Lasers in Manufacturing Conference 2015

Industrial Laser Technologies for Shipbuilding

Valeriy M. Levshakov[a]*, Alexander N. Aleshkin[a], Natalia A. Steshenkova[a], Gleb A. Turichin[a,b], Nikolay A. Nosyrev[a]

[a]*JSC "Shipbuilding & Shiprepair Technology Center", Saint-Petersburg 198095, Russia*
[b]*Institute of Laser and Welding Technology, SPbSPU, Saint-Petersburg 195251, Russia*

Abstract

Laser welding technologies are widely applied for welding of thin-wall constructions. The shipbuilding industry requires high-performance production technologies for the heavy gauges. A hybrid laser-arc welding technology which provides higher productivity, improvement of production effectiveness and reliable quality of welded joints is the most promising technology for this task.
JSC "Shipbuilding & Shiprepair Technology Center" (JSC SSTC) jointly with Saint-Petersburg Polytechnic University performed a complex of studies, including modeling and full-scale experiments, for the purpose of development of industrial hybrid laser-arc welding technologies. The dynamic model of the deep penetration hybrid laser-arc welding process, based on variational principle, was designed. This model specifies the dynamic processes (including self-oscillating) effect on the welding seam formation. Designed model takes into account melt flow, waves traveling on the melted pool surface, viscosity of the melted metal, capillary tension, return pressure and laser radiation parameters. Experimental researches were carried out on the preproduction models of technological complexes developed by JSC SSTC and equipped with 16 kW and 25 kW fiber lasers.
At the present time JSC SSTC is developing the technology for vertical position hybrid welding for high-strength steel over 40 mm thickness. Industrial hybrid laser-arc welding technology for butt-welded and T-joints up to 20 mm thickness was approved by Russian Maritime Register of Shipping (RMRS).

Keywords: hybrid laser-arc welding; vertical position welding; shipbuilding steels

* Corresponding author. Tel.: +7-812-786-26-10; Fax: +7-812-786-04-59.
E-mail address: inbox@ssts.spb.ru

The modern stage of engineering industry in the whole, and shipbuilding in particular is notable for starting implementation of technologies at major enterprises, which can substantially change the image of this previously rather conservative sector. Massive implementation of modern laser techniques is one of the ways to improve quality in shipbuilding and heavy engineering production.

Laser welding technologies are widely applied for welding of thin-wall constructions, primarily for aluminum and titanium alloys, corrosion-resistant and high-alloyed steels. Main advantages of laser welding before conventional arc welding include higher performance, high quality of welding seam, minimum heat-affected zone, minimum consumption of filler materials and almost no thermal deformations. Deformations of structures shall significantly decrease due to low heat input (several times lower than conventional arc welding) [1].

The shipbuilding industry requires high-performance production technologies for the heavy gauges. The main criteria for selection of welding technology/mode is ensuring of appropriate mechanical and viscoplastic properties of weld metal, maximum depth of welding seam and operation in presence of a gap between edges of surfaces being welded [2]. The most promising technology for these tasks is a hybrid laser-arc welding technology which provides higher productivity, improvement of production effectiveness and reliable quality of welded joints. Comparison of calculated thermal cycles show that hybrid laser-arc welding provides better conditions for seam formation, heat adjustment and alloy addition than laser welding [2].

Hybrid laser-arc welding technology has significantly narrower arc column, much higher stability of welding pool and higher performance factor in comparison with arc welding. The advantages before laser welding include softer thermal cycle and lower requirements to gaps and assembling accuracy [3].

JSC “Shipbuilding & Shiprepair Technology Center” jointly with Saint-Petersburg Polytechnic University performed complex of studies, including modeling and full-scale experiments, for the purpose of development of industrial hybrid laser-arc welding technologies. The dynamic model of the deep penetration hybrid laser-arc welding process, based on variational principle, was designed. This model specifies the dynamic processes (including self-oscillating) effect on the welding seam formation. Designed model takes into account melt flow, waves traveling on the melted pool surface, viscosity of the melted metal, capillary tension, return pressure and laser radiation parameters. Experimental researches were carried out on the preproduction models of technological complexes developed by JSC SSTC equipped with 16 kW and 25 kW fiber lasers.

