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# INCREASE OF STRENGTH CHARACTERISTICS OF SPIRALLY-WELDED PIPES OF STRUCTURAL DESIGNATION

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Influence of high-temperature thermomechanical treatment (HTTMT) on strength properties of welds on spirally-welded pipes made from 08kp (rimmed) steel of 1 mm thickness was studied. It is shown that HTTMT of welds in low-carbon steel joints allows producing sound welded joints of pipes with high service properties.

***Keywords:*** *high-frequency welding, spirally-welded pipes, weld, weld strength, blank of structural designation, calculation technique, tread rings, samples*

High requirements made to manufacture and operation of hulls from seamless pipes operating under pressure is a well-known fact [1]. A prime cost of manufacture of the seamless pipes, however, is higher than that of the welded ones, therefore, it is reasonable to evaluate the perspectives of application of spirally-welded pipes (SWP) for manufacture of pressure vessel hulls. High-frequency welding (HFW) as a high efficient and low waste process of joining is applied for manufacture of SWP of various diameters [2].

Usage of HFW in SWP manufacture allows:

- produce various diameter pipes from a strip of equal width due to change of angle of weld inclination in a welded joint;
- produce large diameter pipes and tubular welded structures using relatively simple technological process in comparison with manufacture of longitudinally-welded pipes;
- produce thin-wall pipes of large diameter with high accuracy;
- provide low investments.

A tendency of increase of the requirements to quality of welded pipes, in particular, on index of strength

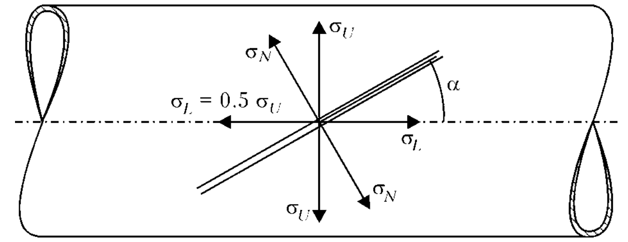


**Figure 1.** Scheme of stresses affecting spiral weld: $\sigma_N$ — normal; $\sigma_L$ — longitudinal; $\sigma_U$ — circumferential stress

of welded joints [3] is observed at present time. In this connection improvement of HFW by means of automation, respectively, of the welding process as well as the operations for manufacture control [4] and its combination with thermomechanical treatment should be considered for the evaluation of perspective of SWP application as an alternative of the welded pipes.

Optimum relationships of pressure of medium being transported and specific quantity of metal of the high-pressure vessels are to be followed for obtaining of acceptable economic indices in operation of high-pressure tanks. This is directly related to the strength indices of applied grades of steels and strength of pipe welds [5].

High speed of welding in comparison with arc processes and capability of manufacture of thin-wall and specifically thin-wall pipes, having ratio of diameter to wall thickness 50 and more, should be referred to significant advantages of SWP manufacture as a result of development and improvement of HFW method.

Formation of a weld in the process of HFW takes place in an electric welding pipe mill, where rate of deformation in obtaining of welded joint can be realized in a range from 15 to 65 % and more depending on blank material and necessary level of contact pressure for removing of a low-melt phase [6–8].

The weld is formed under pressure in a solid phase at submelting of the welded edges that increases area of the weld and promotes minimization of its thickness

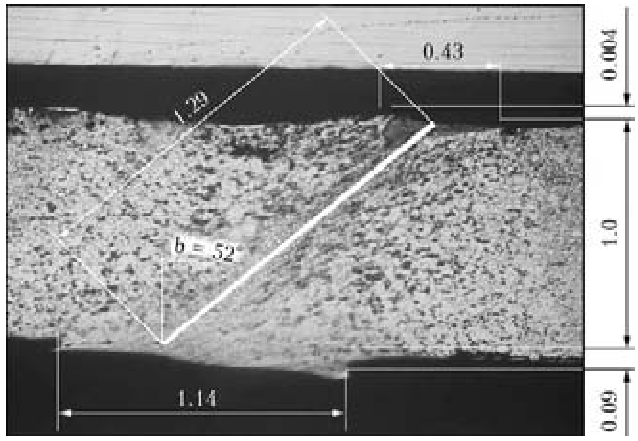


**Figure 3.** Transverse macrosection (×30) of SWP joint (face of SWP — below)

directly in a process of upsetting, i.e. oncoming mutual deformation of heated edges of the items, in compressed space, and further rolling of edges. At the same time the process of weld formation takes place under conditions of guided flow and deformation of the metal of edges at their mutual sliding over various mating surfaces under complex spatial conditions in the electric welding pipe mill.

