The surface roughness of samples formed in the combined technology of laser metal deposition with layer-by-layer remelting

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

E-mail: dubrov.av@mail.ru

Abstract. The surface roughness of the layer formed during laser metal deposition before and after laser remelting is determined. The single-layer objects are formed using austenitic stainless-steel powder at different technological parameters in the combined technology of laser metal deposition with layer-by-layer remelting. The improvement of the roughness after laser remelting is shown.

1. Introduction
The laser remelting (LR) of the metal surface or its alloys was previously used to improve the surface properties of critical parts [1]. The use of LR technology in particular increases the corrosion resistance and abrasion resistance of the surface of products [2]. On the other hand, it is important to take into account the resulting residual internal stresses choosing the LR parameters [3]. The processing of parts obtained in the additive electron-arc technology using metal wire in the LR process for instance made it possible to reduce residual internal stresses and improve the roughness of the treated surfaces [4]. The LR process was applied after each layer in the technologies of synthesis by laser melting of pre-poured SLM powder [5] and laser deposition of metal with a gas-powder jet LMD [6]. The decrease in the surface roughness of the layer treated in the LR process is observe in these studies. There are no specific data in [6] however on the surface roughness of the layer before and after the use of LR. In this paper, the roughness of the layer formed during the LMD process is measured depending on the speed of scanning the sample by laser radiation, the degree of overlap of the tracks in the layer, as well as the surface roughness of the obtained samples after LR.

2. Materials and method
The research facility developed at ILIT RAS was used. The setup includes the ytterbium fiber laser LK-400-V (NTO "IRE-Polyus") with power of 400 W [7]. The robotic manipulator 4 (Kuka KR10 900-2) moves the substrate relative to the laser head (Precitec YC52). The configuration and speed of the feed disc of the powder feeder (GTV PF 2.1 LC) determines the mass flow rate of the powder. The powder of austenitic steel PR-07Kh18N12M2, (JSC "Polema") with a carbon content of about 0.02% (analogous of AISI 316L) was used in the LMD mode of experiments on the formation of the layer on the substrate surface. Granulometric composition of the powder (40 ... 100) microns.
The tracks of 12 mm long were applied sequentially on the 6 mm thick substrate made of 08Kh18N10T steel with the step \( dy \) at the same values of the technological parameters. The step \( dy \) varied in the range of \((0.65...1.2)\) mm depending on the powder flow rate \( G_0 \), the scanning speed \( V \) and the degree of overlap of the tracks \( L \). The scanning speed \( V \) of the substrate relative to the laser head was set of 350, 500 or 650 mm/min to form the layer while the distance between the nozzle and the substrate \( D_z \) 11 mm was keep. The collimator lens is moved to the distance of \( C_z \) 10 mm so the beam size on the surface of the substrate became about 1.43 mm. The mass consumption of \( G_0 \) powder in different series set in 8.5 g/min or 11 g/min. The maximum laser power of 400 watts was used.

The surface roughness then was measured using a Surftest SJ-301 profilometer (Mitutoyo). The LR process geometrically reproduced the course of the LMD process, the powder supply is stopped. The scanning speed at LR varied up to 1.1 m / min. In some experiments, the initial displacement of \( dy0 \) changed from zero to the value \( dy0= dy/2 \). In addition, the LR process was carried out with a reduced value of the laser beam intensity for individual samples of the formed layer. In this case, with an increase in the displacement of the substrate \( D_z \) to 15.8 mm, the size \( d \) of the beam on the substrate increases by one and a half times, the intensity decreases by about half, to 12 kW/cm\(^2\). The image of the surface of the layer formed during the LTD process, \( V=500 \) mm/min, \( L=40\% \) is shown on Figure 1(a). Figure 1(b) shows the surface after the LR with the same scanning speed, and Figure 1 (c) – after the LR process with a wide beam.

![Figure 1](image)

**Figure 1.** Surface of the layer formed in the LMD process, \( V=500 \) mm/min, \( L=40\% \) (a), after the LP with the same scanning speed (b), after the LP with a wide beam (c).

