

Application of Electric-Arc Pulsed Mode for Obtaining Surfacing of Fe–Mo–Cr–Ti–Ni–Cu–Al-System

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Abstract: Method of electric-arc melting with nonconsumable electrode in a protective argon atmosphere with using a pulsed mode was used to show possibility in principle of obtaining multi-component metallic surfacing of Fe–Mo–Cr–Ti–Ni–Cu–Al system on uncooled steel substrate. Features of structure and elemental composition were studied using scanning electron microscopy methods. Component intermixing of the surfacing is observed. Surfacing microhardness is 5 times greater than that of the substrate. «Surfacing-substrate» boundary has high adhesion strength.

Introduction

One of the directions for obtaining materials with high strength properties is the development and creation of multicomponent systems based on a combination of different metals [1-7]. To obtain such systems, various variations of multiple vacuum remelting are often used, followed by ultrafast quenching. Essential disadvantages of such methods are the technological complexity of the processing process, which requires material heating, cleanliness of samples surface and vacuum, low productivity and small dimensions of the obtained samples [8-15].

In the present work, the structure and strength properties of multicomponent metal surfacing of Fe–Cr–Mo–Ti–Ni–Cu–Al system obtained by the electric arc melting method with a non-consumable electrode in a protective argon medium using a pulsed mode have been validated [16-21].

Methods of experimental research

Samples of steel 35 were used as a substrate. Surfacing was obtained by melting a composite billet from metal wires (Fe, Cr, Mo, Ti, Ni, Cu, Al) by an electric arc with a non-consumable electrode. A pulsed regime providing the dynamic character of arc burning was realized: the amplitude of the pulses was 350 A, the duration was 70 microseconds, and the frequency was 2000 Hz. The formation of a protective atmosphere is ensured by the continuous supply of argon to the region of arc formation.

Structural studies were performed using a Tescan Vega 3 SBH (30 kV) scanning electron microscope and an FEI Quanta 200 3D (30 kV) electron-ion microscope with an attachment for determining the elemental composition by the energy-dispersive analysis.



Microhardness ($H\mu$) was determined in the end section by the Vickers method on a Neophot 21 device with a load of 1 N during 15 seconds.

Results and discussion:

Figure 1 shows an overview scanning electron microscopic image of end section of Fe-Cr-Mo-Ti-Ni-Cu-Al system surfacing on a steel 35 substrate. The asterisks denote the microhardness measuring regions (1 – 3) and region for element composition determination by energy-dispersive analysis (1 – 4) at different distances from the substrate. As can be seen from Table 1, the microhardness values of surfacing in region 3 exceed the $H\mu$ of the substrate by 4.7 times, and near the surface (region 1) its value is greater by a factor of ~ 5.2 .

Table 1 – Microhardness values ($H\mu$, GPa) at various distances from the interface "surfacing-substrate".

Region	1 (3.5 mm)	2 (2.5 mm)	3 (1.5 mm)	Substrate
$H\mu$, GPa	7.23	6.81	6.64	1.41

