EQUIPMENT FOR PLASMA-ARC AND HYBRID WELDING, 3D PRINTING AND COATING TECHNOLOGIES

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ABSTRACT

At the stage of post-war reconstruction of Ukraine, the task of creating new technologies and equipment that meet the challenges of modern production arises. For this, research and industrial prototypes of new technological equipment are proposed, which allows for the industrial implementation of innovative high-tech processes of hybrid laser-plasma welding, 3D printing by additive microplasma deposition and coating by plasma-arc spraying of the anode wire. Technological studies of these processes have been carried out. It has been established that their use will contribute to the creation of non-separable joints, metal products and friction surfaces with increased strength and wear resistance characteristics, a reduction in the metal content of products, and an improvement in environmental performance.

Keywords: laser-plasma welding, 3D printing by additive micro-plasma deposition, plasma-arc spraying of wire-anode, steel, aluminum alloys, parameters of technological modes, equipment.

Modern industry reaches new levels of creation of industrial equipment, vehicles, household appliances, etc. This is due to both the use of new materials and the development of new designs [1]. At the same time, the development of the industry is characterized by the use of new approaches that make it possible to obtain high-quality welded joints, finished or almost finished spatial metal parts, coatings with increased functional properties, etc. [2]. Therefore, at the stage of post-war reconstruction, the industry of our country faces the task of creating new technologies and equipment that meet the challenges of modern production.

The relevance of the development and industrial application of innovative technologies and equipment for their implementation is not only related to the need to improve the quality of existing and manufacture new products. Important factors include the need to reduce the energy consumption of welding processes and related technologies. Another relevant issue of the industrial application of any equipment is its compliance with the requirements of preserving the ecology of the environment. Based on the combination of the listed factors, it is advisable to use highly concentrated energy sources for welding, surfacing and coating, which allow to minimize the volume of the welding bath while simultaneously increasing its depth. These energy sources include, first of all, plasma-arc and laser sources [3]. Therefore, it is advisable to use the processes of laser and laser-plasma welding [4], microplasma surfacing and 3D printing [5], and plasma-arc spraying [6] as a basis for the creation of innovative industrial equipment.

The purpose of the work is to create new technological equipment for the implementation of innovative high-tech processes of welding, 3D printing and coating, which will contribute to the creation of integral joints, metal products and friction surfaces with increased functional characteristics.

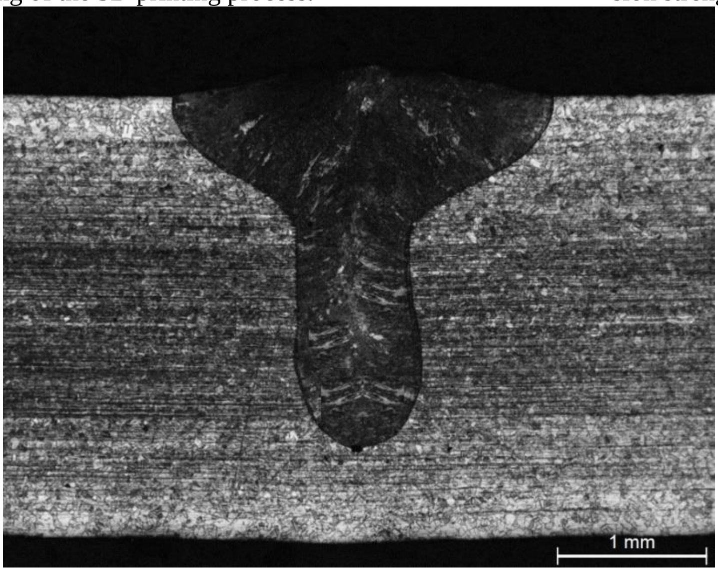
To achieve this goal, the following tasks were solved: carrying out a number of technological studies on laser-plasma welding, 3D printing by micro-plasma deposition, plasma-arc spraying of functional coatings; determination of acceptable areas of mode parameter variation; development and construction of equipment taking into account the specified parameters of the modes.

Carbon steels of type Q235, 1070, stainless steels AISI304, 316L, as well as aluminum alloys 1561, 7005 with a thickness of δ=1-10 mm were used as metal samples for conducting technological experiments on laser-arc welding. AISI304 stainless steel powder with a granulation of 50-150 μm was used as an implant material for 3D printing by microplasma deposition. For plasma-arc sputtering of functional coatings, conductive wires made of Q235 and AISI304 steels with a diameter of 1.2 mm were used, and similar steels were used as the main metal of the samples on which sputtering was carried out.