JSC SSTC developed a manufacturing technique for flat sections production up to 20 mm thick, based on laser cutting and laser-arc hybrid welding. The procedure of hybrid laser-arc welding of plates and webs with integrated grooving by laser cutting was approved by Russian Maritime Register of Shipping. This technique is implemented in automated line for assembly and welding of flat sections up to 12 x 12 m in size (see Fig. 1), designed and constructed in cooperation with IMG, Germany. The innovation solution is a combination of grooving by laser cutting with plates welding by laser-arc method at one position respectively, as well as implementation of hybrid welding for double-side welding of stiffeners. Fiber laser LS-16-P4 of 16 kW maximum power works as multioperator since it is outfitted with 4-channel optical switch, which transfers laser radiation through optic fiber to working positions.

Flat sections production line is composed of the following positions:

- sheet feeding position;
- panel enlarging position;
- enlarged panel transfer position;
- profile mounting position;
- profile fixation and welding position.

Fig. 1. Flat sections production line

Before operation, shop crane puts plates on roll feeder and chain transporters transfer them to panel enlarging position for alignment. This position is outfitted with pressure portal for panel fixation and portal for laser cutting and hybrid laser-arc welding of plate with two carriages each having optical head to render cutting and welding. Laser cutting carriage has optical head with module of inclination from 0 to 15 degrees to perform grooving. Welding carriage has arc-augmented laser welding head and tandem welding head. This allows welding of plates up to 20 mm thick in one pass.

Hydraulic cylinders fix aligned plates at press portal for further successive laser grooving. For plates above 14 mm thickness, cutting of an edge with a blunt is applied. Upon grooving, plates are joined gapless and hybrid laser-arc welded at 1.0-2.5 m/min speed. Welding carriage has seam guidance and tracking system. For thicker plates tandem welding head is applied. Therefore, this line is capable to weld 20 mm thick panels in one pass.

Upon enlarging, the plate is transferred by chain transporter to mounting and welding position for main direction web. Gantry portal transfers selected profile from special cassette to the plate. Transferred profile is aligned as per marking line and then mounted on the plate. The profile is fixed with hydraulic presses installed on fixation portal and hybrid (arc-augmented) welding portal. Upheaval buckling device is used here to compensate welding stresses and deformations. Two-sided hybrid welding of profile to plate is performed in one pass. Welding carriage is positioned ahead. Maximum welding speed is 3 m/min. Average total output power of the laser is 10 kW.

Upon completion of web welding, the plate is transferred with stepping magnet manipulators to the output by length of framing space. Mounting and welding of next profile is performed.

The equipment has maximum automation level and operates as per program launched from operator consoles.

Analysis and testing results for welding seams at longitudinal butt-joints and T-joints made by hybrid laser-arc welding show that viscoplastic properties of weld metal and weld-affected zones remain stable or exceed standard values. Maximum hardness of material equals 300 (HV5), thus staying within tolerable limits [2]. Figure 2 indicates summary data on sample fatigue test. External appearance of shipbuilding steels joints macro sections is given in Figure 3.

