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Communication

Hardness variations during aging process of deformed W-Ni-Fe ternary alloys with high nickel-to-iron ratios

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Abstract: The aging precipitation behavior of β phase in two kinds of alloys with 7/3 and 9/1 nickel-to-iron ratios during aging at 800℃ after deformation was studied. The results show that there are two different kinds of aging hardness variation mechanisms (the softening mechanism and the hardening mechanism) deciding the hardness variations of the alloys. When Ni/Fe is smaller than 8/2, there is only the softening mechanism which results from the decreasing of dislocation density and recovery or re-crystallization. And when Ni/Fe is greater than 8/2 besides the softening mechanism there is still the hardening mechanism that is induced by the precipitation of β phase.

Key words: W-Ni-Fe ternary system; aging; precipitation

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1 Introduction

Tungsten heavy alloys (WHAs) are typical applications of W-Ni-Fe ternary alloys. Nickel-to-iron ratios are of particular importance to the mechanical properties of tungsten heavy alloys. The ratios employed in commercial production and scientific research generally fall between 1/1-8/2 and 7/3 nickel-to-iron ratio is the most preferred. The reason is as following: when nickel-to-iron ratios are lower than 1/1, it is impossible to obtain compact alloys because of lacking enough nickel to enable sintering compactness. When nickel-to-iron ratios fall between 1/1-8/2, good mechanical properties especially good ductility can be acquired from this kind of alloys slow cooled after sintering [1]. And when nickel-to-iron ratios are greater than 8/2, the brittle β phase (WNi_4, bct) will deposit from slow cooled alloys [2-4]. In order to avoid the harmful effect of mass blocks of ß phase to mechanical properties of WHAs, the nickel-to-iron ratio of 7/3 among 1/1-8/2 is widely used as a fundamental parameter to tungsten heavy alloys.

The deposit of β phase is a precipitation of tungsten and nickel atoms from supersaturated Ni-Fe-W solid solution. The precipitation behavior of β should be able to be controllable by some certain heat treatment. Furthermore, the precipitation kinetics of the β phase can be accelerated by aging treatment after deformation [5]. If the β phase could be controlled to deposit depressively then it would be no longer harmful but contributive to the mechanical properties of WHAs. This paper focuses on W-Ni-Fe ternary alloys with high nickel-to-iron ratios and reports the precipitation behavior of β phase and hardening mechanism under aging conditions.

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2 Experimental procedures

The materials used in this study were designed to simulate the γ phase (matrix of commercial tungsten heavy alloys). They were based on 36% (mass fraction) tungsten and 9/1 nickel-to-iron ratios ($BSA_{9/1}$). Also, the alloys with the same tungsten content but 7/3 nickel-to-iron ratios ($BSA_{7/3}$) were used for comparative purposes. The specimens were fabricated by melting the mixture of reduced tungsten powder, carbonyl nickel powder and carbonyl iron powder in hydrogen at 1520℃. After melting the specimens were solid-solution treated at 1200℃ for 2 h and quenched in water. The quenched alloys were rolled with 20% height reduction and subsequently aged at 800℃ in nitrogen. The hardness (Rockwell A) of the aged specimens was measured at different aging times. Transmission electron microscopy was used to study the microstructures of the alloys.

3 Results

Figure 1 shows the aging hardness variations of $BSA_{7/3}$ and $BSA_{9/1}$ after deformation during the aging process. Under the same aging conditions, the alloys exhibit different hardness variations as the aging time increases. The hardness of alloy $BSA_{7/3}$ decreases monotonically with the increase of the aging time. However, alloy $BSA_{9/1}$ has a more complicated variation in hardness.

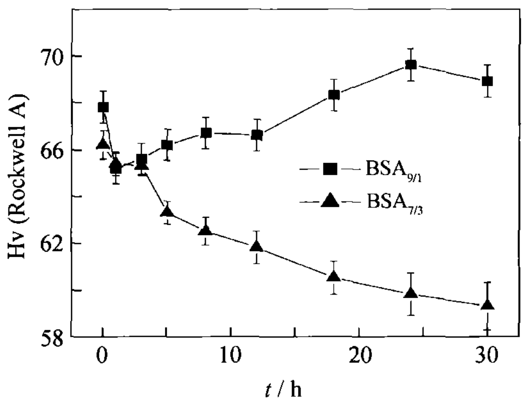

Figure 1 Hardness variations of rolled alloys with different nickel-to-iron ratios.

At the initial aging stage the hardness of $BSA_{9/1}$ also decreases to a level approximately equal to that of $BSA_{7/3}$. As the aging time goes to 3 h the hardness of $BSA_{9/1}$ reaches its lowest level. But as the aging time increases, the hardness turns to increase to a peak at about 24 h. In addition, the hardness of $BSA_{9/1}$ is always higher than that of $BSA_{7/3}$; moreover, the hardness gap between these two alloys is enlarged as the aging time increases. The different hardness variations of alloys $BSA_{9/1}$ and $BSA_{7/3}$ during aging indicate that their hardening mechanisms and microstructures differ with each other.

In the microstructure of aged alloy $BSA_{7/1}$ there is no precipitation can be found. **Figures 2**(a)-(d) show the microstructure of aged $BSA_{9/1}$ at 1, 3, 24, 120 h, respectively. Figure 2(e) is the diffraction pattern of aged $BSA_{9/1}$ at 24 h. TEM observations show that the microstructures of $BSA_{9/1}$ contain fine precipitates distributed uniformly in γ phase. Indexing of the diffraction patterns confirms that this deposit is the ß phase. Figure 2(a) indicates that the $BAS_{9/1}$ aged for 1 h still contains high density of dislocations as well as a small amount of β phase of about 0.2 μm in dimension. With the increasing of the aging time, the dislocation density decreases but the amount of β phase precipitate increases. Figures 2(b) and 2(c) show this tendency. When aged for 24 h the quantity of β phase precipitate becomes large and the dimension of β phase still remains un-grown up. When aged for 120 h, β phase gradually grows to about 2 μm in dimension.

