The applying of layer-by-layer laser remelting in the technology of laser metal deposition

Y N Zavalov and A V Dubrov
Institute on Laser and Information Technologies - Branch of the Federal Scientific Research Centre “Crystallography and Photonics” of Russian academy of Sciences, Svyatoozerskaya 1, 140700, Shatura, Moscow Region, Russia

E-mail: dubrov.av@mail.ru

Abstract. Layer-by-layer laser remelting (LRM) was used in the technology of laser metal deposition in order to reduce the porosity of the layer in the case of single-layer and multi-layer coatings. The layer porosity is shown to decreases with LRM at a rate 5 times higher than the rate of metal deposition. The dependence of the porosity estimated using the method of the hydrostatic weighing on the rate of laser remelting is obtained.

1. Introduction
Reduction of porosity in additive technologies of laser deposition of metals (LMD) is the urgent task of the modern stage of equipment introduction into modern machine-building production of complex shaped products [1–2]. Porosity also occurs in SLM [3] and is associated with the features of the technological process [4], in particular, the occurrence of convective flow in the melt bath [5]. There was indicated in [6] the need for additional drying of the powder in preparation for production. The dependence of porosity on technological parameters was studied in [7] for LMD of titanium aluminium alloys, and stainless steels was used in [2]. In this work, laser remelting technology is used on each layer in the LMD process in the case of single-layer and multi-layer coatings. Earlier, the technology of laser remelting (LRM) a single track formed using the LMD technology was studied in [8, 9]. The mode of melting the track with the incomplete depth was studied in [8], but no data on porosity in the LMD + LRM mode was given. The combined technology was studied in addition to the single track in [9] for the formation of the thin-walled structure. The porosity was shown to decrease first with the increase the power of laser radiation for the single track, and it begins to increase then from the certain power level. The laser power of the optimal LRM technology was concluded to coincide with the power at LMD. The laser power remained on certain level, and the energy effect of laser radiation varied due to changes in the scanning speed in our experiments.

2. Materials and method
The experiments were carried out at the additive synthesis research facility using the technology of laser deposition of metals, created at IPLIT RAS. The flow of PR-07X18H12M2 steel powder (analogue of 316L) with the mass flow rate of 0.14 mg/s and the granulometric composition (40 ... 100) microns was concentrated through the conical nozzle on the surface of the substrate. 68x68x6 mm substrates made of 08X18H10T steel were used. The fibre ytterbium laser LK-400-V was used, the radiation of which passes through the coaxial flow of the gas-powder mixture and focuses near the
substrate. Each track with the length of 16 mm was formed at constant values of the distance from the nozzle to the substrate and the position of the beam focus, scanning speed \( V = 350 \text{ mm/min} \), laser power \( P = 400 \text{ W} \).

Tracks with \( dy \) increments were applied sequentially to each substrate, depending on the degree of overlap. The height of the formed single layer is indicated depending on the degree of overlap. The height change was taken into account in the case of a subsequent remelting operation, see Table 1. The images of the formed layers before remelting (a) and after (b) are shown on figure 1. The seven adjacent tracks were formed sequentially in one direction for a small overlap in total, and 8 tracks were formed for 40% overlap.

**Table 1.** The changing the height of the layer after remelting.

| Overlap | Speed \( V \) \[ mm/min \] | Height \( H \) [LMD] \[ microns \] | Height \( h \) [LMD+LRM] \[ microns \] | \((H-h)\) \[ mm \] | Deviation \[ \% \] |
|---------|------------------|-----------------|-------------------|-----------------|-----------------|
| 10%     | 350              | 730             | 600               | 130             | 18%             |
| 25%     | 350              | 980             | 880               | 100             | 10%             |
| 40%     | 350              | 1188            | 1100              | 88              | 7%              |

The value of the vertical step \( dz \) depended on the degree of overlap in the case of multilayer coatings. More than 12 layers were applied to form the rectangular part with the height of about 16 mm (figure 1 c). The gas pressure (nitrogen) at the feeder inlet was 0.3 MPa, the pressure of the protective gas was 0.6 MPa, the flow rate of the protective gas was 10 nl/min. Samples were made with different degrees of overlap of the tracks in the layer. Samples were made with a layer-by-layer LRM operation in the combined technology [LMD+LRM], the geometry reproduced the geometry of sample manufacturing, but the vertical step value \( dz \) was adjusted in this case, table 1.

