The effect of annealing temperatures on magnetic and electric properties of electrodeposited $Ni_{85,3}Fe_{10,6}W_{1,4}Cu_{2,2}$ alloy

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$Ni_{85,8}$ $Fe_{10,6}$ $W_{1,4}$ $Cu_{2,2}$ alloy powder consisting of an amorphous matrix and nanocrystals of an FCC solid solution of Fe, W and Cu in nickel was produced by electrodeposition. Heating the pressed powder sample over the temperature range of 20 to 600°C permitted structural changes to take place in the alloy, causing changes in its electrical resistivity and magnetic permeability. The alloy exhibits structural stability up to 150°C. In the temperature interval 150-360°C, the alloy undergoes intensive structural relaxation resulting in an increase in electrical conductivity and magnetic permeability. Less intensive structural relaxation occurs at temperatures between 360°C and 460°C. In this interval, under heat treatment, magnetic domain arrangement decreases and, hence, the interaction between magnons and conduction electrons is reduced, leading to a decrease in the temperature coefficient of electrical resistivity (TCER). Amorphous matrix crystallization and FCC crystal growth take place in the temperature interval 460-520°C, causing a decline in electrical resistivity and magnetic permeability.

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1. Introduction

Nanostructured materials have been extensively used in novel technologies due to their specific physical and chemical properties [1-4]. Nanostructured nickel-iron-tungsten alloys exhibit good mechanical, electrical and magnetic properties, high thermal stability and high corrosion resistance [5-18]. The metallurgic production of these alloys is an expensive process. Therefore, more recently, cheaper procedures for their production have been developed [5-18]. Nanostructured nickel-iron-tungsten alloys can be obtained by electrochemical methods from environmentally friendly citrate ammonia solutions without any environmental and health risks.

Electrodeposition can result in the production of alloys with specific mechanical, chemical and physical properties dependent on operating and kinetic parameters of electrolysis [19-29]. More recently, a significant number of works explaining the mechanism of codeposition of tungsten and molybdenum with iron-group metals have been conducted [25-37]. The effects of current density, solution composition, solution pH and temperature on the chemical composition, microstructure, mechanical, electrical and magnetic properties, corrosion and thermal stability of electrodeposited Ni-Fe-W alloys have been reported in several studies [11-18, 37]. Nanostructured alloys exhibit a metastable structure. Annealing changes their microstructure, affecting their mechanical, magnetic, electrical, chemical and other properties [38-42].

Ni-Fe-W alloy powders cannot be electrodeposited from a citrate ammonia bath at high current efficiencies. The codeposition of small amounts of copper, Ni, Fe and W can result in the production of Ni-Fe-W-Cu alloy powder at high current efficiencies and with the desired particle size obtained [43]. The objective of this study was to investigate the magnetic and electrical properties of electrochemically produced Ni-Fe-W-Cu alloys containing a small amount of copper, and determine the effect of heat treatment on these properties.

2. Experimental

Nickel-iron-tungsten-copper alloy powder containing 85,8 wt.% Ni, 10,6 wt.% Fe, 1,4 wt.% W and 2,2 wt.% Cu ($Ni_{85,8}$ $Fe_{10,6}$ $W_{1,4}$ $Cu_{2,2}$) was electrodeposited at a current density of 450 $mAcm^{-2}$ from a citrate ammonia bath onto a titanium cathode. The electrolytic solution contained 0.2 mol dm^{-3} $NiSO_4$, 0.02 mol dm^{-3} $FeSO_4$, 0.004 mol dm^{-3} Na_2WO_4, 0,005 mol dm^{-3} $CuSO_4$, 0.24 mol dm^{-3} $Na_3C_6H_5O_7$, 0.8 mol dm^{-3} NH_4Cl, 0.3 mol dm^{-3} Na_2SO_4. The solution temperature during the electrolysis was 60±0.5°C, and pH was 9.2±0.05. The pH of the solution