Laser powder cladding automated control method based on advanced monitoring system of processing area by CCD-camera

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Abstract. The use of CCD cameras for recording the area of high power radiation exposure during laser cladding process is an urgent task in a view of low cost of used equipment and high information content of obtained graphic data. This approach allows real-time recognition of geometric primitives in melt pool area and based on their analysis to evaluate the quality of processing operation. The main objective of the study was to eliminate, by using external illumination, a large dynamic difference in brightness, which negatively affects the quality of images obtained. As a result of the experiments, it was found that the most effective configuration of the video recording system for laser powder surfacing process is the location of camera and illumination module against the direction of head movement. The developed illumination system for the radiation exposure area made it possible to provide conditions acceptable for the automated recognition of images obtained by the CCD camera.

1. Introduction

Powder cladding is a thermal coating method used in industry to obtain wear-resistant and corrosion-resistant surfaces [1-3]. At present, the most promising approach of powder cladding, devoid of the disadvantages of other technologies, is the use of laser radiation as an energy source [4-6]. Laser powder cladding allows for dynamic local processing, provides high impact stability, has the ability to flexibly configure and control processing parameters during the process [7-9].

To monitor the progress of the technological process, various hardware and software solutions are used [10,11]. Among other automated control systems, methods for processing images of the laser cladding zone obtained from a CCD camera were used [12-14]. This approach allows to perform real-time recognition of geometric primitives in the melt pool area and on the basis of their analysis to correct technological processing parameters (tool movement speed, laser power, powder feed rate).

To increase the efficiency of data processing, it is necessary to obtain the most informative images from the impact area. When using CCD cameras to observe the area of exposure to laser radiation (in the processes of laser welding, heat hardening, cladding), a number of problems arise, the solution of which is a difficult technical task. The main problem is the need to correct the exposure of the camera matrix in a large dynamic range. Most industrial laser heads provide the ability to observe the surface of the workpiece during the preliminary positioning of the head, not allowing to carry out observation directly during processing. The images recorded during laser processing are uninformative, since under the influence of laser radiation the dynamic exposure of the camera is not enough to display the surface not exposed to the laser beam, the zone of solidification of the melt pool and its geometry. In
the area of influence, exposure of the matrix region is observed; information from other areas is not
detected at all due to extremely low luminosity. The use of light filters makes it possible to observe
exclusively areas falling within the dynamic range of the camera's exposure. Replacing light filters
during processing (in the case of using various operating modes) is a low-tech and difficult to
implement solution. Thus, the solution to this problem is to use a system capable of leveling the
illumination of the field recorded by the CCD camera. Existing technological solutions [15] involve
the use of infrared cameras, cameras with a large dynamic exposure value, which allows real-time
monitoring of the area of exposure to laser radiation. These solutions are much more expensive than
silicon CCD cameras and also have disadvantages. In the present work, experiments are described
devoted to selection of optimal configuration of illumination and registration systems arrangement
relative to optical head of powder laser cladding complex.

2. Configuration of video registration system
When developing a video recording system, the optimal configuration of mutual arrangement of laser
exposure area illumination module and an CCD camera was investigated. The aim of this study was to
eliminate a large dynamic difference in brightness at the time of the presence of laser radiation and in
its absence (during the positioning of the surfacing head on the processed material), which cannot be
compensated by adjusting the camera matrix exposure. The system effectiveness was assessed by the
degree of characteristic cladding zones recognition, the absence of image defects that impede analysis,
the minimum exposure time that provides satisfactory image quality, and the number of frames per
second received from camera at a given exposure.

With the location of the illumination and registration systems on the one hand, against the
movement of the cladding head, it is possible to obtain a surface image with the greatest light
efficiency. Illumination points are the flat surface of polished sample, the leading edge of melt pool
surface, containing spherical ejections of liquid phase both during the cladding and at its completion,
the tail of molten pool, which, as a rule, has a higher temperature than leading edge of clad bead
(figure 1). In the image, the surface of clad bead is a dark region, which is caused by a convex shape
and high reflectivity. The backlight radiation incident on the sample is reflected outside the direction
of the camera plane. A vapor-gas cloud formed during welding and surfacing of metal under the
influence of powerful laser radiation is not observed at all. The illumination intensity exceeds the
intensity of the glow of melt pool and laser radiation, which allows to observe the formed surface. The
vapor-gas cloud is facing the nozzle part of the cladding head, has a certain deviation against the
direction of the head movement, and is not an obstacle for the imaging system. The strongly absorbing
surface of the deposited bead is quite dark, which leads to uneven illumination of the image recording
area.

