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# PRESS MAGNETICALLY-IMPELLED ARC WELDING OF HIGH-STRENGTH STEEL TUBULAR PARTS OF HYDRAULIC CYLINDERS

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Materials for carrying out works in the framework of investigating weldability of parts of hydraulic cylinders with diameters from 40 to 200 m and a wall thickness of up to 10 mm, the results of performed metallographic examinations and mechanical properties of welded joints are presented. The basic conditions for forming welded joints of tubular parts of hydraulic cylinders were determined. The process of press magnetically-impelled arc welding of pipes of hydraulic cylinders with a diameter of up to 200 mm and a wall thickness of up to 10 mm was developed. 8 Ref., 4 Tables, 16 Figures.

*Keywords: press magnetically-impelled arc welding, pipes for hydraulic cylinders, joint formation, welding technology*

In different industries a large amount of works is performed on welding of circumferential welds of pipes and tubular parts of hydraulic cylinders with a diameter of 40–220 mm and a wall thickness from 4 to 10 mm, operating under high pressure. In this case, mainly arc welding is used.

The development of technologies and equipment for press welding in the stationary conditions would significantly improve the labour efficiency in the industry and improve the stability of joints quality. The experience gained at the E.O. Paton Electric Welding Institute of the NAS of Ukraine (PWI) in the recent decades in the field of pressure pipe welding has shown the prospect of such developments using the press magnetically impelled arc welding (PMIAB) method.

In recent decades, PMIAB technologies have been developed and successfully implemented in the manufacture of different tubular assemblies at automobile factories in Ukraine and other countries, welding pipes in the construction of greenhouse complexes and welding pipelines in the conditions of permafrost [1–6].

The purpose of recent investigations carried out at the PWI was the development of technology and equipment for PMIAB welding of pipes with a bottom of different assortment and chemical composition of steel, with the diameter of up to 200 mm and a wall thickness of up to 10 mm, covering the most demanded assortment of tubular parts for the manufacture of cylinders (Figure 1).

The chemical composition of the investigated pipe steels is given in Table 1, the values of mechanical properties of base metal and metal of welded joint are shown in Table 2. The standard dimensions of parts to be welded included: diameter — 40–188 mm, wall thickness — 4–10 mm (32 standard dimensions).

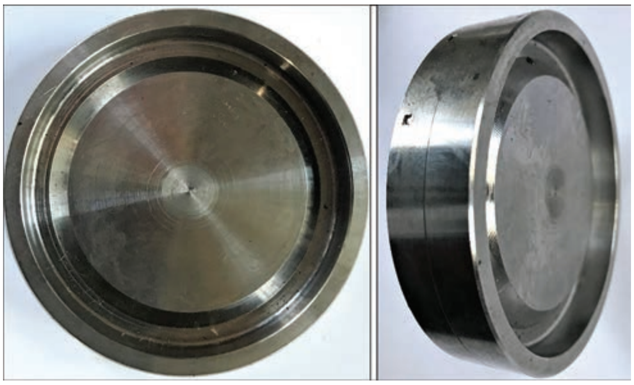

**Figure 1.** Design of bottom of hydraulic cylinder (height is 35 mm)

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

| Steel grade | C | Si | Mn | P | S | Cu | Ni | Cr | Mo | Ti | Nb | B | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St52-3 | 0.18 | 0.52 | 1.35 | 0.02 | 0.03 | 0.28 | 0.24 | 0.23 | – | – | – | – | – |
| 01Star520 (X80) | 0.159 | 0.172 | 1.19 | 0.012 | 0.006 | 0.13 | 0.04 | 0.04 | 0.03 | 0.002 | 0.002 | 0.001 | 0.03 |

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**Table 2.** Basic technological parameters of welding

| Steel grade | Pipe diameter × wall thickness, mm | Welding time, s | Upsetting force, kN | Shortening of pipes, mm |
|---|---|---|---|---|
| St52-3 | 40×4 | 6 | 40 | 4.1 |
| St52-3 | 60×5 | 14 | 57 | 5.4 |
| St52-3 | 120×7.5 | 37 | 257 | 8.2 |
| 01Star520 (X80) | 121×7 | 35 | 250 | 8 |
| 01Star520 (X80) | 121×10 | 43 | 278 | 10 |

All welded joints were tested in accordance with the international API standard [7], and additional bending tests were performed in accordance with the departmental procedures and standards.