As a result of technological research, it was established that for hybrid laser-plasma welding of steels and alloys up to 3-4 mm thick, a fiber laser power of up to 1.5 kW is sufficient. At the same time, the welding current is up to 80 A. To weld steels and alloys up to 10 mm thick in one pass, it is necessary to increase the laser power to 5.0 kW, and the welding current to 150-200 A. Welding of metals with a thickness of 15 mm is possible in two passes, i.e. from two sides.

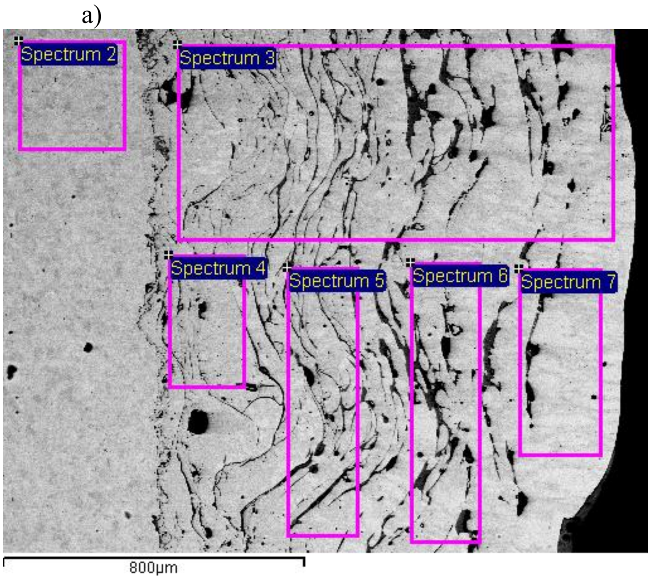
To carry out additive surfacing of bulky metal parts, it is necessary to control the heating temperature of the object being grown. It is important not to allow it to overheat, which leads to residual deformations and deviations from the specified geometric parameters. Due to the temperature control, it is necessary to adjust the deposition current and the speed of the process. This requires the creation of a system for automatic monitoring of the 3D printing process.

For plasma-arc sputtering of functional coatings, the process with sputtering of wire-anode was chosen. The use of sprayed wires in the process of coating makes this process more economical than the plasma-powder spraying process, since it does not require preliminary spraying of the powder from the same wires. In the course of research, the following parameters of the plasma-arc spraying mode of anode wires were determined, which allow additional dispersion of metal drops separated from the anode wire under the influence of a compressed electric arc in the sputtering jet. This, in combination with the acceleration of the spraying jet itself due to intensive blowing with a stream of compressed air, improves the formation of the coating, reduces its porosity to 1.5-2.0% and increases the adhesion strength to the base to 60-80 MPa.



a)

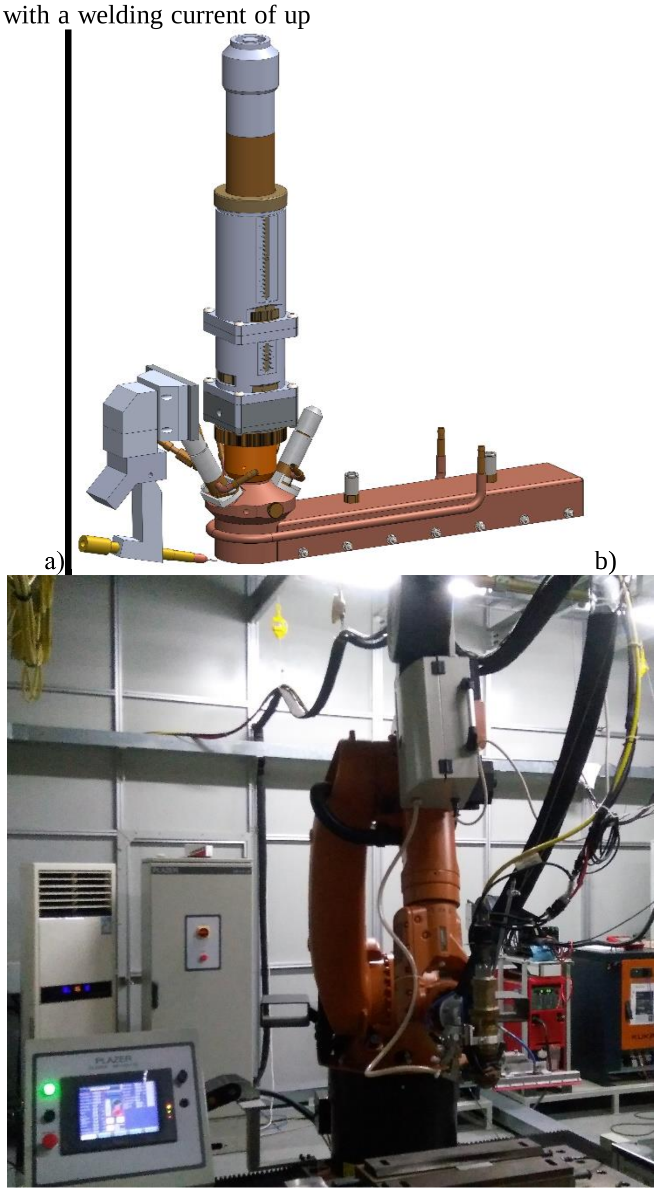
b)



