Effect of Oxygen on Deformation Behavior in (α+β) Ti alloy

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（(α+β）チタン合金の変形挙動における酸素の影響）

区　　分　：甲

論　文　内　容　の　要　旨

There is a very real need in many applications for materials offering both high strength and ductility. Among the many such materials currently available, Ti and its alloys have been extensively utilized due to their desirable combination of high specific strength, light weight and good corrosion resistance. However, the high-cost of Ti production has so far hindered any further expansion of their use. Extensive studies over recent years to further develop Ti alloys have largely focused on replacing expensive alloying elements with less expensive ones. Particular attention has been given to interstitial alloying elements such as oxygen and nitrogen Commercial titanium and titanium alloys contain oxygen as an impurity to a lesser or greater degree. In the case of titanium sheet for press forming, oxygen content is generally required to be lowered for ensuring the sufficient deformability. Given that oxygen has a strong stabilizing effect on the α phase of titanium, its addition should result in a solid solution strengthening of the α phase and a subsequent reduction in the difference in strength between the α and β phases of a (α+β) dual-phase Ti alloy. However, although the effect of oxygen in Ti alloys has been actively investigated, the effect of oxygen strengthening on deformation and strain distribution is still not well understood. Moreover, a suitable explanation of the mechanical properties and microstructural evolution arising from the redistribution of alloying elements during heat-treatment has not yet been developed.

The study presented in this thesis has focused on the effect of oxygen on the microstructure and tensile properties of an (α+β) dual-phase Ti-4Cr alloy. In particular, the difference in work hardening behavior between oxygen-added and oxygen-free alloys was discussed in terms of the inhomogeneous deformation that originates from the strength ratio of the α and β phases. Furthermore, in order to clarify the deformation behavior of the (α+β) dual-phase structure, the effects of chromium and oxygen on the deformation behavior of each phase was investigated separately.

Chapter 1 introduced the background to this study and its main aims.

Chapter 2 investigated the effect of oxygen on the microstructural evolution and hardness of solution- and age-treated (α+β) dual-phase Ti-4Cr alloy, both with and without oxygen. The solution treated Ti-4Cr and Ti-4Cr-0.2O alloys exhibited a structure consisting only of acicular α′ martensite, produced by water-quenching from the β phase region, with no retained β phase detectable. A reversed β phase was formed along the boundary of the α′ martensite during aging in the (α+β) dual-phase region. The difference in hardness between the α and β phases was made negligible by the solid-solution strengthening of the α phase that occurred due to the redistribution of oxygen during aging. An (α+β) dual-phase was formed during aging treatment by a Burgers orientation. The local transformation induced by a memory effect from α phase→reversed β phase was generally completed during aging.

Chapter 3 explored the microstructural evolution and tensile behavior of α and β single phases with different oxygen and chromium contents in relation to the redistribution of alloying elements in each phase during aging. In α single-phase Ti-O alloys, the yield and tensile strengths were found to be gradually raised with increasing oxygen content. The work hardening rate and uniform elongation were also improved by oxygen addition due to occurrence of < c+a > dislocation slip and limiting dislocation slips on a specific plane. Meanwhile, the local elongation was markedly decreased by oxygen addition, as the high dislocation density produced a concentration of strain. In the β single-phase Ti-Cr alloys, the Ti-8Cr alloy demonstrated superior uniform elongation through significant work hardening due to the enhancement of {332}<113>twinning. On the other hand, Ti-12Cr was deformed by slip, leading to a high strength but negligible uniform elongation. The dependence of these deformation modes was related to the stability of the β phase.

Chapter 4 looked at the tensile properties and deformation behavior of aged Ti-4Cr alloy, both with and without 0.2% oxygen, in order to clarify the effect of oxygen addition on ($\alpha+\beta$) dual-phase titanium alloys. Oxygen addition was found to result in an improvement not only in strength, but also in elongation due to the suppression of plastic instability. Furthermore, it also led to an improved work hardening rate at high strain. Through digital image correlation (DIC) analysis, the Ti-4Cr alloy was found to have a concentration of strain in the α phase because of an accelerating void formation at the (α/β) interface generated by the lower hardness of the β phase. In contrast, the β phase was deformed as much as the α phase in the Ti-4Cr-0.2O alloy, because both phases had a similar hardness. This induced the formation of {332}<113>β deformation twins in the β phase, accompanied by the TWIP effect, which contributed to increasing the work hardening rate in the highly strained region of the Ti-4Cr-0.2O alloy. Oxygen is therefore expected to be one of the more effective methods for improving the balance of strength and ductility in ($\alpha+\beta$) dual phase Ti alloys, provided the microstructure is properly controlled.

In chapter 5, a general overview is provided, and suggestions are made for future work