INCREASE OF CRACK RESISTANCE OF SHROUDED TRAVELING ROLLS IN HIGH-SPEED HARDFACING

V.V. CHIGARYOV, V.I. SHCHETININA, S.V. SHCHETININ, K.K. STEPNOV, N.G. ZAVARIKA and V.I. FEDUN
Priazovsky State Technical University, Mariupol, Ukraine

Regularities of influence of high-speed electric arc hardfacing with a low running energy on welding stresses and crack resistance of the deposited metal are established. Method for the high-speed hardfacing of shrouded traveling rolls has been developed.

Keywords: *electric arc hardfacing, shrouded traveling roll, carbon steel, running energy, strain, welding stresses, microstructure, impact toughness, cracks, wear resistance*

Main parts of metallurgical equipment include traveling rolls which are manufactured from high-carbon steels and operate under conditions of high specific pressure. This limits use of the hardfacing for shrouded traveling rolls which are manufactured by interference fit on an axle of the shroud. As a result stresses occur in the shroud which may cause damage of the equipment. Because of this reason hardfacing of shrouded traveling rolls usually is not performed.

Service life of the rolls is determined by their crack- and wear resistance, material consumption factor, specific consumption of materials in the process and production cost of the rolled metal. That's why increase of the service life is an important scientific-technical problem.

For the purpose of increasing crack resistance the high-speed electric arc hardfacing [1] with low running energy is used, characteristic for which are change of the arc existence conditions, reduction of heat input, increase of the rate of heating and cooling of the molten metal and heat-affected zone (HAZ) that causes change of conditions of the pool solidification [2, 3], level of strains, welding stresses and quality of the deposited metal.

This influence of running energy on crack resistance of the deposited metal is contradictory [2, 4, 5], and action of the electrode shape and running energy on strains, welding stresses and properties of the deposited metal was investigated not sufficiently yet.

The goal of this work is investigation of peculiarities of increasing crack resistance of the deposited metal and development of the method for high-speed hardfacing of shrouded traveling rolls at low running energy.

In electric arc hardfacing vacancies occur in structure of the deposited metal under action of heat. In zone of their formation occurs disturbance of static equilibrium of the interatomic interaction forces, which stipulates shift of the adjacent atoms from their equilibrium positions and microdistortion of the crystalline lattice [2].

As a result of heat input in process of hardfacing the metal is subjected to action of the heat strain cycle, upon which depend microdistortion of the crystalline lattice and microstresses. The heat strain cycle was determined using the strain gage, function of which performed an electron micrometer operating on basis of a movable-electrode tube. Observed strains ε_o and thermal cycle of heating of a point located between legs of the strain gage were measured using the strain gage on basis 0.01 m. Change of the strain level in process of hardfacing and thermal cycle of heating of the point were registered using the oscilloscope. Natural strains of the base metal located at distance $5\cdot10^{-3}$ m from the fusion zone were determined using the differential method [6–8]:

$$\varepsilon = \varepsilon_{elast} + \varepsilon_{pl} = \varepsilon_o - \varepsilon_w,$$

where ε_{elast}, ε_{pl}, ε_w are respectively elastic, plastic and welding strains.

Hardfacing of rib of a plate of approximately $(30 \times 125 \times 400)\cdot10^{-3}$ m size was performed using a built-up electrode [9] consisting of two wires and an U-shape tape using the ZhSN-5 ceramic flux which ensured production of the deposited metal of the 25Kh5FMS type. Occurrence of the strains was registered in direction of hardfacing. As a result of measurement of heat strain cycles (Figure 1) it was established that in process of the hardfacing first at bringing nearer of the arc compression of the metal in area of the measurement under action of the expanding metal occurs, and when the arc is located in area of measurement of the heat strain cycle, expansion of the metal in the zone and its extension occur. By means of moving the arc away and cooling compression of the base metal occurs. Both at heating and at cooling instant values of ε_o and ε_w significantly differ which causes development of natural strains ε and welding stresses.

For investigation of the running energy influence on the base metal strains, welding of plates of $(8 \times 120 \times 900)\cdot10^{-3}$ m size and hardfacing of plates of $(30 \times 120 \times 900)\cdot10^{-3}$ m size were performed using a built-up electrode with different running energies. It was established that at increase of the welding speed and reduction of running energy because of reduction of heat input, the base metal strains and welding stresses reduce (Figure 2).

Dependence of welding stresses upon efficient running energy is determined from the expression [8]

$$\sigma \geq \mu E \frac{q_e}{vF}, \quad (1)$$

where μ is the Poisson's ratio for carbon steel; E is the modulus of elasticity equal to $19.68 \cdot 10^4$ MPa; F is the plate cross section.

