

Modeling of bead formation process during laser cladding

S L Stankevich, R S Korsmik and E A Valdaytseva

Peter the Great Saint-Petersburg Polytechnic University, 195251,
Saint-Petersburg, Russia

E-mail: s.stankevich@ilwt-stu.ru

Abstract. The article shows a numerical solution to the problem of heating of the powder particles and the substrate with the limited sizes by laser radiation. The powder transfer coefficient and the dimensions of the cladding bead are calculated based on estimates of the size of the molten pool.

1. Introduction

The cladding technology has found wide application in the field of repair, restoration, protective coatings and the creation of new products with special surface properties [1], due to its uniqueness and cost-effectiveness. Laser cladding is superior to other cladding technologies due to small areas of thermal influence, therefore microstructure and strength properties of the material remain unchanged.

Many parts of modern industrial equipment (parts of turbodrills, rotors of screw and centrifugal compressors, plungers and rods of artificial lifts, shafts, bearings, etc.) fail because friction and aggressive environment cause their surface to wear. This problem increases with specific load. This makes the works aimed at creation of functional coatings and devoted to reconditioning and reinforcing of the working surfaces of rapidly wearing parts very important [2]. Laser cladding consists of a few interrelated physical processes: the interaction of laser radiation with metal powder and substrate, heating and melting of the filler material and the substrate, etc. The bead is formed when the powder makes contact with the zone of the melt, is mixed with the base metal in a thin layer and undergo subsequent solidification. The powder jet is usually wider than the area of the melt so the powder of the additive does not fall into the molten pool and is blown away from its surface [3].

2. Heating of the powder particles

Consider the heating process of a gas-powder jet. The distance from the nozzle to the substrate is small while the velocity of powder particles in a stream of protective gas is high. To simplify the calculation, we assume that the trajectory of the particle is rectilinear, and the distribution of powder particles in the jet is uniform. The intensity distribution in the spot of the fiber optic laser is uneven and represents a Gaussian function. Knowing the distribution of the intensity and the trajectory of the powder particles, it is possible to estimate the heat flux affecting a particle of powder. To evaluate the heating of the powder particles we use the solution of the problem of temperature distribution in a homogeneous sphere of radius R with the initial temperature T_0 in the case of a constant heat flux with density q on the surface [4]:

$$T(r,t) = T_0 + \frac{qR}{\lambda} \left(\frac{3\chi t}{R^2} - \frac{3R^2 - 5r^2}{10R^2} \right) - \frac{2q}{\lambda R r} \sum_{i=1}^{\infty} \frac{\sin(\mu_i r)}{\mu_i^3 \cos(R\mu_i)} \exp(-\chi \mu_i^2 t), \quad (1)$$



where χ is thermal diffusivity; λ is thermal conductivity and μ_i is the positive root of the equation $\operatorname{tg}(R\mu) = R\mu$.

The figure 1 shows the distribution of temperature field inside a powder particle with a diameter of 100 μm with physical properties of Inconel alloy 625. The figure shows that the surface melting of the powder particles is possible.

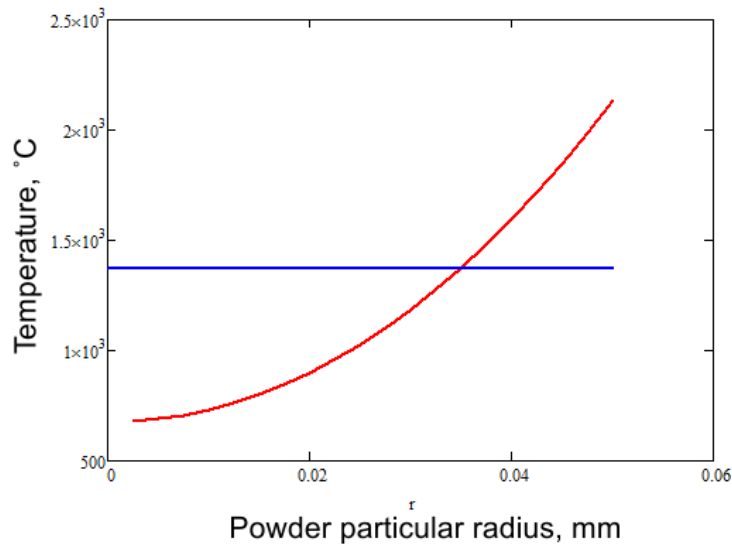


Figure 1. The distribution of temperature field within the powder particles after the interaction with laser radiation (red line shows the temperature change from the center to the periphery; the blue line is the melting temperature).

The temperature of the powder particles varies depending on the particle's path length in the zone of action of laser radiation as expected. The scheme of heating of particles in the gas-powder stream is shown in figure 2(a) and figure 2(b) shows surface temperature distribution of the powder particles at the time of contact with the substrate.