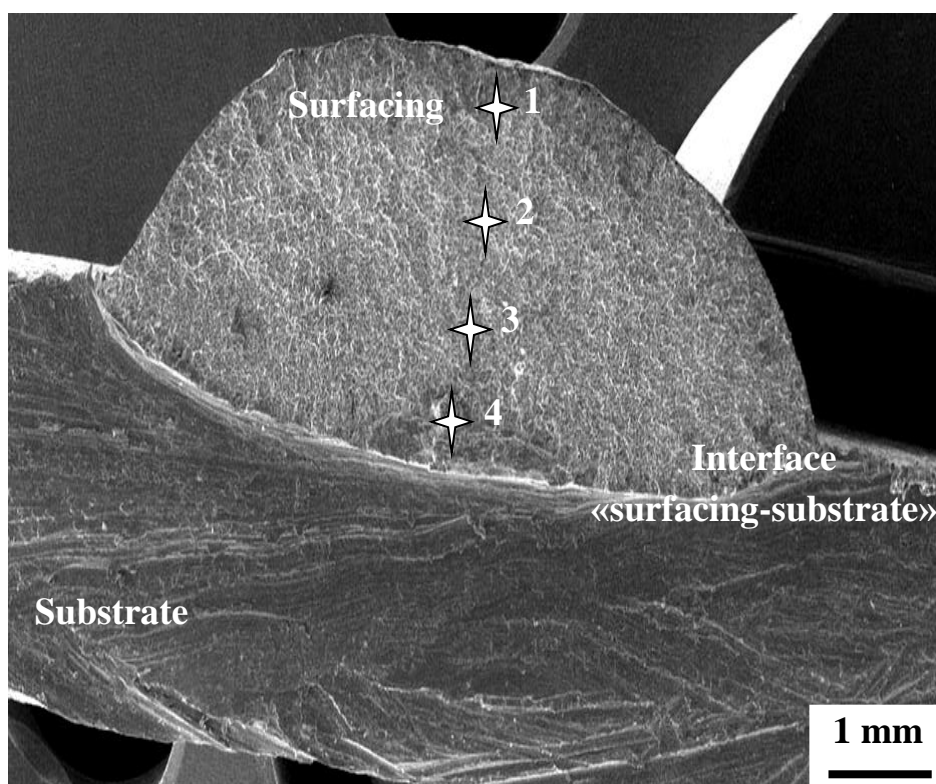


Fig. 1. Electron-microscopic image of end section of Fe-Cr-Mo-Ti-Ni-Cu-Al system surfacing on a steel 35 substrate.

Table 2 shows the results of qualitative-quantitative energy-dispersive analysis. The distribution and the corresponding concentrations of elements, as well as the absence of liquation inhomogeneities, attest to the intensive mixing of the material of the formed surfacing during melting. The increased Fe content in regions 2, 3, 4 is a consequence of mixing with the substrate material.

The lenticular shape of the interface "surfacing-substrate" (Fig. 1), determined by the geometric dimensions of the weld pool, also indicates intensive mixing of the formed surfacing with the substrate. As a result of the bending test at room temperature, there was no detachment or cracking of the formed surfacing from the substrate, which indicates a high adhesive strength.

Table 2 – Elemental composition of surfacing at different distances from the interface "surfacing-substrate".

Region	Elements concentration, wt. %						
	Fe	Cr	Mo	Ti	Ni	Cu	Al
1 (3.5 mm)	36.85	7.26	1.85	4.73	24.24	19.13	5.95
2 (2.5 mm)	50.36	5.02	1.42	3.74	18.02	16.85	4.59
3 (1.5 mm)	53.44	4.52	1.74	2.98	16.39	16.63	4.31
4 (0.5 mm)	48.72	4.72	2.30	5.25	18.55	15.95	4.50

The fractograph of the surfacing break is shown in Figure 2. Near the interface "surfacing-substrate", a viscous character of fracture is observed. At a distance of about 0.3 mm from this boundary, the fracture mechanism changes from viscous to brittle with elements of intercrystalline fracture, which is typical for the surfacing bulk. At the same time, in near-surface layers (0.3 mm) intercrystalline fracture changes to intracrystalline fracture, as evidenced by the river relief characteristic of fracture by cleavage.

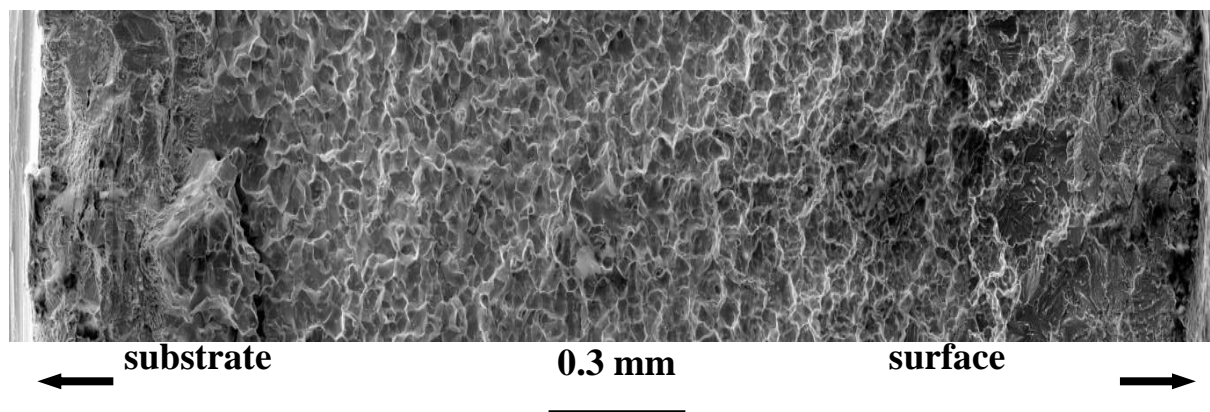


Fig. 2. Fractograph of surfacing break after the bending test at room temperature. Panoramic electron microscopic image

In the process of detailed analysis in the region of intercrystalline fracture, it was revealed that the characteristic sizes of the crystallites reach 30 microns (Fig. 3a), and on their surface (boundaries) a slightly-marked river relief is observed. As a result of a complex analysis of electron microscopic images and maps of the distribution of elements, it was established that the composition of crystallites is characterized by a solid solution of Fe-Cr-Mo-Ni system (regions 2 and 3 in Fig. 1, Table 2), which is close to elemental composition of heat-resistant high-alloy steels. Within the crystallites, particles of 1 to 3 microns in size are found, which are Ti-Al system based compounds (indicated by white arrows in Fig. 3a), and the boundaries between the crystallites are enriched in copper (Figure 3b).

