

Electron Beam Fusion of the Stainless Steel on the Plain Carbon Steel

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Abstract – Using the relativistic electron beam extracted into atmosphere, fusion of stainless steel plates placed onto plain carbon steel basis have been made. The surface structure and hardness as well as corrosion stability have been studied in the work. The comparative analysis of coating properties with 12X18H10T stainless steel properties has been carried out. Using this method, the possibility of formation of high corrosion-resistant protective layers, which were additionally strengthened by chromium carbides, on the low-carbon steel surface is shown.

1. Introduction

Steel corrosion resistance is increased by means of adding the elements generating protective layers on the surface into steel. Those protective layers have strong cohesive bond with basic metal and protect the steel from a contact with the environment. Mainly, chromium, which generates the oxide $(Cr, Fe)_2O_3$ protective layer on the surface and sharply reduces corrosion rate, is added.

To improve the mechanical properties of corrosion-resistant steels, nickel, which expands an austenitic range and improves strength and plasticity, is added into them additionally. The representative of those steels is 12X18H10T steel. Nevertheless, the chrome nickel steels are expensive. One of the methods of saving the expensive alloying elements is generation of corrosion-resistant protective layer on the surfaces of products.

The new method of generation of two-layer materials is relativistic electron beam fusion [1–3]. As opposed to the vacuum-electron-beam fusion method, the new technique allows product treatment in atmospheric air. It characterized by high process productivity, ease of alloying elements insertion and high-quality of fused layer. The obtained coatings are strongly connected with a basis.

The purpose of this work was generation of corrosion-resistant layers by means of 12X18H10T stainless steel plate fusion on the steel St3 surface with the use of relativistic electron beam and research of their properties.

2. Materials and methods

Electron-beam fusion was made by electron accelerator ELV-6 designed and manufactured by Budker Institute of Nuclear Physics, Novosibirsk. The accelerator provided with the device of concentrated extraction of electron beam into atmosphere with multi-step pumping system. The following radiation parameters have been used: 1.4 MeV electron power and 21–24 mA beam current. The distance between extraction window and the sample surface was 90 mm, beam diameter was 1.2 mm. The beam scanning was carried out in the direction perpendicular to the direction of sample travel. Scanning swing was 50 mm and sample migration speed was 1 cm/s.

As a basis material for fusion a low-carbon steel St3 has been chosen. As a fused material the stainless steel plates 12X18H10T of 0.8; 1.2; 1.5 and 2 mm thickness, which were put on the samples and were irradiated without any secured operations and without flux use, have been taken. In a separate experiment the surface 12X18H10T steel layer preliminary covered by Cr_3C_2 carbide powder layer has been fused.

The metal structure has been studied by optical microscope. The X-ray phase analysis was carried out. Distribution of alloying elements in fused and interface layer was studied by means of emissive spectral analysis technology by prism spectrograph. For this purpose the samples have been exposed by electric discharge in three points. The operation was repeated many times at successive remove of surface layers.

Distribution of microhardness in fused layers in direction between surface and sample depth was measured. Corrosion resistance was determined by measuring of mass loss at dissolving the samples in 100 % nitric and 100 % hydrochloric acids.

3. Results and discussions

Initial structure of stainless steel is shown in Fig. 1, a. In accordance with X-ray phase analysis it is pure austenite. The deformation twins are visible on those micrographs.

