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IMPROVEMENT OF CRACK RESISTANCE OF BANDED SUPPORT ROLLS AT HIGH-SPEED SURFACING WITH LOW ENERGY INPUT

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The objective of the work is improvement of deposited metal crack resistance and development of the process of high-speed surfacing of banded support rolls with a low energy input. In order to achieve the set objective, we developed the process of improving the crack resistance due to high-speed surfacing of banded support rolls with a low energy input. In keeping with the equation of heat propagation at high-speed surfacing with a low energy input, increase of deposition rate is accompanied by lowering of the heat input, narrowing of melting isotherm width and HAZ. Calculation and experimental methods were used to establish that at increase of deposition rate, lower heat input results in decrease of deformations and welding stresses, and reduction of the HAZ, where cold cracks form, that prevents delamination of the deposited metal. Melting and solidification rates rise, time of the pool staying in the liquid state is reduced that prevents liquid metal flowing out of the weld pool and improves deposited metal formation. Established regularities were the base for development of the process of high-speed surfacing with low energy input, at which the heat input and welding stresses decrease, HAZ is reduced and deposited metal delamination is prevented, melting and solidification rates increase, time of the pool staying in the liquid state becomes shorter, and crack resistance of banded support rolls becomes higher. Developed process of high-speed surfacing of banded support rolls with a low energy input provides a lowering of the heat input and welding stresses, HAZ reduction, increase of melting and solidification rates and crack resistance, and absence of deposited metal delamination or band failures. 11 Ref., 6 Figures.

K e y w o r d s : high-speed surfacing with low energy input, melting isotherms, heat input, welding stresses, HAZ, crack resistance, banded support rolls

In manufacture of banded support rolls by fitting the band on the axle with tension, stresses develop in the band that is why it is necessary to ensure minimum residual welding stresses in surfacing, which, adding up with the inherent stresses, cannot lead to band fracture. The band is made from high-carbon 90KhF steel prone to hot and cold cracking. Therefore, increase of crack resistance of banded support rolls is an important science and technology problem.

Cold and hot crack resistance is largely determined by the speed and energy input of the surfacing process. It is generally known that at reduction of energy input, the probability of cold cracking becomes higher, due to increase of the cooling rate [1, 2]. M.M. Prokhorov [1], however, notes that considerable reduction of the energy input and increase of the heating rate may lead to lowering of cold cracking probability.

In order to increase the crack resistance, of great importance are the works on studying the stress-strain state of welded structures [3−5], which are of considerable theoretical and practical interest.

Banded support rolls of 3000 mill with body diameter of 2.1 m, body length of 3 m, and weight of 120 t, are made by pulling a heated band over the axle. Here, the band diameter becomes greater and after cooling it is reduced, that ensures band fitting on the axle with tension. Here, inherent residual stresses develop in the band.

Support rolls, which prevent sagging and fracture of cast iron working rolls, are operated under the conditions of high specific pressures that leads to wear and reduction of their diameter. Therefore, after operation, arc surfacing is performed for strengthening and reconditioning.

Due to inherent residual stresses and deposition of a band from 90KhF steel, prone to cracking, it is necessary to ensure minimum residual welding stresses at surfacing, which, while adding up with the inherent residual stresses, may lead to band fracture.

As was established, at arc surfacing of banded support rolls at high energy input of 2.2 MJ/m, after heat treatment and slower cooling, the band broke before it was mounted in the rolling mill. Fracture mode was brittle, the band cracked, and a piece of the band flew like a shell with high kinetic energy. The energy, applied to the band, at deposition with a high energy input, was transformed into kinetic energy.

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An effective method to increase the crack resistance is high-speed surfacing at low energy input, the impact of which on crack resistance of the deposited metal is insufficiently studied [6–8].

The objective of the studies is improvement of the deposited metal crack resistance and development of the process of high-speed surfacing of banded support rolls with low energy input that prevents band breaking.

High-speed surfacing with a low heat input corresponds to the scheme of bead deposition on a massive body by a powerful quickly moving arc, for which the temperature field is described by the developed by M.M. Rykalin [9] equation of the process of heat propagation:

$$T(X,Y,Z)=\frac{q_a}{2\pi\lambda(-X)}\mathring{a}^{-\frac{VY^2}{4a(-X)}}, \qquad (1)$$

where q_a is the effective thermal power of the arc (q_a = $= 0.24IU\eta_a$, 5356.8 cal/s); λ is the heat conductivity coefficient, 0.1 cal/cm·s·°C; a is the thermal diffusivity (0.1 cm^2/s); V is the deposition rate (2.08; 1.39; 0.695 cm/s); X is the abscissa along the surfacing direction, cm; Y is the ordinate normal to the surfacing direction, cm; I is the current (800 A); U is the arc voltage (31 V); η_a is the effective efficiency (0.9 in submerged-arc welding).

