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Selection of optimal thermal deformation parameters for high-frequency welding of longitudinal pipes

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ABSTRACT: This article presents a study of thermal deformation parameters during high-frequency welding of straight-seam pipes from low-carbon low-alloy steels

KEY WORDS: High frequency current welding, thermal deformation, draft, weld, oxide film

I. INTRODUCTION

High-frequency welding in the manufacture of small diameter pipes is widely used in the Tashkent Pipe Plant named after V.L. Halperin ”(Republic of Uzbekistan). When current flows in the surface layer of the heated product, thermal energy is released and its temperature rises.

Favorable current distribution, a high degree of power concentration provide the possibility of conducting the process with the melting of a thin layer on the surface of the welded edges and obtaining a durable high-quality welded joint. Heated edges of the product are crimped using rolls and welded. The quality of the welded joint and the energy consumption are closely related to the flow characteristics of the so-called hours on conductors.

II. LITERATURE SURVEY

For the first time, the idea of using high frequency currents (incl.) For welding metals was proposed in 1946 in Russia by A.V. Ulitovsky. In the 50s of the 20th century, intensive research began on the creation of technology and equipment for high-frequency pipe welding, and somewhat later for cable sheaths and profiles. A method of industrial application of high-frequency welding was created, in which the product in front of the welding unit is molded in the form of a workpiece with a V-shaped gap between the welded edges. To the edges by means of sliding contacts or an inductor, t. h. so that it passes from one edge to another through the place of their convergence. Due to the surface effect and the proximity effect, which increases as the edges approach each other, a high current concentration is achieved at the convergence point of the edges [1].

The surface effect is manifested in the uneven distribution of alternating current over the cross section of the conductor. The highest current density is observed at the outer surface of the conductor. As you move away from the outer surface, the current density gradually decreases. The higher the frequency, the faster the current density decreases. At a very

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high frequency, the current passes only through a thin surface layer of the conductor. The surface effect significantly increases the active resistance of the conductors, which greatly complicates the transmission of alternating current. However, the surface effect allows one to concentrate the energy release in the surface layers of the heated product [2]. The metal layers lying closer to the surface receive more energy and the temperature rises faster. Therefore, a temperature difference appears and energy transfer begins from the surface layers to layers located deep in the body. The heat transfer process reduces the temperature of the surface and increases the temperature of the deep layers. The influence of heat transfer is stronger, the longer the heating time, the higher the coefficient of thermal conductivity [3]. The influence of heat transfer is stronger, the longer the heating time, the higher the coefficient of thermal conductivity. For the case of heating with high-frequency currents of a semi-limited space (tube billet), if we neglect losses from the surface of the medium, the temperature is a function of the dimensionless parameter

$$u = x / \left[2\sqrt{\lambda t / (c\gamma)} \right], \quad (1)$$

where x is the coordinate of the point, measured from the surface of the body, m; t is the time, s; λ is the coefficient of thermal conductivity, W / (m • ° C); s - specific heat, W / kg • ° C; γ is the density, kg / m3 [4].
When calculating heat transfer, the following cases are distinguished:
1) pronounced surface heating, in which the nature of the power distribution has little effect on the temperature distribution;
2) deep heating of a medium with constant characteristics (μ = const, ρ = const);
3) deep heating of a ferromagnetic medium when there is a layer on the surface with constant characteristics (μ = 1, ρ - const) [5].

III. METODOLOGY

In the manufacture of longitudinal pipes, the most widespread are high-frequency pressure welding with reflow. The welded pipe assortment is limited by the ratio D / 2s - the outer diameter of the pipe D to the wall thickness s. The maximum value of D / 2s is determined by the condition of stability of a workpiece of a given diameter during upsetting with optimal pressure, i.e., the thinness of the welded pipe workpiece depends on the welded diameter and material of the workpiece. The maximum value of the wall thickness at a given pipe diameter is determined by the allowable electrical losses in its body, and with very small ratios, by the capabilities of the molding process.

Welding of pipes, the thickness of which is determined by the ratio D / 2s, can be carried out in a wide range of current frequencies. Therefore, the decisive factor is the simplicity and reliability of the design of the current transmission system, which depends largely on the transmitted current. The higher the frequency and longer heating time, the less current.

Reducing the welding current by increasing the heating time is impractical, since this increases the heat loss due to heat removal to the body of the welded workpiece. The most effective decrease in current by increasing the frequency to 200-500 kHz. A further increase in the frequency, as a rule, is undesirable, since this does not significantly reduce the current.

