https://doi.org/10.37434/tpwj2020.10.01

DEVELOPMENT OF TECHNOLOGY AND EQUIPMENT FOR PRESS WELDING OF TUBULAR PARTS UNDER THE CONDITIONS OF PRODUCTION FOR THE PURPOSE OF SAVING RESOURCES AND INCREASE IN THE REALIABILITY OF HIGH-LOADED PRODUCTS

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Replacement of outdated technologies in the production of tubular parts is an urgent task. The paper presents the materials of carried out investigations on press welding of high-loaded steel tubular parts with a diameter of up to 120 mm and wall thickness of up to 6 mm, development of control system, metallographic and mechanical examinations on determination of the properties of welded joints. The main technological advantages of press welding of high-loaded products are shown. 7 Ref., 3 Tables, 6 Figures.

Keywords: high-loaded steel tubular parts, press magnetically-impelled arc welding, control system of welding process, technological parameters of welding process

Recently, the volumes of works on manufacture of brass parts with a diameter from 40 to 120 mm at the enterprises of the industry of Ukraine have considerably increased. To solve the problems before the industry of Ukraine, it is proposed to replace outdated existing technologies of works on application of expensive brass and precision presses of 350 t used in the production of tubular parts, with the new technology using welded steel tubular billets. This will significantly save resources by replacing brass, which has a much higher cost, with cheaper steel billets, increase the efficiency and improve working conditions, reduce electric power consumption and shorten production costs.

The welding method is used in industry mainly for joining parts of a tubular cross-section with a wall thickness of up to 4 mm and a diameter of up to 100 mm, which are used in the automotive industry. In this case shielding gases are used [1–4] and also PMIAB process without the use of shielding gas is possible [5, 6].

At the beginning of the investigations, the problems of testing the design and technology of manufacturing welded steel tubular parts were solved, which require solving the whole range of issues regarding the operation of high-loaded tubular parts. Theoretical and experimental investigations were carried out, directed on solving basic questions of manufacturing welded steel parts. The technology was developed, which provides mass production of steel tubular parts at factories of the branch.

As the basis of the technological system an industrial computer began to be used, operating under the OS WINDOWS10 and the specially developed software. The software was developed taking into account the gained experience and the latest achievements in the field of computer technology regarding the accumulation and processing of information. In the construction of the control system and registration of welding parameters, generally available elements and devices were used, which greatly simplifies the adjustment of technological parameters of the system and welding process control.

The system for control of the welding machine for PMIAB process is based on the processes of scanning the system sensors, processing of the received data and generating data files and a derived file of the daily report, in which the following parameters are fixed:

- welding time by heating stages T1, T2 T3, T4, T5, T6;
- current of welding arc by heating stages I2, I3, I4, I5;
- voltage of welding arc at the three stages of heating parts U2, U3, U4 (U1 is the voltage of the

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excitation stage and the beginning of constant arc movement (arc acceleration) under the action of the magnetic field at the edges of parts is not taken into account, because before the constant movement, the arc takes values from short-circuit to open-circuit mode of the welding arc power source);

● total amount of energy spent on heating parts E_a;

● upsetting rate V_{ups} (hereinafter referred to as the initial speed of coming of the moving part of the welding machine with the stationary part together, i.e. it was experimentally established that this is the average speed of counter-movement per 1.5 mm of arc gap before the contact of welded parts);

● upsetting area S_{ups} (value of total deformation of the parts);

● upsetting pressure P_{ups} (maximum value of pressure drop in the hydraulic system of the welding machine during realization of upsetting);

The deviation of these parameters beyond the tolerances depends on many reasons. Therefore, it is necessary to develop the algorithms of:

● control of the two-level system, which provide correcting the welding mode in order to stabilize the process and, accordingly, the required weld butt quality;

● weld butt quality evaluation;

● evaluation of the technical condition of welding machines and conditions of their operation;

● formation of recommendations with correcting the parameters of the technological process.

