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Depth Dependency of Hardness Change of Ti-Mo Alloys

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SYNOPSIS

We investigated the effects of resolved interstitial oxygen or nitrogen atoms and of quenched-in strain on the hardening of the single crystals grown from molten Ti-14 and 20wt pct Mo alloys. The aging treatment at 623K in atmosphere much more increased in the hardness of specimen surface than that in argon atmosphere. The quenched-in compressive stress enhanced age hardening due to omega formation. We surveyed in detail the hardness changes toward the center of plate-shaped single crystal.

1. INTRODUCTION

Beta-Ti alloys are well known as one of excellent structural materials. The omega phase formed during aging in this alloy is undesirable as the cause of embrittlement. Therefore, in engineering level, aging treatment has been achieved without using the aging temperature range of omega formation. On the other hand, in academic level, especially in reseaching pre-transformation, there has been interested in the formation mechanism of omega and the origin of embrittlement owing to isothermal omega phase. The isothermal omega phase has been considered to be caused by displacive transformation, unlike G.P.zone formation in Al alloys[5]. In order to elucidate the transformation mechanism, we have to overcome the experimental

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difficulties coming from thermal stress and absorption which cause atomic displacement for the omega formation. Many reports in regarding to omega formation include the role of oxygen[4] and of compressive stress on omega formation[2-4], and their remarkable effects on hardness[1-4]. These factors give the alloys a certain inhomogeneity of omega formation from place to place.

Here we report some results of preliminary experiments to reveal the factors causing the inhomogeneity. In the present work, the change of hardness depending on depth was investigated on two kinds of Ti-Mo alloys prepared for the present measurement. One of them is Ti-14wt pct Mo alloy being thermally instable beta phase alloy. The other is Ti-20wt pct Mo alloy being comparatively stable.

2. EXPERIMENTAL PROCEDURE

Button shaped ingots of Ti-14 and 20wt pct Mo (abbreviated to 14Mo and 20Mo later, respectively) alloys were prepared by a non-consumptive arc-melting practice from same materials[1]. The ingots were zone-melted in pure argon atmosphere in order to grow large scale grains. Plate-shaped single crystals were sliced off from the zone-melted ingots and the surface normal of plate was <110> direction. The plate-shaped single crystals were mechanically polished. A silica capsule(vacuum 1.3mPa) containing plate-shaped single crystals was heated for 4.5ks at 1223K, quenched in ice water and then mechanically fractured immediately after immersion. The quenched single crystals were divided into comparatively small pieces (about 4×4×0.8mm). The aging treatment was performed at 623K for 10^5s in air or pure argon atmosphere. After aging treatments, specimens were ground with emery paper by about 20μm. Micro-Vicker's hardness at 0.3kgf load was measured with 8 indentations, and was determined by using the mean values. The measurements toward the center were performed by a repetition of the same procedure as grinding by 20μm just mentioned above.

3. RESULTS

3.1 14Mo alloy

Figure 1 shows the change of hardness depending on the depth from surface of the specimens respectively treated for 14Mo.

The curve marked by X shows the change of the as-quenched specimen that was ground with emery paper. The hardness rapidly falls from 320 on the top to about 270 at 20μm in depth just under the oxide layer. The classification of other marks in this report is shown in Table 1.

Table 1.
Classification of the marks in figures

mark	aging atmosphere	aging condition of the surface
○	air	20μm in depth
●	air	oxide film
△	argon	20μm in depth
▲	argon	oxide film
◭	argon	110μm in depth
□	aged in atmosphere after experiment marked by ◭	

The polished surface of the specimens were changed to a dark yellow in atmosphere, on the other hand, done to a light one in argon atmosphere. With regard to aging atmosphere, the hardness level for the specimen aged in air is higher than the that for argon.

The hardness marked by ● rapidly falls in the region of oxide layer (from the top to about 20μm in depth). However its feature is similar to the hardness change marked by ○ shown as a mountainous curve, except for the region of oxide layer.

As to the aging in argon atmosphere, every change of hardness (marked by △,▲,◭) monotonously decreases. The specimen marked by ◭ was aged again in argon atmosphere after measuring the hardness change marked by × in order to investigate the effect of residual stress on age hardening. Furthermore the specimen marked by □ was aged in air atmosphere after carrying out a series of experiment marked by △, that is, we obtained three results for one specimen under three conditions. In spite of the aging in air atmosphere, the change of hardness marked by □ does not show any obvious increase like the result marked by ○ or ●. The deviation of hardness was at most within $\Delta Hv=\pm 8$ in hardness through all specimens of 14Mo.

