PROSPECTS OF APPLICATION OF LASER AND HYBRID TECHNOLOGIES OF WELDING STEELS TO INCREASE SERVICE LIFE OF PIPELINES

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The experiments on development of techniques of multipass hybrid laser and laser-arc welding of pipe steels are described. Structure of produced joints, as well as their impact toughness and corrosion resistance were investigated. Rationality of further developments of appropriate technological processes for application of mentioned methods of welding to extend the service life of pipeline transport is shown.

Keywords: *multipass laser welding, hybrid laser-arc welding, impact toughness, corrosion resistance*

The growth of service life of main pipelines is directly connected with further increase of quality of welded joints at high welding efficiency [1, 2]. This is especially actual for large pipeline systems, including intercontinental and transnational, those of high pressure (approximately 10–15 MPa for land and 20–25 MPa for off-shore pipelines). A need in increase of welding quality was stipulated also by application of steels of increased strength (X70, X80 and X100) for pipelines.

One of the ways to solve specified tasks is the application of laser radiation [3]. Owing to small sizes of weld pool and angle of convergence of focused radiation the laser welding enables significant decrease of angle of preparation of edges to be welded. Due to high speed of laser welding the comparatively low input energy allows minimizing heat influence on the parts being welded, and consequently, reducing the size of HAZ and residual deformations. Fine-grain structure of cast metal of weld and HAZ contributes to increase of corrosion resistance of welded joints.

Over the last decade a number of scientific research works was carried out, as a result of which technical solutions allowing use of laser and hybrid laser-arc welding for assembly of main pipelines were appeared. Thus, VITS company (Langenseld, Germany) together with BIAS Research Institute (Bremen, Germany) developed the method of a single-pass welding of position butt welds on main pipelines with thickness of wall $\delta \leq 20$ mm using radiation of powerful (about 20 kW) fiber laser. At the Institute of Welding (Halle, Germany) a machine for two-pass hybrid laser-arc welding of position butt welds on main pipelines was developed and successfully tested. Moreover, the second pass was performed using arc welding, i.e. the laser radiation was used only to form a root weld. The «Fronius» company (Austria) offered a hybrid tandem method of welding steels where two-arc tandem with consumable electrodes is combined with laser radiation located ahead [4].

The investigations of laser and hybrid laser-arc welding of pipe steels are carried out also at the E.O. Paton Electric Welding Institute. The experiments on hybrid laser-arc welding were initially performed in accordance with technological scheme presented in Figure 1 [5], which shows that laser radiation is positioned ahead of welding process, and the arc of consumable electrode is at the tail part. The main task of laser radiation is reaching of required penetration depth, and that of the arc is the formation of upper reinforcement and providing of such thermal cycle of welding at which the undesirable bainite and martensite structures are not formed.

The investigations carried out by the mentioned scheme showed that in a single-pass welding of steels of more than 5 mm thickness the 1.0 kW of arc power can substitute 0.5 kW of laser radiation power. It means that hybrid welding allows decreasing the cost of applied equipment and one running meter of a weld

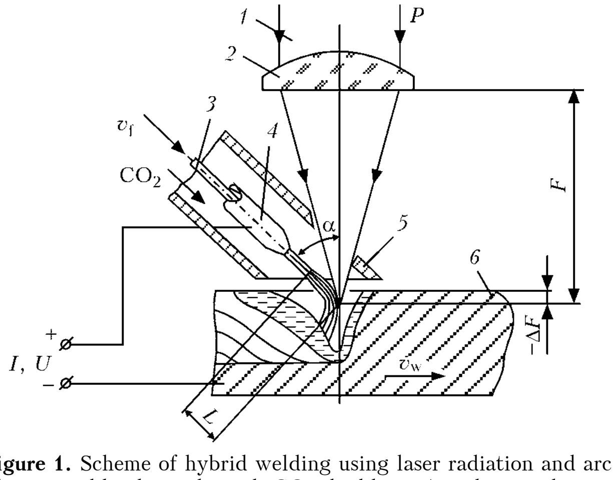

Figure 1. Scheme of hybrid welding using laser radiation and arc of consumable electrode with CO_2 shielding: *1* — laser radiation of power P, kW; *2* — focusing lens with focal distance F, mm; *3* — filler wire; *4* — shielding nozzle; *5* — copper current-carrying nozzle; *6* — specimen; v_w — welding speed, m/h; v_f — filler wire feed rate, m/h; ΔF — embedding of mouth of caustic of radiation relatively to the surface of specimen, mm; α — angle of electrode inclination to the axis of laser beam, deg.; L — length of arc, mm; I — welding current, A; U — arc voltage, V

