New materials for welding and surfacing

N A Kozyrev, G V Galevsky, R E Kryukov, D A Titova and V M Shurupov
Institute of Metallurgy and Materials Science, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia

E-mail: kozyrev_na@mtsp.sibsiu.ru

Abstract. The paper provides description of research into the influence of new materials and technologies on quality parameters of welds and deposited metal carried out in the research and production centre “Welding processes and technologies”. New welding technologies of tanks for northern conditions are considered, as well as technologies of submerged arc welding involving fluxing agents AN - 348, AN - 60, AN - 67, OK.10.71 and carbon-fluorine containing additives; new flux cored wires and surfacing technologies, teaching programs and a trainer for welders are designed.

1. Introduction
The basic requirement of industrial safety consists in assuring the needed level of mechanical characteristics of a weld. Here, mechanical characteristics are pre-determined by non-metallic impurity degree and total content of gas in a weld. Most non-metallic impurities in welds are oxide ones irrespectively to their exogenous or endogenous nature, the quantitative and qualitative composition of the latter depends on the total concentration of oxygen. The issue of new fluxes and their additives development has been currently attracting much attention, as well as the research into their influence on welding and technological characteristics of a weld and on the concentration of oxygen and non-metallic impurities in a weld [1-5].

2. Materials and methods of research
Most grades of the domestically produced fluxes, applied for welding low-alloyed steels, are oxidizing ones and ground on silicon-manganese oxidation-reduction processes. Here, the products of these reactions are oxide compounds of silicon, manganese, ferrum, aluminum etc., which often cannot surface and assimilate by the slag formed from a welding flux; as a result, the level of impurity of weld metal by non-metallic admixtures increases, causing deterioration of physical and mechanical characteristics. Obviously, reducing agents forming gaseous products of reactions should be applied in order to avoid impurity of weld metal. Carbon can serve as a reducing agent forming gaseous compounds CO₂ and CO when reacting with oxidizers.

Taking into account these pre-conditions a series of research activities has been carried out into the influence of additives to various fused and ceramic fluxes on the quality parameters of welds.

In recent years exploration of oil fields in the North has necessitated manufacturing of wall plates for bulk-oil tanks suitable for northern conditions. At JSC “Novokuznetsk Plant of Reservoir Metalwares” manufacture of tanks for northern conditions has been developed according to “Standards of vertical cylindrical steel tanks for oil and oil products”PB-03-605-03 and Construction norms and regulations (SNiP) II – 23-81.
The technological process of assembling, welding, controlling and rolling of wall plates is performed on special roll facilities. Silicon-manganese steel 09G2S (State Standard (GOST) 6713-91) is used for tanks manufacturing. As a result, an optimal technology has been developed for two-side welding of tank wall plates operating in low temperature conditions: inside the tank it is welded by Sv-08GA wire (on the upper tier) with mixed fluxing agents AN-67B and AN-348A taken in proportion 1:1, outside the tank it is welded by Sv-10NMA wire (on the lower tier) with welding fluxes AN-60 and AN-348A taken in proportion 1:1. Flaw welding was carried out up to 18 mm of plate thickness. On the upper tiers flat butt welds are made at reduced power modes, which provide penetration into metal up to 0.55 of plate thickness. On the lower tier the welding was carried out in the conditions of high current providing penetration up to 0.7 of plate thickness.

Weld metal consists principally of re-melted base 09G2S and added Sv-10NMA metals. The mechanical properties of joint welds and welds were determined at temperature 20°C, impact strength of weld metal and thermal impact zone KCU were measured at temperature -50°C. Mechanical characteristics and impact strength of a weld and thermal impact zone exceeded the required normalized values.

The developed technology made it possible to obtain a range of required mechanical properties and the impact strength of tank metalwares at temperatures below zero, avoid defects – cracks during manufacturing [6]. This technology was patented in the Russian Federation [7, 8].

The influence of carbon and fluorine containing additive to AN-348, AN-60, AN-67 fluxing agents and imported fluxing agent OK.10.71 on refinement of weld metal was experimentally tested [9,10]. As a result, it was found out, that the growing content of carbon and fluorine-containing additive in various fluxing agents at a permitted slight increase of carbon concentration (Figure 1) causes the drop of total concentration of oxygen in the weld (Figure 2), and considerable improvement of mechanical properties, especially of impact strength at temperatures below zero (Figure 3).