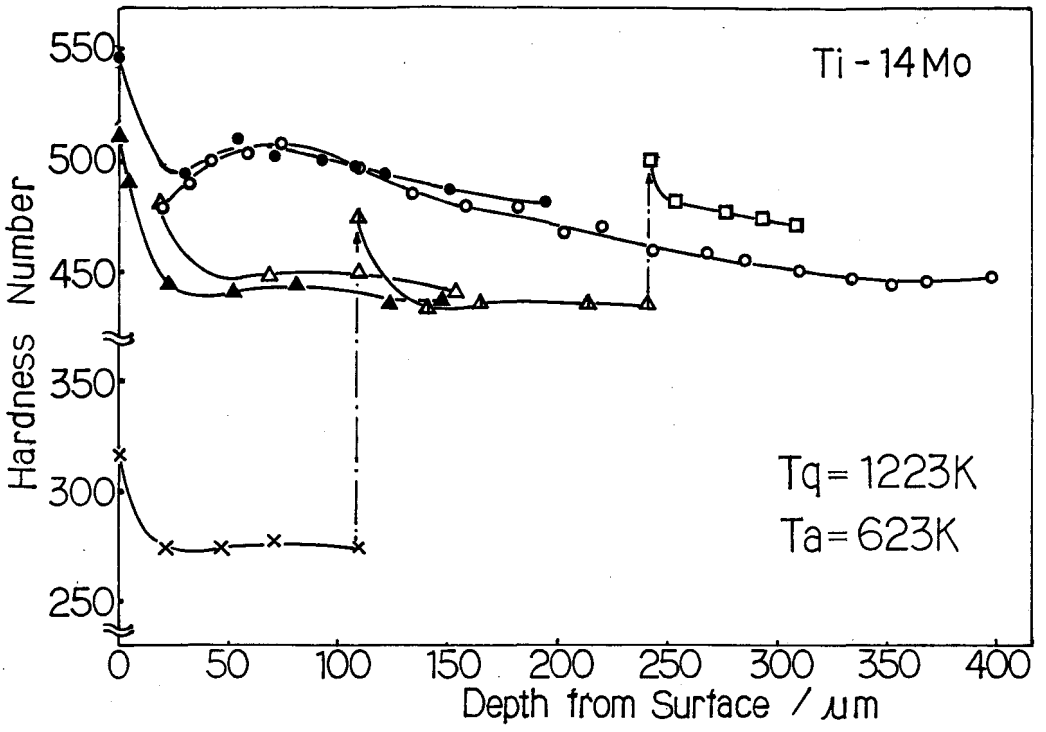

Figure 1. Change of hardness depending on depth in Ti-14Mo.

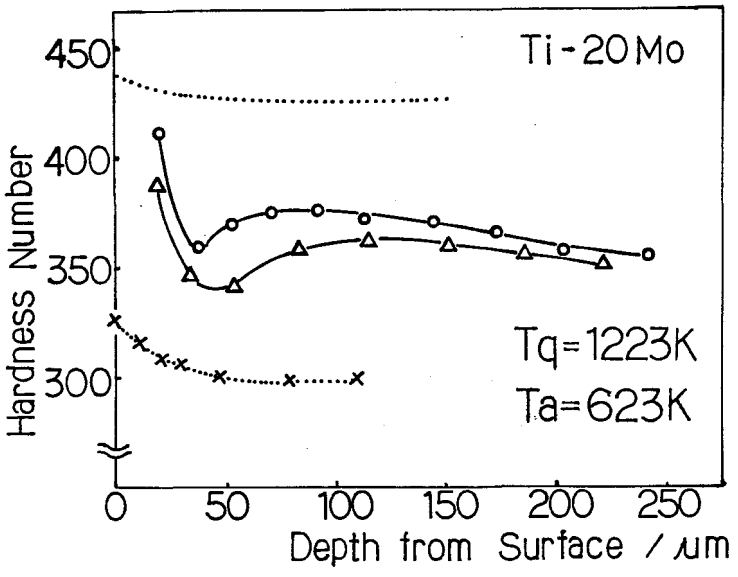

Figure 2. Change of hardness depending on depth in Ti-20Mo.

3.2 20Mo alloy

Figure 2 shows the change of hardness depending on depth from the surface of specimens of 20Mo alloy under the following experiments.

The dotted line marked by × shows the change of the as-quenched specimen. Only the dotted curve shows the change of the specimen aged for very long time of 10^6s in air atmosphere without removing oxide layer. These curves are referred from the results of Hida et al.[1].

