STRUCTURE OF MULTILAYER SAMPLES SIMULATING SURFACED TOOLS FOR HOT DEFORMING OF METALS

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Structure of multilayer deposited samples, which simulate the surfaced tools for hot deforming of metals and alloys by composition of deposited metal and sizes of deposited layers, was investigated. The surfacing was performed on samples of low-alloy medium-carbon steel 40Kh. To perform surfacing of working layer, the flux-cored wire PP-Np-25Kh5FMS was used, producing deposited metal of type of tool semiheat-resistant steel. To deposit a sublayer, two wires were applied: solid wire Sv-08A or flux-cored wire PP-Np-12KhMF. The investigations showed that the deposited metal 25Kh5FMS has a structure, consisting of bainite-martensite mixture and residual austenite, structure of sublayer 12KhMF is sorbite-like pearlite, and that of sublayer, deposited by wire Sv-08A, is ferrite. It was found that depending on chemical composition and structure of deposited sublayer the residual stressed state of deposited wear-resistant layer is greatly changed. In particular, the surfacing of sublayer by flux-cored wire PP-Np-12KhMF approximately 3 times decreases the residual stresses in working wear-resistant layer. 9 Ref., 2 Tables, 7 Figures.

Keywords: *arc surfacing, multilayer surfacing, structure of deposited metal, sublayer, thermal fatigue*

In metallurgy and machine building the tools and fixture for hot deforming of metals, which are applied under conditions of wear and simultaneous action of cyclic thermal and mechanical loads, are rather widely used. They include mill rolls, dies of hot stamping, rollers of machines for continuous casting of billets, knives of hot cutting, etc. As a rule, the defects in the form of thermal fatigue cracks are appeared on the surface of above-mentioned parts after several thousands of thermal cycles. At the same time the fatigue damages are appeared as a result of service cyclic mechanical loads after several millions of cycles.

To deposit a working layer on these parts, in particular on steel mill rolls, the materials of type of tool heat-resistant or semiheat-resistant steels are used. Taking into account that carbon or high carbon non-alloyed or low-alloyed structural steels are used as a base metal for mill rolls, the surfacing of steel mill rolls is performed with a ductile sublayer to improve the weldability. For the sublayer surfacing the wires Sv-08A, Sv-08G2S and other similar types are used [1–3].

Thermal fatigue cracks are propagated, as a rule, for a small depth from the roll surface. Therefore, after their appearance the damaged working deposited layer is periodically removed and resurfacing of part is made. Theoretically and in practice, the resurfacing can be made before the appearance of fatigue cracks in the roll from cyclic mechanical loads, which can lead to its fracture.

Residual (technological) and service thermomechanical loads, imposed on them, significantly influence the fatigue life of surfaced tools for hot deforming of metals. The experimental evaluation of effect of these characteristics on thermal and mechanical fatigue life of surfaced parts is complicated enough and requires great expenses.

To solve this problem, the authors of work [4] suggested the mathematical models and method of calculation of stress-strain state of deposited part directly after surfacing and during service. In particular, it was shown that surfacing of a ductile layer leads to the reduction and redistribution of residual stresses in the deposited working wear-resistant layer, thus leading to the increase in its thermal resistance. An important role in calculations is given to the processes of changing the structural state of base metal, deposited sublayer and working layer in the process of surfacing and next service. During calculations the thermokinetic diagrams of overcooled austenite decay [5] in the materials investigated and approaches, developed in works of V.I. Makhnenko, were used [6, 7].

The aim of this work was the experimental investigation of structure of multilayer deposited samples and comparison of their results with calculated data. In both cases the low-alloy medium-carbon steel 40Kh was selected as a base metal. For surfacing the working layer the flux-cored