**Figure 1.** Registration and illumination systems are located on one side of the cladding head;
registration parameters: performance – 48 frames per second, exposure time – 800 ms.

The location of illumination and registration systems on different sides of cladding head provides
almost uniform brightness of processed surface images (figure 2). The flare points are molten metal
with a high reflectivity (liquid phase splashes at the clad bead leading edge, melt pool surface). When cladding beads of sufficiently high height, it is possible to detect a defect in the form of a shaded area in front of the clad bead leading edge. A vapor-gas cloud is still not observed, since it faces the nozzle part of the head and is not an obstacle for the image registration system. In the absence of laser radiation, the image has high contrast and detail, defects associated with an exposure error were not detected. Illumination of the image registration area is fairly uniform.

Using an image registration system located coaxially with the laser beam, it is possible to obtain a surface image of sufficiently high quality, devoid of the shaded areas formed during cladding of bead (figure 3). The defect in this configuration of the system is a vapor-gas cloud, which serves as an obstacle to observing a laser radiation area. A vapor-gas cloud scatters both the incident laser radiation and radiation of illumination system (figure 3b). This defect makes it difficult to recognize the leading edge of clad bead, thereby causing problems in image analysis, and, as a consequence, the correction of cladding mode. Registration of deposited structure in the absence of laser radiation has high contrast and detail, there are no defects associated with the exposure error. Liquid phase emissions are not observed due to the presence of a vapor-gas cloud.

Attempts to provide effective illumination of the exposure area with a coaxial arrangement of registration and illumination systems relative to laser radiation (figure 4) did not lead to the desired effect. The design of commercial laser head does not provide sufficient throughput for illumination system. The radiation of illumination module, passing twice through the beam splitter, dichroic mirror, and vapor-gas cloud (in the forward and backward directions), is significantly weakened, the CCD camera does not register the laser radiation exposure area, but the reflection from the optical surfaces
of cladding head components. With intense laser radiation, the surface of a vapor-gas cloud is weakly traced. The images obtained in this configuration are not presented due to their full uninformative. The presented disadvantages can be eliminated by careful selection of optical elements when creating a cladding head, which is quite expensive. Based on previous studies, it can be assumed that there is significant reflection from the surface of vapor-gas cloud and the central part of laser radiation exposure region due to orientation of the illumination coaxially to the laser beam. Thus, the use of this configuration of a video recording system is a technically complex and inefficient solution.

![Diagram of coaxial arrangement of illumination system and image registration system relative to laser radiation.](image)

**Figure 4.** Coaxial arrangement of illumination system and image registration system relative to laser radiation.

Thus, on the basis of experimental data, it can be concluded that the best image of laser radiation exposure region during the powder cladding process provides the location of camera and illumination module against the direction of head movement. Observed image defects do not affect processing efficiency when performing automated analysis.

3. **Automated control system of laser cladding process**

To enable automated control of the powder laser cladding process, a module was developed for processing images recorded by CCD camera in the cladding area. Detection of region of interest (ROI) of the front and processing zone itself was carried out using pre-created templates, which were obtained on the basis of experimental data of this study.

In real time, the developed algorithm using machine vision and mathematical statistics detects ROI. Each ROI area is simultaneously examined for the content of geometric primitives characterizing conditions for implementation of laser cladding technological process. The result of the ROI study allows real-time adjustment of the processing mode technological parameters, as well as the identification of defects associated with mismatch of the geometry of selected primitives with the predefined standards. Processing parameters are deposited bead width, shape of surfacing region leading edge, homogeneity of material melt pool, which is shown in figure 5.

