Features of the process of laser welding of cast iron with steel

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Abstract. The article presents the results of research on laser welding of cast iron with steel on a robotic laser technological complex. A system of technical vision for precision focusing of laser radiation on the joint of welded elements is presented, which provides control of the movement of the laser beam along the welded joint and adjustment of the radiation power, depending on the temperature of the joint. The welding process is carried out in a protective atmosphere of inert gases. Rough guidance of the beam is carried out by the robotic complex until the point "start of welding" falls into the field of view of the technical vision system, which is built into the process head. Precision positioning of the beam focus on the seam is provided by turning the focusing lens to a certain angle by a piezo actuator. The results of metallographic studies of the welded seam of cast iron and steel are presented.

1. Introduction

Modern machine-building enterprises are successfully developing technologies related to the introduction of robotic laser technology complexes (RLTC) into production. The implementation of laser welding (LW) technology as a final assembly operation without subsequent mechanical processing increases labor productivity and economic efficiency of production [1,2]. The quality of the welding seam is ensured by the preset parameters of technological process (TP) and all geometrical dimensions of the welded node is not beyond the tolerance, which can be tens of microns.

RLTC provides a number of technological advantages over other types of fusion welding. The advantages of drugs using RLTC are determined by the following factors. This is a software control of the position of the focus of laser radiation (LI), with the possibility of precision pointing it at the joint of the welded parts.

The advantages of HP are high operating speeds of the technological process (TP), small zones of thermal impact (ZTI), which ensures minimal thermal deformations, with a high degree of automation, the probability of repeatability of the process increases, with the specified quality indicators (QI) [3].

2. Theoretical and experimental studies

Improving the performance of individual welded parts of parts and assemblies for multifunctional purposes, for example, in mechanical engineering, is largely determined by the technologies of their manufacture, while using dissimilar metals. Welding of dissimilar metals is required when different parts of the part operate under different conditions and require different physical and chemical properties of these parts [3-4]. Such welding is justified by the economic efficiency of production.

Analysis of the relationship of the parameters of LTK and quality of the welding process showed that the largest effect on the temperature of the interface provides the stability, and the quality indicators of TP welding depend on the temperature and precise positioning of the focus of LI [5].
In the manufacture of automotive products, welding of its individual elements from dissimilar metals, cast iron and steel is often required. This task of laser welding, which ensures the production of a weld with a given quality, with increased physical and mechanical properties and operational characteristics, is relevant.

The solution of this problem is associated with many technical difficulties, such as stabilization of the set parameters of the TP, precision positioning of the focus of the LI, etc.

Studies have shown that non-compliance with the requirements of TP leads to a sharp decrease in the quality of welding. For example, LW in the case of cast iron with vermicular graphite without heating, with a high cooling rate, the formation of cracks is observed.

Figure 1 shows the microstructure of the joint at a high cooling rate, welding was carried out in an argon medium.

![Figure 1](image1.png)

**Figure 1.** Microstructure of the weld seam of the plates CIWVG30 (left) and CIWVG35, magnification x50, (the section is etched).

The study of the microstructure was carried out in the cross-section of the transverse micro-section relative to the weld of the plates. The presence of "hot" cracks was revealed in the weld. The microstructure of cast iron plates was evaluated in accordance with the scales of GOST 3443-87, is identical and represents graphite:
- the shape of graphite inclusions-spherical regular ShGd5 and sinuous VGf2;
- diameter of the graphite inclusions of spherical shape - ShGd25;
- the amount of spherical graphite is less than 40%.

The microstructure of the metal base of the CIWVG30 plates is a ferritic-perlite structure, the ratio of perlite and ferrite in percent P6 (F94), perlite plate Pt1 (Fig. 2).

![Figure 2](image2.png)

**Figure 2.** Martensite in the zone of thermal influence of the weld seam of the CIWVG30 plate, magnification x500.

In the weld, the presence of "hot" cracks was revealed, the cavities of which are filled with oxides, through which the weld was destroyed from the side of the CIWVG35 plate.

During the welding process, at a high rate of heating of the part to a temperature below the boiling point, diffusion processes do not have time to occur, and this can lead to non-welding [6-7].

The solution of the problem of controlling the focus position is possible with the help of a technical vision system implemented either on a line of photodetectors (FD) or a FP matrix [9-10]. The sensitive layer of a multi-element coordinate photodetector (MCD) consists of several separate elements enclosed in a single housing. The use of MCD simplifies the construction of some types of optical-electronic
converters (OEC), since it eliminates mechanical scanning. Viewing of the angular field of view in the OEC with MCD is carried out using a high-speed switch that connects individual elements to the input of the electronic signal processing path [8-10]. A semiconductor laser is used to illuminate the junction line. Due to its energy characteristics and various spectral, spatiotemporal parameters, LI allows implementing a precision optoelectronic system for focusing the technological LI on the joint of welded parts of any curvature [9-10].