Strain of the plates depends upon welding stresses:

$$f = 0.613 l \sqrt{\frac{\sigma - \sigma_{cr}}{E}}, \quad (2)$$

where l is the plate length; σ_{cr} is the critical value of welding stresses which are determined using formula

$$\sigma_{cr} = \frac{\pi^2 E}{12} \left(\frac{\delta}{l}\right)^2, \quad (3)$$

where δ is the plate thickness. At $\sigma > \sigma_{cr}$ deformation of the plate occurs.

It follows from the expressions presented above that welding stresses depend upon strain of the plate:

$$\sigma = \frac{f^2 E}{0.613^2 l^2} + \frac{\pi^2 E}{12} \left(\frac{\delta}{l}\right)^2. \quad (4)$$

By means of the running energy reduction at increase of the welding speed the welding stresses reduce (Figure 2) which significantly increases crack resistance and impact toughness of the welded joints that qualitatively characterizes crack resistance and depends upon structure of the deposited metal.

Influence of the electrode shape and running energy on structure of the deposited metal was established at five-layer hardfacing of plates of $(30 \times 300 \times 400) \cdot 10^{-3}$ m size using wire of $4 \cdot 10^{-3}$ m diameter and tape of $(0.5 \times 45) \cdot 10^{-3}$ m size, which was arranged in longitudinal and cross directions, and the built-up electrode. Hardfacing was carried out using the ZhSN-5 ceramic flux under optimum for each method conditions. Hardfacing using the Sv-08G2S wire electrode of 4 mm diameter was performed under the conditions: current — 650–750 A; arc voltage — 31–33 V; welding speed — $(0.56, 0.83$ and $1.10) \cdot 10^{-2}$ m/s. Hardfacing using the built-up electrode, consisting of the Sv-08G2S wire of 4 mm diameter and tape from the 08kp (rimmed) steel of 0.5445 mm^2 section, was performed under the conditions: current — 1950–2050 A, arc voltage — 29–31 V; welding speed — $(1.4, 2.1$ and $2.8) \cdot 10^{-2}$ m/s. Running energy for each method of welding varied within q_e/v = 1.8, 2.7 and 3.6 MJ/m.

Crack resistance of the deposited metal is determined to a great degree by welding stresses in it which are summed up at hardfacing. In connection with the fact that hardfacing of the wear-resistant layer is performed using five and more runs, welding stresses sharply increase. Due to summing of the welding stresses, thickness of the deposited layer is limited by 25 mm, while increase of these values causes significant increase of welding stresses and formation of spallings in zone of fusion with the base metal which was confirmed in hardfacing of traveling rolls of the mill 1700. The investigations were carried out at a five-layer hardfacing. Properties of the weld metal were determined by investigation of its structure and measurement of the tempering zone and impact toughness of the welded joints.

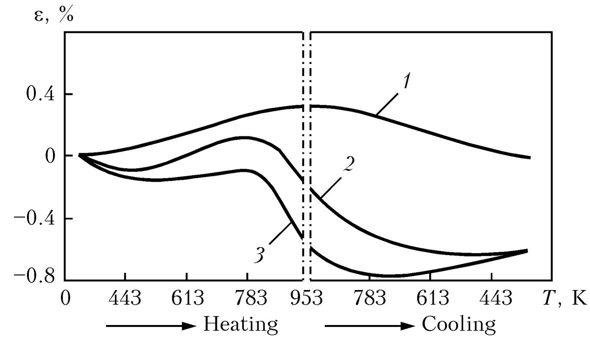

Figure 1. Curves of HAZ thermal strain cycle obtained in direction of hardfacing with application of built-up electrode (q_e/v = 3.6 MJ/m) at distance $5 \cdot 10^{-3}$ m from fusion zone: *1* — free strains; *2* — observed strains; *3* — natural strains

It was established that at increase of the heating and cooling rates structure of the deposited metal gets refined, contact area and interatomic bond forces increase, and crack resistance gets higher. In hardfacing using the tape, arranged in longitudinal direction, structure of the deposited metal is coarse-grain and inhomogeneous, in case of perpendicular arrangement of the tape the structure gets refined insignificantly and remains the coarse-grain one. In hardfacing using wire and built-up electrodes also refining of the deposited metal structure occurs, it gets finely dispersed and homogeneous and represents a ferrite-cementite mixture.

