Development of New Materials and Technologies for Welding and Surfacing at Research and Production Center "Welding Processes and Technologies"

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Abstract. The paper provides description of research into the influence of new materials and technologies on quality parameters of welds and added metal carried out at research and production center «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.

Introduction
The basic requirement of industrial safety consists in assuring 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 attracting much attention currently, as well as 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].

Materials and methods of research
The most grades of 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 can’t surface and assimilate to formed of welding flux slag when welding; as the result, the level of impurity of weld metal by non-metallic admixtures increases, causing deterioration of physical and mechanical characteristics. Obviously, restoratives, which form gaseous products of reactions, are advisable to apply in order to avoid impurity of weld metal. It is carbon that can be a restorative of this kind, 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 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 Open Joint Stock Company «Novokuznetsk Plant of Reservoir Metalware» manufacture of tanks suitable for northern conditions has been developed according to «Standards of vertical cylindrical steel tanks for oil and oil products» PB-03-605-03 and SNIP II – 23-81. The technological process of assembling, welding, controlling and rolling wall plates is performed on special roll facilities. Silicon-manganese steel 09G2S (GOST 6713-91) is used for tanks manufacturing. As the result, an optimal technology has been designed and developed for two-side welding tank wall plates maintained in low temperature conditions: inside the tank it is welded by Sv-08GA wire (on the upper tier) with mixed fluxing agents АN-67B and АN-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. Flay welding was carried out up to 18 mm thick plate. On upper tiers flat butt welds are made in reduced power conditions, which provide penetration into metal up to 0.55 plate thickness. On the lower tier welding was carried out in conditions of high current providing penetration up to 0.7 plate thicknesses.

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

The developed technology made it possible to obtain the whole range of required mechanical properties and impact strength of tank metalware at temperatures below zero, and avoid defects – cracks when manufacturing [6]. This technology is 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 that of imported fluxing agent OK.10.71 on refinement of weld metal is experimentally tested [9,10]. As the result, it has been found out, that the growing content of carbon and fluorine containing additive in various fluxing agents at permitted slight increase of carbon concentration (Figure 1) causes the drop of total concentration of oxygen in a weld (Figure 2), and considerable improvement of mechanical properties, especially that of impact strength at temperatures below zero (Figure 3).

Fraction gas analysis conducted by reduction melting with gas analyzer «LECO» TS-600 revealed, that oxygen redistributed in impurities depending on oxidation and basicity of slag system.

The designed submerged arc welding technology of metalware maintained in conditions of extremely low temperatures rely on theoretical pre-conditions and practical try-out of carbon and
fluorine containing additive technology. The flux of FD – UFS additive is produced at Open Joint Stock Company «Novokuznetsk Plant of Reservoir Metalware named after N.E. Kryukov». The designed welding technologies of metalware involving flux-additive are patented in Russian Federation [11], the composition of new basic welding flux is also patented in the Russian Federation [12].

Surfacing forming rolls is widely applied at manufacturing enterprises in Russia for restoration and improvement of resistance. Despite the significant number of systems used for surfacing, two systems are applied more often: $\text{C–Si–Mn–Cr–W–V}$ and $\text{C–Si–Mn–Cr–V–Mo}$.

![Figure 2](image1.png)

Figure 2. The change in total oxygen concentration in fluxing agents in dependence on carbon and fluorine additive.

![Figure 3](image2.png)

Figure 3. The change in impact strength in dependence on carbon and fluorine additive concentration.

One of the elements in the first system is PP-Np-35W9Cr3SiV flux cored wire containing up to 10% valuable and expensive tungsten and it is applied for wear-resistant surfacing steel rolls of different hot-rolled mills. Metal, which is surfaced with this wire, is distinguished by significant
abrasion resistance at high temperatures, but it is quite low thermally resistant; therefore, rolls surfaced with the wire often fail because of erosion and chipping cracks. Sometimes stripe wear is possible caused by areas of added metal with inhomogeneous structure and hardness. Such areas can be found when multilayer surfacing alloyed steels with overlapping of a bead made before.