Three factors are specified to affect the level of surface roughness of the layer: 1) the ripple surface relief, composed of separate tracks formed with a given overlap of adjacent tracks, 2) fused powder particles, and 3) the inherent surface roughness of the melt. The measurements were made when the profilometer sensor moves along the center of one of the tracks along the direction of layer formation to assess the third component, the roughness of the melt. The roughness data with a repeatability of about \( \pm 7\% \) are shown in table 1 for several cases of layer formation in the LMD+LR technology with an overlap of \( L=40\% \) without additional displacement of the trace geometry at the LR stage, \( dy0=0 \).

| S. speed, mm/min | Beam size \( d \), mm | Ra, \( \mu m \) | Rz, \( \mu m \) |
|------------------|---------------------|-----------|-----------|
| 500+500          | 1.43                | 1.3       | 7.7       |
| 500+750          | 1.43                | 1.8       | 9.3       |
| 500+500          | 2.14                | 1.2       | 6.5       |

### 3. Results and discussion

The roughness data for the layers formed at a powder rate \( G_0 \) of 8.5 g/min are shown in figure 2. Small values of the layer surface roughness were measured for samples that passing the LR process with the
same scanning speed as in the LMD mode. The roughness $Ra$ (figure 2 a) decreases within (10...20) microns with an increase in the scanning speed of the LMD and with the increase of the overlap degree for the powder rate $G_0$ of 8.5 g/min. As a result of the LR process, the roughness decreased by about 5-6 times, to $Ra$ (2...3) microns, and practically does not depend on the scanning speed and the degree of overlap. The roughness $Rz$ (figure 2b) varies within (60 ... 120) microns and is related to the size of the powder particles on the surface of the formed layer. The roughness $Rz$ decreases in the process of LR, the range of measured values $Rz$ of (10...20 microns) as the consequence of the melting of particles on the surface of the layer.

![Figure 2](image_url)

**Figure 2.** Dependence of the $Ra$ (a) and $Rz$ (b) roughness in the LMD/LMD+LR technology on the scanning speed for different $L$ values, consumption 8.5 g/min.

The surface roughness $Ra$ of the layer formed in the LMD mode varies within (16 ... 25) microns for the rate of 11 g/min and is noticeably higher in the case of formation at the speed of 650 mm/min with the degree of overlap of 10% and 25% than at lower speed. The $Ra$ roughness is 14 microns ±10%, at 40% overlap regardless of the scanning speed. These results are related to the ratio of the technological parameters of the LMD process: for a laser power of 400 W, the consumption of 11 g/min and the speed of 650 mm/min are limiting in terms of the energy required to form a high-quality track, neighboring tracks at the specified percentages of overlap, 10% and 25%, form a relief with a high drop. With a degree of overlap of 40%, the depressions between the tracks are not so noticeable and the terrain is smoother, the roughness is lower.

In the case of a flow rate of 11 g / min with the same scanning speed [LMD+LR], the $Ra$ roughness was reduced to less than 3 microns at the overlap degrees of 25% and 40%, figure 3. The roughness increased to 3.3 microns±20% in the case of [LMD+LR] with a scanning speed of 500 mm/min with a wide beam with a reduced intensity. The increase in roughness in this case as follows from figure 1 (c) is associated with a low degree of penetration of the powder particles remaining on the surface of the layer after the LMD. The roughness increases for the layer with the overlap of 10% with the increase in the scanning speed of the LP to values slightly higher than 4 microns, which affects the high relief of the original layer.

The layer surface roughness at 40% overlap in the case of [LMD+LR], 11 g/min are shown also on figure 3 with LR scanning rates higher than the LMD rate: (350+500), (500+750), (650+1150) [mm/min], for two cases, without the initial offset and with the offset $dy0=dy/2$. The roughness increases as the LR speed increases. The displacement of $dy0$ by half the width of the track leads to a noticeable reduction in roughness, by (10...15) % in the case of LR speeds of 750 mm/min and below. This is due to the influence of the relief on the roughness, the depressions between the tracks are more effectively smoothed in the case of displacement during melting. The roughness is almost twice as high and does not depend on the value of the initial offset of the scanning path in the case of a speed of 1150 mm/min. In this case, the roughness is determined primarily by the degree of penetration of the powder particles remaining on the surface of the layer after the LMD.
Figure 3. Dependence of the Ra (a) and Rz (b) roughness in the LMD/LMD+LR technology on the scanning speed for different $L$ values, consumption 11 g/min.

4. Conclusions
Thus, the dependences of the roughness $Ra$ and $Rz$ of the samples obtained in the LMD process with the 400 W laser on the scanning speed, the degree of overlap of the tracks of the layer are given. It is shown that the roughness decreases by a factor of (5...6) during laser remelting at the same scanning speed. The effects of reducing the intensity, increasing the scanning speed to 1.1 m/min, and introducing an offset of half the track width on the surface roughness of the layer formed in the LMD mode using the powder of austenitic steel PR-07Kh18N12M2 are shown.

Acknowledgements
The work was supported by the Ministry of Science and Higher Education of the Russian Federation within the framework of the Task of the Federal State Budgetary Institution “Crystallography and Photonics" of the Russian Academy of Sciences in terms of the scientific problem, as well as with the grant support of the Russian Foundation for Basic Research in terms of the developed methodology, grant No. 18-29-03249, as well as grant No. 20-21-00158 in terms of conducting experiments and the experimental results obtained.

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