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Authors: Andrzej Mazurkiewicz, Andrzej Poprzeczka

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Evaluation of the quality of metal powder layers applied by laser deposition technology

ANDRZEJ MAZURKIEWICZ**ANDRZEJ POPRZECZKA ***

* Dr inż. Andrzej Mazurkiewicz, <https://orcid.org/0000-0002-3723-6733>, andrzej.mazurkiewicz@uthrad.pl – Wydział Mechaniczny Uniwersytetu Technologiczno-Humanistycznego w Radomiu, Radom, Polska

Dr inż. Andrzej Poprzeczka, <https://orcid.org/0000-0002-7256-5698>, andrzej.poprzeczka@uthrad.pl – Wydział Mechaniczny Uniwersytetu Technologiczno-Humanistycznego w Radomiu, Radom, Polska

The article presents the research results of welding of non-alloy steel C45 by laser metal deposition (LDT) with Stellite powder and high-chromium. The occurrence of cracks in the weld was found, with specific production parameters, which should be associated with variable parameters of heat supply and heat dissipation on the unheated substrate.

KEYWORDS: laser welding, LDT, laser powder deposition technology, surface layer, dendrites

Introduction

The main criterion for the division of layered production is the method of material feeding: using a filled platform and regularly leveled with the powder (powder bed) or direct point deposition (direct deposition) [1].

There are many manufacturing methods, in which a model is shaped by the continuous increase of the material until the required shape is obtained [2, 3]. LDT (laser deposition technology) plays an important role. It is a process, in which metal powder is injected into a focused beam of high power laser in strictly controlled atmospheric conditions.

Quality of the manufactured element or layer is affected by the impact of laser radiation on the material, which depends primarily on:

- type of material,
- radiation wavelength,
- radiation power density,
- radiation exposure time to the material.

By using different combinations of power density and exposure time, it is possible to run various technological processes. Most of them use the effect of heating and melting the surface layer.

The force of laser beam interaction on the material is related to the absorption of laser radiation (photons). Absorption capacity mainly depends on the radiation length and temperature of the material. The shorter the wavelength, the higher the absorption.

The lowest absorption capacity is observed for metals with high thermal conductivity. Absorption of radiation increases with temperature due to the surface oxidation. Oxides absorb radiation much better. This means that pre-heating of the surface increases the absorption of radiation [4].

Absorption of high-energy laser radiation in a short period of time can cause a pressure wave in the material, which in turn causes tensile stress leading to microcracks.

The occurrence of tensile stress in the surface layer in the case of a laser alloying of steel with Stellite is presented, among others, in works [4, 5].

The structure and quality of element produced by deposition of metal powder is largely influenced by the value of the feed of the working table. This is due to the connection with the rate of heat dissipation [6, 7].

Concentrated laser beam melts the surface of the target material and produces a small molten layer of the base material. Material, in the form of powder, is supplied to the pool of the base material in a continuous manner and melts there at a very high speed, as a result of which a thin layer of alloy of parent material and powder forms on the surface of the element (fig. 1).

Fig. 1. The essence of LDT technology

Material and test method

The main purpose of the work was to determine the selected qualitative properties of padding welds produced in the laser metal powder deposition (LDT) technology, such as: microstructure, hardness and macrostructure. The padding weld was formed on a C45 non-alloy steel base.

The padding weld materials were Stellite 21, powder with $45 \div 180 \mu\text{m}$ gradation, and high-chromium high-carbon steel in the form of powder with $45 \div 180 \mu\text{m}$ gradation.

Chemical composition of the padding weld deposit is presented in tab. I and II. Multilayer laser welding was performed applying the standard RPMI 557 system for laser metal powder deposition. Technological production parameters are presented in tab. III.

TABLE I. Chemical composition of the Stellite 21 padding weld material

Chemical composition [%]							
Co	C	Mo	Ni	Fe	Mn	Cr	Si
rest	0.26	5.4	2.4	0.2	0.68	27.8	0.9

TABLE II. Chemical composition of the steel padding weld material

Chemical composition [%]								
Fe	C	Mo	Ni	Cr	Mn	Si	Mg	S
rest	1.82	4.4	16.4	27.8	0.68	1.31	0.74	0.9

TABLE III. Parameters for producing the Stellite (N) and steel (S) padding welds by means of laser metal powder deposition (LDT)

Sample number and grade (Stellit 21, steel)	Scan speed [cal/min]		Powder feeding [g/min]		Laser power [W]	Number of layers	
	N	S	N	S		N	S
N1/S1	30	30	9,6	6,9	2740	14	4
N2/S2	30	21	7,6	5,0	2740	14	3
N3/S3	30	15	5,8	5,0	2740	14	5
N4/S4	24	21	5,8	5,0	2740	14	5

The appearance of the samples cut in the central part of the padding weld and the surface intended for microscopic observation are presented in fig. 2.