Fraction gas analysis conducted by the method of reduction melting using the gas analyzer “LECO” TC-600 revealed that the redistribution of oxygen in impurities depends on oxidation and basicity of slag system.

The designed submerged arc welding technology of metalwares, operating in the conditions of extremely low temperatures, relies on theoretical pre-conditions and practical try-out of carbon and fluorine-containing additive technology. The flux of FD-UFS additive is produced by JSC “Novokuznetsk Plant of Reservoir Metalwares n.a. N.E. Kryukov”. The proposed welding technologies of metalware welding involving flux-additive are patented in the Russian Federation [11], the composition of the new basic welding flux is also patented in the Russian Federation [12].

![Figure 1. Influence of carbon- and fluorine-containing additive on carbon concentration in a weld.](image-url)
Surfacing of forming rolls is widely applied at manufacturing enterprises in Russia for restoration and improvement of resistance. Despite a wide range of systems used for surfacing, two systems are applied more often: C–Si–Mn–Cr–W–V and C–Si–Mn–Cr–V–Mo.

One of the elements in the first system is PP-Np-35V9H3SF flux cored wire containing up to 10% of rare and expensive tungsten, applied for wear-resistant surfacing of steel rolls in different hot-rolled mills. The deposited metal is distinguished by a significant abrasion resistance at high temperatures, but its thermal resistance is quite low; therefore, rolls surfaced with the wire often fail because of erosion and chipping cracks. Sometimes stripe wear is caused by areas of deposited metal with inhomogeneous structure and hardness. Such areas can be found after multilayer surfacing of alloyed steels with overlapping of a bead made before.

Figure 2. Change in the total oxygen concentration in fluxing agents depending on carbon and fluorine additive.

![Figure 2](image_url)

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Figure 3. Change in the impact strength depending on carbon and fluorine additive concentration.

![Figure 3](image_url)
The surfaced metal of the same type as economically alloyed chromium-molybdenum and chromium-tungsten-molybdenum steels demonstrated good results after restoration of steel rolls at hot-rolled mills. These steels are not worse than chromium-tungsten ones in terms of heat resistance, and outperform them regarding thermal fatigue resistance. Vanadium alloying is also applied to improve the thermal resistance and abrasion strength of added metal.

Machining of deposited layer is rather difficult when surfacing rolls with complex grooves because of its relatively high hardness. Surfacing materials like martensite-ageing or disperse-hardening steels are promising ones for the above mentioned rolls. After being surfaced such steel have hardness to 28...35 HRC_E, and they are easy to be machined. After tempering the hardness increases up to 48...55 HRC_E, and the deposited metal gains sufficient service qualities. However, special equipment is needed for heat treatment.

The second system provides the highest thermal fatigue resistance of metal. This system represented by PP-Np-25H5FMS flux cored wire makes it possible to gain significant impact strength of the deposited metal at high temperatures.

As a result of laboratory and experimental-industrial research it is recommended to use PP-Np-35V9H9SF flux cored wire for surfacing rolls of continuous bar mills, pipe-rolling, and wire mills; and PP-Np-25H5FMS flux cored wire on blooming mills (blooming, slabbing), on heavy section and rail and structural steel mills, as well as on medium and small section sheet mills.

The samples of standard PP-Np-25H5FMS flux cored wire were fabricated in the laboratory conditions. Multilayer surfacing of samples was carried out with the preliminary heating of sheets up to 350°C and subsequent slowed cooling (after surfacing). 5-layer surfacing of 09G2S steel sheets was performed by welding tractor ASAW-1250 and fabricated flux cored wire; the surfacing conditions were: welding current I_a = 400 A, arc voltage U_d = 32 W, rate of welding u_s = 0.8 cm/s.