As can be seen from the figure, the use of a lateral illumination system made it possible to provide an image contrast sufficient for correct operation of processing system. Due to short exposure time, the performance of automated analysis system does not decrease. In turn, the lack of external illumination leads to insufficient coverage of registration area, which makes it impossible or reduces the quality of the desired geometric patterns recognition (figure 6).
4. Conclusion
As a result of the experiments, it was found that the illumination of laser radiation exposure region allows to provide acceptable conditions for the automated recognition of images obtained by an CCD camera. The most effective configuration of video recording system for laser powder cladding is the location of the camera and illumination module against the direction of head movement. The totality of taken decisions made it possible to solve the problem of using an CCD camera with a silicon photodetector to record processes occurring in the field of laser radiation exposure during laser powder cladding. It became possible to provide automated recognition of impact area, on the basis of which the processing parameters (laser power, flow rate of cladding material and carrier gas) can be adjusted to homogenize the melt pool and reduce the surface roughness of formed clad layer.

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References

[1] Pajukoski H, Nääki J, Thieme S, Tuominen J, Nowotny S and Vuoristo P 2016 High performance corrosion resistant coatings by novel coaxial cold- and hot-wire laser cladding methods J. Laser Appl. 28 012011

[2] Lei J, Shi C, Zhou S, Gu Z and Zhang L C 2018 Enhanced corrosion and wear resistance properties of carbon fiber reinforced Ni-based composite coating by laser cladding Surf. Coatings Technol. 334 274-285

[3] Baidridge T, Poling G, Foroozmehr E, Kovacevic R, Metz T, Kadekar V and Gupta M C 2013 Laser cladding of Inconel 690 on Inconel 600 superalloy for corrosion protection in nuclear applications Opt. Lasers Eng. 51 180-184

[4] Zhao C, Tian F, Peng H R and Hou J Y 2002 Non-transferred arc plasma cladding of Stellite Ni60 alloy on steel Surf. Coatings Technol. 155 80-84

[5] Turichin G, Kuznetsov M, Sokolov M and Salminen A 2015 Hybrid Laser Arc Welding of X80 Steel: Influence of Welding Speed and Preheating on the Microstructure and Mechanical Properties Physics Procedia 78 35-44

[6] Turichin G, Kuznetsov M, Tsibulskiy I and Firsova A 2017 Hybrid Laser-Arc Welding of the High-Strength Shipbuilding Steels: Equipment and Technology Physics Procedia 89 156-163

[7] Brückner F and Lepski D 2017 Laser Cladding Springer Series in Materials Science 119 263-306

[8] Salonitis K, D’Alvise L, Schoinoccharitis B and Chantzis D 2016 Additive manufacturing and post-processing simulation: laser cladding followed by high speed machining Int. J. Adv. Manuf. Technol. 85 2401-2411

[9] Turichin G A, Zemlyakov E V., Pozdeeva E Y, Tuominen J and Vuoristo P 2012 Technological possibilities of laser cladding with the help of powerful fiber lasers Met. Sci. Heat Treat. 54 139-144

[10] Chkalov R, Khorkov K, Kochuev D, Davydov N, Davydov N, Prokoshev V and Kostrov V 2018 Computerized laser complex for monitoring and controlling of the precision micromachining processes Proceedings of the International Conferences on WWW/Internet 2018 and Applied Computing 2018 pp 395-399

[11] Chkalov R, Khorkov K and Prokoshev V 2019 Development and application possibilities of multifunctional femtosecond laser complex for precision processing 2019 International Conference on Industrial Engineering, Applications and Manufacturing, ICIEAM 2019 pp 1-5

[12] Asselin M, Toyserkani E, Iravani-Tabrizipour M and Khajepour A 2005 Development of trinocular CCD-based optical detector for real-time monitoring of laser cladding IEEE International Conference on Mechatronics and Automation, ICMA 2005 pp 1190-1196

[13] Smurov I, Doubenskaia M, Grigoriev S and Nazarov A 2012 Optical monitoring in laser cladding of Ti6Al4V Journal of Thermal Spray Technology 21 1357-1362

[14] Doubenskaia M, Bertrand P and Smurov I 2004 Optical monitoring of Nd:YAG laser cladding Thin Solid Films 453 477-485

[15] Purtonen T, Kalliosaa A and Salminen A 2014 Monitoring and adaptive control of laser processes Physics Procedia 56 1218-1231