HYBRID LASER-PLASMA WELDING OF STAINLESS STEELS

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Welding of thin-sheet stainless steel joints receives acceptance in many industries. As a rule, argon-arc, resistance or plasma welding processes are used for these purposes. Investigation of the advanced world experience in application of welding processes shows that the intensive research is underway now on hybrid laser-plasma welding used to address the above problems. This study is dedicated to investigation of technological capabilities of this welding process. Technological investigations of hybrid laser-plasma welding of stainless steels of the austenitic and ferritic grades were carried out, and its comparison with the plasma and laser welding processes was performed. Mechanical properties of the hybrid welded joints were evaluated, and their structure was examined. Prospects of practical application of laser-plasma welding of thin-sheet stainless steel joints were shown. The ranges of parameters of hybrid welding of stainless steels, where there is no need to use filler materials, were found. It was established that the joints produced by this method are not inferior in their mechanical properties and quality of the weld formation to the laser welded ones, but in a number of cases are superior to them, and are much superior in quality of the weld formation to the plasma welded joints. Productivity of hybrid welding is 2–3 times higher than that of laser welding, and up to 4 times higher than that of plasma welding. 9 Ref., 2 Tables, 6 Figures.

Keywords: *stainless steels, hybrid laser-plasma welding, laser radiation, diode laser, hybrid effect, structures, microhardness, mechanical properties, prospects of application*

At present there are many industries that face a number of problems related to the need to weld thin-sheet parts of stainless steels, such as manufacture of expansion bellows for nuclear power engineering and food industry, tanks of refrigerating units to store milk products, etc. The problems posed here include welding of food and commercial stainless steels up to 3–4 mm thick with the butt, overlap and sometimes slot welds. As a rule, such problems are solved by using resistance [1] or argon-arc welding [2], and more rarely — plasma welding [3].

The issue of using this or other welding method is associated with certain optimisation requirements (price of the equipment and its operating cost, quality of the resulting joints, their strength and service life, presence or absence of residual distortions, etc.). Unfortunately, the applied welding methods do not always meet in full the said requirements. For example, one of the best welding methods (with the absence of residual distortions and production of the high-quality and durable joints) is laser welding. However, this method has not received wide acceptance now because of a comparatively high price of laser equipment. One of the ways of reducing the price of the laser equipment is to decrease its output power by partially replacing it with the plasma-arc component in the welding process. This process is called hybrid laser-plasma (or laser-arc) welding [4, 5]. A new promising welding technology may result, providing that the quality of the welded joints in this case is kept close to that of the laser welded joints. So, this study was dedicated to investigation of this possibility.

Investigations of the process of hybrid laser-plasma welding of stainless steels were carried out in accordance with the flow diagram shown in Figure 1. The diode laser with 0.808 and 0.940 μm radiation wavelengths was used in the experiments. Diameter of the focal spot was var-

Table 1. Chemical composition of stainless steel specimens, wt.%

Steel grade	C	Si	Mn	Cr	Mo	Ni	V	W	S	P	Cu	Ti
08Kh17T	≤0.08	≤0.8	≤0.8	16–18	≤0.3	≤0.6	≤0.2	≤0.2	≤0.025	≤0.035	≤0.3	≤0.8
Kh18N10T	≤1	≤0.8	≤2	17–19	≤0.4	10–12	≤0.2	≤0.2	≤0.2	≤0.035	≤0.4	≤0.7

ied in a range of 1.0–1.5 mm by using the focusing optics. The laser beam was combined with the constricted electric arc. The direct-action integrated plasmatron was developed for this purpose [6]. In this plasmatron the laser beam and the constricted arc were guided jointly via the common nozzle (2.0–2.5 mm diameter) to a workpiece to be welded, which was located at about 2 mm from the exit section of the nozzle. The focal plane of the laser beam was located at a depth of 0–0.5 mm from the workpiece surface. The straight-polarity continuous-action electric arc was used in the experiments. The arc current of the integrated plasmatron was gradually adjusted up to 110 A at an arc voltage of up to 20 V.