In similar way gets refined structure of the deposited metal and HAZ in high-speed hardfacing at low running energy (Figure 3) because of increase of the

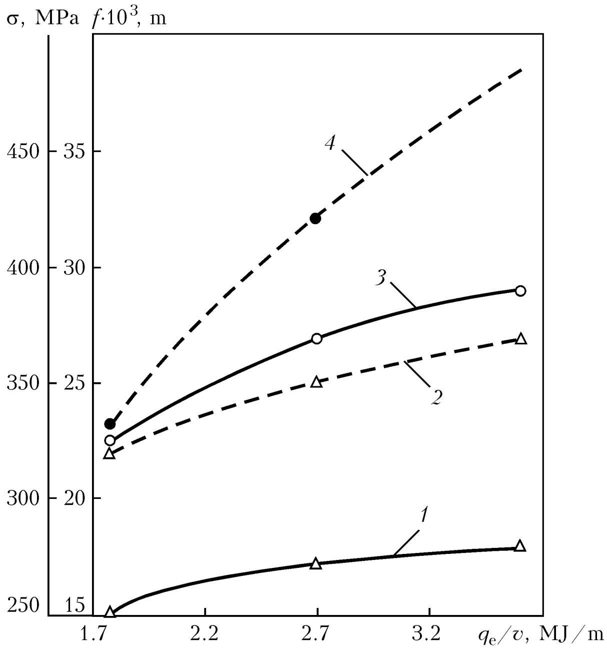

Figure 2. Dependence of welding stresses σ (*3, 4*) and strains f (*1, 2*) in plates of $(8 \times 120 \times 900) \cdot 10^{-3}$ m (dash curves) and $(30 \times 120 \times 900) \cdot 10^{-3}$ m (solid lines) size upon running energy of welding

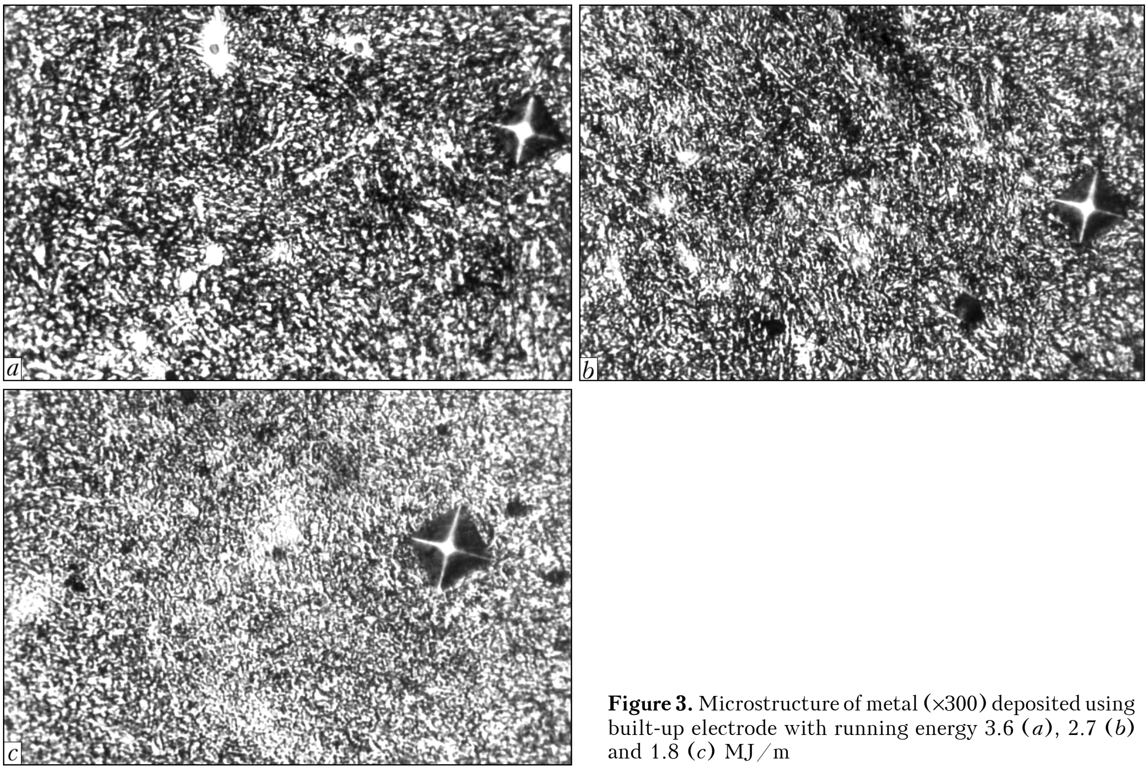

Figure 3. Microstructure of metal (×300) deposited using built-up electrode with running energy 3.6 (*a*), 2.7 (*b*) and 1.8 (*c*) MJ/m

heating, cooling and solidification rates in proportion to the hardfacing rate. Because of minimum microdistortions of the crystalline lattice, changes of microstresses, density of dislocations and fine-dispersed homogeneous structure, crack resistance increases, and joints, produced at low running energy, are characterized by high impact toughness and strength characteristics.

