Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Laser treatment with 625 Inconel powder of hot work tool steel using fibre laser YLS-4000

L.A. Dobrzański [a],*, E. Jonda [b], W. Pakieła [b], M. Dziekońska [b]
[a] Medical and Dental Engineering Centre for Research, Design and Production ASKLEPIOS, ul. Jana III Sobieskiego 12/1, 44-100 Gliwice, Poland
[b] Faculty of Mechanical Engineering, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding e-mail address: leszek.dobrzanski@centrumasklepios.pl

ABSTRACT

Purpose: The purpose of this investigation was to determine the changes in the surface layer (Inconel 625), obtained during the laser treatment of tool-steel alloy for hot work by the use high-power fibre laser.

Design/methodology/approach: Observations of the layer structure, HAZ, and substrate material were made using light and scanning microscopy. The composition of elements and a detailed analysis of the chemical composition in micro-areas was made using the EDS X-ray detector. The thickness of the resulting welds, heat affected zone (HAZ) and the contribution of the base material in the layers was determined.

Findings: As a result of laser cladding, using Inconel 625 powder, in the weld overlay microstructure characteristic zones are formed: at the penetration boundary, in the middle of weld overlay and in its top layer. It was found that the height of weld overlay, depth of penetration, width of weld overlay and depth of the heat affected zone grows together with the increasing laser power.

Practical implications: Laser cladding is one of the most modern repair processes for eliminating losses, voids, porosity, and cracks on the surface of various metals, including tool alloys for hot work. Laser techniques allow to make layers of materials on the repaired surface, that can significantly differ in chemical composition from the based material (substrate material) or are the same.

Originality/value: A significant, dynamic development in materials engineering as well as welding technologies provides the possibility to reduce the cost of production and operation of machinery and equipment, among others by designing parts from materials with special properties (both mechanical and tribological) and the possibility of regeneration of each consumed element with one of the selected welding technologies.

Keywords: Laser cladding, Microstructure, High-power fibre laser, Inconel 625, Hot work tool steel, Heat affected zone, Thickness of the welds

Reference to this paper should be given in the following way:

L.A. Dobrzański, E. Jonda, W. Pakieła, M. Dziekońska, Laser treatment with 625 Inconel powder of hot work tool steel using fibre laser YLS-4000, Journal of Achievements in Materials and Manufacturing Engineering 91/2 (2018) 60-67.

PROPERTIES

1. Introduction

The weld overlay is formed as a result of acting laser beam's energy in the gas shield on the additional material in the form of a powder or wire and simultaneous melting of the substrate metal. The melting speed of additional material fed to the pad welding area is very high, so the very thin layer of liquid material, that is formed, is perfectly melted on the very low depth of the substrate material creating a very high quality metallurgical connection (Fig. 1) [1-5].

