Influence of Laser Radiation Transversal Oscillation on a Quality Formation at the Direct Laser Deposition

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Abstract Research results of a influence spot diameter and laser radiation transversal oscillation amplitude on the quality formation of the built-up layers at the direct laser deposition is described in the publication. Productivity of the direct laser deposition and quality formation thin wall were increased using research results.

1. Introduction

Using laser systems provides high quality of a laser radiation, high process productivity, economy of a materials and human resources. Laser systems consist from different components depends from solving tasks. So laser heads with Gaussian distribution of a laser radiation are using at the laser welding usually because of maximal depth penetration, low welding deformation and high productivity of the process. Nevertheless, Gaussian distribution of the laser radiation imposes some limitations at the laser cladding, laser thermal treatment and direct laser deposition because of non-uniform heating of a sample surface.

Laser radiation generating with uniform distribution is researched widely. Some methods and systems for creation laser radiation distribution type “flat-top” were created. The methods and systems include enlargement of a radiation spot diameter: absorption [1], holographic method [2], non-spherical Fabri-Perot resonator [3], with using two non-spherical lenses [4], diffraction optical elements [5] and others.

The main different at the laser treatment process using static optic and scanning optic is increasing of a spot area at the laser radiation scanning at the creation uniform laser radiation distribution on the treatment surface using last type of the optic [6]. Digital adjustment of the scanning amplitude allows controlling width of the treatment layers. Modulation of a laser power scanning system allows changed cross distribution of the laser radiation because of local changing of the laser radiation power [7]. So, digital adjustment of the laser power prevents of an active metal melting and evaporation at the laser hardening and laser cladding [8].

Ytterbium fiber laser with maximal output power 15 kW equipped single-axis scanator was used for laser cladding metal powder Inconel 625 and 316L on the samples from low-carbon steel. Cladding layers with portion of the parent metal about 1% at the productivity process about 16-17 kilograms per hour were created using transversal scanning of a laser radiation [9].
So it can be possible to cladding layers formation control using scanning optics at the laser cladding and direct laser deposition. Research of influence laser radiation distribution on the quality of a layers surface roughness at the direct laser deposition using laser radiation scanning is the aim of the publication.

2. Set-up of experiments

2.1. Experimental equipment and welding materials

Experimental part of the research was created using laser technological system (Fig. 1a) created using ytterbium fiber laser LS-5 (IRE-Polus), robot-manipulator 200iB (Fanuc), two-axis positioner (Fanuc). In addition, laser head FLW-D30W (IPG Photonics), equipped two-axes scanator. Focal distance was 250 mm.

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![Figure 1](image1.png)

**Figure 1.** Laser technological system for direct laser deposition:

a – general view; b - jet coaxial nozzle

Titanium alloy powder VT6 accordingly GOST 19807-91 with fractional composition 45-90 µm was fed using jet coaxial nozzle (Fig. 1b). Chemical composition of the metal powder is shown in the Table 1.

| Steel grade | Fe   | C    | Si    | V   | N   | H   | O    | Al   | Zr   | Ti  |
|-------------|------|------|-------|-----|-----|-----|------|------|------|-----|
| VT6         | ≤0,3 | ≤0,1 | ≤0,15 | 3,5-5,3 | ≤0,05 | ≤0,01 | ≤0,2 | 5,3-6,8 | ≤0,3 | Base |

2.2. Research equipment and inspection methods

All samples were inspected visually and optically. Cross-sections of the welds were created using grinding preparing system (Buehler). Samples geometry (width) was measured using optical microscope DMI 5000 (Leica).