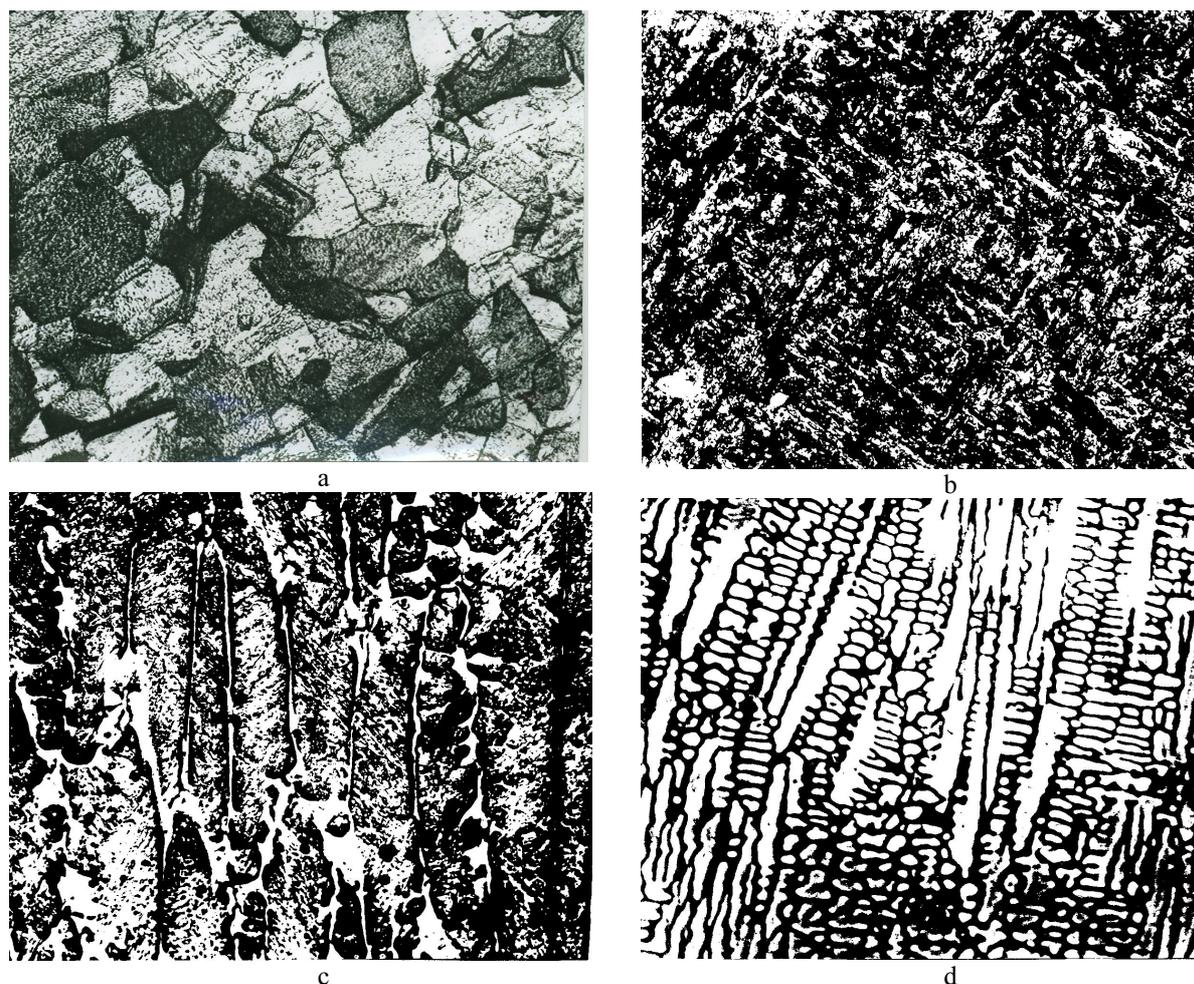


Fig. 1. 12X18H10T steel structure (a), structure of the surface layer fused onto St3 steel at 12X18H10T steel plate thickness 1.2 (b) and 2 mm (c) and the structure of carbide Cr_3C_2 powder layer fused onto 12X18H10T steel (d), $\times 500$

During the fusion of 0.8–1.2 mm 12X18H10T steel plates onto St3 steel the fusion 2.3–2.5 mm layer is formed following the dilution by basic metal. The micrographs show the forming of bainite structure in fusion layer the basic phase term of which is martensite, i.e. white untreated areas at the photos (Fig. 1, b). X-ray analysis shows sharp decrease of diffraction maximum height at roentgenograms for γ -iron and the occurrence of α -iron (martensite) strong lines.

In accordance with emission spectral analysis the distribution of alloying elements in fused layer is relatively uniform (Fig. 2). Rather overestimated concentration at the surface are the sequence of slag emission. In comparison with initial stainless steel, during the fusion of 1.2 mm plate chromium and nickel concentration are decreased in two times. As the thickness of fused layer in this case twice exceeds the thickness of initial plate, we may establish that alloying elements burning is insignificant. At 0.8–1.2 mm thickness of the plate being fused the

average hardness is 3500–4000 MPa. That is significantly higher than initial steel hardness and is a consequence of solid martensite component appearance. At fusion of a 1.5 and 2 mm plate the thickness of fused layer runs up to 2.4–2.6 mm, an average hardness in which is about 3000 MPa (Fig. 3, a). That shows that mixing of plate metal together with basic metal, in this case, is insignificant and chrome and nickel content in fused layer is closer to their content in 12X18H10T steel, as, due to emission spectral analysis, the burning of alloying elements at electron-beam fusion is small.

When hardening such a system from liquid state after the electron beam operation is finished a dendritic-cellular crystallization occur. The structure form, where solid solution primary grains, being bainitic transformed, are surrounded by eutectic phase mixture (Fig. 1, c) including special chromium carbide Cr_{23}C_6 .

