Semi-automatic welding in the environment of protective gases of welded structures from hardening steels with regulation of thermal cycles

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Abstract. In order to increase the technological and operational strength of welded joints of type X12CrMo5 steels in the process of welding in a protective gas environment, it is possible to use vibration deformation treatment of a welded joint with a pearlite joint to form a metal structure of a welded joint with minimal sensitivity to the formation of cold cracks due to an increase in the rate of heating and cooling, reduction of residence duration and provision of conditions of high-temperature decay of austenitic metal structures in seam and near-seam zones above critical temperatures. The work carried out research on the process of semi-automatic welding in the medium of protective gases in the mixture of carbon dioxide and argon with pearlite and austenitic welding materials of welded structures from hardening steels of grades 12Kh2M1 and X12CrMo5 with regulation of thermal cycles (RTC) due to the use of vibration deformation treatment and accompanying forced cooling.

1. Introduction
For welded joints made by austenitic welding materials, welding in the environment of protective gases by multilayer welding with layer-by-layer cooling of butt joints is regulated. Control of the thermodeformation cycle of welding due to accompanying forced cooling ensures hardening of austenite seam metal on austenite and reduction of the width of hardened hard sections of the zone of thermal influence (ZTI) to a critical value, at which their presence practically does not adversely affect the bearing capacity of welded joints. Use of austenitic welding option is allowed for equipment operating in media that do not cause corrosion cracking [1-5].

This technology applies to the assembly and welding of structural elements of oil and gas chemical equipment from low-carbon chromomolybdenum hardening steels of grade 12Kh2M1 and X12CrMo5 according to GOST 20072-74 by semi-automatic welding in the environment of protective gases with uniform pearlite welding wires with subsequent thermal treatment and austenitic welding materials without heating and thermal treatment.

2. Experimental procedures
To increase the technological and operational strength of welded joints of steels of type X12CrMo5, welding of butt joints in a mixture of carbon dioxide and argon is provided. At the same time, in order to ensure the transition from large-drop to jet transfer of molten metal of welding wire, better formation of weld metal and less spraying, the best shape of the wire is regulated welding modes providing high current densities - 150 A/mm² or more. For welded joints made by homogeneous pearlite welding wires, it is possible to use vibration deformation treatment of the welded joint to form the structure of the welded joint metal with minimal sensitivity to cold crack formation due to ensuring the decay conditions...
of austenitic structures of the ZTI metal above critical temperatures and increasing the time between welding and subsequent thermal treatment according to the high tempering mode.

For thick-walled welded joints made by austenitic chromium-nickel wires with the addition of manganese, the use of concomitant forced cooling is regulated, which ensures the hardening of the austenitic seam on austenite and a decrease in the width of the hardened hard sections of the thermal influence zone to critical ones, in which the negative effect of these sections practically does not affect the bearing capacity of the welded joint. Due to exclusion of preliminary and concomitant heating during welding and possibility of mechanized welding at increased modes higher labor productivity is provided. Welding in the medium of \( \text{CO}_2 \) and in the mixture of protective gases (\( \text{Ar} + 20-25\% \text{CO}_2 \)) is carried out at direct current of reverse polarity from power sources with a rigid or falling characteristic [6-9].

Use of a welding wire of 2NM307 (GOST 2246-70) is allowed for the weld joints working at a temperature not above 450 °C. It is necessary to apply a high-nickel welding wire of Sv-05kh5n40g7m8t to structural elements which weld joints are exposed to heating to temperature above 450 °C. Preparation of welded parts edges for welding shall be performed mechanically in accordance with the requirements of GOST 5264-80 and GOST 16037-80, technical specifications, drawing, corresponding instructions. Thermal preparation of edges is allowed only in case of impossibility of mechanical treatment. Thermal cutting should be carried out with preliminary heating of cutting point up to 250-350 °C and subsequent delayed cooling in heat insulation. After heat treatment, the edges shall be cleaned with abrasive tools to a depth of at least 2-3 mm, counting from the deepest depression of the crack surface, with subsequent inspection of the edges through a magnifying glass of 4-7 times increase. When cracks are detected, edges are subjected to additional treatment with abrasive tools until cracks are completely removed, followed by color flaw detection. Grind burrs throughout the machined contour.

In the process of welding with uniform pearlite electrodes, in order to increase the time between welding and thermal treatment in order to prevent cracking before the start of high-temperature thermal treatment, the welding process in the protective gas medium must be carried out using vibration (frequency 50Hz, amplitude up to 1 mm) treatment. Low-frequency vibration loading during welding operations ensures uniformity of residual stress removal in the welded joint area.

When welding the root layer, it is necessary to monitor the complete penetration of the edges. The surface of the root layer on the back side should be made with uniform reinforcement and smooth transition to the base metal. Before welding it is necessary to grind the tack points with a grinding wheel to pure metal with smooth transition to the main metal. When welding single-layer butt seams and the first layer of multi-layer seams, it is recommended to move the seam burner progressively without transverse oscillations. In case of accidental arc break, light it again, retreating 15-20 mm back from the crater, having previously cleaned the seam to pure metal; well boil the arc break places. In order to avoid defects in the root layer, it is necessary to ensure that the tack is completely melted.