The existing quality testing, during which the obtained data are compared with the reference ones, is a logical function: the quality indices are in the tolerance while simultaneously all the controlled parameters are in the tolerance. At such testing, the following indices are not considered:

● significance of the impact of each of the parameters on the quality index;

● uncertainty of the limit of tolerances of the process parameters for different products;

● possible increase in the influence of totality of a certain combination of deviations on welding quality.

An algorithm for welding quality testing was developed based on the analysis of process parameters at three stages of its realization.

1. Heating of tubular parts. Period of temperature field formation at the ends of welded parts.

2. Forcing. Stage of providing shielding environment in the arc gap.

3. Upsetting. Formation of joint in the solid phase.

The conclusion about the quality of a produced welded joint with a certain degree of probability is made on the basis of logical rules, compiled based on the results of investigations of technological features of the PMIAB process.

To control the welding process, the following parameters are used:

● welding time by the stages (T1–T6); current value at the stages of heating (12–15);

● voltage values at the stages of arc existence (U2–U4); upsetting rates and values (V_{ups} and L_{ups}); pressure in the hydraulic system during upsetting P_{ups}; energy spent on heating parts E_a.

The development of the scheme of control of the machine K-872 for PMIAB welding was performed by replacing outdated equipment and upgrading and improving the software of the control module. To provide realization of the quality control algorithm, the control cabinet was modernized and the control system executive devices were partially replaced. A modern PC was applied, adapted for using in the industrial conditions.

The registration of the welding process parameters in the upgraded machine K-872 took place according to the scheme shown in Figure 1.

The correspondence of the computer evaluation of quality testing with the real state of affairs is the provision of the abovementioned system with real initial data. In the case of PMIAB, such data are current and voltage of the welding arc, mutual arrangement of the welded pipes and pressure in the hydraulic system during upsetting.

Obtaining data from the sensors of the registration system is as follows. The input of the normalizing in-

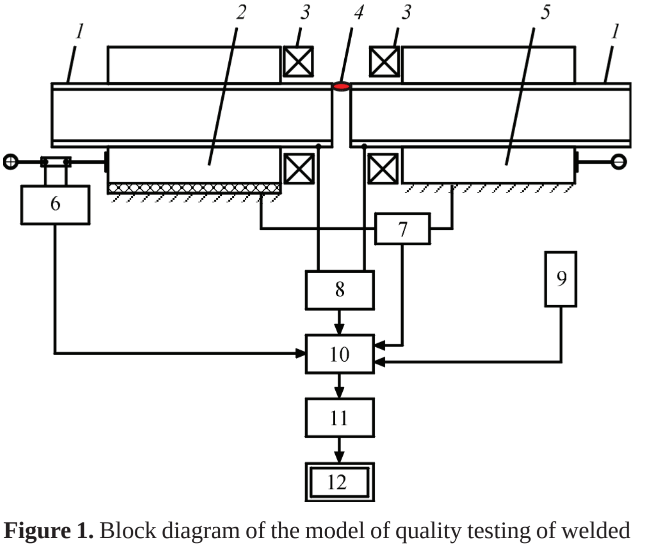

Figure 1. Block diagram of the model of quality testing of welded joints: *1* — welded pipes; *2* — moving clamping device; *3* — elements of magnetic system; *4* — electric arc column, moving along the edges of welded pipes; *5* — fixed clamping device; *6* — current sensor with instrumental signal amplifier; *7* — sensor for position of moving part of the welding machine; *8* — sensor for voltage drop on the welding arc; *9* — sensor of measurement of absolute pressure of hydraulic system built in a rod cavity of the cylinder, upsetting of welding machine; *10* — normalizing instrumental amplifier (with low pass filter $F_{cut\text{-}off}$ = 100 Hz); *11* — receiving analogue-to-digital converter (ADC), *12* — personal computer

Table 1. Chemical composition of welded steels, wt.%

Steel	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Al
20	0.19	0.30	0.50	0.005	0.004	0.16	0.12	0.08	0.05	0.01
35	0.39	0.32	0.68	0.004	0.024	0.08	0.03	0.04	0.05	0.01