A surfaced metal similar to economically alloyed chromium-molybdenum and chromium-tungsten-molybdenum steels demonstrated good results when restoring steel rolls of hot-rolled mills. These steels are quite similar to 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 added layer is rather difficult when surfacing rolls with various passes because of its relatively high hardness. Surfacing materials like martensite-ageing or precipitation hardening steels are promising ones for above mentioned rolls. After being surfaced hardness of these steels can amount to 28...35 HRC, and they are easy to be machined. After tempering the hardness increases up to 48...55 HRC, and added 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-25Cr5VMoSi flux cored wire makes it possible to gain significant impact strength of added metal at high temperatures.

From the standpoint of laboratory and experimental-industrial research it is recommended to use PP-Np-35W9Cr3SiV flux-cored wire for surfacing rolls of continuous bar mills, pipe-rolling, and wire mills; and PP-Np-25Cr5VMoSi 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-25Cr5VMoSi flux cored wire were fabricated in laboratory conditions. Multilayer surfacing of samples was carried out as follows: sheets were pre-heated up to 350°C and cooled down slowly after surfacing. 5-layer surfacing of 09G2S steel sheets was performed by welding tractor ASAW-1250 with fabricated flux cored wire, surfacing conditions: welding current I_a=400 A, arc voltage U_a = 32W, rate of welding v_n=0.8 cm/s.

When wire fabricating concentration of silicon, manganese, chromium, vanadium was varied more enormously than values of these elements required for PP-Np-25Cr5VMoSi wire by GOST 26101-84. 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_2O_3 = 2.1 – 3.3; C = 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 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, which are there in metal and slag, as the result, carbon oxides form. To simulate oxidation and reduction processes, taking place when surfacing, weakly 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 reduced partially from slag. The experiments demonstrated that forming slag hardly ever oxidized alloying elements of added metal.

Chemical composition of added 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 in different zooming modes after etching in alcohol solution of nitric acid, as well as in solution of hydrofluoric acid. Hardness was measured by ultrasonic hardness testing instrument UZIT -3. The information on chemical composition of flux cored wires, hardness of added metal and volume concentration of retained austenite is provided in Table 1.

If amorphous graphite was used as an additive in the structure of added metal (samples 1 and 2) there is martensite and retained austenite in axle spacing. Some oxygen inclusion lines are found.
Point vanadium and chromium carbides are distributed over the grain. It is worth noting, that adding more than 3% vanadium caused a considerable drop in added metal hardness.

Metallographic analysis has demonstrated that metal structure, which was surfaced with flux cored wire, includes an acicular troostite with martensite and formed along the borders of grains 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 weld metal and formation of fine-dispersed carbides, all this may improve thermal strength in practice.

Austenite forming nickel added to flux cored wire facilitated additional grinding of grains. If the system C—Si—Mn—Cr—V—Mo of the wire was added carbon and fluorine containing additive and nickel as well the degree of added metal impurity by oxide non-metallic inclusions dropped, grain grinding was improved, and fine-disperse carbides formed. In case of application it can improve thermal resistance of forming rolls.

| №  | Mass concentration of elements, % | HRC (HB) | CRA |
|----|----------------------------------|----------|-----|
|    | 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 | 4.3 |
| 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) CRA – volume concentration of retained austenite, 2) samples 1 and 2 included amorphous graphite; 3) samples 3 and 6 included carbon and fluorine containing dust with different concentration.

We have mentioned above that the most stressed heat forming rolls are strengthened by surfacing with PP-Np-35W9Cr3SiV flux cored wire according to GOST 26101-84, which contains more valuable tungsten. From the experience of surfaced forming rolls maintenance we know that their surface doesn’t wear evenly. In the process forming rolls are subject to cyclic thermomechanical stresses, corrosion and abrasive wear. Stripe wear caused by added metal with different structure is possible and caused by added metal areas of different structure and hardness. Such areas can be found when multilayer surfacing of alloyed steels with overlapping previously surfaced bead. 35W9Cr3SiV added metal is well-wear resistant at high temperatures, but its thermal strength isn’t sufficient enough, therefore, beads, surfaced with this wire can often fail because of heat cracks and chipping.