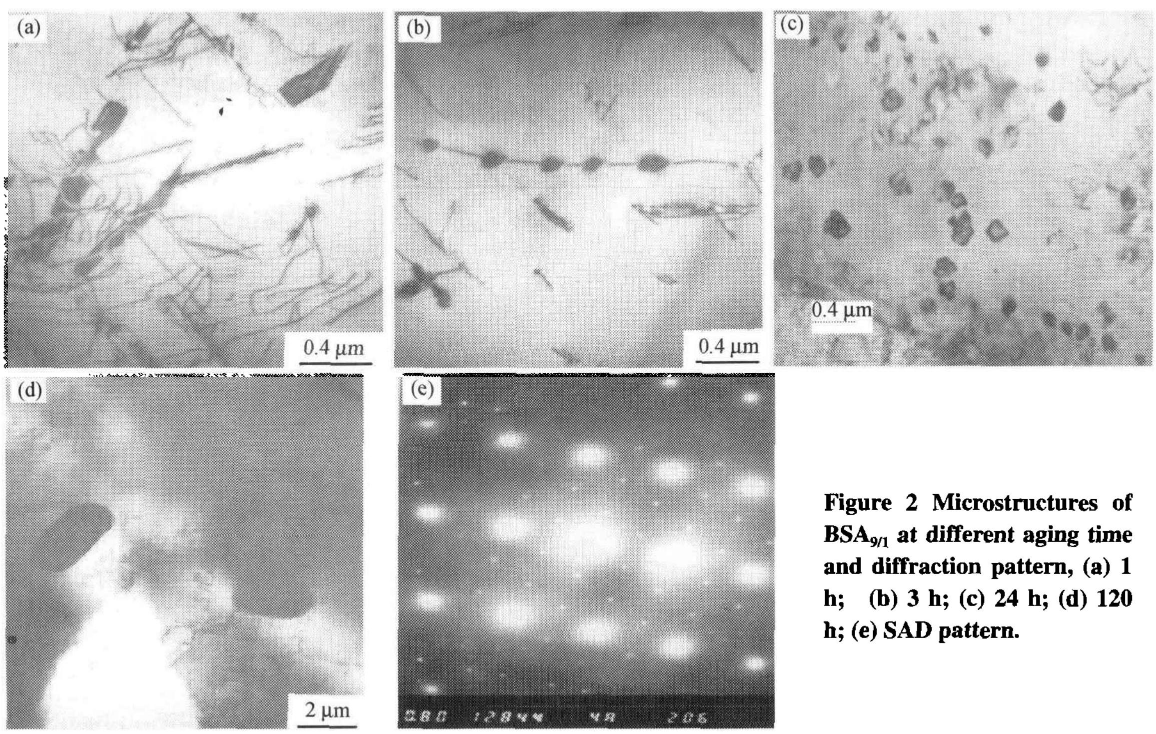

Figure 2 Microstructures of $BSA_{9/1}$ at different aging time and diffraction pattern, (a) 1 h; (b) 3 h; (c) 24 h; (d) 120 h; (e) SAD pattern.

4 Discussions

The different microstructures result in different hardening mechanisms in the two alloys. The alloys will be solid-solution strengthened after quenching and be deformation strengthened after cold rolling. The strengthening effects will be weakened to some extent in the succeeding aging process at 800℃. The solid solubility of the alloy after aging is much lower than that after quenching, but the residual stress introduced by cold working will be eliminated and recovery or re-crystallization will occur during aging at 800 ℃. In alloy $BSA_{7/3}$, there is no β phase precipitate, so the softening mechanism becomes the only aging mechanism, which results in the hardness loss throughout the whole aging process. For alloy $BSA_{9/1}$, the fine dispersed β phase precipitated during the aging process of alloy $BSA_{9/1}$ after deformation strengthened and hardened the alloy. The softening and hardening mechanisms interact with each other and result in complex hardness variations in the aging process. In the initial aging stage, the small amount of β phase precipitate brings little strengthening, so the softening mechanism plays a dominant role, and during this period the hardness of alloy $BSA_{9/1}$ decreases. As the aging time increases, more and more β phase gradually deposits from the matrix and consequently causes greater strengthening. Therefore, the hardness of $BSA_{9/1}$ increases with increasing the aging time and the hardness gap between alloys $BSA_{9/1}$ and $BSA_{7/3}$ is enlarged.

5 Conclusions

There are two kinds of hardening mechanisms in the aging process of W-Ni-Fe ternary alloys after deformation: one mechanism is the softening mechanism resulted from the decrease of dislocations and the restore and recovery; the other mechanism is the hardening mechanism resulted from the dispersed precipitation of β phase. When nickel-to-iron ratios are smaller than 8/2, there is no β phase precipitation and there is only the softening mechanism which leads the aging hardness of W-Ni-Fe ternary alloy to decrease monotonically. And when nickel-to-iron ratios are greater than 8/2, β phase deposits from the aged alloys and there are the softening mechanism and the hardening mechanism which act with each other and make the aging hardness increase at first and then decrease with the increasing of the aging time.

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