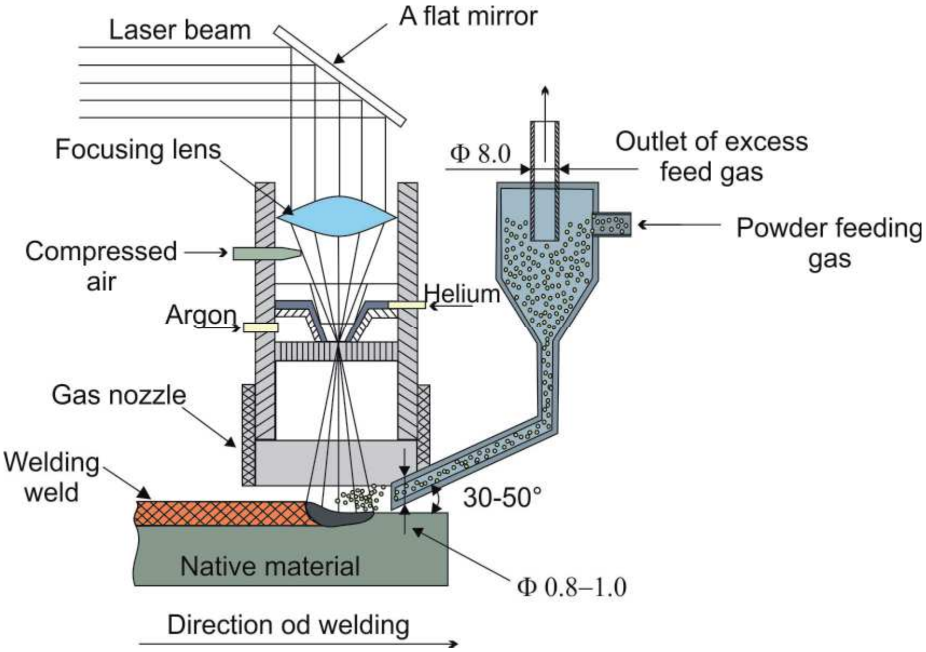

Fig. 1. The schema of the laser cladding process [1]

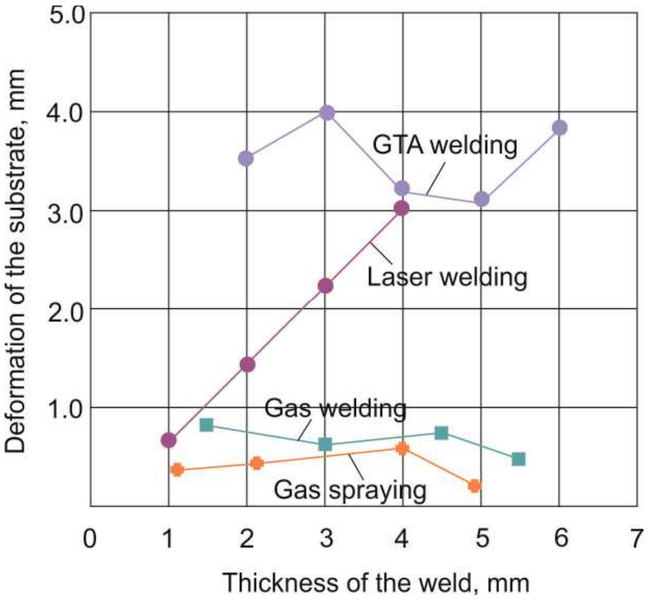

Fig. 2. The comparison of the object deformation from low alloy steel welded with GTA laser, gas rod and gas sprayed powder [1]

The process allows making weld overlay from materials that differ significantly in chemical composition from the substrate material, for example, welding of structural steels with the ceramic material. The obtained weld overlay solidifies in the inert gas shield with speeds of about 106°C/s causing a fine grain structure and high metallurgical purity. Thermal impact on the cladded object is very limited, and the existing strains and stresses are very small, which is caused by the high power of the laser beam (Fig. 2). Depending on the type of laser device, auxiliary material and cladding technique, it is possible to make a weld overlay of 0.1-5 mm in one pass and width 5-8 mm with the use of a straight path of the laser head and up to 30 mm at the pendulum movement of the laser head [6-11].

Laser cladding is an automated process depending on the conditions like the shape and size of the workpiece, can be done by numerically controlled movement of the welding head, workpiece movement or both movements simultaneously. The process is very precise and ensures repeatability of any surface. This type of laser processing is mainly used in the automotive, energy and aerospace industries, on low-alloy steel, high-alloy steel, nickel alloys, titanium, cast iron, etc. substrates. In the laser cladding process, it is essential that it is a process that ensures the highest quality of weld overlay in all cladding processes, as well as a fine-grained, defect-free weld overlay structure. Laser cladding process is one of the more expensive methods of applying coatings with special properties, therefore it is mainly used to clad metal layers based on nickel or cobalt on objects made of low and high-alloy steel, e.g. tools for machining, dies, turbine blades etc. [12-16].

2. Investigation method

Investigations were carried out on the test pieces X40CrMoV5-1 hot work tool steel compositions according to PN-EN ISO 4957 standard. The samples of the investigated steel were subjected to the heat treatment consisting of quenching and tempering according to PN-EN ISO 4957 standard – as a delivery state of hot work tool steel.

Laser cladding was made as a one-step process, i.e. an additional material – Inconel 625 (Fig. 3) in powder form was fed into the area of the weld pool, which was formed on the welded overlay surface and then laser-welded. Inconel 625 with chemical composition (%) C – 0.02; Mn – 0.2; Si – 0.2; Cr – 22; Ni – matrix ; Mo – 9; Nb – 3.3; Fe – 1 is characterized by a very good resistance to wear under operating conditions.

