Modeling of temperature patterns and hardness of surfaces obtained by additive technique

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***Abstract*—Temperature patterns and hardness of surfaces produced by laser cladding is modeled. The mathematical model includes the description of all important physical phenomena taking part in the process. Experimental values of resultant hardness are also provided.**

Keywords—laser cladding, mathematical model, numerical analysis, experimental data, hardness

I. INTRODUCTION

Laser cladding [1] is a modern technology mainly used for improving quality and physical parameters of steel surfaces. The layer of deposited material represents a very good protection against wear, corrosion, fatigue and extends the service life of parts treated in this manner.

The process of cladding is explained in Fig. 1. The laser head moves in the direction perpendicular to the drawing.

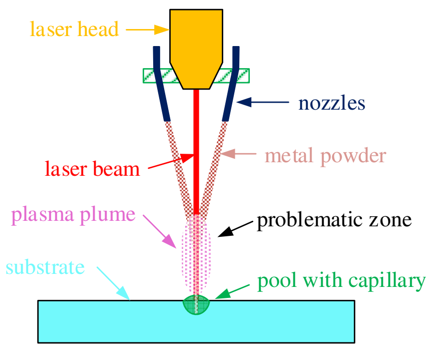

Fig. 1: Basic arrangement of process. Problematic zone denotes area where delivered powder crosses path of laser beam and where also plasma plume occurs.

The substrate is located below the laser head. The beam continuously heats its surface and also the metal powder that is sprayed to the exposed spot using one or more nozzles. At the irradiated spot, the substrate and powder are heated. The heat-affected area is, however, small, so that the power of the laser beam makes fast their temperature high enough for melting both the surface layer of the substrate material and the powder. Subsequently, a pool of melt is formed there with a thin capillary in its center. The capillary contains evaporated particles of metal that form a cloud of plasma above the pool. Its existence may lead to a certain decrease of the power of the laser beam, which may be significant in some cases, when a part of this power is absorbed here and another part is reflected back.

After shifting the substrate (or the laser head), the pool begins to solidify. In this manner, the track is successively formed. Several tracks deposited next to one another then produce the covering layer.

II. MATHEMATICAL MODEL AND ITS SOLUTION

The mathematical models of particular phenomena include:

- The temperature field generated by the laser beam described by the heat transfer equation [2] and supplemented with the correct boundary condition.
- The field of flow providing the distribution of velocities of particles of melt in the pool. During this turbulent process, some ionized particles of material evaporate and penetrate through the thin capillary above the substrate, forming there a plasma plume. The interaction between the temperature and flow fields is here very strong and must be solved in the hard-coupled formulation [3].
- Effects of the plasma plume influencing the power delivered by the laser beam to the irradiated spot. A part of the laser power is absorbed in the plasma plume, another part is reflected back [4].
- Field of mechanical strains and stresses providing the distribution of these quantities in the deposited layer. This model is relatively complicated and must incorporate material nonlinearities, full geometry and works with the theory of large deformations starting from the Green-Lagrange strain equations [5].
- Hardness of the surface. It normally follows from the continuous cooling transformation (CCT) diagram of the deposited material. These diagrams are, however, available mostly for massive hardening (for instance by induction heating), while for laser heating, the final hardness must be found experimentally.

The numerical solution of the model is realized by an own improved algorithm.

III. ILLUSTRATIVE EXAMPLE

As an example, authors present a 3D model of laser cladding of four concentrated circular tracks on a cylindrical substrate. The arrangement is shown in Fig. 2.

The substrate is made of steel S355, while the make of the metal powder is H13. The power delivered by the laser beam to the surface of the substrate was 360 W. The radius of the laser beam was 2 mm. The velocity of the laser head was 30 mm/s. The injected powder was delivered at a mass rate of 15 g/min. The ambient (initial) temperature was 25 °C and the modified coefficient of convection that includes also the influence of radiation was $\alpha = 25\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$.

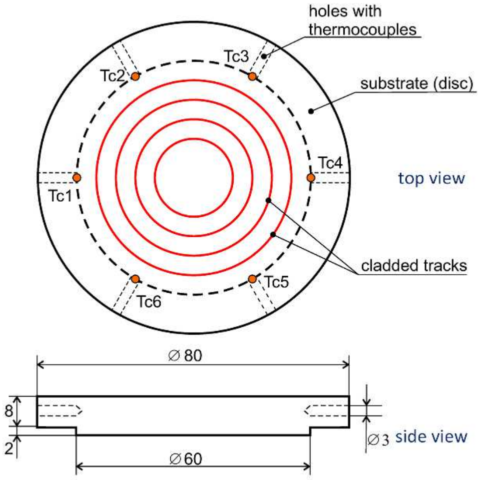

Fig. 2: Solved arrangement: red circles show the axes of four tracks, the positions of thermocouples are marked as Tc1,…, Tc6. All dimensions are given in mm.

