Study on Coarsening Behavior of γ' Precipitates and Compression Properties in a Novel Co-Ni-Al-W Superalloy

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Abstract: In the present study, the coarsening behavior of γ′ phase at different temperatures and the compression property of a novel Co–Ni–Al–W superalloy was investigated. The evolution of the mean radius and volume fraction of the γ′ phase indicates that the coarsening behavior follows the classicalLSW model. The coarsening rate of the γ' phase exhibits a significant dependence on the aging temperature, increasing from 1.30×10-27 m3/s at 800 ℃ to 9.56×10-27 m3/s at 900 ℃. The activation energy of γ′ phase, influenced mainly by W diffusion in the γ matrix, is found to be 210 kJ/mol. In particular, the Co-Ni-Al-W alloy possesses a good combination of a high γ′ solvus temperature of 1221 ℃ and a low density of 8.7 g/cm³. Besides, compression yield strength of the developed Co-Ni-Al-W alloy at ambient and high temperatures are higher than those of other recently γ′-strengthened Co-based superalloys.

Keywords: Co-Ni-Al-W superalloy, Microstructural evolution, Coarsening behavior, Compression property

1 Introduction

Recent studies have discovered the γ′-Co_3(Al, W) phase with an $L1_2$ structure in Co-Al-W-based superalloys. The γ′ phase is stable at high temperatures and is coherent with the γ matrix, exhibiting superior high-temperature mechanical properties compared to traditional Co-based superalloys. This discovery makes it feasible to develop novel γ′ phase-strengthened Co-based superalloys.

This paper focuses on the microstructural evolution of Co-Ni-Al-W-based alloys under different aging temperatures and times. Specifically, it focuses on the morphological, size, and volume changes of γ′ phase during aging, exploring factors affecting its coarsening. Furthermore, the microstructure stability of the alloy at high temperatures is evaluated, and its compressive performance is analyzed.

2 Experimental procedure

The Co-Ni-Al-W alloy was melted at 1480 ℃, then treated at 1230 ℃ for 24 h, and aged at 800, 850, and 900 ℃ for 24-216 h. The SEM was used to study the size and distribution of the γ′ phase, and compression tests were conducted using a Gleeble-3800 thermo-simulator system.

3 Result and discussion

Microstructural evolution during aging

The size and shape of the γ′ phase change as the aging temperature and time increase. The γ′ phase grows and becomes coarser, with the fastest coarsening occurring at 900 ℃ (Fig.1(b)) and the slowest at 800 ℃ (Fig.1(a)). Higher aging temperatures result in faster growth. The phase changes from near-spherical to cuboidal shape due to the competition between elastic strain energy and interface energy. Changes in composition and element diffusion during aging treatment cause variations in latticeparameters and speed up the change in phase morphology.

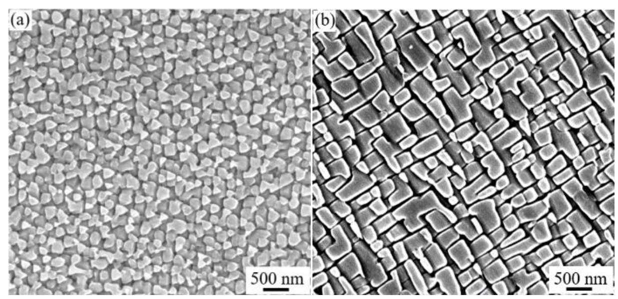

Fig.1 SEM images after aging at (a) 800 ℃, (b) 900 ℃ for 216 h.

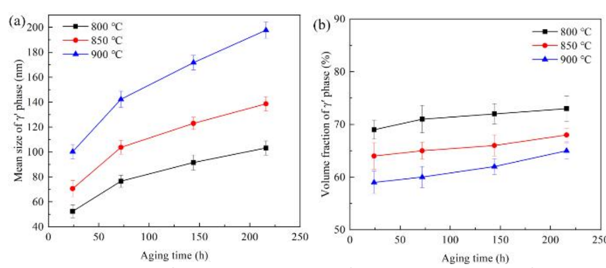

Fig.2Evolution of (a) mean radius of γ′ and (b) volume fraction of γ′ during aging treatment.

