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Laser technologies in modern shipbuilding

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Abstract

The level of technological development determines the competitiveness of industrial enterprises and particular in shipbuilding area. Massive implementation of modern laser techniques is one of the ways to improve quality in shipbuilding and heavy engineering production. JSC «Shipbuilding and Shiprepair Technology Center» is a leading design and engineering center in Russian shipbuilding sector and takes an active part in the development and application of laser technologies for shipbuilding.
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.
Results of welding process simulation and experimental researches fulfilled on the preproduction models of technological complexes developed by JSC SSTC (based on fiber lasers up to 25 kW power) are presented. The welding technological processes for shipbuilding steels 16-40 mm thickness in different spatial positions were designed (including approved by qualification agency Russian Maritime Register of Shipping (RMRS)).
The article presents results on researching and development of technology and robotized equipment, based on modular approach, for laser welding and cladding of maritime machinery items.
Implementation of laser technologies allow to achieve a new level of productivity and manufacturing of structures in shipbuilding and heavy engineering.

Keywords: hybrid laser-arc welding; laser welding; hull structures, laser cladding, marine engineering

JSC «Shipbuilding and Shiprepair Technology Center» (JSC SSTC) is a leading State Scientific Center in Russian Federation, focusing on designing and modernization of shipbuilding and shiprepair facilities and creation of modern technologies and advanced complex of automated and robotized technological

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equipment for shipbuilding industry. To support the process of equipping shipbuilding and ship repair enterprises with laser technological complexes, a Laser Center of Shipbuilding Center was established in JSC SSTC, incorporating experimental facilities for research and mastering of technologies for laser cutting, laser and hybrid laser-arc welding, cladding, marking and labeling. Over the past 5 years, the specialists of the Center managed to make a breakthrough in the creation of a number of technologies and also to organize their adaptation to real production. JSC SSTC is a member of Russian Laser Association (LAS) and takes an active part in the cooperation of developments (participating in TP “Photonics”) in the field of industrial laser technologies for the macro processing of materials.

Over the 50 years JSC SSTC (previously RPA “Ritm”, FSUE “CRIST”) develops and supplies shipbuilding industry with gantry thermal cutting machines. The recent models are the laser cutting machines, based on fiber lasers with power from 1 to 3,5 kW. The gantry laser cutting complexes “RITM” (see Fig. 1) characterized by high reliability and ease of maintenance and was proved on Russian shipbuilding and engineering enterprises.

Fig. 1. Gantry complex for laser cutting RITM-LASER

In addition to gantry laser cutting systems there are several software-controlled complexes for the hull structures production and robotized equipment for laser cutting, welding and cladding in various spatial positions for shipbuilding and shiprepair enterprises. The robotic complexes are built on a modular basis, which provides the possibility of flexible reconfiguration of equipment at the stage of technology development, and allows to provide technical requirements of the customer with minimum capital costs, to increase the accuracy and reliability of the complexes, to facilitate their operation and repair.

Precise laser cutting and welding of ships structures components and assemblies in various spatial positions is provided by robotized complex (see Fig. 2) equipped with 25 kW fiber laser with optical switcher and quick-adjusting heads for laser cutting and arc augmented laser welding. Such configuration secures production of large-dimensioned components and assemblies without extra movement and repositioning of the same, thus significantly increasing production performance and manufacturing accuracy.

a b c

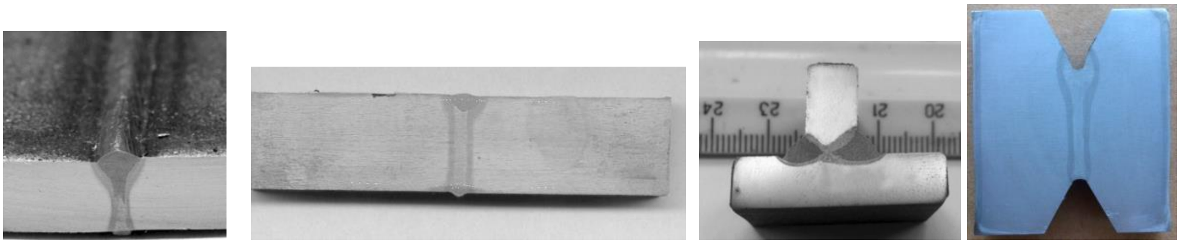
Fig. 2. Robotized complex for laser welding and cutting in various spatial positions: (a) general view of the complex, (b) 3D-laser cutting, (c) hybrid laser-arc welding process