We tested two variants denoted as A and B, see Fig. 3. In variant A, all layers were deposited at once from the outer track towards the center. Therefore, most of the heat was generated in the center of the substrate. In variant B, the layers were also deposited from the largest circle to the inner circle, but only by one. In this way, heat could be distributed to the entire volume.

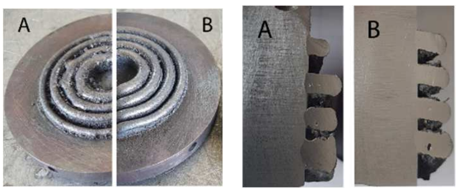

Fig. 3: Two solved variants (left) and cut through particular tracks (right).

Selected results are depicted in the following figures. Figure 4 shows the points where the hardness was measured in case of the variant A. The same was done for the variant B. The distribution of hardness measured in the outermost track for both variants is depicted in Fig. 5. Figure 6 shows the time evolution of temperature at the place of the thermocouple Tc6. The agreement between measurement and modeling is excellent. Finally, Fig. 7 depicts the time evolution of temperature at the measuring point and center of the substrate.

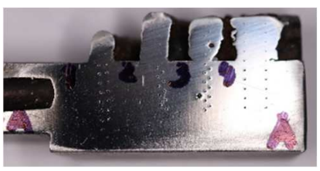

Fig. 4: Points at which hardness was measured.

Based on the model, we can obtain information about the behaviour of the whole system. While at the measured points the temperature waveforms for variants A and B are almost identical and do not indicate any problem, the temperatures in the center of the substrate (generally anywhere in the system), which cannot be easily measured, already show a clear problem. For variant A, there is clearly a problem in heat build-up leading to poor quality and softer filaments, as can be seen in Fig. 7.

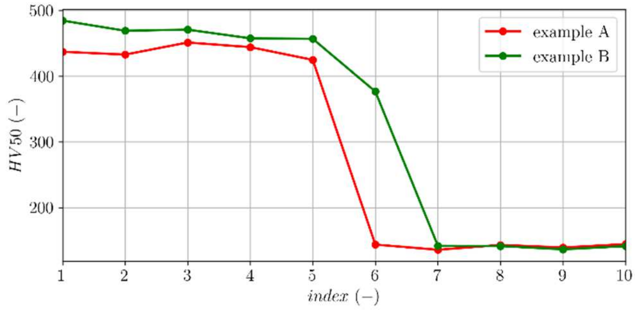

Fig. 5: Hardness measurements - hardness curve for ten measuring points in the outermost track for variants A and B.

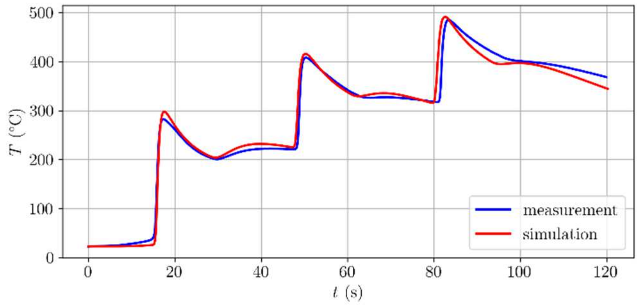

Fig. 6: Time evolution of temperature at thermocouple Tc6 for variant B (see Fig. 2).

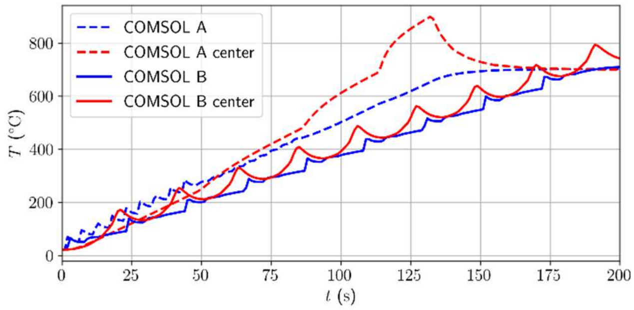

Fig. 7: Temperature waveforms obtained from model at measurement point and at center of substrate.

Acknowledgment

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