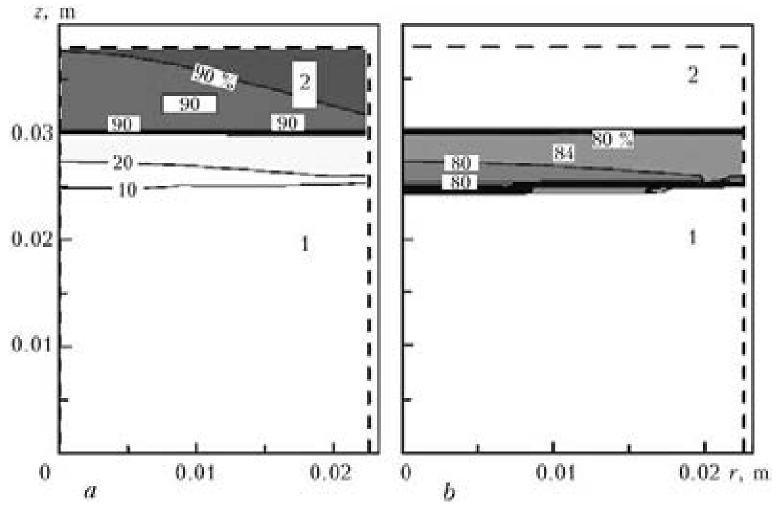

Figure 1. Calculation structure of sample deposited without sublayer: *a* — martensite; *b* — bainite; 1 — base metal, steel 40Kh; 2 — deposited wear-resistant layer of 25Kh5FMS

wire PP-Np-25Kh5FMS, was used providing the deposited metal of type of tool semiheat-resistant steel of appropriate composition. For surfacing the sublayer two wires: solid wire Sv-08A or flux-cored wire PP-Np-12KhMF were used. The flux-cored wire PP-Np-12KhMF had to provide the higher mechanical properties in the deposited steel sublayer.

As an example, Figures 1 and 2 give data about the microstructure of two deposited samples, determined by the calculation method. Two types of samples were studied: first one is the surfacing by flux-cored wire PP-Np-25Kh5FMS on steel 40Kh without sublayer (Figure 1); second one is the surfacing of sublayer by solid wire Sv-08A on steel 40Kh and then surfacing of base layer by flux-cored wire PP-Np-25Kh5FMS (Figure 2).

In the first sample the calculated concentration of a martensitic phase in external wear-resistant layer of 25Kh5FMS reaches 90 %, the rest ones are bainite and carbides (Figure 1, *a*). In the transition zone on the side of 40Kh steel the basic structure constituent is bainite (about 80 %), there is also a small amount (up to 10 %) of martensite (Figure 1, *b*).

In the sample, deposited with a sublayer, the structure of deposited working layer, corresponding to tool steel 25Kh5FMS, consists also of martensite (about 88 %), bainite (about 10 %) and carbides (Figure 2, *a*). Sublayer, corresponding to steel, containing 0.08 % of carbon, has a ferritic structure. In the transition zone from sublayer to base metal (steel 40Kh) a bainite-pearlite structure is observed (Figure 2, *c*).

In carrying out of experimental investigations of microstructure three types of semi-products were surfaced by above-mentioned wires using submerged arc method: No.1 — surfacing by flux-cored wire PP-Np-25Kh5FMS on steel 40Kh without a sublayer; No.2 — surfacing by flux-cored wire PP-Np-25Kh5FMS on steel 40Kh with a sublayer, deposited by flux-cored wire PP-Np-12KhMF; No.3 — surfacing by flux-cored wire

