Large plastic deformation of interstitial oxygen added Ti-Nb-Ta-Zr alloys for biomedical applications

Plastic deformation behavior was investigated among Ti-29N-13Ta-4.6Zr alloys (TNTZ) with oxygen content of 0.1−0.7 mass%. With the increase in oxygen content, the tensile strength and 0.2% proof stress of all the alloys increase normally, while their elongations reveal special change, which is contradictory to that reported conventionally. The elongation firstly decreases as usual, but then increases with the increase in the oxygen content. Therefore, TNTZ with high strength and high ductility due to the addition of high oxygen content (0.7mass%) can be obtained.

An attractive β-type titanium alloy, Ti-29Nb-13Ta-4.6Zr alloy (TNTZ), which is composed of non-toxic and allergy-free elements, has been developed for biomedical applications. TNTZ exhibits low Young's modulus of around 60GPa, which is relatively similar to that of bone (10-30 GPa). However, it should be noted that its strength is still not sufficiently high to satisfy the requirements of a long service life. It is, therefore, necessary to further increase the strength and not to increase concomitantly the Young's modulus. From this viewpoint, interstitial elements are very promising because their addition to TNTZ is expected to improve its strength via solution strengthening. Therefore, the effect of oxygen content, particularly at the rather high level, on the tensile properties of TNTZ was investigated in this study [1,2].

In this study, three types of TNTZ ingots containing 0.14 mass%, 0.33mass%, and 0.70mass% oxygen were prepared. They were hot rolled at 1273K, followed by air cooling (HR14, HR33, and HR70, respectively). Then, the hot rolled specimens were subjected to solution treatment at β transus temperature + 50 K for 3.6 ks, followed by water quenching (HRST14, HRST33, and HRST70, respectively).

The microstructures of HR14, HR33, HR70, HRST14, HRST33, and HRST70 were observed by optical microscopy (OM). In all the cases, the microstructures consisted of a single phase, and the grain size and its morphology of HRST series were more uniform as compared to those of HR series. The occurrence of some small grains in the microstructures of HR series indicates the emergence of recrystallization during hot rolling. The single phase shown in every specimen was identified as β phase by X-ray diffraction (XRD).

Figure 1 shows the Young's moduli of HR14, HR33, HR70, HRST14, HRST33, and HRST70. As a reference, the Young's modulus of Ti-6Al-4V ELI alloy, that is a conventional titanium alloy for use in biomedical applications is also shown in this figure. The Young's moduli of both HR and HRST series increase with increasing oxygen content. The Young's moduli of HR70 and HRST70 are a little higher than that of usual TNTZ, but less than around 75 GPa, which is much less than

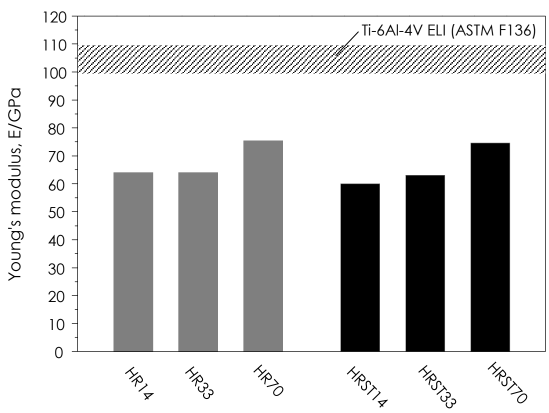

Fig.1 Young's moduli of TNTZ containing 0.14mass%, 0.33mass%, and 0.70mass% oxygen subjected to hot rolling (HR14, HR33, and HR70), and subsequent solution treatment (HRST14, HRST33, and HRST70).