Inside the crystallites of near-surface layer (region 1 of Figure 1, Table 2), a significant increase in the concentration of Cr, Mo, and Ni occurs with a significant decrease in the Fe concentration. In turn, the decrease in the size of crystallites, which leads to an increase in the specific area of the intercrystallite boundaries, is the reason for an increase in the concentration of copper along the boundaries. In addition, an increase in the particle density on the basis of the Ti-Al system was observed inside the crystallites.

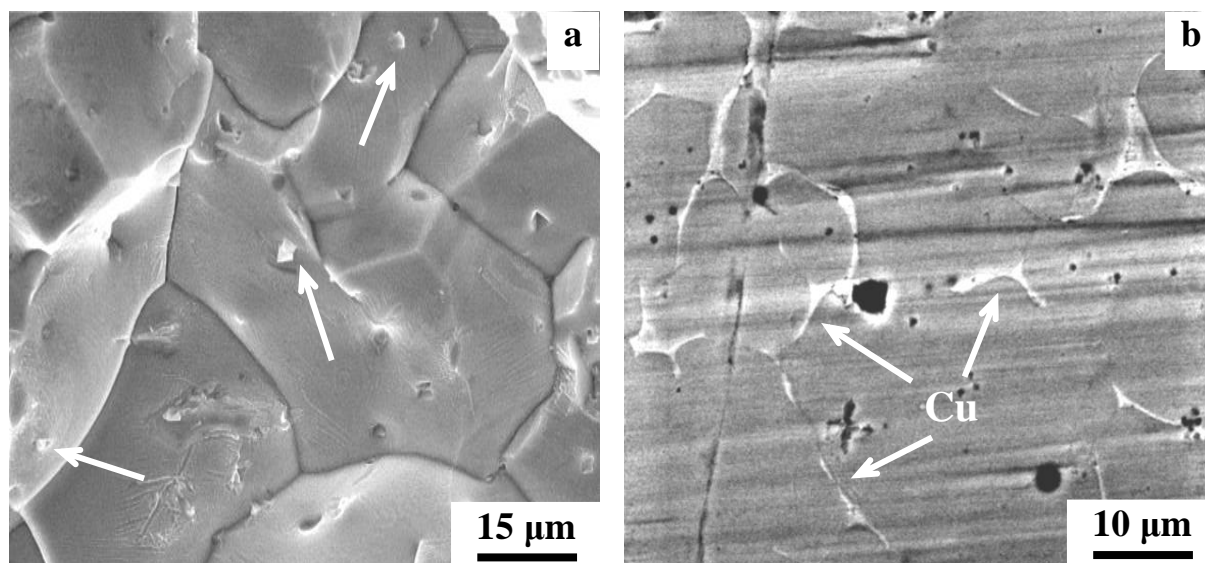


Fig. 3. Electron microscopic images of crystallites with Ti-Al-system based particles (a) and copper-enriched regions (b)

Thus, the surfacing formed is characterized by gradients of the grain structure, element composition and strength properties. The viscous nature of fracture, which is characteristic for plastic state, determines the high adhesion strength of the "surfacing-substrate" interface near the substrate. A gradual change in the elemental composition in the bulk of the material determines a smooth increase in microhardness from the substrate to the surface of surfacing, characterized by maximum values.

It is important to note that heat-resistant high-alloy steels (type EI680), which are close in elemental composition, are characterized by microhardness of 1.8 GPa [22], which is almost 4 times lower than the microhardness of the resulting surfacing.

Conclusions

By the example of Fe-Cr-Mo-Ti-Ni-Cu-Al system, the fundamental possibility of obtaining multicomponent metal surfacing on uncooled steel substrate using a pulsed regime of arc burning is demonstrated.

The resulting gradient surfacing, on the one hand, provides a highly reliable connection with a less strong substrate, on the other, allows the formation of high-strength states in the near-surface layers subjected to the strongest external effects in practical applications.

The work was carried out using technological equipment of NR TPU and research equipment of the Tomsk Materials Science Collective Use Center of NR TSU.

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