the following sequence: welding up the root pass and groove root in the area of the cladding layer — by austenitic material of 04Kh20N9G2B type; making the transition weld from low-carbon ferrite metal (Armco-iron); filling the groove with electrode material, designed for welding the base weld (Sv-08G1NMA, Sv-10GNMA in argon-arc welding, PT-30 electrodes in manual arc welding) with compulsory preheating and concurrent heating; performance of local high-temperature tempering of the joint. Such an approach ensures a uniform structure and low level of residual (after tempering) stresses in the zone of welded joint of the base low-alloyed layer that should improve the service reliability of the joint as a whole.

Thus, the result of the performed work is confirmation of basic possibility of performance of welding from one side of pipe butt joints of clad 10GN2MFA steel. A feature of the proposed development is making the transition weld with low-carbon ferritic metal to eliminate formation of brittle interlayers. Application of the developed technology allows considerably lowering the labour cost, and improving the sanitary-hygienic working conditions of personnel. The proposed approach also allows replacing the traditional technology of welding the clad pipes using austenitic weld metal by making a ferritic weld that enables improvement of welded joint strength.

1. Kakhovsky, N.I. (1975) *Welding of high alloy steels*. Kiev: Tekhnika.
2. Fartushny, V.G., Evsyukov, Yu.G. (1977) Transition welds in welding of two-layer steels. *Avtomatich. Svarka*, **10**, 30–33.
3. Zemzin, V.N. (1966) *Welded joints of dissimilar steels*. Moscow; Leningrad: Mashinostroenie.
4. Gotalsky, Yu.N. (1981) *Welding of dissimilar steels*. Kiev: Tekhnika.
5. Kasatkin, O.G., Tsaryuk, A.K., Skulsky, V.Yu. et al. (2007) Method for improving local damage resistance of welded joints in NPP pipelines. *The Paton Welding J.*, **3**, 27–30.
6. Tsaryuk, A.K., Skulsky, V.Yu., Kasperovich, I.L. et al. (2006) Development and certification of automatic narrow-gap argon-arc welding technology of MPC Dn 850 elements at NPP. *Ibid.*, **5**, 19–25.

# CHROMIUM-MANGANESE CONSUMABLES FOR WELDING OF HIGHER-STRENGTH STEELS WITHOUT PREHEATING AND HEAT TREATMENT

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Data on new chromium-manganese electrodes of grades ANVM-2, ANVM-3 and flux-cored wire PP-ANVM-3, designed for welding and surfacing of higher strength steels, are given. The paper presents the results of the evaluation of the structure and mechanical properties of welded joint metal made with new welding consumables, as well as areas of their application.

***Keywords:*** *arc welding, chromium-manganese electrodes, flux-cored wire, alloyed carbon steel, austenitic weld metal, fusion zone, mechanical properties, area of application*

Current mining, metallurgical and other branches of machine building provide for a manufacture of different parts and assemblies from alloyed steels 40Kh, 30KhGSA and others of high strength $\sigma_t$ = 600–800 MPa and higher. The necessity of application of preheating and post-weld tempering is caused by the cold cracks that can be formed in welding of such hardenable steel. This complicates a technological process and can be impossible during manufacture of massive large dimension parts.

High-alloy nickel welding consumables Sv-08Kh20N25G8M6, Sv-08Kh20N9G7T and others providing formation of austenite weld metal structure are as a rule used for welding of the hardenable steels in order to avoid performance of labor-consuming thermal operations. Low strength of the austenitic weld metal provides a necessity of its performance with high reinforcement in order to increase strength of the welded joint. Labor-intensiveness of welding and consumption of expensive welding consumables dramatically increase due to this. At that rising of concentration of stresses in the places of transfer from thickened weld to base metal results in reduction of working capacity of the welded joint.