Table 2. Results of carried out tests on tear and impact toughness of base metal of pipe and welded joint

Steels	Size of pipes, mm	σ_t, MPa		*KCV*, +20 °C, J/cm^2	
		Base metal	Welded joint	Base metal	Welded joint
20 + 35	102×6.0	508–525 516.5	510–524 517.5	67–84 75–5	78–81 79–5
20 + 35	42×3.5	508–525 516.5	516–527 522.5	67–84 75.5	88–85 86

put amplifier 8 is connected directly to the terminals, which are located on the clamping devices. In the amplifier, the voltage drop of the welding arc, which occurs at the beginning of the process and is in the range of 20–30 V of direct current, is normalized to the output voltage of 2–3 V. For the further processing and analysis, the derived signal of welding voltage drop from the output of the amplifier *8* is sent to the input of the analogue-to-digital converter (ADC). During the start of the software operation, ADC is set up in such a way that the sampling frequency of the analogue inputs is 10 sampling points per one reading of the data from the ADC output. A more accurate data transfer to the control program is achieved.

The software of the control complex was finalized by changing the functional parameters of the existing software modules. This allowed expanding the time and parametric limits of operation of the executive devices when performing the adjustment of the parameters of the PMIAB process. The software performs the database formation, which, in turn, allows analyzing the data obtained during welding for the entire operation of the equipment, which greatly simplifies the search for optimal parameters of the welding mode [7].

Figure 2. Welded joint of tubular parts of 102×6 mm

The course of the heating process during welding is influenced by different factors, which makes it necessary to test the quality of welded joints. The process of joints formation is influenced by the following factors:

- condition of end surfaces (surface temperature, presence of microroughnesses, oxide films and other contamination);
- temperature distribution at the ends of parts;
- value and nature of plastic deformation of the ends during upsetting.

The experimental welds were produced, research and industrial technology was developed and examinations of the specimens of welded joints of tubular parts with a diameter of 102×6 mm of grade steel 35 + steel 20 were performed (Figure 2).

The chemical composition of welding steels is given in Table 1. Mechanical properties of welded joints of tubular parts are given in Table 2. Comparative indices of electric power consumption during welding of one pipe butt during manual arc welding (MAW) and PMIAB are given in Table 3.

Figure 3 shows the specimens of the base and welded joint metal after the tests on impact toughness.

At the place of joining the parts, defects are not observed (Figure 4), decarbonized metal band at the joint boundary is absent. The boundaries conjugation of the metals of steel 20 and steel 35 along the welded joint line is observed (Figure 4).

Table 3. Comparative indices of electric power consumption during welding of a one pipe butt during MAW and PMIAB welding

Size of pipe, mm	Welding method	Electric power consumption per 1 butt, kW/h
102×6.0 mm	MAW PMIAB	0.98 0.042

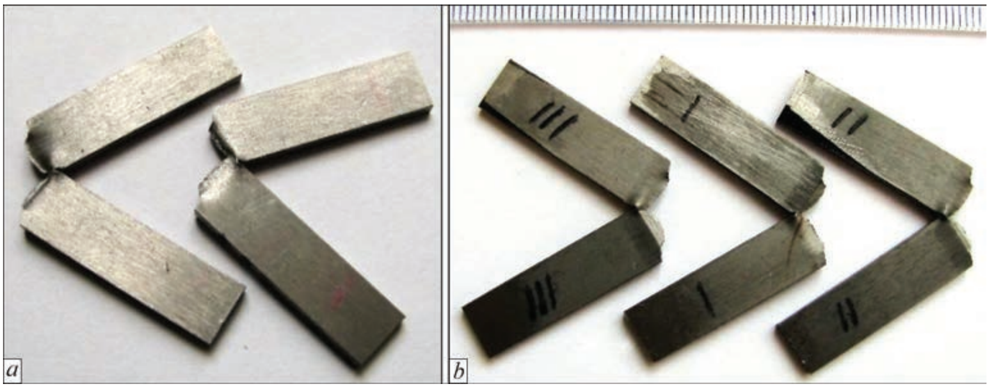

Figure 3. Appearance of fractured specimens: *a* — base metal; *b* — welded joint

