity flow field cloud diagrams of right-angle nozzles with three different particle entrances. It can be seen from the figure that The maximum speed of the air flow in the right-angled nozzle at particle entrance *A* is 663.4 m/s; the maximum speed of the air flow in the right-angled nozzle at particle entrance *B* is 643.6 m/s; the maximum speed of the air flow in the right-angled nozzle at particle entrance *C* is 652.8 m/s; among them, the speed of the right-angle nozzle of particle entrance A is the largest; the maximum airflow speed areas of the right-angle nozzle of the three particle entrances are all it is located at the center of the exit, indicating that the gas in the right-angle nozzle is always in an accelerated state and does not reach the maximum speed before the nozzle exit. This is the same as the result in the study in reference [8].

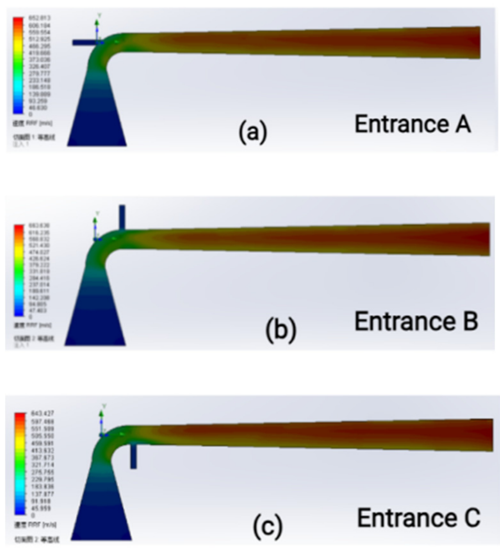

Fig. 5. Velocity flow field cloud diagram inside the right-angle cold spray nozzle with different spray particle entrances

It can be seen from Fig. 5(*a*) that there is an obvious coupling phenomenon between the particle entrance airflow of the right-angle nozzle at particle entrance B and the airflow after 90° turning, so that the speed of the airflow in the expansion section of the nozzle is symmetrically distributed along the axial direction; particle entrance *A* and for the right-angle nozzle *C*, the coupling between the airflow at the particle entrance and the airflow after 90° turning is small, resulting in the high-speed zone inside the nozzle located in the upper part of the nozzle expansion section, showing an asymmetric distribution, but as the right-angle nozzle expansion section as the length increases, the velocity distribution of the airflow gradually becomes symmetrical, so at the end of the right-angle nozzle; due to the influence of the viscous boundary layer, the velocity near the inner wall of the nozzle is lower and the velocity in the center area is larger.

2.2 Analysis of particle velocity in right-angle nozzle

Fig. 6 shows the velocity characteristic curves of five types of particles in right-angle nozzles with different entrances. It can be seen from the figure that the five types of particles are accelerated in the right-angle nozzle until they flow out from the nozzle outlet. This is different from that in Fig. 5 the results of the velocity flow field nephogram inside the right-angle nozzle are the same; the speed of the five kinds of particles is smaller than the speed of the gas, because the acceleration of the particles in the right-angle nozzle is driven by the drag force of the high-speed gas in the nozzle. During the acceleration of the particles in the right-angle nozzle. There is friction, which satisfies Newton's second law. The velocity curves of the five types of particles in Fig. 6 represent the acceleration of the particles. The particles move with decreasing acceleration in the right-angle nozzle. From the analysis of the smoothness of the curve, the right angle of the particle entrance *A* the velocity curve of the cold spray nozzle is relatively smooth, followed by the particle entrance *B* and *C*. Under the same working conditions, the velocities of the five types of particles are different, which is determined by the physical properties of the particles themselves.

As shown in Fig. 7, the velocity characteristic curves of five types of particles in right-angle nozzles with different particle entrances; it can be seen from the fig. 7 that the particle entrance A right-angle nozzle has the best acceleration effect on the particle, and the speed of the particles can reach the maximum value; because the particle entrance is located on the left side of the throat, which increases the acceleration time and distance of the particles, so that the particles are always accelerated when they reach the exit of the right-angle nozzle. This is the expected result of the study; it shows that the expansion section of the right-angle nozzle has the length affects the time it takes for the particles to be accelerated, thus determining the maximum velocity of the particles in the right-angle nozzle.