c)

Fig.1. The results of technological studies: a) – laser-plasma welding in a plate made of AISI304 steel (δ=3.0 mm); b) – a wall made of 316L steel obtained by additive microplasma surfacing; c) – the structure of the material layer obtained by plasma-arc spraying of the anode wire made of 1070 steel.

As research has shown, for hybrid laser-plasma welding of steels and alloys with a thickness of up to 10-15 mm, it is advisable to use the radiation of a fiber laser with a power of up to 5.0 kW in combination with a compressed plasma arc with a welding current of up to 200 A. To achieve such indicators, a suitable experimental and industrial equipment of the PLAZER Hybrid-L5Pl model (Fig. 2), the characteristics of which are given in Table 1.



a) b)

Fig.2. Computer model (a) of the welding head and appearance of the robotic installation (b) of PLAZER Hybrid-L5Pl laser-plasma welding.

Table 1.

The main technical characteristics of the PLAZER Hybrid-L5Pl laser-plasma welding installation.

№	Parameter name	Dimension
1	The voltage of the three-phase alternating current power supply network with a frequency of 50 Hz, V	400 (±15%)
2	Consumption current for each phase, and no more	25
3	Operating current of the direct polarity arc of a non-fusible electrode in plasma welding processes, A	< 200
4	Power of laser radiation, kW	< 5,0
5	Shielding gas for welding	Ar; Ar + CO_2
6	Plasma-forming and optics-protecting gas in hybrid laser-plasma torching	Ar
7	Operating voltage of the power source, V	12-36
8	The number of blocks of the specialized plasmatron power supply system, pcs.	1
9	Pressure of working gases at the entrance to the gas preparation system, bar	2 - 6
10	Gas consumption:	
	- protective, l/min	4 - 40
	- plasma-forming, l/min	1,0 – 10,0
11	The number of tungsten non-fusible electrodes in the hybrid head, pcs.	1
12	The diameter of the tungsten non-fusible electrode in the hybrid head, mm	4,0
13	Focal distance of the collimator lens, mm	100
14	The course of manual adjustment of the collimator lens, mm	±20
15	Accuracy of manual adjustment of the collimator lens, mm	±0,25
16	Focal length of the focusing lens, mm	200
17	The progress of adjusting the focal length, mm	±25
18	The accuracy of the movement of the manual adjustment of the focal distance of the focusing lens, mm	±0,25
19	Number of optical elements, pcs.: - collimator lens - focusing lens - protective glass	 1 1 1
20	Diameter of focusing and protective optics, mm	50,8
21	ACU cooling water consumption, l/min	7 – 10
22	Feed speed of the planting wire, m/h	50…500
23	Diameters of the planting wire, mm	0,8-1,6
24	The length of the cable-hose package, m, no more	10

For 3D printing by microplasma deposition, it is necessary to provide a compressed direct arc current of up to 80 A at a voltage of up to 40 V. In the case of supplying a powder filler material, this will allow printing of metal parts with a minimum wall thickness of 2.5-3.0 mm. In the case of feeding the wire grafting material, the minimum wall thickness increases to values of the order of 3.0-4.0 mm. At the same time, the productivity of 3D printing by microplasma deposition of metal parts will be of the order of 0.5-5.0 kg/h. In order to achieve such indicators, appropriate experimental and industrial equipment was designed (Fig. 3), the characteristics of which are given in Table 2.

