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Deposition of multicomponent coatings by Cold Spray

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ABSTRACT

Cold Spray multicomponent coatings are deposited by a new powder injection method that consists of separate injection of each component of the powder mixture into a different zone of the carrier gas stream. Temperature and velocity of 10–40 μm-sized aluminium and copper particles at the nozzle outlet are calculated. It is shown that these values depend considerably on the location of the point where the powder was injected into the gas stream. The method is experimentally validated by producing a composite aluminium–copper coating.

1. Introduction

Cold Spray is an effective way to produce powder coatings. Due to its relatively low temperatures the process allows minimizing or even eliminating oxidation of the spray material that otherwise affects the coating characteristics and properties [1].

Deposition of multicomponent coatings is one of the most important objectives in Cold Spray pursued by researchers and practitioners working in the field. Various composite metal and cermet coatings have been successfully deposited [2–5]. The obtained composite coatings can be post-treated to modify their physical and chemical properties. Composite coatings are usually sprayed from preliminarily prepared powder mixtures. Although this method is straightforward, it has several drawbacks. The first major drawback is the impossibility to change the components ratio in the powder mixture during the spraying process. This makes it impossible to spray coatings with through-thickness compositional gradient. The second major drawback is defined by the peculiarities of the physical phenomena involved in Cold Spray. It is known that for effective cold spraying, critical values of the particle in-flight parameters such as velocity and temperature must be reached. Absolute values of these parameters are strongly dependent of the nature of the spray material [2,6]. Another point of importance is that heating particles above the critical temperature disturbs the spraying process. For example, the over-heated carrier gas provokes aluminium particles sticking together in the stream and to the nozzle. In the case of the preliminarily prepared powder mixtures, particles achieve certain velocity and temperature that may be appropriate for spraying one component but ineffective for another. Taking into account the above points, one may conclude that using preliminarily prepared powder mixtures is not always convenient to spray composite coatings, especially if the components are characterized by considerably different spraying parameters.

Therefore, the most effective method to spray multicomponent coatings would be heating and accelerating each component under spraying conditions appropriate for this particular component. In the present study, one of the ways to reach this goal is proposed, namely, the separate injection of each component into a different zone of the carrier gas stream.

2. Influence of the location of the powder injection point on the particle parameters

The Cold Spray prior art proposes two methods of powder injection into the gas stream. In the first method, particles are fed into the subsonic part of the nozzle under a pressure exceeding the stagnation pressure of the carrier gas p_0 (Fig. 1a). Stagnation pressure of the carrier gas is typically in the range p_0 = 1.0–3.0 MPa. Particles injected into the prechamber are carried by the gas stream along the nozzle and are heated and accelerated to high velocities. This method is largely employed, e.g. [2,7]. In the second method, particles are injected into the diverging supersonic part on the nozzle beyond the critical section (throat) (Fig. 1b) and thus their heating and acceleration take place only in the supersonic part. This injection method is employed in a number of Cold Spray apparatus [2,8].

It is natural to suppose that particle parameters at the nozzle outlet depend strongly on where the injection point is located: in the converging subsonic or diverging supersonic part of the nozzle.

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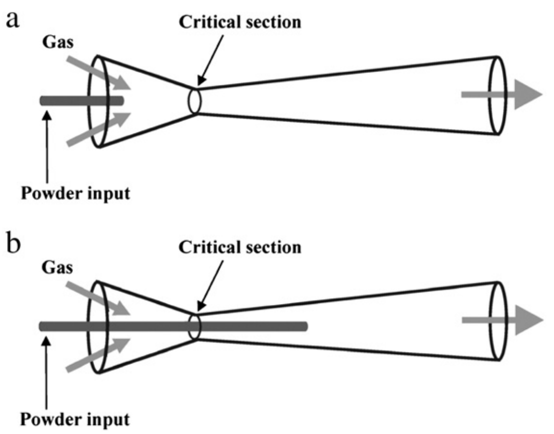

Fig. 1. Nozzles with the different location of the powder injection: in (a) the subsonic and (b) supersonic parts.

Numerical calculations were carried out to assess the influence of the location of the powder injection on the particle in-flight parameters. The calculation method used to this end is described in details in [2]. The calculations were performed for 10, 20 and 40 μm aluminium particles accelerated in an axisymmetric Laval nozzle with geometry specified in Table 1.

The carrier gas was nitrogen that is typically used in Cold Spray, the pressure was 1.5 MPa. Two locations of the powder injection were considered: in the subsonic (first injection point) and supersonic part of the nozzle at a point 50 mm beyond the throat (second injection point). The particle initial temperature was 300 K.

Fig. 2a,b shows temperature and velocity distributions of aluminium particles of different sizes along the nozzle axis injected at the two different points at the gas stagnation temperature T_0=473 K.