The metal structure of steel 20 near the joint line is ferritic-pearlitic. The amount of ferrite significantly prevails. Ferrite is precipitated along the former austenite grains (polygonal). The main mass is a lamellar ferrite with an ordered and disordered second phase (Figures 5, 6). The grain ball in the area of overheating (coarse grain) near the joint line corresponds to No.6 according to GOST 5639–82. The further distance from the joint line, the grain is refined to Nos 8, 9 according to the GOST scale.

In the region of a complete recrystallization, the structure is fine-grained, the grain size number is 10, and the structure is ferritic-pearlitic.

The structure of the base metal is ferritic-pearlitic, the grain size number is 8 according to GOST 5639–82. The width of HAZ regions:

- area of coarse grain (area of overheating) — 2300 μm;
- area of fine grain (area of complete recrystallization) — 2000 μm;
- area of partial recrystallization — 1500 μm;
- width of HAZ — 5000 μm.

The metal structure of steel 35 near the joint line is pearlitic-ferritic. The amount of pearlite significantly prevails (Figures 5, 6). In the area of overheating in the HAZ structure pearlitic grains are present, bordered by a ferritic grid along the boundaries of the former austenite grains. The amount of ferrite is very small (Figure 6). The grain size number at the area of overheating in the joint line corresponds to 5 (GOST 5639–82). The further distance from the joint line, the grain is refined to number 8.

The area of fine grain differs by a refined structure (ferritic-pearlitic), the grain size number is 10.

Defects in HAZ and the base metal were not detected. Width of HAZ regions are:

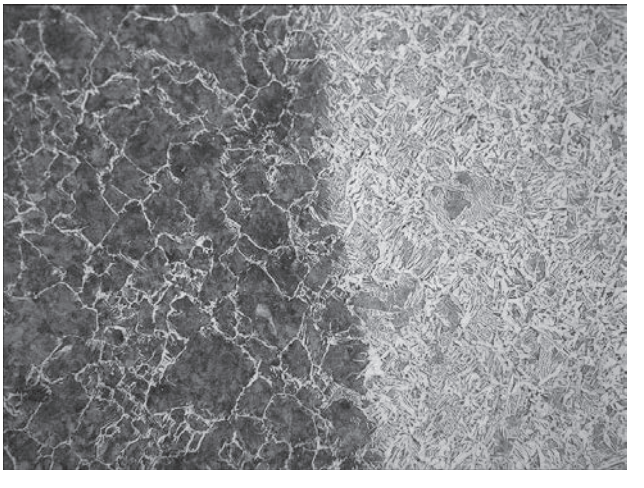

Figure 5. Microstructure (×100) of metal of joint steel 35 + steel 20

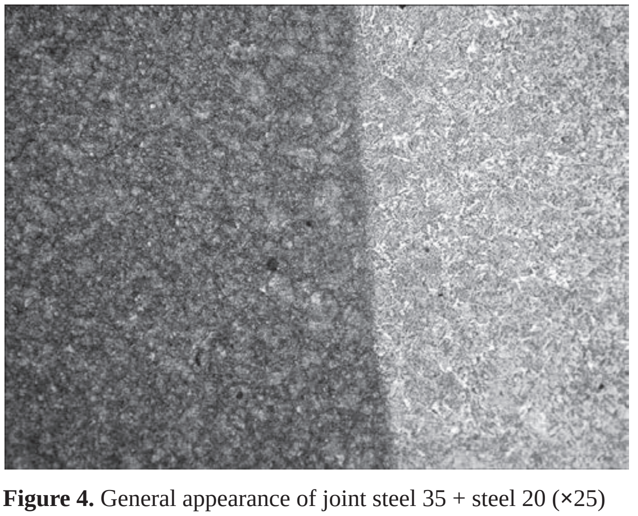

Figure 4. General appearance of joint steel 35 + steel 20 (×25)

