Hybrid Laser-Arc Welding Tanks Steels

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Abstract. The results investigate hybrid laser-arc welding of high strength steels using design responsible metallic construction and the highest strength body of vehicles. Welds from modern high strength steels grade Hardox 400, Hardox 450, Armox 600T and AB were created. High power fiber laser LS-15 with output 15 kW and arc rectifier VDU - 1500 DC were used in the experiment. Results of the metallographic research and mechanical tests are presented.

1. Introduction

At present high-strength steels are used at the creation of responsible engineering constructions widely because the steels have high strength and hardness with sufficient ductility and toughness properties. The modern steels increase life cycle of constructions, which working in difficult conditions, vehicle capacity at the maintaining mass of the construction and the dynamic characteristics of vehicles at reducing mass and maintaining strength characteristics of the construction [1].

More than half of gross revenue is created by welding and relation technologies in the heavy machinery. Up to two-thirds of the world's consumption of rolled steel is used for manufacturing welded constructions and facilities. However, most of the welding technologies used in Russia are not completely suitable for welding new material due to low productivity and high cost. Therefore, the critical issue of a technological development of the Russian Federation is the introduction of a new welding technology.

The most perspective solution of the problem is the technology of hybrid laser-arc welding (HLAW). The main advantages of the HLAW are high-performance, low welding deformation, the possibility of the welding with gap, the possibility of varying the chemical composition and mechanical properties of welds due to the melting of the electrode [2]. HLAW is more actually for using in the pipe building [3], shipbuilding [4] bridge building [5], rail carriage and automotive industry [6] thanks to its advantages.

Technical and economic calculation of the implementation of HLAW at the welding of a root pass at the large-diameter pipes creation, on the example Chelyabinsk pipe factory showed an increase welding productivity in 2-5 times, reducing energy consumption in 2 times, the flow of protective gas in 5 times, consumption of welding wire in 3 times at higher weld quality and overall performance of manufacturing large diameter pipes on 7%.

One of the important task at the HLAW of the high-strength steels is to get uniform strength of the weld metal and base metal, which depend from cooling rate of a weld joint, chemical composition and type of a welding wire [7]. Also arc type [8,9], width of a gap [10] and welding position of the HLAW in the space [11] effect on the wire alloying elements penetration.

This research is devoted to the experimental investigation technological possibilities of the HLAW of high-strength steel Hardox 400, Hardox 450, Armox 600T and AB with thicknesses from 7 mm to 20 mm in different welding positions in a single pass using different welding wires.

2. Experimental methods

The HLAW was carried out using a laser-arc technological complex based on a high power fiber laser LS-15 and an arc rectifier VDU - 1500 DC.

Swedish steel: Hardox 450 (thickness 12mm), Hardox 400 (15mm), Armox 600T (7 mm) and the Russian steel AB (48mm) were welded in the experiments. Mechanical properties of the steels are shown in the Table 1. Metal powder and solid welding wires Power Bridge 60M (Pb 60M), Sv-10H19N11M4F and Sv-08GSMT were used as welding electrode. The chemical compositions of the wires are given in the Table 2.

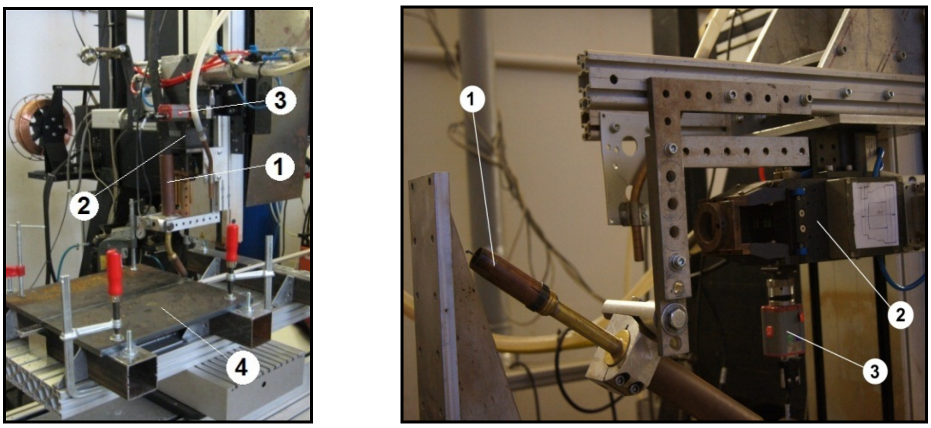
The HLAW of Swedish steel was carried out without mechanical preparation edges of the plates. The plates from AB steel had X-shaped edge preparation with dulling of 20 mm and edge angle 200. Plates from Hardox 450 and Armox 600T were welded in the PA welding position, Hardox 400 and AB – in the PG welding position. Photo of the experimental setup is shown on the Figure 1.

