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High-Production Laser and Plasma Welding Technologies for High-Speed Vessels Production

V. M. Levshakov, N. A. Steshenkova, N. A. Nosyrev

***Abstract*—**Application of hulls processing technologies, based on high-concentrated energy sources (laser and plasma technologies), allow improve shipbuilding production. It is typical for high-speed vessels construction using steel and aluminum alloys with high precision hulls required. Report describes high-performance technologies for plasma welding (using direct current of reversed polarity), laser, and hybrid laser-arc welding of hulls structures developed by JSC "SSTC"

***Keywords*—**Flat sections, hybrid laser-arc welding, plasma welding, plasmatron.

I. Introduction

COMPETITIVE strength in shipbuilding industry strongly depends on efficiency of technologies being applied and production quality. In general, quality changes in shipbuilding industry are mostly related to implementation of innovative high-performance technologies with high automation level at shipbuilding enterprises.

One of methods to increase shipbuilding production quality is implementation of hull processing technologies which use high power sources, such as laser and plasma technologies. This is important for building of high-speed vessels both from steel and aluminum alloys, where strong demands are applied for manufacturing accuracy of hull structures and flatness of superstructures and boards.

Currently, construction of high speed vessels is dynamically developing branch of shipbuilding aimed to solve transportation and defense tasks. Economic efficiency of high-speed vessel strongly depends on such basic specifications as main dimensions, power plant type, and especially hull structure and material.

JSC "Shipbuilding & Shiprepair Technology Center" is a leading design and technology shipbuilding center in Russia. For 75 years upon establishment (since 1939) it has been developing and implementing high-efficient technologies for domestic shipbuilding related to marine equipment construction, operation and repair. In particular, JSC SSTC actively develops and applies laser and plasma technologies for shipbuilding industry.

V.M. Leshakov is Candidate of Sciences, Director of RTF "Sudotechnologiya", JSC "Shipbuilding & Shiprepair Technology Center", 7 Promyshlennaya Street, St. Petersburg, 198095, Russia (phone +7-812-786-26-10; fax +7-812- 786-04-59; e-mail: inbox@sstc.spb.ru).

N.A. Steshenkova is Head of Laser Centre of Shipbuilding, JSC "Shipbuilding & Shiprepair Technology Center", 7 Promyshlennaya Street, St. Petersburg, 198095, Russia (phone +7-812-786-26-10; fax +7-812- 786-04-59; e-mail: inbox@sstc.spb.ru).

N.A. Nosyrev is Process engineer of Laboratory of laser technologies in shipbuilding, JSC "Shipbuilding & Shiprepair Technology Center", 7 Promyshlennaya Street, St. Petersburg, 198095, Russia (phone +7-812-786-26-10; fax +7-812- 786-04-59; e-mail: inbox@sstc.spb.ru).

II. Plasma Welding Technology

Analysis of modern ship hulls shows, that flat panels made from aluminum alloys are widely used in structure of: decks, platforms, board, bottom, bulkheads. These panels constitute 70-75% and 85-90% of ship hulls and superstructures respectively.

For this purpose, it is necessary to manufacture cost-effective and accurate hull structural components from aluminum that may be obtained by high-accuracy assembling methods and minimal welding deformations.

JSC SSTC developed technology and equipment for plasma welding (using DC (direct current) of reversed polarity) for aluminum alloys of 1.5–20 mm thickness: automatic equipment for plate integration (portal machine APS-01, Fig. 1) and mechanized equipment for web welding and assembly (semi-automatic machine PPN-200, Fig. 2).

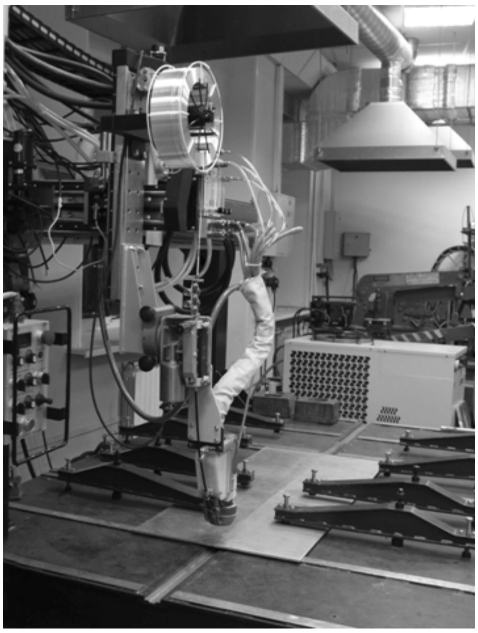


Fig. 1 Portal plasma welding machine APS-01

Main advantage of plasma welding on reversed polarity of aluminum alloys is destruction of oxide layer Al_2O_3. Therefore, welding is applied to pure metal only and welding seam smoothly adjoins to parent metal (without undercutting), which is particularly important for structures operating under alternate stresses [1].