In accordance with X-ray phase analysis, when increasing the fused plate thickness, the content of

austenite in fusion layer grows. That is expressed in increase of γ -iron diffraction maximum intensity. This is connected with a growth of nickel content stabilizing austenite in a layer.

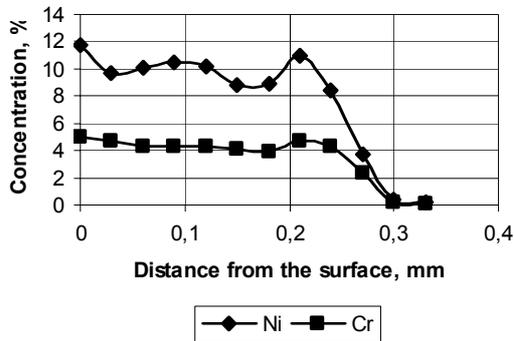


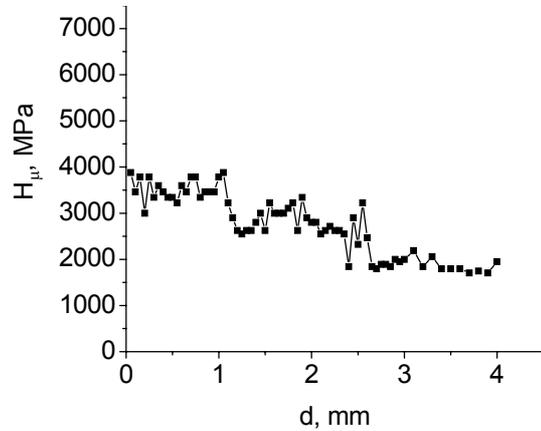
Fig. 2. Distribution of alloying elements in surface layer at fusion of 1.2 mm 12X18H10T steel plate onto St3 steel

When fusing chrome carbide onto stainless steel, the 0.5 mm fusion layer with high hardness is formed (Fig. 3, *b*). H_{μ} values near the surface of fusion layer are maximum and equal to 7000 MPa. When increasing the distance from a surface the hardness noticeably decreases approaching to the hardness of main metal near fusion zone bottom. A typical cast structure of hypoeutectic cast iron forms in the layer. Here austenite dendrites elongated towards thermal sink is surrounded by ledeburite eutectic including carbides (Fig. 1, *d*). In accordance with X-ray phase analysis chrome carbide Cr_7C_3 predominates. The samples of stainless steel with surface layer fused by chrome carbide have been tested for abrasive wear-resistance test with using of unfixed abrasive particles (GOST 203.208-79). The tests showed the three-times increase of wearing capacity in comparison with non-hardened 12X18H10T steel.

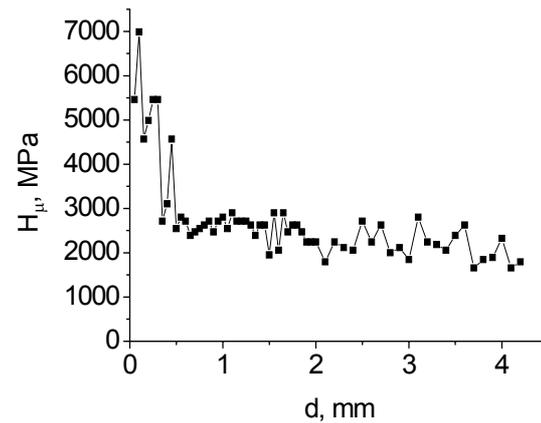
The measuring results of sample corrosion resistance in concentrated nitric acid are shown in Fig. 4, *a*. St3 steel is of low corrosion resistance (curve 1) and, after being soaked during 24 hours in nitric acid, loses 3 % from initial mass. Stainless steel is dissolved very slowly. In 24 hours its mass is decreased for 0.05 % only (curve 2). Corrosion resistance of fusion layers is rather lower than 12X18H10T steel corrosion resistance (curves 3 and 4).

High corrosion resistance of 12X18H10T steel is explained by the fact that 12X18H10T steel contains chrome, which promotes formation of protective film of $(Cr,Fe)_2O_3$ type at a surface. This film provides an increase of electrochemical potential and conversion of the steel into passive state with respect to corrosive medium. [6]. A decrease of corrosion resistance in case of 12X18H10T steel fusion onto St3 steel is connected with average chrome concentration reduction. That fact is indicated by conversion of austenite structure into bainite structure (Fig. 1, *a, b*).