Table 1. Mechanical properties of the steels.

Grade of steel	Yield strength, MPa	Tensile strength, MPa	Hardness, HBW	KCV, J (-20^{0}C)
Hardox 400	1000	1250	370-430	45
Hardox 450	1100-1300	1400-1600	425-475	27
Armox 600T	1500	2000	570-640	12
AB	-	1000	-	-

Table 2. Chemical composition of the welding wires.

Grade of wire	C	Si	Mn	P	S	Cr	Ni	Cu	Mo	N_2	As	Ti	Al	V
Power Bridge 60M	0.04-0.08	0.4-0.8	1.3-1.6	<0.015	<0.015	-	0.4-0.6	-	-	-	-	-	-	-
Sv-08GSMT	0.09	0.47	1.07	0.013	0.016	0.22	0.15	0.17	0.23	0.01	0.008	0.06	0.043	0.005
Sv-10H19N11M4F	0.1	1.0-1.5	1.0-2.0	<0.025	<0.02	18.0-20.0	10.0-11.0	-	3.5-4.5	-	-	-	-	1.0-1.6



a b

Figure 1 – Location of the laser head and the torch at HLAW: a – PA welding position; b – PG welding position: 1 - torch, 2 - laser head, 3 - camera, 4 - weld samples.

Surface of the plates were cleaned up to metallic luster by angle grinders and degreased before welding by acetone. The plates were tacked before welding. Welding was carried out by straight butt joints. Mixture of shielding gas 80% Ar-20% CO2 and Ar of high purity with rate 25 l/min were used for protection of the welding bath from the atmosphere gases on the top and root sides of the seam. Metallographic studies were carried out on microscope DMI 5000 (Leica) with Tixomet software. Microhardness (HV1) of samples was determined using Microhardness tester Buehler Micromet 5103.

3. Results and discussion

3.1 HLAW of high-strength steel Hardox 450 and Hardox 400

Metal powder wire Power Bridge 60M, 1.6 mm in diameter was used at the HLAW of the Hardox 450; Sv-08GSMT with diameter 1.2 mm was used at the HLAW of the Hardox 400. The HLAW was carried out at the following values of the regime parameters: laser power (P) 14 kW, arc current (I) 396 A, arc voltage (U) 25.2 V, welding speed (V) 35 mm/sec, wire rate (Vw) 6.6 m/min (Hardox 450) and P=15 kW, I=276A, U=25.2V, V=35 mm/sec, Vw=9.12 m/min (Hardox 400). The appearance and cross macrosections of welds are shown on the Figures 2 and Figure 3, respectively.

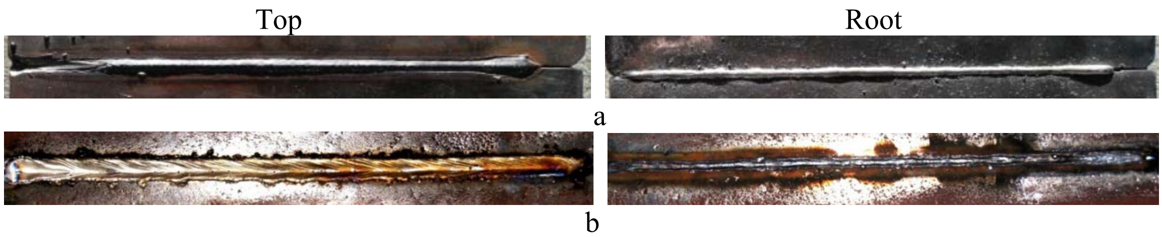


Figure 2 – The appearance of the welds: a - Hardox 450; b - Hardox 400.