Weld zone is the most important element in SWP. Longitudinal welds are exposed to higher loads than transverse ones as a result of internal pressure in operation. In this case the spiral weld takes to some extent intermediate position. Its under load stress value depends on angel of the weld to axle of the pipe (Figure 1). At that the loads affecting it make 60–70 % of the loads affecting longitudinal weld [9].

The spiral weld in a process of formation is exposed to complex influence of a series of factors [10, 11], i.e. bending of initial metal of the strip along a radius of produced pipe; strip stretching at an angle of inclination of spiral weld to generant of produced pipe; rolling of obtained weld; differentiated heating of base metal as well as welded edges in welding; forced cooling of obtained weld; heating for removing of residual stresses and normalizing of weld metal structure.

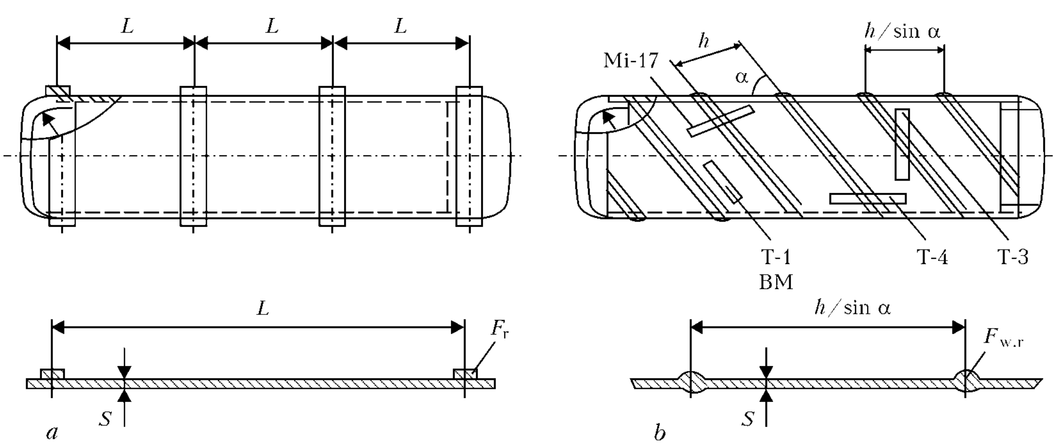


**Figure 2.** Scheme of cutting out of samples: *a* — hull from thin-wall pipe and with thread rings; *b* — same, but from SWP; T-1 — samples from base metal; Mi-17 — samples of welded joint with classical positioning of weld; T-4 — samples Mi-18 with oblique-like welded joint cut out along generant of SWP; T-3 — samples Mi-18 (special) with oblique-like welded joint cut out along radial surface of SWP; $F_r$, $F_{w.r}$ — area of thread ring and weld reinforcement, respectively

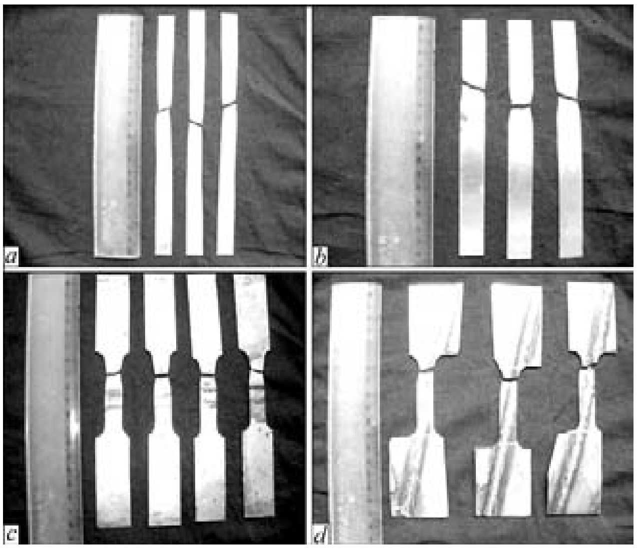

**Figure 4.** Appearance of the samples T-1 (*a*), Mi-17 (*b*), T-4 (*c*) and T-3 (*d*)

It should be taken into account that edges of the strip are cold-hardened as a result of cutting of roll of sheet for strip, thus, their welding is performed in hardened state, and weld temperature reaches 1200 °C in the process of HFW, i.e. metal of SWP is exposed to HTTMT during welds' performance.