Metallographic examinations were performed after etching in a 4 % $HNO_3$ solution in alcohol. The measurements of microhardness were carried out in the LECO M-400 hardness tester at a load of 10; 100 and 1000 g. Taking pictures of the structure of the welded joints was performed in the Neophot-32 optical microscope.

The PMIAB process is characterized by the fact that under the action of an external control magnetic field, the arc moves in the gap between the ends of the tubular parts to be welded. A relatively high speed of the arc movement, up to 170 m/s, allows redistributing thermal energy of the welding arc over the entire surface of the ends of parts. A relatively uniform heating of pipe ends to be welded is achieved. A welded joint is formed during compression and joint plastic deformation of ends of the parts [8]. The process of welding parts of hydraulic cylinders is performed in air, without the use of shielding gases.

**Figure 2.** Traces left by welding arc during heating of the outer edges of pipe

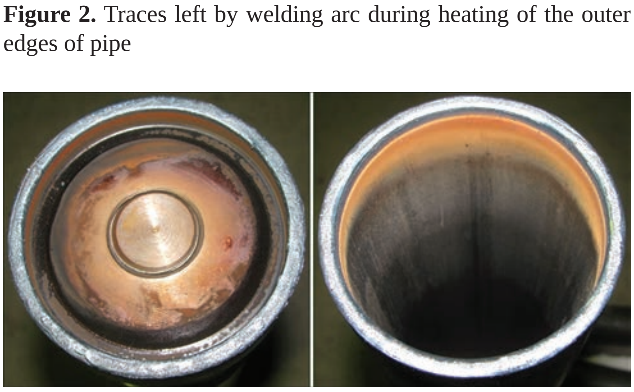

**Figure 3.** Surfaces of pipe and bottom ends covered with a layer of melt metal

Taking into account different conditions of heat removal from the parts, the aim of the investigations was to find the ways for control of the heating process, providing a steady movement of the welding arc across the entire cross-sectional area of the ends of pipe and bottom, achieving their uniform heating.

As a result of investigations carried out at the PWI, a method was developed, which provides a control of the movement of the arc over the entire cross-sectional area of tubular parts. The process of heating the ends is performed during movement of the welding arc along the outer edges, in the area with a higher value of a radial component of the controlled magnetic field (CMF) induction (Figure 2).

After achieving a uniform heating, which provides the necessary conditions for plastic deformation of the ends, a program change in the technological parameters of welding occurs, which leads to scanning of the welding arc on the surface of the pipe ends (Figure 3). The quality formation of welded joint of the pipe with bottom can be provided without any gas shielding under the condition that the frequency of the arc rotation at the moment before upsetting is selected so that the layer of melt metal at any point on the surface of the ends does not have a time to solidify at the time intervals when the arc passes through these regions. Then upsetting is performed.

On the basis of these investigations the system of automatic control of the process of PMIAB welding of pipe with bottom, the optimal programs for changing the basic parameters in the process of welding, and also the algorithms of their control with the use of feedbacks were developed [5]. Technologies of PMIAB welding of parts of hydraulic cylinder and welding equipment were developed. The main parameters characterizing welding modes are given in Table 2.

