C4-P-005302

SURFACE HIGH SPEED STAINLESS STEEL ALLOYING WITH COPPER *

Yu.F. IVANOV, E.A. PETRIKOVA, A.D. TERESOV, N.A. PROKOPENKO, M.S. PETYUKEVICH

Institute of High Current Electronics SB RAS, Tomsk, Russia

The using copper as an alloying element, the addition of which in small concentrations to low-carbon steel instead of expensive elements - niobium, titanium and vanadium, leads to the appearance of high corrosion and mechanical characteristics associated with the formation of Fe-Cu precipitates in the bulk of the material [1-3]. It has been established that these precipitates are nanosized particles of a saturated (more than 1% at.) solid solution of copper in iron, while in the equilibrium state the maximum solubility of copper in iron does not exceed 0.38% at. In this case, one should speak about the properties of the material as a function of near-surface transition states. Nanosized copper-enriched particles in α-Fe formed during cooling provide high ductility and fracture toughness and cause dispersion strengthening of the steel.

The formation of the "film (Cu)/(steel 321) substrate" system was carried out on the QUINTA installation [4] by sputtering copper films 0.5 μm thick onto steel specimens. High-speed alloying of steel with copper was carried out by irradiating the "film (Cu)/(steel 321) substrate" system with a pulsed electron beam using a SOLO setup [4]. The irradiation mode corresponded to the liquid-phase alloying of the steel surface layer with copper.

Studies performed by scanning electron microscopy showed that at an electron beam pulse duration of 50 μs (15 J/cm^2, 15 pulses, 0.3 s^{-1}) a nanocrystalline structure with a crystallite size of (80-120) nm is formed on the specimen's surface. At an electron beam pulse duration of 200 μs (30 J/cm^2, 15 pulses, 0.3 s^{-1}), regions with a lamellar structure are formed on the specimens surface. A structure of cellular crystallization is observed in the bulk of the plates. The cell sizes vary within (0.58-0.81) μm. X-ray microanalysis revealed a decrease (more than 4 times) in the concentration of copper in the steel surface layer with an increase in the duration of exposure to the electron beam from 50 μs to 200 μs.

Using X-ray phase analysis methods, it was shown that at an electron beam pulse duration of 50 μs, a solid solution of copper in a crystal lattice based on γ-Fe and a $Fe_{0.5}Cu_{0.5}$ phase with a bcc crystal lattice are formed in the surface layer. With an increase in the pulse duration to 200 μs, a two-phase structure is formed in the surface layer - γ-Fe and a phase of $Fe_{0.7}Cu_{0.3}$ composition, which has an fcc crystal lattice.

Cu as a separate phase is not detected. An increase in the electron beam pulse duration from 50 μs to 200 μs leads to an increase in the crystal lattice parameter of γ-Fe from 0.35191 nm to 0.35300 nm. Taking into account the ratio of the sizes of the atomic radii of Fe (R(Fe) = 0.126 nm) and Cu (R(Cu) = 0.128 nm), we can conclude that the process of replacing iron atoms in the crystal lattice of the γ-phase by copper atoms increases with an increase in the duration of the electron beam pulse, which leads to an increase in the lattice parameter.

Thus, a two-stage mechanism of solid solution decomposition in the "film (Cu) / (steel 321) substrate" system irradiated with a pulsed electron beam was revealed, as a result of the performed studies. At an electron beam treatment duration of 50 μs, the formation of nanosized particles of the $Fe_{0.5}Cu_{0.5}$ phase, which has a bcc crystal lattice, is observed. With an increase in the duration of exposure to the electron beam to 200 μs, the formation of $Fe_{0.7}Cu_{0.3}$ composition phase, which has an fcc crystal lattice, is recorded in the steel surface layer.

REFERENCES

[1] L.A. Dreval. «Thermodynamic properties of liquid alloys of copper and iron with chromium, cobalt and nickel», Abstract of the dissertation of Cand. chem. Sciences. Kiev: Kiev National University, 2011.

[2] Yu.N. Gornostyrev, I.N. Karkin, L.E. Karkina, «Interaction of dislocations with nanoscale precipitates of the metastable phase and dispersion strengthening of the Fe-Cu alloy», Solid State Physics, V.53, No. 7, 2011.

[3] S.N. Saltykov, A.M. Hoviv, A.A. Maksimenko, «On the issue of polymorphic modifications of iron in a thin-film state», Journal of Inorganic Chemistry, V. 56, No. 3, 2011.

[4] S.V. Grigoriev, N.N. Koval, V.N. Devjatkov, A.D. Teresov, «The automated installation for surface modification of metal and ceramic-metal materials and products by intensive pulse sub-millisecond electron beam», Proc. 9th Intern. Conf. on Modification of Materials with Particle Beams and Plasma Flows. – Tomsk, 2008.

* *The work was supported by the Ministry of Science and Higher Education of the Russian Federation (Number: FWRM-2021-0006).*