Undetectably Low Concentration of Quenched-In Vacancies in High-Entropy Alloys/Mechanical Property Evolution in Beta-Titanium Alloys via Diffusionless Isothermal Omega Transformation

In this report, we introduce two of our research topics: (i) high-entropy alloys (HEAs) and (ii) titanium alloys. Understanding the atomic transport mechanisms in HEAs, including the formation and migration of equilibrium point defects, is essential to clarify their extraordinary properties, such as high irradiation resistance. Positron annihilation lifetime spectroscopy measurements revealed that the concentration of quenched-in thermal vacancies in HEAs with a face-centered cubic structure is as low as below the detection limit (in the order of 10^{-6}). We recently defined the diffusionless isothermal omega (DI-ω) transformation, which gradually proceeds in beta (β)-titanium alloys even at above the ω-transformation temperature. The evolution of mechanical properties, including Vickers hardness, submegahertz internal friction, and elasticity, with the progression of the DI-ω transformation can be explained by the concept of quenched-in thermal concentration fluctuations.

Single-phase solid-solution alloys consisting of multiple principal elements in (nearly) equimolar fractions, often referred to as high-entropy alloys (HEAs), have attracted extensive attention owing to their extraordinary properties, such as high strength, corrosion, and irradiation resistance. Although the formation and migration behavior of vacancies in HEAs is important to understand bulk diffusion and radiation tolerance, there are contradictions between previous reports on the concentration of thermal vacancies in HEAs. Thus, positron annihilation lifetime spectroscopy measurements were conducted to investigate the concentration of thermally induced and quenched-in vacancies in a series of single-phase solid-solution alloys ($Cr_{0.3}FeNi_{0.2}$, CrFeNi, CoCrFeNi, CoCrFeMnNi, and $Al_{0.3}CoCrFeNi$) quenched from temperatures close to their melting point as a function of the configurational entropy. The quenched-in vacancy concentration estimated by the mean positron lifetime decreased with the increase in configurational entropy and could fall below the detection limit (in the order of 10^{-6}) of quaternary and quinary alloys [1].

Understanding the ω-transformation mechanism in β-titanium alloys is essential because the ω-phase dominates the microstructure and mechanical properties of titanium alloys. We recently proposed the diffusionless isothermal ω (DI-ω) transformation mode [2], which can gradually occur near room temperature. We investigated variations in the microstructure and mechanical properties of β-Ti–V alloys with the progression of the DI-ω transformation using transmission electron microscopy, differential scanning calorimetry, and measurements of the Vickers hardness, internal friction, and inelastic X-ray scattering [3]. As shown in Fig. 1(a), the Vickers hardness increased with aging at 373 K, where no atomic diffusion occurred. The relative increase in hardness is larger as the vanadium composition is lower. This hardening behavior can be attributed to the DI-ω transformation and interpreted by the concept of the quenched-in concentration distribution of the β-stabilizing element (Fig. 1(b)) [3].

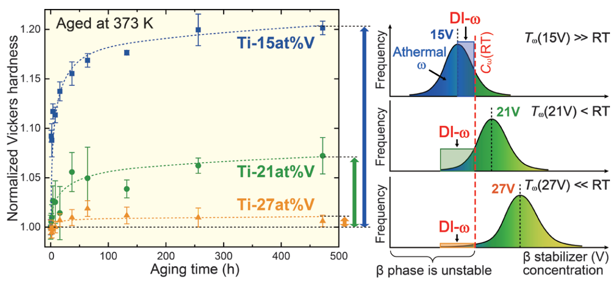

Fig.1. (a) Variation in Vickers hardness as a function of annealing time at 373 K for Ti-15, 21, and 27 at.%V alloys. (b) Schematics of the concentration distribution of the β-stabilizing element (V) for the interpretation of the hardness increase.

References

[1] L. Resch, M. Luckabauer, N. Helthuis, N. L. Okamoto, T. Ichitsubo, R. Enzinger, W. Sprengel, and R. Würschum, Phys. Rev. Materials **4**, 060601(R) (2020).

[2] M. Tane, H. Nishiyama, A. Umeda, N. L. Okamoto, K. Inoue, M. Luckabauer, Y. Nagai, T. Sekino, T. Nakano, and T. Ichitsubo, Phys. Rev. Materials **3**, 043604 (2019).

[3] N. L. Okamoto, S. Kasatani, M. Luckabauer, R. Enzinger, S. Tsutsui, M. Tane, and T. Ichitsubo, Phys. Rev. Materials **4**, 123603 (2020).

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