RADIATION RESISTANCE OF AMORPHOUS ZIRCONIUM ALLOYS AFTER IRRADIATION WITH HELIUM IONS

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Many amorphous alloys have completely different properties compared to crystalline alloys of the same composition. Amorphous alloys can absorb a larger dose of radiation than crystalline alloys, can have better strength characteristics, and can be more resistant to corrosion. This is due to the amorphous structure, which is characterized by the absence of long-range order.

In thermonuclear reactors, the synthesis of deuterium and tritium can occur, one of the products of this reaction is helium. Helium is poorly soluble in metals, so it tends to accumulate inside the material, which can lead to deterioration of its mechanical properties [1, 2]. One of the potential ways to solve this problem can be the use of amorphous alloys, since they, in fact, do not have point defects [3], and, after the atom moves as a result of irradiation, the structure will not actually change. Moreover, after irradiation with helium, the characteristics of amorphous alloys can be improved [4, 5]. Given the resistance of zirconium alloys to blistering, it makes sense to study amorphous zirconium alloys, the purpose of which is to absorb the maximum possible doses of helium ions without significant changes in characteristics or with subsequent improvement in the characteristics of the alloy.

In this paper, we consider two alloys containing a significant part of zirconium: A1 ($Zr_{51.32}Ti_{17.54}Ni_{15.18}Cu_{14.61}In_{1.35}$) and A2 ($Ti_{65.23}Zr_{34.77}$). The samples were obtained by high-speed hardening [6] and are small thin quadrangular metal plates. The molten alloy enters the cooled drum, after which it is rapidly cooled. Due to the high cooling rate, the atoms do not have time to be distributed in an orderly manner, an amorphous structure appears. Due to the temperature gradient, the samples are heterogeneous, that is, there are two sides that differ from each other: matte (adjacent to the drum) and mirror (reverse side). In this work, only the matte side of the samples is considered, since the fastest cooling and, consequently, the solidification of the alloy occurred in this region.

The samples were irradiated with helium ions with an energy of 40 keV and a fluence of 5×10^{17} cm^{-2}. After that, the phase composition of the samples before and after irradiation was studied by X-ray diffraction analysis on a Rigaku Ultima IV diffractometer using copper radiation (λ = 0.15418 nm). To study the effect of implanted helium on the near-surface layer, the samples were taken at a small fixed angle of incidence of X-rays (1°). The change in free volume was evaluated, and with the help of the RAD program, plots of the radial distribution for the samples were obtained, from which the short-range order values were found before and after irradiation.

Figures 1 and 2 show X-ray patter of two samples before and after irradiation. X-ray diffraction pattern A before irradiation has two amorphous peaks, indicating that the Al alloy sample is completely amorphous. After irradiation, the sample did not undergo any significant changes; the intensity of the peaks only slightly decreased. On X-ray B before irradiation, there is a large crystalline peak and 3 more smaller ones, two of which are not visible due to the scale, as well as a small amorphous peak. After irradiation, a significant amorphization occurred in the A2 alloy sample, the intensity of the first crystalline peak significantly decreased, therefore, it can already be concluded that there are significant changes in the structure.