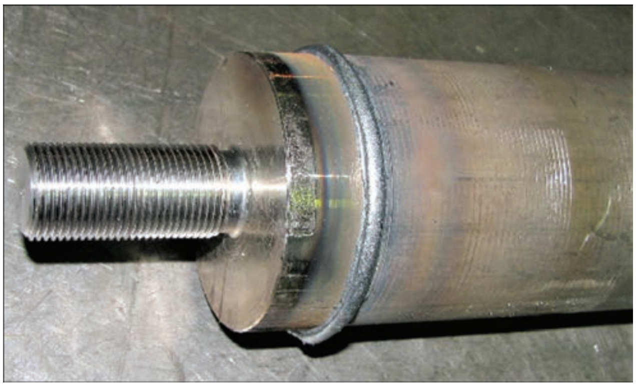

**Figure 4.** Welded joint of the pipe with bottom of 120×7.5 mm diameter

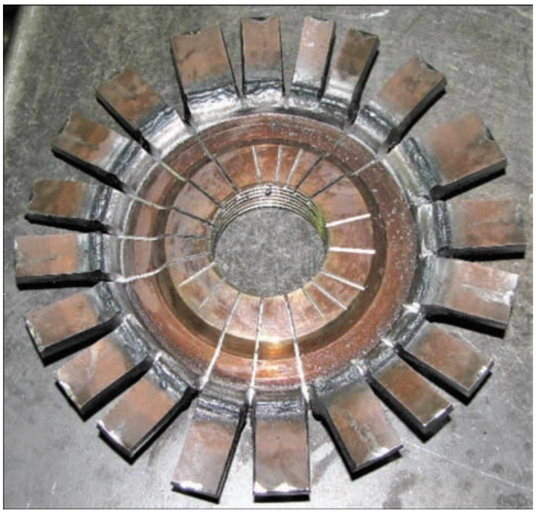

**Figure 5.** Results of bending tests of welded joint

High-strength steel tubular parts, operating under high-pressure are used in the manufacture of hydraulic cylinders. A photo of appearance of such welded joints is shown in Figure 4.

Mechanical tests such as tensile, bending (Figure 5) and rupture, hardness measurements and metallographic examinations were performed in accordance with the standard API 1104 [7].

Mechanical properties of welded joints of pipes are given in Table 3.

Comprehensive mechanical tests show a practical equal strength of welded joints and base metal and meet the standard requirements.

Metallographic examinations were performed on the fused end of the product of 90 mm diameter (Figure 3) at the moment before upsetting and in the welded joint of 120×7.5 mm diameter (Figure 4) of St52-3 steel. The specimens for investigations were manufactured on high speed discs using diamond pastes of different dispersion. Revealing of the structure was performed by chemical etching in a 4 % $HNO_3$ solution in ethyl alcohol. Examinations were performed in the microscopes Neophot-32 and Poluvar at different magnifications. The hardness of the melt layer was measured in the LECO M-400 hardness tester.

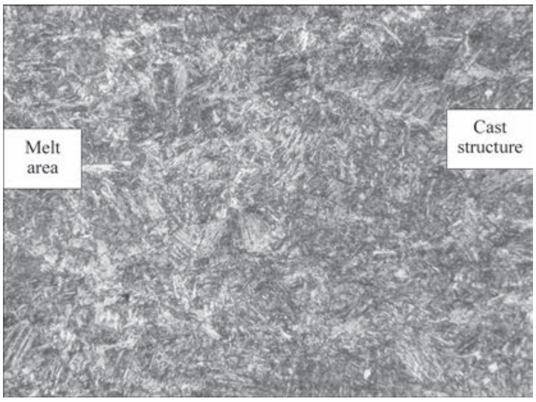

**Figure 6.** Microstructure (×200) of cast metal and melt area

Specimen after heating without upsetting (see Figure 3). At the fused end of the specimen there is an area with a cast structure (Figure 6). The width of the area is 300–400 μm. The structure of metal is ferrite-pearlite, ferrite is released along the crystallite boundaries. At this area, polygonal and Widmanstätten types of ferrites were found and along the crystallite boundaries polyhedral one (in a small amount) was detected. The hardness at this area is *HV*1–2240 MPa; *HV*1–1850 MPa; *HV*1–2280 MPa; *HV*1–2060 MPa. At the overheating area, the structure consists of upper and lower bainites with a hardness of *HV*1–2830 MPa; *HV*1–3090 MPa; *HV*1–3360 MPa and *HV*1–3480 MPa. The width of this area is 2000 μm, then in the structure pearlite appears, the amount of bainite is reduced, the hardness decreases to *HV*1–2490 MPa; *HV*1–2450 MPa.