2.3. Design of experiment

88 samples with transversal scanning of the laser radiation were manufactured by direct laser deposition (Fig.2). Laser power (P) (from 1.5kW to 3.0kW with step 0.1kW), speed of the laser head
at the laser deposition (V) (from 15 mm/sec to 30 mm/sec with step 5 mm/sec), scanning amplitude (A) (from 1.0 mm to 3 mm with step 0.5 mm), spot diameter (d) (from 1.5 mm to 3 mm with step 0.5 mm), powder feeding (r) (from 20% to 30% mm with step 5%) and step of the layer on Z axis were variable (0.6-0.8mm with step 0.2 mm). Frequency (F) of a scanning was 300 Hz (some modes in table 2).

Table 2. Mode parameters of direct laser deposition

| №  | P, W | V, mm/s | A, mm | r, %  | d, mm | dz, mm | F, Hz |
|----|------|---------|-------|-------|-------|--------|-------|
| 1  | 2300 | 30      | 2.5   | 30    | 3.0   | 0.6    | 300   |
| 2  | 2000 | 30      | 2.5   | 30    | 2.5   | 0.6    | 300   |
| 3  | 1500 | 20      | 2.0   | 30    | 2.0   | 0.8    | 300   |
| 4  | 1400 | 30      | 1.5   | 35    | 2.0   | 0.8    | 300   |

Figure 2. Appearance of the manufactured sample created

3. Experimental results
3.1. Flame formation at the direct laser deposition with transversal scanning
Part of powder metal particles evaporates at the direct laser deposition with high laser power density with creating flame. Flame creation leads to heating and soot deposition on the nozzle and laser head shielding glass and breakage of the last component. Laser power density providing maximal productivity of the direct laser deposition without flame creation was detected (Fig.3).

Figure 3. Body of the flame creation
Laser power density and productivity of the deposition process increases at the increasing spot area and scanning amplitude without flame creation. So, accordingly research results, flame doesn’t create at the laser power density less than 153 Wt/mm^2. So it was detected that direct laser deposition productivity and coefficient of using materials were increased from 15 g/min up to 22 g/min and from 27.6% up to 44.4% accordingly using transversal laser radiation. It was because of laser radiation has uniform distribution.

3.2. *Influence of spot diameter and scanning amplitude on depositional sample geometry*

Spot diameter and scanning amplitude influence on the depositional wall width because of interaction area of laser radiation and metal powder increases. It detected that width of the depositional wall increase at the scanning amplitude (A) and spot diameter (d) increasing (Fig.4).

![Figure 4. Influence scanning amplitude and spot diameter on the depositional wall width](image)

3.3. *Influence scanning parameters on the laser radiation distribution.* Laser welding of a base material with different spot diameter and scanning amplitude was carried out. Cross-section of some welds are show on the Figure 5. Spot diameter was changed from 1.5 mm to 3.0 mm with step 0.5 mm at the laser power 2 kW, linear speed of the process 30 mm/sec, scanning amplitude 2.5 mm and scanning frequency 300Hz.

![Figure 5. Cross-sections: melting form at the laser scanning with different spot diameter](image)
It detected that melting form depend from laser radiation with scanning and base metal interaction time and determined as ratio of spot diameter \( (d) \) and scanning amplitude \( (A) \). When the ratio equal one melting zone has form that is equal. But it was detected that non-equal laser radiation distribution which shows on the Figure 5a is better at the direct laser deposition samples with thin wall (Figure 6). Because of the distribution provides with good quality formation of the edges of the wall (Fig.6b). Bad quality formation with non-melting of the edges was created at the direct laser deposition with static optics (Fig.6a).

![Figure 6. Cross-section of the thin wall: a – without laser radiation scanning; b – with transversal scanning of the laser radiation](image)

**Conclusions**

Influence of laser scanning parameters on the surface sample at the direct laser deposition was researched. The main results are presented below:

1. Flame formation creates at the laser radiation density more than 153 W/mm².
2. Direct laser deposition productivity and coefficient of using materials were increased from 15 g/min up to 22 g/min and from 27.6% up to 44.4% accordingly using transversal laser radiation.
3. Thin wall with good quality formation of the surface creates at the using of the laser radiation transversal scanning with more time interaction between laser radiation and last layer on the edges.

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