Fig.3. A robotic set of equipment for automatic 3D printing of small and medium-sized metal objects by microplasma deposition, limited by the reach of the robot arm up to 1400 mm: 1 – an intelligent control system with an integrated automatic monitoring system; 2 – movement mechanism (robot); 3 – microplasmatron; 4 – plasma module; 5 – power source; 6 – powder dispenser-feeder; 7 – powder feeder control unit; 8 – autonomous cooling unit; 9 – assembly and surfacing device, surfacing table.

Table 2.

The main technical characteristics of the installation of automatic 3D printing of small and medium-sized metal objects by microplasma deposition.

№	Parameter name	Dimension
1	The voltage of the three-phase alternating current power supply network with a frequency of 50 Hz, V	400 (±15%)
2	Consumption current for each phase, and no more	25
3	Operating current of the arc of direct polarity of a non-fusible electrode in the processes of microplasma surfacing, A	< 80
4	Shielding gas for surfacing	Ar; Ar + CO_2
5	Plasma-forming and optics-protecting gas in a microplasmatron	Ar
6	Operating voltage of the power source, V	10-50
7	The number of blocks of the specialized plasmatron power supply system, pcs.	1
8	Pressure of working gases at the entrance to the gas preparation system, bar	2 - 6
9	Gas consumption:	
	- protective, l/min	2 - 20
	- plasma-forming, l/min	0,1 – 1,0
	- transporting gas for powder supply, l/min	1 - 10
10	The number of tungsten non-fusible electrodes in the microplasmatron, pcs.	1
11	The diameter of the tungsten non-fusible electrode in the microplasmatron, mm	2,0
12	ACU cooling water consumption, l/min	5 – 10
13	Feed speed of the planting wire, m/h	20…200
14	Diameters of the planting wire, mm	0,8-1,2
15	Planting powder consumption, g/s	0,1 – 1,0
16	Granulation diameter of planting powder, μm	0 – 300
17	The length of the cable-hose package, m, no more	10

For plasma-arc sputtering of functional coatings using a conductive wire, it is necessary to use a plasmatron with a non-fusible tungsten cathode Ø4.0 mm and a copper plasma-forming nozzle with an inner diameter of ~3.0 mm. A current-conducting wire Ø1.0-3.2 mm acts as the anode (the best option is Ø1.2-1.6 mm). Wires can be used both solid (for example, from steels Q235 and AISI304), and powder (with a tubular sheath made of steel and powder filler). A current of 100-250 A must be provided to melt the wire and disperse the resulting liquid droplets. In order to achieve such indicators, the appropriate experimental and industrial equipment PLAZER SA-AW 30PL-W (Fig. 4) was designed, the characteristics of which are given in Table 3.

Fig.4. The appearance of the PLAZER SA-AW 30PL-W semi-automatic installation.

Table 3.
Technical characteristics of the technological complex of plasma-arc spraying PLAZER SA-AW 30PL-W.

Parameter name	Dimension
Energy consumption, kVA no more	30
The voltage of the three-phase alternating current supply network with a frequency of 50 Hz, V	380
No-load voltage, V	160
Operating current adjustment range, A	100 – 250
Operating voltage adjustment range, V	30 – 80
The longest duration of inclusion, PV%	100
Air consumption at a pressure of 0.6 MPa, nm^3/h	50
Argon consumption at a pressure of 0.1 MPa, nm^3/h	2
Wire feed speed, m/min	5 – 15
Cooling of the plasmatron	aerial
The resource of the plasmatron nozzle and cathode, hours of machine time, no less	100
Overall dimensions, mm: - power sources - control cabinets	 501 x 478 x 503 605 x 605 x1600

When conducting technological research, it was established that due to the use of laser and plasma processes, the locality of the thermal effect on the base metal increases. This contributes to the reduction of the size of the liquid metal bath and, accordingly, to the evaporation of harmful welding aerosols. Due to this, the negative impact of welding and related processes on the external environment and human health is reduced. That is, the replacement of traditional welding processes with the proposed ones improves the surrounding ecological situation.

Conclusion.

Thus, in order to improve the characteristics of the three technological processes and increase the quality of products obtained thanks to them, experimental and industrial prototypes of new technological equipment were created. Such equipment allows the industrial implementation of innovative high-tech processes of hybrid laser-plasma welding, 3D printing by additive micro-plasma deposition and coating by plasma-arc spraying of the anode wire. This will contribute to the creation of integral joints, metal products and friction surfaces with increased strength and wear resistance, reduce the metal content of products, and improve environmental performance.

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