Measurements of impact toughness were performed on welded joints of the 09G2S steel. The 9KhF and 09G2S steels have different chemical composition and propensity to formation of hardening structures. As in hardfacing of the 9KhF high-carbon steels it is difficult to avoid cracks, so in welding of the 09G2S steel it is difficult to ensure impact toughness which would qualitatively characterize crack resistance.

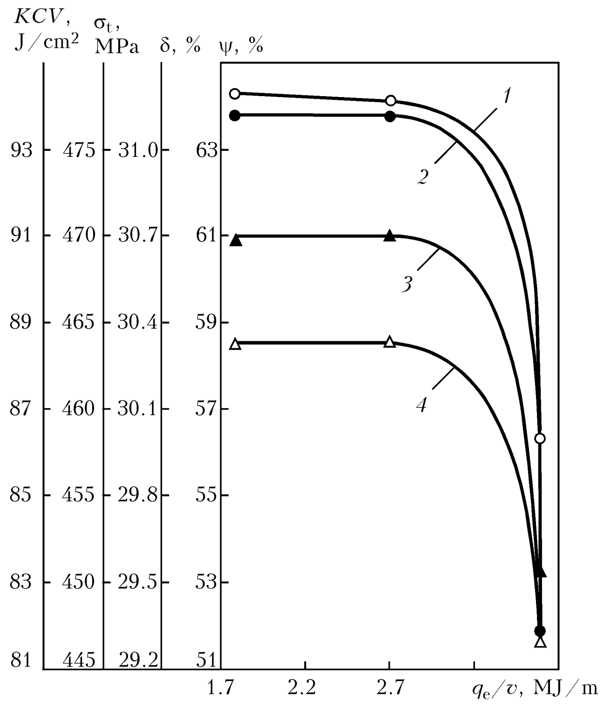

Figure 4. Mechanical properties of welded joints at one-sided welding using built-up electrode: *1* — tensile strength σ_t; *2* — impact toughness KCV; *3* — reduction in area ψ; *4* — relative elongation δ

At increase of the welding speed up to 0.021 m/s and reduction of running energy up to 2.7 MJ/m impact toughness first sharply increases and then remains practically invariable (Figure 4). At increase of the welding speed growth of the impact toughness occurs due to refining of the deposited metal structure and reduction of the crystalline lattice distortions, microstresses and density of dislocations, with which origination of the cracks is associated [10]. Similar to impact toughness, under the same conditions change ultimate strength, relative elongation and reduction in area. High values of impact toughness, relative elongation and reduction in area prove increased crack resistance of the deposited metal.

Tensile strength at increase of the welding speed and reduction of running energy gets higher. Its high values and high values of impact toughness and relative elongation are achieved at running energy 2.7 MJ/m and lower, which is confirmed by results of the experiments.

Similar data were obtained in investigation of the electrode shape and running energy influence on static fracture (Figure 5) on specimens of $(957 \times 5520) \cdot 10^{-3}$ m size with V-notch. It was determined that maximum value of static load is ensured at the running energy value 2.7 MJ/m and lower.

It was established in five-layer hardfacing using the ZhSN-5 flux that by means of increase of its rate due to increase of the cooling rate and dispersity of the deposited metal structure, microhardness of the metal gets higher. In HAZ microhardness, measured