Fig. 2. Shape of the samples after cutting and the surface intended for microscopic observation – Stellite padding weld on the left, high-chromium steel padding weld on the right

Results

Stellite padding weld

The padding welds had a regular, repeatable shape with particles of unmelted powder visible on the surface (fig. 2), which is characteristic for padding welds made of powder material. The padding welds made of high-chromium steel have a similar appearance.

The macrostructure of the *N3* sample (fig. 3) shows the execution of 14 layers from the fusion zone. Among the samples made with different parameters (tab. III), the *N3* sample is distinguished by significant number of cracks inside the padding weld. The cracks nucleate already in the first layer from the base and reach the upper surface of the sample. These cracks are arranged in accordance with the direction of heat dissipation, particularly intensively to areas of the unheated base. Formation of cracks is the result of natural stress. To prevent cracks, annealing is used before or after laser modification of the workpieces.

Possibilities of cracks occurrence due to tensile stress in the surface layer in the case of materials with low thermal conductivity, such as Stellite, are presented in [8].

The microstructure of the cross-section of the *N4* sample (fig. 4) is characteristic for the samples tested.

The microstructure of layers of padding welds materials is dendritic (fig. 5a). The dendrite axes are consistent with the directions of heat dissipation during crystallization. Dendrites are fairly large in size and run across the boundaries of the layers, i.e. they retain their crystallographic directions, and subsequent layers do not inhibit their growth (fig. 5b). Dendrites have long main axes, but are weakly branched, which indicates rapid directional crystallization. At the boundaries of dendrite “packages” running in different directions, there is no shrinkage porosity or cracks. To assess the padding weld properties, the microhardness measurement (fig. 6) was used in a cross-section perpendicular to the padding weld surface, i.e. from the external padding weld surface, through the metallurgical connection zone, to the steel base.

Fig. 3. View of the cut surface, sample *N3* with visible cracks in the direction of layer formation, magnification 7×

Fig. 4. Cross-section microstructure of the *N4* sample, welded with Stellite 21 powder on a C45 steel base, made using the LDT multilayer laser deposition technique, *N* – padding weld, *SW* – welding zone, *SWC* – heat impact zone, *MP* – base material

Fig. 5. Microstructure of the padding weld material (sample N2) at various magnifications, digestion with 80 ml HCl, 80 g FeCl₃, 6 g CuCl₂, 1000 ml H₂O; a) dendritic structure of the padding weld material, b) dendritic structure running through several layers

Fig. 6. Hardness distribution in transverse section of the padding weld layer of N3 sample, from Stellite 21 powder on C45 steel, made using the LDT multi-layer laser deposition technique

High chromium steel padding weld

Unlike the Stellite padding weld, the high-chromium steel weld has no internal cracks at the sample production parameters applied.

Among the observed samples made with different parameters (tab. III), the S2 and S4 samples stand out having significant cracks in the edge padding weld areas including the first external layers (fig. 7). These are the places of the first contact of the padding weld material with cold surface, which must promote fast heat dissipation.

The cracks are arranged according to the shape of the welding of the padding weld material. Possibility of a tensile stress at the surface in chromium laser-melted steels is indicated by some studies [4, 8].

Fig. 7. View and crack site of the S2 sample occurring in the extreme application paths of the first layer of padding weld

Structure of the padding weld material layers is dendritic, especially in the first layer closer to SWC. Large dendrites with axes directed towards heat dissipation during crystallization are visible. As in the case of the Stellite padding weld, dendrites are quite large and run across the boundaries of the layers.

The steel padding weld has a large structure diversity, resulting from different crystallization conditions of the material during the manufacturing process (fig. 8). It is possible to homogenize the structure by heat treatment. Similar situation occurs during production of elements in the selective laser melting technology – SLM, in which the heterogeneity of the layered structure has also been removed by homogenizing annealing [3].

Microstructure of the cross-section of the S4 sample (fig. 9) is characteristic for all accepted parameters of multilayer weld padding.

Fig. 8. Structure disturbances on the cross-section of the S2 sample padding weld, indicating large heterogeneity of the structure

Fig. 9. Microstructure of the cross-section of the S4 sample weld padded in LDT technology with high-chromium steel powder (markings as in fig. 5)

Fig. 10. Distribution of average hardness values in cross-section of the S4 sample padding weld made of high-chromium steel powder on a C45 steel base made using the LDT multi-layer laser deposition technique

The microhardness variability in both areas also indicates the heterogeneity of the padding weld structure and native material (fig. 10).

Conclusions

Weld padding by laser deposition of metal powdered Stellite 21 and high-chromium steel by means of LDT technique allows for coating common construction materials with materials with high performance characteristics. Such coatings have repeatable shapes and geometry.

The assessment of the microstructure of sample cross-section surface after weld padding with the LDT technique indicates good metallurgical quality of the padding weld with a clear weld and small heat-affected zone, about 0.7 mm.

Microstructure of padding welds after multi-layer laser weld padding applying LDT technique is characterized by longitudinal, weakly branched, dendrites, associated with the directional process of heat dissipation, which proves the rapid directional crystallization in different directions.

Variable parameters of heat supply and dissipation can affect the heterogeneity of the padding weld structure, especially of high-chromium steel.

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