At the area of complete recrystallization, the structure is fine, consisting of ferrite, pearlite and a small amount of bainite. In the structure, the traces with bands appear (Figure 7), which are absent in the overheating area (Figure 8). The hardness is *HV*1–2060–2240 MPa.

The area of incomplete recrystallization after upsetting has a fine-grained ferrite-pearlite structure (grain number 9 according to GOST 5639–82), where the bands of ferrite and pearlite are alternated (Figure 7). The hardness of metal at the area is *HV*1–

**Table 3.** Mechanical properties of welded joints of pipes

| Steel grade | Pipe diameter x wall thickness, mm | $\sigma_t$, MPa | | $KCV_{20}$, J/cm$^2$ | |
|---|---|---|---|---|---|
| | | Base metal | Welded joint | Base metal | Welded joint |
| St52-3 | 90×5 | 492–513<br>498 | 480–492<br>486 | – | – |
| 01Star520 | 121×10 | 685–708<br>696 | 630–645<br>638 | 125–168<br>147 | 60–168<br>114 |
| 01Star520 | 191×7 | 638–665<br>651 | 618–674<br>656 | 116–154<br>135 | 87–152<br>119 |
| St52-3 | 120×7.5 | 491–512<br>497 | 478–489<br>483 | – | – |

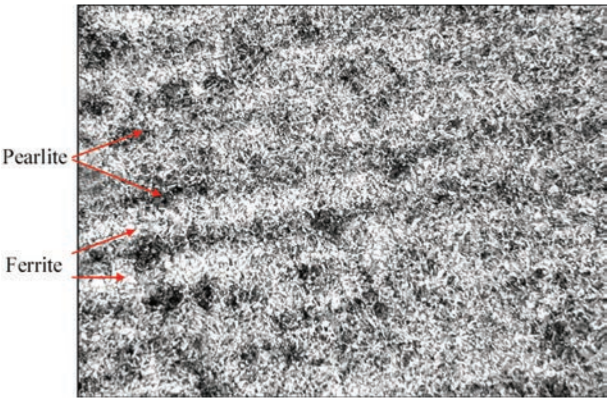

**Figure 7.** Microstructure (×200) of the area of full and partial recrystallization on the bottom side

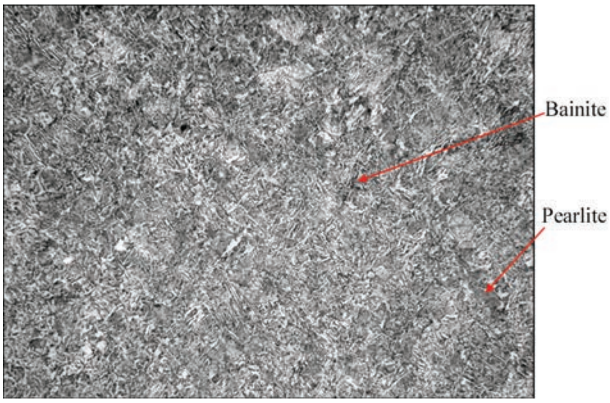

**Figure 8.** Microstructure (×200) of the overheating area on the bottom side

1880–1960 MPa (ferrite) and *HV*1–2060–2240 MPa (pearlite).

The base metal has a ferrite-pearlite structure in the form of bands with a ferrite grain number Nos 7–8 according to GOST 5639–82 and a hardness of *HV*1–1870–1760 MPa. The width of the heat-affected-zone is 4000 μm.

Macrosection of welded joint with a diameter of 120×7.5 mm is shown in Figure 9. The joint line represents a discontinuous white band of up to 40 μm thickness in the central area of the welded joint and extends up to 80 μm to the edges of the specimen. The structure of the joint line is ferrite with the hardness of *HV*1–1650–1810 MPa. From the distribution of hardness it is seen that the joint has a slight increase in the hardness of ferrite band to *HV*1–1800 MPa, which is higher than the hardness of base metal of tubular parts. The distribution of hardness in the butt indicates the absence of significant changes in strength at the main areas of the weld. The values of hardness on the joint line are also close to the similar values of base metal. During PMIAB, the structure of metal in the HAZ is more homogeneous. No defects on the joint line were detected (Figure 10).

