Properties of multilayer coatings produced by coaxial laser cladding

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Abstract. This article contains results of the study of multilayer coatings produced by laser cladding on the substrate steel 34HMA using iron based powder PR-10R6M5 as the filler material. The coatings were produced with consistent application of the tracks with fixed overlapping. The dependencies between the characteristics of tracks and the technological mode of deposition were revealed. Properties of coatings were determined for various overlapping of tracks and directions of the cladding layers.

1. Introduction
Laser cladding is an additive technology for materials processing. It is an actively developing processing technique, which is penetrating to the industry. This technology allows to create coating on the surface of the workpiece to restore the damaged parts whose manufacturing is time-consuming and expensive. In addition, claddings are used to impart desirable properties to the workpiece surface, e.g. corrosion or wear resistance. The destruction of parts often starts with surface defects [1], thereby laser cladding technology allows to improve part characteristics by creating layer with the desired properties on the surface.

Apart from a laser, the energy source for cladding may be an arc, electron beam, plasma and others. The laser cladding features the possibility of creating coatings with minimal heat affected zone (HAZ) and minimal mixing of filler material with the substrate [1]. Wires, ribbons, or powders may be used as a filler material. Cladding using a metal powder allows to achieve maximum uniformity of coating, enables local surface treatment and producing any existing coating by mixing the powders. Other advantages of laser cladding of powders were analyzed in more detail in [2–6].

2. Experimental equipment
Experimental equipment is shown in figure 1. Cladding processing cell (1) is equipped with a control unit (2). Figure 2 shows the inside of the cell (1) consisting of a 5-axis positioning system, optical head with water cooling and supply of protective gas and powder from the feeder (3) SulzerMetco Twin 10-C, as well as an industrial digital camera for positioning parts and monitoring the process. As an energy source we used fiber laser (4) LS-3.5 with power up to 3.5 kW, manufactured by IPG.

The metal powder is fed into the treatment zone via a coaxial nozzle. Under the impact of laser radiation it is heating and melting. Simultaneously, the substrate surface is melting. The track is produced during the motion of the nozzle relative to the substrate after cooling. New layers are formed

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by sequential application of tracks with some overlapping. Workpiece of the substrate was prepared for cladding before the experiment. First, the cleaning of the working surface of samples with a wire brush was performed. Then the work surface was treated by acetone wiping.

Figure 1. Experimental equipment.  
Figure 2. View of optical head and positioning system inside the cell.

3. Results of the cladding study

3.1. One track

Initially, we produced cladding of tracks with different technological modes and determined their geometric characteristics: width and height of the track, and the depth of penetration of filler material in the substrate. The measurements showed that the width of the cladding track and the filler material penetration depth in the substrate are mainly influenced by a change of the laser power, while the height of the tracks is mostly affected by the powder feed rate. We selected the most appropriate mode for further research based on the following parameters: uniformity of the track form, the absence of pores and cracks, the minimum level of mixing between substrate materials and powder, and a minimum depth of penetration of filler material in the substrate combined with good adhesion of the coating without delamination from the substrate.

Optimal mode for a single track cladding was selected in accordance with all the above mentioned requirements: laser power 400 W, substrate movement speed 37.5 cm/min, powder feed rate 1 g/min, and the height of the nozzle above the surface of 5 mm. We carried out a study of topography and microstructure of the surface as well as the elemental composition of the samples using the electron microscope (SEM) Carl Zeiss EVO 50 XVP. The microhardness was determined by the Vickers method in the HVS-1000 setup with automated loading of the indenter to the load of 1 N. The dwell time under the load has been fixed at 20 s. The results showed (figure 3) that the HAZ is 300 µm, cladding structure is the equiaxed mesh, dendritic structure is observed near the substrate boundary, and the grain boundaries are enriched in heavy elements (Mo, W). The structure of the HAZ is a milled grain ferrite-pearlite with traces of partial martensitic transformation. The structure of the substrate is the polyhedral (equiaxed) grains of ferrite and pearlite. The substrate-cladding boundary is distinct, there is no peeling, cracking, or porosity. Microhardness (figure 4) changes at the boundary of the substrate and cladding, from 5700 MPa (cladding) to 2000 MPa (substrate material).
Figure 3. Single track produced in optimal regime.  

Figure 4. Change of microhardness over the cross section.

3.2. Single layer coatings  
The layers were created under selected track mode with different overlapping: 0.33, 0.5, 0.66. We conducted a similar study of the microstructure and microhardness of coatings. For all coatings with different surface overlapping, the structure is equiaxed mesh, near the boundary with the substrate the dendritic structure is observed, grain boundaries are enriched in heavy elements (Mo, W). The structure of the HAZ is a milled grain ferrite pearlite with traces of partial martensitic transformation. The boundary between the substrate and cladding is distinct, there is no peeling, cracking, or porosity. Microhardness changes at the boundary with the cladding and the substrate from 5000 MPa (cladding) to 2000 MPa (substrate material). The Fe content in the powder is 80%, and about 98% in the substrate. The measurements of the Fe content in the cladding, depending on the coefficient of overlapping shows that a layer with overlapping 0.33 has 86% content of Fe, with overlapping 0.5 – 85%, and with overlapping 0.66 – 83% . It can be seen that increasing overlap reduces the content of Fe in the coating, thus decreasing the mixing of materials and improving the quality of the cladding. Iron content in a layer depends on the strategy of its preparation.

3.3. Two layer coatings  
The layers were created with the same mode of overlapping the tracks, but with a different direction of the second layer cladding: 0°, 45°, 90°. Structure of coatings is presented in figures 5–7. It is a non-equiaxed mesh, with the dendritic structure near the boundary with the substrate -, and the grain boundaries enriched in heavy elements (Mo, W). The width of the HAZ is 300 µm, its structure is the crushed grain ferrite-pearlite with traces of partial martensitic transformation. The iron content in the three cases was 85%. The microhardness increased to 6000 MPa (figure 8), its dependence is more uniform in the case with the direction of the clad layers of 0°. Since the remaining measured coating characteristics are the same, one can conclude that the best quality of cladding is obtained when depositing layers at 0° angle.
4. Conclusion

Results of the study showed that the width of the cladding track and the penetration depth of filler material in the substrate are mainly influenced by a change of the laser power, while the height of the tracks is mostly affected by the powder feed rate. Monolayer coatings with a coefficient of tracks overlapping 0.66 exhibit lower level of mixing between powder material and the substrate than the coatings with coefficients 0.33 and 0.5. This is a consequence of smaller area of thermal effects on the substrate. Bilayer coatings with the direction of the clad layers 0° are more uniform than those with a direction angle of 45° and 90°. Differences in the ratio of mixing for the three different directions are not observed.

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5. References

[1] Grigoryants G, Shiganov I, and Misyurov I 2006 Technological processes of laser processing (Moscow: MGTU) (In Russian)
[2] Murzakov M, Petrovskiy V, Birukov V, Dzhumaev P, Polski V, Markushov Y, and Bykovskiy D 2015 Phys. Procedia 71 202–206
[3] De Damborenea J and Vzquez A 1993 J. of Materials Science 28 4775–4780
[4] De Oliveira U, Ocelk V, and Hosson J D 2005 Surface and Coatings Technology 197 127–136
[5] Nenadl O, Ocelk V, Palavra A, and Hosson J T D 2014 Phys. Procedia 56 220–227
[6] Hasui A and Morigaki O 1985 Surfacing and spraying (Moscow: Mashinostroenie) (In Russian)