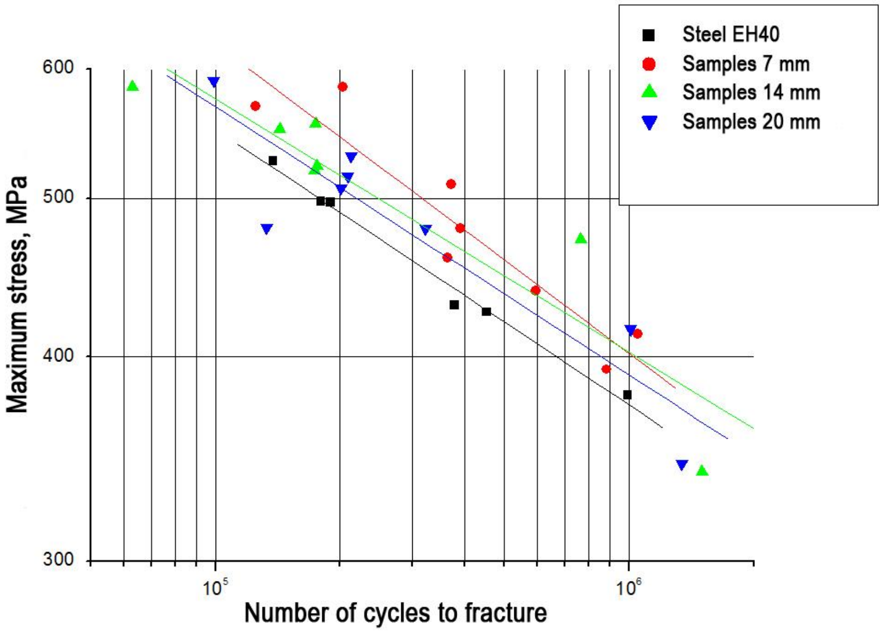
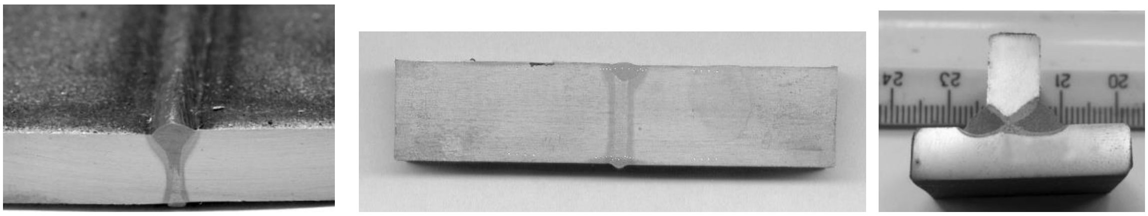


Fig. 2. Results of welding sample fatigue testing



a b c

Fig. 3. Macrosections of hybrid laser-arc welding joints: (a) butt-joint 7 mm and (b) 20 mm thickness, (c) T-joint 7 mm/7 mm thickness

The main advantages of laser technologies implementation in the flat sections production are:

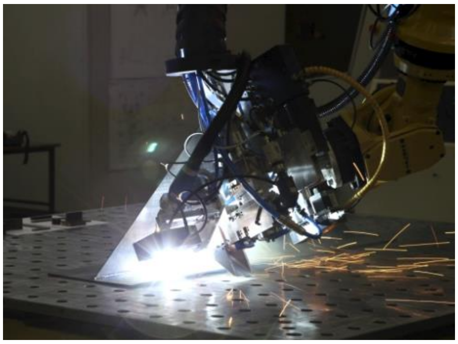
- 1.5–3.0 times higher performance;
- 20.0–40.0% lower material and power consumption;
- Minimum residual welding stress and deformations of welded structures.

Application of laser technologies allows to obtain non-deformed high-quality flat sections with required dimensions (see Fig. 4) which have notable advantages compared to sections manufactured with the use of arc welding.

Fig. 4. Flat panel (7mm) produced with laser technologies

To provide welding of structures with complex geometry, JSC SSTC developed robotized complex for laser cutting and welding in various spatial positions (see Fig. 5). Complex is based on modular design and performs laser and hybrid laser-arc welding of steel constructions up to 20 mm thickness and aluminum alloys up to 12 mm. The machine is unique due to the use of 25 kW laser LS-25, one of the most powerful in Russia, and optical four-channel switch, allowing to use laser optical heads in turn for welding and cutting at the same machine, thus substantially reducing welded structures manufacturing time. Application of such equipment reduces hull manufacturing cost by 30%, increases labor production by 10% and reduces welding deformations by 30% compared to conventional welding methods.

a



b

Fig. 5. Robotized complex for laser welding and cutting in various spatial positions: (a) general view of the complex, (b) hybrid laser-arc welding process

At the present time JSC SSTC is developing the technology for vertical position hybrid welding for high-strength steel over 40 mm thickness.

Vertical welding with the horizontal laser beam causes a problem of the welding direction choice: uphill or downhill, the prevention of the liquid weld pool pouring without forming devices and butt welding possibility without beveling edges simultaneously with weld metal alloying by the filler material.

The weight of the weld pool molten metal, which is not compensated by surface tension, is the reason for limiting of welded plates thickness. In this case the metal is poured, resulting to the unsatisfactory reverse bead formation—as a rule, repetitive dropwise on the reverse side of the seam appear.

Avoidance of such defect formation caused by the amount of molten metal in the weld pool can be attained by its minimization that is actually achieved at increased welding speeds. Thus, to avoid dripping from the back side of the weld during through penetration of approximately 14 mm thickness metal, welding speed should not be below 1.8 m/min.

