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Impact Analysis Of Changes In Gas-Dynamic Process Parameters During Laser Welding Of Steels On The Mechanical Characteristics Of Welded Joints

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Abstract – Abstract—The aim of this study is the establishment of the regularities of parameter influence during gas-dynamic processes of laser welding in steels on the mechanical characteristics of welded joints. When using GOST 09G2S steel, the increase in hardness is facilitated by the increased content of manganese (1.3...1.7%). The increase in hardness is also partly related to the change in the transparency of the plasma torch, which is formed above the steam-gas channel, as well as to the conditions of heat removal when using different protective gas media. Thus, the depth of penetration has decreased by more than two times due to shielding of radiation by the plasma torch in the case of using argon as the shielding gas. At the same time, the cooling rate of the liquid metal has increased, which led to an increase in the microhardness of the welding seam metal. The results obtained over the course of the study are planned to be used in the development of laser welding technologies for products of various industries, including but not limited to: aerospace, chemical, tooling as well as others.

Keywords – laser welding; steels; gas protection; mechanical characteristics; microhardness.

I. INTRODUCTION

Laser welding of structural materials significantly developed in a relatively short period of time, has passed the path from precision pulsed microwelding of electronic components to welding with deep penetration of high-strength steels of large thickness [1-3]. Simultaneously with the development of industrial equipment and technology of various methods of laser welding [4-6], the scientific foundations of a new direction in welding were formed in a form of various interaction models of the powerful laser radiation with metal that were created, in which the melting zone effects were studied [7-9].

However, according to the results of the authors' literary source analysis, no data on the results of fundamental scientific research, that would allow for conscious control of the gas-dynamic process parameters during laser welding were found, and through this – no ways of influencing the structure formation, geometry and mechanical characteristics of welded steel joints were found. Therefore, establishment of the influence regularities of the gas-dynamic process parameters during laser welding of steels and alloys is an urgent problem that requires comprehensive consideration.

The purpose of this study is the establishment of the regularities of parameter influence during gas-dynamic processes of laser welding in steels on the mechanical characteristics of welded joints.

II. RESULTS AND DISCUSSION

During the study, the recommended welding modes were determined first. This made it possible to obtain welded joints with a given geometry. For this purpose, welds were performed in samples made of low-alloy GOST 09G2S steel with a δ=10 mm thickness in the lower position, using different protective systems and with different diameters of nozzles, using CO_2 and Ar as shielding gas.

When using a gas protection system in the form of a tube located at a 25° angle to the axis of the laser beam, welding was carried out with the location of the protective system both in front and behind the laser beam (Fig. 1). Nozzles with an opening diameter of 0.7 mm, 1.0 mm, and 1.5 mm were located at the end of the tube. The welding mode was as follows: P=4.4 kW, V=1 m/min, ΔF=-2 mm, shielding gas was supplied with a flow rate from 1 l/min to 32 l/min. According to the results of the study of the macrostructure of the cuts, it was established that when welding with the placement of gas protection in front of the laser radiation, the linear nature of the change in the penetration depth does not depend much on the gas consumption. In this case, the difference in the absolute values of the penetration depth exceeds 10% for different nozzle diameters and all gas flow ranges. When changing the position of the shielding gas and placing it behind the laser radiation, the nature of the dependency's changes from linear to curvilinear with clear maximum values. At the same time, the difference in the values of the penetration depth reaches 30% of the obtained penetration depth.

Fig.1. – Photo of the system for supplying additional gas at a 25° angle to the laser radiation axis

At the same time, an increase in shielding gas consumption does not always lead to an increase in the penetration area. This is confirmed by the non-linear character of the obtained corresponding dependencies. This is due to changes in the shape of the weld caused by the influence of the gas component of the welding process.

A protective system in the form of a coaxial nozzle with nozzle diameters varying between 1.0, 2.0 and 3.0 mm was also used (Fig. 2). Located above the sample at a distance of 3 mm. Its use has shown that with a decrease in the diameter of the nozzle, less protective gas is required to ensure the greatest penetration depth value. At the same time, as the diameter of the nozzle increases, the depth of penetration and the width of the seam also increases.