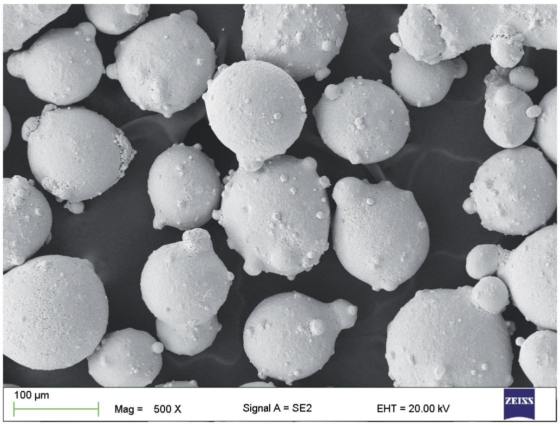

Fig. 3. The Inconel 625 carbide used for welding (SEM)

Surface treatment was performed on fibre Ytterbium Laser System YLS-4000 with a wavelength of l = 1070 nm. The maximum power of the laser beam was 4 kW. Laser head was mounted on a 6-axis robot REIS RV30-26 coupled with a tilt-and-swivel positioning system (Tab. 1).

Table 1.
The parameters of the laser cladding process

Laser beam power, kW	2, 2.5; 3
Scanning rate of laser, m/min	0.2
Velocity, l/min	5
Beam spot, mm diameter	5
Treated distance,	10
Protective gas	Hel

Structure investigation was performed using the light microscope Axio Observer supplied by Zeiss in a magnification range of 50-500x and on scanning microscope using EDX analysis. The size and shape of the weld overlay – its height, width, depth of penetration and the zone of heat influence – were measured according to the scheme shown in Figure 4. The measurements of roughness were made using Surtronic 25 by Taylor Hobson.

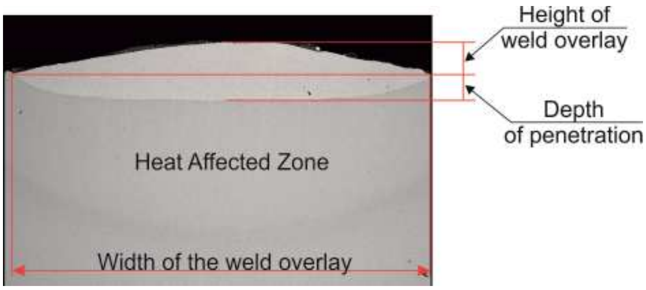

Fig. 4. Cross-section of weld overlay

3. Investigations results

On the base of the performed tests, a significant effect of the laser cladding parameters on the shape and quality of the obtained weld overlay can be observed (Fig. 5).

As a result of laser cladding, using Inconel 625 powder, in the weld overlay microstructure characteristic zones are formed: at the penetration boundary, in the middle of weld overlay and in its top layer. It was found that the height of weld overlay, depth of penetration, width of weld overlay and depth of the heat affected zone grows together with the increasing laser power, which was confirmed by the results presented in Table 2.

The largest weld overlay width was obtained as a result of laser cladding 3.0 kW (5072.04 µm), and the smallest for 2.0 kW (3813.27 µm) power. In the area of the face obtained by laser cladding using the lowest laser power (2.0 kW), numerous insoluble particles of Inconel 625 embedded powder were observed, which has a significant impact on the quality and functional properties of the obtained surfaces (Fig. 5a). Using 3.0 kW laser power for cladding, no similar structural defects in the weld overlay were observed. The increase in the power of the laser used for cladding also results in an increase in the thickness of the remelted zone (SWC). The largest thickness of the remelted zone was obtained with the laser power 3.0 kW (1408.56 μm), the smallest (1190.75 μm) – 2.0 kW. Based on the observations made, it can be concluded that the increase in the thickness of the weld overlay is directly proportional to the applied laser beam power. The largest thickness of the weld overlay was obtained during the cladding beam with the power of 3 kW (256.93 μm), while the lowest one for the power of 2 kW (140.29 μm). This effect is related to the increase in the absorption of laser radiation by the surface of the investigated steel, due to the higher absorption coefficient of the Inconel 625 powder compared to the absorption coefficient of the substrate material (steel) surface. The increase in absorption intensity causes an improvement of the entire laser surface treatment process of the steel surface layer. Obtaining of different thickness of the cladded trays may be connected also with the feed rate.