Application of Cr–Mn alloying system ($\sigma_t$ = = 590–690 and 980 MPa) at 0.2 and 0.4 wt.% C

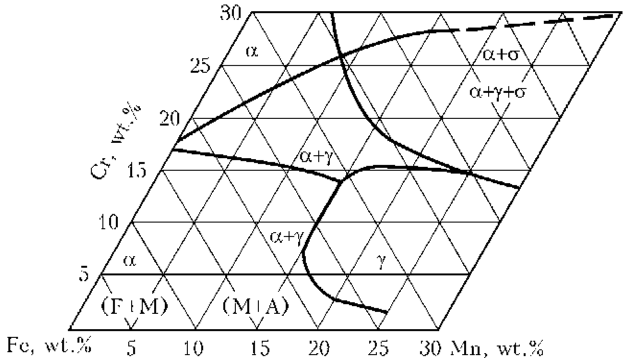


**Figure 1.** Constitutional diagram of steels of Fe–Cr–Mn system [1, 3]

[1] provides increased strength of the austenite steels and welds. For comparison [2] $\sigma_t$ of Cr–Ni steels and welds makes 485–580 MPa. Increase of C + N up to 1.6 % promotes linear rise of the strength properties of Cr–Mn metal up to $\sigma_t$ = = 1220 and $\sigma_{0.2}$ = 800 MPa [3–5].

Aim of the present work is a development of welding consumables providing the austenitic Cr–Mn weld metal with increased strength and working capacity of welded joints from hardenable steels being welded without preheating and heat treatment.

Austenite structure of low-carbon steel is formed at content of more than 3–7 wt.% Cr and not less than 15 wt.% Mn in it in accordance with the constitutional diagram of steels of Fe–

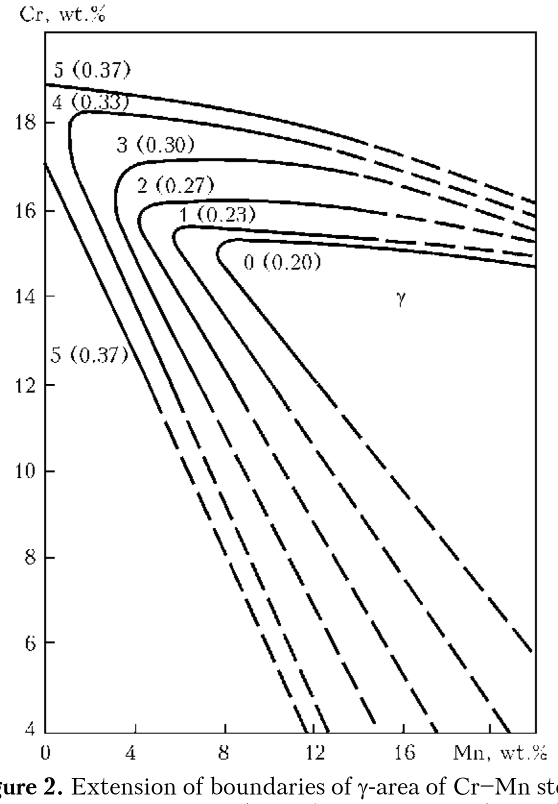


**Figure 2.** Extension of boundaries of γ-area of Cr–Mn steels containing 0.10–0.12 wt.% C and 0.08–0.15 wt.% N at their alloying by nickel (figures — content in weight percents) [2, 3] or in increase of total C + N content (figures in the brackets): dashed lines — data extrapolation

Cr–Mn system (Figure 1) [1, 3]. Minimum content of manganese necessary for obtaining of the austenitic metal with 0.10–0.12 wt.% C and 0.08–0.15 wt.% N can be reduced up to 8 wt.% rising the chromium content up to 15 wt.% (Figure 2) [2, 3]. Additional alloying by nickel up to 5 wt.% provides a reduction of manganese and chromium. Increase of the total content of carbon and nitrogen by 5/30 = 0.17 wt.% corresponds to the mentioned above (as for equivalent influence on the structure). Rise of concentration of the latter from 0.20 up to 0.37 wt.% gives the possibility for reduction of the total content of chromium and manganese from 22.5–28.0 up to 16.5–17.0 wt.% (extrapolated in area of small values of chromium given in Figure 2). Crack formation (Table 1) was experimentally detected in the welds with 16.9 wt.% total content of chromium and manganese and less and 0.08–0.11 wt.% C due to occurrence of martensite constituent and increase of metal hardness.