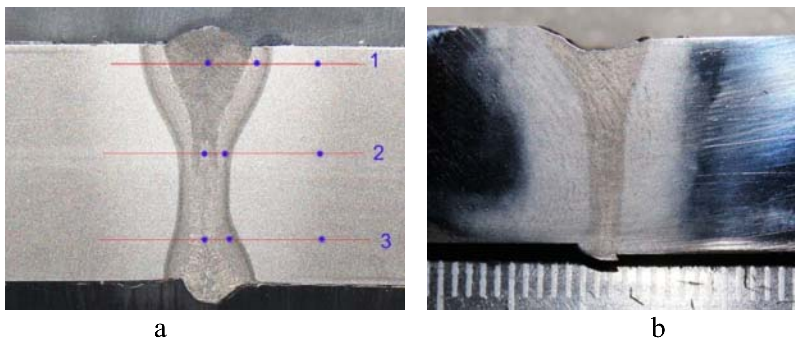


Figure 3 – Cross macrosection of the welds: a - Hardox 450; b - Hardox 400.

External and internal defects weren't detected at the visual inspection of the welds and of the cross macrosections. The HLAW of steel Hardox 400 has been implemented with offset by 1 mm of the welding edges, Figure 3b. The hardness test results for weld from steel Hardox 450 showed a discrepancy between real value of the base metal (BM) hardness and specification value and similar hardness of the weld metal (WM) and BM, Table 3.

Table 3. The results of measuring the hardness HV1 of the Hardox 450.

Measuring location	1	2	3	Av.v.
WM	354	362	378	364.7
HAZ	386	420	324	377
BM	367	359	374	366.7

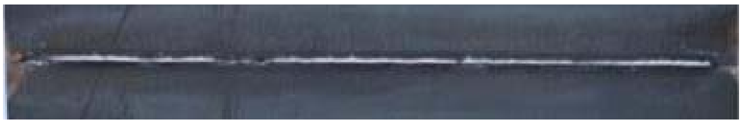
The average hardness of the heat affected zone (HAZ) was higher approximately on a 10 HV1 than average hardness of the BM and WM. It should be noted, that the width of the HAZ in both cases was 1-1.5 mm, which incomparably smaller than the width of the HAZ of welded joints formed by arc welding processes.

3.2 HLAW of high-strength steels Armox 600T

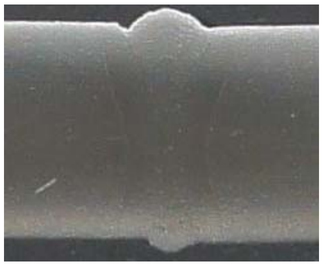
The plates from steel Armox 600T with 7 mm thick was welded in a single pass in PA welding position using welding wires Pb 60M, Sv-10H19N11M4F and Sv-08GSMT.

The HLAW was carried out with parameters: P=7 kW, I=250 A, U=20 V, V=40 mm/sec. Appearance and cross macrosection of the weld formed at the HLAW with welding electrode Sv-10H19N11M4F is shown on the Figure 4.

Top



Root



Cross macrosection

Figure 4 - The appearance of weld (Sv-10H19N11M4F)

Internal or external defects weren't detected by visual inspection and metallographic researches of the welds. The results of the microhardness tests for welds formed at the HLAW and laser welding are shown in the Table 4.

Table 4. The results of measuring the hardness HV1 of the Hardox 450.

Grade of the wire	WM	BM	HAZ
Sv-10H19N11M4F	571	558	617
Sv-08GSMT	563	584	645
Pb 60M	542	601	635
Laser welding	659	581	700

The maximum values of the microhardness found in the HAZ. The average microhardness of the WM, in the case of laser welding, is higher than the average microhardness of WM at the HLAW. Maximum values average microhardness of the WM and HAZ at laser welding can explain because of highest metal cooling rate and the formation of the martensitic structure.

The maximum value of the WM average microhardness was detected at the HLAW with electrode Sv-10H19N11M4F (570.5 HV1). It can be explained because of the nickel presence in an amount sufficient to completely or partially suppress the diffusion of a carbon at the γFe → αFe polymorphic transition with forming a martensitic or beanitic-martensitic structure of WM. The minimum value of microhardness (542 HV1) was detected at the HLAW with electrode Pb 60M. The width of the HAZ was less than 1mm.

From the weld formed during the HLAW with electrode Sv-10H19N11M4F were made samples for static tension test. Test samples were broke at the WM at values on the 15% lower than tensile strength of the BM. The results of the static tension test are shown in the Table 5.

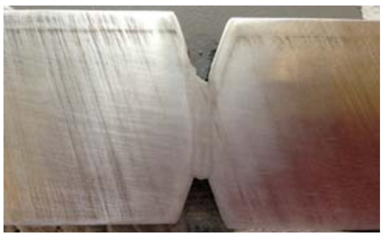
Table 5. Results of static tensile test.

