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MODELING OF LASER CLADDING WITH DIODE LASER ROBOTIZED SYSTEM

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I. Introduction

In laser processing to choose the working conditions may appear not very easy task. Unlike at any other conventional processing the final results at laser processing may be influenced by more than 100 different factors: 1) laser beam parameters (its wavelength, mode, level of focusing/defocusing, power/energy distribution in the focusing spot, pulse duration and frequency for pulsed irradiation, etc.); 2) material properties (elements content, surface optical properties, thermo-physical properties, component dimensions, etc.); 3) conditions of laser irradiation (speed of irradiation, overlapping coefficients, the amount and type of irradiated spots distribution on the surface of the component, angle of surface irradiation, etc.); 4) additional conditions (beam scanning, use of additional energy - hybrid processing, application of surface coatings, etc.).

As a final goal of processing the large variety of factors may be considered as well: dimensions, surface roughness, micro hardness, size of HAZ (Heat Affected Zone), distribution of chemical elements, wear resistance, strength, etc.

Considering the complexity of laser processing, the best way to its study may be the use of processing simulation which gives the possibility to reduce the time, labor and cost of research and to predict the final result of processing. For the moment there had been developed the variety of different tactics of different process modeling [1–6].

The most efficient models are considered as follows.

- Physical simulation (model)
- Numerical simulation
- Statistical simulation

Physical simulation (model) is based on application of fundamental physical laws. Because such laws may not be known for some unusual conditions of laser interaction with matter, the results of such simulation may be valid only for limited known conditions. This makes it impossible to use such tactics for practical purposes.

Numerical simulation is based as well on fundamental physical laws but model may be adequate only when all dependencies are known (which is unrealistic) in real conditions.
So such simulation is very difficult to use for practical purposes.

As opposite to previous tactics, the **statistical simulation** is based on gained real experimental data. Thus it is very simple for realization. Its main advantages are minimum experiments to create the model and possibility for wide practical use with given ahead statistical mistake. As disadvantages the following may be named: simulation is valid only within the limited experimental space and it doesn’t disclose the physical mechanism of the processing.

II. Development of the model based on statistical simulation

At statistical simulation the studied process is considered as a “black box” which is influenced by the number of independent variables (working conditions) and affects the final results (dependent variables) of processing (Fig. 1).

In general it may be described mathematically as following regression equation:

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$$y = b_0 + \sum_{i=1}^{i=k} b_i x_i + \sum_{i \neq j=1}^{i \neq j=k} b_{ij} x_i x_j + \sum_{ii=1}^{ii=k} b_{ii} x_{ii}^2$$

where: k – number of technological factors; b_0, b_i, b_{ij}, b_{ii} – regression equation coefficients; i, j – indexes.

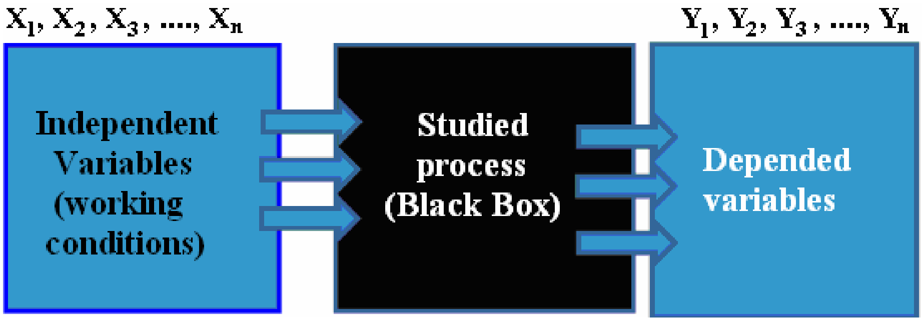

Fig. 1. Scheme of the relations between studied process and different variables

As independent variables (working conditions) the following factors are considered:

- Properties of laser beam
- Properties of material to be processed
- Additional conditions

As final result of the processing the different dependent parameters may be considered:

- Component Properties (wear resistance, strength), $Y_1, Y_2, ..., Y_N$
- Surface roughness (Y_i), Dimensions of HAZ (Y_j), Size of tempered zone (Y_l) Chemical elements distribution (Y_m) and etc.