Welding of the pipe billet is carried out in a welding machine of a pipe-welding mill (Fig. 1). It carries out heating and the formation of a welded joint.

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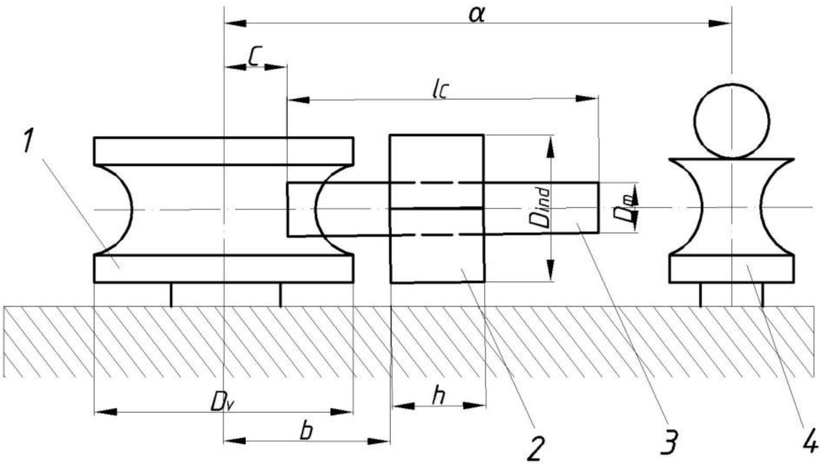

Fig. 1. The scheme of the welding machine of the mill of high-frequency welding of longitudinal pipes:
1 - seam crimping roll with a diameter of D_V;
2 - inductor with an inner diameter D_{ind} and a height h located at a distance b from the axis of the seam crimping rolls;
3 - ferrite core with a diameter of D_M of length l, located at a distance b from the axis of the rolls;
4 - roll seam guide stand, the center of which is located at a distance a from the axis of seam crimping rolls.

The current to the welded edges is transmitted using an inductor. When welding pipes of small diameters, multi-turn cylindrical inductors are used, when welding pipes of medium diameters - single-turn. Multi-turn inductors are made of copper tube. The turns of the inductor are electrically isolated with a glass tape impregnated with silicone varnish. Electrical insulation also protects the inductor from inter-turn breakdowns when small metal particles introduced into the workpiece and the crystallized outbursts from the weld zone get onto the threads. In a single-turn inductor, such a breakdown is possible only between the current-carrying buses connecting the terminal blocks to the active part of the inductor. Tires are insulated by means of an insulating strip, and the active part of the inductor is not insulated.

The design of a ring single-coil inductor for welding pipes of small and medium diameters at radio frequency frequencies is optimal. Typical designs of inductors most commonly used in the production of welded pipes are shown in Fig. 2.

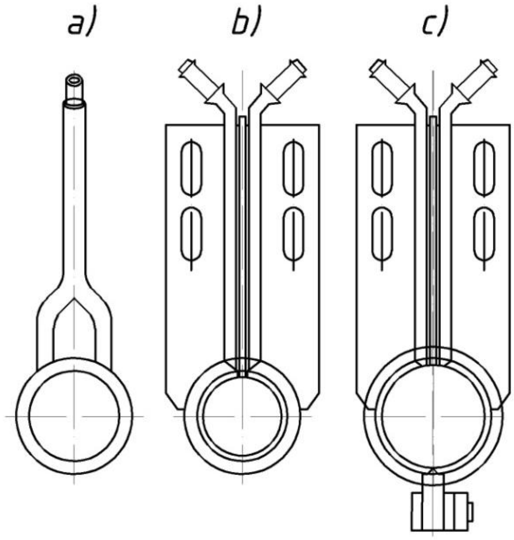

Fig. 2. Designs of inductors for welding longitudinal pipes:
a - multi-turn one-piece; b - single-turn one-piece; in - single-turn detachable.

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However, when welding pipes with a diameter of up to 40-50 mm, it is technologically simpler to use a multi-turn inductor. Therefore, more often when welding pipes of small diameters (up to 57 mm), multi-turn cylindrical inductors are used, when welding pipes of medium diameters - single-turn.

Multi-turn inductors are made of copper tube. The turns of the inductor are electrically isolated using a glass tape impregnated with organosilicon varnish. Electrical insulation also protects the inductor from inter-turn breakdowns when small metal particles introduced into the workpiece and crystallized surges from the weld zone get into the turns. In a single-turn inductor, such a breakdown is possible only between the current-carrying buses connecting the terminal blocks to the active part of the inductor. Tires are insulated by means of an insulating strip, and the active part of the inductor is not insulated.