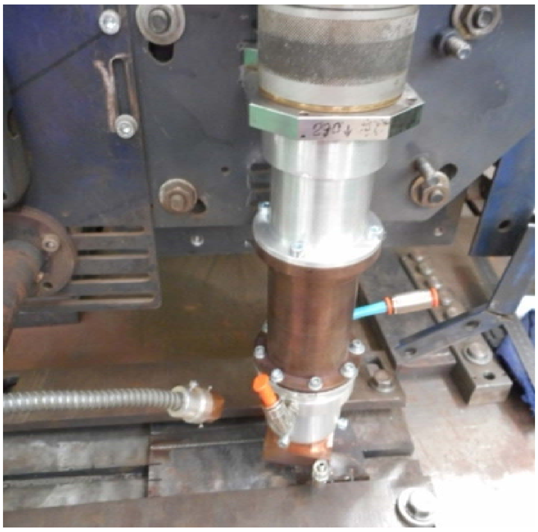

Fig.2. – Coaxial welding head when conducting experimental studies on measuring the pressure field under the influence of gas flow on the bath surface

Laser welding of butt-welded joints made of GOST 09G2S steel was performed at the selected modes (on samples with 3+3 mm; 1.7+1.7 mm and 3+4 mm thickness). Tensile tests of butt-welded joints of steel 09G2S were carried out on a servo-hydraulic machine MTS 318.25. The mechanical properties of the base metal and welded joints were determined on standard samples in accordance with GOST 1497-84 and GOST 6996-66 standards based on the test results of standard samples. As a result of the tensile test of butt joints made out of GOST 09G2S steel (on samples of 3+3 mm; 1.7+1.7 mm and 3+4 mm thickness) on the "MTS 318.25" testing machine, the tensile strength limit and the position of rupture were determined in a butt-welded joint. All samples collapsed in the base metal area at the tensile strength of 436...465 MPa.

As a result of the joint tensile test in the GOST 09G2S steel gusset (on samples 3+3 mm and 1.7+1.7 mm), the breaking force during stretching and the location of the break in the gusset welded joint were determined. All samples collapsed in the base metal area, the breaking force during stretching was 23...28 kN. It was established that the introduction of an additional gas jet of the required configuration changes the shape of the seam, increases the penetration depth to 30%, and the metal volume of the seam to 45…50%.

Fig. 3 shows 3 graphs for samples №1426.4 (welding in the lower position when using a coaxial nozzle with a hole diameter of 3 mm; calculated value of the gas flow speed – 38.09 m/s), №1449.4 (welding upwards in a vertical position when using a coaxial nozzle with a hole diameter 3 mm; calculated value of gas flow speed – 38.09 m/s), №1450.4 (welding downwards in a vertical position using a coaxial nozzle with a hole diameter of 3 mm; calculated value of gas flow speed – 38.09 m/s). In this figure, graphical dependencies allow comparison of changes in microhardness and structural changes at the same pressure and flow rate, but different spatial positions or directions of movement.

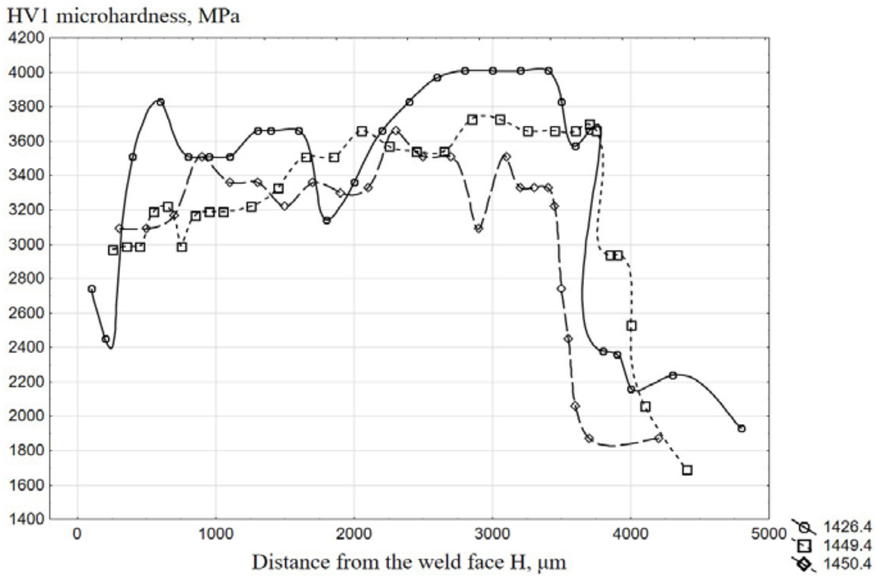

Fig.3. – Comparison of changes in microhardness in samples №1426.4, 1449.4, 1450.4

From the graphs shown in Fig. 3, it can be asserted that during deep movement towards the root of the seam, the microhardness of the weld generally increases, reaching maximum values at a distance of 2600…3500 µm from the reinforced seam. At the same time, a sharp drop in microhardness in the heat-affected zone (both in coarse-grained and fine-grained areas) is observed on all samples.

