Electrolytic Deposition of a Cobalt-Lead Alloy with Magnetic Properties

O. A. Surzhko

South-Russian State Technical University, Novocherkassk Polytechnic Institute, Novocherkassk, Rostov-on-Don oblast, Russia
e-mail: eng_ecology@bk.ru

Received September 1, 2011

Abstract—Electrolyte for obtaining a cobalt–lead alloy was suggested. The electrochemical parameters at which cobalt and lead are simultaneously deposited from the pyrophosphate electrolyte were determined. The magnetic parameters of the alloy were measured.

DOI: 10.1134/S1070427213020092

A study of the process in which alloys are formed in systems with noninteracting components deserves attention because alloys of this kind can only be produced by electrochemical methods. Computer simulations prognosticate that intermetallic compounds exist in binary systems formed by components that do not interact under heating [1].

Problems associated with syntheses of new materials and, in particular, alloys possessing valuable physicochemical, e.g., magnetic, properties are rather topical [2]. Among methods used to obtain alloys, the electrochemical technique has a number of specific features: possibility of obtaining alloys in systems with mutual insolubility of components in solid and liquid states (cobalt–silver, nickel–lead, copper–lead), formation of equilibrium (CoSn, InSb) and metastable (CuPb) intermetallic compounds absent in constitution diagrams (NiSn), and deposition of magnetic coatings on profiled surfaces.

The cobalt–lead system is composed of components that do not interact in the solid and liquid states, and, therefore, has the form of two stratifying fluids at temperatures above 1713 K. According to Schank, the solubility of cobalt in liquid lead at 1873 K is 0.84 at %, and that of lead in liquid cobalt, 0.29 at % [3]. The so low mutual solubility at high temperatures gives no way of metallurgically obtaining an alloy that would be of technical importance, e.g., would possess magnetic characteristics.

Such magnetic systems as cobalt–platinum and cobalt–rare earth metals have been produced on the basis of cobalt. Cobalt being the key element determining the magnetic properties, it is of interest to replace high-cost metals in cobalt-based systems with lead. The possibility of such a replacement is confirmed by the crystal-chemical similarity of the elements to be replaced. Indeed, lead, platinum, yttrium, and praseodymium have crystal lattices of the same type (cubic) and close values of their atomic radii: 1.75, 1.33, 1.84, and 1.83 Å, respectively.

Owing to the possibility of replacing platinum and rare-earth metals with lead, it can be assumed that the cobalt–lead alloy will possess magnetic properties. Therefore, determining the magnetic properties of the cobalt–lead alloy is of particular interest.

The goal of the study was to examine processes of joint electrolytic deposition of cobalt and lead, which are metals noninteracting in the molten state, and to obtain an alloy possessing magnetic properties.

EXPERIMENTAL

Electrolytes base on complex compound of cobalt and lead, which made it possible to make substantially
Closer their discharge potentials, were chosen for the study. As the main electrolytes used to obtain the alloy were pyrophosphate electrolytes, which are nontoxic, stable in operation, have a high throwing power, and enable electrodeposition with high cathodic polarization [4]. The principal disadvantages of these electrolytes are the low solubility of pyrophosphates in water and the passivation of anodes [5, 6].

Cobalt–lead anodes were used in the pyrophosphate electrolytes under study, which contain a buffer additive, ammonium chloride. These anodes are not passivated at 60°C due to the depassivating effect of sodium citrate and Seignette salt. It was found experimentally that cobalt anodes are not passivated at current densities of up to 5 mA cm⁻², and cobalt anodes, up to 10 mA cm⁻². To find conditions leading to joint deposition of cobalt and lead in potentiostatic and potentiodynamic modes, polarization measurements of electrolytes containing pyrophosphate complexes of cobalt and lead together and separately were performed.

It was experimentally found that no hydrogen evolution occurs when the Co–Pb alloy is produced from the electrolyte suggested by the author at pH 9.7. The alloy coating is finely crystalline, smooth, and high-quality. Figure 1 shows results of polarization measurements on a lead electrode in an electrolyte containing pyrophosphate complexes of cobalt. At equal electrode potentials Ec, Seignette salt (potassium sodium tartrate) has the strongest depolarizing effect on the pyrophosphate complexes of cobalt and lead together and separately were performed.

Measurements of the cathode current density on a lead electrode in an electrolyte with the above additives at $E_{st} = -1.05$ V demonstrated that, as the temperature is raised from 298 to 333 K, the current density become 6.3 times higher. In addition, raising the temperature promotes an increase in the admissible zero-passivation (limiting) current density on the cobalt anode.

The polarization curves corresponding to discharge of pyrophosphate complexes of lead at various relative amounts of additives are shown in Fig. 2.

The effect of the additives on the lead deposition process is similar to that on the discharge of pyrophosphate complexes. The strongest depolarizing influence is exerted by Seignette salt; however, its effect on the discharge rate of the pyrophosphate complex of lead is substantially weaker than that in the case of cobalt deposition. The steady-state potentials of the lead electrode are $-498$ mV in solutions corresponding to curves 1–3 in Fig. 2 and $-508$ mV for curve 4. Raising the temperature from 298 to 333 K leads to a 1.9-fold increase in the current density at a potential of $-1.25$ V. An increase in the lead deposition rate is favored by agitation of the electrolyte.

If cobalt- and lead-containing electrolytes are poured

---

**Fig. 1.** Current density $i_c$ vs. the potential $E_c$ in electrolyses of solutions with various compositions. $T = 333$ K, pH 9.7, potential sweep rate $V = 0.7$ mV s⁻¹; the same for Fig. 2. Solution composition (g L⁻¹): (1) $\text{CoSO}_4\cdot7\text{H}_2\text{O}$ 23.8, $\text{K}_4\text{P}_2\text{O}_7\cdot3\text{H}_2\text{O}$ 300, pH 9.7; (2) 1 + $\text{NH}_4\text{Cl}$ 10; (3) 2 + sodium citrate 30; and (4) 3 + Seignette salt.

**Fig. 2.** Potentiodynamic cathodic polarization curves in electrolyses of solutions with various compositions. Solution composition (g L⁻¹): (1) $\text{PbCl}_2$ 6.7, $\text{K}_4\text{P}_2\text{O}_7\cdot3\text{H}_2\text{O}$ 300, pH 9.7; (2) 1 + $\text{NH}_4\text{Cl}$ 10; (3) 2 + sodium citrate 30; (4) 3 + Seignette salt 15; and (5) 4 with agitated electrolyte.