INVESTIGATION OF STRUCTURE AND SERVICE PROPERTIES OF DEPOSITED METAL FOR RECONDITIONING AND STRENGTHENING OF ROLLING MILL ROLLS

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Structure and service properties of deposited metal designed for strengthening and reconditioning of various-purpose forming rolls have been studied. Metal deposited with flux-cored wire PP-AN132 has the highest high-temperature resistance, hot hardness and wear resistance at metal-on-metal friction at high temperatures, however, it has the lowest thermal stability. Metal deposited with flux-cored wire PP-AN130 has the highest thermal stability, although it is inferior to other materials as to a number of other indices. Metal deposited with flux-cored wire PP-AN147 takes an intermediate position by all the indices.

Keywords: *arc hardfacing, forming rolls, flux-cored wires, deposited metal, macrostructure, wear resistance, thermal stability, heat resistance*

PWI developed flux-cored wires PP-AN130 (Fe–C–Cr–Mo–V alloying system), PP-AN132 (Fe–C–Cr–W–Mo–V) and PP-AN147 (Fe–C–Cr–Mo–Ni–V) used in arc hardfacing of tools and jigs for hot forming of metals, in particular, forming rolls for different purposes [1]. Some publications [2–4] give data on the structure and certain properties of metal deposited with these wires. However, this testing was often conducted by different procedures and in different scope, so that it did not seem possible to provide a sufficiently objective assessment of the advantages of a particular type of deposited metal and give substantiated recommendations on its application. This paper presents generalized results on studying the structure of metal deposited with these wires, as well as its service properties obtained at testing under the same conditions and by the same procedures.

To study the structure and properties of the deposited metal each of the three flux-cored wires was used to deposit four to five layers on blanks, from which samples were cut out for metallographic investigations, studying thermal stability, heat resistance, hot hardness and wear resistance at metal-on-metal friction at high temperatures.

It is known that the structure and properties of the deposited metal significantly depend on its cooling rate in the region of temperatures of the lowest stability of austenite. Arc hardfacing of forming rolls, which are usually made of carbon and high-carbon steels, is performed with preheating up to 300–350 °C and delayed cooling in a furnace or thermostat. It was experimentally established that at hardfacing without preheating and cooling in quiet air the cooling rate of the hardfaced part is equal to approximately 3–4 °C/s, and in hardfacing with preheating and delayed cooling in a furnace or thermostat, it is equal to about 0.018–0.020 °C/s. Proceeding from that, the structure of the deposited metal of three types after heating up to 950 °C and cooling at the rate of 0.018 and 3 °C/s, respectively, was studied. Investigations were conducted in Chevenard dilatometer, which provides cooling of samples with such rates.

It is established that first bainite, and then martensite transformation is observed in the metal deposited with flux-cored wire PP-AN130 at cooling rates of 0.018 and 3 °C/s. The distinctive feature consists in that at a lower cooling rate the quantity of bainite is higher, and deposited metal hardness is lower. As a result, the structure of deposited metal of this type consists of martensite, bainite, residual austenite and carbides (Figure 1, *a, b*). Deposited metal hardness is *HRC* 44–47.

In the metal deposited with flux-cored wire PP-AN132 at cooling rate of 0.018 °C/s, first bainite transformation is observed, which is followed by martensite transformation. At cooling rate above 3 °C/s just the martensite transformation is observed as a result of a higher content of carbon and alloying elements (compared to PP-AN130 wire). Hardness of deposited metal of this type is equal to *HRC* 48–50, its structure consists of martensite, residual austenite, carbides and a small amount of bainite (Figure 1, *c, d*).

In the metal deposited with flux-cored wire PP-AN147 bainite and martensite transformations are also observed at these cooling rates. Deposited metal microstructure after cooling consists of martensite, bainite and residual austenite with carbides (Figure 1, *e, f*). Deposited metal hardness is equal to *HRC* 46–49.

Properties of deposited metal of three types were studied.