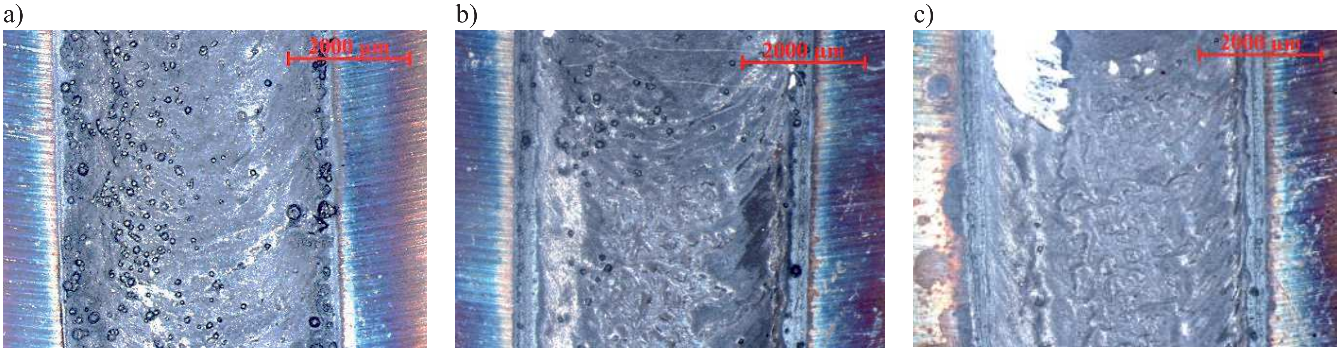

Fig. 5. Shape of the laser tray of the X40CrMoV5-1 steel cladded with Inconel 625 powder, laser power: a) 2 kW, b) 2.5 kW, c) 3.0 kW

Table 2.
The influence of laser power on the size of weld overlay

Laser power, kW	2.0	2.5	3.0
The height of weld overly, μm	509.74	591.49	575.99
The depth of penetration, μm	3813.27	4717	5072.04
The width of the heat affected zone (SWC), μm	1190.75	1385.25	1408.56
The depth of penetration, μm	140.29	210.15	256.93

The hot work tool steel has a ferritic structure with homogeny distributed carbides in the metal matrix in the annealed state [17]. In each of the analysed cases, the layer closely adhered to the substrate material. In the area of the connection, the substrate material-weld overlay, did not reveal any structural defects in the form of porosity of discontinuities and cracks (Fig. 6).

In the weld overlay area, a dendritic and cell-dendrtic structure was shown, in which the increase of dendrites in the liquid alloy occurs in the direction of heat dissipation (Fig. 7).

The observation carried out in the Zeiss Supra 35 scanning electron microscope confirmed obtaining a homogeneous weld overlay on the substrate of tested steel, and on the basis of the EDS analysis, all elements consisting the material used for the deposition (Spheroidal Inconel 625 powder) were found. No segregation of alloying elements, porosity and discontinuities in the entire weld overlay area was found (Figs. 8, 9).

The roughness of a processed surface is often higher in comparison with the initial base material surface (X40CrMoV5-1 Ra = 0.353 μm). This phenomenon is related to the amount of heat introduced into the modified region, the melting rate and is disadvantageous in terms of quality and usefulness under certain operating conditions. With the increase of laser power used for cladding the roughness of the surface layer/weld overlay increases, which is caused by the presence of strong convection movements in the remelting area. The smallest increase in surface roughness (Ra = 1.58 μm) in comparison with a roughness of the substrate material was observed for cladding with laser power 2.0 kW, while the highest (Ra = 2.17 μm) when 3.0 kW laser power was applied. Results of roughness measurements are shown in Table 3.