Batches of Cr–Mn electrodes of 3–5 mm diameter with coefficient of coating weight 0.9–1.0 and flux-cored wire of 2.8 mm diameter with coefficient of filling 0.42 were manufactured considering mentioned above. The rods and strips Sv-08, Sv-08A, Sv-08kp (rimmed) of 0.4 × × 12.0 mm cross section from low-carbon steel were used at that. Alloying of the weld metal (deposition) was provided by the components in composition of the electrodes and core of the flux-cored wire, i.e. metal chromium and manganese, nitrated manganese, ferrovanadium, electrode graphite (crystalline), as well as ferrotitanium, preventing manganese oxidation. Dolomite or marble, fluorite and feldspar, forming basic slag [($CaO$ + $MgO/SiO_2$ > 5], carbon oxide and carbon dioxide during melting and dissociation, provide the gas-slag shielding of welding zone. Stable arcing at that is provided through introduction of alkali and alkali-earth elements in the arc atmosphere. Interaction of $CaF_2$ and $SiO_2$ with formation of gaseous $SiF_4$ is accompanied by bounding of hydrogen into insoluble in liquid metal HF that promotes the

**Table 1.** Effect of chemical composition (wt.%) on crack resistance of Cr–Mn weld metal

| C | Cr | Mn | Si | Ti | Cr + Mn | Presence of cracks |
|---|---|---|---|---|---|---|
| 0.10 | 8.9 | 18.4 | 0.22 | 0.07 | 27.3 | Not |
| 0.08 | 6.3 | 16.4 | 0.20 | 0.09 | 22.7 | Same |
| 0.08 | 8.8 | 12.4 | 0.21 | 0.17 | 21.2 | » |
| 0.08 | 6.8 | 10.1 | 0.22 | 0.18 | 16.9 | Yes |
| 0.11 | 3.5 | 4.8 | 0.21 | 0.16 | 8.3 | Same |

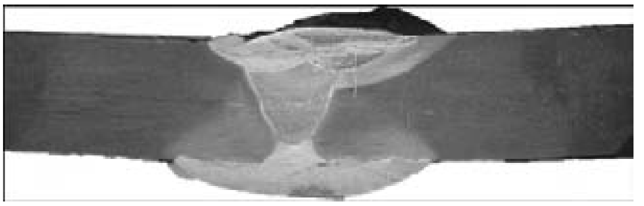

**Figure 3.** Macrostructure of 30KhGSA steel butt joint with austenitic Cr–Mn weld obtained using pilot consumables

rapid reduction of porosity [6] in combination with the increased solubility of hydrogen in austenitic weld metal. A rutile was introduced in the flux-cored wire instead of feldspar.

Application of clean charge materials with regard to sulfur (≤0.02 wt.%) and phosphorus (≤0.03 wt.%), small content of silicon with maintaining of Si/C << 5, replacement of nickel by manganese in combination with introduction of nitrogen in the metal, and high basicity of formed slag are the basis for preventing of formation of the hot cracks in austenitic welds [2]. Crack resistance of the austenitic welds possibly increases as a result of the additional refining and disorientation of metal structure through its alloying by vanadium and modification using present dispersed chromium and titanium oxides [2].

Manual and mechanized welding (surfacing) of 40Kh, 30KhGSA, 18G2AF, 15Kh5M, 20, 09G2S and 110Kh13L steels (in similar and dissimilar combinations) by Cr–Mn electrodes and self-shielded flux-cored wire in keeping of $I_w$ = = 90–180 and 250–350 A and $U_a$ = 28–32 V are characterized by stable arcing, moderate spattering of electrode metal, acceptable separability of slag crust and satisfactory formation of the welded joint without cracks and pores (Figure 3). However, increase of diameter of coating of the electrodes with 4 and 5 mm core up to 8.3–9.8 mm complicates their operation at small edge opening that can result in defect formation in the root part of the joint. Defect-free joints are obtained in performance of the root weld using the electrodes with 3 mm diameter core and 6.6–6.8 mm diameter coating.

Chemical composition of the weld metal (deposit) made using developed electrodes and flux-cored wire changes in the following limits, wt.%: 0.10–0.39 C; 7.5–10.2 Cr; 16.5–25.8 Mn; 0.42–0.56 Si; 0.05–0.12 Ti; ≤0.4 V; ≤0.2 N; 0.010–0.025 S and 0.02 and 0.03 P at Cr + Mn = 26.5–35.9. Weld metal has mainly austenite structure (Figure 4, *a*). Hardness *HV* 180–260 in the weld metal of 15Kh9G19AT type is commensurable with the hardness of austenitic Cr–Ni weld (*HV* 190–280) performed by LO-1 electrodes [7], and weld metal of 35Kh9G22FT type has *HV* 260–306, higher values of which correspond