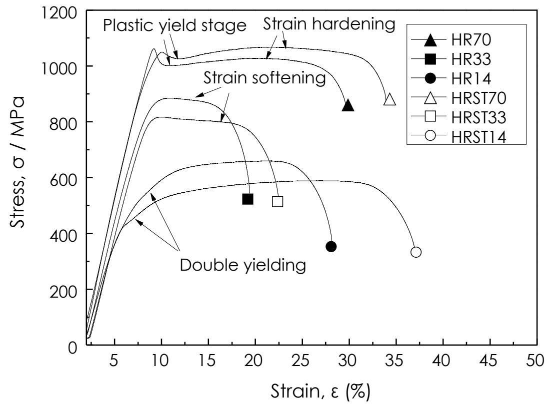

Fig.2 Tensile stress-strain curves of TNTZ containing 0.14mass%, 0.33mass%, and 0.70mass% oxygen subjected to hot rolling (HR14, HR33, and HR70), and subsequent solution treatment (HRST14, HRST33, and HRST70).

that of Ti-6Al-4V ELI. According to the microstructural analysis using OM and XRD, every specimen consisted of the single β phase. Therefore, it is considered that the increase in Young's modulus of both HR and HRST series could be attributed to oxygen dissolution in the β phase.

Figure 2 shows the tensile stress-strain curves of HR14, HR33, HR70, HRST14, HRST33, and HRST70. With the increase in oxygen content, the tensile strength increases, but the elongation firstly decreases and then increases in both HR and HRST series. This result is contradictory to that reported conventionally. The previous study indicates that the tensile strength increases with the addition of oxygen, but the elongation correspondingly decreases [3]. In this study, HR70 and HRST70 exhibit particularly good ductility in spite of high strength. Both the tensile strength and elongation of HR70 and HRST70 are larger than those of Ti-6Al-4V ELI (minimum tensile strength: 860MPa, minimum elongation: 10%, which are registered values in the ASTM F136 standard).

Further, during the tensile tests, a double yielding occurs in HR14 and HRST14, which is well-known phenomenon for the deformation-induced martensite transformation. The occurrence of the deformation-induced martensite improves the elongation and enhances the slight strain hardening. After tensile tests, in HR14 and HRST14, deformation-induced α'' martensite laths were clearly observed by OM as shown in Fig. 3, and these laths were not present in the undeformed state (before tensile test). The α'' phase could be correspondingly detected by XRD and transmission electron microscopy (TEM). Furthermore, a plenty of dislocations could be observed in deformation-induced α'' phase by TEM. However, no new phase could be observed and detected in HR33, HR70, HRST33, and HRST70 after tensile tests. This result indicates that the addition of oxygen decreases the martensite transformation start temperature (Ms), leading to the suppression of α'' phase formation.

Moreover, the tensile stress-strain curves of HR70 and HRST70 reveal obvious yielding and strain hardening. Strain hardening suggests the possibility of plastic deformation mechanism being under the aid of dislocation motion. However, the mechanism for large elongation of these specimens is still unclear. This point will be investigated by collaboration with Professor Niinomi's group in future.

References

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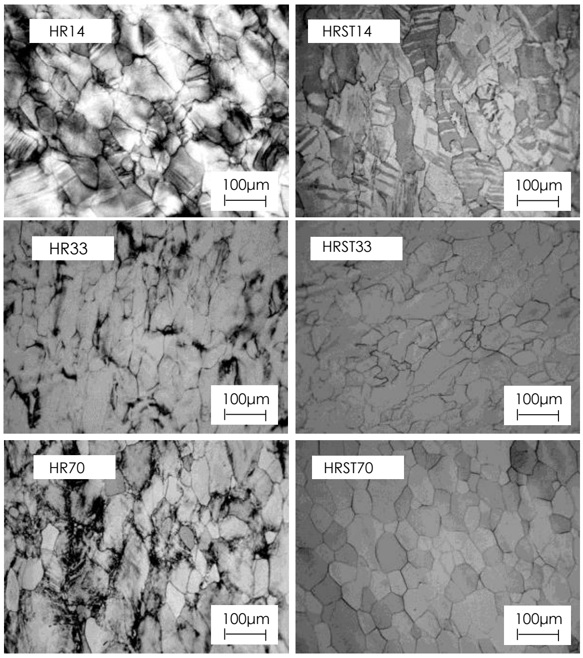

Fig.3 Optical micrographs of TNTZ containing 0.14mass%, 0.33mass%, and 0.70mass% oxygen subjected to hot rolling (HR14, HR33, and HR70) and subsequent solution treatment (HRST14, HRST33, and HRST70) after tensile tests. The observation was carried out after polishing.

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