THE EFFECT OF SUBSTRATE ON POWDER CONCENTRATION DISTRIBUTION IN COAXIAL LASER CLADDING

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Summary A steady numerical 3D model for coaxial laser cladding has been developed to predict powder concentration distribution from coaxial nozzle to substrate. Substrate has been considered as boundary condition of the numerical model. Powder concentration distribution has been investigated with various melt pool sizes. According to the results, gas flow field, as well as powder particles rebound by substrate, plays an important role in the powder concentration distribution.

INTRODUCTION

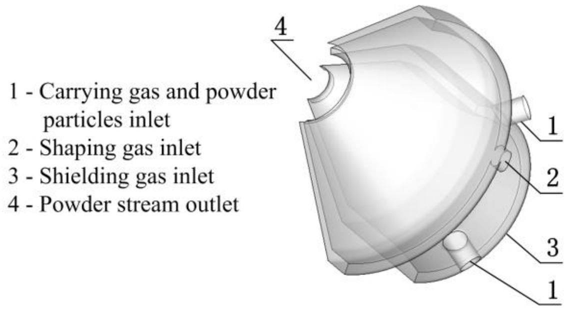
Laser cladding is an important surface modification technology by introducing metal powder into the melt pool. Laser cladding with coaxial powder injection attracts more and more attentions because it has advantages of low dilution, good property of alloying, non-directional, multi-adjustable parameters, and good quality of cladding layers, etc [1].

During coaxial laser cladding process, powder flow, gas flow and the laser beam interacts with one another in the space between coaxial nozzle and the substrate. Powder concentration distribution, especially close to the surface of substrate, has an important impact on the quality of laser cladding. Much research has been performed to explore the relationship between powder concentration distribution and process parameters, such as powder feed rate and inlet gas velocity [2-3]. However, up to now, there are few investigations on the effect of substrate on powder concentration distribution. In this paper, a steady numerical 3D model for coaxial laser cladding is used to study the effect of substrate on powder concentration distribution from the coaxial nozzle to substrate.

NUMERICAL MODEL

In the powder stream, carrying gas, shaping gas and shielding gas should be considered as the continuous phase, and powder particles act as a discrete phase in the continuous phase [4]. The continuous phase modeling is based on Navier-Stokes equations which are solved for each time step. The trajectory of a discrete phase powder particle is calculated by force balance equations in Lagrange reference frame. Mass, momentum and energy can be exchanged between discrete phase and continuous phase.

(a) Coaxial nozzle



(b) Schematic of numerical model

Fig 1 Coaxial nozzle and schematic of numerical model

The coaxial nozzle and schematic of numerical model is showed in Fig.1. Because the cladding width is several orders of magnitude smaller than the width of substrate, the substrate surface is simulated as plane. Since the geometry and boundary conditions are symmetric, half of geometry can be used as computational domain to save calculation time.

Air as shaping gas, shielding gas and carrying gas is used during the laser cladding process. The gas velocity at shaping and shielding gas inlet is 5m/s, while at carrying gas inlet is 1m/s. WC powder feed rate at the inlet is 4 g/min. The substrate is located 10mm below the outlet of the coaxial nozzle.

RESULTS AND DISCUSSION

Substrate can be considered as boundary condition of the numerical model. At the beginning of the laser cladding process, the substrate acts as an obstacle to the gas flow, and powder particles rebound when they reach the substrate. When the melt pool is formed, the thermal exchange between liquid metal and gas flow should be considered. Moreover, powder particles have been absorbed by the melt pool instead of rebounding by substrate. These particles are not considered at the next time step in the numerical calculation.