When performing penetration and butt welding of workpieces of stainless steels Kh18N10T (austenitic) and 08Kh17T (ferritic) with thickness δ = 1.0–3.5 mm, the range of adjustment of the laser power was 0.7–2.0 kW, and that of the welding current was 50–110 A at an arc voltage of 18 V. Chemical composition of the steels used is given in Table 1. Welding was carried out using no filler metals. The plasma and shielding gas was argon. The welding speed was varied from 14 to 108 m/h (3.8–30 mm/s). Three welding methods were investigated: laser, plasma and hybrid laser-plasma ones. The experimental results are given in Table 2.

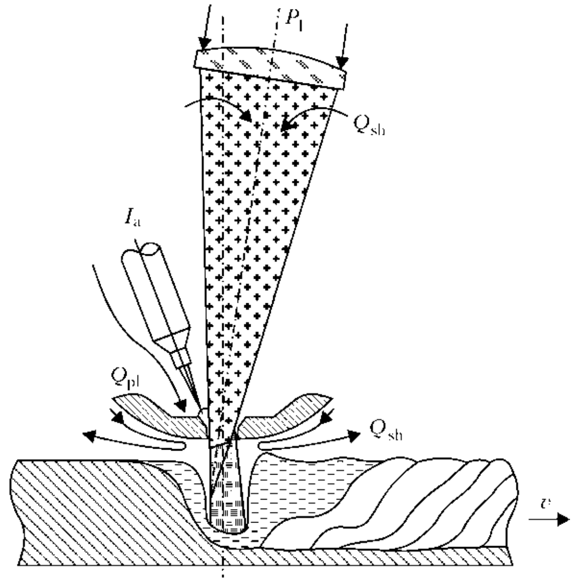
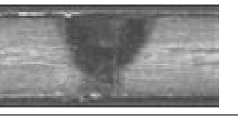
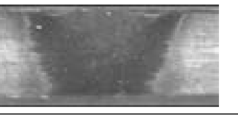
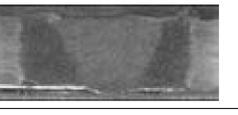
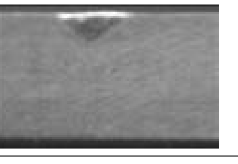
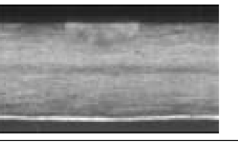
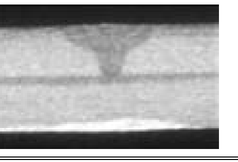


Figure 1. Flow diagram of the process of laser-plasma welding of stainless steels: P_l — laser radiation power; v — welding speed; I_a — arc current; Q_{pl} — plasma gas flow rate; Q_{sh} — shielding gas flow rate

Table 2. Parameters of welding of butt (steel 08Kh17T) and penetration (steel Kh18N10T) joints (plates 3 mm thick)

Steel grade	Welding method	Heat input, J/mm	Laser power, kW	Welding speed, m/h	Welding current, A	Arc voltage, V	Result
08Kh17T	Laser	360	2	20	–	–	
08Kh17T	Plasma	357	–	20	110	20	
08Kh17T	Hybrid	375	1	20	60	20	
Kh18N10T	Laser	75	1	50	–	–	
Kh18N10T	Plasma	140	–	50	110	20	
Kh18N10T	Hybrid	137	1	50	50	20	

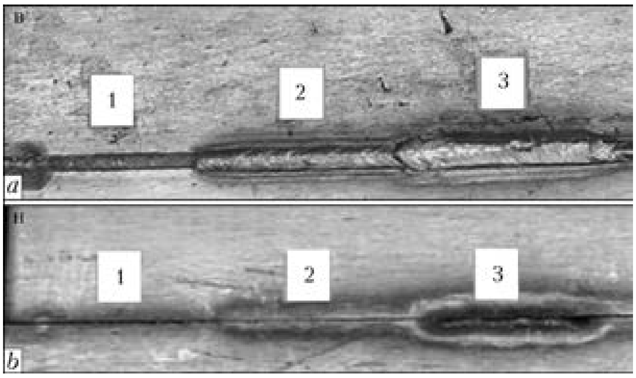


Figure 2. Appearance of the upper (*a*) and lower (*b*) sides of the butt joint on the specimens made from steel 08Kh17T (δ = 3.5 mm): *1* — laser; *2* — plasma; *3* — hybrid welding

In the majority of cases, at a selected ratio of workpiece thicknesses and welding speeds the laser and plasma processes taken separately did not allow achieving the complete penetration, whereas hybrid laser-plasma welding provided the quality weld formation (Figure 2). Drawbacks of the plasma process also include deviation of the anode spot from the joint, which was observed even at a minimal deplanation of the joint assembled in a clamp. This drawback is related not only to the deplanation of the workpiece being welded, but also to the effect of wandering of the anode spot, the higher the welding speed, the more pronounced being this effect [3].