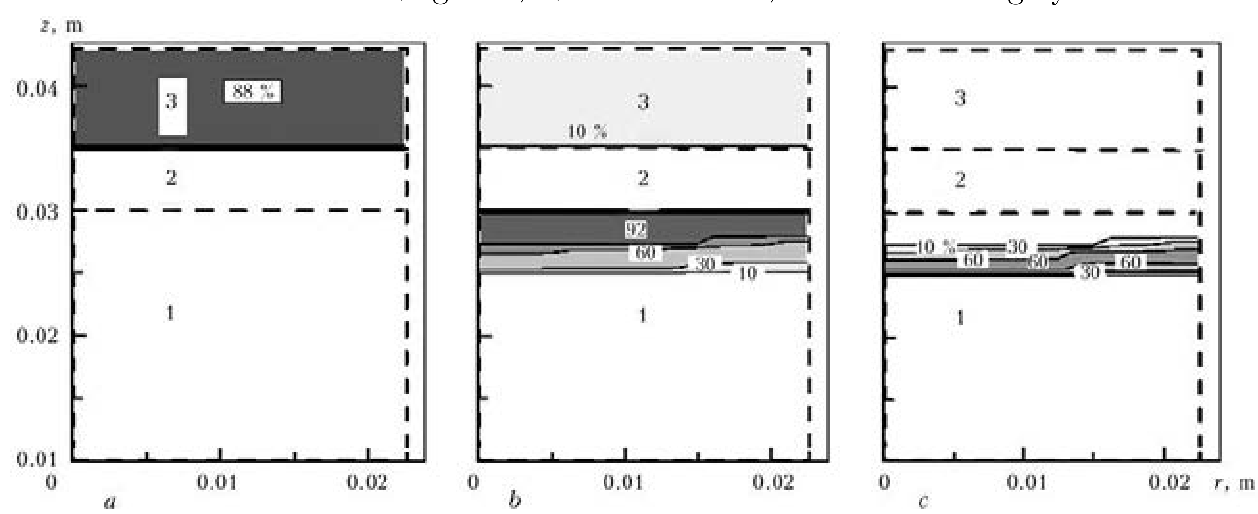

Figure 2. Calculation structure of sample, deposited with sublayer: *a* — martensite; *b* — bainite; 1 — base metal, steel 40Kh; 2 — deposited ductile layer of Sv-08A; 3 — deposited wear-resistant layer of 25Kh5FMS

PP-Np-25Kh5FMS on steel 40Kh with a sublayer deposited by solid wire Sv-08A.

Chemical composition of metal, deposited by these wires, is given in Table 1.

Samples were cut out of deposited semi-products for examination of microstructure and hardness of deposited metal and transition zone, as well as for their X-ray spectral and X-ray diffraction microanalyses.

Microstructure of deposited metal 25Kh5FMS and transition zone with base metal, steel 40Kh, (sample No.1) is presented in Figure 3. The deposited wear-resistant layer, steel 25Kh5FMS, has a martensitic-bainitic structure of hardness *HV*0.5 — 3410–4120 MPa (Figure 3, *a*). Small amount of light regions in structure can be classified as a residual austenite. It should be noted that deposited metal 25Kh5FMS has the same structure and hardness in two other experimental samples. Microstructure of transition zone, steel 40Kh + 25Kh5FMS, on the side of base metal is bainite and small amount of martensite (Figure 3, *b*).

Microstructure of sample No.2 is presented in Figure 4. In the transition zone (Figure 4, *a*) on the side of wear-resistant deposited metal 25Kh5FMS the transition from martensite-bainite structure (steel 25Kh5FMS) to structure of sorbite-like pearlite (steel 12KhMF) is observed. Microhardness on the side of steel 25Kh5FMS is *HV*0.5 — 2860 MPa, while on the side of sublayer 12KhMF it is *HV*0.5 — 2320–2340 MPa. Hardness of sublayer 12KhMF on the side of base metal 40Kh is within the ranges *HV*0.5 — 2570–2600 MPa. Such increase in hardness on the side of base metal can be explained by diffusion of carbon from steel 40Kh into sublayer 12KhMF. Microstructure of deposited sublayer 12KhMF is sorbite-like pearlite (Figure 4, *b*) with hardness *HV*0.5 — 2570–2600 MPa.

Table 1. Chemical composition of investigated types of deposited metal

Wire grade	C	Mn	Si	Cr	Mo	V
PP-Np-25Kh5FMS	0.33	0.60	0.54	6.05	1.30	0.68
PP-Np-12KhMF	0.12	0.64	0.35	1.16	0.41	0.32
Sv-08A	0.07	0.47	0.05	<0.3	–	–

Figure 5 presents a microstructure of sample No.3 (PP-Np-25Kh5FMS + Sv-08A). In the transition zone from sublayer to wear-resistant deposited layer 25Kh5FMS a coarse-grain ferrite structure is formed (*HV*0.5 — 1750 MPa) with fine-dispersed precipitations of pearlite along the grain boundaries (Figure 5, *a*). The sublayer has a pure ferritic structure with a rather smaller size of grain (Figure 5, *b*). Hardness in this zone is *HV*0.5 — 1550 MPa.