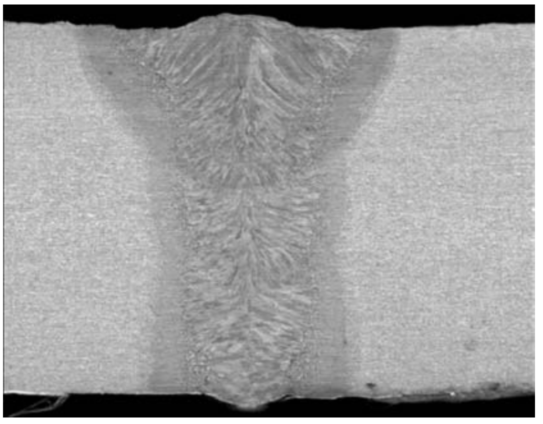

Figure 2. Macrosection of butt joint of steel 10G2FB (δ = 19 mm) produced using hybrid welding for 4 passes at the condition: P = = 2.7 kW; v_w = 2.5 m/h; v_f = 400 m/h (diameter of electrode wire of 1.2 mm); I_w = 200 A; U_a = 25 V; shielding gas — CO_2, consumption Q = 20 l/min

as compared with a laser welding. However, it was revealed that at the fixed power of laser radiation the maximal depth of penetration is also a fixed parameter, i.e. at decrease of welding speed the value of this parameter stops its growth at a certain moment (the width of a weld grows). In our case at the power of CO_2 laser radiation of up to 3 kW and close value of arc power the depth of penetration reaches 10 mm at the speed of welding of 30 m/h. Consequently, in welding of pipe steels of larger thickness it is possible either to increase the power of laser radiation or to use the multipass welding. Both these approaches have disadvantages: the first one needs considerable costs and reduces duration of thermal welding cycle, therefore, facilitates formation of undesirable hardened structures; the use of the second one leads to decrease in efficiency.

We have carried out investigations of multipass laser-arc welding of pipe steels of thickness of up to 20 mm into narrow groove. The examples of macrosections of butt joints produced during experiments are presented in Figures 2–4. Along with the selection of parameters of technological condition the metallographic peculiarities of specimens of butt joints, their corrosion resistance and impact toughness were studied.

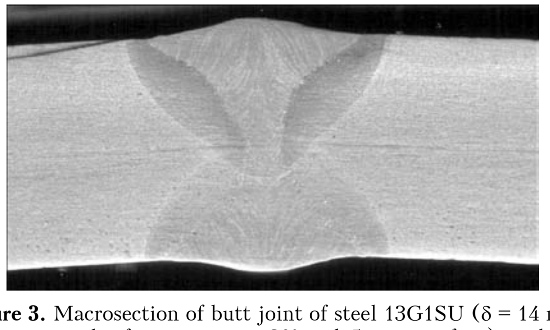

Figure 3. Macrosection of butt joint of steel 13G1SU (δ = 14 mm, X-groove, angle of preparation is 30° with 5 mm root face) produced for 2 passes using hybrid welding by arc with consumable electrode Sv-08G2S of 1.2 mm diameter and radiation of Nd:YAG laser at the condition: P = 4.0 kW; I_w = 260 A; U_a = 27 V; v_w = 30 m/h; v_f = 510 m/h; shielding gas — mixture Ar + 18 % CO_2, Q = = 14 l/min

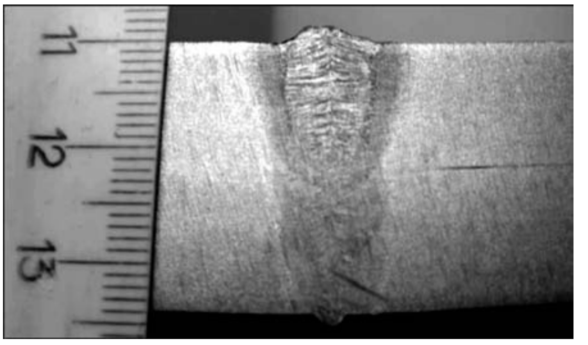

Figure 4. Macrosection of butt joint of steel 09G2S (δ = 25 mm) produced by narrow-groove hybrid welding for 6 passes using arc with consumable electrode Sv-08G2S of 1.2 mm diameter and radiation of Nd:YAG laser at the condition: P = 4.4 kW; I_w = 300 A; U_a = 30 V; v_w = 60 m/h; v_f = 700 m/h; shielding gas — CO_2, Q = 30 l/min

Except of welding of butts, the task of performance of a root weld using laser and hybrid welding was investigated. It was established that to produce the quality bead of reverse reinforcement of a weld on the side of a groove, the latter should have U-shape or rectangular shape. In case of Y-groove the shrinkage of weld metal occurs, i.e. defective formation of a joint. The task is significantly simplified in welding on the side of root face (opposite groove). To produce quality reverse reinforcement, we offer to perform laser welding in accordance with the scheme shown in Figure 5. In accordance with this scheme the root face of 5–7 mm is welded by radiation of CO_2 laser (or laser of another kind) of the power of up to 5 kW without use of a filler wire. Such technological method allows obtaining of reinforcement of the height of about 0.5–1.0 mm due to increase of volume of remelted metal. In this case the structure of weld metal and HAZ is fine-grained and characterized by increased resistance to corrosion, which is an important moment, as far as such weld is produced inside a pipe, i.e. at the place of contact with aggressive environment. Using the offered technological procedure the admissible gap between edges to be welded should not exceed 0.1–0.3 mm.

