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Technology of double-sided laser-arc hybrid welding for production of T-beams

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Abstract. An arc augmented laser-arc welding technology which provides higher productivity, improvement of production effectiveness and reliable quality of welded joints is the most promising technology for advancing of hull production process, in particular for T-beams production. Results obtained in executed work ensure the qualitative formation of T-beams using double sided hybrid laser arc welding with high power fiber lasers. The analysis of different mutual positions of welding heads has been conducted in this work. A method for calculating the expected total welding deformations for hybrid welding of T-beams with different wall thicknesses and girdle from shipbuilding steels of normal and high strength was also developed. The study has found the estimated ratios for the additional mechanical load to prevent welding deformations. Technology of double-sided laser-arc hybrid welding for production of T-beams was developed.

1. Introduction
The characteristic feature of shipbuilding industry is the use of special designed details (including special stiffeners, T-beams, flat sections etc.) for hull structures production, comparing with other machinery sectors mainly working with standard profiles and metal blanks. The most labor-intensive process is the obtaining of extended (12 meters and more) structures with minimal deviations from the given (theoretical) dimensions, required by project documentation.

Competitive strength in shipbuilding industry strongly depends on efficiency of technologies being applied and production quality. 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, straightening operations take about 25% of the building construction complexity [1].

As a result 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. Research carried out in recent years, verifies 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].

Different joint configurations, materials and material thickness in hybrid welding have been investigated by a number of research groups. Hybrid welding has also shown a very good weld bead reinforcement junction to the base material of different joint configurations (Figure 1) [3]. According to the description in [4], when a 3 kW Nd:YAG laser using a 0.6mm fiber or a 6 kW CO2 laser was used, the welds were crack- and pore-free of sufficient strength produced at very high speeds.

Figure 1. Macrosections of the different configuration hybrid-welded joints for 6-8 mm heavy section steel (a-e) and 2 mm thin sheet steel (f).

Despite the advantages described, an implementation of arc augmented laser welding technology for shipbuilding production requires a number of investigations. Extremely vital issue is the control of residual welding deformations in the manufacture of long and voluminous hull structures. The main task of executed work was the creation of production technology for obtaining of hull structures, using high power fiber laser source, with minimal deviations from the given (theoretical) dimensions, required by design documentation.

2. Double sided hybrid laser-arc welding

Vessel hull production requires the welding of a large number of stiffeners. It is proposed to apply double sided hybrid welding technology to weld a set of hull structures.

It is necessary to take into account several parameters describing hybrid welding process:

1) Laser parameters: laser power, focal point diameter, focal point position, focal length, laser wavelength, beam orientation angle (longitudinal and transversal), beam quality, Rayleigh length (depth of focal point), fiber core diameter;

2) Arc parameters: current, voltage (arc length), pulse parameters (pulse duration, pulse frequency, pulse shape), torch orientation angle (longitudinal and transversal), wire feed speed, wire diameter, wire chemical composition, polarity, contact tip-to-work distance), wire stick-out, metal transfer mode, nozzle diameter;

3) Combined parameters: welding speed, longitudinal process distance, transversal process distance, longitudinal distance between laser spot centre and torch centre, transversal distance between laser spot centre and torch centre, mutual orientation of two welding modules (for double sided welding), shielding gas composition, shielding gas flow rate;
4) Joint design parameters: thickness, air gap, edge preparation (surface quality), type of joint, welding position;
5) Material parameters: chemical composition, physical properties, surface quality.

In connection with hybrid laser-arc welding is a complex multivariate process, the estimation of parameters influencing on welding seams quality demands a large number of experiments.

For full-scale test optimization purposes a process simulation using LaserCad [5] 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.

Hybrid welding requires an appropriate selection of the flexible system set-up and basic parameter configurations. Special technological model for double sided hybrid laser arc welding (Figure 2) was designed. It includes 16 kW laser generator, movement system with two carriages, complex of equipment for arc welding, control system and special system for geometrical and technological adaptation of welding process.

