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Specifics of the Surface Structure of Stainless Steel Elements on Thin-Sheet Basis Applied via Laser Cladding

Mykola Sokolovskyi[1], Oleksandr Siora[1], Yurii Yurchenko[1], Volodymyr Lukashenko[1], Artemii Bernatskyi[1], Iryna Siora[2], Oleksandr Danyleiko[3]

[1]E.O. Paton Electric Welding Institute of the National Academy of Science of Ukraine

Kyiv, Ukraine

[2]Chuiko Institute of Surface Chemistry of the National Academy of Science of Ukraine

Kyiv, Ukraine

[3]E.O. Paton Electric Welding Institute of the National Academy of Science of Ukraine,

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Kyiv, Ukraine

Corresponding author: Artemii Bernatskyi; avb77@ukr.net

Abstract— In modern conditions, creation of construction elements on thin-sheet steel parts is becoming an increasingly actual problem for various industries. However, the complexity and price of current technological methods applied for creation of such elements cannot cover the current industry needs. One of the ways to solve this problem – usage of laser cladding methods, makes it possible to obtain the required properties of the working surface of the alloyed part with a relatively low per-piece price of the process. Over the course of the study, combined method of laser cladding of an element on a thin-sheet stainless steel surface was analyzed, its technological capabilities were determined, and the structural-phase state of surface layers, formed during cladding of stainless-steel elements on thin-sheet basis. During comparative studies of samples obtained by both methods of surface cladding, it was found that in the case of laser-plasma cladding, the observed structure and carbide phases are smaller in size, with a low density and uniform distribution of dislocations in the metal of the alloyed layer. After various analysis, it was established that during both laser and laser-plasma methods of surface cladding, the crack formation tendencies was mostly attributed to various structural and concentration changes associated with the redistribution of elements, leading to the formation of sharp grain-boundary concentration gradients. An increase in the number of cracks is observed in regimes with higher heating temperatures, increased duration of exposure to high temperatures and reduced cooling rates.

Keywords — laser cladding; stainless steel; structural study; microstructure; alloying elements.

I. Introduction

In modern industries, such as rocket manufacturing, chemical, nuclear, and others thin-walled parts are used that contain functional elements which can differ significantly from the specified part in terms of their characteristics (geometry, chemical composition, mechanical or other properties) (for example, lugs, reinforcing belts, protrusions, functional platforms, etc.) and are intended to perform a variety of specific responsible operational tasks. The production of these structural elements requires the improvement of technological approaches and is one of the pressing challenges of modern applied materials science and material processing technologies. To address this issue, it is proposed to utilize a modified laser cladding process to produce these elements.

One of the current directions in solving this problem is the development of optimal laser cladding modes as well as various technological measures to ensure proper construction of the element without negatively affecting the base thin-sheet layer. Recently, more and more publications on the use of laser radiation for production of various parts, utilizing both classic laser cladding [1,2], as well as various laser additive manufacturing methods, have appeared in the modern scientific and technical literature [3-6]. These processes, due to the partial overlap of the laser melting area between cladding passes, can account for a myriad of structural changes in the clad material. By correcting the technological parameters and applying various technological measures to the process, it is possible to ensure the quality of created clad elements without damaging the base thin-sheet metal part.

The purpose of this study is to analyze the method laser cladding of elements on thin stainless-steel surfaces, determine its technological capabilities and compare the structural-phase state of surface layers, that are formed during laser cladding during utilization of various working modes.

II. Experimental Methodic

For experimental studies, steel AISI 316Ti was chosen as a base, and steel AISI 316L was chosen as the powder metal to be clad. These metals are used in the chemical, oil, and gas industries, for the production of food tanks, belts, pipelines, in energy engineering, pulp and paper production, manufacturing of cutting tools, heat exchangers, turbine blades, machine parts, and compressors. A laboratory stand for conducting experiments on laser cladding was created on the basis of a three-coordinate manipulator manufactured at the PEWI (Paton Electric Welding Institute, Ukraine).

The Nd:YAG laser "DY044" by "ROFIN-SINAR" (Germany) with a laser radiation wavelength λ=1.06 µm was used in this study. Laser radiation was transmitted to the treatment site via an optical fiber with a diameter of 600 microns and a length of 20 meters. From the optical fiber, laser radiation entered the collimator, where it was transformed using a system of optical elements, acquired the required geometric dimensions and then fell on a focusing quartz lens $\varnothing$ = 50 mm with a focal length F = 200 mm. The surface cladding was carried out by varying the laser radiation power within the range P=1.5...2.5 kW, processing speed V=2000 mm/min and defocusing value ΔF=+12 mm.