Fig. 2 Semi-automatic plasma welding machine PPN-200

Plasma equipment has modular structure. Main modules are the following:

– plasmatron (plasma generator);
– plasmatron cooling station;
– control cabinet;
– welding current source.

High quality welding joint is provided by plasmatron, the unique development of JSC “SSTC” (Patents granted: RU 2248868 C1 “Non-consumable electrode for arc welding procedures” and RU 2318639 C2 “Arc-jet welding plasmatron”.

Main components of plasmatron (Fig. 3) are: non-consumable-electrode with tungsten insert, plasma-supporting and protective nozzles. Plasmatron also distributes cooling gas/liquid flows.

Fig. 3 Plasmatron of APS – 01 machine

The following demands were made in course of plasmatron development: high quality welding for wide range of currents, long life time of wear parts (electrode in particular), stable plasma arc and uniform non-sprayed atomized melting of filler wire above welding pool.

During welding of 1.5 to 20 mm aluminum layer at reversed polarity, the welding current modify from 40A to 700 A. Welding pool diameter may reach 20-30 mm and become dependent on welding current density. When current density exceeds 20 A/mm^2, the welding pool shall boil up and further welding becomes impossible. Electrode is the main unit of plasmatron for shaping the required current density. Therefore, special electrode with tungsten insert (vacuum embedded) was designed. Selected ratio between vacuum insert and outer diameter of electrode provide stable arcing due to distribution of arc anode spot over all surface of tungsten insert and limitation of current density at 20 A/mm^2 level. This prevents boiling of welding pool and allows forming of welding seam without splashing.

Main parameters of plasma welding by APS-01 machine: welding current, diameter of plasma-supporting nozzle, welding wire feed speed/diameter, consumption of plasma-supporting and feed gas, path of welding wire injection into welding pool, and plasma arc length. Sample of welding connection made with APS-01 portal machine from AMG-5 alloy is given on Fig. 4.

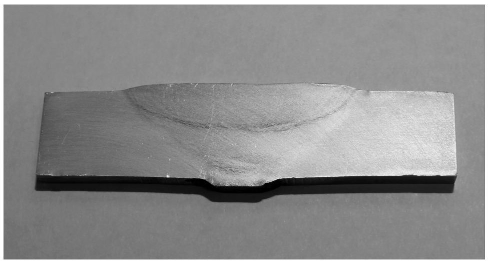


Fig. 4 Sample of plasma welding connection made on DC of reversed polarity

Main advantages of plasma welding are:

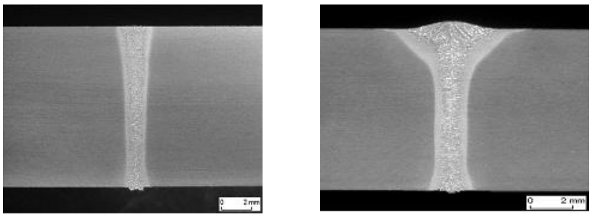
– Concentrated application of heat and automatic feed of welding wire increases performance, decreases welding deformation and improves welder’s working conditions.
– Application of plasma discharge (DC, reversed polarity) during welding of aluminum alloys increases performance, improves quality of welding joints due to full destruction and removal of oxide layer, enhances formation of seam metal, greatly decreases geometric stress in transition points between seam and parent metal and increase lifetime of welding connections operating under alternate stresses .
– No spray above welding pool due to atomized melting of welding wire.

III. Laser and Hybrid Laser-Arc Welding Technology

Laser welding represents another high-performance welding technology for hulls of high-speed ships. Main advantages of laser welding before conventional arc welding are: 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) [2].

Specialists of JSC "SSTC" made series of experimental works on laser and hybrid laser-arc welding and developed technologies and equipment for hull manufacturing.