Test sample	Size a, mm	Size b, mm	Location of destruction	Maximal load, kN	Tensile strength, MPa
1–1	5.22	14.95	WM	139.26	1784.5
1–2	5.29	14.97	WM	137.02	1730.3

3.3 HLAW of the high strength steel AB

The HLAW of the steel AB was carried out in a single pass in the PG welding position. Welding wire Sv-08GSMT was used. The HLAW was carried out with the parameters: P=15 kW, V=18mm/sec, Vw=18m/min, I=410 A, U=40 V. Appearance and cross macrosection of the weld are shown on the Figure 5.

The appearance of the welded joint



Cross macrosection

Figure 5– The welded joint (steel AB)

The weld had through penetration without visible external and internal defects. Results of the static tensile test of the weld and BM are shown in Table 6. WM and BM had similar tensile strength values.

Table 6. Results of sample measurements and average results of tests at static tensile .

Sample	Destruction	Sample thickness, mm	The width of the sample, mm	The maximum load, kN	Tensile strength, MPa
WM	WM	9.97	20.57	203.7	993.3
BM	BM	diameter – 5.95		28.72	1000

3.4 Metallographic research of welded joints

Metallographic research was carried out for Hardox 450 steel, Figure 6.

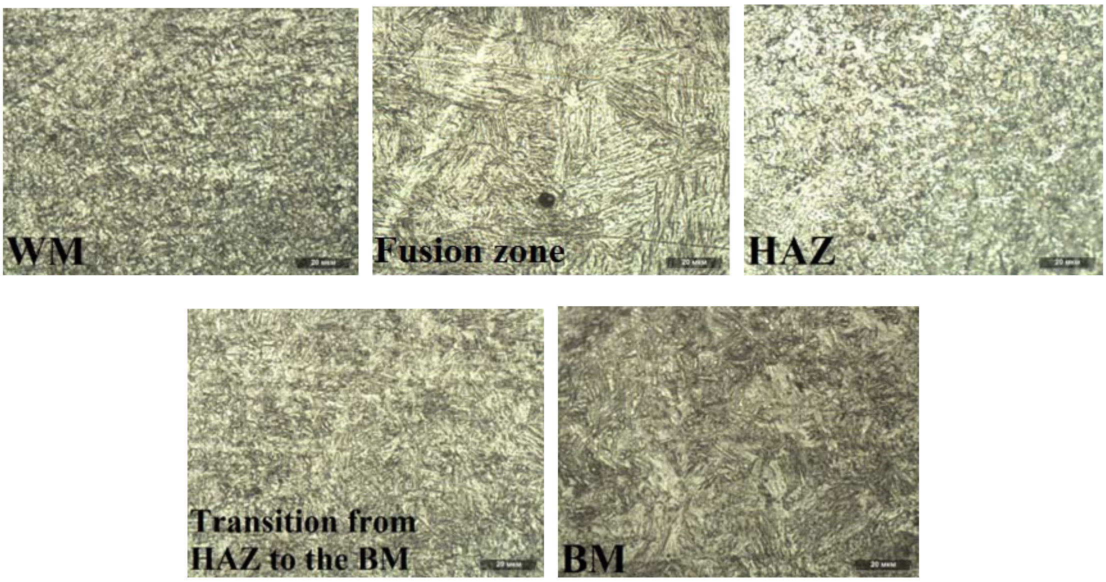


Figure 6 - The microstructure of the weld in different zones (of steel Hardox 450)

Martensite was found in the some areas of the weld structure. In the structure of WM was found martensite and carbides. Also fusion zone mostly consists of martensite. Less than 5 % of the martensite was found in the middle area of a HAZ. The main structural component of the HAZ middle part was the beanite with upper and granular morphology. Fine structure with predominantly beanite with granular morphology was defined in the transition zone from HAZ to the base metal. The microstructure of BM had beanite with lower and granular morphology and carbides.

Also it can be conclude, that thermal effect from HLAW slightly distorts of the base metal original structure in the weld joint metal, whereby the mechanical properties of the metal are stored.

4. Conclusions

The results of the research demonstrate not only the technological ability, but also the efficiency of the using hybrid laser-arc process for welding of the modern high-strength steel of large thicknesses.

At the HLAW of the high strength martensitic steel with thickness of 7 mm to 20 mm in different welding positions welds with mechanical properties on the level of base metal can be formed.

The effect of alloying elements of the welding electrode on the mechanical properties of welds was experimentally determined.

The results of metallographic research showed slight divergence of the weld structure with the structure of the base metal.

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