The outer surface of plain samples made of structural alloy steel 316Ti underwent post-processing. For laser cladding, a mechanical mixture of powders with granulation of 50...153 µm of an AISI 316L austenitic steel was used.

When carrying out laser cladding experiments, the sample was placed on the object table and fixed in a stationary manner, while the laser focusing head was located on the movable carriage as a part of a three-coordinate manipulator. The design of the laser focusing head made it possible to process the sample with a coaxial delivery of both laser radiation and filler powder. The filler powder was transported directly into the nozzle part of the laser head using argon. Filler powder dosing was carried out using a rotating feeding device, developed at the PEWI. When conducting experiments on laser cladding, the laser focusing head was mounted on a moving carriage. The samples were fixed, specifically mounted on top of a special copper cooling element with water cooling system installed. During processing, straight alloyed tracks were obtained due to the longitudinal movement of the carriage. A melt pool up to 1,4 mm deep was formed on the surface of the sample, into which a mechanical mixture of powders was supplied by a jet of laminar argon gas.

Templates measuring 10 × 20 × 10 mm were cut out from the obtained samples. For 12 groups of samples that differed in the parameters of technological modes, metallographic studies of each sample were carried out in areas of the alloy layer, the fusion line zone and the base metal.

The studies included scanning microscopy using Vega 3 by Tescan (Czech Republic) scanning electron microscope, as well as microdiffraction transmission electron microscopy using JEM-200CX by "JEOL" (Japan).

Structural changes and chemical composition at local points and its distribution along the depth of the layer from the outer surface of the alloyed layer to the base metal, dislocation structure, and the formation of phase precipitates were studied.

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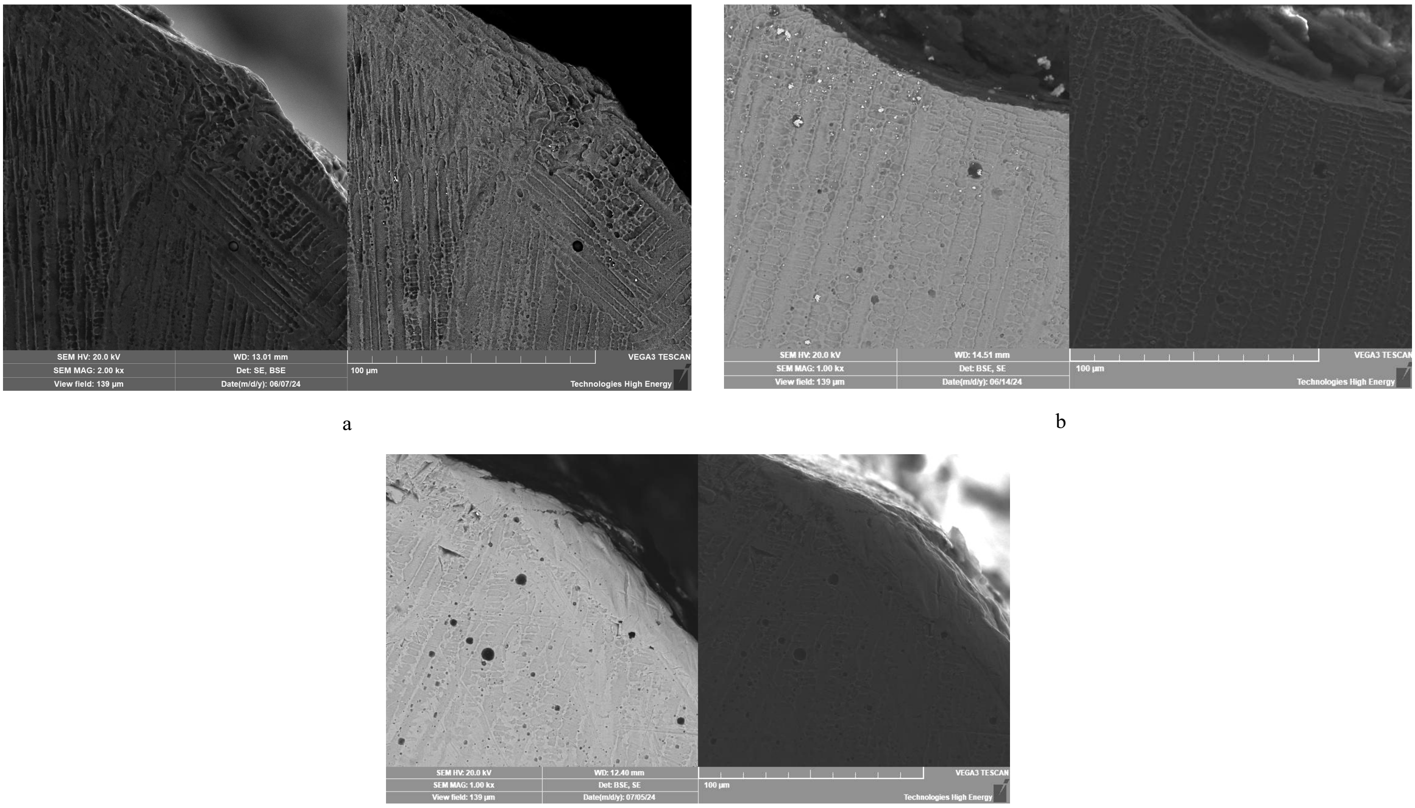
Particular attention was paid to the nature of the formation of microcracks, namely their distribution, size and establishing the cause of their appearance.