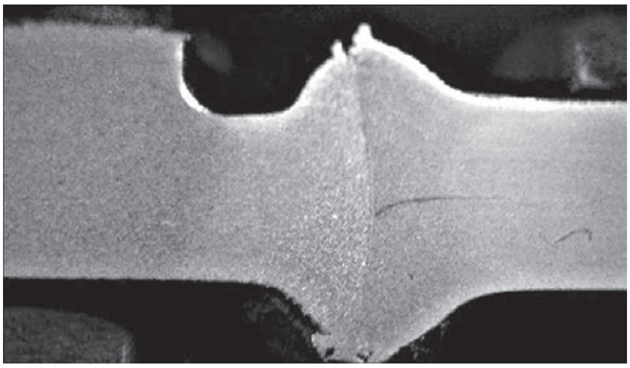

**Figure 9.** Macrosection of welded joint of the pipe and bottom of 120×7.5 mm diameter

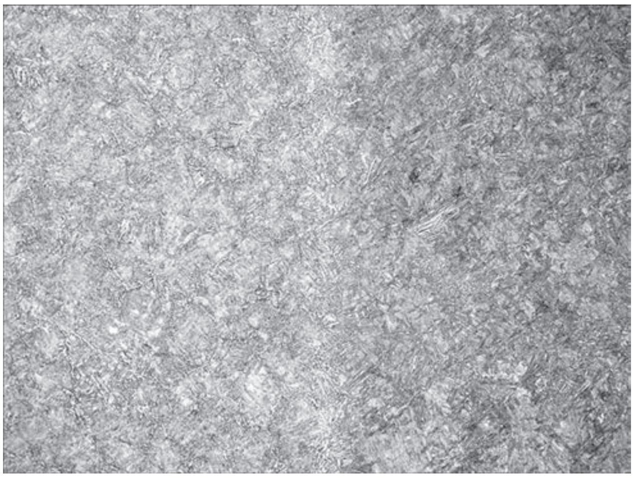

**Figure 10.** Microstructure (×200) of welded joint

The structure of the overheating area on the side of the lid has small regions of pearlite and ferrite of different modifications, mainly ferrite with an ordered second phase. In addition, it has polyhedral ferrite, Widmanstätten ferrite and polygonal ferrite in the form of fragments of ferrite bands along the borders of former austenitic grains.

The hardness of the metal in this area is *HV*1–1830–2160 MPa (Figure 10).

With distance from the joint line, the structure is refined, the number of polygonal and polyhedral ferrite increases.

At the area of complete recrystallization, the structure is fine-grained (grain number 10–11 according to GOST 5639–82) ferrite-pearlite.

The base metal has a ferrite-pearlite structure with a grain number No.8 and the hardness of *HV*1–1560–1760 MPa. The HAZ width is approximately 6000 μm.

The overheating area on the side of the pipe has almost the same structure as the area on the side of the lid (Figures 11, 12). The difference is that a predominant amount of ferrite with a disordered second phase and structure on the overheating area is finer. The hardness of metal in the overheating area is *HV*1–1780–2060 MPa. With distance from the joint line, the structure is refined. The width of the overheating area is 2700 μm. The width of the overheating area is

