

Analysis of the Laser-Cladding Process for Stellite on Steel

A. FRENK, M. VANDYOUSSEFI, J.-D. WAGNIÈRE, A. ZRYD, and W. KURZ

Laser-cladding experiments have been performed with STELLITE 6 powder on mild steel substrates, using a 1.5 kW linearly polarized continuous wave CO₂ laser as a heat source. The clad height, the mass efficiency, the dimensions of the melt pool, as well as the global absorptivity, were measured as functions of the powder feed rate and the scanning speed. A quantitative analytical model of the process is proposed, based on the overall mass and energy balance. It allows the calculation of the mass efficiency and of the global absorptivity, taking into account the incorporation of the powder into the melt pool as well as the energy absorbed by the powder jet and the substrate. It successfully explains the experimental results and demonstrates the role played by the melt pool inclination with respect to the substrate. A processing diagram is given to find rapidly the optimal laser treatment conditions and the desired clad height. It is discussed with respect to the other limiting conditions of the process, the geometrical maximum powder efficiency, the porosity, the dilution, and the maximum power of the laser installation.

I. INTRODUCTION

LASER cladding is a modern process of producing metallurgically well-bonded coatings of a great variety of materials of intermediate thickness (typically between 0.1 and 2 mm). It can produce much better coatings, with minimal dilution from the substrate, minimal distortion of the workpiece, and good surface quality than with other techniques, such as arc welding. Furthermore, with high speed cladding, extremely fine and homogeneous microstructures, characteristic of rapid solidification processes, can be obtained on the surface of massive pieces.¹⁻³

In the past, there have been various contributions which have improved the understanding of the process. As early as 1983, Weerasinghe and Steen⁴ proposed a numerical model for calculating the heat flux in the process. They took into account effects such as shadowing of the particle cloud, heat absorption of the particles, and overlapping of the traces. Later, Steen *et al.*⁵ produced processing maps and qualitatively analyzed the physics of dilution, intertrack porosity, and continuity of clad trace. Hoadley and Rappoz⁶ undertook a detailed two-dimensional (2-D) heat flux analysis, which allowed the computation of the steady-state temperature field, the approximate shape of the melt pool, and the position of the liquid with respect to the laser beam axis. They studied the influence of processing parameters such as laser power and processing speed on dilution and clad thickness. Ollier *et al.*⁷ also considered in their 2-D heat flux calculations melt convection and angle-dependent power absorption for a *p*-polarized laser beam. Picasso and Hoadley⁸ developed a numerical 2-D model for laser remelting and cladding. Convection driven by thermocapillary forces and by the process of particle injection was taken into account. Picasso *et al.*⁹ developed an analytical

model for the cladding process. This model contains all the important elements of the real process and allows calculation of the temperature field under simplified assumptions. Most of these publications were concerned essentially with modeling aspects of the problem, and detailed quantitative comparisons of the experimental results with the predictions of the models were mostly not included.

An optimal setting of the processing parameters is required to achieve the deposition of dense, porosity-free coatings, presenting a good metallurgical bond with the substrate due to some dilution. It is important to minimize this dilution in order to preserve the chemical composition and the properties of the clad. The complexity of the interaction of the many process variables with the product makes the optimization of this process a difficult task, even more so as a quantitative understanding, which is a prerequisite for any rational process development and on-line control, is still insufficient.

The aim of this article is to contribute to a better quantitative understanding of the laser cladding process by in-depth examination of two key phenomena: (1) energy coupling between the laser beam and the workpiece, given by the global absorption, β_g , which takes into account the energy absorption of the substrate and of the powder; and (2) the mass flow or incorporation of the powder into the molten pool. In the following discussion, these two aspects will be treated in some detail. New experimental results will be presented and compared with physical models.

II. EXPERIMENTAL

Figure 1 shows the principal elements of the process as used by the present authors. A high-power CO₂ laser locally remelts the surface of a workpiece. The hard-facing alloy, in powder form, is injected into the molten pool with the aid of a protective gas through a coaxial nozzle. Powder entering the molten pool is completely remelted and mixed within the liquid due to strong convection currents generated by the high thermal gradients at the surface (Marangoni effect¹⁰). A single-clad track is formed by moving the specimen relative to the beam in the *y*-direction, and wider clad areas are obtained by successive deposition of overlapping tracks.

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Karin Nielsen-Saines



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