III. Results and discussion

Over the course of the study, experiments have shown, that as a result laser cladding, the alloyed layer has a clearly defined austenite-ferritic crystalline structure. However, on surface (Fig. 1), the grains obtained during cladding at P = 1.5 kW (Fig. 1a) have chaotic directions, while at P = 2 and 2.5 kW, they are universally directed at a 10 degree angle from the perpendicular to the fusion line. The width of the crystallites is corresponding to the value of laser power: at P = 1.5 kW, the width of a single crystallite is that of a 20-50 µm; at P = 2 kW, it is 40-80 µm; and at P = 2,5 kW, it is 60-120 µm.

In the case depth of the clad metal (Fig. 1), the crystallites are both more extended and more cellular in nature. They are universally directed in the nearly vertical direction (Fig. 2). During examination of all samples, no microcracks were recorded. However, while no microcracks may be present in the alloyed layer, a singular crack was recorded inside the clad metal at P = 2.5 kW. The width of the crystallites is recorded to be similar to that at the surface layers of clad material, however, grains with less elongated and thicker crystallites have been noted to appear in all three samples.



a b

c

Fig. 1. Microstructure of the sample surface (×1000) of a clad AISI 316L powder metal: a) P = 1.5 kW, b) P=2 kW, c) P = 2.5 kW.

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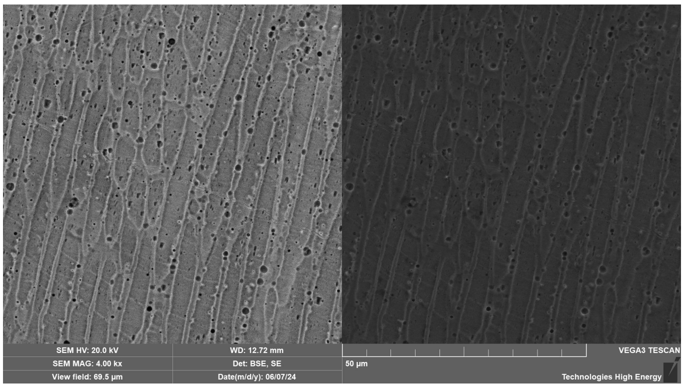

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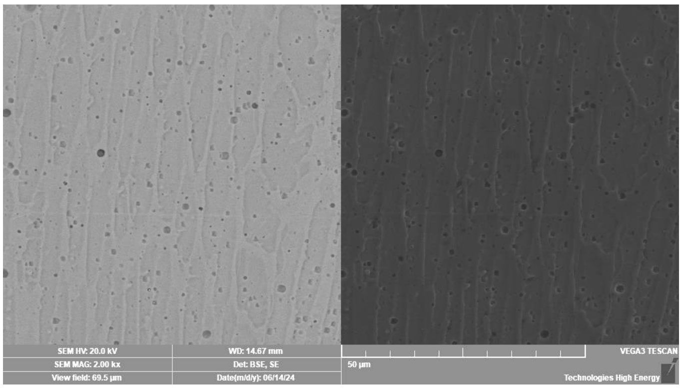

