Structure and Properties of Fe–Cr–C–N–Mn Coating Obtained by the Electron-Beam Surfacing

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Abstract – Coatings deposited by multipass electron beam surfacing of powders that contain nitrogen in equilibrium concentration was investigated. Distribution of crystal lattice microstrains in the coating, which form stresses of the 1st and 2nd kinds, was experimentally obtained.

1. Introduction

For the last half a century, great advances were made due to the efforts of many scientific schools in the study of High Nitrogen Steels (HNS) [1, 2]. New composition materials are developed for coating deposition on the basis of HNS [3–6]. Prospectivity of new coatings based on nitrogenous solid solutions is caused by low energy of stacking fault and effective hardening under plastic deformation and friction loading of nitrogen austenite. The important performance factors for a detail, hardened by the coating, are the mechanical properties of the coating material as well as bimetallic composition behavior under external loading conditions and under the action of residual stresses as a whole. Coatings with the property of relaxing the residual stresses have significant advantages, providing high adhesion strength, stability of shape and size of the hardened product.

The aim of this work is to study the structural properties of nitrogenous coating, obtained by the electron-beam surfacing, on the 65Mn steel plate.

2. Experiments

Steel powder 60Cr24N0.7Mn16 is taken as a base of the deposition material. It is prepared by mechanical milling of steel chips pre-aged at 700°C during 3 h. The obtained powder is sieved to separate the fraction for deposition with good flowability, namely, with the particle size 50–400 μm.

Electron beam surfacing described in [7] is performed using an ELU-5 installation equipped with a powder feeder. An electron beam is split into two. One beam forms a molten pool on the substrate surface moving with the velocity of 3 mm/s, into which the deposition powder is fed through the feeder with the rate of 7–10 g/min. The second beam remelts the pool and captures the substrate. A coating 2.5–3 mm thick is obtained after several passages, each of which forms a layer ~0.5 mm thick. We use, as the substrate, 65Mn steel plates measured 20×100×10 mm, which are heat-treated by induction hardening to provide the hardness 56 HRC.

The coating structure is studied by an Axiovert metallurgical microscope. The X-ray structural analysis is performed using a DRON-4M diffractometer with CoKα-radiation.

3. Results and discussion

Nitrogenous coating is formed by the electron-beam surfacing in nonequilibrium conditions caused by high rate of heating, fusion, crystallization and cooling of the coating as well as technologically required air vacuum in deposition chamber. These conditions in combination with directional cooling predetermine the crystallized coating formation, with modified chemical and phase compositions in relation to surfacing powder. According to the Auger spectroscopy data, the chemical composition of nitrogenous coating has practically not changed, whereas the coating one was subjected to essential modifications. In the surfacing powder, the nitrogen is in the bound state in the form of chromium nitrides, and in the surfaced coating, the nitrogen completely passes into solid solution owing to the high cooling rate. In the surfaced coating, the zone 300 μm thick of coarse-crystalline austenite grains, stretched out in a direction perpendicular to the base material, is revealed. Grain size in cross-section varies from 30 up to 120 μm with nonequiaxity coefficient k equal 2. The diffractogram analysis, obtained without rotation from the end face of the sample has shown that crystallization texture with significant increase in diffraction intensity from the planes {111}, is formed in this coating layer, as compared to non-turized Fe. The diffractogram analysis registered from the same coating layer in a direction parallel to the base metal surface, has revealed another preferred orientation of austenite grains in the polished section plane, corresponding to the family of planes {200}, Fig. 1.
Coating Deposition

Fig. 1. Diffractograms, obtained by registration of coating fusion zone, deposited by powder 60X24Ag16 from the endface polished section (polished section plane is perpendicular to the base material plane of steel plate 65Г): a – and from the coating layer, adjacent to the fusion zone; b – diffractogram, obtained from the plate, cut out parallel to the base material plane.

It indicates the complex texture forming in the process of coating crystallization and caused not only by directional cooling but also by temperature gradient in the hot spot by the electron beam. Texture in surface layers of the coating is shown in a far less degree.