Fig. 5 shows two typical macrosections of laser and hybrid laser-arc welding of 11 mm thick steel for technologies comparison. Welding speed – 2.2 m/min. Laser output power – 10.2 kW/10,5 kW for laser/hybrid laser-arc welding respectively. Arc parameters: I = 243 A, U = 25.3 V, welding wire diameter – 1.2 mm.



(a) (b)

Fig. 5 Macrosections of welding connections made with laser welding (a) and hybrid laser-arc (b)

In course of operation, the computer-aided engineering analysis system LaserCAD [3] was used. It calculates geometric parameters of intended welding connection, selects optimal parameters/equipment for processing and selects material depending on assumed properties of welding connection.

Fig. 6 shows comparison of seam welding depth by laser/hybrid laser-arc welding at 10/15 kW output power respectively. Welding speed is 1.6 m/min. It also indicates calculation of welding cycle temperature upon applying S-curves of austenite's decay to define phase composition of deposited weld metal.

On basis of given comparison, one may conclude, that laser/hybrid laser-arc welding provide more than 10 mm welding depth at 2 m/min welding speed. However, main criteria for selection of welding technology/mode is provision of: appropriate mechanical and viscoplastic properties of weld metal, maximum depth of welding seam and operation in presence of gap between edges of surfaces being welded.

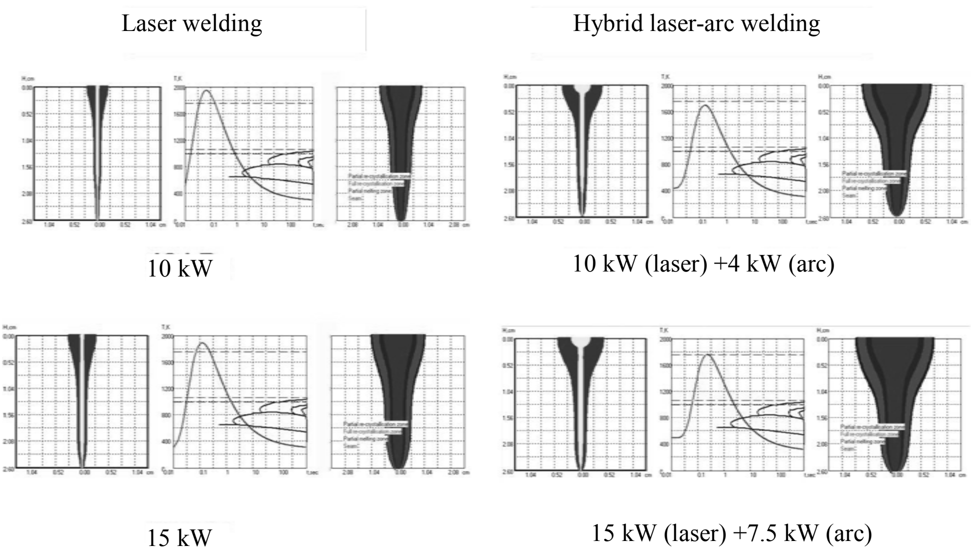


Fig. 6 Comparative penetration calculation for laser and hybrid laser-arc welding

Laser welding is applied for aluminum and titanium alloys, corrosion-resistant and high-alloyed steels. However, comparison of thermal cycles show, that hybrid laser-arc welding provides better conditions for seam formation, heat adjustment and alloy addition.

JSC "SSTC" developed flat sections manufacturing technology based on application of laser cutting and hybrid laser-arc welding, and obtained approval of Russian Maritime Register of Shipping (RMRS) for typical hybrid laser-arc welding process of plates and profiles of ship's hull structures with laser cut groove preparation.

JSC "SSTC" and German company IMG jointly manufactured sample of automated welding and assembly line for flat sections production (Fig. 7). This line can manufacture sections up to 12 m x12 m size, 20 mm thickness using flow-positional method and other technological solutions never applied before in world shipbuilding industry.

Fig. 7 Sample of flat panel production line

The innovative solution applied on the line is combination of laser cutting for edge's preparation hybrid laser-arc butt welding of panels in one position respectively. 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.

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 20mm 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 – 3 m/min. Average total power output of the laser – 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 visco-plastic properties of weld metal and weld-affected zones remain stable or even exceed standard values. Maximum hardness of material equals 300 (HV5), thus staying within tolerable limits. Fig. 8 indicates summary data on sample fatigue test. External appearance of macro sections is given in Fig. 9.

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 are: softer thermal cycle and lower requirements to gaps and assembling accuracy [4].