Local peaks and dips in microhardness are present in all three plots, hinting at the possible local formation of heterogeneous microstructures or cracks.

Sample №1426.4, welded in the lower spatial position, shows the highest microhardness values throughout the seam. Its microhardness pattern has only one local dip in the microhardness index around 1900 µm from the edge of the weld surface. Sample №1449.4 has very stable values of microhardness in the 1500…3500 µm zone. Sample №1450.4 is the most unstable, with two pronounced peaks, one bright and one gradual microhardness drop. The drop in the microhardness value in this sample also begins earlier, which indicates a smaller penetration depth in this case.

Fig. 4 shows graphs of changes in microhardness for samples №1426.1, 1426.4, 1426.7 welded by a laser in the lower spatial position when using a coaxial nozzle with a hole diameter of 3 mm when the pressure (flow rate) changes. Accordingly: for sample №1426.1, the calculated value of the flow speed was 9.52 m/s; for sample №1426.4, the calculated value of the flow speed was 38.09 m/s; for sample №1426.7, the calculated value of the flow velocity was 66.67 m/s.

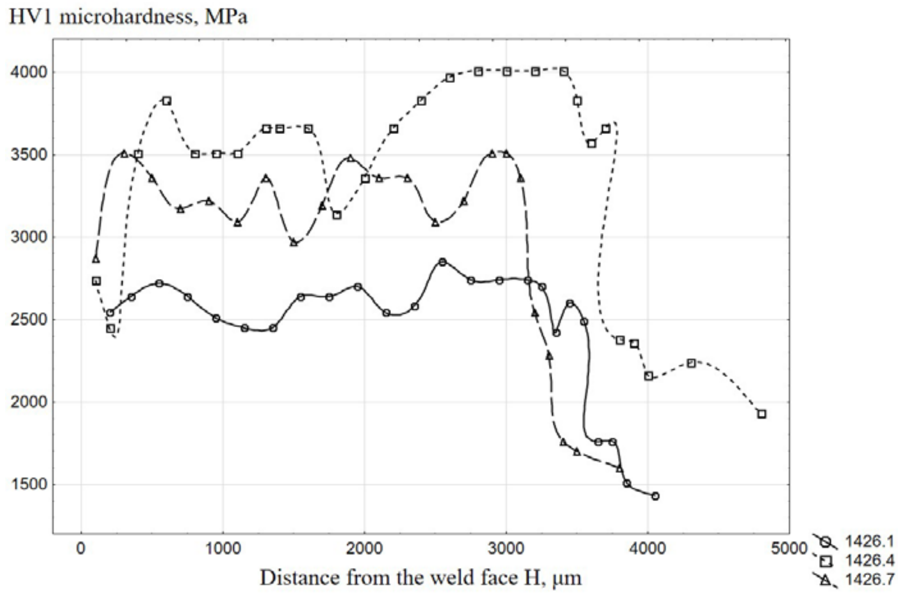

Fig.4. – Comparison of microhardness changes in samples №1426.1, 1426.4, 1426.7

Looking at the graphs shown in Fig. 4, we can discern that when moving deep towards the root of the seam, the microhardness of the weld is generally stable, reaching maximum values at a distance of 2600-2800 μm from the surface of the weld. At the same time, a sharp drop in microhardness in the thermally affected zone (both in coarse-grained and fine-grained areas) is observed on all samples.

The №1426.4 and №1426.7 sample graphs show local peaks and dips in microhardness, hinting at the possible local formation of heterogeneous microstructures or cracks. In the №1426.1 sample graph, the microhardness changes smoothly, indicating a more uniform structure or a more stable course of the welding process.

Sample №1426.1 has fairly stable microhardness values in the zone up to 3000 μm, with a local decrease in hardness before a sharp drop in the value in the heat-affected zone. Specimen №1426.4 shows the highest microhardness values throughout the seam. Its microhardness graph has one significant local dip in the microhardness index around 1900 μm from the edge of the weld surface. Specimen №1426.7 is the most unstable, with numerous peaks and dips in microhardness. The drop in the value of microhardness in this sample begins earlier, which indicates a smaller penetration depth in this sample.

Fig. 5 shows 5 graphs for samples №1426.1, 1426.4, 1426.7, 1449.4, 1450.4 (the figure is of a complex comparative (generalizing) nature in comparison with Fig. 3 and Fig. 4).