For modeling realization depending on different consideration (amount of experiments, their duration and cost, expected accuracy, etc.), different techniques (plans of experiments) may be proposed. Among them we will name only few:

1. Composite plan –**26-42** experiments
2. Plan of experiments (Hartly) -**30** experiments
3. Super full plan of experiments (Rechtchafner), (Hartly) –**21** experiments
4. Symmetrical Composite plan –**45-58** experiments
5. Plan of experiments (Box) – **44-76** experiments

Considering constrains of time, labor and cost the following plan had been chosen:

- Nonsymmetrical almost full Hartley plan of experiments;
- Total amount of experimental points –N=17, repetition experiment in point – nu=3
- Total amount of experiments – N*nu=17*3=51
- Repetition of experiment in one point – n_1=3, Total experiment 17+3=20

Levels of variation and intervals of changes for technological parameters (dependent variables) are given in Table 1.

Table 1. Levels of variation of the factors

Levels of variation and intervals of change Technological factors	Code Scale	Power (P)	Distance between focusing point of powder stream and sample (FP)	Operation Speed (V)	Feeding Rate (FR)
Unit		W	mm	mm/min	g/min
Main (Ground) level	0	1700	0	650	10
Interval of variation	1	200	6	350	5
High level	1	1900	6	1000	15
Low level	-1	1500	-6	300	5

III. Experimental equipment and procedures

The experimental part of the work had been done by using the equipment shown at Fig.2. It includes the following devices:

1. Robot: IRB 2400 ABB (Switzerland) is a 6-axis industrial robot, designed specifically for manufacturing industries that use flexible robot-based automation. The robot has an open structure that is specially adapted for flexible use, and can communicate extensively with external systems. Its main parameters: the load limit is 16 kg,positioning accuracy is 0.70mm, and arm working radius is 1.4m.

2. Laser: LDF400-2000 Fiber-Coupled Diode Lasers, Laserline GmbH (Germany). Its main parameters: the wavelength is 900-980 nm, output Power is 2000 W, and transverse mode is multi-mode.

3. Powder feeder: Sulzer Metco 9MP (USA) Closed-loop feed rate monitoring and control. Rotameter and mass flow carrier gas metering models available. The powder feeding rate is from 2 g/min to 50g/min.