During fabrication of wire the concentration of silicon, manganese, chromium, vanadium was varied wider than the values of these elements required for PP-Np-25H5FMS wire by GOST 26101. Nickel was added to chemical composition of some samples, and amorphous carbon was changed into carbon and fluorine containing dust (wastes of metallurgical production), chemical composition was as follows, mass %: Al_2O_3 = 21 – 46; F = 18 – 27; Na_2O = 8 – 15; K_2O = 0.4 – 6%; CaO = 0.7 – 2.3; SiO_2 = 0.5 – 2.5; Fe_3O_4 = 2.1 – 3.3; C_eq = 12.5 – 30.2; MnO = 0.07 – 0.9; MgO = 0.06 – 0.9; S = 0.09 – 0.19; P = 0.10 – 0.18. The dispersion of this material enables good mixing with metal constituent of flux cored wire burden. Previously the conducted research into application of this material as an additive to welding flux agents revealed that carbon as a component of carbon and fluorine containing dust is super active, it deoxidizes metal and reduces oxides contained in metal and slag, as the result, carbon oxides are formed. To simulate oxidation and reduction processes, taking place during surfacing, the low oxidizing flux agent AN–67 was used according to GOST R 52222-2004. Manganese was not added to chemical composition of the wire because of its reduction from forming slag. Silicon was partially reduced from slag. The experiments demonstrated that the formed slag can hardly oxidize the alloying elements in the deposited metal.

The chemical composition of the deposited metal was determined by roentgen-fluorescent method with spectrometer XRF-1800 and by atom-emission method with spectrometer DFS-71. Metallographic research into micro-sections was carried out by optical microscope OLYMPUS GX-51 in bright field at different zooming modes after etching in the alcohol solution of nitric acid, as well as in solution of hydrofluoric acid. Hardness was measured by ultrasonic hardness testing instrument UZIT -3. The data on chemical composition of flux cored wires, hardness of the deposited metal and volume concentration of retained austenite are provided in Table 1.

When amorphous graphite was used as an additive, in the structure of deposited metal (samples 1 and 2) martensite and retained austenite in the axle spacing were found. Significant oxygen inclusion lines are found. Vanadium and chromium carbides are distributed over the grain. It should be noted that that introduction of more than 3% of vanadium caused a considerable drop in the deposited metal hardness.
Metallographic analysis demonstrated that the structure of metal surfaced by flux cored wire includes an acicular troostite with martensite and formed along the grain boundaries of separate thin austenite fringes containing some carbide impurities. Carbon- and fluorine-containing additive to wire burden facilitated removing of oxide non-metallic impurities, smoother distribution of carbon in the weld metal and formation of fine-dispersed carbides that in practice should lead to improvement of thermal strength.

Austenite-forming nickel added to the flux cored wire facilitated additional grain refinement. Introduction of the system \( \text{C-Si-Mn-Cr-V-Mo} \) carbon-fluorine containing additive and nickel into the wire would significantly decrease the level of oxide non-metallic impurities in the deposited metal, refine the grains, and forms fine-disperse carbides, improving thermal resistance of the forming rolls.

As we mentioned above the most loaded hot forming rolls are strengthened by surfacing with PP-Np-35V9H3SF flux cored wire according to GOST 26101-84 with high content of tungsten. From the experience of surfacing forming rolls and their operation we know that their wear of their surface does not occur evenly. In the process the forming rolls are subjected to cyclic thermo-mechanical stresses, corrosion and abrasive wear. Stripe wear, caused by the areas with the deposited metal of different structure and hardness, is possible. Such areas are observed after multilayer surfacing of alloyed steels with overlapping of the previously welded bead. The deposited metal of 35V9H3SF type has high wear resistance at increased temperatures, but its thermal strength is relatively low, therefore, rolls, surfaced with this wire, can often fail due to heat cracks and chipping.

**Table 1.** Chemical composition of the tested flux cored wires and hardness of the deposited metal of the system \( \text{C-Si-Mn-Cr-V-Mo} \).

