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Optimisation of refractory coatings realised with cored wire addition using a high-power diode laser

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Abstract

The objective or our research was to obtain refractory alloys using the high-power diode laser (HPDL) coating technique. After optimisation using factorial experiments, two different cladding regimes were clearly distinguished. It was also shown that a very narrow transition zone exists between the two regimes, and, inside this zone, clad layers having a satisfactory compromise between the response functions (surface aspect and cavity presence) were obtained. The main objective of our study, namely, the control of the operating parameters (geometrical and kinematical) to realise adequate coatings, without cavities and having a good surface aspect (for a thickness >1 mm), was also achieved using factorial experiments.

Keywords: Laser; Cladding; Refractory alloys; Factorial experiments

1. Introduction

The valorisation of domestic and industrial refuse and the development of new production concepts, such as “green coal”, e.g., must be made using new technologies, having the main goal to preserve the environment.

Nowadays, on the other hand, technological options must take into account more and more important material stresses, the last ones having for mission to be more competitive without forgetting the economical aspects. Such alloys, which can resist important environmental stress (surface temperature of 400 °C, the presence of halides, carbon or sulphur oxides, etc.), kept the attention of many research laboratories during the last decade, as in the case of nickel-based alloys [1–4]. However, due to the economical aspect, the industry tried lately to guide its choice to the super-ferrite stainless steels.

Currently, we could have the alternative of many cladding techniques, such as MIG process, although the heat-affected zone (HAZ) and the dilution are too significant. In such conditions, choosing laser processes seems to be a better solution, since the HAZ obtained in this case has limited dimensions and the dilution is less than 5%. These coatings must be corrosion resistant, thus guiding our preferences for the adding material to the super-ferrite stainless steel in a cored wire shape.

This kind of technology allows a real flexibility, knowing that the adding material can have various shapes, such as powder, wire, cored wire, strip, etc. As in many industrial cases, economical indicator is the first one to take into account, and using cored wire shape for added material appears to be the most adapted solution from the above-mentioned point of view. Cored wire, due to its constitution (powder having specific composition, placed inside a rolled strip), induces phenomena characterising

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laser–material interactions, which are different from a regular wire used as adding material. Therefore, it becomes important to explore and optimise such type of cladding processes. Using laser techniques in this configuration can lead to the cavities formation at the substrate–coating interface, in a more or less important manner. To reduce (or even eliminate) the negative effects of such a phenomenon, factorial experiments were conducted to optimise the kinetic and kinematical parameters of the employed mounting device.

Three criteria were retained for a suitable response to our goals: cladding height, greater than 1 mm; compact structure for the coatings, meaning free of porosity or cracks; and uniform coating surface. After establishing these important criteria, a factorial experiment was designed for two working angles (30° and 45°) to optimise the geometrical and kinematical parameters that lead to appropriate coating layers. Consequently, it can be said that the main goal of our work is to find an optimum domain for the cladding parameters that should lead to the wanted coatings properties.

2. Experimental configuration

2.1. Materials

The coatings were realised on a steel substrate (type 1.0037, according to NF EN 10025) having the following geometric characteristic: $10\times60\times100$ mm^3. The samples were sanded before the cladding process for the reason of reproducibility.

The adding material is a super-ferrite stainless steel [5], with a cored wire shape having a diameter of 1.6 mm and a chemical composition presented in Table 1.

2.2. Experimental device

A "LASERLINE" diode laser having a maximal power of 1500 W was employed in our study. The cw laser beam is bichromatic (800 and 940 nm of wavelength). After leaving the laser cavity, the laser beam is shaped into a rectangular spot of 2.5×5 mm^2 (Fig. 1).

Due to the cored wire used to realise the coating layers, a reel wire device was also employed. The added amount of wire (the "feeding rate") is controlled by the wire unfolding speed (2.5 to 6 mm/s). The wire is guided towards the interaction zone through a copper nozzle. The spatial position of this nozzle is assured by a four-axis micropositioning

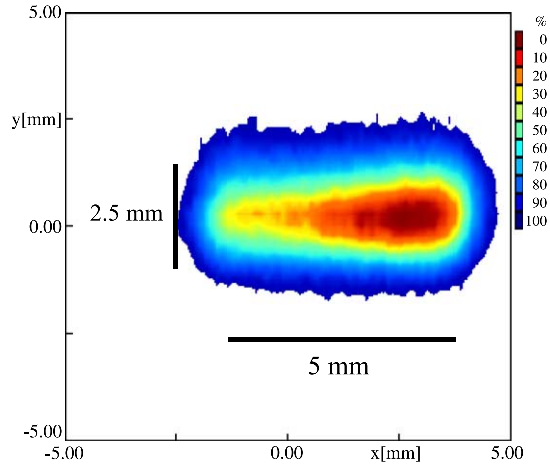

Fig. 1. 2D laser beam energetic repartition, 1500 W.

system, which has three linear axis and a rotational one, as shown in Fig. 2. The system's origin is given by the intersection point between the laser beam axis and the sample surface.

2.3. Working configuration selection

The choice of wire direction is the result of a study realised by Jae-Do Kim and Yun Peng [6], which tested three wire directions, as shown in Figs. 3–5.

In the "pushed configuration", the formed coating layer can perturb the added wire when the angle between the sample and the wire nozzle is small. This working configuration allows the minimisation of laser beam–material interaction perturbations. However, the wire is mainly melted by conduction, within the molten pool, and when a high wire speed is employed, the melted state cannot be regularly reached. Consequently, the wire can arrive in front of the interaction zone in a solid state, which has severe influences on the process stability. It can be thus concluded that pushed sense is a configuration that might be very delicate to practically realise [6,7].

The second configuration is when the wire direction is almost perpendicular to the sample surface (Fig. 4). In such a case, the wire melting process can be incomplete when working with important wire speeds. Moreover, the coating layers might result dissymmetric, if the relative position between the added wire and the laser beam is not rigorous maintained [6].

Finally, the third case is the "pull configuration" (Fig. 5), which allows high "flow rates", and the formed coatings have no negative influences for the cladding phase for any working angle (α between the nozzle and the sample). The only inconvenience of this configuration is that the added wire interaction with the laser beam limits the absorbed energy during the laser beam–material interaction. Therefore, the working configuration must be

Table 1
Wire chemical composition (EDF)

Element	Fe	Cr	Ni	Mo	Si	Nb	Ce
wt.%	60.92	27.4	3.7	4.2	3.1	0.58	0.1