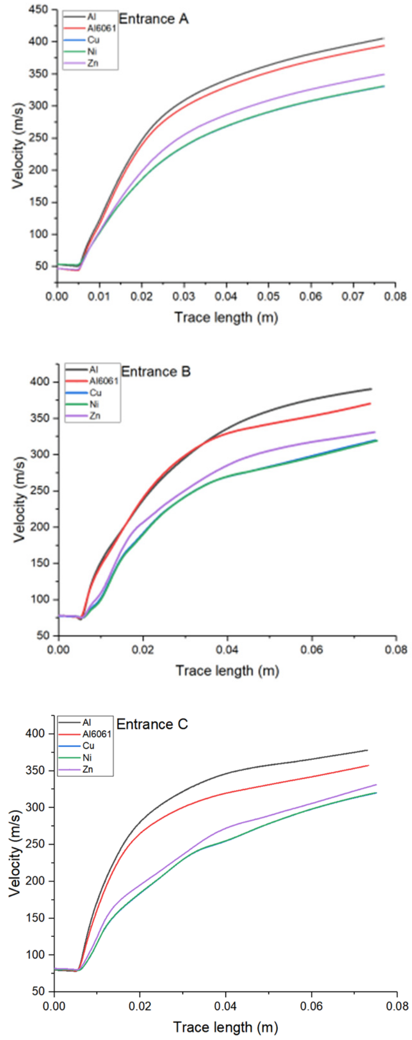

Fig. 6. Velocity characteristic curves of five types of particles in right-angle nozzles with different entrances

Fig. 8 shows the accelerated flow conditions of five types of particles in right-angle nozzles with different particle entrances. From Fig. 8, it can be seen that the right-angle nozzle with particle entrance *C* has the worst acceleration effect on particles, and the location of the particles flowing out of the nozzle offset from the center of the nozzle outlet; the right-angle nozzle at particle entrance *A* and *B* has a better acceleration effect on particles. The outflow position of the particles is close to the center of the nozzle outlet. However, according to the analysis of the flow of particles in the right-angle nozzle, the particles the accelerated particles in the right-angle nozzle at the entrance *B* deposit multiple times on the inner wall of the right-angle nozzle, resulting in the loss of kinetic energy of the particles, which is detrimental to the acceleration of the particles; combined with the velocities of the five types of particles in the right-angle nozzle in Fig. 7 analysis shows that it is better to choose the right-angle nozzle with particle entrance *A*.

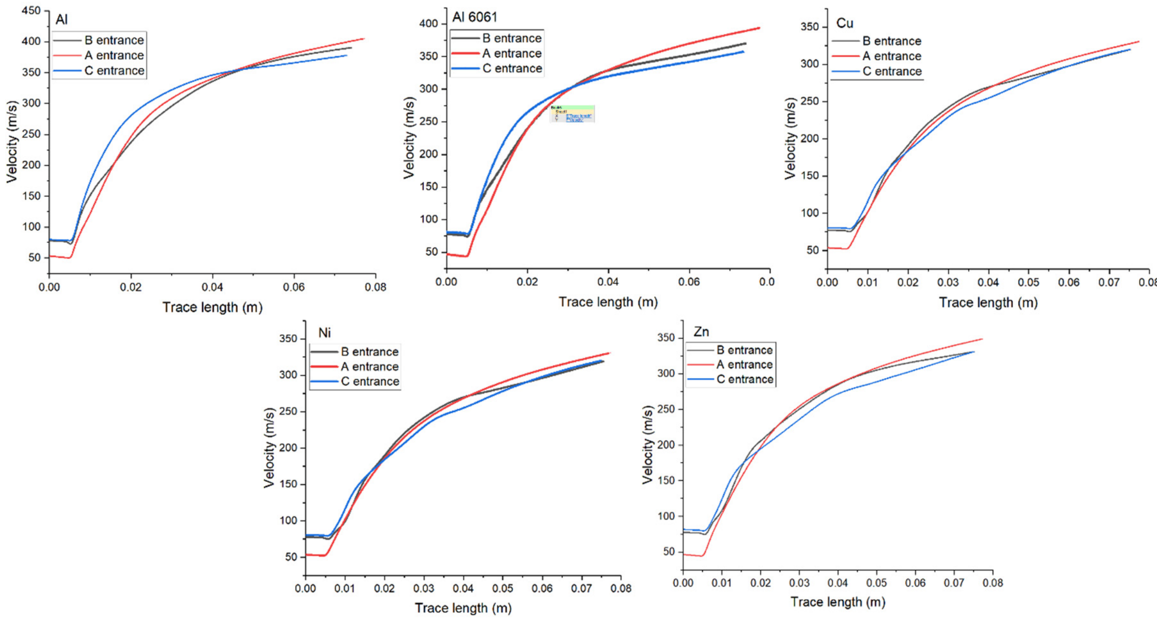

Fig. 7. Velocity characteristic curves of five types of particles in right-angle nozzles with different particle entrances