For body surface $Z = 0$, the equation of heat propagation at high-speed surfacing at a low heat input has the following form:

$$\frac{2\pi\lambda T(-X)}{q_a}=\mathring{a}^{-\frac{VY^2}{4a(-X)}}, \qquad (2)$$

then:

$$-\frac{VY^2}{4a(-X)}=\ln\frac{2\pi\lambda T(-X)}{q_a}$$

$$Y^2=-\frac{4a(-X)}{V}\ln\frac{2\pi\lambda T(-X)}{q_a} \qquad (3)$$

$$Y=\sqrt{-\frac{4a(-X)}{V}\left(\ln\frac{2\pi\lambda T}{q_a}+\ln(-X)\right)}.$$

Calculation of isotherms at wire electrode surfacing is performed on a personal computer by a specially developed program, for base metal surface (Z = = 0), the thermal condition of which determines weld formation.

The adequacy of the equation of the process of heat propagation at high-speed surfacing with a low heat input was confirmed by good convergence of the calculated and experimental data of melting isotherms

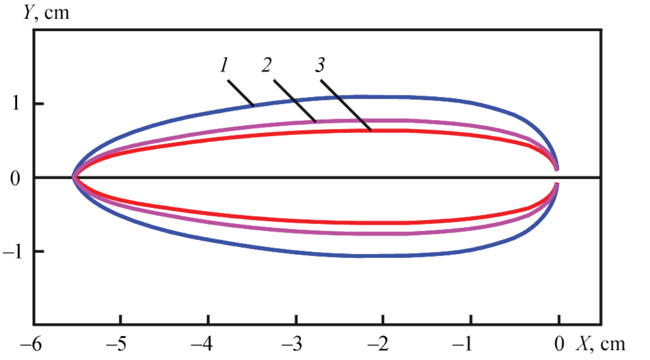

Figure 1. Dependence of melting isotherm on deposition rate: *1* — 25; *2* — 50; *3* — 75 m/h

and weld width, obtained at high-speed surfacing with PD-Np 25Kh5FMS wire of 3.6 mm diameter, with flux AN-26P of plates from St.3 steel of 30×300×400 mm size. Arc surfacing was conducted in the following mode: current of 750–800 A, arc voltage of 30–32 V, speed of 0.7; 1.4; 2.1 cm/s. Here, the heat input was equal to 3.3; 1.65; 1.1 MJ/m. VDU 1604 rectifier was used as the heat source.

As was established, at increase of the deposition rate, the width of melting isotherms becomes smaller (Figure 1), that is in good agreement with the experimental data on weld width, as a result of lowering of the heat and energy input.

At arc surfacing, vacancies develop in the deposited metal under the impact of thermal excitation [1], as the energy of vacancy appearance is smaller than that of formation of interstitial atoms. In the zone of vacancy occurrence, the static equilibrium of the forces of interatomic interaction is disturbed, that leads to shifting of adjacent atoms from their equilibrium positions, microdistortion of the crystalline lattice, microstresses, increase of dislocation density and residual welding stresses.

Cracks form, when welding stresses become greater than the interatomic bonds [6]. Therefore, in order to avoid band breaking at surfacing the banded support rolls, it is necessary to ensure minimum residual welding stresses, which are determined by heat input and deformations.

In order to study the impact of deposition rate on longitudinal deformation, surfacing of plates $(8\times120\times900)\cdot10^{-3}$ m and $(30\times120\times900)\cdot10^{-3}$ m was performed by a composite electrode at different speeds.