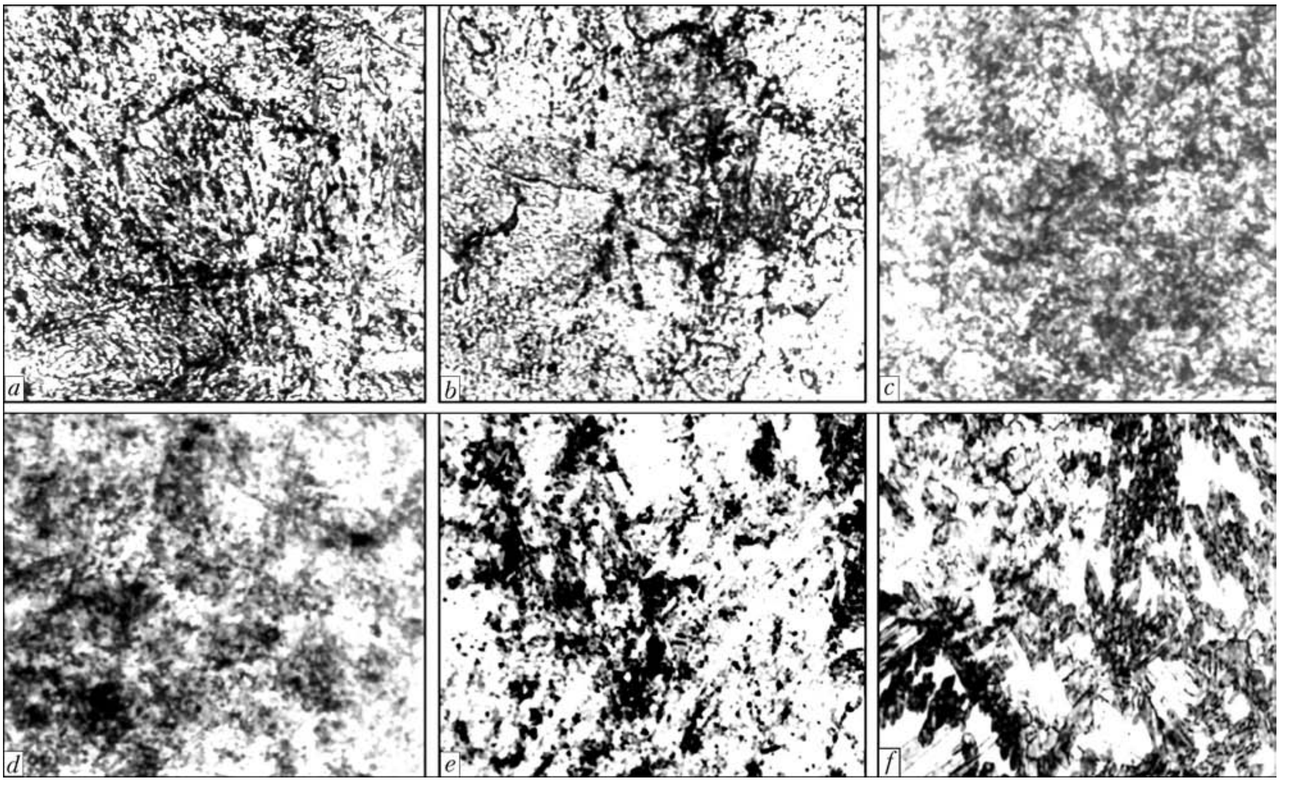

Figure 1. Microstructures (×500) of metal deposited with flux-cored wire PP-AN130 (*a, b*), PP-AN132 (*c, d*) and PP-AN147 (*e, f*): *a, c, e* — cooling rate of 3; *b, d, f* — 0.018 °C/s

Heat resistance. This is the capability of steel to preserve the structure and properties required for deformation or cutting at working edge heating during operation. Heat resistance of stamping steels is usually characterized by the temperature of two-hour tempering, after which hardness is equal to *HRC* 40 [5]. Nine samples of each type of the deposited metal of 15 × 20 × 20 mm size were made to study the heat resistance. The samples were first subjected to two-hour tempering at temperatures in the range of 200–700 °C. After cooling down the hardfaced surface of the samples was ground and hardness was determined (Figure 2).