The aging conditions marked by ○ and △ are the same one mentioned in the section 3.1. Hardness level marked by ○ is higher than that marked by △. However the feature of hardness change is similar each other, and the gap between the two curves marked by ○ and △ becomes to be smaller as deeper the measurement position is. In comparison with 14Mo alloy, the hardness level of 20Mo is low, and the scatters of hardness values, $\Delta Hv=\pm 15$ from place to place are large for the same aging time.

4. DISCUSSION

4.1 14Mo alloy

It can be roughly said that oxide film on the surface influenced the alloys to keep a certain residual stress and to modify the diffusivity of interstitial impurities.

First, there is the essential difference for the hardening behavior between in atmosphere and in argon gas as pointed out in Fig.1, the specimen aged in argon gas (see the curve marked by △) shows a monotonous decrease in the hardness toward the depth of the specimen, and on the other hand the aging treatment in atmosphere gives a broad maximum, besides the monotonic decreasing by the factor of interstitial impurities (see Fig.3(a))

Second, the as-quenched specimens have a certain thermally induced compressive stress near the surface and on the contrary a given tensile one in the region near the center of specimen[1]. From this facts isothermal omega phase is seemed to be formed easily near the

surface by the retained compressive stress. Therefore, this resultant effect causes the decrease in hardness in the interior of specimen (see Fig.3(b)) .

Third, on the other hand, as the formation of omega phase is suppressed by resolved oxygen atoms, it necessarily follows that the closer to the surface of specimens the measuring position is, the higher the hardness is. In spite of an additional aging in air, the fact that the remarkable increase in hardness was not observed shows no residual compressive stress on the surface after our grinding out about 400μm or more in thickness (see Fig.3(c)).

When these factors are totally superimosed so as to be shown in the schematic diagram (see Fig.3(d)), it is reasonable that the profile of hardness vs. the depth becomes to the curve marked by O of the aging treatment in atmosphere in Fig.1.

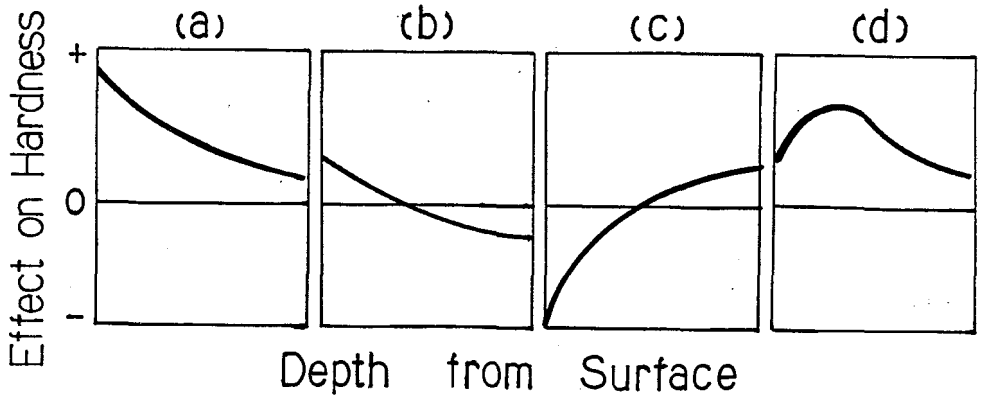

Figure 3. Effects on hardness
(a);effect of interstitial atoms, (b);effect of omega phase induced by residual compressive stress, (c);effect of omega phase formation suppressed by interstitial oxygen atoms, (d);superimposition of (a),(b) and (c).

4.2 20Mo alloy

As beta structure is considerably stable in 20Mo, the isothermal omega phase formation is difficult and the solution hardening by interstitial impurities plays relatively an important role for the profile and the level of hardness curve. However the solubility of

oxygen in 20Mo alloy seems to be more limited than 14Mo alloy[6]. Therefore we have to take into consideration specific factors belonging to 20Mo alloy, besides the ones on the hardness changes of 14Mo.

It may be explained by the effect of solution hardening that the difference of hardness between the curves marked by ○ and △ becomes to be smaller at deeper site in the specimen. But we can not recognize the remarkable difference of the effects caused by aging atmosphere between in air and in argon gas on the depth dependency of hardness change. Aging time of 10^5s for 20Mo alloy was not enough to reach the maximum hardness. If the time was prolonged, the hardness profile might be monotonous such as the dotted curve obtained by Hida et al.[1]. Because, as the isothermal age-hardening retarded near surface is stimulated by the compressive stress owing to disoluved interstitial atoms, the hollow of the curve around 20μm from surface might be lifted up and the hardening profile must be monotonous.

5. CONCLUSION

The change of hardness depends on composition, quenched-in stress and atmosphere. 14Mo has a sensitive dependence of the hardness on both the ease of omega formation and on the amount of interstitial atoms.

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