To evaluate electrochemical heterogeneity of steel 13G1SU welded joints performed using laser, hybrid laser-arc and arc methods of welding, the measurements of distribution of potential of electrochemical corrosion under the drop were carried out. As an electrolyte, the 3 % solution of sodium chloride in water

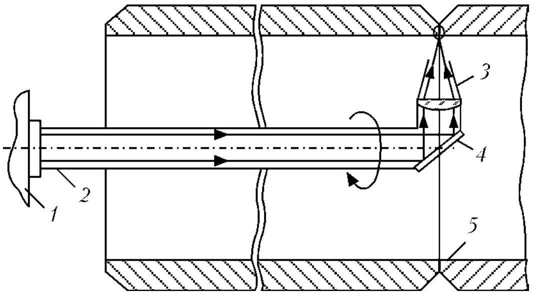

Figure 5. Scheme of orbital welding of a root weld for assembly of pipe butts: *1* — CO_2 laser; *2* — rotary beam conductor; *3* — laser welding head; *4* — rotary mirror; *5* — position butt joint

Potentials of electrochemical corrosion of butt joints of steel 13G1SU (δ = 14 mm) produced by different welding methods using 1.2 mm diameter wire Sv-08G2S

Welding method	Potential in base metal E_{BM}, V	Potential in weld E_w, V		Potential in HAZ E_{HAZ}, V*		Difference of potentials of base metal–weld ΔE, V
		Top	Root	Top	Root	
Laser	−0.58	−0.51	−0.53	−0.53	−0.58	−0.07
Hybrid laser-arc	−0.58	−0.52	−0.52	−0.52	−0.54	−0.07
Arc	−0.58	−0.48	−0.49	−0.49	−0.54	−0.10

*Values of E_{HAZ} for HAZ positioned on the both sides of a weld are the same.

was used. The results of these investigations are given in the Table. It was established that a joint produced using welding arc with consumable electrode is distinguished by a higher heterogeneity. The joints produced using laser and hybrid welding are characterized by lower values of potential of electrochemical corrosion, they are more electrochemically homogeneous. Basing on this fact one can conclude that for the same steels using the same filler (electrode) wire and same gas shielding of weld pool, the laser and hybrid methods of welding are capable to provide higher corrosion resistance as compared with the arc welding.

The measurements of impact toughness *KCV* carried out by the Charpy method on the specimens with a sharp notch at −20 °C gave the following results (Figure 6). In two-pass laser-arc welding the weld metal is characterized by much higher impact toughness as compared with the base metal than in four-pass welding. Unlikely, the HAZ metal in four-pass welding has somewhat higher ductility than in two-pass welding (as compared with base metal). This can be explained by the fact that in four-pass welding each next pass influences the previous one and in two-pass welding performed on both sides of a specimen, such influence is practically excluded. Thus, in four-pass welding the recrystallization of weld metal and normalization of HAZ occurs and in two-pass welding mainly those structures are preserved which were formed initially. It is also proved by results of metallographic investigations. Thus, in four-pass welding in weld metal and HAZ the ferrite-pearlite structures are prevailed (see Figure 2). The similar structures are available in weld metal performed for two passes (see Figure 3). However, in HAZ metal of the latter the areas of upper bainite and martensite are formed that promotes the increase in hardness of these areas above the limiting values (*HB* 260–280).

In HAZ metal the highest hardness is observed in the place of transition of zone of coarse grain to the zone of fine grain (Figure 7), being the most critical to impact and cyclic loadings. Therefore, the specimens for measuring impact toughness, the values of which are given in Figure 6, were tried to be made so that the sharp notch was at this zone. The obtained results prove that, in spite of the sufficiently high values of impact toughness, the further investigations, directed to decrease of HAZ hardness in laser-arc welding, are required. However it should be taken into account that using this method of welding, as well as laser welding, there is a risk of formation of hardened structures in HAZ metal and in cast weld metal. Nowadays, the question on whether such structures are admissible (in connection with their fine dispersity and ductility) or they should be removed by post heat