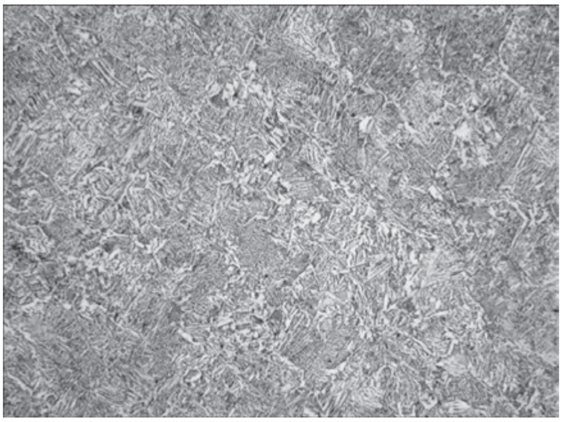

**Figure 11.** Microstructure (×200) of the overheating area on the bottom side

**Figure 12.** Microstructure (×200) of the overheating area on the pipe side

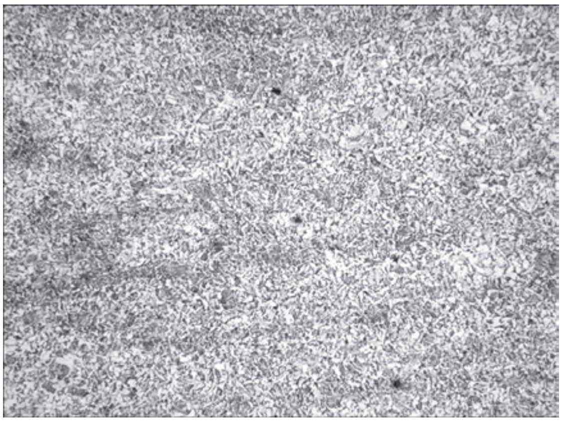

**Figure 13.** Microstructure (×200) of the area of complete and partial recrystallization on the pipe side

smaller after upsetting and is 2700 μm as compared to 3500 μm after heating without upsetting.

The structure of the area of complete recrystallization of ferrite is pearlite fine-grained with the predominance of a ferrite component (Figure 12). Traces of bands are visible at the area of incomplete recrystallization. The bands appear in the area of partial recrystallization. The structure at this area is ferrite-pearlite, consisting of alternating bands of ferrite and pearlite. The HAZ width is approximately 5000 μm.

**Figure 14.** Microstructure (×200) of base metal of the pipe

**Figure 15.** Hydraulic cylinders ready for operation

**Figure 16.** Welding machine MD-205

The base metal represents a fine-grained (grain number 10–11) ferrite-pearlite structure (Figure 13) with a hardness of *HV*–1660–1990 MPa.

Defects in the HAZ are not observed. The hardness of the pearlite band is *HV*1–2050 MPa, *HV*1–1990 MPa, *HV*1–2050 MPa. The hardness near the pearlite ferrite mixture is *HV*1–1560–1600 MPa.

**Table 4.** Technical specifications of the machine for PMIAB welding of hydraulic cylinders

| Machine index | Diameter of welded pipes, mm | Wall thickness, mm | Efficiency, butts/h | Power consumption, kW | Weight, kg |
|---|---|---|---|---|---|
| MD-205 | 30–200 | 3–10 | 80 | 40 | 1500 |

For PMIAB welding of tubular parts of hydraulic cylinders, the MD-205 machine was designed, which provides an industrial welding in stationary conditions (Table 4). Using this technology, more than 17,000 parts of hydraulic cylinders with diameters from 42 to 178 mm were welded (Figure 16).

The MD-205 machine (Figure 15) is designed for press welding of tubular parts of different purpose and consists of:

- welding head;
- hydraulic pumping station;
- control cabinet with portable control panel;
- source for power of welding arc.

MD-205 is a tong-type welding machine, which is characterized by a separate clamping of pipes to be welded. In terms of design, the machine is capable of loading and unloading welded pipes on the side.

## Conclusions

1. The optimal conditions were determined which allow a steady movement of the arc in a narrow gap to achieve a relatively uniform heating of welded ends of the pipes.

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

3. The basic conditions for forming welded joint of tubular parts of hydraulic cylinders were determined.

4. PMIAB process was developed that allows welding pipes with a wall thickness, exceeding the sizes of active spots of the arc column.

5. Technologies of PMIAB welding of tubular parts of high-strength steels were developed in the production of hydraulic cylinders with a diameter of up to 200 mm and a wall thickness of up to 10 mm.

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