The aim of the present work lies in evaluation of influence of HTTMT on strength properties of SWP. For this SWP with the welds exposed to HTTMT were manufactured on laboratory unit at the E.O. Paton Electric Welding Institute.

The areas with various positioning of the spiral weld (Figure 2) were chosen over a body of SWP. The samples cut out from the body of SWP were used for investigations, determination of strength properties and performance of metallographic investigations.

Diameter of SWP made from 08kp steel was 108.3 mm; thickness of used strip $S$ = 1 mm; width of used strip $h$ = 101 mm; inclination angle of spiral weld to generant of the produced pipe $\alpha$ = 25°.

Figure 3 shows a macrosection of a joint. Welded edges of the strip with a lap heated with high frequency currents were delivered into the welding rolls, where upsetting with removing of submelted metal took place, and then the weld formed was exposed to rolling at high temperatures. The weld in cross-section deviated from a vertical line per angle $\beta$, approximating to 52° as a result of complex plastic strain. At that its length made 1.29 mm at base metal thickness 1 mm that significantly improves the conditions of failure resistance of the welded joint [12].

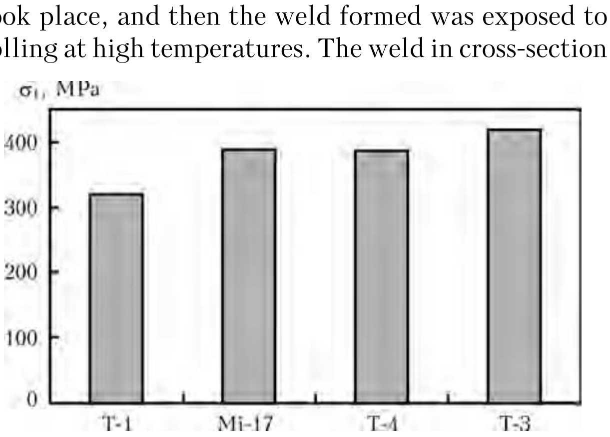


**Figure 5.** Tensile strength of the samples tested in accordance to cutting scheme (see Figure 2)

External weld reinforcement made 0.9 mm, width was 1.14 mm, and internal one equaled 0.04 mm at width 0.43 mm. At that upset force made 1600 H and area of contact spot was 1 mm$^2$.

The following samples in accordance with DSTU 3245–95 [13] (see Figure 2) [14] were chosen from the produced pipe: T-1 — 3 pcs, Mi-17 — 3 pcs, T-4 — 4 pcs, T-3 (Mi-18) special — 3 pcs, and were exposed to tensile tests.

Tensile strength of T-1 sample made 320 MPa; Mi-17 — 404.4, 380.7, 383.2; T-4 — 384.2, 389.5, 390.5, 394.4; T-3 — 445.4, 407.3 and 408.4 MPa.

Failure of all samples took place along the base metal (Figure 4). Formation of Chernov lines (Luders' lines) (Figure 4, *b*) indicate the presence of displacements of surface layers of metal under effect of circumferential stresses $\sigma_U$ (see Figure 1) [15]. It can be seen from Figure 5 that normal and longitudinal stresses ($\sigma_N$ and $\sigma_L$) of the weld samples (see Figure 1) exceeded standard failure stress of the base metal samples by 22 % and circumferential stresses $\sigma_U$ by 30 %, that is, obviously, caused by HTTMT.

Four samples were cut out from SWP for performance of metallographic investigations of the hardened weld. They included sections of spiral weld and were taken uniformly along the length of welded structure.

Macrostructure of a weld zone shows no lacks of fusion, discontinuities, pores and other defects at large magnification.

It is determined that structure of the base metal near the HAZ is polygonal ferrite with carbon precipitates along the grain boundaries in a form of tertiary cementite [16] as well as separate round carbide inclusions.

Change of the structure from pure ferrite to ferrite-pearlite is observed further at transfer from the base metal to weld direction. At that, the round inclusions of cementite gradually dissolve and pearlite revealing in a form of spots with higher etching than ferrite (see Figures 3 and 6, *a*) is formed at their place.

The closer to the weld, the higher is the process of pearlite formation at former places of carbide accumulation (Figure 6, *b*). Change of HAZ metal structure from ferrite to ferrite-pearlite is an evidence of heating of metal in this zone up to temperature of dissolution of iron carbide (over $A_{c_1}$ point) with subsequent cooling [16].

