DEVELOPMENT OF FLUX-CORED WIRE OF THE FERRITIC GRADE FOR SURFACING OF HIGH-CARBON STEEL PARTS

Ya.P. CHERNYAK
E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

The issue of current importance is reconditioning of parts with a carbon content of more than 0.5 %. Traditional methods for crack control, such as preliminary and concurrent heating, in surfacing of parts made from high-carbon steels are not always possible to apply, because of a large weight of the parts or economic inexpediency. The investigation results presented in the article allowed the development of a new surfacing consumable of the ferritic grade, which provides the defect-free deposited layer when using no preliminary and concurrent heating. The key element of the Fe–Ti–Mn–Si–Mo alloying system is titanium. Considering its affinity for carbon and stoichiometric ratio, this made it possible to produce a soft ferritic matrix in the deposited layer, the content of carbon in the base metal being up to 1 %. The positive result of experimental-industrial verification of the developed flux-cored wire in surfacing of tram rails made from steel M76 with a carbon content of up to 0.8 % permitted recommending this wire for commercial application. Specifications of Ukraine TUU 28.7.05416923.066–2002 were worked out for commercial manufacture of wire PP-Np-06T3GM (PP-AN203). Ferritic flux-cored wire PP-Np-T3SGM provides the absence of all types of cracks in the deposited metal and HAZ, including spalls, within a wide range of surfacing parameters. It is recommended for application in surfacing of parts made from high-carbon steels without preliminary and concurrent heating. 4 Ref., 2 Tables, 3 Figures.

Keywords: *arc surfacing, surfacing consumables, high-carbon steels, flux-cored wire, ferritic deposited metal, preliminary and concurrent heating*

Many components of metallurgical equipment, railway transport, construction machinery, etc. are manufactured from high-carbon steels with a carbon content of more than 0.5 %. In surfacing of these components it is necessary to take measures to prevent formation of cold cracks in the deposited metal and HAZ. The most common method for prevention of cracks is still preliminary and concurrent heating followed by tempering, allowing a substantial decrease in residual surfacing stresses induced by formation of martensitic structure in the deposited metal and HAZ. If heating is impossible, surfacing is performed by using austenitic electrode materials, which is not always reasonable both from the technical and economic standpoints [1].

The purpose of this study was to develop a consumable for surfacing of parts made from high-carbon steels without or with minimal heating, providing the defect-free deposited metal corresponding in structure to alloyed steel of the ferritic grade [2]. To eliminate formation of martensite, carbon transferring from the base metal into the deposited one is fixed into strong carbides in such a proportion that it remains in matrix in the minimal amount. In this case, the matrix retains a relatively soft and ductile ferritic structure, and the deposited and base metals have close thermal expansion coefficients, this leading to decrease in residual surfacing stresses.

The Fe–Ti–Mn–Si–Mo alloying system of the deposited metal was selected for investigations. The titanium content of the deposited metal was chosen based on the following considerations. Titanium is known to actively react with carbon to form carbide TiC with stoichiometric ratio of 4:1. It was planned to perform surfacing on steel with a carbon content of 0.7–0.9 %. In penetration of the base metal equal to about 30–40 %, the carbon content of the first deposited layer may amount to 0.35 %. To fix this amount of carbon it is necessary to have about 2 % Ti, which should provide formation of a soft ferritic matrix and, as a result, the absence of cracks in the deposited metal.

Titanium is also known to strongly oxidise during the surfacing process. Experiments were carried out on surfacing of specimens of high-carbon steel with a carbon content of 0.8 % by using the 2.6 mm diameter self-shielding wire of the investigated alloying system to determine its required content in the deposited metal and, correspondingly, in the flux-cored wire charge. Surfacing was performed with the open arc under

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Table 1. Content of titanium in metal of the first deposited layer depending on its content in the self-shielding flux-cored wire charge

Calculated content of titanium in flux-cored wire charge, wt.%	Actual content of titanium in deposited metal, wt.%
2.17	0.68
3.26	1.15
3.95	1.31
4.05	1.51
4.87	2.05
5.62	2.50
7.04	2.73