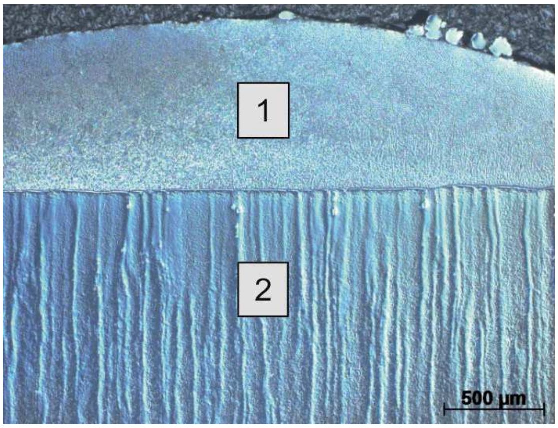

Fig. 6. Microstructure of weld overlay-cross section, 1 – weld overlay Inconel 625, 2 – substrate materials steel X40CrMoV5-1

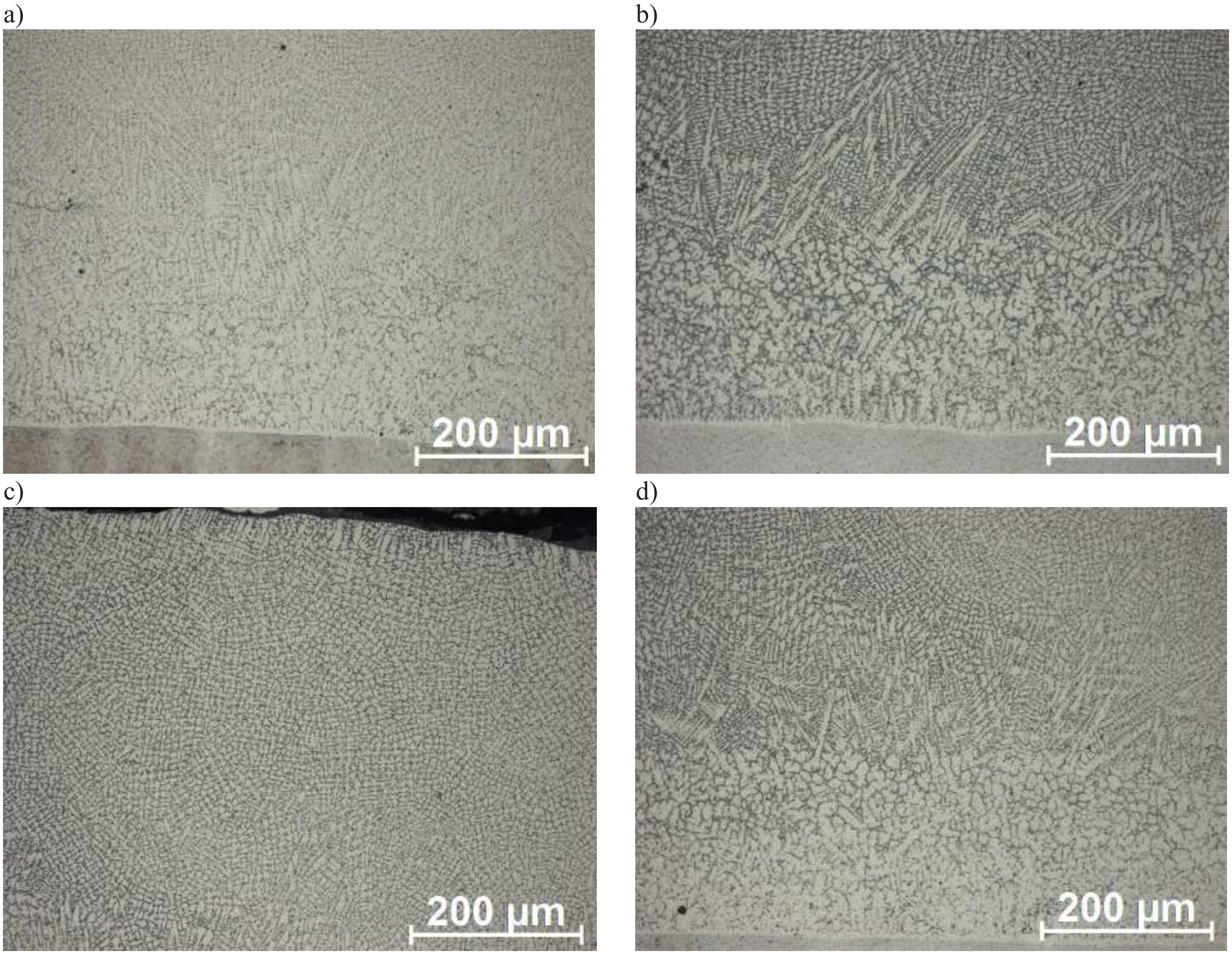

Fig. 7. Microstructure of weld overlay at the penetration bonduary, power laser: a) 2.5 kW, b – d) 3 kW