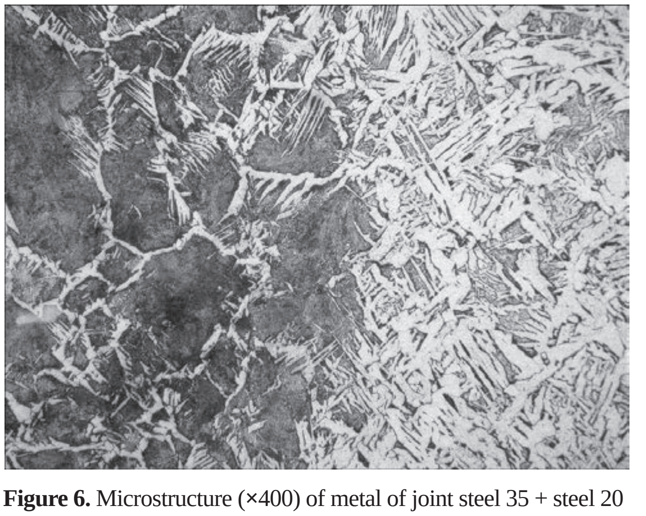

Figure 6. Microstructure (×400) of metal of joint steel 35 + steel 20

● area of coarse grain (overheating area) — 1500 μm;

● area of fine grain (area of complete recrystallization) — 2400 μm;

● area of partial recrystallization — 2000 μm;

● width of HAZ — 6000 μm.

The results of measuring hardness in the direction of BM steel 20 — HAZ — JL – HAZ — BM steel 35, at a load of 100 g with a step of 100; 200; 500 μm.

Step 500 — BM — 1760, steel 20: HAZ — 1560, 1510, 1570; step 200 – 1760, 1760, 1690, 1690, 1690, 1810, 1810, 1720, 1640, 1640, 1760, 1870, 1850, 1870, 1870, 1870, 1870, 1870, 1930, 1930; step 100 — 2130, 1930, 1930; step 50 – 1930.

JL — 2060, 1930, 1930, 1930.

Steel 35. HAZ: step 100 — 2060, 2280, 2300; step 200 — 2280, 2260, 2450, 2360, 2600, 2540, 2240, 2160,2130, 1990, 1990, 2130, 2130, 2130, 2130, 1910, 1890, 1810, 1810; step 500 — 1930, 1930, 1990, 2060.

Step 500 — BM — 1920, 1810.

As is seen from the given Table, to weld one butt, in PMIAB it is used almost 22 times less electric power than in MAW. This saving is achieved by reducing the welding time of a one butt joint. In addition, arc welding consumes a lot of electric power to melt a larger pool of liquid metal.

The main technical advantages of the developed experimentally industrial technology of welding high-loaded tubular parts are:

● relatively short welding time;

● high efficiency, especially in mass production;

● low energy and materials consumption;

● concentrated heating of ends of welded parts;

● minimum tolerances for flashing and upsetting;

● absence of strict requirements to roughness of side and welded surfaces;

● absence of problems with tolerances of preliminary preparation;

● high ductile properties of welded joints;

● relatively small spattering of metal;

● absence of metal spattering on the inner surface of welded pipes;

● ability to control and register the basic technological parameters during the welding process.

Conclusions

1. The optimal conditions were determined, which allow moving the arc steadily in a narrow gap to achieve a relatively uniform heating of welded ends of the tubular parts.

2. A control method was developed that allows moving the arc over the entire welded cross-sectional area of the pipes and forming a uniformly distributed melt on it.

3. The basic conditions for the formation of a welded joint of high-loaded tubular parts were determined.

4. The research and industrial technology of PMIAB of high-loaded tubular parts with a diameter of up to 120 mm and a wall thickness of up to 6 mm was developed and tested.

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Received 30.09.2020