Analysis of microstrain component distribution of austenite crystal lattice, measured for the planes (111), (200), (220), (311), and (222) in the system substrate-coating and, responsible for the formation of residual stresses of the 1st kind, has shown that tensile stresses are formed in the coating layers adjacent to the fusion zone in a direction perpendicular to the base material plane, and compression stresses are formed in a direction parallel to the base material plane (Fig. 2).

On the contrary, surface layers of the coating, are deformed by the compression in direction of σ₁ and extension in direction of σ₂. Deformation gradient of crystal lattices of base steel material 65Mn and coating is observed in the fusion zone. Since the hardenable plate was rigidly fixed at deposition, partially residual stresses, succeeding the yield limit, relaxed by deformation of the coating material.

At metallographic study of polished sections, cut out in two mutually perpendicular directions, the multiple twinning Fig. 3 is observed in single, probably, in most favorably-oriented austenite grains, which is one of the basic deformation mechanisms of alloys with low energy of stacking fault. The deformation twins are observed in the bulk of the whole coating.

As shown in [8], the observed multiple twinning points out the high-rate intermittence of thermoplastic deformation in materials, treated by concentrated energy flows.

Fig. 2. Distribution of lattice microstrain components γ-Fe and α-Fe in the coating deposited by the powder 60X24Ag16 in the fusion zone and steel substrate 65Г in direction of stress vector projection σ₁, perpendicular to the base material surface (ψ = 90°) (a) and in direction of stress vector projection σ₂, parallel to the base material surface (ψ = 0°) (b). (Point h = 0 on the x-axis corresponds to the fusion zone.)

Fig. 3. Coating structure in the layer, adjacent to the fusion zone

Moreover, it has been established that as a result of plastic deformation in coating structure, two kinds have appeared, which cause the atomic displacement from the lattice points at dislocation nucleation and motion, at doping of solid solution. As an etalon for determination of intrinsic broadening, a coating segment was used after quenching from 1150 °C in water and electropolishing. The aim of the assigned heat treatment was to recrystallize the coating and form
a structure that is maximum approximate to the coating structure after electron-beam surfacing. It has been established by approximation method that diffraction maxima broadening from the planes (111), (220), (311), (222) are conditioned entirely by crystal lattice microstrains. Size of coherent scattering blocks essentially exceeds 100 nm that allows excluding the effect of coating structure refinement for broadening (procedural error exceeds the measured value of D). Microstrains in the coating layer, located near the fusion zone with a structure of coarse-crystalline austenite, and in the surface layer make 0.0173 and 0.009%, respectively. Dislocation density $\rho$, calculated by $\rho = A \cdot \beta^{-2}$, where $\beta$ is the intrinsic broadening of the austenite line (111), rad and $A$ is the constant factor equal to $2 \cdot 10^{16}$ in the coating layer, located near the fusion zone makes $2.44 \cdot 10^{10}$ cm$^{-2}$, and in the surface layer $2.25 \cdot 10^{10}$ cm$^{-2}$. A lot of factors including the doping level of solid solution can affect the increase of diffraction maximum width. Insignificant increase of microstrains and dislocation density in the coating layer, integrating with base material, occurs due to the effect of non-deforming base material on it, temperature gradient in adjacent coating bulks and base material with different types of crystal lattices, and also due to the ultimate solution of carbide particles. It is confirmed by structural and x-ray phase studies. The carbide particles (Cr, Fe)$_7$C$_3$ and Cr$_2$3C$_6$, located mostly on austenite grains boundaries are revealed in the coating structure by x-ray and metallographic studies. Volume fraction of carbide particles in the coating layer with coarse-crystalline austenite is much less 1–2%, than in the coating bulk, where much larger irregular particles with volume fraction 5–6%, which restrain the grain growth, are observed at cooling the multilayered coating.

4. Conclusions

High-speed quenching of nitrogenous coating with austenite structure formation, hardened by chromium carbide particles with expressed crystallization texture occurs at electron-beam surfacing of nitrogen steel 60Cr24N0.7Mn16. Owing to the thermal and structural gradients in multilayered coating, the complex stress is formed, which is characterized by sign change of crystal lattice deformation through the coating thickness and increased dislocation density. Due to the action of residual stresses in the coating, the relaxation processes are developed by means of mechanical multiple twinning.

References