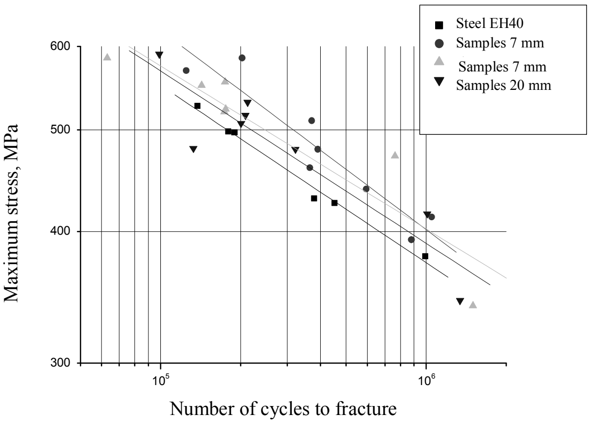
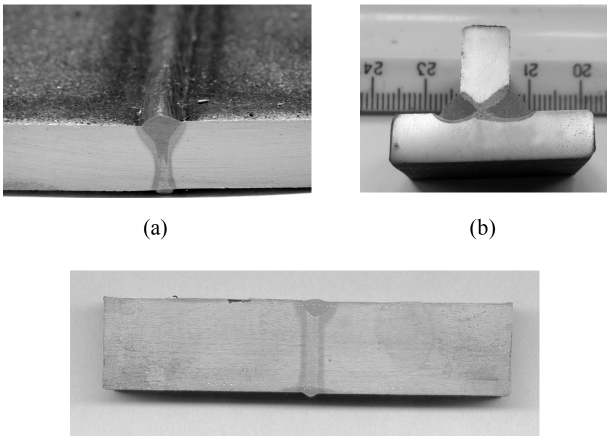


Fig. 8 Results of welding sample fatigue testing


(a) (b)

(c)

Fig. 9 Macrosections of hybrid laser-arc welding joints: butt-joint 7 mm (a) and 20 mm (c) thickness, T-joint 7mm/7mm thickness (b)

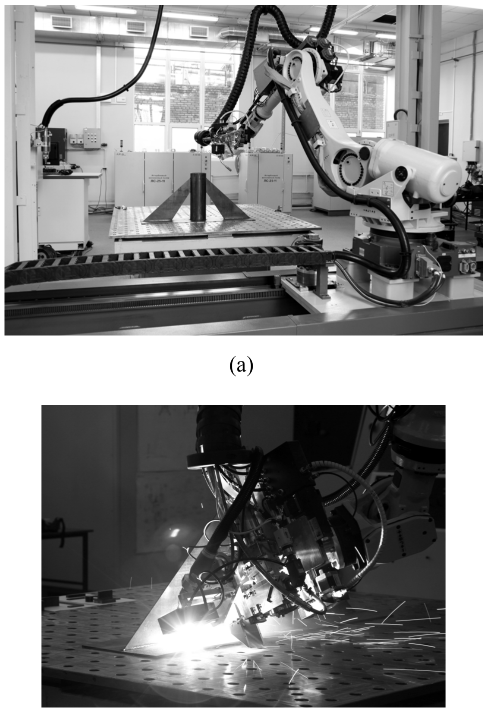
The main advantages of laser technologies in production of flat sections are:

- Much higher performance (in 1.5–3.0 times);
- Low material and power consumption (by 20.0–40.0%);
- Minimum residual welding stress and deformations of welded structures.

Application of laser technologies allows obtaining non-deformed high-quality flat sections with required dimensions (Fig. 10) which have notable advantages before sections manufactured with use of arc welding [5].


Fig. 10 Flat panel (7 mm) 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 (Fig. 11). Application of such equipment reduced hull manufacturing cost by 30%, increase labor production in 1.1 times and reduced welding deformations in 1.4 times comparing with conventional welding methods.


(a)

(b)

Fig. 11 Robotized complex for laser welding and cutting in various spatial positions: general view of the complex (a), hybrid laser-arc welding process (b)

Optimization of weight load components is very important for high-speed vessels with high power-to-weight ratio. Most critical components are power supply system and hull. This article reviewed two high performance and promising methods which are based on application of high-power sources for manufacturing of hull structures with minimum residual deformations. Application of laser and plasma welding technologies for high-speed ship hulls shall maintain competing ability of shipbuilding enterprises.

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