A single-turn inductor can be made of a copper bus with a soldered copper tube through which coolant (water, in rare cases, emulsion) is passed. There are designs in which the inductor is cooled by irrigation from the outside. The designs of single-coil inductors for welding pipes of medium diameter, as a rule, are split.

A magnetic core (ferrite core) is introduced into the internal cavity of the workpiece to be welded to increase the shunt inductance. Therefore, its use is mandatory for welding thick-walled pipes.

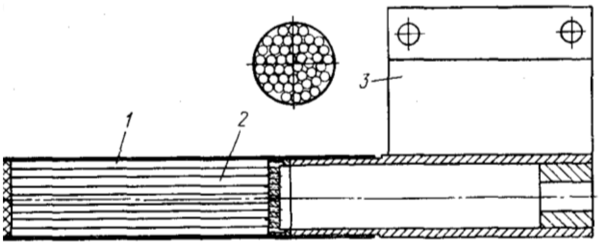

Fig. 3. Ferrite core of cylindrical section:
1 - ferrite rods; 2 - a protective casing; 3 – plates fastenings

When welding thick-walled pipes of small diameter D (D≤40 mm, D / 2s = 8 ÷ 10, s is the thickness of the pipe wall, mm) it is advisable to produce a ferrite core with the maximum possible cross-sectional area and intensive water cooling, since the core works with magnetic inductions close to saturation. The core is composed of thick-walled ferrite rings on a tube of non-magnetic material. Cooling is carried out by water supplied through a tube. When welding thin-walled pipes of this diameter, a core consisting of rods can be used.
When welding pipes with a diameter of 40–130 mm, the core is drawn from standard rods with a diameter of 8–10 mm and placed in a cylinder, which is both a supporting structural element and a safety casing. The back of the cylinder ends with a threaded fitting, with which the core is attached to an adjustable bracket or rod of the welding machine; Coolant (water or emulsion) is introduced into the core. The cylinder in which the ferrite rods are placed is recommended to be made of non-magnetic material (austenitic steel, aluminum alloys, copper). Along the axis along the side of the cylinder facing the V-shaped slit, a slot is made 2–2.5 times wider than the gap between the welded edges. The slot is covered by heat-insulating material.

The seam crimping and seam guiding stands should provide conditions for stable heating and the formation of a welded joint. The pressure in the seam crimp stand is created due to the difference in the perimeters of the welded workpiece and the caliber of the seam crimp rolls. In this case, the total pressure on the rolls P0 is the sum of the pressures in the areas of the forming of the Russian Federation and welding of the P_{WELD}

$$P_0 = P_ф + P_{WELD} \tag{2}$$

where $$P_ф = \frac{\tau_s 4s^2 r_к r_p b_н}{l_{кк}(r_к + r_p)к}, \tag{3}$$

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$\tau_s = \sigma_s^{'} / \sqrt{3}$ — the average value of the yield strength, independent of l_{draft} (at the settlement temperature), rrolling and rflange are the radii of the working surface and the flanges of the crimping roll; b_{knife} is the thickness of the knife seam guide; $l_к$ is the distance from the point of convergence of the edges to the axis of the roll; r are the radii of the pipe at the exit of the welding gauge.

Welding pressure

$$P_{weld} = P_{draft} + P_p, \tag{4}$$

where

$$P_{draft} = \frac{\sigma_s^{'}}{\sqrt{3}} 2sl_{draft}\left[4 + \frac{2s}{\Delta_{draft}} \ln\left(1 + \frac{\Delta_{draft}}{H_к}\right)\right] \tag{5}$$

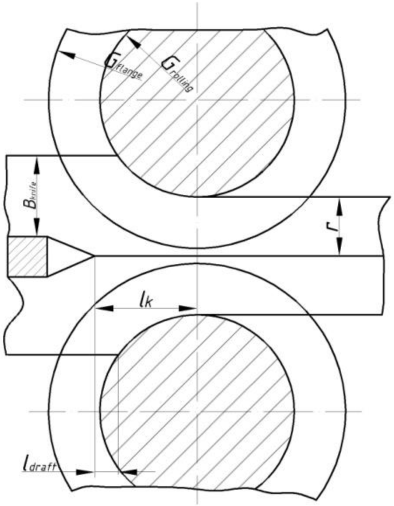

Fig. 4. Diagram of upsetting edges when welding a pipe billet of radius r:
$l_к$ - full contact length; l_{draft} - precipitation zone; b_{knife} - knife thickness; $g_{rolling}$ and g_{flange} are the radii of the crimp roll along the rolling diameter and flange; r is the radius of the pipe at the exit of the welding gauge

$$P_p = (D_н + D_к) l_p P_н / 2 \tag{6}$$

Here Din and D_{out} are the diameters of the pipe at the inlet and outlet of the crimp stand; l_p is the length of the molding zone (Fig. 4); P_{init} - Specific Initial Force.

