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ROZPRAWA DOKTORSKA

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Struktura i właściwości stopów o wysokiej entropii $AlCoCr_xFeNiSi_y$ oraz AlCoFeNi(Ti,Si) wytwarzanych metodami szybkiego chłodzenia

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ABSTRACT

This doctoral thesis describes research conducted on high entropy alloys (HEA) AlCoCrxFeNiSiy (x=0; 0.5; 1; y=0; 0.25; 0.5; 0.75; 1) and AlCoFeNi(Ti,Si), which aim to better understand the structure, properties and potential applications of these materials. The introduction of the doctoral thesis focusses on the importance of HEA alloys and presents the purpose and research plan. The review of the literature discusses the characteristics of HEA alloys, the effects characteristic of high-entropy alloys, the parameters that predict structure, the selected properties, and potential applications. The structure of HEA alloys was also compared with that of classic alloys, highlighting differences in structure and manufacturing techniques. Research on HEA alloys is relatively new, but these alloys show promising performance properties, such as high strength and good corrosion resistance. These properties make them potential candidates for applications in the aviation, energy, nuclear, and biomedical industries.

The research part presents the results of research on the structure and properties of the discussed alloys immediately after induction melting in the form of ingots and plates produced by pouring a liquid alloy into a copper mould. Microstructure studies confirmed the formation of BCC and B2 structures. It was found that the cooling rate had a significant impact on the number of phases formed and the homogeneity of the structure. The addition of silicon in the case of the AlCoFeNiTiSi alloy contributed to the creation of a two-phase alloy, which is an important observation for further applications of these materials. Alloys containing silicon (AlCoCrFeNiSi) show lower phase transition temperatures compared to alloys without silicon (AlCoCrFeNi). For example, for the AlCoCrFeNiSi alloy, an endothermic peak was observed at a temperature of approximately 1370 °C, and for AlCoCrFeNi at approximately 1398 °C. The addition of silicon in the B2 structure reduces the phase transition temperatures.

Mössbauer spectroscopy showed that in AlCoCrFeNiSi alloys, iron atoms are mainly distributed in the BCC structure. These studies confirmed the presence of both paramagnetic and ferromagnetic phases, which makes it possible to control the magnetic properties by modifying the chemical composition and cooling conditions. It was found that faster cooling from the liquid state leads to a random arrangement of Fe atoms, which reduces hyperfine magnetic fields. Spinodal decomposition in HEA alloys leads to spontaneous decomposition of the solid phase, which affects the structure of the material. In the AlCoCrFeNiSi alloys, a diffuse thermal effect was observed on the DTA curves, which suggests the presence of spinodal decomposition and the formation of areas with different chemical composition.

The analysis of the hardness, nanohardness and Young's modulus test results for HEA alloys indicates significant differences in mechanical properties resulting from differences in chemical composition and in the cooling and solidification conditions of the liquid alloy. Five-component alloys such as AlCoCrFeNi, AlCoCr0.5FeNi, and AlCoFeNiTi have a lower hardness, which can be attributed to a lower crystal lattice distortion. In turn, alloys containing six elements, especially with the addition of silicon, show greater hardness, which may be the result of the formation of the Cr3Si phase. Replacement of chromium with silicon, as in the case of AlCoCrFeNi and AlCoFeNiSi alloys, promotes an increase in hardness, which indicates the influence of the smaller atomic radius of silicon on lattice distortions and the formation of hard phases. The hardness of the rapidly cooled plates is similar to the hardness of primary alloys cast at a slower cooling rate, which may be due to the high entropy of the liquid alloy and the high cooling rate, which do not allow the formation of larger ordered areas.

Nanoindentation studies have shown that some alloys, such as AlCoFeNiTiSi, have higher nanohardness and Young's modulus values, suggesting their potential for high-strength applications. In tribological tests, it was observed that alloys containing silicon added showed a lower friction coefficient, which may be related to the presence of high-hardness phases, such as Cr3Si. Higher hardness alloys also exhibit less plastic deformation and further improve their wear resistance.

The analysis of the decolorization process showed that the effectiveness of this process depends on the even distribution of elements throughout the entire volume of the alloy. A more heterogeneous structure of the alloy promoted a faster decolorization reaction. Studies of the catalytic activity of alloys in advanced oxidation processes showed high activity even at neutral pH.

Magnetic tests confirmed that the magnetic properties of HEA alloys are strongly dependent on the chemical composition and cooling rate. Saturation magnetization and magnetic remanence are higher in silicon-containing alloys, while the coercivity field is smaller. The chemical composition of the alloys has a significant impact on their corrosion resistance in a 3.5% sodium chloride solution. The addition of silicon in alloys such as AlCoFeNiSi leads to increased corrosion resistance compared to alloys without Si. Fast-cooled HEA alloys in the form of plates show better corrosion resistance in a 3.5% NaCl solution.