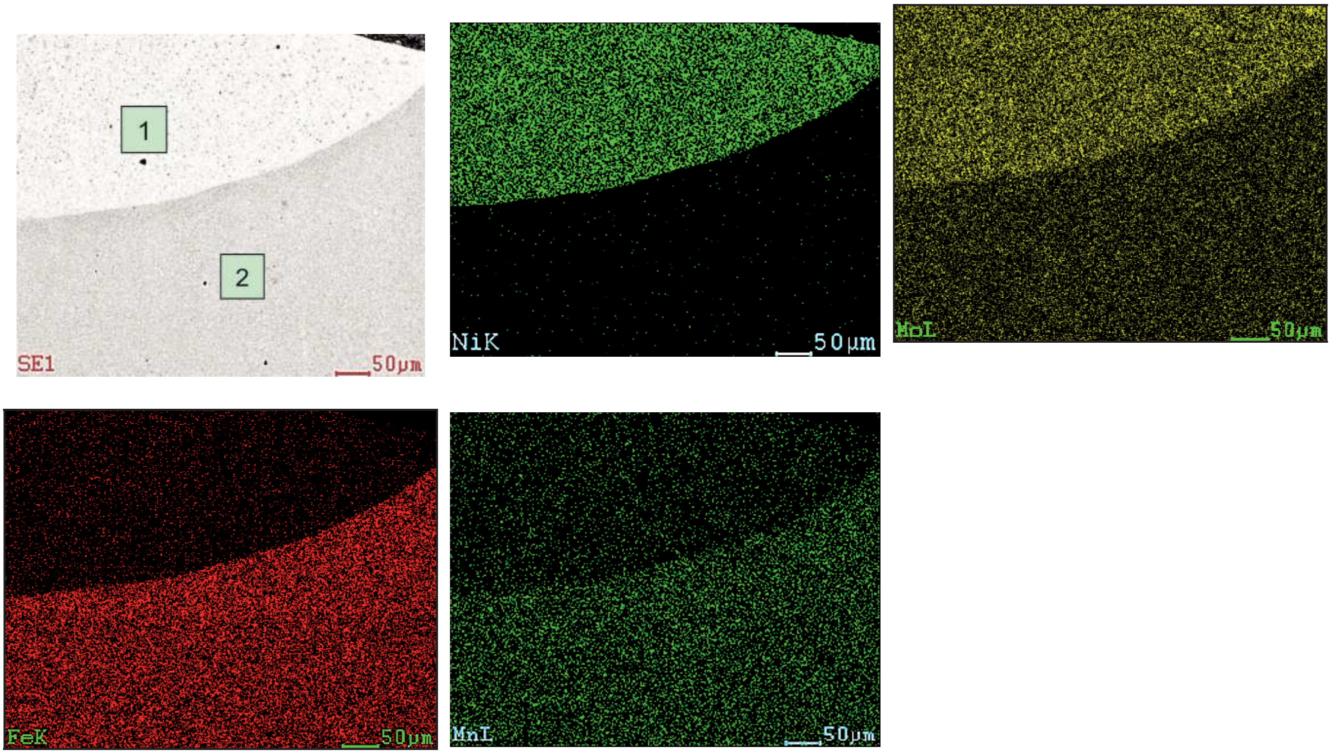

Fig. 8. Chemical distribution of elements from microstructure of weld overlay, laser beam power 2 kW

Table 3.
The average roughness value

Roughness, µm		Ra	Rp	Rv	Rz
		The value of average roughness			
Power laser, kW	2	1.58	4.10	3.39	7.49
	2.5	2.10	3.23	4.58	7.81
	3	2.17	3.76	5.24	8.99
		The standard deviation			
	2	0.83	2.18	1.62	3.83
	2.5	0.49	0.45	1.20	1.20
	3	0.50	0.76	0.82	0.84
		The coefficient of variation			
	2	0.52	0.53	0.48	0.51
	2.5	0.24	0.14	0.26	0.20
	3	0.23	0.20	0.16	0.09

*Ra – roughness average; Rp – maximum profile peak height; Rv – maximum profile valley depth; Rz – average maximum height of the profile.