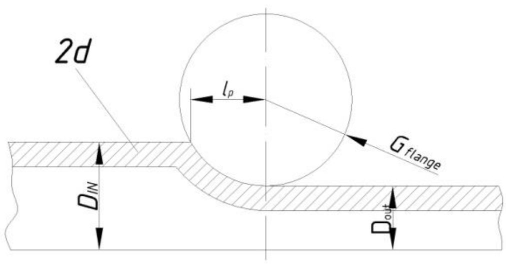

Fig. 5. Caliber seam crimping unit

Calculations show that the main share in the welding pressure on the squeeze rolls is the reduction pressure (P_p) - 60–80%, and the pressure in the upsetting section (R_O) - 15–30%. These pressures increase with increasing welding speed. The molding pressure is practically independent of the speed of the process.

To obtain a high-quality welded joint, it is necessary that all the molten metal present at the convergence site of the elements to be welded is removed during upsetting. This can be achieved provided that the precipitation rate is

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sufficient and the molten metal does not lose its fluidity. The time interval Δt_0, sufficient for cooling the metal from temperature T_1 (at the point of convergence of the elements) to the temperature of fluidity loss T_2, in butt welding with continuous reflow

$$\Delta t_0 = \frac{\delta_p \gamma \left[c(T_1 - T_2) + m_0 \right]}{\lambda (dT / dx)} \tag{7}$$

where is the thickness of the liquid metal at the point of convergence of the welded elements; , c and m0 are the density, specific heat and latent heat of fusion of the metal being welded; dT / dx - temperature gradient per unit length in the cross section of the elements to be welded.

Obviously, for guaranteed removal of liquid metal and, consequently, oxides during precipitation, it is necessary that the precipitation time Δt be less than Δt_0 (and this is the less, the less $T_1 - T_2$ and more dT / dx). We define, based on the crystallization interval of alloys, which can be divided into two parts:

1) the interval where the grown dendrites of the solid solution are separated by a continuous layer of the liquid phase (liquid-solid state);

2) the interval (below the temperature boundary of the liquid-solid state), where dendrites partially merge and form a hard skeleton from them with further solidification of the entire liquid phase. Alloy at a temperature above the temperature of formation of the crystalline skeleton, which is in a liquid-solid state, has a high fluidity. Therefore, we can take $T_2 = T_{cr}$ for the temperature at which the transition from liquid-solid to solid-liquid occurs.

The dT / dx gradient can be determined by calculating the temperature field in the weld cooling zone, that is, in the area from the point of convergence of the welded elements and further under the following assumptions:

1) the heat source is constant and acts during the heating period;

2) the exponential law of the distribution of densities of heat sources is adopted;

3) the thermophysical characteristics of the alloy are constant in time;

4) the heat transfer from the surface of the welded edges due to radiation and convection is negligible.

Using the obtained data, we determine the precipitation rate:

$$v_{draft} \geq \frac{l_{draft}}{t_0} = 100 \div 500 \, мм / c \tag{8}$$

The lower limits of precipitation rates used in high-frequency reflow welding may be insufficient for welding metals and alloys with a melting temperature of oxides higher than T_m, and to remove them during the precipitation process, it is necessary to significantly increase the welding speed. Thus, there is a minimum critical welding speed $v_{sv.kr}$, below which it is impossible to obtain a high-quality welded joint

IV.CONCLUSION

Research work on determining the influence of thermal deformation parameters during high-frequency welding on the quality of welded joints of longitudinal welded pipes of low-carbon and low alloy steels revealed that:

- a decrease in the welding current due to an increase in the heating time is impractical, since this increases the heat loss due to heat removal to the body of the workpiece being welded. The most effective decrease in current by increasing the frequency to 200-500 kHz;

- when welding thick-walled pipes of small diameter D (D≤40 mm, D / 2s = 8 ÷ 10, s is the pipe wall thickness, mm) it is advisable to produce a ferrite core with the maximum possible cross-sectional area and intensive water cooling, since the core works when magnetic inductions close to saturation;

- the main share in the welding pressure on the squeeze rolls is the reduction pressure (Pp) - 60–80%, and the pressure at the draft site (RO) - 15–30%. These pressures increase with increasing welding speed. The molding pressure is practically independent of the speed of the process.

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