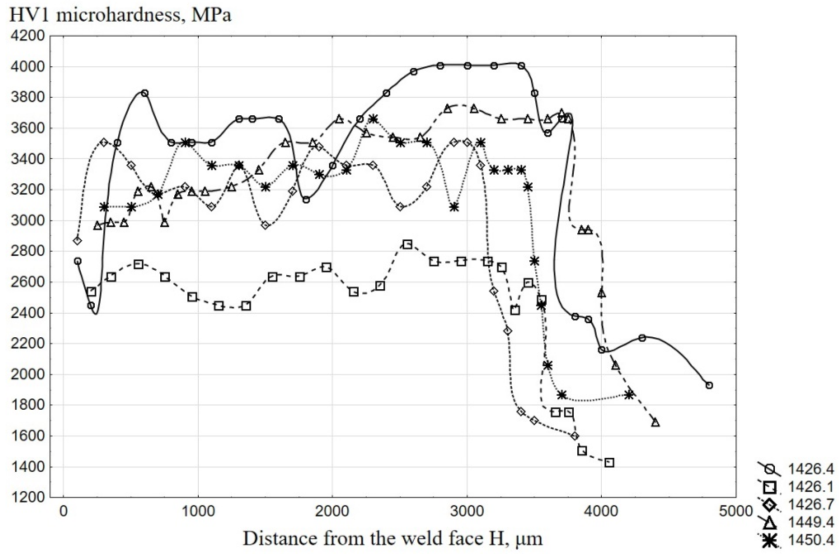

Fig.5. – Comparison of changes in microhardness in samples №1426.1, 1426.4, 1426.7, 1449.4, 1450.4

Figure 6 shows graphs of changes in microhardness for samples №1432.2, 1432.5, 1432.7, which were all welded in the lower spatial position using a nozzle Ø=1.5 mm, located in front of the laser head at a 25° angle to the laser radiation axis. A comparison was made in microhardness and structural changes with changes in pressure (flow rate). Sample №1432.2 was welded in a mode in which the calculated gas flow velocity was 18.83 m/s. Sample №1432.5 was welded in a mode in which the calculated gas flow velocity was 47.08 m/s. Sample №1432.7 was welded in a mode in which the calculated gas flow velocity was 87.75 m/s.

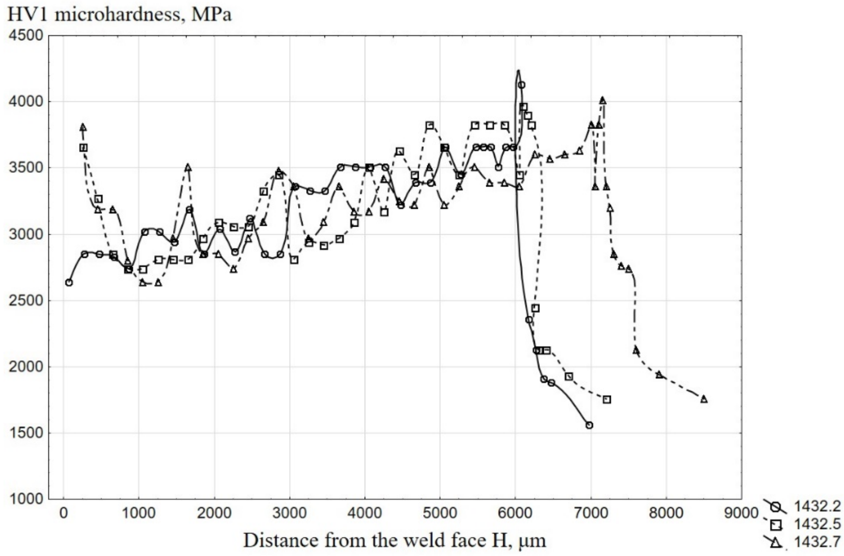

Fig.6. – Comparison of changes in microhardness in samples №1432.2, 1432.5, 1432.7

From the examination of these graphs, it can be summarized that when moving deep into the root, the microhardness of the weld generally increases, reaching maximum values at the border of the root of the weld in the large-grained section of the heat-affected zone. A sharp drop in microhardness in the heat-affected zone is observed on all samples.

Local peaks and dips in microhardness are observed in all sample graphs, hinting at a highly heterogeneous weld structure with possible local formations of heterogeneous microstructures or the presence of a large number of cracks. Considering the metallographic study, it is possible to hypothesize that this microhardness instability is observed due to the presence of various ferrite structures inside the seam.