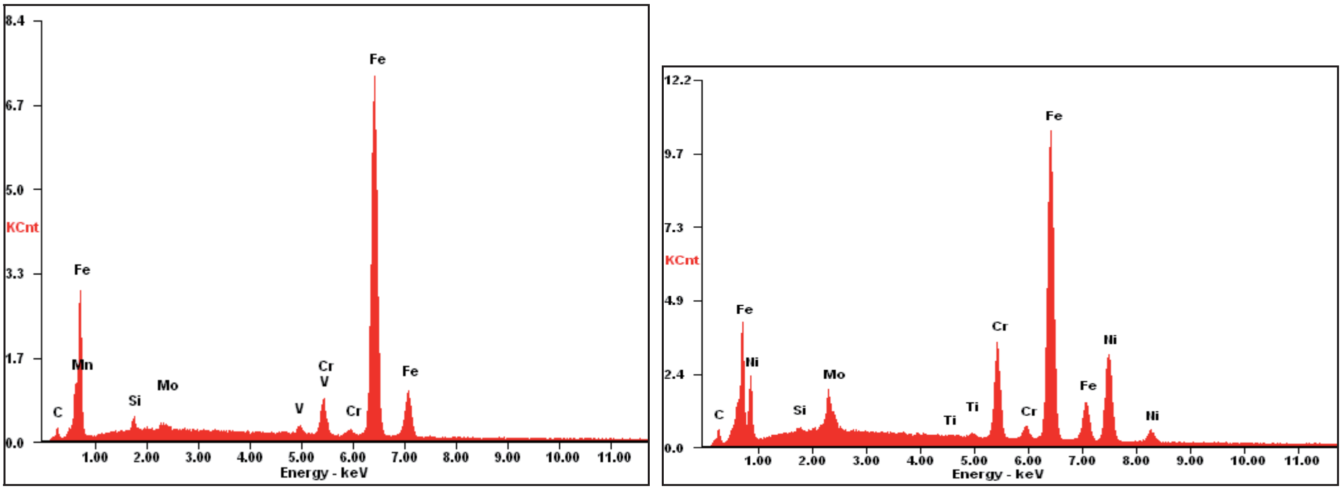

Fig. 9. Result of EDX analysis of microstructure from Figure 8; 1 – weld overlay of Inconel 625, 2 – base material, X40CrMoV5-1 steel

4. Conclusions

Based on the analysis of the performed tests, it was shown that:

1. The use of laser cladding using Inconel 625 powder allowed to obtain a homogeneous layer closely connected to the substrate.
2. As a result of the surface layer cladding with 3.0 kW laser beam, a weld overlay thickness of about 33% greater than that obtained with the 2.0 kW laser beam.
3. In weld overlay area, a dendritic and cell-dendritic structure was revealed, in which the increase of dendrites in the liquid alloy occurs in the direction of heat dissipation.
4. The analysis carried out with the use of a scattered X-ray detector confirmed the homogeneous distribution of elements in the weld overlay area for each variant of the laser beam power used.
5. Surface geometry measurements using a contact profilometer revealed an increase in roughness parameters along with an increase in laser beam power. The average roughness (Ra) of the weld overlay obtained with the 3.0 kW laser power was 27% higher than in the layer obtained with the power of the 2.0 kW laser beam.

References

[1] L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz, The technologies of shaping the structure and properties of the materials engineering surface using laser radiation and other welding technologies, Open Access Library 5 (2011) 181-225 (in Polish).

[2] L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz, Materials surface engineering; Compendium of knowledge and academic textbook, Open Access Library Annal VIII (1) (2018) 1-1140 (in Polish).