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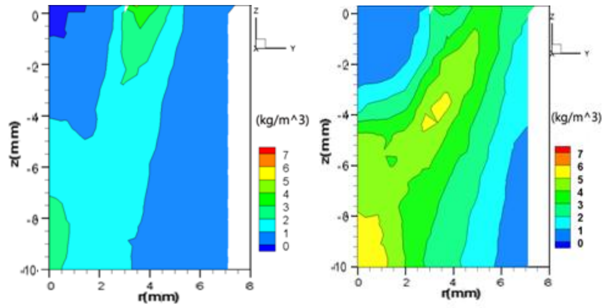


(a)without substrate (b)with substrate

Fig.2 Powder concentration distributions without and with considering the effect of substrate

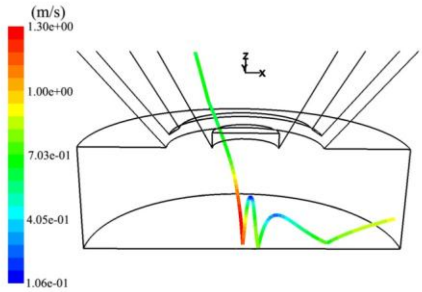
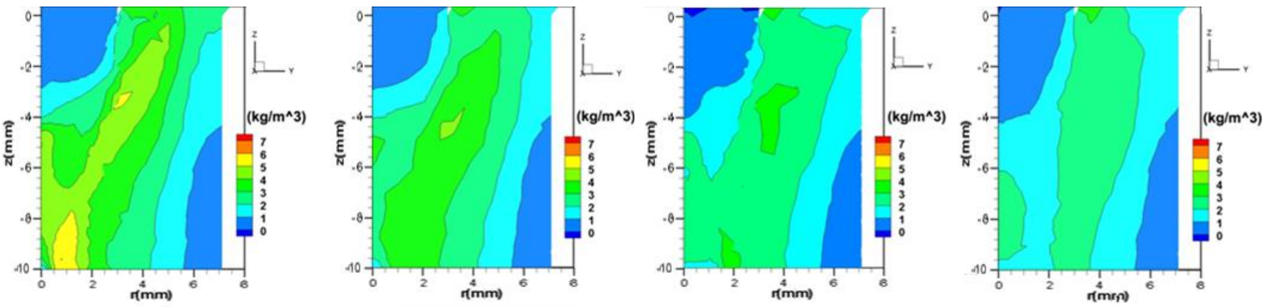


Fig.3 Rebound of a powder particle on substrate

The results show that, due to the outlet of coaxial nozzle perpendicular to the substrate, a high-pressure and low-velocity air mass is formed in the center of axisymmetric air flow on the substrate surface, resulting in the change of air flow direction and powder concentration distribution. Fig.2 shows powder concentration distribution along longitudinal cross-section considering the effect of substrate or not. The powder concentration near the substrate increases more than 2 times when considering the effect of substrate, not only because of the changes of gas flow field, but also the powder particles rebound by substrate. Fig.3 shows powder particle close to the central axis can rebound many times within the space near the central axis due to its low radial velocity.



(a) 1.0mm (b) 2.0mm (c) 3.0mm (d) 4.0mm

Fig.4 Powder concentration distributions along longitudinal cross-section with various melt pool diameters

When the melt pool is formed, it affects gas flow due to its high temperature, which results in the change of the powder concentration distribution correspondingly. But according to the simulation results, the velocity and pressure of gas flow have been changed less than 0.1% considering the thermal effect of melt pool. The reason is that the size of melt pool is relatively small and the interaction time is short. Therefore, the thermal effect of melt pool on the powder concentration distribution can be ignored. But the size of melt pool deeply affects the powder concentration distribution, as is shown in Fig 4. For all cases, the powder concentration above substrate is smaller because of the absorption of powder particles by melt pool. When melt pool becomes larger, the effect of particle rebound is weaker, and gas flow field becomes the key factor to determine the powder concentration distribution. As the result, when the size of melt pool is large enough, the powder concentration distribution is similar to the case in which substrate is not considered, except that the powder concentration is much smaller near the melt pool surface.

CONCLUSIONS

Effects of substrate on powder concentration distribution have been investigated based on a 3D numerical model of laser cladding. A low-velocity and high-pressure air mass is formed due to the existence of substrate, resulting in the change of powder concentration accordingly. Powder concentration distribution is mainly influenced by the size of melt pool, and to a much less extent, by the thermal exchange between melt pool and gas flow. When the size of melt pool is large enough, gas flow field becomes a key factor to determine the powder concentration distribution.

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