It is established that all the types of deposited metal are characterized by a sufficiently high heat resistance — 630–650 °C. However, the best heat resistance is found in the metal deposited with flux-cored wire PP-AN132. The shape of its curve is the same as that of metal deposited, for instance, with flux-cored wire PP-AN130. The difference consists only in that hardness lowering in this type of deposited metal starts at higher tempering temperatures.

In all the three types of deposited metal a slight increase of hardness is observed as a result of tempering in the temperature range of 500–550 °C. Secondary hardening effect is observed as a result of decomposition of residual austenite with formation of martensite and carbides, which is what leads to hardness increase.

Wear resistance at metal-on-metal friction at elevated temperatures. It is known that during hot forming of metals and alloys (rolling, forging, stamping) specific pressure of metal on the tool can be quite considerable and by some data reaches 300–500 MPa. Metal slipping is always found in the deformation site as a result of its drawing, which alongside high specific pressures leads to wear of the tool working surface at metal-on-metal friction at elevated temperatures. Therefore, determination of deposited metal wear resistance under these conditions is important.

The main test parameters include specific pressure on the tested sample, sample heating and cooling temperature, rate of relative displacement of rubbing elements (friction speed), and kind of material of the fretting ring. Laboratory wear testing at metal-on-metal friction at elevated temperatures by ring–plane schematic was conducted in an all-purpose testing unit [6]. For this purpose samples of 40 × 10 × 17 mm size were made from the hardfaced blanks, the deposited layer thickness being 8–10 mm. During testing the sample was pressed with the hardfaced plane to a rotating ring-counterbody, which was heated by a gas torch. In addition, the sample makes a reciprocal displacement in the vertical plane, sliding over the surface of the rotating ring-counterbody. Testing conditions were as follows: load of 800 N (specific pressure of about 100 MPa); speed of counterbody rotation of 30 rpm; sample oscillation amplitude in the vertical plane of 20 mm; oscillation frequency of 62 min^{-1}; sample temperature in the fretting zone of 600 °C; testing time of 1 h. Rings of 120 mm diameter from steel 45 were used as the counterbody.

Friction rate in the experiments was equal to 20–22 m/min, which corresponds to modes the most widely accepted in industry at hot forming of metals.

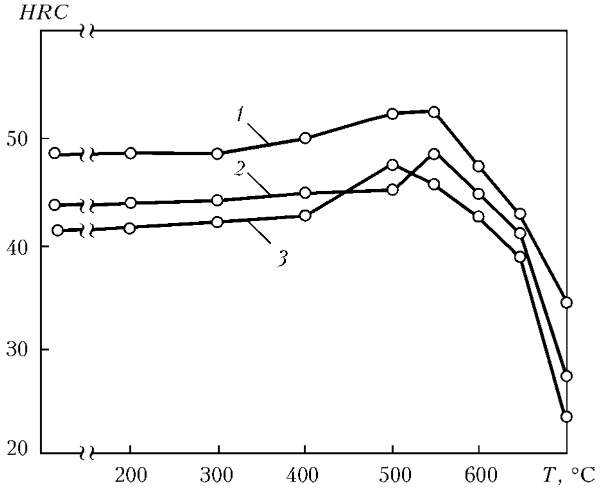

Figure 2. Dependence of hardness of metal deposited with different flux-cored wires on tempering temperature: *1* — PP-AN132; *2* — PP-AN147; *3* — PP-AN130

Fretting ring was heated by oxygas flame. Owing to a strictly controlled flow rate of combustible gas and oxygen, the fretting ring temperature was kept constant at 950–980 °C, and ring temperature was periodically controlled using optical pyrometer.

Results of wear testing at metal-on-metal friction at elevated temperatures are given in Figure 3, *a*. The lowest wear was found in metal deposited with flux-cored wire PP-AN132, the highest wear was found with flux-cored wire PP-AN130. Higher wear resistance of deposited metal of the first type is, apparently, attributable to a higher content of carbon and alloying elements and its higher heat resistance and hardness.