| № | Mass concentration of elements, % | HRC (HB) | VCA  |
|---|----------------------------------|---------|------|
|   | C  | Si  | Mn  | Cu  | Cr  | Mo  | Ni  | Al  | W   | V   | Ti  |       |
| 1  | 0.16 | 1.77 | 2.25 | 0.26 | 3.51 | 1.51 | 0.16 | 0.044 | 0.107 | 3.25 | 0.018 | (186.2) | - |
| 2  | 0.15 | 1.59 | 1.67 | 0.18 | 0.35 | 1.11 | 0.16 | 0.032 | 0.06  | 0.35 | 0.006 | 43.2   | 43  |
| 3  | 0.20 | 1.33 | 2.16 | 0.17 | 3.52 | 1.51 | 0.13 | 0.04  | 0.09  | 0.36 | 0.020 | 48.1   | 5.6 |
| 4  | 0.24 | 0.93 | 2.11 | 0.15 | 3.18 | 1.31 | 0.21 | 0.054 | 0.071 | 0.46 | 0.021 | 51.8   | 15.6|
| 5  | 0.31 | 1.19 | 2.13 | 0.20 | 3.50 | 1.34 | 0.32 | 0.064 | 0.074 | 0.47 | 0.022 | 53.4   | 14.7|
| 6  | 0.24 | 0.92 | 1.93 | 0.22 | 3.00 | 1.85 | 0.38 | 0.034 | 0.081 | 0.43 | 0.014 | 54.14  | 8.4 |

**Notes:**
1) VCA – volume concentration of retained austenite,
2) samples 1 and 2 include amorphous graphite;
3) samples 3 and 6 include carbon- and fluorine-containing dust at different concentrations.

The samples of standard PP-Np-35V9H3SF flux cored wire, which is used forsurfacing hot forming rolls and rolls of roller conveyers were fabricated in laboratory conditions. Multilayer surfacing was carried out as follows: sheets were pre-heated up to 350°C and then slowly cooled down. The surfacing was carried out by the welding tractor ASAW-1250 using the produced flux cored wire on the steel sheets 09G2S in 5 layers; the surfacing mode: welding current \( I_a = 400 \, \text{A} \), arc voltage \( U_a = 32 \, \text{V} \), rate of welding \( \upsilon_s = 0.8 \, \text{cm/s} \).

In the process of wire fabrication the concentration of expensive tungsten and chromium was calculated lower than required by GOST 26101-84 for PP-Np-35V9H3SF. A number of wire samples were produced with nickel and amorphous carbon was substituted by carbon- and fluorine-containing dust. Chemical composition of the deposited metal was defined by roentgen-fluorescent spectrometer XRF-1800 and atom-emission spectrometer DFS-71. Metallographic investigation of micro-sections...
were conducted by optical microscope OLYMPUS GX-51 in bright field in different zooming conditions after etching in alcohol solution of nitric acid, as well as in solution of hydrofluoric acid. The data on chemical composition of flux cored wires, and hardness of the deposited metal are provided in Table 2.

Provided that amorphous graphite is used as an additive (sample 1) the deposited metal gets a dendrite structure (martensite with retained austenite in axial spacing). There are a lot of oxygen inclusion lines, which are stress concentrators and areas of brittle cracks formation. Point tungsten and chromium carbides are distributed over the grains.

Metallographic analysis demonstrated that metal structure, which was surfaced with flux cored wire, includes an acicular troostite with martensite and formed along the grains boundaries separate thin austenite fringes containing some carbide impurities. Carbon- and fluorne-containing additive to wire burden facilitated removing of oxide non-metallic impurities, smoother distribution of carbon in weld metal and formation of fine-dispersed carbides, all this may in practice improve thermal strength. Nickel was added to flux cored wire to improve thermal resistance of metal through stabilization of austenite and grain refinement. The change in volume concentration of retained austenite in the surfaced layer with various concentration of nickel is provided in Table 3.

Therefore, the experiments demonstrated that carbon- and fluorne-containing additive and nickel added to wire of the system C–Si–Mn–Cr–W–V could reduce considerably the degree of the deposited metal impurity by oxide non-metallic inclusions, and facilitated formation of fine-dispersed carbides, thus, thermal resistance of forming rolls can in practice improve. Chemical composition of these flux cored wires and their modifications is protected by patents of the Russian Federation [13, 14].