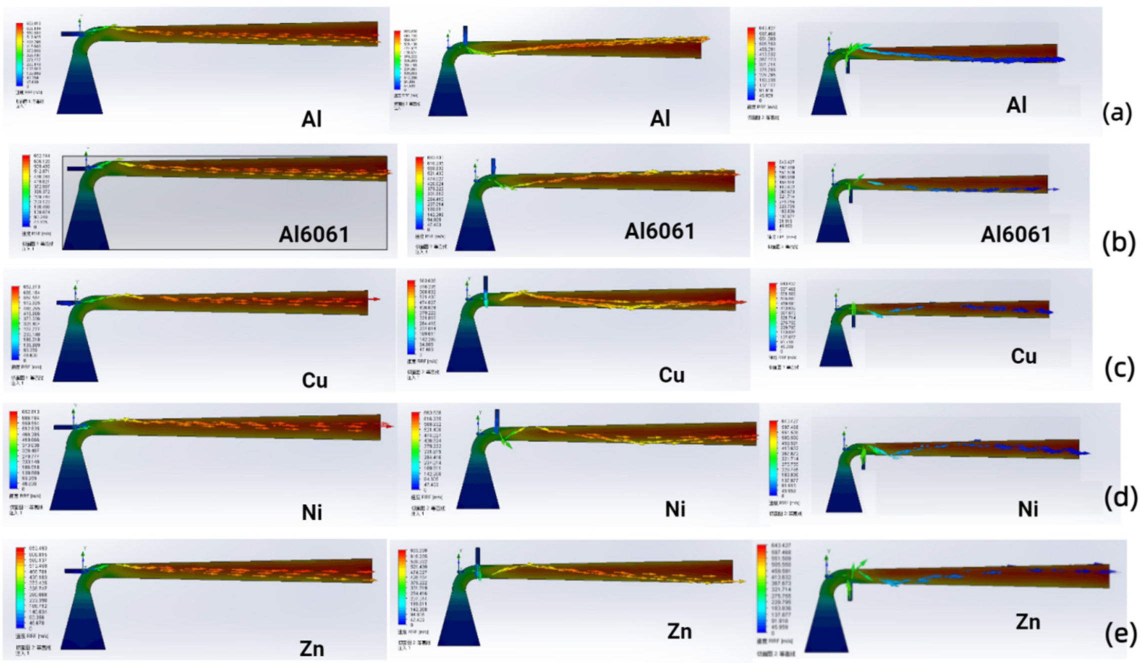

Fig. 8. Accelerated flow conditions of five types of particles in right-angle nozzles with different particle entrances (*a*): Al; (*b*): Al6061; (*c*): Cu; (*d*): Ni; (*e*): Zn

3. Conclusions

1. The exit center velocity of a circular nozzle with the same throat section is greater than that of a rectangular nozzle; the viscous boundary layer effect is better and the effective flow area is larger, so the circular nozzle has a better effect than the rectangular nozzle.

2. The maximum speed of the airflow near the exit of the right-angle nozzle at particle entrance *A* is 663.4m/s. The five types of particles accelerate best in the right-angle nozzle at particle entrance *A*.

3. The particle entrance A right-angle nozzle can effectively prevent particles from colliding inside the right-angle nozzle, thereby reducing the loss of kinetic energy during the acceleration of particles in the right-angle nozzle.

4. The maximum speed of the right-angle nozzle airflow for three different entrances is located near the outlet, which indicates that the airflow does not reach the maximum speed before the outlet. It is recommended to further study and discuss the impact of the length of the expansion section on the speed of the accelerating gas and spray particle.

Acknowledgements

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Аналіз входу частинок розпилювача в прямокутну форсунку холодного розпилення на основі CFD

Кун Тан[1]

[1] *Національний аерокосмічний університет ім. М.Є. Жуковського "Харківський авіаційний інститут", Харків, Україна*

Анотація. *Технологія холодного розпилення - це технологія твердотільного осадження, а сопло є важливою частиною системи холодного розпилення. У цій статті запропоновано прямокутне сопло. Особливістю цього сопла є те, що воно може змінювати напрямок потоку газу всередині сопла для реалізації розпилення на поверхні спеціальних деталей; досліджено прискорення частинок прямокутним соплом з різними входами частинок. Результати показують, що вихідна центральна швидкість прямокутного сопла з круглим перерізом горла більша, ефект в'язкого прикордонного шару кращий, а ефективна площа циркуляції більша; максимальна швидкість повітряного потоку біля виходу прямокутного сопла на вході частинок А становить 663. 4 м/с; він також може ефективно уникнути осадження частинок всередині прямокутного сопла, тим самим зменшуючи втрати кінетичної енергії під час прискорення частинок у прямокутному соплі; дослідження структури нової прямокутної форсунки для холодного розпилення може слугувати посиланням на насадку технології холодного розпилення Opinion.*

Ключові слова: *холодне розпилення, прямокутне сопло, вхід частинок, швидкість.*