Thermal stability. This is a most important property, which characterizes the resistance of the deposited metal to fire cracking at multiple repetition of heating–cooling cycles. As a rule, the fatigue life of tools for hot forming of metal depends primarily on this property [1, 7, 8].

Procedure of thermal stability testing should envisage optimum dimensions and shape of the hardfaced sample; temperature and rates of its heating and cooling, close to these characteristics for the hardfaced parts, etc. To assess the thermal stability of materials used for hardfacing the tools for hot forming of metals, a sample should have a sufficient mass, so as to ensure a gradient of temperatures and stresses simulating the actual conditions, during its surface heating.

Thermal stability tests of the deposited metal were conducted in a unit for comprehensive assessment of deposited metal properties [6]. For this purpose 30 × × 40 × 40 mm samples were cut out of the hardfaced blanks and the hardfaced surface of the samples was polished. The sample was mounted in the holder of the testing machine with the ground surface up, which was heated by a flame cutter. Uniform heating was obtained on a heated spot of 15–20 mm diameter. Heating was continued for 11 s with cooling by a powerful water jet for 8 s. After stabilization of the testing conditions the maximum sample temperature in the heated spot was equal to 650–700 °C, at cooling it was 60–80 °C. Thermal stability was assessed by the number of cycles of heating–cooling on the surface of a hardfaced sample up to appearance of a net of fire cracks, visible for a naked eye (Figure 3, *b*).

The best thermal stability was found in metal deposited by flux-cored wire PP-AN130, and metal deposited with PP-AN147 wire was somewhat inferior to it. Metal deposited with flux-cored wire PP-AN132 had lower thermal stability.

As is known [5], thermal stability is adversely affected by structural inhomogeneity of steels: presence of carbide (intermetallic) excess phases required for increase of heat and wear resistance. Thermal stability starts markedly decreasing, if their quantity exceeds 10–12 %. Apparently, this can account for the

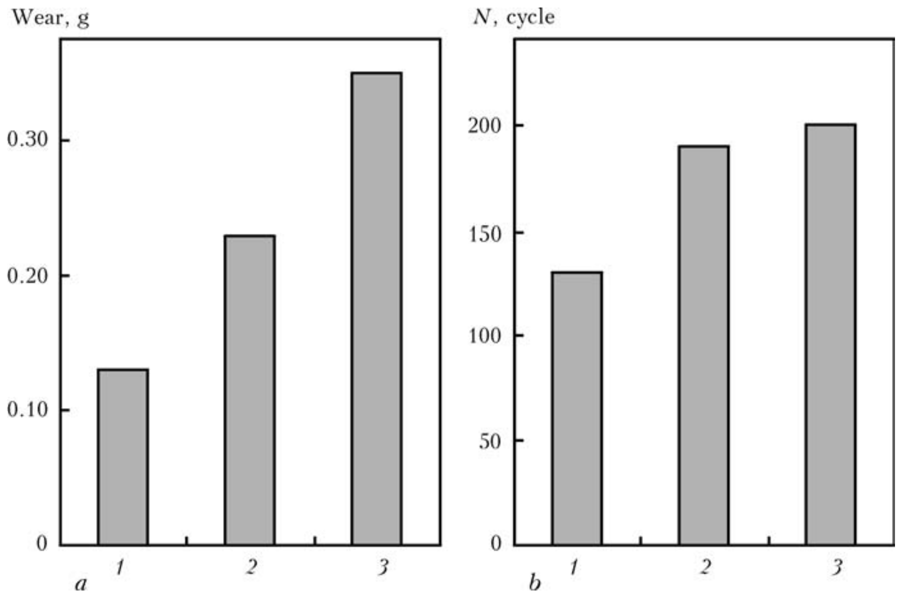

Figure 3. Wear at metal-on-metal friction at elevated temperatures (*a*) and thermal stability (*b*) of metal deposited with different flux-cored wires: *1* — PP-AN132; *2* — PP-AN147; *3* — PP-AN130

lower thermal stability of metal deposited with flux-cored wire PP-AN132.