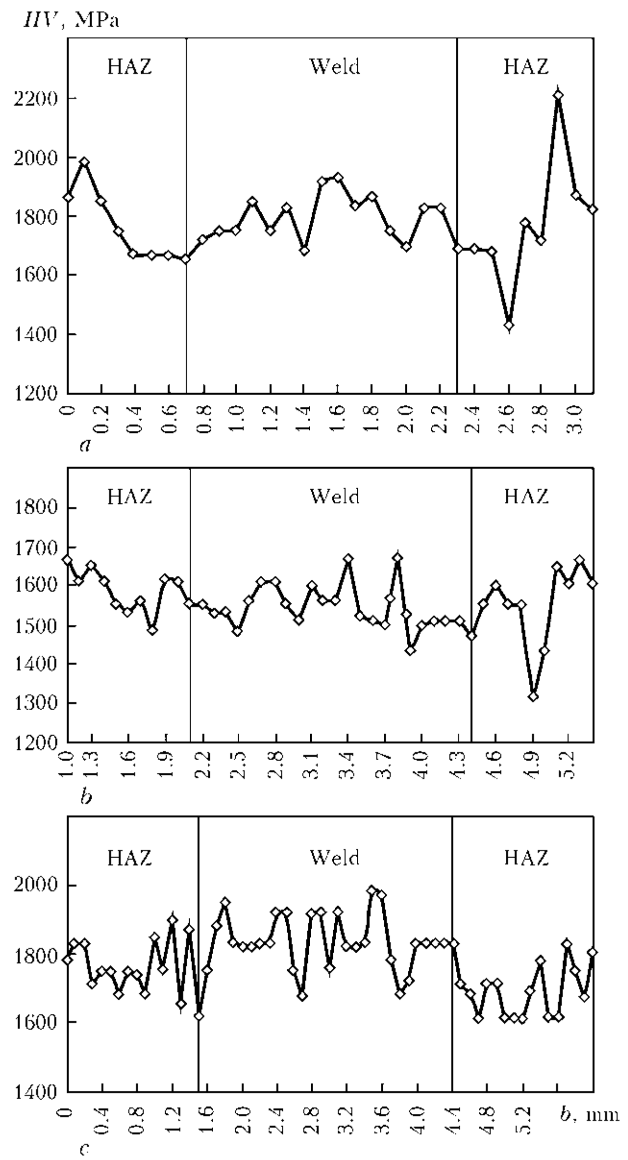


Figure 3. Measurements of microhardness (load of 50 g) in cross section of the welds of specimens made from steel 08Kh17T (δ = 3.5 mm): *a* — laser; *b* — plasma; *c* — hybrid method

In all the cases the upper bead formation was of high quality. The lower bead formation (the hybrid process) depended on the laser beam power density, i.e. the size of the focal spot. At a minimal size of the spot (with growth of the radiation power density) the lower bead formation stability increased, and the effect of wandering of the anode region of the plasma arc minimised. It is the opinion of the authors that this process was strongly affected by stabilisation of the plasma arc by the beam (fixation of the arc to the focused beam [7]), rather than the laser radiation power.

The experiments established the presence of the «hybrid» effect, which consists in the non-additive increase in volume of the molten weld metal in the laser-arc process, compared to the total volume of the weld metal melted separately by the laser and plasma methods (see Table 2). Also, it was established that as the size of the focal radiation spot decreases (with growth of the radiation power density), the weld width decreases with a simultaneous increase in the penetration depth, i.e. the hybrid effect becomes more pronounced.

Another important result of technological investigations of the hybrid welding process was defining of such process parameters which did not require the use of any filler metal. It was found that if the laser-arc method provides the weld in a joint between the 3.0–3.5 mm thick sheets, in which width of the lower bead is not in excess of quarter of width of the upper bead, the weld may have no sag. Moreover, the bead reinforcement approximately 0.5 mm high may form in the weld. In this case the shape of the cross section of the weld will be closest to that observed in laser welding.