Hardness of this ferrite-pearlite structure somewhat higher than that of ferrite in the base metal structure and makes, approximately, $HV$ 180–200, i.e. exceeds hardness of the base metal by 12–25 %. Hardness of the base metal is on the level of $HV$ 160, and size of grains larger than in the weld metal (see Figure 6).

Metal in the weld region (Figure 6, *b*) has ferrite structure with uniformly distributed carbides, size of the grains is smaller than in the base metal and HAZ, that is an evidence of heating up to temperature field of homogeneous austenite, i.e. exceeding $A_{c_3}$ point [16]. Hardness of this area is higher than base metal hardness and makes around *HV* 180–190.

It is determined that hardness of weld and HAZ metal exceeds that of the base metal by 12–25 % (Figure 7).

HTTMT affect causes metal hardening in the weld and near-weld zone. Application of HTTMT promotes hardening of the weld metal in SWP, that in turn increases strength indices of pipe itself as a blank of structural designation.

Method for calculation of indices of strength of SWP with weld exposed to HTTMT was approved at the E.O. Paton Electric Welding Institute for evaluation of influence of treatment on strength indices of SWP itself as a blank of structural designation. Existing and approved techniques [1, 12, 15, 17] were used for calculation. At that the strength indices of SWP were compared with those of seamless pipe of similar geometry.

The following allowances were accepted:

- pipe blanks have similar geometry, diameter and wall thickness *S*;
- both pipe blanks withstand similar internal pressure *P*;
- hardning was observed in weld zone as a result of HTTMT of SWP, i.e. strength indices in the weld are higher than in the base metal;
- the calculation were performed taking into account sequential installation of external thread rings (effect of thread rings equal to effect of hardened weld in SWP) over the pipe blank, manufactured from seamless pipe, for compensation of effect of hardened weld in the blank from SWP.

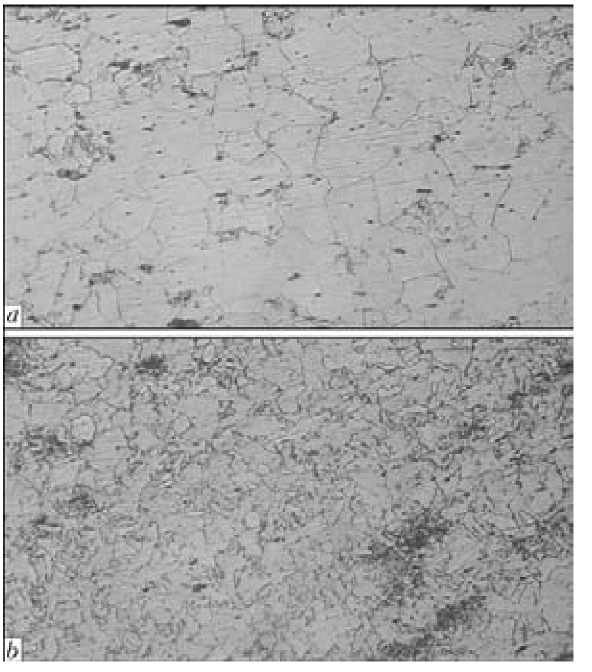

Figure 6. Microstructure (×400) of the base (*a*) and weld metal (*b*)

The calculations performed showed that:

- the external thread rings are to be installed in series over the pipe blank with calculated distance *L* for preventing the loss of shape of pipe blank manufactured from seamless pipe under effect of limiting external pressure *P*;
- distance *L* between the external thread rings over the pipe blank, manufactured from seamless pipe,