In keeping with literature data [8], the dependence of residual welding stresses on deposition rate is as follows:

$$\sigma\geq\mu E\frac{q_a}{VF}, \text{ Pa}, \qquad (4)$$

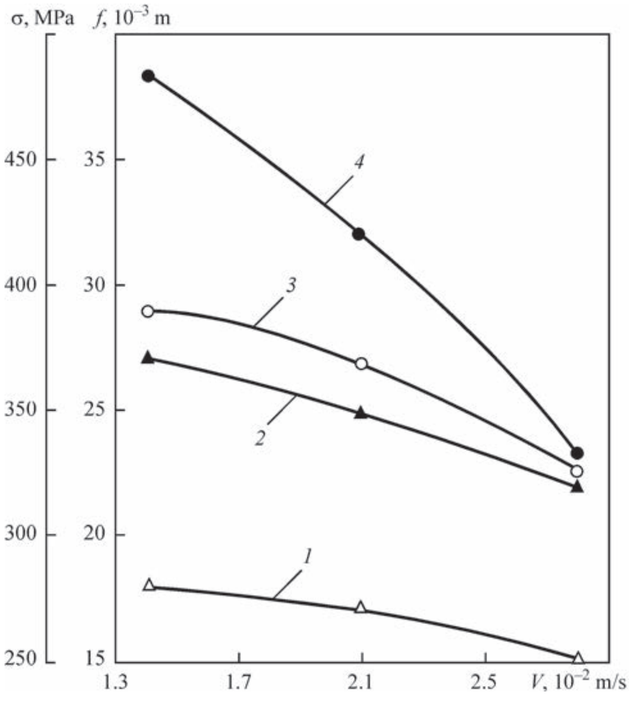

Figure 2. Regularity of the impact of deposition rate V on deformations f (*1*, *2*) and welding stresses σ (*3*, *4*) in plates of $(30\times120\times900)\cdot10^{-3}$ m (*1*, *3*), $(8\times120\times900)\cdot10^{-3}$m (*2*, *4*) size

where μ is the Poisson's ratio (for carbon steel $\mu = 0.33$); E is the modulus of elasticity (for carbon steel $E = (2.0–2.1)\cdot10^5$ MPa); q_a is the effective thermal power (J/s); V is the deposition rate, m/s; q_a/V is the energy input, MJ/m; F is the plate cross-section, m^2.

Longitudinal plastic deformation of the plates depends on residual welding stresses [8]:

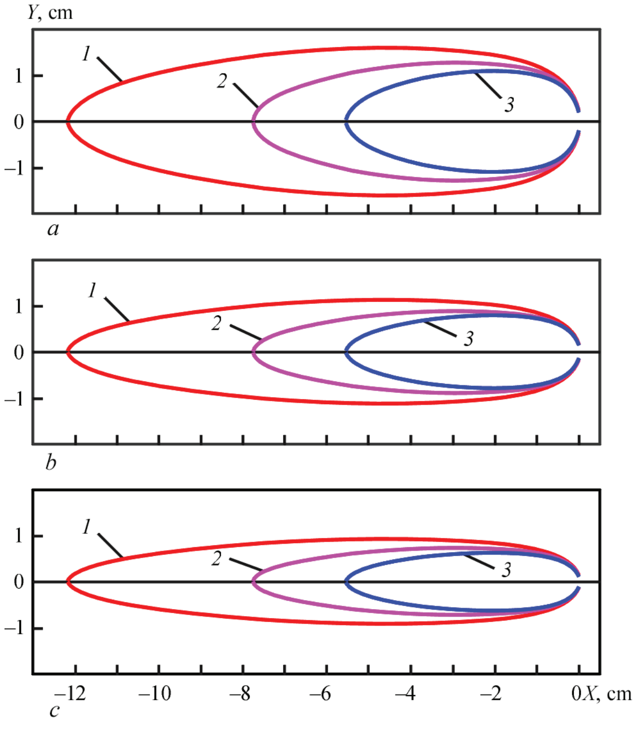

Figure 3. Temperature field at deposition at the rate of 25 (*a*), 50 (*b*), 75 m/h (*c*): *1* — $T = 700$; *2* — 1100; *3* — 1539 °C

$$f = 0.613l\sqrt{\frac{\sigma - \sigma_{cr}}{E}}, \text{ m}, \quad (5)$$

where l is the plate length, m; σ_{cr} is the critical value of welding stresses, Pa.

Critical value of residual welding stresses, which leads to plastic deformation is [8]:

$$\sigma_{cr} = \frac{\pi^2 E}{12}\left(\frac{\delta}{l}\right)^2, \text{ Pa}, \quad (6)$$

where δ is the plate thickness, m.

At stresses above the critical value, plastic deformation of the plate occurs.

It follows from the given expressions, that the residual welding stresses are directly proportional to plate deformation [8]:

$$\sigma = \frac{f^2 E}{0.613^2 l^2} + \frac{\pi^2 E}{12}\left(\frac{\delta}{l}\right)^2, \text{ MPa}. \quad (7)$$

As was established, at increase of the deposition rate and lowering of the energy input, decrease of the heat input results in reduction of base metal deformation and residual welding stresses (Figure 2) that considerably increases the crack resistance.