![Figure 2. Set-up for double-sided hybrid laser-arc welding.](image)

A system for geometrical and technological adaptation is important for stable formation of welding seams because of limitations of hybrid laser-arc welding due to the sensitivity of technology to the presence of random deviation of the blanks joining line, as well as fluctuations of the gap values between welded edges and the quality of edge preparation. The most effective way to ensure high quality and reliability of welded structures is the management of technological process. Due to the fact that the hybrid welding process as a control object is a complex multifactor object, the most promising is the adaptive process management.

Algorithm of the designed system of geometrical and technological adaptation establishes a relationship between the parameters of the hybrid laser-arc welding, welded structures elements (cutting edges), formed seam geometry and position of the welding tool. From a mathematical viewpoint, the objective of the geometric adaptation algorithm is a four independent control loop with feedback. Two control loops control each welding tool drive (vertical and horizontal).

The work of the algorithm of technological adaptation is based on the probability estimation of the quality indicators overrun (for example, depth of penetration, height and width of the seam). This task is common to all technological operations. The difference of used procedure for quality assessing consists in the object of analysis. The object of analysis is a computer model of a joint forming for this welding method. For such analysis, the process model should reproduce the influence of all significant technological factors on basic indicators of the welded joint quality. Models based on the numerical
solution of mathematical physics equations, which strictly describe physical phenomena at welding in a wide range of process parameters fulfil described requirement. The procedure for predicting quality includes the formation of computational experiment on a process model, processing results of modelling and estimation of probability of defects.

Series of experiments were made to ensure the ability of qualitative formation of hull structures using double sided hybrid laser arc welding as well as to validate the results of modelling. It was found that mutual position of welding heads strongly influences on bead formation. Different gaps were tested for assembling the joint before welding. The optimum value doesn’t exceed 0.4 mm. Mechanical methods and laser cutting used for edge preparation of the samples. The welding specimens show that viscoplastic properties of weld metal and weld-affected zones remain stable or exceed standard values. Maximum hardness of material stays within tolerable limits up to 300 (HV5).

Welding sample of T-joint 7 mm thickness from shipbuilding steel with normal strength is shown on figure 3. This sample was achieved with following welding essential parameters:
- Welding position – PB, leading torch;
- Laser power (for each side) – 4 kW;
- Welding speed – 2,5 m/min;
- Wire feed rate – 13 m/min;
- Current – 336 A;
- Voltage – 26,9;
- Stick out – 16 mm;
- Shielding gas (90Ar/10CO2) flow – 26.5 l/min.

The hardness test was made in accordance with ISO 6507-1 and ISO 9015-1 (Figure 4). The maximum hardness value in weld metal zone is 294 (HV5), HAZ (heat affected zone) shows the values from 214 to 257 (HV5).

In the course of the work, a comparative analysis was carried out on various approaches to the calculation of welding deformations. There is a known method applied for solving this technological task: traditional engineering calculation of the expected welding deformations using analytical dependencies. Another approach is to create models of solving a thermoplastic problem by means of a computer. Both approaches have different advantages and disadvantages. It was established that in order to fulfil the design estimations of expected welding deformations at hybrid welding of extended joints the existing engineering method is difficult to apply, since there is no analytical model, which suitable for quite accurate describing the thermal processes under the action of several moving heating sources with different distribution of heat flow, displaced relative to each other. A method for calculating the expected total welding deformations for hybrid welding of T-beams with different wall
thicknesses and girdle was developed (Figure.5). The technique provides the estimation of the expected values of deflection arrows and shortening of a structure without the need to perform resource-intensive nonlinear calculations and can be used for large beams of a ship's set.

![Figure 5. Calculation of the expected total welding deformations.](image)

A technique has been developed for calculating residual welding deformations in hybrid laser-arc welding and methods for their compensation (if necessary).

3. Conclusion

On basis of executed works can conclude that implementation of double sided hybrid laser-arc welding allow to achieve a new level of productivity and manufacturing of non-deformational structures in shipbuilding.

On the basis of expert evaluation along 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.

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