In a systematic approach to welding cast iron with steel, which is a form of integration of scientific knowledge in the field of laser technologies, it is necessary to consider a set of tasks. These are temperature conditions, heating and cooling rates of the welded product, the gas environment in which welding takes place and its consumption, as well as the positioning of laser radiation relative to the joint of the welded parts. It should be noted that at loads of more than 3500 H so cast iron.

Solving the questions raised, specifying the parameters of the technological process, ensures the successful implementation of the required quality of laser welding. The automatic control system (ACS) of the robotic laser technological complex (RLTK) was developed.

The main link of the RLTK control system, which determines the quality indicators of the technological process, is the link of monitoring the position of the LI relative to the joint of the welded parts. The developed control scheme makes it possible to position the LI focus relative to the joint with the required accuracy.

The establishment of functional relationships between the quality indicators of TP and technological parameters RLTC based on a complex physico-chemical processes of interaction with metals, the effect of the TP parameters on quality of weld area, highlighting the main perturbing factors, allows to identify new approaches to the complex task of designing automatic control systems RLTC.

Figure 3 shows a block diagram of the RLTK with a conditional display of a four-site FP at the junction of the welded parts with controls for precision movement of the LI focus.

![Figure 3](image.png)

**Figure 3.** Block diagram of the RLTK with a conditional display of the four-site FP at the junction of the welded parts with the control elements of the precision movement of the focus of the LI.

The optical head placed on the robot arm is combined with a rotary mirror that directs the emitter beam LI to the joint of the welded parts. This technological operation is carried out during the control of the joint position relative to the center of the four-site FP. Information about the offset is transmitted to the NC from the MP. During laser welding, the NC issues control signals, by means of the CPS on the RLTK, thereby precision positioning of the focus of the LI relative to the joint is carried out. The mismatch signal occurs when the illuminated parts of the upper and lower regions of the FP sensitive areas, which are photo resistive layers, are unequal.

Control of the piezo drive is carried out by the CPS through the interface with the NC. The piezo drive moves the optical head of the laser at an angle of no more than 1 degree, and this ensures that the focus LI is moved along the X-axis about 1 mm with a long-focus lens.
Stabilization of the RLTK parameters is carried out by introducing a negative feedback of the ACS on the parameters measured in real time [9-10]. Positioning LI at the junction is a difficult task. The block diagram of the ACS RLTK has two control circuits for the position of the focus of the LI. The rough positioning contour is carried out by linear movement of the workpiece using a robotic complex along the Y axis and works with software control.

Figure 4 shows the appearance of the weld surface of cast iron and steel plates.

![Figure 4. Appearance of the weld surface of cast iron and steel plates (A-front side, B-reverse side).](image)

Figure 5 shows the microstructure of the weld with the results of measurements of the microhardness of the metal base of the sample in units of HV 0.05 in the cross-section of the etched microshift, x 50.

![Figure 5. Microstructure of the weld with the results of measurements of the microhardness of the metal base of the sample in units of HV 0.05 in the cross-section of the etched microchip, x 50.](image)

No "hot" cracks were detected in the weld. The microstructure of the sample metal is: - weld austenite and carbides; - metal base of MM-medium-needle martensite, residual austenite, then troostomartensite.

3. Conclusion
Cracks in the welding of cast iron without a plastic metal additive are formed due to the presence of brittle and hard structural components in the joint. The high content of carbon in the composition of cast iron and the formation of its oxides, gas saturation during welding leads to the formation of pores in certain areas of the joints.

To reduce residual stresses and prevent the formation of hot and cold cracks in the weld, preheating the workpieces to be welded to a temperature of is recommended 400...550 °C.

The main influence on the process of precision welding of dissimilar materials is exerted by the physical and chemical properties of both the materials themselves and the environment in which the technological process takes place [4-9]. This is due to the distribution of the thermal field in different materials characterized by different chemical activity and thermophysical properties (thermal conductivity, heat capacity, melting point, crystallization temperature, etc.)
The main factors influencing the high quality of joints when welding cast iron with steel are the chemical composition and thermophysical properties of the flux when using an additive material with a high nickel content, the precise positioning of the focus of the LI on the joint and the provision of thermal welding conditions at the beginning and end of the process.

The contour of precise positioning is carried out by a piezo drive, which provides precise adjustment of the focus of the LI relative to the joint. Control of the focus position is provided by a matrix photodetector (MP), which allows for precise adjustment LI of the focus position.

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