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Microstructure Refinement by Hydrogen Heat Treatment in a Ti-6.6Al-3.4Mo-0.3Si-1.7Zr Titanium Alloy

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Hydrogen treatment is a thermal hydrogenation and dehydrogenation process. Hydrogen can be easily charged into or discharged from Ti alloys with an isothermal aging process. Actually, hydrogen is taken as a temporary alloying element for modifying microstructure and thus improving mechanical properties of Ti alloys [1-3].

In this article, microstructure evolution with hydrogen treatment (hydrogenation-solution treatment-dehydrogenation) in a wrought Ti-6.6Al-3.4Mo-0.3Si-1.7Zr alloy (wt%), a typical (α+β) two phase Titanium alloy (TC11 alloy), has been studied with OM, TEM, HRTEM, SEM, and EDS/STEM. Mechanical property tests are used to evaluate the efficiency of hydrogen treatment.

The microstructure of the as-received Ti alloy shows a mixture of equiaxed α grains and basket-weave structure (Fig. 1). The basket-weave structure is composed of α thin plates with different orientations distributed inside a big eutectic β grain surrounded by a continuous grain boundary α thin layer. α phase is hexagonal (h.c.p, a=0.295 nm c=0.468 nm), and β phase is cubic (b.c.c, a=0.332 nm). Fig. 2 shows the microstructure of the Ti alloys isothermally charged with 1.0 wt% hydrogen content at 500°C in a 99.99% pure hydrogen atmosphere. All the three morphologies of α phase became dark (see the insert in Fig. 2a), implying hydrides formed in α phase. No hydride is observed inside β phase because of the higher solubility of hydrogen in β phase (up to 45 at%) than in α phase (up to 7.9 at%). SEM images show that many short hydride plates formed in the three morphologies of α phase: α plates, grain boundary and equiaxed grains (Fig. 2a-2c). The hydrides are indexed as δ-TiH_2 phase (CaF_2 type, f.c.c, a=0.44 nm). HRTEM shows a semi-coherence atomic array along δ and α phase interfaces (Fig. 2d). After the hydrogenated Ti alloy was solutionized at 850°C for 1 hr, vague needle-like feature formed (Fig. 3a and the insert). BSE image gives more details about the distribution and morphology of the needle structure (Fig. 3b). High Magnification SEM shows that the coarse basket-weave structure was destroyed (Fig. 3c). The needle phase is indexed as α" martensite phase (Orthorhombic, a=0.31 nm, b=0.49 nm c=0.47 nm) with electron diffraction patterns. The formation of α" phase indicates that β→α" phase transformation occurred during the solution heat treatment. It is a stress induced phase transformation and promoted by the presence of hydrogen in the Ti alloy. Twinning structure is always observed inside α" needle phase (Fig. 3d). After the solutionized titanium alloy was dehydrogenated (vacuum annealing) at 800°C for 4hrs, the needle α" phase was decomposed into fine (α+β) structure in the alloy (Fig. 4). Equiaxed or near equiaxed-like α grains are surrounded by thin β phases. The α grains comprise subgrains formed by dislocations in a low energy configuration. In conclusion, microstructure refinement has been successfully achieved during the hydrogenation-solution treatment-dehydrogenation process of this Ti alloy, leading to the improvement of mechanical properties, especially the ductility [4].