The main technology of shipbuilding is welding. Traditional welding technologies used for the manufacture of large-sized and critical hull structures (multi-pass manual and automated arc welding in shielding gas or under a flux) do not allow achieving the mechanical characteristics of weld metal and weld zone comparable to the base metal. The required characteristics are achieved by increasing the amount of weld metal to create a reinforcement weld. Metal structures made with the use of traditional technologies are distinguished by a high level of welding deformations. In connection with this fact, about 25% of the complexity of the building construction is occupied by straightening operations [1].

One of the key tasks in advancing of hull production technology is a minimization of welding deformations and simultaneous provision of high production performance. This task can be obtained by arc augmented (hybrid) laser welding technology. On the basis of the research carried out in recent years, it can be concluded that hybrid laser-arc welding provides better conditions for seam formation, heat adjustment and alloy addition than laser or arc welding separately. 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 [2]. With simultaneous reducing of welding deformations in 1.4 times comparing to conventional arc welding, use of laser equipment allows to reduce overall cost of hull construction by up to 30%, and to increase productivity of hull structures manufacturing more than in 1.1 times.

In connection with hybrid laser-arc welding is a complex multivariate process, the estimation of parameters influencing on welding seams quality demands a numbers of material and labor-consuming complicated experiments. For full-scale test optimization purposes a process simulation using LaserCad [3] was made. A used model specifies the dynamic processes (including self-oscillating) effect on the welding seam formation. 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 high-power (up to 25 kW) fiber lasers. The welding technological processes for shipbuilding steels 16-40 mm thickness in different spatial positions were designed. Results obtained on executed work ensure the qualitative formation of welding joints (see Fig. 3) of hull structures using hybrid laser arc welding with high power fiber lasers. 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.



a b c d

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, (d) vertical welding 48 mm thick

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 for the first time 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. 4), designed and constructed in cooperation with IMG, Germany. The general properties are: work sheets thickness – 4-20 mm, web height – up to 300 mm, maximum weight of section – 80 ton. 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.

Fig. 4. Flat sections production line

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 effectiveness and vitality for shipbuilding production are proved.

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.

Laser welding represents high-performance welding technology for thin-wall shipbuilding constructions, especially in marine engineering. 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) [4].

In this connection for the purposes of laser welding in marine engineering implementation, a technique and robotized program-controlled complex were developed (see Fig.5), intended for welding thin-walled shells to solid structures, e.g. in marine pumps or valves, and for welding thin-walled tubes into tube plate (in heat exchangers). The system includes 8 kW fiber laser, welding robot, laser head for welding in hard-to-reach places, and/or laser scanning head for welding of tube plates.

