Abstract

„Influence of alloying additives on the magnetic, catalytic properties and crystalline structure of high-induction iron-based soft magnetic materials"

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High-induction amorphous and nanocrystalline soft magnetic Fe-based materials are increasingly used in power electronics as materials for magnetic cores in power transformers, stators in electric motors, and magnetic components in energy storage systems. Their main advantages include high saturation induction, low coercive field strength, and minimal energy losses. These properties result from the appropriate selection of alloy chemical composition and heat treatment conditions, which control the material's microstructure. Even slight changes in alloy composition can significantly affect magnetic exchange between atoms, the ability to form an amorphous phase during ribbon casting and the process of nucleation and growth of α-Fe crystallites from the amorphous matrix. Additionally, the chemical composition and crystalline structure influence the electrochemical potential and oxidation susceptibility of the outer layer, as well as the catalytic activity of the material in advanced oxidation processes.

The main objective of this doctoral dissertation was to develop a manufacturing technology for high-induction (> 1.5 T) amorphous and nanocrystalline Fe-M-B soft magnetic materials in the form of metallic ribbons, and to determine the correlations between the influence of selected alloying additions (M = Cu, Co, Mo, Nb, Cr) and heat treatment on thermodynamic parameters, crystallization processes, crystal structure, and selected magnetic, electrochemical, and catalytic properties.

This dissertation presents the influence of alloying additions (M = Cu, Co, Nb, Mo, Cr) on the crystallization process, crystal structure, and magnetic, electrochemical, and catalytic properties of Fe-M-B alloys ($Fe_{86-x}Cu_xB_{14}$, $Fe_{85-x}Cu_xB_{15}$, $Fe_{85,45}Co_xCu_{0,55}B_{14}$, $Fe_{84,4}Co_xCu_{0,6}B_{15}$, $Fe_{83,8}Co_xCu_{1,2}B_{15}$, $Fe_{85,3-(x+y)}Co_xMo_yCu_{0,7}B_{14}$, $Fe_{86-x}Cr_xB_{14}$, $Fe_{79,4}Co_5Cu_{0,6}Mo_xB_{15}$, $Fe_{79,4}Co_5Cu_{0,6}Nb_xB_{15}$). In total, 31 amorphous ribbon materials were obtained using the *melt-spinning* method. To optimize magnetic properties through controlled crystallization, the alloys were subjected to isothermal heat treatment. The crystallization process of amorphous materials was analyzed using differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and theoretical models. The crystalline structure was investigated by X-ray diffraction (XRD), neutron diffraction, transmission electron microscopy (TEM), and scanning electron microscopy (SEM). Magnetic properties of as-cast and annealed samples were characterized using the Remacomp system, vibrating sample magnetometry (VSM), impedance analysis, and strain gauges. The local magnetic environment around Fe atoms was examined using Mössbauer spectroscopy. Electrochemical properties of selected materials were studied by open circuit potential (OCP) measurements and dynamic tests in a 3.5% NaCl solution. The catalytic activity of the ribbons was evaluated in the photo-Fenton degradation of methylene blue dye, monitored using UV-VIS spectroscopy.

The results were presented in a series of eight scientific publications published in peer-reviewed journals in the field of Materials Engineering, with a total Impact Factor (IF) for 2024 of 28.5, a Cite Score for 2024 of 53.6, and a total of 1,110 points according to the Polish Ministry of Science and Higher Education (MNiSW). The collected works present fundamental and applied research results, highlighting the potential applications of the studied alloys in power electronics and catalytic processes. As a current outcome of this work, four patents have been acquired based on the results obtained during the implementation of the industrial PhD project.