References

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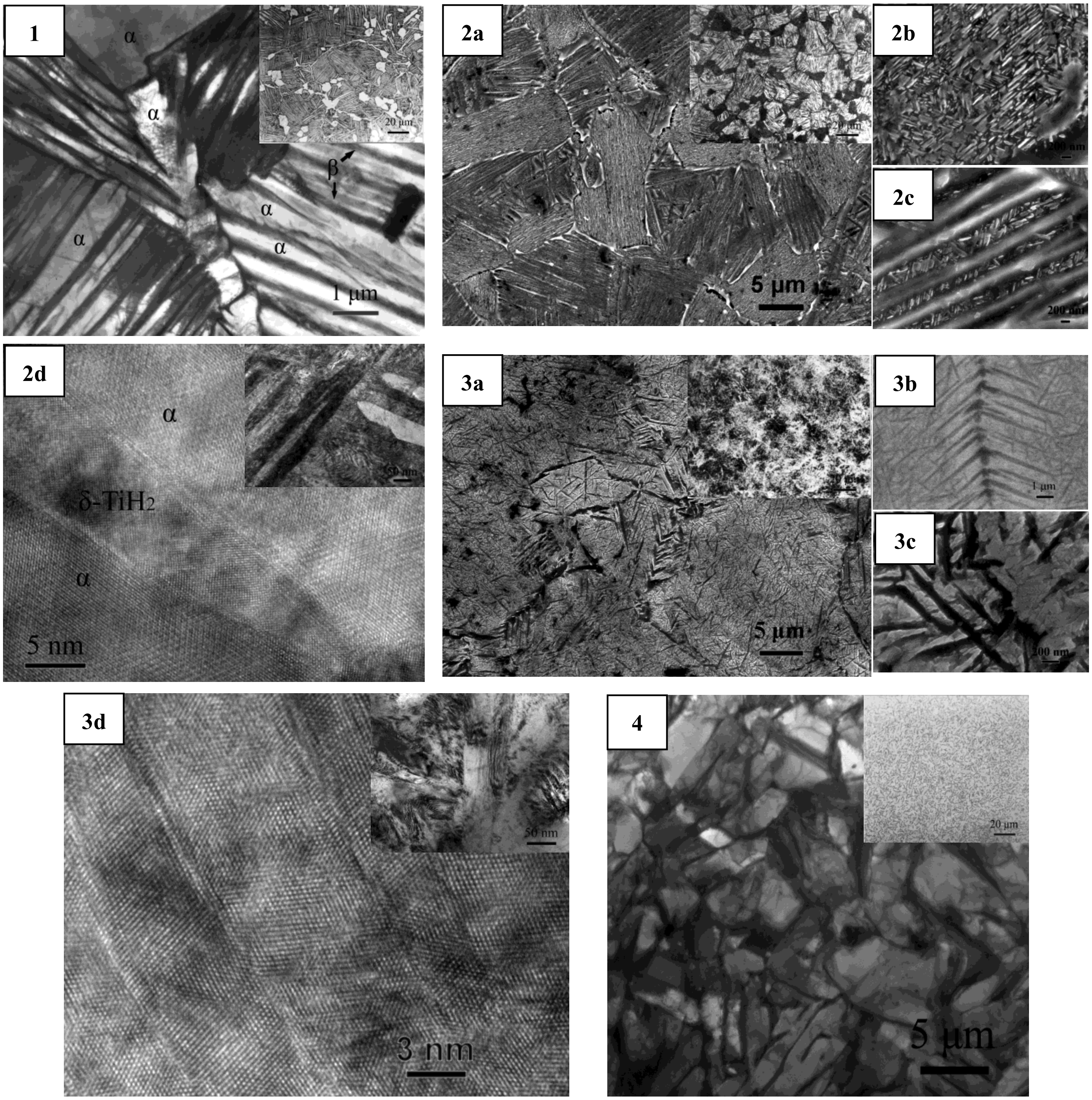

FIG. 1. TEM microstructure of the as-received Ti alloy (The insert is the metallograph).

FIG. 2. Microstructure of the Ti alloy charged with 1.0 wt% H at 500ºC: a) SEM (The insert is metallograph); b) SEM of an equaixed α grain; c) SEM of the basket-weave structure; d) HRTEM (The insert is the TEM micrograph).

FIG. 3. Microstructure of the hydrogenated Ti alloy subjected to a solution heat treatment at 850ºC: a) SEM (The insert is metallograph); b) BSE; c) SEM; d) HRTEM of α'' phase (The insert is the TEM micrograph).

FIG. 4. TEM Microstructure of the Ti alloy dehydrogenated at 800 ºC for 4 hrs (The insert is the metallograph).

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