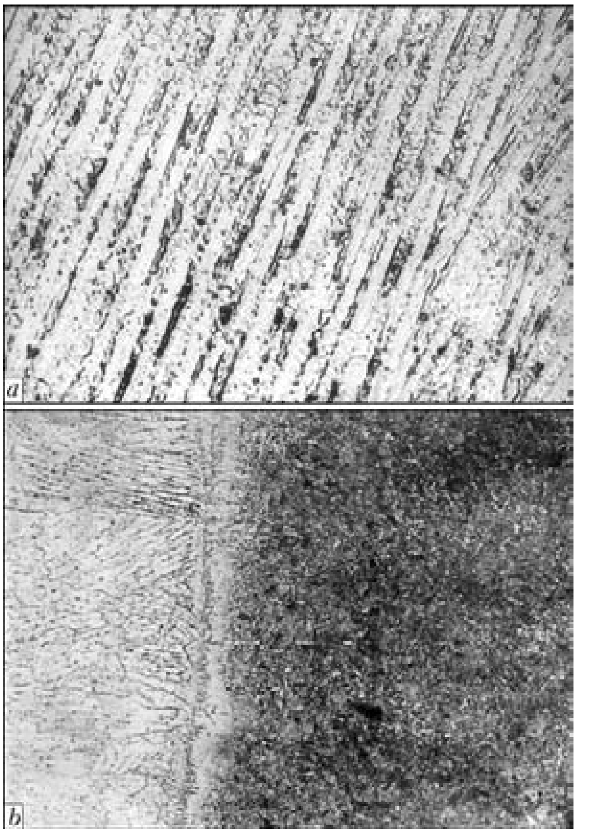


**Figure 4.** Microstructures (×400) of weld metal of 35Kh9G22FT type (*a*) and its fusion zone with alloyed steel 30KhGSA (*b*)

to its root part with increased portion of the base metal (Figure 5).

More intensive mixing of a weld pool and possibility of reduction of thickness of transition layer of the weld near the base metal are caused by decreased toughness and surface tension of manganous melt with respect to chromium-nickel one [8]. Martensitic Cr–Mn interlayer (Figure 4, *b*) formed in the transition layer is comparable with the Cr–Ni one on thickness and hardness. Thickness of the transition layer and martensitic interlayer as well as hardness of the latter reduce with the increase of total content of chromium and manganese and, thus, resource of austenite

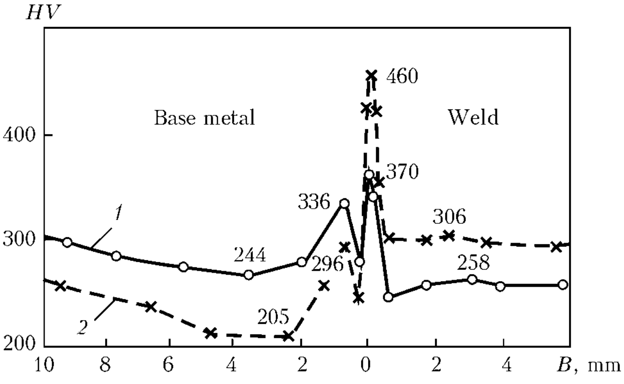


**Figure 5.** Distribution of hardness in cross section of the heat hardened steel 30KhGSA welded joint with weld metal of 35Kh9G22F type in the upper (*1*) and root (*2*) part

**Table 2.** Influence of type of weld metal alloying on transition layer parameters

| Type of alloying | Thickness, μm | | Hardness *HV* |
|---|---|---|---|
| | Transition layer | Martensitic interlayer | |
| 10Kh9G19AT | 10–22 | 4–10 | 288–415 |
| 10Kh9G14AT | 14–26 | 6–15 | 440–600 |
| 08Kh20N9G7T | 12–24 | 4–15 | 325–415 |
| 08Kh20N9T | 18–29 | 6–18 | 415–512 |

level of the weld metal (Table 2). Nitrogen in the weld metal provides reduction of the specified parameters of the fusion zone, structural-and-mechanical inhomogeneities in it, tendency to hardening of transition zone metal, and promotes increase of portion of residual austenite with significant refinement of structural components of the martensitic interlayer [9, 10]. Additional increase of content of Cr + Mn and carbon in the weld metal without nitrogen introduction (type of alloying 35Kh9G19FT) does not promote significant change of hardness (*HV* 370) of the martensitic interlayer. Larger rise of its hardness up to *HV* 460 takes place in the root part of the joint with increased portion of base metal in the weld metal.