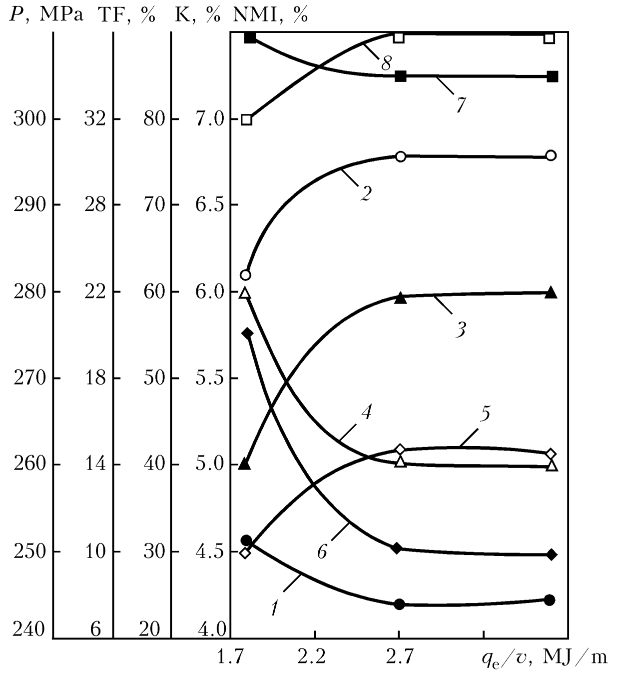

Figure 5. Influence of electrode shape and running energy on quality of welded joints produced with application of wire (*1, 3, 5, 7*) and built-up electrode (*2, 4, 6, 8*): *1, 2* — static load *P*; *3, 4* — non-metal inclusions (NMI); *5, 6* — tough fracture (TF); *7, 8* — quasi-spalling (K)

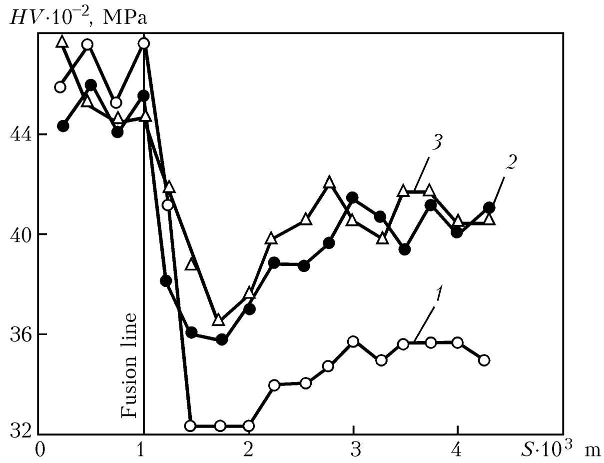

Figure 6. Influence of running energy on microhardness *HV* of deposited metal: *1* — q_e/v = 3.6; *2* — 2.7; *3* — 1.8 MJ/m; *S* — HAZ width

by the PMT-3 hardness gauge with automatic loading, reduces (Figure 6). Size of the tempering zone depends upon the electrode shape. Its minimum size is characteristic for hardfacing using the tape arranged perpendicularly, which is the result of minimum heat input into side edges of the pool. At longitudinal arrangement of the tape, tempered zone size increases. Use of wire and built-up electrode (Figure 6) increases of the tempered zone size due to increase in heat input into side edges of the pool.

At increase of the hardfacing rate size of the tempering zone reduces as a result of running energy lowering (see Figure 6) which matches available data [11]. Reduction of size of this zone increases resistance against lamination (because in this zone cold cracks may form), improves quality of the deposited metal, and reduces specific loads in rolling which increases wear resistance of the rolls.

At high-speed hardfacing in case of the running energy reduction, penetration depth and share of the base metal participation reduce, gradient of carbon concentrations increases and its diffusion in HAZ into the weld metal intensifies. As a result carbon equivalent in HAZ equals less than 0.45 and cracks do not form.

Despite the fact that the investigations were carried out only for the 09G2S steel, the data obtained were confirmed in hardfacing of the shrouded traveling rolls from the 9KhV steel, because in high-speed hardfacing at a low running energy welding stresses significantly reduce, structure of the deposited metal gets refiner, ductility increases, the HAZ size and specific pressure in rolling of the metal reduce, that excludes failure of the shrouds and increases crack resistance of the deposited shrouded traveling rolls.

For increasing wear resistance of the shrouded traveling rolls, the energy conservation method of high-speed hardfacing at low running energy was developed [12]. High-speed hardfacing of the shrouded traveling rolls was performed with preliminary and accompanying heating up to 300–350 °C. First a buffer layer was deposited using the Sv-08G2S wire of 5 mm diameter and the AN-60 flux, and then — the wear-resistant layer. Its hardfacing was performed using the Sv-08G2S wire of 5 mm diameter and the ZhSN-5 ceramic flux at running energy 1.3 MJ/m under the following conditions: current — 750–800 A; arc voltage — 32–34 V; hardfacing rate — 75 m/h. After hardfacing heat treatment and slowed cooling were performed.

Energy conservation method of high-speed hardfacing at low running energy was developed which ensures minimum welding stresses, formation of a fine-dispersed homogeneous structure of the deposited metal and, as a result, high crack and wear resistances of the shrouded traveling rolls.

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