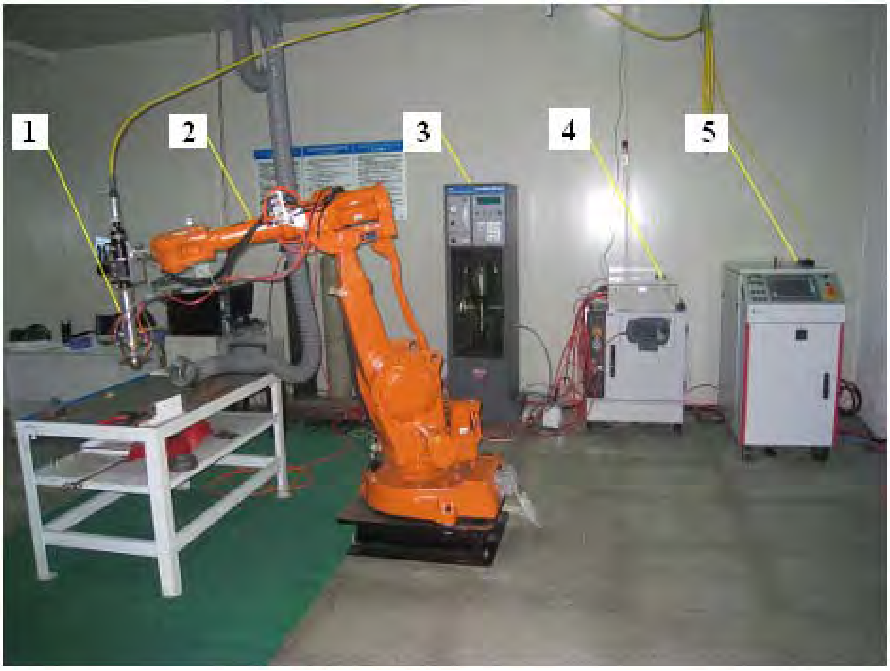

Fig. 2. The general view of industrial robotized system based on diode laser Coaxial with powder nozzle laser beam focusing system; 2 –Robot; 3 – Feeder; 4 – Robot controller; 5 – Fiber-Coupled Diode Laser

Samples for experimental research had been prepared from the stainless steel 2Cr13 (C - 0.21%, Cr - 13%, Si-1.16%, Ni- 0.77%, Fe- the rest). Samples had been irradiated at focused beam diameter ø4mm according to the plan of experiments.

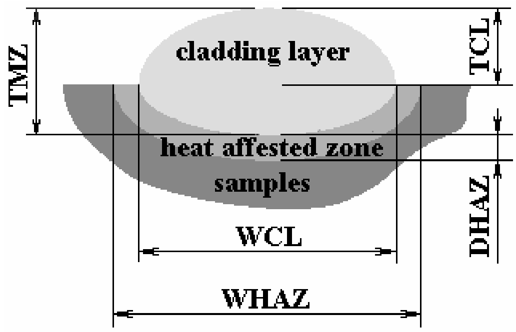

Fig. 3. Scheme of the cross section structure

Sample dimension is 40×100×11(mm^3), and 2Cr13 powder with particle size of 50-75μm was used. The wire electrical discharge machine had been used to cut sample crosssection. After sectioning samples had been subjected to standard metallographic procedures for futher studies. Micro-hardness and dimension measurements had been done using digital microhardness meter HDX-100 (China). Typical crosssection structure of treated layers is demostrated at Fig.3, where TCL - the thickness of cladding layer, DCL - depth of cladding layer, WCL – width of cladding layer, HCL - hardness of cladding layer, DHAZ - depth of heat affected zone, HHAZ – its hardness.

IV. Discussion of the results

As a result of calculations the coefficients for regression equation had been found. To describe the dimensions parameters of the processed layers and micro hardness changes these coefficients are presented as a range diagrams (Fig. 4a and 4b). Analyzing these results one may see that the main factors which are influencing the cladding quality are the following: laser radiation power (and hence the power density), distance between the focusing point of focused laser beam and sample, operational speed of cladding and the powder feeding rate.

Based on the same algorithm the dependences of other cladding process results (dimensions of the processed area, surface roughness, micro hardness, size of HAZ (Heat Affected Zone), distribution of chemical elements, wear resistance, strength, etc.) from various working conditions may be determined.

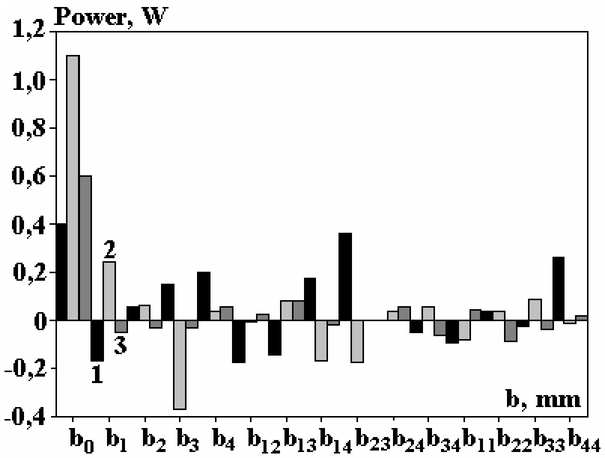

Fig. 4,a. Regression coefficients for thickness of cladding layer (TCL), depth of cladding layer (DCL) and depth of the heat affected zone (DHAZ). 1 – TCL; 2 – DCL; 3 – DHAZ; x1 – power; x2 – distance between focusing point of laser and sample; x3 – operation speed; x4 – feeding rate