Table 2. Chemical composition and hardness of metal deposited with flux-cored wire PP-Np-T3SGM

Bead number	Content of elements, wt.%							Hardness *HV*
	C	Mn	Si	Cr	Ni	Ti	Mo	
1	0.4	0.9	0.9	–	–	2.6	0.4	185–195
3	0.2	1.0	1.2	–	–	3.3	0.6	170–180

the following conditions: I = 430–450 A, U = = 24–26 V, and v_s = 36.8 m/h. The use was made of the basic-type gas-slag system (CaF_2 + + $CaCO_3$ + [SiO_2 + K_2O + Al_2O_3]). Titanium was added in the form of ferrotitanium FTi-70 with 69 % Ti.

The mean coefficient of transfer of titanium into the first deposited layer metal equal to about 40 % was calculated from the data of Table 1, which gives the investigation results. Therefore, to provide the required amount of titanium in the first deposited layer equal to 2 %, its content of the flux-cored wire charge should be approximately 5 %.

Based on the data on transfer of titanium into the deposited metal, experimental flux-cored wire PP-Np-T3SGM was made for the investigations, and surfacing was performed on steel with a carbon content of 0.8 % under the above conditions. The results of investigation of chemical composition and hardness of the deposited metal of the first and third beads are given in Table 2.

As shown by metallographic analysis, metal of the first and third layers had a ferritic structure (Figure 1). Its characteristic feature is the presence of disoriented fine crystalline grains with dispersed inclusions that precipitated along their boundaries and in their bulk, these inclusions being mostly carbonitrides of different compositions. Low hardness (*HV* 170–195) is also indicative of the absence of martensite in matrix of the deposited metal of the first and third beads.

Structural and phase transformations occurring in the deposited metal during the heating and cooling process were studied by using a fast-response dilatometer designed by the E.O. Paton Electric Welding Institute [3, 4]. In this dilatometer the rates of heating and cooling of specimens simulate the thermal surfacing (welding) cycles. The specimens were made from metal of the first layer deposited by using wire PP-Np-T3SGM on steel with a carbon content of 0.8 % (see Table 2).

As seen from Figure 2, *a*, the specimens in cooling at a rate of 36 °C/s (according to the most rigid thermal surfacing cycle) retain their initial ferritic structure. This is evidenced by monotony and reversibility of the curves.

The plotted curves were compared with a dilatometry pattern of core iron containing 4–5 % Si and having a stable ferritic structure (bcc lattice) in a range from room temperature to melting point (Figure 2, *b*). It can be seen from comparison of dilatometry patterns of the T3SGM deposited metal and core iron that they are similar and have an identical slope, i.e. their struc-

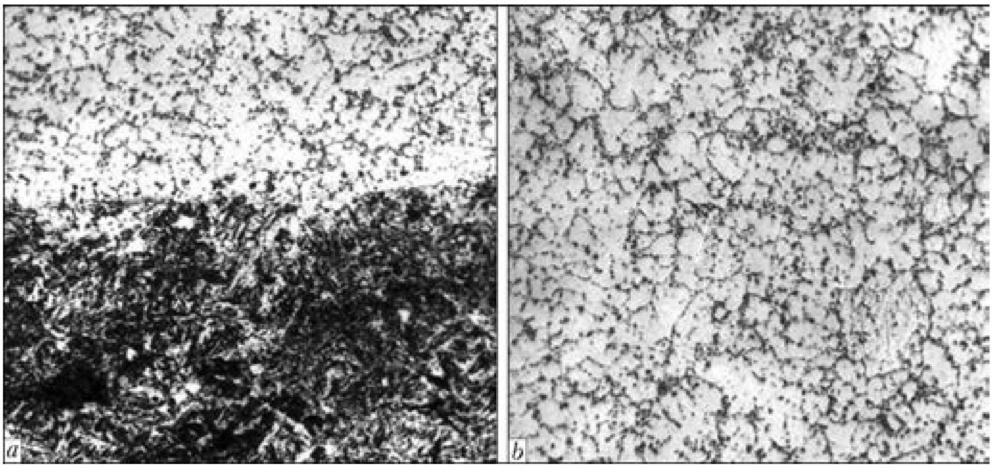

Figure 1. Microstructure (×500) of metal deposited with flux-cored wire PP-Np-T3SGM: *a* — fusion zone; *b* — first bead centre