Smaller local rises of hardness of the hardenable steel welded joint are also observed in a short distance from the weld (0.6–0.8 mm) where the metal experienced the phase transformations in a process of welding (Figure 5). Hydrogen diffusion from the base metal in the weld pool levels such a rise and provokes a local decrease of hardness of HAZ metal in areas of 0.1–0.3 mm width close to the weld. Heating up to tempering temperature in welding provides softening of HAZ metal in several millimeters distance from the weld. Its larger softening takes place in the root part of multilayer joint subjected to repeated welding heating.

Investigations of stressed state of the welded joints of 30KhGSA steel and resistance of metal of fusion zone to cold crack formation were carried out on the procedure [11] developed at the E.O. Paton Electric Welding Institute. It was determined that the temporary (at 450 °C) and residual stresses made 30–65 and 105–160 MPa, respectively, in welding by 35Kh9G22FT type flux-cored wire with formation of austenitic weld metal. They are virtually the same as in welding using austenite wires Sv-08Kh16N25M3 and Sv-08Kh20N9G7T (Table 3), and welding speed decrease promotes their increase. High values of the temporary (30–75 MPa) and residual (90–160 MPa) stresses are also found at 0.15 wt.% C and the total content of chromium and manganese 25.7–31.4 wt.% (Table 4). Increase of temperature interval of transformations of supercooled austenite in the metal of near-weld zone of hardenable steel is observed, tempering and reduction of tetragonal structure of formed martensite with rise of possibility of its crystals to microplastic deformation and relaxation of local microstresses take place, resistance to delayed fracture of the welded joints [12] significantly rises under the effect of increased temporary welding stresses in a presence of high-alloyed weld metal. No fracture of the samples after welding without preheating is found in delayed fracture testing after cooling up to 50–20 °C.

**Table 3.** Influence of type of electrode metal alloying on stresses in welded joints

| Type of alloying | Welding speed, m/h | Stresses, MPa, at temperature, °C | |
|---|---|---|---|
| | | 450 | 20 |
| 35Kh9G22FT | 8<br>12 | 65<br>30 | 160<br>105 |
| 08Kh16N25M3 | 8<br>12 | 60<br>35 | 150<br>100 |
| 08Kh20N9G7T | 8<br>12 | 60<br>40 | 145<br>110 |

**Table 4.** Effect of chromium and manganese in weld metal (0.15 wt.% C) on temporary and residual stresses in welded joints

| Weight fraction of elements, % | | | Stresses, MPa, at temperature, °C | |
|---|---|---|---|---|
| Cr | Mn | Cr + Mn | 450 | 20 |
| 7.5 | 19.5 | 27.0 | 30 | 110 |
| 9.0 | 19.8 | 28.8 | 47 | 140 |
| 10.2 | 19.3 | 29.5 | 60 | 155 |
| 9.2 | 16.5 | 25.7 | 42 | 90 |
| 9.0 | 19.5 | 28.5 | 50 | 150 |
| 9.4 | 22.0 | 31.4 | 75 | 160 |

Table 5 shows the mechanical properties of metal of the welds. Increase of strength with rise of carbon content is accompanied by reduction of ductility and toughness of Cr–Mn weld. Austenitic weld metal has hardness *HRC* 21–22 in as-welded condition and *HRC* 39–50 after cold plastic deformation.

**Table 5.** Mechanical properties of Cr–Mn weld metal

| Type of metal | $\sigma_{0.2}$, MPa | $\sigma_t$, MPa | δ, % | ψ, % | *KCU*, J/cm$^2$ |
|---|---|---|---|---|---|
| 15Kh9G19AT | 380–540 | 610–720 | 20–46 | 38–46 | 95–140 |
| 35Kh9G22FT | 420–610 | 670–760 | 21–28 | 34–36 | 110–190 |

Fracture of the 30KhGSA steel welded joints in as-delivery condition and after heat strengthening (from $\sigma_{0.2}$ = 830 and $\sigma_t$ = 935 MPa) with $\sigma_t$ = 725–730 and 910 MPa, respectively, takes place along the base metal or area of softening. Fracture of special cylinder sample with cavity (stress concentrator) in the fusion zone takes place along the weld near the fusion zone at $\sigma_t$ = = 795 MPa. Obviously, that the martensitic interlayer in the fusion zone of Cr–Mn weld with alloyed steel provides no limitation of working capacity of the welded joint at static loading. Impact toughness of the samples with notch along the fusion zone of the welded joints of hardenable steel makes $KCU_{+20}$ = 63–124 and $KCU_{-40}$ = = 17.5–23.6 J/cm$^2$. The fractures take place along the near-weld zone or more distant from the weld areas of HAZ metal without detection of influence of martensitic interlayer.