Investigations of microhardness of the welds showed that in the case of laser and plasma welding the instability of hardness in the cast weld metal and HAZ metal was higher than in the case of hybrid laser-plasma welding. This dependence is more pronounced for the steels that are sensitive to formation of quenching structures. In our

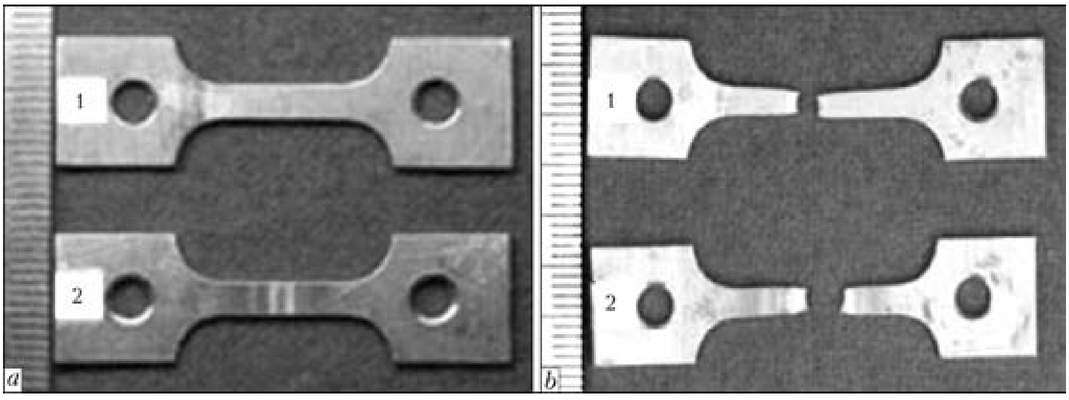


Figure 4. Appearance of specimens Mi-96 (steel Kh18N10T, δ = 3.5 mm) before (*a*) and after (*b*) tensile tests: *1* — BM; *2* — butt joint

case it is steel 08Kh17T (Figure 3). Note that formation of structures with an increased hardness in laser welding is caused to a greater degree by a high thermal locality of the process and small sizes of the weld and HAZ (Figure 3, *a*). This also leads to formation of quenching structures in the HAZ metal. Unlike laser welding, formation of the increased-hardness structures in hybrid welding is caused primarily by a high speed of the process. Therefore, increase in hardness is observed mainly in the cast weld metal (Figure 3, *c*). In laser welding, some decrease in impact toughness may be expected in the HAZ metal, and in hybrid welding — in the weld.

To conduct mechanical tests the following specimens: Mi-96 (GOST 6996–66) — for determination of tensile strength (Figure 4), and Mi-50 (GOST 9454–78) — for determination of impact toughness, were cut out from the quality regions of the welds made by the three methods being compared. The tensile tests were carried out by using tensile testing machine TsDM-4 at +20 °C. For this, three templates were cut out from specimen 195 for the hybrid butt welded joint, and three templates — for the base metal (BM). The test results on tensile strength σ_t of the butt joints on steel Kh18N10T (fracture location — near-weld zone) showed that the level of σ_t for the welded joints is equal to about 0.85σ_t of BM (σ_t = 620–679 MPa for the welded joint at σ_t of BM equal to 750–760 MPa), which is higher than the corresponding values for the welded joints made by the arc methods [8]. These results are in good agreement with the data on electron beam welding of specimens of the American 304 type steel performed in a pressure chamber [9].

Templates of the laser and hybrid welded joints (series of three pieces) made at the same process parameters were prepared to conduct tensile tests of specimens of steel 08Kh17T (δ = = 3.5 mm).The specimens of BM were prepared as well. The tests were carried out at +20 °C. It was found that strength of the specimens welded by the hybrid method was 3–5 % higher than that of the specimens made by the laser method, and approximately 5–7 % lower than that of BM (Figure 5).