### Table 2. Chemical composition of tested flux cored wires and hardness of the deposited metal of system C–Si–Mn–Cr–W–V*.

| Sample No. | Mass concentration of elements, % | C  | Si  | Mn  | Cu  | Cr  | Mo  | Ni  | Al  | W   | V   | Ti   | HRC |
|------------|----------------------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|
| 1          |                                  | 0.27 | 1.62 | 1.42 | 0.19 | 2.93 | 0.14 | 0.14 | 0.04 | 11.39 | 0.47 | 0.02 | 49  |
| 2          |                                  | 0.23 | 0.69 | 1.04 | 0.21 | 1.92 | 0.09 | 0.16 | 0.039 | 5.58 | 0.15 | 0.019 | 50.8 |
| 3          |                                  | 0.24 | 0.83 | 1.83 | 0.24 | 2.16 | 0.09 | 0.29 | 0.054 | 7.49 | 0.27 | 0.019 | 53.3 |
| 4          |                                  | 0.26 | 0.77 | 1.72 | 0.26 | 2.17 | 0.09 | 0.33 | 0.042 | 6.12 | 0.29 | 0.016 | 53.0 |
| 5          |                                  | 0.33 | 1.37 | 1.06 | 0.22 | 2.80 | 0.10 | 0.61 | 0.07 | 10.71 | 0.42 | 0.04 | 54.8 |

* sample 1 included amorphous graphite, samples 2-5 were fabricated using carbon- and fluorne-containing dust and nickel powder with different concentrations.

### Table 3. Volume concentration of retained austenite in the deposited layer (mean for three fields).

| Test | 2     | 3     | 4     |
|------|-------|-------|-------|
| Volume concentration of austenite, % | 15.4  | 5.2   | 6.8   |

Most welding defects are caused by low qualification of welders. Taking into account, that the most significant factor is the length of the arc, and constant control results in eye fatigue decreasing training efficiency, various training devices are used at the first stage of welders training.

To develop correct psychomotor skills that would help to meet the standard requirements (length of arc space, incline angle of welding electrode, displacement from the grooving center of work pieces to be welded, welding rate) in different spatial positions, to increase training efficiency through control of the required parameters of welding and reduce costs, a training device is used for training at the
department (Figure 4); it consists of the following elements: 1 – screen; 2 – lamp; 3 – simulator of the electrode holder; 4 – headphones; 5 – unit of signal receiving.

![Principal scheme of welder training device.](image)

Training of welders with this training device is performed according to the following method. On the screen there are transparent lines imitating the trajectories of arm movement in conditions of various welding techniques. If the simulator of electrode holder is over the transparent line the light from the source gets into the photoreceiver, which is placed on the end of the electrode model, there is no acoustic signal meaning that the technique of welding is correct. Provided that the end of the electrode model is displaced for a period of time within the limits 0.5 – 1 s, an acoustic signal is given meaning the displacement from the set trajectory, an error, respectively. On the light-proof screen there are various transparent lines, imitating different depths of the base metal fusion and weld formation, depending on transverse vibrations of the electrode. After the movement skills are acquired, the welder improves them through more complicated the trajectories of transparent lines. Training device makes it possible to consolidate and unify the technical skills of electrode movement and create a correct electrode inclination angle towards the product and welding direction, which predetermines the quality of weld formation.

Application of this training device in groups of welders during their preliminary training for certification showed that after training welders groups without using the training device, the number of welds meeting the requirements of quality amounted to 45-50 %, whereas after training on the training device – 87-95%. The training device is protected by the patent of the Russian Federation [15]

3. Conclusions

1) The technologies of new carbon-containing additives to welding fluxes have been developed, which can reduce the level of steel oxide non-metallic impurity, as well as gas content in a weld, and improve the required mechanical properties. These technologies are introduced into production process and used for welding bulk-oil tanks in conditions of low temperatures. Flux-additive FD-EFS is produced and protected by the patent of the Russian Federation.

2) Flux cored wires of the systems C–Si–Mn–Cr–W–V and C–Si–Mn–Cr–V–Mo with the added carbon and nickel containing elements, used for surfacing forming rolls, have been developed and are protected by the patents of the Russian Federation. Application of flux cored wires for surfacing provides efficient removal of oxide non-metallic impurities, even distribution of carbon in weld metal, and improvement of thermal resistance of the surfaced product.

3) For training and formation of correct psychomotor skills in the process of manual arc welding a training device for welding simulation has been developed and introduced into the training process, also patented in the Russian Federation.
4. Acknowledgements
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