Rockwell hardness of deposited metal and transition zone was measured (Figure 6). In the sample, deposited without sublayer and with sublayer 12KhMF, a smooth transition from base

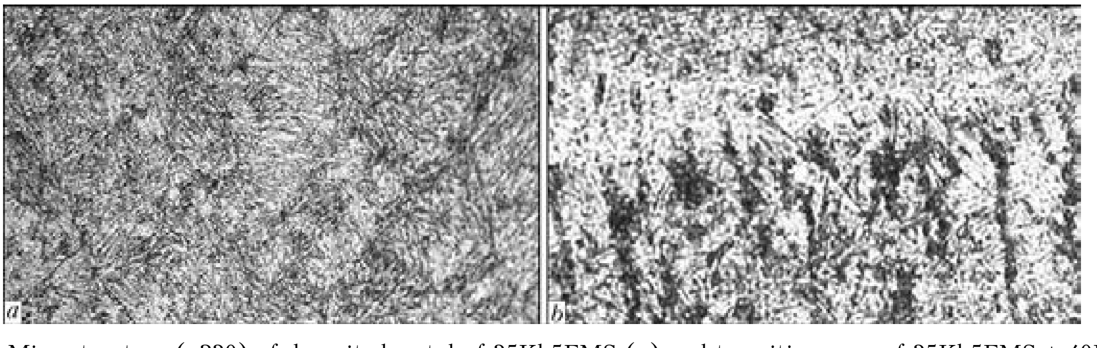

Figure 3. Microstructure (×320) of deposited metal of 25Kh5FMS (*a*) and transition zone of 25Kh5FMS + 40Kh (*b*)

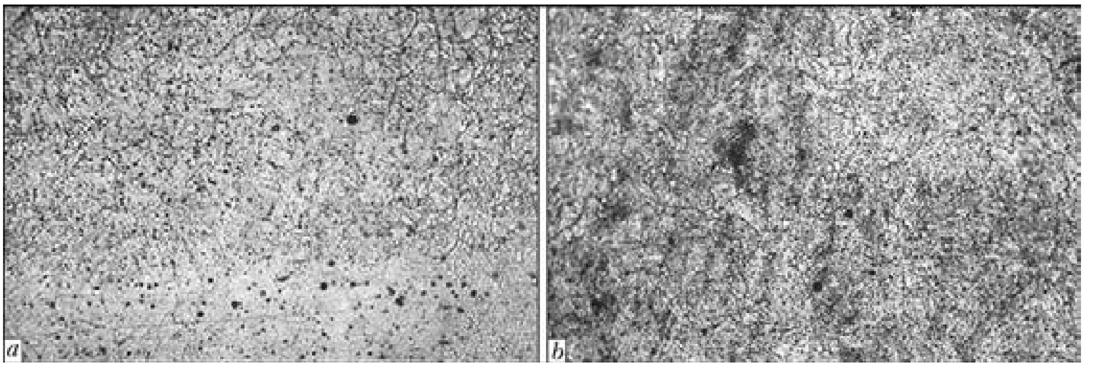

Figure 4. Microstructure (×320) of transition zone of 25Kh5FMS + 12 KhMF (*a*) and deposited sublayer of 12KhMF (*b*)

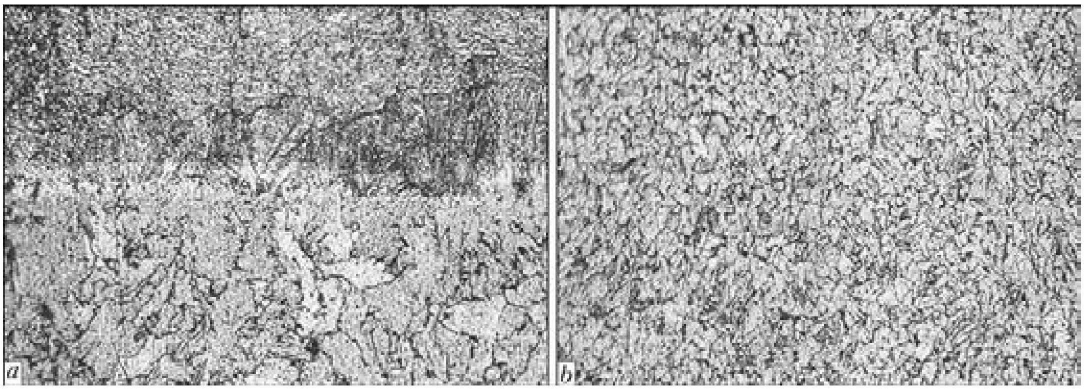

Figure 5. Microstructure (×320) of transition zone of 25Kh5FMS + Sv-08A (*a*) and deposited sublayer of Sv-08A (*b*)