The tests to impact toughness *KCV* (by the Charpy method) were carried out according to

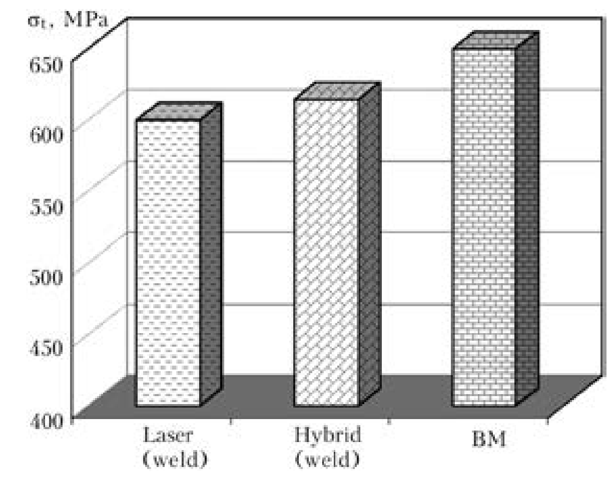


Figure 5. Tensile strength of specimens made from steel 08Kh17T

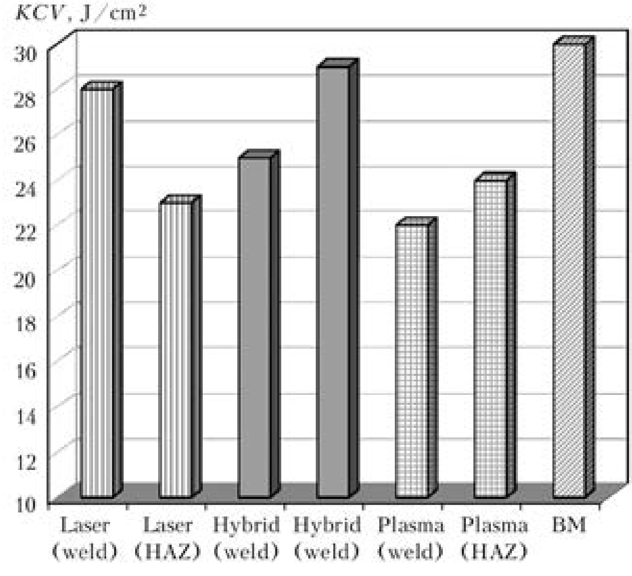


Figure 6. Impact toughness of specimens made from steel 08Kh17T

GOST 9454–78 by using pendulum hammer K-15 at +20 °C. Results of these tests obtained on specimens Mi-50 from steel 08Kh17T (δ = = 3.5 mm) are shown in Figure 6. As expected, decrease in impact toughness of the laser welded joints was observed in the HAZ metal, and decrease in impact toughness of the hybrid welded joints — in the cast weld metal. The distribution of impact toughness in the welded joints made by the plasma method was similar to that observed with the hybrid method, the only difference being that toughness in the plasma weld was lower approximately by 10 %, and in the HAZ metal — by 15–18 %.

Therefore, as proved by the investigations, the hybrid laser-plasma welding method holds promise for addressing industrial problems of joining thin-sheet (up to 3–4 mm thick) stainless steels of both austenitic and ferritic grades. It was established that hybrid welding of such steels does not require the use of filler metals. The welded joints made by this method are not inferior in their mechanical properties to those made by laser welding, and in a number of cases are superior to them, and are much superior in quality to the plasma welded joints. The productivity of hybrid welding is 2–3 times higher than the productivity of laser welding, and up to 4 times higher than that of plasma welding.

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Received 04.09.2012

NEWS

Devices for Improvement of AC Arc Stability

Devices for arcing stabilization (DAS) are the instruments, connection of which to any arc welding transformers (earlier manufactured by industry and those manufactured now) allows an essential widening of the field of their application, additionally giving them the technological properties of welding rectifiers for coated-electrode manual arc welding and nonconsumable electrode argon-arc welding systems. The device uses the principle of energy pulse transfer into the welding arc at the moment of reversal of polarity of the latter.

Technical and economic advantages: Compared to analogs the device greatly improves welding quality — process stability, weld appearance, weld metal structure and its mechanical properties; improves labour conditions-work can be performed by welder of a lower qualification level. Power saving is up to 15 %.

Efficiency: Increase of labour efficiency by 20 % due to increased time of stable arcing and reliability of its initial ignition.

State of development: DAS samples have been successfully tested in industry in argon-arc welding by nonconsumable electrodes of stainless steels, aluminium and its alloys, welding by coated electrodes, designed both for AC and DC, of different steel grades, in particular, positive results were obtained in welding of critical products and structures by UONI type electrodes.