Laser Powder Cladding Complex: Principles of Advanced Automated Control

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Abstract. Currently, the laser powder cladding process is one of the most promising methods for producing wear and corrosion resistant sealing surfaces of high hardness. To solve the problem of high-quality automated production of coatings, that meet specified requirements, on the surfaces of critical parts, it is necessary to identify key factors, as well as determine the contribution of each of them in the process of laser powder cladding. In view of the foregoing, the urgent task is to develop an integrated system that allows monitoring and recording parameters of ongoing physical processes, as well as ensuring reproducibility of experimental results. Since such an installation includes many disparate technical units and transition modules of various integration levels, each of which has its own functionality, a specialized software package has been developed, the purpose of which is to combine individual components into a single organized and controlled system. As an approbation of the experimental complex work, the results of laser cladding process are shown.

1. Introduction

The use of focused laser radiation for cladding metals can significantly expand the technological capabilities of the process, increase its productivity and improve the quality of resulting coatings. In comparison with traditional methods of powder cladding [1–3], the following key advantages of such approach can be distinguished:

- General increase in operation productivity due to decrease in mixing zone of substrate material and clad layer [4], and as a result, a decrease in thickness of applied intermediate layer, in complexity of cladding process and subsequent machining;
- Improving the processability, efficiency, increasing the adhesion resistance of applied material to substrate, reducing the porosity and the number of non-metallic inclusions characteristic of processing methods using fluxes [5–7];
- The ability to identify defective workpieces at cladding stage by developing an effective real-time process control system [8–10].

Since the laser cladding process is caused by the appearance of a number of concomitant physical phenomena that directly affect both geometry of clad bead and characteristics of coating being formed, it is of interest to develop a control system that enables automated correction of processing mode in real time, based on data recorded by sensors in areas of laser exposure.

2. Automated laser powder cladding complex

In general case, the process of laser powder cladding includes the following mechanism of action. The powder mixture enters the laser radiation propagation region, where, under the influence of radiation,
material is melted, followed by deposition on the surface of the workpiece (figure 1) [11]. The process can take place both using shielding gas in processing area and in a chamber isolated from atmospheric air. Moving the cladding head is carried out by positioners of various types, in most cases, robotic manipulators are used to deliver the deposited mixture. The combination of technological equipment elements with a robotic manipulator into a single industrial complex is called a laser robotic cladding complex. The main variable parameters of laser cladding are powder feed rate, laser radiation power, as well as the speed of cladding head movement. Changing these values leads to a change in geometry of clad layer, in mixing coefficient of substrate material and deposited powder, the area of propagation of temperature front in a volume of material.

To automate the coating process on surface of critical parts, it is necessary to identify key factors that influence the process of laser cladding, as well as determine the contribution of each of them. So, the work [12] describes the inheritance of powder material structure in cladding process of 03X17H14M3 steel. The work [13] examined the problems of crack formation during direct laser cladding SS316. A negative effect of sulfur, phosphorus and silicon on the resistance to cracking during direct laser cladding was revealed. In addition to material properties, processing mode also directly affects laser cladding result. The location of the sample being processed relative to the focusing optical system focal plane and the nozzle part is of great importance [13, 14]. Both the height of the deposited structure and the uniformity of the clad bead depend on the focal plane orientation relative to the sample and the region of powder flow convergence. In [15], a study was made of the influence of cladding on the formation of defects and properties of deposited materials. It was found that rapid heat dissipation contributes to obtaining a fine-grained structure with better mechanical properties compared to samples subject to prolonged heat exposure [12–14].

In view of foregoing, an urgent task is to create an integrated system for monitoring technological processing parameters for evaluating the effectiveness of powder cladding process in real time. To monitor the progress of different types of laser technological process, various hardware and software solutions are used [16–17]. The complex under development allows monitoring and fixing the parameters of ongoing physical processes, as well as ensuring reproducibility of results. Among other things, this approach allows to collect an array of experimental data, which could allow a comparison of the results with the modeling data presented in modern scientific papers [18–22].

The complex of automated laser powder cladding includes the following main technical components: a cladding head equipped with a set of temperature sensors (pyrometers), a video recording system and a triangulation sensor; a system for spatial positioning of the head, made in the

![Figure 1. Laser powder cladding process.](image.png)
form of an industrial robotic manipulator, a system for the part pre-heating, which is a tubular heater located in a heat-insulating casing, as well as an operator terminal that controls the setup (figure 2).

Figure 2. Scheme of the robotic laser cladding complex.

One of the most structurally complex elements of the technological complex is a cladding head. The configuration of cladding head is the most important factor, since it directly determines the physics of the process. The presented complex is equipped with a multi-jet powder supply system with the possibility of programmed control of transport gas flow, powder feed rate, and laser radiation power. The head is additionally equipped with a set of sensors for monitoring the cladding process, for which a system of brackets has been developed that allows recording devices to be located at a distance of 150–200 mm from the processing zone to prevent damage caused by cladding products. The combination of sensors used allows to obtain comprehensive information about the nature of physical processes occurring in processing area, on the basis of which it is possible to adjust the parameters of laser cladding in real time.

3. Experimental results
At the current stage, a series of experiments is being conducted on automated correction of the laser radiation power based on data obtained from a CCD camera (figure 3). Laser cladding of separately located tracks and cladding of tracks with overlap was performed. The obtained samples were examined for the dependence of the formed tracks geometric characteristics on the exposure parameters. The data obtained were used to adjust the laser complex control algorithm.

Figure 3. Images of laser cladding area obtained by CCD camera.
As a result of optimization of the control program, it was found that the use of an CCD camera to correct the processing mode based on data on deposited tracks geometric characteristics (track width) allows constant control and maintenance of a given width of clad layer by varying the parameters of laser power and cladding speed. Maintaining the geometric characteristics of the weld beads must be performed constantly, since during the multilayer cladding the thermophysical characteristics of the processed substrate change, which leads to a change in geometry of weld bead.

Figure 4 shows the end section of deposited tracks made of AISI 316 steel onto a substrate surface of the same material with a 4 mm overlap. The basic parameters were: laser radiation power – 2800 W, powder consumption – 15 g / min, cladding head speed – 6 mm / s. In this experiment, the geometric characteristics of the deposited coating were corrected by changing the laser radiation power.

4. Conclusion
The use of focused laser radiation for welding metals can significantly expand the technological capabilities of welding processes, increase their productivity and improve the quality of the welded joints, which makes this method of powder cladding the most promising. The developed laser cladding complex allows solving a wide range of scientific and applied tasks of selecting optimal coating conditions by structuring and analyzing the data of physical processes recorded in the field of laser exposure.

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