metal to deposited wear-resistant layer 25Kh5FMS is observed. As was expected, in surfacing with sublayer Sv-08A an abrupt reduction in hardness directly in the sublayer was observed.

Using the X-ray spectral microanalyzer Camebax SX50 the distribution of basic alloying elements in all three samples was examined. The total length of scanning was 150 μm, pitch — 2 μm. Figure 7, *a* shows the distribution of chromium and molybdenum in surfacing by flux-cored wire PP-Np-25Kh5FMS directly on steel 40Kh (sample No.1). Distribution of the same elements in the fusion zone of wear-resistant layer and sublayer in samples Nos. 2 and 3 is given in Figure 7, *b* and *c*, respectively.

Analysis of data, given in Figure 7, shows that the narrowest transition zone (29.2 μm) is observed in surfacing by flux-cored wire PP-Np-25Kh5FMS directly on steel 40Kh. The transition zone between the sublayer and wear-resistant layer is wider. It is about 51 μm with sublayer, deposited by wire Sv-08A and about 58 μm with sublayer, deposited by flux-cored wire PP-Np-12KhMF (Table 2).

X-ray diffraction microanalyses of all the deposited samples were carried out that allowed determining their phase composition in a quantitative ratio and comparing it with calculated data (see Figures 1 and 2). Table 2 gives generalized data about microstructural state of deposited samples and data about stressed state of wear-resistant layer, determined from the results of X-ray diffraction analysis.

If to compare the calculated data (Figures 1 and 2) with data of X-ray diffraction microanalysis (Table 2), then, first of all, the presence of

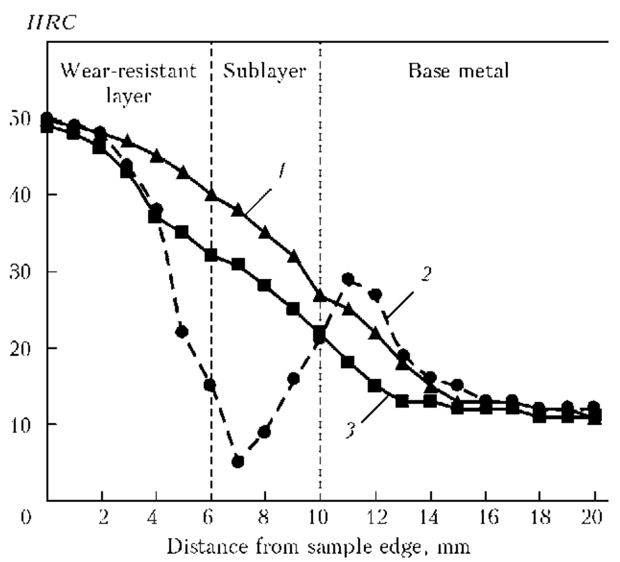

Figure 6. Hardness of deposited metal and transition zone in investigated samples: *1* — sample without sublayer; *2* — with sublayer of Sv-08A; *3* — with sublayer of 12KhMF