Cold cracking resistance of the deposited metal is largely determined by the residual welding stresses, which add up at deposition that leads to cracking. Deposition of wear-resistant layer is performed in five or greater number of passes, therefore welding stresses increase abruptly, and deposited layer thickness on the radius is limited by the value of 0.025 m, exceeding which leads to considerable increase of residual welding stresses and deposited metal delamination in the zone of fusion with the base metal. This is confirmed at surfacing of working rolls of 1700 mill, when at deposition of 0.04 m on the radius, the deposited metal separated from the base metal. Therefore, investigations were conducted at five-layer surfacing. Weld metal properties were found by measuring the HAZ, which was determined by melting isotherms at 1539 °C and at the temperature of 1100 °C.

As was established (Figures 3, 4), with increase of the deposition rate and lowering of energy input, the heat input and HAZ are decreased that ensures lowering the susceptibility to cold cracking and deposited metal separation.

In the weld pool crater, the arc melts the base metal with the speed of welding on the axis, which rises from 25 to 50 and 75 m/h with increase of welding speed (Figure 5). As the base metal in the crater melts, in the area of the side edges the speed drops from the welding speed to zero in the area of crater transition to

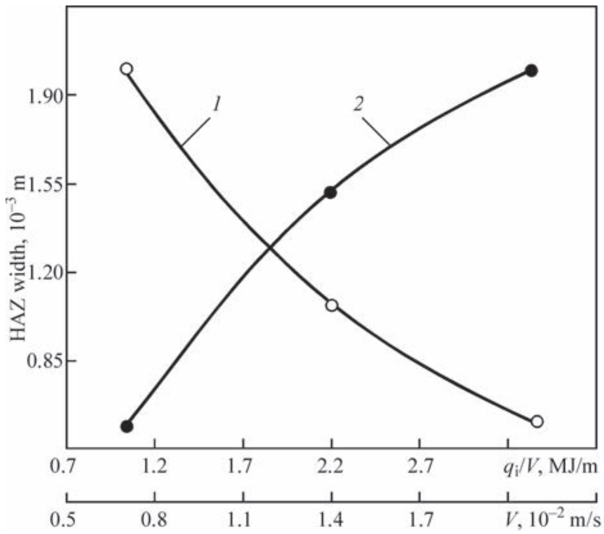

Figure 4. Dependence of HAZ width of deposition rate *V* (*1*) and energy input q_a (*2*)

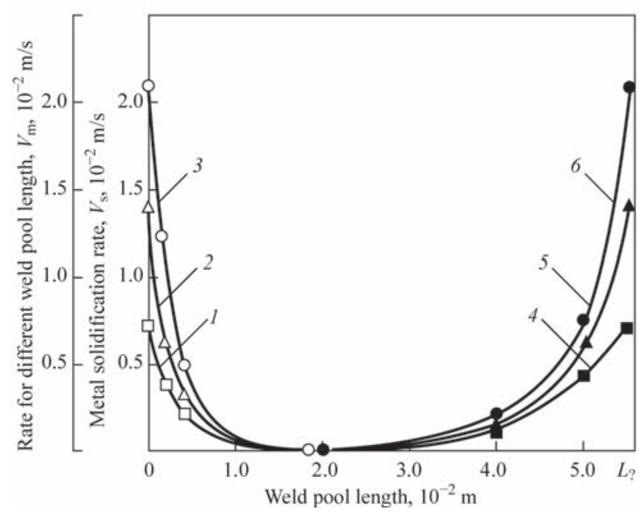

Figure 5. Base metal melting rate v_m (*1–3*) and solidification of weld pool liquid metal v_s (*4–6*) at deposition rate of 25 m/h (*1*, *4*), 50 (*2*, *5*) and 75 (*3*, *6*)

the tail part of the weld pool, where the solidification rate of liquid metal of the weld pool rises from zero in the area of the side edges, to the welding speed on the axis of the pool tail part.

Three times increase of the heating rate, from 200 up to 600 °C, has a greater impact on refinement of the austenite grain, than does the increase of the cooling rate by 25 times, from 10 up to 250 °C [10], that should be taken into account, when studying the brittle fracture and cold cracking susceptibility.

The regularity of the change of base metal melting rate in the weld pool crater and of the solidification rate in the pool tail part coincides with the melting isotherm, in keeping with the equation of heat propagation at high-speed surfacing with low energy input.