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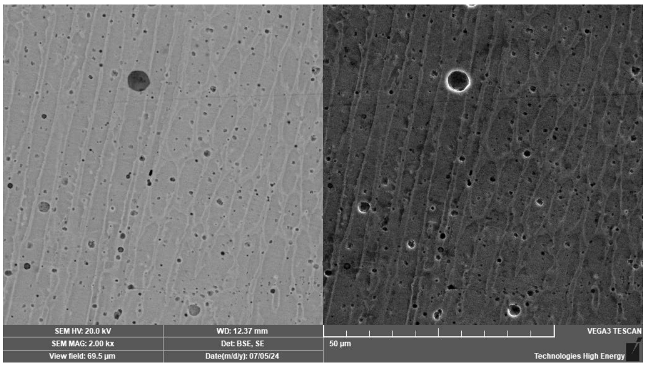
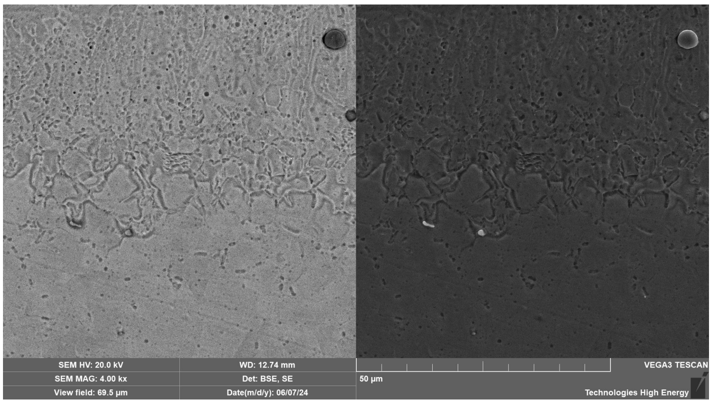


c

Fig. 2. Microstructure at the depth of the clad material (x2000) of a clad AISI 316L powder metal: a) P = 1.5 kW, b) P=2 kW, c) P = 2.5 kW.



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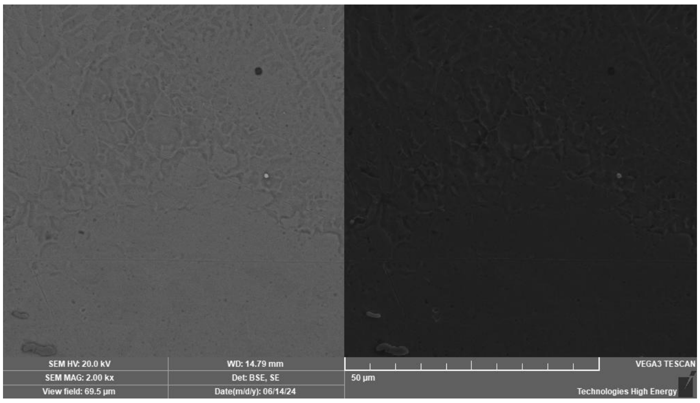

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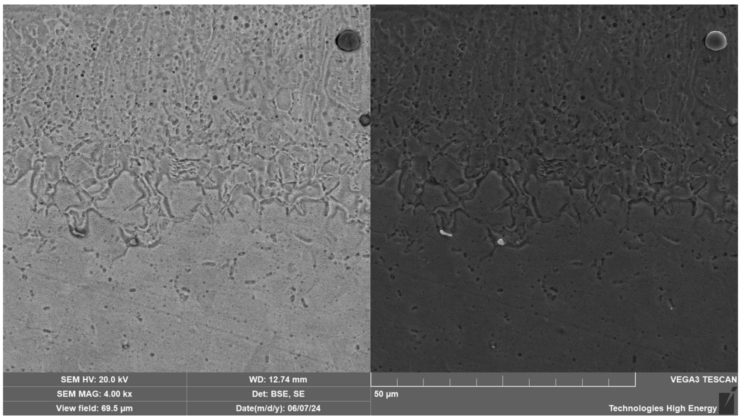

c

Fig. 3. Microstructure at the fusion line (×1550) of a AISI 316L powder metal and the AISI316Ti steel sample obtained by laser cladding: a) P = 1.5 kW, b) P=2 kW, c) P = 2.5 kW.

At the same time, the structure at the fusion line is characterized by small crystallite structure of various sizes and, accordingly, with different internal structure, formed mainly along the grain boundaries of crystallites and the fusion line. A sharp gradient is observed is observed at the fusion line, as the structure shifts to that of a thin base material of a AISI316Ti plate.