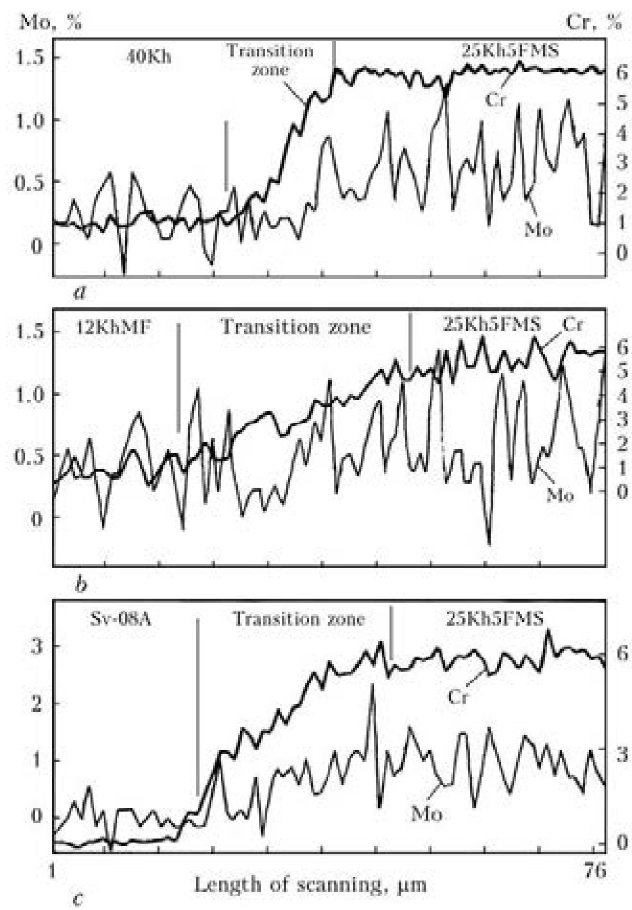

Figure 7. Distribution of chromium and molybdenum in fusion zone of sample Nos. 1 (*a*), 2 (*b*), 3 (*c*)

Table 2. Microstructural state of deposited samples

Sample number	Microstructure	Length of transition zone on side of deposited metal 25Kh5FMS, μm	Phase composition of steel 40Kh, %	Phase composition of deposited metal 25Kh5FMS, %	Stresses in wear-resistant layer of 25Kh5FMS, GPa
1	Wear-resistant layer is bainite-martensite mixture and residual austenite; base metal is pearlite-ferrite mixture	≈29.2	85 — pearlite; 15 — ferrite	92.3 — α; 7.7 — γ	−0.2
2	Wear-resistant layer is bainite-martensite mixture and residual austenite; sublayer is sorbite-like pearlite; base metal is pearlite-ferrite mixture	≈58.0	87.2 — pearlite; 12.8 — ferrite	90.57 — α; 9.43 — γ	−0.062
3	Wear-resistant layer is bainite-martensite mixture and residual austenite; sublayer is ferrite; base metal is pearlite-ferrite mixture	≈51.0	83 — pearlite; 17 — ferrite	90.32 — α; 9.68 — γ	−0.15

austenite in the amount up to 10 % in the deposited layer 25Kh5FMS should be noted. This fact should be taken into account in precise calculations of stress-strain state of samples and appropriate deposited parts. The base metal, steel 40Kh, has a ferritic-pearlitic structure, the sublayer, deposited by wire Sv-08A, has a ferritic structure, and structure of sublayer, deposited by wire PP-Np-12KhMF, is sorbite-like pearlite. Identification of structure and, in particular, the determination of quantitative ratio of its separate constituents in transition zones encounters significant difficulties, moreover, all they in this case refer, in principle, to α-Fe.

The determination of stresses in wear-resistant deposited layer of samples was performed on the basis of results of X-ray diffraction analysis by the procedure, described in work [8]. The highest stresses are observed in wear-resistant deposited layer in sample, deposited without a sublayer. They are somewhat lower in the sample, deposited with a sublayer Sv-08A. Minimum stresses were in sample No.2, in which the sublayer was deposited by flux-cored wire PP-Np-12KhMF. Qualitatively, these data coincide with calculated data given in work [9].

Conclusions

1. It was found that depending on chemical composition and structure of deposited layer the residual stressed state of deposited wear-resistant layer is changed to a great extent. In particular, the surfacing of sublayer by flux-cored wire PP-Np-12KhMF approximately 3 times decreases the residual stresses in working wear-resistant layer as compared with surfacing without sublayer and approximately 2 times — as compared with surfacing with sublayer Sv-08A.

2. It is shown that unlike the calculated data, the structure of deposited metal 25Kh5FMS of experimental samples contains up to 10 % of residual austenite. This fact should be taken into account in calculations of stress-strain state and possible service life of multilayer deposited parts.

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