One can see that particles injected at the first point reach the maximum temperature in the subsonic part. In the supersonic part they are accelerated while their temperature drops down. Another situation is for particles injected into the supersonic part. The temperature of d_p>10 μm particles at the nozzle outlet differs significantly from that of the particles injected at the first point (Fig. 2a) while the particle velocities are much less dispersed (<10%) as it can be seen from the comparison between curves 2, 3 and curves 5, 6 in Fig. 2b.

Influence of the gas stagnation temperature and the location of the powder injection on the particle outlet velocity and temperature are shown in Fig. 3a,b.

One can see that the temperature of 20 and 40 μm particles at the nozzle outlet is strongly influenced by the location of the powder injection. For example, the gas stagnation temperature of 475 K is needed for 20 μm-sized particles injected at the first point to reach the temperature of 325 K at the nozzle outlet. In the case of injection at the second point, 20 μm-sized particles reach the outlet temperature of 325 K at the gas stagnation temperature of 675 K. For 10 μm and smaller-sized particles, the values of the outlet temperature are close to each other for both injection points. However, the plot in Fig. 2a shows that 10 μm-sized particles injected at the first point are heated in the subsonic part to the gas stagnation temperature and then cooled.

Table 1

Geometry characteristic	Value
Total length of the nozzle	145 mm
Length from the throat to the second powder injection point	50 mm
Diameter of the critical section (throat)	3 mm
Outlet diameter	6.5 mm
Length of the converging part of the nozzle	20 mm

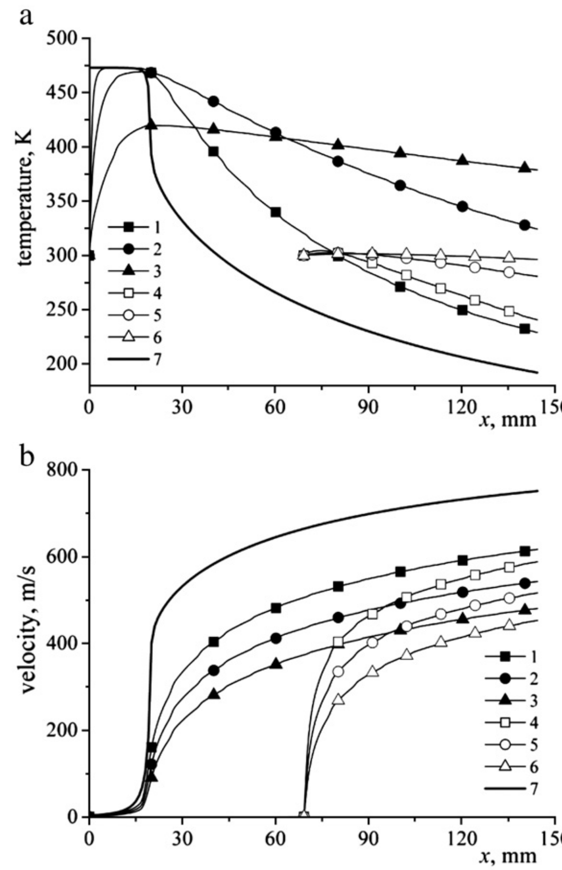

Fig. 2. Axial temperature and velocity distribution of the gas and of the 10, 20 and 40 μm-sized aluminium particles inside the nozzle for the two locations of the powder injection: in the subsonic (1st point) and supersonic parts (2nd point) of the nozzle, *x* — distance along the nozzle axis: (a) particle temperature and gas static temperature; (b) particle and gas velocity. Curves 1, 2, 3 correspond to 10, 20, 40 μm particles, 1st point of injection; curves 4, 5, 6 correspond to 10, 20, 40 μm particles, 2nd point of injection; curve 7 corresponds to the gas parameters.

Thus, the numerical simulations show that under certain conditions, the location of the powder injection has strong effect on the particle in-flight temperature. This effect may be used for spraying multicomponent coatings from powders with significantly different spraying parameters. By simultaneously injecting the different components at different points of the nozzle one may achieve a dense multicomponent coating as each component would have optimal in-flight characteristics.

3. Equipment and materials

To verify experimentally the simulation results on the separate injection of the powder components into the stream, an axisymmetric nozzle with two points of powder injection was developed and fabricated (Fig. 4).

A particular feature of the new nozzle design is that a barrel with a constant cross-section is mounted to its diverging part. The major geometric characteristics of the nozzle (length, cross-sectional area of the throat and of the outlet, distance between the throat and the second injection point) are specified in Table 1. This nozzle was integrated with the Cold Spray equipment as shown in Fig. 5. Two separate feeders were used for injecting powder in the subsonic and supersonic parts of the nozzle.

This equipment allows varying gas stagnation pressure in the range of 1.0–2.0 MPa and gas stagnation temperature in the range of 300–850 K.