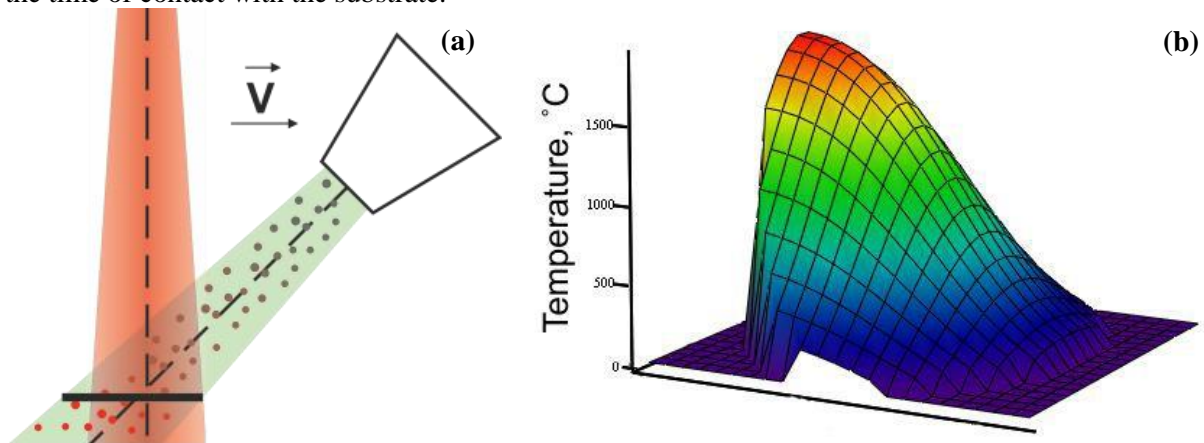


Figure 2. Scheme of the heating process of gas-powder jet by laser radiation (black line is the substrate level) (a); surface temperature distribution of the powder particles at the time of contact with the substrate (b).

3. Heating of the substrate by laser radiation

Since the defocused laser beam is a distributed heat source:

$$q(x, y) = k_{\text{abs}} I(x, y, z_0), \quad (2)$$

where k_{abs} is an absorption factor.

Heating of the substrate can be described as the ultimate state of the process of heat spreading from this source moving with constant velocity on the surface of a semi-infinite body relative to the moving XYZ coordinates [5]:

$$T(x, y, z) = \int_{-r}^r \int_{-r}^r \frac{q(x_i, y_i)}{2\pi\lambda R(x - x_i, y - y_i, z)} \exp\left(-\frac{Vx}{2\chi} - \frac{VR(x - x_i, y - y_i, z)}{2\chi}\right) dx_i dy_i. \quad (3)$$

Taking into account the limited size of the substrate we will use the known method of introducing fictitious heat sources. Then the resulting thermal field in the product takes the form:

$$T_{\text{fin}}(x, y, z) = T(x, y, z) + T(x, y + 2r, z) + T(x, y - 2l, z) + T(x, y, z + 2h). \quad (4)$$

4. Measurement of the cladding bead size

The cladding bead is formed by the molten powder mixed with the base metal into the molten pool. Assuming that powder transfer coefficient is the ratio of the surface area of the molten pool to the area of the fall of the gas-powder jet on the substrate it is possible to determine the amount of powder from which the bead is formed. We shall also take the width of the cladding bead as the width of molten pool. Then, considering that theoretical and practical [1] researches have shown that the cladding bead is ellipsoidal in cross-section, it is easy to calculate the height h of the bead:

$$h = \frac{2S}{w\pi}. \quad (5)$$

The resulting model was verified experimentally in the case of cladding of Inconel 625 powder on a substrate of heat-resistant alloy. Experimental and calculated values of the width of cladding bead and micro section are shown in figure 3. The experimental height of the bead is $h_t = 0.8$ mm and the calculated value is $h_t = 0.79$ mm.

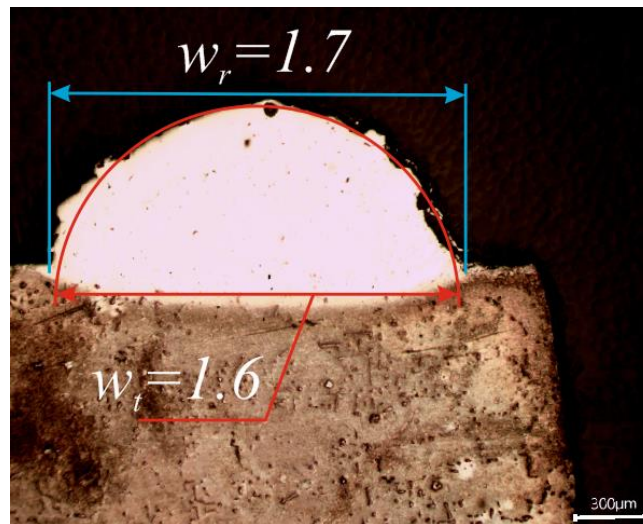


Figure 3. Metallographic sample of the cladding bead with parameters: power = 700 W; powder consumption = 4 g/min; speed – 5 mm/s; beam diameter on the substrate is 1.3 mm; (red line shows the calculated value of w_r and w_t experimental and calculated values of the width of the molten pool, respectively).

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