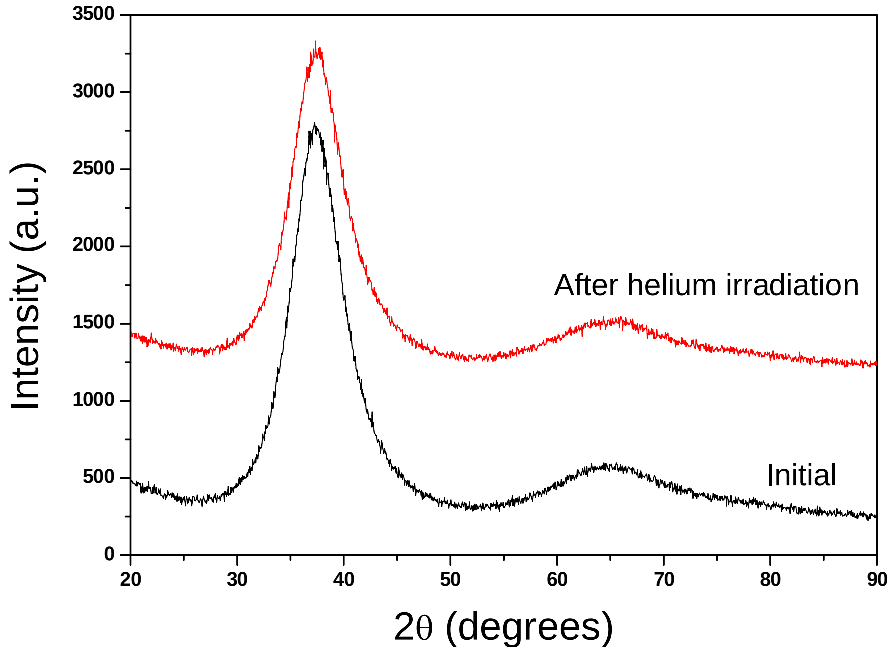

Fig. 1. XRD spectra of non-irradiated and irradiated with He ions $Zr_{51.32}Ti_{17.54}Ni_{15.18}Cu_{14.61}In_{1.35}$ samples

Table 1 shows the values of the change in free volume and short-range order in the samples after irradiation with helium ions. In the sample from alloy A1, there were no significant changes in the free volume and the short-range order did not change. Significant changes in both parameters occurred in the A2 alloy sample.

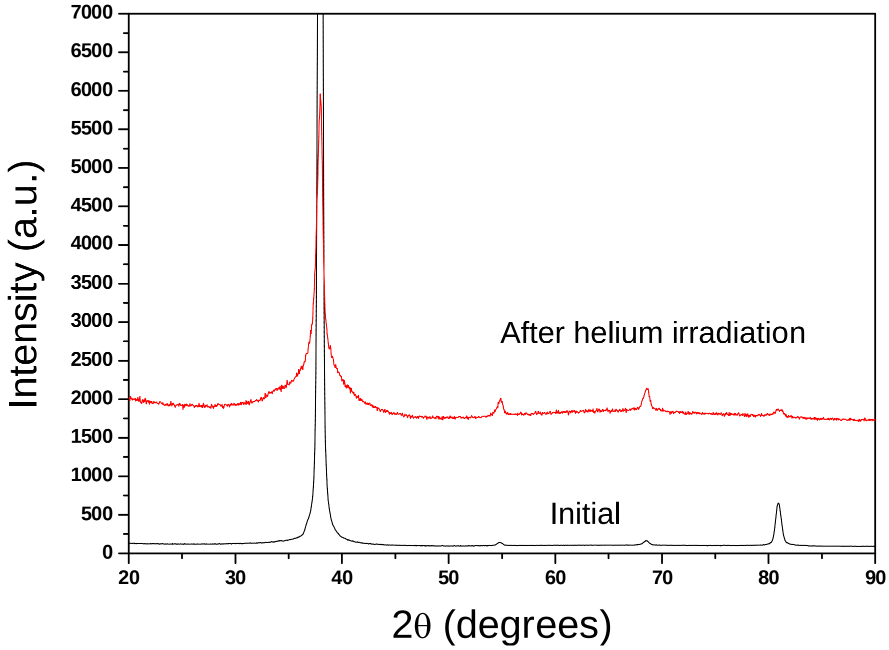

Fig. 2. XRD spectra of non-irradiated and irradiated with He ions $Ti_{65.23}Zr_{34.77}$ samples

Tabl. 1. Changes in the short-range order $\Delta r/r_0$ and changes in the free volume of the first amorphous peak $\Delta V_1/V_0$ and the second amorphous peak $\Delta V_2/V_0$ for samples from A1 and A2 alloys

Sample	Phase composition	$\Delta r/r_0$,%	$\Delta V_1/V_0$, %	$\Delta V_2/V_0$, %
A1	Amorphous	0.00	0.39	-0.82
A2	Amorphous and crystalline	7.86	-2.24	10.14

Based on the results obtained, it can be concluded that amorphous alloys practically do not change after irradiation with helium ions; When amorphous-crystalline alloys are irradiated with helium ions, significant changes occur in the structure of the alloy and, consequently, its mechanical characteristics change. This may be due to the fact that during irradiation, incident particles, interacting with target atoms, knock them out of the crystal lattice nodes, thereby deforming it. In amorphous alloys, after irradiation, the structure actually does not change, since it is not ordered initially, while implanted helium can accumulate in a free volume.

Thus, the considered amorphous zirconium alloy A1 ($Zr_{51.32}Ti_{17.54}Ni_{15.18}Cu_{14.61}In_{1.35}$) remained almost unchanged after irradiation with helium ions with a fluence of 5×10^{17} cm^{-2}, which makes it promising for further research or modification.

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