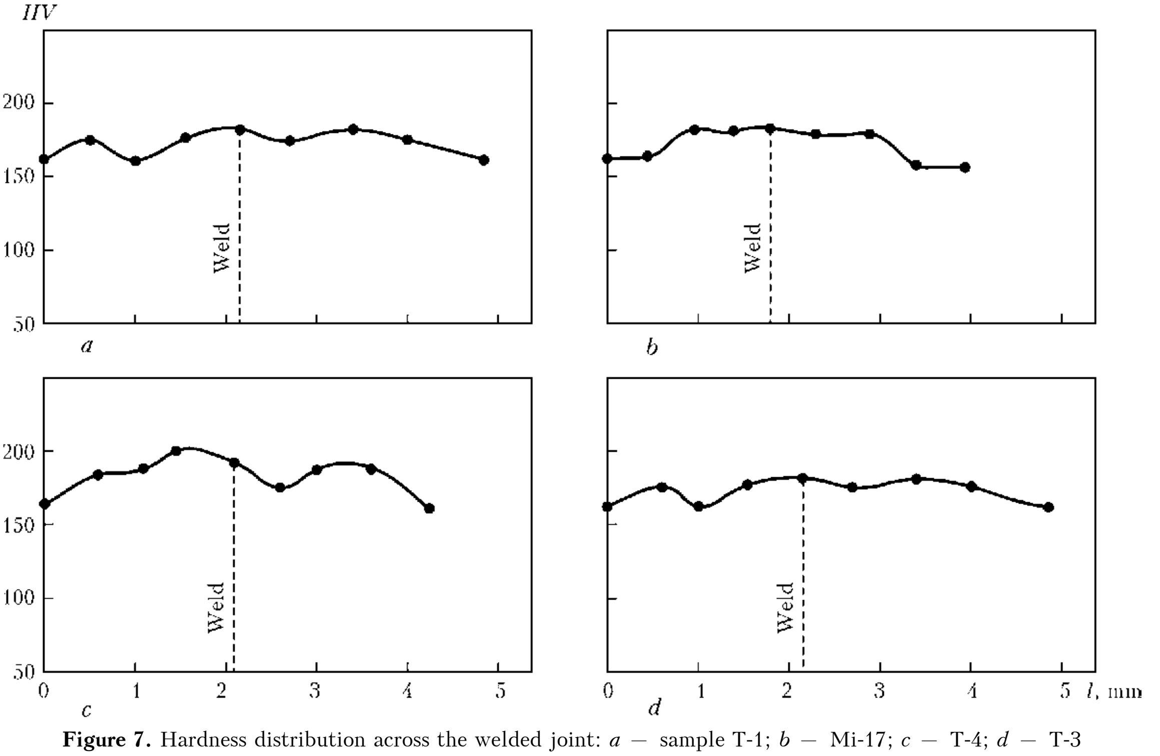


**Figure 7.** Hardness distribution across the welded joint: *a* — sample T-1; *b* — Mi-17; *c* — T-4; *d* — T-3

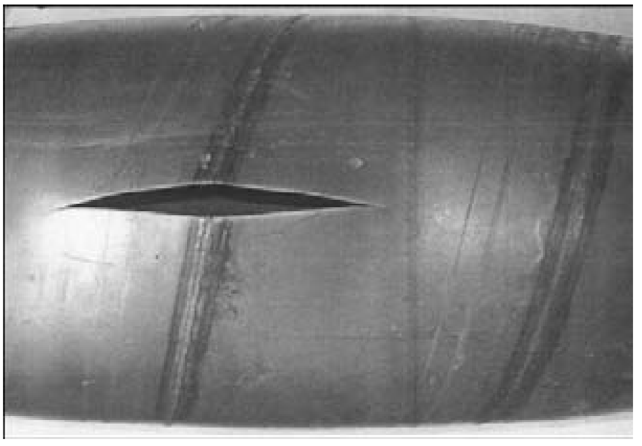

**Figure 8.** Failure of cylindrical surface of hull

should exceed 2 or more times (depending on steel grade) distance between the winds of the hardened weld $h/\sin\alpha$, i.e. $L > h/\sin\alpha$; density of strip winding increases at $h/\sin\alpha \to 1 << L$ and strength of welded SWP rises, correspondingly;

• sum effect of the hardened weld exceeds strengthening effect of the thread rings per unit of length of SWP.

Results of calculations were experimentally verified using a real sample of SWP. Fragment of SWP with welded-in blind plugs was used as a model of pressure vessel which was pressurized using internal pressure and brought to failure [1]. Hydrostatic failure pressure exceeded calculated one by 18 % in failure of the model of vessel hull. The vessel hull acquired barrel-like form that is an evidence of shape loss. The failure itself took place along the generant of cylindrical surface of the hull, i.e. along the base metal (Figure 8).

## CONCLUSIONS

1. Weld, exposed to HTTMT, acquires a gain factor equal 1.22–1.31 relative to the base metal, and hardness exceeds that of the base metal by 12–15 %.

2. Failure stress of the samples with weld exceeds standard stress of failure of the base metal samples by 22–30 %.

3. HTTMT of the welds in SWP from structural low-carbon steels, in particular 08kp, allows obtaining quality joints with high service indices that increases structural strength of SWP by 18 %.

4. Designing and manufacture of welded structures using SWP as a blank of structural destination acquire further investigation as for higher strength steels.


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