Sample №1432.2 has several fairly stable zones of microhardness in the zone up to 6000 µm, after which the maximum value of microhardness is observed in the large-grained segment of the heat-affected zone before the typical decline of microhardness in the fine-grained segment of the heat-affected zone. Most likely, this is related to the bainite structure of the seam at the root, the formation of crystallites and the proximity to the fusion line. Specimen №1432.5 shows average microhardness values throughout the seam. Specimen №1432.7 is the most unstable, with numerous peaks and dips in microhardness. At the same time, the drop in the microhardness value in this sample begins later than the others, which indicates a greater penetration depth. At the same time, samples №1432.5 and №1732.7 have characteristically higher microhardness on the surface layers of the weld.

On Fig. 7 shows 5 graphs comparing the change in microhardness for samples №1432.2, 1432.5, 1432.7, 1444.2 (welded in the lower spatial position using a nozzle with a Ø=1.5 mm diameter, located behind the laser head at an angle of 25° to the laser radiation axis; the calculated value of the gas flow rate was 18.83 m/s), №1444.5 (welded in the lower spatial position using a nozzle with a Ø=1.5 mm diameter, located behind the laser head at an angle of 25° to the axis of laser radiation; the calculated gas flow velocity was 47.08 m/s).

From the review of these graphs, it can be said that during deep movement towards the root, the microhardness of the weld generally increases, reaching maximum values at the border of the root of the weld in the large-grained segment of the heat affected zone. A sharp drop in microhardness in the heat-affected zone is observed on all samples.

Local peaks and dips in microhardness are observed in all sample graphs, hinting at a highly heterogeneous weld structure with possible local formations of heterogeneous microstructures or the presence of a large number of cracks. Considering the metallographic study, it is possible to hypothesize that this instability of microhardness is observed due to the presence of various ferrite structures inside the seam.

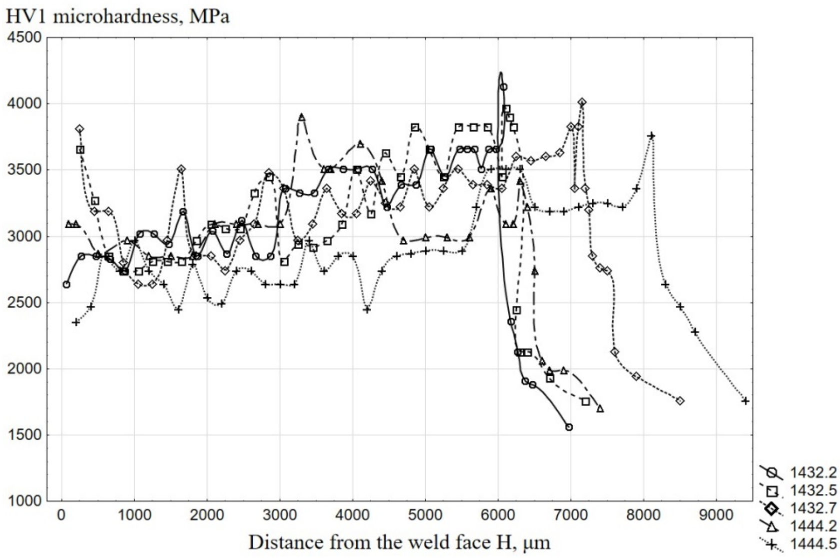

Fig.7. – Comparison of changes in microhardness in samples №1432.2, 1432.5, 1432.7, 1444.2, 1444.5

Sample №1444.2 differs from the general observation of unstable growth of microhardness with a characteristic segment with a sharp increase in microhardness in the period of 3000...4500 µm. Sample №1444.5 is the most stable of all presented, with a large number of zones with a relatively static value of microhardness. At the same time, this sample has several distinct peaks and dips, which may indicate local concentrations of alloying elements and chemical compounds.

III. Conclusions

When using GOST 09G2S steel, the increase in hardness is facilitated by the increased content of manganese (1.3...1.7%). The increase in hardness is also partly related to the change in the transparency of the plasma torch, which is formed above the steam-gas channel, as well as to the conditions of heat removal when using different protective gas media. Thus, the depth of penetration has decreased by more than two times due to shielding of radiation by the plasma torch in the case of using argon as the shielding gas. At the same time, the cooling rate of the liquid metal has increased, which led to an increase in the microhardness of the welding seam metal.

The use of a 82% Ar + 18% CO_2 mixture leads to a small (10...30%) increase in the seam width in combination with a significant improvement in the formation of the upper reinforcement and the elimination of the tendency to the formation of undercuts. At the same time, the penetration depth does not increase.

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