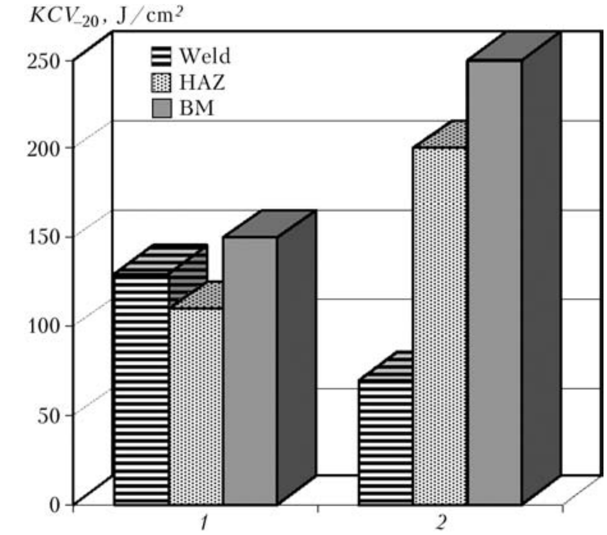

Figure 6. Results of measurement of impact toughness KCV_{-20} of weld and HAZ metal of specimens of steel 13G1SU (δ = 14 mm) produced using hybrid method of welding for 2 passes (*1*) and of steel 10G2FB (δ = 19 mm) produced for 4 passes (*2*)

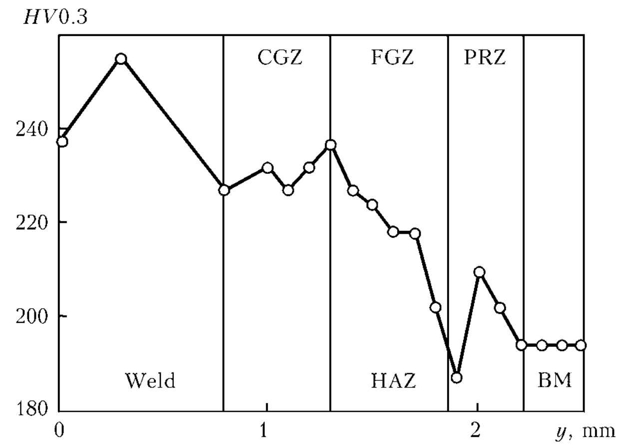

Figure 7. Distribution of hardness $HV0.3$ in a cross section y of welded joint of steel 13G1SU (δ = 14 mm) produced using four-pass hybrid welding (v_w = 60 m/h): CGZ — coarse grain zone; FGZ — fine grain zone; PRZ — partial recrystallization zone

treatment or application of additional technological procedures, is at the stage of investigations.

Therefore, the results of investigations of structure of pipe steel welded joints produced using multipass laser and laser-arc welding, and also their impact toughness and corrosion resistance allows considering the above-mentioned methods of welding to be challenging for increase of service life of pipeline transport. The hybrid laser-arc welding of pipe steels ($\delta > 5$ mm) allows the decrease in the power of laser radiation and partially its replacement by a less expensive power of electric arc, coming from the calculation of 1.0 kW of an arc instead of 0.5 kW of laser radiation power. At the power of laser radiation of up to 3 kW the application of hybrid welding process of steels is rational at the thickness of sheet of up to 10 mm, above this value the depth of penetration does not increase even at decrease of welding speed. To weld sheets of large thickness it is rational to use radiation of a higher power. With this purpose it is offered to use multipass laser and hybrid welding. In hybrid welding the width of a weld and HAZ is larger as compared with that of a laser one. The increase of welding speed and carbon content in base metal leads to formation of undesirable martensite structures in HAZ. The methods of elimination of this disadvantage require further study.

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NEW BOOK

(2010) **Paton school:** Scientific-informational edition. — Kyiv: Naukova Dumka. — 440 p. Il., ISBN 978-966-00-0953-1.

The book contains information about the world recognized Paton scientific-engineering school in the field of welding and related technologies. The course of life of famous scientist Prof. Evgeny O. Paton, founder of the Electric Welding Institute, is described. The purposeful fundamental research works, started by him and his school, became a theoretical basis of welding science, transformed it into powerful tool of technical progress, providing revolutionary achievements in many branches of industry.

Under the leadership of Prof. E.O. Paton, the Paton school experienced the further rapid development, significantly expanded the topicality of investigations and developments, founded new scientific-technical directions, gained high authority and wide recognition in the world.

This school brought up a generation of famous scientists, members of the National Academy of Sciences of Ukraine, doctors and candidates of sciences, talented engineers who follow the ideas and methods of work of their teachers, basic principles and traditions of school, bring up new generations of pupils and successors multiplying a good fame of their alma mater.

The book is useful for scientific and engineering-technical personnel, post-graduate students, students, and also those who are interested in history of development of science and technology.

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