Hot hardness. Under the operating conditions of hot metal forming tools metal hardness at increased temperatures (hot hardness) is highly important. Material resistance to wear depends on its ability to resist plastic deformation, i.e. hardness at elevated temperatures and material ability to preserve hardness for a long time. As a rule, steels containing molybdenum, tungsten, chromium, vanadium have high wear resistance at elevated temperatures, and their initial room temperature hardness is not very important.

Hot hardness of deposited metal of the selected types was studied. Sample heating was performed in a special inductor in vacuum, hardness measurements were conducted at 1 kg load, with 60 s soaking under load. As noted in [7], temperature of forming rolls in the deformation site is equal to 600–650 °C, that is why hot hardness of the deposited metal was determined at this temperature and at 20 °C for comparison (Figure 4).

Deposited metal of all the three types has approximately the same hardness at room temperature. High temperature hardness is different to a greater degree: metal deposited with PP-AN132 wire has hardness on the level of *HRC* 35; for PP-AN147 wire — *HRC* 32; for PP-AN130 wire — *HRC* 30.

Thus, the best heat resistance, hot hardness and wear resistance at metal-on-metal friction at high temperatures is found in metal deposited with flux-cored wire PP-AN132; however, it has the lowest thermal stability. Metal deposited with flux-cored wire PP-AN130 has the best thermal stability, although it is inferior to two other type of deposited metal by other service properties. Metal deposited with flux-cored wire PP-AN147 takes an intermediate position by all the service properties.

CONCLUSIONS

1. Investigations of microstructure of metal deposited with flux-cored wires PP-AN130, PP-AN132 and PP-AN147 showed that at simulation of thermal cycle of arc hardfacing of forming rolls (preheating and delayed cooling after hardfacing) the structure of all the three types of deposited metal consists of martensite, bainite, residual austenite and carbides in different proportions. In all the three types of deposited metal a slight increase in hardness is noted as a result of tempering in the temperature range of 500–550 °C. Secondary hardening occurs as a result of residual austenite decomposition with formation of martensite and carbides, which is what leads to hardness increase.

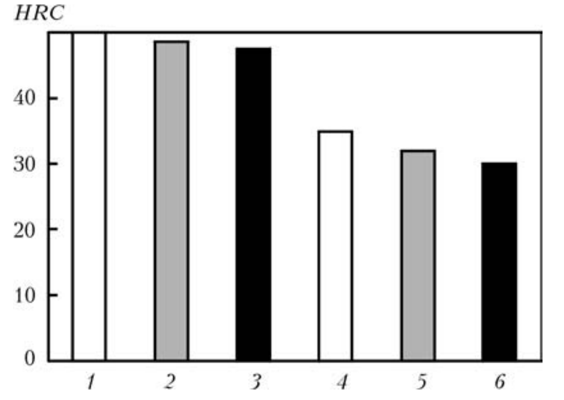

Figure 4. Hardness of metal deposited with different flux-cored wires at temperatures of 20 (*1–3*) and 600 (*4–6*) °C: *1, 4* — PP-AN132; *2, 5* — PP-AN147; *3, 6* — PP-AN130

2. Proceeding from the deposited metal properties, flux-cored wire PP-AN130 can be recommended for hardfacing of rolls of bloomings and slabbings and roughing stands of rolling and hoop mills, in which deformation of metal heated up to the highest temperatures takes place. It is rational to use flux-cored wire PP-AN132 for hardfacing forming rolls of leader and roughing stands, in which metal deformation proceeds at relatively low temperatures and there is no need for high thermal stability of the deposited metal, while its wear resistance and hot hardness have a more essential role. Flux-cored wire PP-AN147, which has the most optimum combination of all the service properties, can be recommended for hardfacing heavy-duty rolls of roughing mills in pipe and section rolling mills.

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