Crack resistance largely depends on the rate of heating and melting, cooling and solidification, and time of the pool staying in the liquid state.

At high-speed surfacing with low energy input for a powerful quickly moving heat source, the time of the pool staying in the liquid state is determined by the equation for the melting isotherm and weld pool length [9]:

$$T_m = \frac{q_a}{2\pi\lambda V t_l}, \ ^\circ\text{C}, \qquad (8)$$

from which it follows that the time of the pool staying in the liquid state depends on the surfacing speed and energy input:

$$t_l = \frac{q_a}{2\pi\lambda V T_w}, \ ^\circ\text{C}. \qquad (9)$$

With increase of the deposition rate, the time of the pool staying in the liquid state is reduced (Figure 6), that results in prevention of liquid metal flowing out of the weld pool and ensuring sound formation of the deposited metal.

In order to increase the crack resistance of banded support rolls, a method of high-speed surfacing of high-carbon steels [11] with a low energy input of 1.1 MJ/m was developed, using the following mode: current of 750–800 A, arc voltage of 30–32 V, and deposition rate of 75 m/g.

The process effectiveness was confirmed at high-speed surfacing of banded support rolls of 3000 mill with low energy input, at surfacing which with low energy input the band did not break. High-speed surfacing of the rolls was performed with preheating up to 300–350 °C, by deposition of a buffer layer by Zv08G2S low-carbon wire of 4 mm diameter, with AN-60 flux, and deposition of a wear-resistant layer by PD-Np-25Kh5FMS flux-cored wire of 3.6 mm

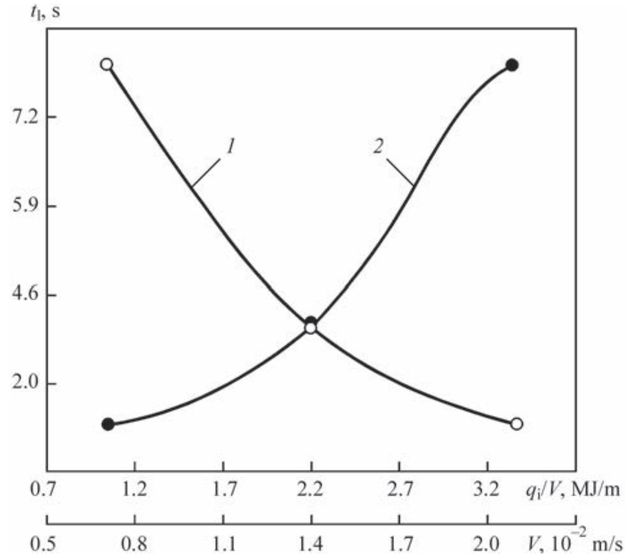

Figure 6. Dependence of the time of the pool staying in the liquid state t_l on melting rate *V* (*1*) and energy input q_a (*2*)

diameter with flux AN-26P and energy input of 1.1 MJ/m, heat treatment and retarded cooling.

Preheating temperature, with increase of the carbon content, rises from 150–200 °C for steel 45, to 300–350 °C, for steel 90KhF.

After arc surfacing, in order to lower the welding stresses, roll heat treatment is performed in the following modes: roll temperature before heat treatment — 300 °C; heating up to the temperature of 400–450 °C at the rate of 5–10 °C/g; soaking at this temperature for 8–10 h; cooling to the temperature of 300 °C at the rate not higher than 10–15 °C/g.

After the temperature of 300 °C has been reached, the roll is placed into a thermostat for retarded cooling.

The developed process of high-speed surfacing of banded rolls at a low energy input ensures minimum heat input and residual welding stresses, reduction of the HAZ, cold cracking susceptibility and probability of deposited metal delamination; increase of melting and solidification rate, improvement of crack resistance and no band breaking.

Conclusions

1. Adequacy of the equation of heat propagation at high-speed surfacing with a low heat input is confirmed by good convergence of the calculated data of melting isotherms and experimental data on the weld width.

2. Proceeding from the calculated-experimental data, it was found that at high-speed surfacing with a low energy input, the heat input and residual welding stresses, HAZ, cold cracking susceptibility and probability of deposited metal delamination, and time of the pool staying in the liquid state are reduced, while melting and solidification rate is increased, that improves the crack resistance of banded support rolls.

3. The process of high-speed surfacing with a low energy input of banded support rolls was developed, which ensures lowering of the heat input and residual welding stresses, reduction of the HAZ, increase of the melting and solidification rate, and cracking resistance, absence of deposited metal delamination or band breaking.

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