The study of concentration changes in the alloyed layer showed that in the case of laser power of P = 1.5 kW in the volumes of crystallites, a chromium content of 16.51%, nickel 11,49% is observed, and at the boundary crystallites, their content increases to 17.85% and 12.6%, respectively. When the laser power is increased to P = 2 kW, the concentration changes and an increase in the percentage of elements compared to P = 1.5 kW is observed. In the volume of crystallites, the chromium content is on average 16,49%, nickel 12.25%, and at the boundary there is an increase in chromium content to 18%, and nickel to 12.67.

With an increase in the laser power to P = 2.5 kW in the volume of crystallites, the contents of chromium drops to 16.27%, nickel 11.82%, and at the boundary it increases on average for chromium to 17.91%, for nickel to 12.54%.

During the examination of the distribution of cladding elements in the depth of the clad material (Fig. 4), it has been established that as the laser radiation power value was increased to 2.5 kW, a drop in the proportion of cladding elements inside the crystallites and in the intercrystallite position was noted. It can be attributed to many factors, such as longer cooling times, partial evaporation of clad metal, as well as various diffusion processes. Further research into this subject may be required.

However, this drop in the percentage of cladding elements may also explain the drop in the hardness and heat resistance characteristics of this material with an increase in the power of laser radiation, which was discovered in the previous studies [7].

Such an important feature as the presence or absence of cracks was also considered.

In all layers, a series of small defects was noted in the depth of the thin sheet base of the AISI 316Ti metal, however, due to its form and specifics, it was attributed to a defect in its production process (rolling against grain). More importantly, a wide crack was spotted in the midst of the sample, created using laser power level of 2.5 kW (Fig. 5).

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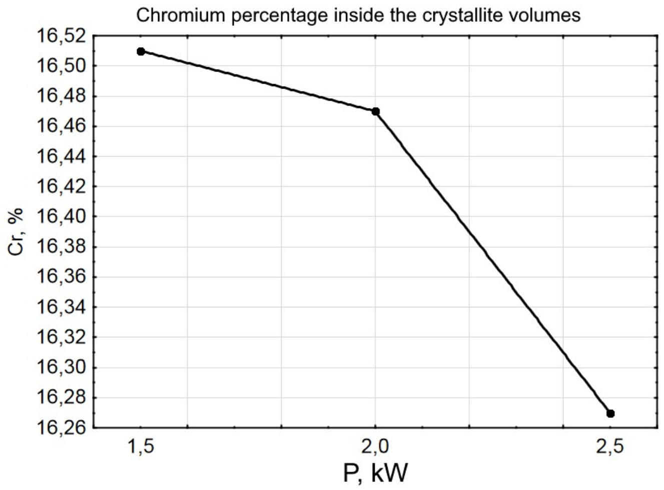
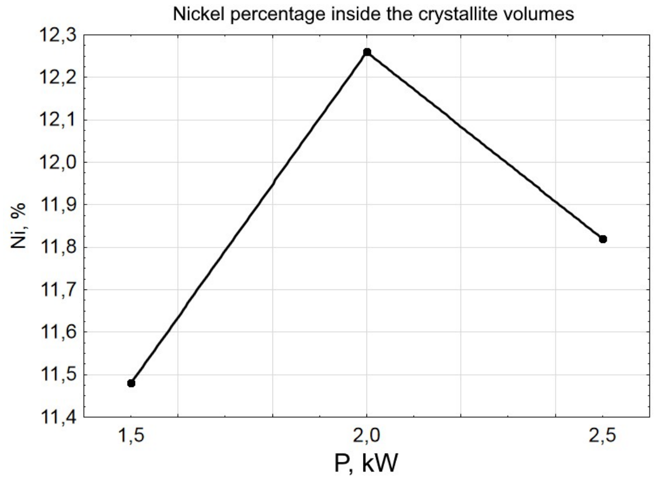


a)