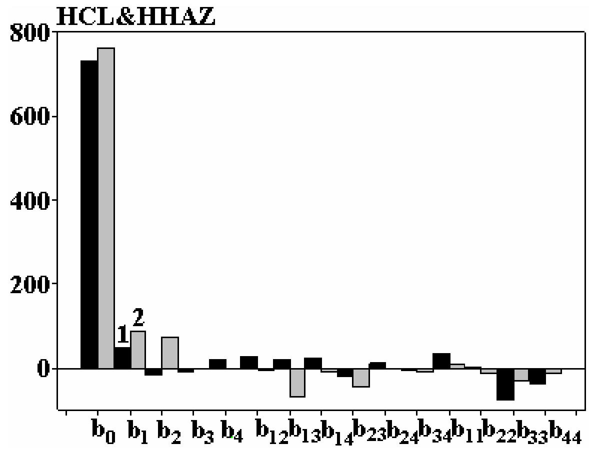

Fig. 4,b. Regression coefficients for hardness of cladding layer (HCL) and Hardness of the heat affected zone (HHAZ). 1 – HCL; 2 – HHAZ

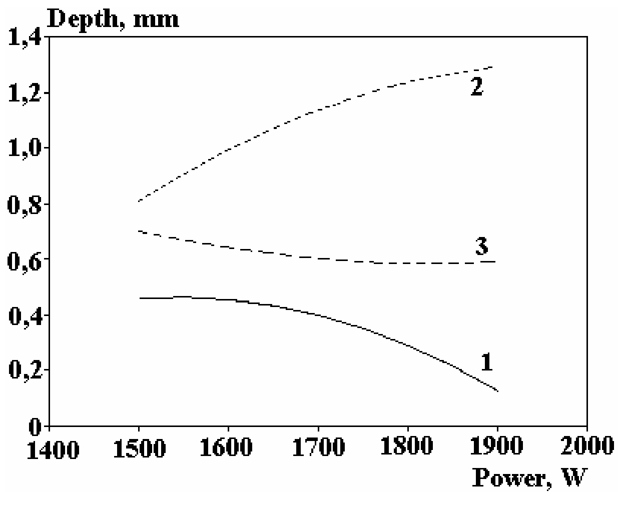

Fig. 5. Thickness and depth of cladding layer, depth of HAZ VS Power. 1 – TCL vs Power; 2 – DCL vs Power; 3 – DHAZ vs Power

V. Conclusions

1. To describe the laser cladding processing the statistical model based on results of experimental research had been developed.

2. Considering constrains of time, labor and cost, the nonsymmetrical almost full Hartley plan had been chosen for modeling realization.

3. The dimensions and hardness of the cladding layers are mainly influenced by the following factors – power and movement speed of the heating source, the mass feeding rate of the injected powder, the position of component in relation to the powder stream, etc.

4. The developed model is valid within the limits of the given multifactors space.

5. Model may be used for practical choosing of optimal working conditions for laser cladding at industrial level.

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Summary

The choice of proper working conditions is a problem for any processing. But for laser processing this procedure is much more serious. The final results of the processing are usually influenced by over 100 factors. So the best way to choose more cheaply and fast the working conditions is to use the processing simulation. Different tactics of this procedure is discussed and the statistical modeling is accepted. The actual model for laser cladding is developed based on the experimental results of steel cladding with diode laser robotized system. This model can be used to find the optimal working conditions for laser processing in practical use.