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AlCoCrFeNi High Entropy Alloys as Possible Nuclear Materials

Miguel Lopez Rios[1], Viviana Lucero Baldevenites[1], Ionelia Voiculescu[2] and Julia Mirza Rosca[1]

[1]University of Las Palmas de Gran Canaria, Las Palmas de GC, Canarias, Spain, [2]Politehnica University of Bucharest, Bucharest, Bucuresti, Romania

For maintaining a sustainable energy supply and ensuring the safe operation of nuclear reactors, the development of new and advanced nuclear materials is in high demand.

Recently, a new generation of structural materials, termed as multicomponent high-entropy alloys (HEAs), has been developing. The concept of high entropy provide a new path of developing advanced materials which may potentially break the properties limits of tradicional materials obtained by the conventional micro-alloying methods based on one dominant element. The HEAs consist of at least five principal metallic elements with an approximately equiatomic ratio for maximizing the compositional entropy and form a solid solution phase. Mixing of various elements results typically in high atomic-level stress, which leads to the possibility of achieving high irradiation resistances through unique damage healing mechanisms [1].

A typical HEA, the alloy AlCoCrFeNi, have been extensively studied and reported in the literature [2]. Aluminum is an interesting element because possesses the dualism of metal and nonmetal characteristics due to its special electronic structure and the properties of the alloy vary significantly with aluminum concentration. In this study, HEAs from AlxCoCrFeNi system with concentrations in aluminum varying from 0.6 to 1.0 were investigated using X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Vickers hardness tester and Electrochemical Impedance Spectroscopy (EIS). The surface roughness was examined by Atomic Force Microscopy (AFM).

It can be observed that the particular elements of each alloy refer to the morphology of the phases and the general appearance of microstructures is dendritic. Thus, in the case of x = 1 and x = 0.6, the appearance of the dendrites is relatively rounded, while for x = 0.8 acicular formations oriented in different directions are observed. At higher magnification powers, the specific characteristics of each alloy are highlighted. Thus, in the case of x = 1, the microstructure is composed of phases arranged neatly in the metal matrix, surrounded by rectilinear grain boundaries. The microstructure of x = 0.8 sample shows the tendency of formation of the acicular phases, the grain boundaries being much wider. In the case of x = 0.6 sample, the microstructure is similar to that of x = 0.8, the presence of the two phases being better highlighted.

After EDAX analysis, two areas were considered on the HEA´s surface: one dendritic area (D) and another interdendritic area (ID) with clear differences in the element composition. A segregation parameter, segregation ratio (S_R), was introduced to demonstrate the degree of segregation of elements. The nanoscale analysis showed the D area with Fe and Co rich but Al and Ni depleted and the ID area with Al and Ni rich but Fe and Co depleted. Only Cr does not show evident differences in the two zones with a slightly higher concentration in interdrenditic area.

As Al concentration increases, the chromium effect is stronger and Co does not show evident difference in the two areas.

From Vickers tests and EIS measurements it can be observed that the increase of Aluminum concentration greatly enhanced hardness and, in consequence, the Young´s modulus and yield strength of these alloys.

Further studies regarding planned extensions in the operating life time for reactors are needed and must be supported by accompanying materials R&D for continued safe, reliable and cost-effective utilization of water-cooled nuclear reactors for electricity production.

References

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