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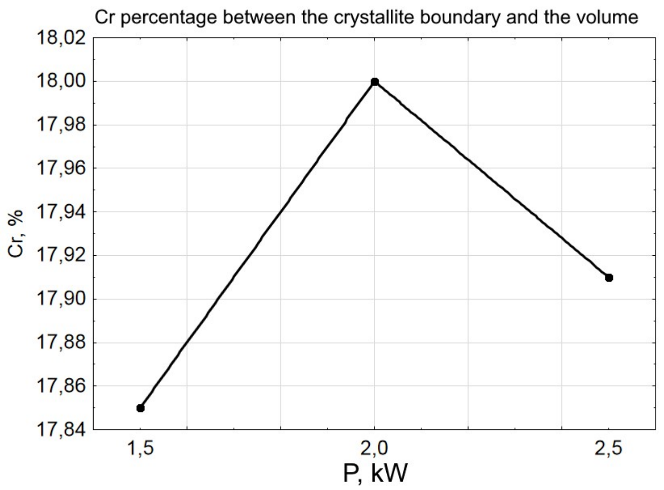
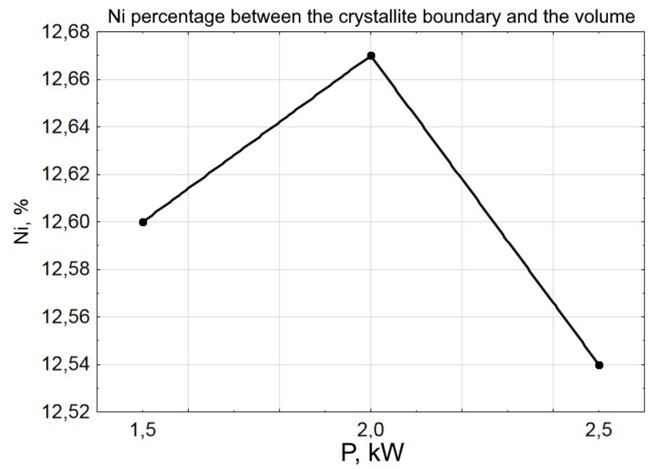


c)



d)

Fig. 4. Distribution of cladding elements in the depth of the clad material: a) Cr percentage inside the crystallite volumes, b) Ni percentage inside the crystallite volumes, c) Cr percentage between the crystallite boundary and the volume, d) Ni percentage between the crystallite boundary and the volume.

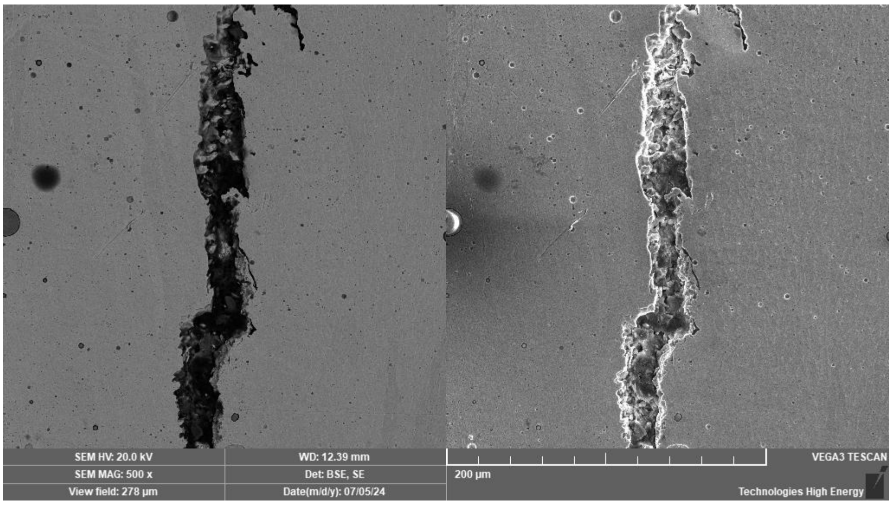


Fig. 5. Crack and microstructure surrounding it (x500), spotted during laser cladding of the AISI 316L powder steel utilizing 2.5 kW laser power.

IV. Conclusions

Over the course of the study, it was established that when using laser cladding, the tendency to formation of cracks is attributed, first of all, to structural and concentration changes associated with the redistribution of elements, namely a drop in the concentration of alloying elements in the clad material. This, in turn, leads to the formation of sharp grain-boundary concentration gradients, which contributes to the formation of carbide phases in the border zones and, accordingly, sources of initiation and propagation of cracks. An increase in the number of cracks is observed in regimes with higher heating temperatures, increased duration of exposure to high temperatures and reduced cooling rates, all of which are factors, related to the value of laser power.

When comparing samples obtained by all levels of laser power, it was found that the observed structure present clad material with unitary austenitic-ferritic crystallitic structure, with a low density and uniform distribution of dislocations in the clad metal. This indicates the absence of structural conditions for the formation of internal stress concentrators at laser power of P = 1.5 and 2 kW. The latter characterizes the structural state of the surface as optimal and is confirmed by the practical absence of cracks.

When comparing all three levels of laser power during cladding, it was found that the best results are noted at speeds of the order of 2000 mm/min and radiation power of 1.5…2 kW. This is explained by the absence of cracks, a low level of internal stress concentrators, high wear resistance, and also higher hardness values.

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