[3] M. Hawryluk, Review of selected methods of increasing the life of forging tools in hot die forging processes, Archives of Civil and Mechanical Engineering 16 (2016) 845-866, DOI: http://dx.DOI:0.1016/j.acme.2016.06.001.

[4] Z. Gronostajski, M. Kaszuba, S. Polak, M. Zwierzchowski, A. Niechajowicz, M. Hawryluk The failure mechanisms of hot forging dies, Materials Science and Engineering. A, Structural Materials: Properties, Microstructure and Processing 657 (2016) 147-160, DOI: https://doi.org/10.1016/ j.msea.2016.01.030.

[5] J. Kusiński, Lasers and their applications in materials engineering, WN Akapit, Kraków, 2000 (in Polish).

[6] S.R. Lewis, R. Lewis, D.I. Fletcher, Assessment of laser cladding as an option for repairing/enhancing rails, Wear 330-331 (2015) 581-591, DOI: https://doi.org/10.1016/j.wear.2015.02.027.

[7] A. Mertens, R. Carrus, J. Lecomte-Beckers, J. Tchufang Tchuindjang, Laser cladding as repair technology for Ti–6Al–4V alloy: Influence of building strategy on microstructure and hardness, Materials & Design 85 (2015) 497-510, DOI: https://doi.org/10.1016/j.matdes.2015.07.035.

[8] I. Hutchings P. Shipway, Surface Engineering, in: Tribology. Friction and Wear of Engineering Materials, Second Edition, Butterworth-Heinemann, 2017, 237-281, DOI: https://doi.org/10.1016/B978-0-08-100910-9.00007-6.

[9] A. Wypych, Microstructure and service properties of Inconel 625 as a thermal spraying surface layers, Welding Review 12 (2011) 56-58 (in Polish).

[10] H. Smoleńska, J. Łabanowski, W. Kończewicz, Regeneration of marine engine valves using laser surfacing, Welding International 30/2 (2016) 103-106, DOI: 10.1080/09507116.2014.937615.

[11] T.E. Abioye, D.G. McCartney, A.T. Clare, Laser cladding of Inconel 625 wire for corrosion protection, Journal of Materials Processing Technology 217 (2015) 232-240, DOI: https://doi.org/10.1016/j.jmatprotec.2014.10.024.

[12] Z. Peilei, L. Xiaopeng, L. Yunlong, Y. Hua, Y. Zhishui, L. Chonggui, L. Qinghua, Microstructure and wear behavior of Cu–Mo–Si coatings by laser cladding, Applied Surface Science 311 (2014) 709-714, DOI: https://doi.org/10.1016/j.apsusc.2014.05.141.

[13] J. Mazumder, Laser-aided direct metal deposition of metals and alloys, in: M. Brandt (Ed.), Laser Additive Manufacturing. Materials, Design, Technologies, and Applications, Woodhead Publishing Series in Electronic and Optical Materials, 2017, 21-53, DOI: https://doi.org/10.1016/B978-0-08-100433-3.00001-4.

[14] B. Cevik, B. Gülenc, The effect of welding speed on mechanical and microstructural properties of 5754 Al ($AlMg_3$) alloy joined by laser welding, Materials Research Express 5/8 (2018) 086520 2-11, DOI: 10.1088/2053-1591/aad3b0.

[15] K. Schaumberger, V. Mann, M. Mödl, K. Hofmann, S. Stein, S. Rot, M. Schmidt, Influence of focal spot diameter and beam oscillation on the process efficiency of laser beam welding utilizing a direct diode laser, Procedia CIRP 74 (2018) 466-469, DOI: https://doi.org/10.1016/j.procir.2018.08.149.

[16] E.O. Olakanmi, S.T. Nyadongo, K. Malikongwa, S.A. Lawal, S.L. Pityna, Multi-variable optimisation of the quality characteristics of fiber-laser cladded Inconel 625 composite coatings, Surface and Coatings Technology 357 (2019) 289-303, DOI: https://doi.org/10.1016/j.surfcoat.2018.09.063.

[17] E. Jonda, Z. Brytan, K. Labisz, A. Drygała, The influence of laser surface alloying on the thermal fatigue resistance of hot work tool steels, Archives of Metallurgy and Materials 61/3 (2016) 1309-1314, DOI: https://doi.org/10.1515/amm-2016-0216.