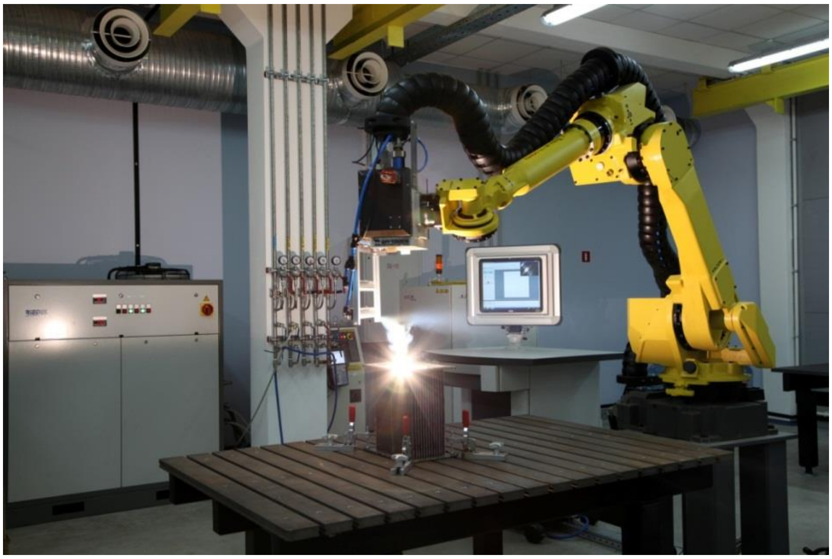


Fig. 5. Robotized system for laser welding of maritime machinery items

Laser welding technologies are also applicable for shiprepair area, but the most promising technology for it's specific tasks is laser cladding for reconstruction of marine machinery items (shafts, valves, spiral wheels, etc). Analysis of the use of marine diesel engines shows that many engineering components used in their design (pistons, valves, valve seats, etc.) often fail before the scheduled overhaul. For a long time JSC SSTC develops equipment and technologies for cladding (hardfacing) with high automation level for manufacturing and reworking the critical engineering parts (mainly for plasma cladding). In order to implement laser cladding technology for marine engineering manufacturing the robotized complex for laser powder cladding has been developed (see Fig. 6).

Laser cladding complex is equipped with 4 kW fiber laser source, module of movement, powder feeding unit and control system, providing complex adjusting and work in manual and automatic mode.

The main task in the development laser cladding process was obtaining a high quality coating (without pores), with good adhesion to the base material. It is required to ensure a minimum mixing and dissolving the deposited material to the substrate. The optimum spot size and power density at which the maximum deposition rate is provided can be determined for a given velocity of movement and feed rate of filler material (powder).

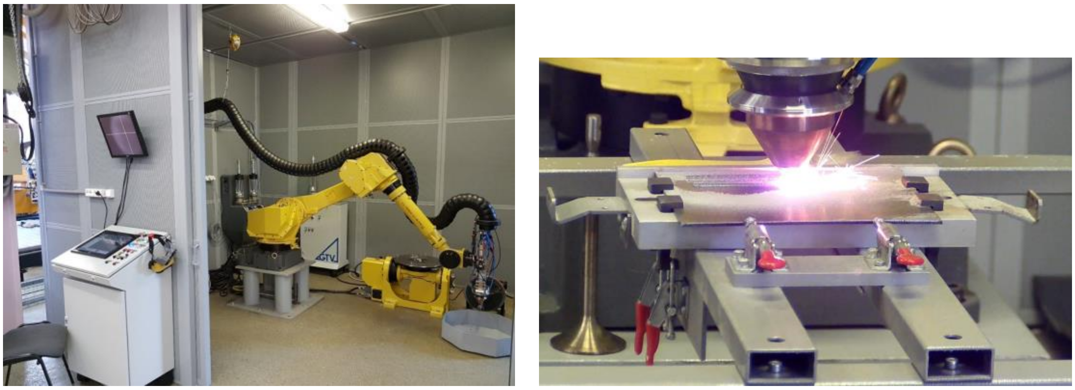


Fig. 6. Robotized complex for laser powder cladding

Laser powder cladding adaptability for marine engines valves, in order to increase their performance under cyclic loading, were proved. The main task at the same time was to obtain the hardened surface of the valve plate, the end surface of which is subjected to the influence of large mechanical and thermal loads, and subject to wear.

Laser cladding comparing to conventional technologies allows to achieve some advantages:

• Low heat inputs and heat distortions (laser cladding inputs less than 20% of the heat compared to arc cladding the same part);

• Small heat affected zone;

• Very low dilution with the base metal;

• Thin clad layers and control of part configuration.

Implementation of laser cladding technologies in the production cycle can significantly reduce the costs of high-tech products manufacturing. Reducing the cost by reducing the time of manufacture simultaneously with material saving is one of the main advantages of additive technologies and laser cladding in particular, over traditional reworking and metal-working technologies including machining on CNC machines or technology of casting with further machining.

On basis of executed works can conclude that implementation of laser technologies allow to achieve a new level of productivity and manufacturing of structures in shipbuilding, marine engineering and heavy engineering.

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