Inclusive a welding wire of 2NM307 and wall up to 20 mm thick inclusive a welding wire of Sv-05kh5n40gm8t to make welding of joints wall up to 14 mm thick with layer-by-layer cooling. In this case, welding of each subsequent layer is recommended when the previous one cools to a temperature not higher than plus 100 °C, and in case of welding at negative temperatures - to a temperature of plus 200-250 °C [10-15].

In order to increase the technological strength of thick-walled welded joints, improve the structure of thermal influence zones and weld metal, it is recommended to weld the second and subsequent layers with accompanying cooling with water or water-air mixture (figure 1).
v_св – welding speed; l_0, b_0 - cooling parameters

**Figure 1.** Schematic diagrams of accompanying cooling during welding.

Cooling device is installed directly under welding arc and moves during welding in direction of arc movement at welding speed. In order to more effectively affect the shear zones of the tucker, cooling is carried out by two liquid flows directed to the high-temperature regions of the zones of thermal influence adjacent to the fusing line.

3. **The results of studies and their discussion**

Effective length of cooling zone l_0 at cooling with water-air mixture is 8-10 mm. The width of the cooling zone b_0 is 10-20 mm. For multi-layer welding with filling of the preparation with layers for the entire width of the butt seam with a V-shaped bevel of edges at a preparation angle of 60° b_0, it is recommended to select from the graph shown in figure 2. The distance from the nozzle to the cooling surface is 35-40 mm. Cooling water flow rate as well as air pressure during welding shall be controlled by means of adjustment valves on the cooling device by liquid flow meter and pressure gauge. At accompanying cooling with water-air mixture water flow rate is 0.8-1.2 l/min, air pressure - 0.3-0.4 MPa.

![Graph](image)

**Figure 2.** A graph to select the width of the cooling zone depending on the fill height of the "C" groove during semi-automatic welding CO_2 a multi-layer butt weld with rollers applied over the entire width of the groove.

The welding zone should be blown with protective gas before the welding arc is excited. The distance from the burner nozzle to the surface of the welded part shall not exceed 25 mm. The estimated flow rate of protective gas during wire welding with a diameter of 1.2 mm is 9-12 l/min; during wire welding with diameter of 1.6 mm - 14-18 l/min; at welding with wire with diameter of 2.0 mm - 16 - 20 l/min.
The order of layering during welding of horizontal joint of pipes is shown in figure 3.

![Diagram showing layering during welding](image)

**Figure 3.** How to apply layers when welding a horizontal pipe joint with a diameter up to 219 mm (a), diameter more than 219 mm (b).

After each pass of the multilayer seam, it must be externally inspected to detect cracks and other defects. If detected, the defects are eliminated before the next pass. To improve the quality of the weld joint, it is recommended to grind the previous layer to pure metal with a grinding wheel or a metal brush before applying the next layer. To provide an annealing effect on the metal structure of the thermal influence zone in order to eliminate the martensitic structure and increase operability, the order of seaming during multilayer welding must be performed with layer-by-layer cooling and compliance with the sequence of seaming. Weld layers on the metal edges must be made at maximum speed without oscillating the electrode wire. The recommended procedure for placing rollers when welding joints of vertically and horizontally located pipes is shown in figure 4 [16-18].

![Diagram showing welding roll stacking order](image)

**Figure 4.** Approximate Welding Roll Stacking Order.

When pearlite welding materials are used after welding works completion, structures are subject to mandatory heat treatment - high tempering, according to GOST 34347-2017. Tempering is carried out at a temperature of 730...760°C. Holding time 2...2.5 h (with wall thickness 10...20 mm) and 4...4.5 h (with thickness up to 30 mm). Next, cooling with the furnace to 500°C and final cooling in calm air. Heat treatment shall be carried out not later than 48 hours after completion of welding works. Do not
perform any operations with the article before heat treatment. Heat treatment is not performed using chromium-nickel electrodes.

Quality control of welded joints is carried out operationally in accordance with the requirements of GOST 34347-2017, product specifications, drawings and relevant instructions.

Maximum permissible width of solid sections in ZTI $h_t$ for welded joints from steels of type X12CrMo910 shall not exceed the value calculated according to the formula

$$h_t \leq S \left[ \frac{1}{a^2} + \frac{\kappa_B - 1}{2ak_B(1 - \kappa_{BT})} \right] - \frac{1}{a},$$

where $S$ – thickness of the structural element, mm;

$$\kappa_B = \frac{\sigma_T}{\sigma_B^M};$$

$$\kappa_{BT} = \frac{\sigma_B^M}{\sigma_T};$$

$\sigma_B^M$, $\sigma_T$ - respectively, the time resistance of the soft (main) and solid (zone of thermal influence) metals;

$\sigma_T$ - yield strength of solid metal;

$\bar{a}$ – correction factor ($\bar{a} \approx 30$).

Removal of defective areas and their brewing are carried out in compliance with the same technological procedures that are provided for when welding products according to the relevant instructions. Correction of the same area is allowed not more than twice.

4. Conclusions

As a result of the work done, it has been shown that the control of the thermo deformation cycle of welding due to the accompanying forced cooling ensures the quenching of the austenite seam on austenite and the reduction of the width of the hardened hard sections of the thermal influence zone to critical ones, at which the negative effect of these sections practically does not affect the bearing capacity of the weld joint.

Due to exclusion of preliminary and concomitant heating during welding and possibility of mechanized welding at increased modes higher labor productivity is provided.

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