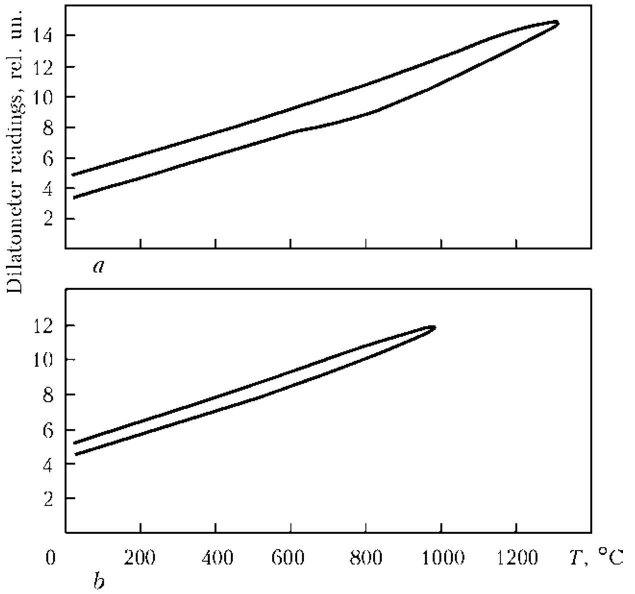

Figure 2. Dilatometry curves of heating and cooling of T3SGM deposited metal (*a*) and core iron (*b*)

tures and thermal expansion coefficients are close.

Therefore, the investigations performed show that even at a carbon content of the deposited metal equal to 0.5 %, due to alloying with titanium this metal solidifies as the ferritic one and undergoes no transformations in the solid state.

Investigation of mechanical properties of metal deposited with wire PP-Np-T3SGM proves that they are sufficiently high: σ_y = 393 MPa, σ_t = 638 MPa, δ = 18.5 %, and ψ = 24.5 %.

The developed flux-cored wire with a carbon content of up to 0.8 % was subjected to experimental-industrial verification in surfacing of tram rails made from steel M76.

As shown by measurements of hardness of the HAZ metal, the maximal hardness value near the fusion line under the first deposited bead is approximately *HV* 400 (Figure 3). Microstructure in this zone consists of tempered martensite + bainite (see Figure 1, *a*). It should be noted that there is almost no carbide ridge at the fusion line. The rest of the HAZ regions have a ferritic-pearlitic structure with hardness *HV* 280–350, and are not dangerous in terms of cold cracking.

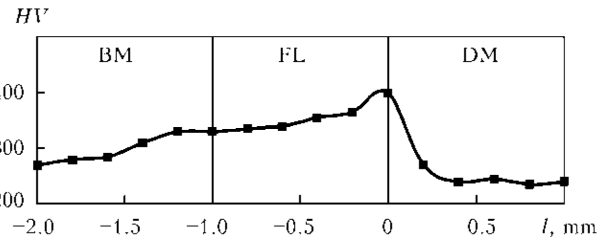

Figure 3. Hardness of fusion zone under the first deposited bead

Results of the experimental-industrial verification show that the developed flux-cored wire PP-Np-T3SGM provides the absence of all types of cracks, including spalls, in the deposited and HAZ metals over a wide range of surfacing parameters. Another advantage of flux-cored wire PP-Np-T3SGM is that it contains no scarce and expensive alloying elements. Hence, its price is not high.

Conclusions

1. Flux-cored wire PP-Np-T3SGM was developed. It provides the ductile ferritic structure of the deposited metal and, as a result, the absence of cold cracks in surfacing of parts made from high-carbon steels without preheating.

2. The investigations and experimental-industrial verification performed allow flux-cored wire PP-Np-T3SGM to be recommended for surfacing of parts made from high-carbon steels without preliminary and concurrent heating.

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