![Figure 1](image)

**Figure 1.** The part of the obtained specimens: a) and b) two-layer and c) multi-layer specimens.

Then the samples underwent the operation of removing the top layer, and the porosity of each sample was measured by hydrostatic weighing ("Archimedes’ method"). The weighing instrument was used with the minimum division value of 0.1 mg. The obtained results are shown in figure 2. The samples are divided by the degree of overlap and are listed at the same degree in ascending order of the LRM speed in the figure. The empty markers indicate the speed of the layered LRM operation, the last one shows the porosity of the sample without the LRM operation (a large circle). The increase in the LRM rate, the effect of reducing porosity worsens in general. The first two samples were obtained at LRM rate significantly lower than the sample formation rate for each overlap value. The porosity at a reduced LRM rate significantly worsened compared to the [LMD+LRM] technology in the case of
overlap degrees of 10% and 40%. The porosity worsened was not observed in the case of an overlap degree of 25%. And special mention the initially porosity was noticeably less in samples with the overlap degree of 25%.

Figure 2. The dependence of the porosity value for different LM+LP samples. The degree of overlap of the tracks in the layer is indicated in the figure caption. Hollow markers - the scanning speed of the LP (right scale).

3. Results and discussion
To estimate the thermal effect of laser radiation on metal, we use the value of the energy $E_s$ per unit surface:

$$E_s = \frac{p}{\omega \cdot V}$$  \hspace{1cm} (1)

To estimate the thermal effect of laser radiation on metal, we use the value of the energy $E_s$ per unit surface area, where $\omega$ is the radius of the laser beam in the plane. Previously, the study of the residual intra-layer porosity (ILP) in multilayer samples obtained by the isolated LMD technology was carried out in the energy supply range (1.2...9) kJ/cm$^2$ [10]. The dependence of the ILP on the specific energy is shown non-monotonic, the minimum of defects is observed at the average values of the energy from the used range. Figure 3 shows the dependence of the porosity of the obtained data and Figure 2 shows the dependence on the specific energy of irradiation $E_s$ at the layer-by-layer LMR stage. The samples are formed into three groups depending on the degree of overlap, and in each group, they are numbered in ascending order $E_s$. The effect of reducing porosity worsens at above 6 kJ/cm$^2$ with an overlap of 10%, at the degree of overlap of 25% the porosity also decreased at an $E_s$ value of about 10 kJ/cm$^2$.

4. Conclusions
The parametric study of the residual porosity of multilayer LMD+ LRM samples obtained at different speeds of the LRM process and different degrees of overlap of the tracks in the layer is carried out.

The addition of the LRM stage with the selected parameters is shown to make it possible to achieve the decrease in porosity in all the studied LMD modes. The minimum porosity values achieved after LRM are from 0.43% to 0.95%. That is about 2-3 times less than the initial porosity of the LMD. When using LMR speeds of 5...6 times higher than the LMD speed, a porosity reduction of about two times is achieved. The influence of the degree of overlap of the tracks in the layer on the porosity is shown. The optimal overlap value corresponds according to the minimum porosity criterion to the degree of overlap closer to 25%. The porosity decreases with an increase in the specific irradiation
energy $E_s$ at the layer-by-layer LMR stage. However, the porosity increases with the increase in $E_s$ above 6 kJ/cm$^2$ in the case of an overlap degree of 10%.

**Figure 3.** The dependence of the porosity value for different LM+LP samples. The degree of overlap of the tracks in the layer is indicated in the figure caption. Hollow markers – the dependence of the specific irradiation energy $E_s$ at the layer-by-layer LMR stage (right scale).

**Acknowledgements**

The work was carried out with the support of the Ministry of Science and Higher Education of the Russian Federation within the framework of the State Task of the FSRC “Crystallography and Photonics” of the Russian Academy of Sciences in terms of setting the problem, as well as with the grant support of the Russian Foundation for Basic Research in terms of the developed methodology, as well as in terms of the experimental results obtained, grant No. 20-21-00158.

**References**

[1] Li L 2006 *J. Mater. Sci.* 41 7886–93
[2] Susan D F, Puskar J D, Brooks J A and Robino C V 2006 *Mater. Charact.* 57 36–43
[3] Grasso M and Colosimo B M 2017 *Meas. Sci. and Technol.* 28 044005
[4] Kobryn P A, Moore E H and Semiatin S L 2000 *Scr. Mater.* 43 299–305
[5] Ng G K L, Jarfors A E W, Bi G and Zheng H Y 2009 *Appl. Phys. A* 97 641
[6] Zhong C, Gasser A, Schopphoven T and Poprawe R 2015 *Opt. & Laser Technol.* 75 87–92
[7] Khanzadeh M, Chowdhury S, Marufuzzaman M, Tschopp M A and Bian L 2018 *J. Manuf. Syst.* 47 69–82
[8] Porto R M, de Souza Pinto Pereira A and Pereira M 2020 *J. of Laser Appl.* 32 022069
[9] Xin B, Zhou X, Cheng G, Yao J and Gong Y 2020 *Opt. & Laser Technol.* 127 106087
[10] Zavalov Y N and Dubrov A V 2021 *J. Phys. Conf. Ser.* (IOP Publishing) 1954 012056