The samples of standard PP-Np-35W9Cr3SiV flux cored wire, which is used for surfacing 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. 5-layer surfacing of 09G2S steel sheets was performed by welding tractor ASAW-1250 with fabricated flux cored wire, surfacing conditions: welding current Iₘ=400A, arc voltage Uₘ = 32W, rate of welding vₘ=0.8 cm/s.

When wire fabricating concentration of valuable tungsten and chromium was calculated lower than required for PP-Np-35W9Cr3SiV wire according to GOST 26101-84. A number of wire samples were added nickel and amorphous carbon was changed into carbon and fluorine containing dust. Chemical composition of added metal was tested by roentgen-fluorescent spectrometer XRF-1800 and atom-
emission spectrometer DFS-71. Metallographic tests 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 information on chemical composition of flux cored wires, and hardness of added metal is provided in Table 2.

Provided that amorphous graphite is used as an additive (sample 1) added metal has 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 grains.

Metallographic analysis has demonstrated that metal structure, which was surfaced with flux cored wire, includes an acicular troostite with martensite and formed along the borders of grains 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 weld metal and formation of fine-dispersed carbides, all this may improve thermal strength in practice. Nickel was added to flux cored wire to improve thermal resistance of metal through stabilization of austenite and grain grinding. The change in volume concentration of retained austenite in a surfaced layer with various concentration of nickel is provided in Table 3.

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

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

| № | 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 of carbon and fluorine containing dust and nickel powder with different concentrations.

Table 3. Volume concentration of retained austenite in an added layer (the mean in three fields)

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

The most defective goods when welding are caused by low qualification of welders. Taking in account, that the most significant fact is the length of the arc and constant tracking results in ocular fatigue and decreasing training efficiency, various training devices are used at the first stage of welders training.

To develop correct psychomotor skills of the trained person focusing on keeping standard parameters (the length of arc space, angle of welding electrode incline, displacement from the grooving center of workpieces to be welded, welding rate) in different attitude positions, to increase training efficiency through controlling required parameters of welding and reducing costs a training
device is used in the course of training at the department (Figure 4); it consists of the following elements: 1 – screen; 2 – lamp; 3 – simulator of electrode holder; 4 – headphones; 5 – unit of signal receiving.

![Figure 4. Principal plan of welder training device](image)

Welder training with the training device is based on the following methods. On the screen there are transparent lines imitating the trajectory 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 top of electrode model, at the same time there is no acoustic signal meaning that the technique of welding is correct. Provided that the top of 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 light-proof lines, imitating different depths of base metal fusion and weld formation, depending on transverse vibrations of the electrode. After the skills of movement are mastered by a welder he improves them through complicating the trajectory of a light-proof line. 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; in this way quality of weld formation is predominated.

From the experience of training device application in groups of welders while pre-training for welder certification we know that after training in groups without training device the number of junctions in reference samples of welds meeting the requirements of quality amounted to 45-50 %, whereas after training with a training device it was 87-95%. The training device is protected by patent of Russian Federation [15].

**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 required mechanical properties. These technologies are introduced into production process and used for welding bulk-oil tanks maintained in conditions of low temperatures. Flux-additive FD-UFS is produced and protected by 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 have been developed and protected by patent of the Russian Federation with the added carbon and nickel containing elements used for surfacing forming rolls. Application of flux cored wires when surfacing provides efficient removing oxide non-metallic impurities, even distribution of carbon in weld metal, and improvement of thermal resistance of surfaced product.

3. For training and formation of correct psychomotor skills when manual arc welding a training device of welder has been developed and introduced into the training process, as well as patented in the Russian Federation.
The work was performed in Siberian State Industrial University within the project of State Order of Ministry of Science Russian Federation № 11.1531.2014/k. For tests, investigations, measuring we used equipment of Collective Center “Material Science” of Siberian State Industrial University.

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