In case of the vertical joint through penetration pouring of molten metal from both front and back sides of the weld may occur. It is observed at welding speeds below 1.0 m/min. Therefore, further experiments on the laser-arc source penetrating ability are performed at a rate that provides the preservation of the metal in the melting zone.

During the uphill or downhill welding experiments it was noted that the position of the arc source influences on the weld formation process. Satisfactory formation of the weld is observed when impact force is directed against the gravity. During the ascent welding the uneven roller and pouring metal from the bath were observed. During the slope welding seam is characterized by a smooth weld bead with a low metal pouring.

For the purpose of the deep penetration capability, hybrid laser-arc welding with a gap horizontal beam welding experiment was conducted. Vertical joints of mild steel specimens assembled with a gap were welded. When combining action of the laser and welding arc, laser beam provides a narrow penetration zone of about 18 mm deep.

In accordance with experimental results basic process configuration has been selected: welding arc moves ahead, melting the metal on the top of the gap; laser beam following the arc formes a narrow and deep welding seam. Figure 6 shows a photograph of the vertical weld macrostructure of high-strength steel 20 mm thick. The process parameters are as follows: laser power P = 15 kW, arc voltage U = 32 V, arc current I = 297 A, welding speed V = 1.5 m/min, filler wire feeding speed V_{fw} = 11.2 m/min.

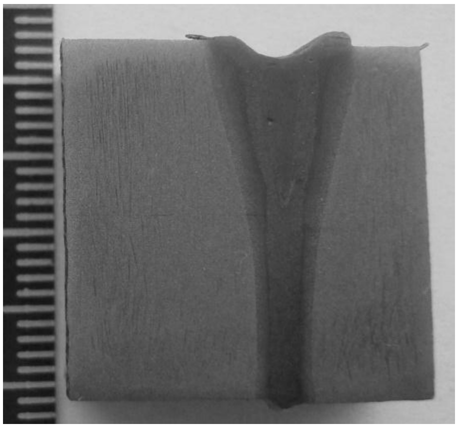


Fig. 6. Macrostructure of the vertical welding seam

During the experiments vertical joints of high strength shipbuilding steel samples of 48 mm thick with X-shaped edges were welded. The value of blunting was 20-24 mm. Welding of the blunting was performed by hybrid welding. The macrostructure of the weld cross section is presented in Figure 7. The process parameters are as follows: P = 15 kW, U = 40 V, I = 370 A, V = 1.0 m/min, V_{fw} = 18.0 m/min.

Fig. 7. Macrosection of high strength shipbuilding steel, 48 mm thick

A characteristic feature of the hybrid laser-arc horizontal beam welding process is a high welding speed. Normally, with the cooling rate corresponding to such welding speed in case of arc welding the hardening structure is formed which results in a strength and viscoplastic properties decreasing. Though the cooling time for the hybrid laser arc welding in the temperature range of 800°C − 500°C $t_{8/5}$ averages 0.5 – 1.5 seconds, the mechanical properties of the weld zone are at a high level.

For the industrial implementation of the vertical hybrid laser-arc welding technology and approval of experimental work a preproduction model of automatic vertical welding technological complex was designed (see Fig. 8).

Fig. 8. Technological complex for automatic vertical hybrid laser-arc welding

Although hybrid laser-arc welding is a complicated multi-parameter process, and its implementation at the shopfloor leads to certain technical problems and considerable investments, its efficiency and vitality for shipbuilding production are proven.

Development and implementation of laser technologies allow to achieve a new level of productivity and manufacturing of structures in shipbuilding and heavy engineering.

References

[1] V.M. Levshakov, N.A. Steshenkova, N.A. Nosyrev. Experience in development of laser technologies for hull structures production "Shipbuilding and shiprepair technology herald" No.21 2013 p. 47-49.

[2] V. M. Levshakov, N. A. Steshenkova, N. A. Nosyrev. High-production laser and plasma welding technologies for high-speed vessels production, International Science Index Vol: 8 No: 9 Part XIV p. 1815-1820.

[3] G.A. Turichin, I.A. Tsibulsky, M.V. Kuznetsov. Prospectives on implementation of arc-augmented laser welding for heavy metal plates // Ritm. - 2010. Iss. 10. p. 28-31.