The decrease of stainless steel surface layer corrosion resistance at chrome carbide fusion is caused by low corrosion resistance of interdendritic gaps filled with eutectic (Fig. 1, *d*) in which chrome promoting corrosion resistance is bound into $Cr_{23}C_6$ carbides and its content in solid solution is decrease.



a



b

Fig. 3. Distribution of hardness in surface layer at fusion of 2 mm 12X18H10T steel plate onto St3 steel (a) and at fusion of Cr_3C_2 powder on 12X18H10T steel substrate

At the next research point the corrosion resistance tests have been carried out in higher corrosive medium, i.e. in hydrochloric acid. The reason of high activity of HCl is connected with a presence of active Cl ions in electrolyte. Adsorbing at a surface of passive oxide film those Cl ions displace and replace oxygen ions what makes the film soluble and leads to formation of pores with corresponding anode process acceleration. The anode process proceeds more easily due to the change of potential jump in double layer [6].

Fig. 4, *a* shows that it is possible to note two stages on the curves describing the mass loss of a sample depending on its storage time in corrosive medium. At the first stage the process proceeds quickly. At the

second stage a corrosion speed decreases and the curves run up to saturation. At the second stage a mass of stainless steel did not change at all. Evidently, transition to the second stage corresponds to the formation of oxide protective film.

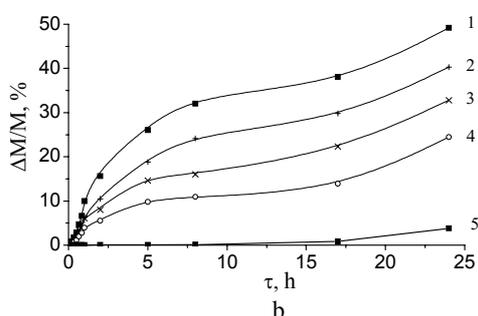
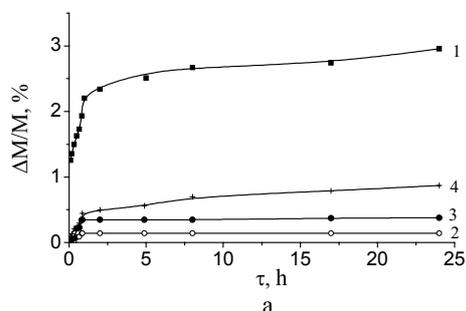


Fig. 4. Dependence of relative mass loss of samples on a time of their holding in corrosive medium: a – holding in nitric acid of steel St3 (1); 12X18H10T steel (2), fusion of 12X18H10T (1.2 mm) steel plate onto St3 steel (3); – fusion of Cr_3C_2 carbides onto 12X18H10T steel (4); b – holding in hydrochloric acid at 0.8 (1); 1.2 (2); 1.5 (3) and 2 mm (4) thicknesses of fused plate and 12X18H10T steel sample (5)

The purpose of such an experiment was acceleration of corrosion process and its realization in more severe conditions in order to discover the differences in corrosion resistance of layers fused by different thicknesses (from 0.8 to 2 mm) plates.

To carry out the test the plates of equal thickness and of same surface area, which were consisted from fusion metal only and without basis metal, have been cut from a surface. The test results are shown in Fig. 4, b.

Unlike the case of solution in nitric acid, corrosion lasts not two but three stages. The nature of sample mass change at two first stages at corrosion tests in nitric and hydrochloric acids is similar. At

curves $\Delta M/M(t)$, for the samples tested in hydrochloric acid, when increasing a storage time from 17 to 24 hours, third stage is observed. At third stage the process of corrosion activity is accelerated.

Generation of third stage is connected with through destruction of the plates being tested. The corrosion effect intensification (local corrosion) is observed at single sections of a sample surface up to through destruction of plates. At through destruction an area of sample contact with corrosive medium increases and corrosion rate rises significantly (Fig. 4, b).

Conclusion

1. Electron beam fusion method allows obtaining of 2 mm 12X18H10T stainless steel fused layers with particularly saved austenite structure on the cheap plain carbon steel St3.
2. In comparison with base metal corrosion resistance of such surfaces is raised tenfold. It rises at the increase of thickness of the plate being used for fusion. That is connected with the increase of chrome content in a fused layer.
3. Chrome carbide fusion onto stainless steel provides three time hardening and wearing capacity of surface layer due to carbide eutectic formation. In this case, in comparison with 12X18H10T steel corrosion resistance is insignificantly decreased.

The work was supported by Russian Fundamental Research Fund (project code 05-03-32402-a).

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