Specific emissions of solid constituent of the welding fumes containing, wt.%: 27 Fe, 21 Mn, 2.3 Cr, 2 silicon oxide, 5 fluoride 5, make 29 g/kg of consumed electrodes, as was determined in a course of hygiene and sanitary investigations. Cr–Mn electrodes are close to high-alloyed Cr–Ni–Mn electrodes on indices of emission of harmful substances. New consumables are permitted for application with a local exhaust ventilation. Application of individual facilities for defense of respiratory organs is possible, if necessary.

Developed electrodes ANVM-2 and ANVM-3 (deposited metal of 15Kh9G19AT and 35Kh9G22FT type) as well as self-shielded flux-cored wire PP-ANVM-3 were industrially tested at PJSC «Krivoj Rog Mining Equipment Plant» in welding without preheating and heat treatment of the butt joints of 20Kh2NM and 30KhGSA steels, welding-in of cast defects and welding of bucket teeth. It was also determined that the Cr–Mn electrodes can be used for welding of steel saturated with sulfur and other surface and internal impurities. This allows performing quick welding repair without cleaning of difficult-to-access areas damaged during operation of parts. It is not reasonable to use the Cr–Ni electrodes for that due to bad formation of the welds and development of the hot cracks. The Research Center «Consumables for Welding and Surfacing» of the E.O. Paton Electric Welding Institute mastered manufacture of the Cr–Mn consumables. They are 2–3 times cheaper than the Cr–Ni welding consumables.


1. Khimushin, F.F. (1962) *Alloying, heat treatment and properties of heat-resistant steels and alloys*. Moscow: GNTIO.
2. Kakhovsky, N.I. (1975) *Welding of high-alloy steels*. Kiev: Naukova Dumka.
3. Pridantsev, M.V., Talov, N.P., Levin, F.L. (1969) *High-strength austenitic steels*. Moscow: Metallurgiya.
4. Pikering, F.B. (1982) *Physical materials science and development of steel*. Moscow: Metallurgiya.
5. Sagaradze, V.V., Uvarov, A.I. (1989) *Strengthening of austenitic steels*. Moscow: Nauka.
6. Pidgaetsky, V.V. (1970) *Pores, inclusions and cracks in welds*. Kyiv: Tekhnika.
7. Snisar, V.V., Demchenko, E.L., Gajvoronsky, A.A. (1993) Influence of structure on properties of heat-affected zon of 30Kh2N2M steel welded joint. *Avtomatich. Svarka*, **9**, 43–45.
8. Ershov, G.S., Bychkov, Yu.G. (1983) *Properties of metallurgical melts and their interaction in steelmaking processes*. Moscow: Metallurgiya.
9. Elagin, V.P., Snisar, V.V., Savitsky, M.M. et al. (2001) Chemical and structural inhomogeneity in the zone of fusion of low-carbon steel with austenitic weld during shielded-gas welding. *The Paton Welding J.*, **4**, 7–12.
10. Snisar, V.V., Elagin, V.P., Grabin, V.F. et al. (1999) Effect of nitrogen and oxygen in shielding atmosphere on structure and properties of fusion zone of austenitic metal with low-alloy steel. *Avtomatich. Svarka*, **7**, 15–19, 48.
11. Sterenbogen, Yu.A., Vasiliev, D.V. (1998) New procedure and energy criteria in evaluation of resistance of welded joint metal fusion zone to cold cracking. *Ibid.*, **6**, 2–8.
12. Gordonny, V.G., Gajvoronsky, A.A., Sarzhevsky, V.A. (1992) Influence of weld metal type on structure, properties and resistance of high-strength hardenable steels to cold cracking. *Ibid.*, **11/12**, 13–18.