The growth of the γ′ phase results in a gradual increase of its volume fraction as the aging time progresses, as shown in Fig. 2. However, increasing the aging temperature leads to a decrease in the precipitation of the γ′ phase, resulting in a lower volume fraction of the γ′ phase. Additionally, the merging of γ′ phases, with larger ones consuming smaller ones, ultimately results in a decrease in the volume fraction of the γ′ phase. Aging at lower temperatures leads to a higher volume fraction of the precipitated γ′ phase due to higher solute supersaturation than aging at 900 ℃.

4 Coarsening behavior of γ′ phase during aging

The aging time exponent fits with the LSW model theory, indicating that the coarsening of the γ′ phase in the Co-Ni-Al-W alloy follows the LSW model.Theequation for the coarsening kinetics of γ′ phase canbe obtainedthrough linear regression analysis. The equation takes the following form:

$$r_t^3 - r_0^3 = K\cdot(t - t_0) \qquad (1)$$

The coarsening rate coefficient K of γ′ phase is determined through the slope of the curve obtained from linear fitting (Fig. 3). The results show that the coarsening rate of γ′ phase is mainly influenced by aging temperature. Moreover, increasing the aging temperature enhances the coarsening rate of γ′ phase. Furthermore, the coarsening of the γ′ phase in the alloy conforms to the LSW model, suggesting that the diffusion of solute elements regulates the coarsening process of the γ′ phase.

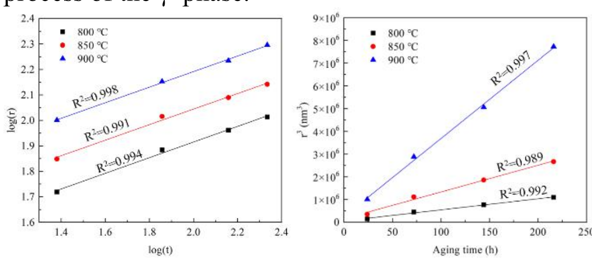

Fig.3 (a) The logarithm of size of γ′ phase vs. the logarithm of aging time, (b) A linear fit of the size of γ′ phase (r^3) versusaging time.

The diffusion activation energy of the solute elements in the Co-Ni-Al-W alloy during aging at 800-900 ℃ is determined to be 210 kJ/mol through linear fitting computations.In Co-Al-Wbased alloys, the coarsening process of γ′ phase is mainly influenced by the diffusion of W element in the alloy. Hence, it inferred that the lower W content in the Co-Ni-Al-W alloy is the main reason for its relatively lower diffusion activation energy.

5 Solvus temperature and density

The studied alloy stands out with an exceptionally advantageous combination of solvus temperature (1221 ℃) and density (8.7 g/cm³).These exceptional characteristics establish the Co-Ni-Al-W alloy as a superior alternative to traditional Co-based alloys, particularly in applications where weight reduction is crucial, as shown in Fig. 4.

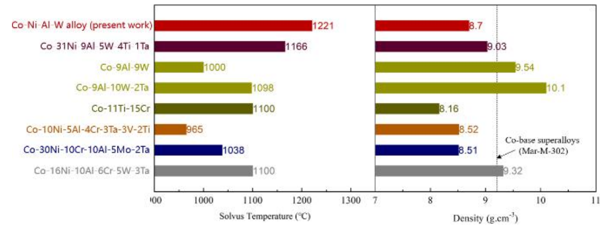

Fig.4 Solvus temperatures and density of the Co-Ni-Al-W alloy, and other Co-based superalloys from literature.

compression properties

The curve of the compression yield strength of the Co-Ni-Al-W alloy with temperature is divided into three stages, as shown in Fig. 5. At temperatures between 25 to 650 ℃, yield strength decreases from 761 to 714 MPa. It exhibits a positive temperature dependence from 650 to 850 ℃. At 850 ℃, it reaches a maximum of 774 MPa. Above 850 ℃, it shows negative temperature dependence. The alloy shows an anomaly behavior in yield strength between 650 to 850 ℃. The phenomenon is associated with the Kear-Wilsdorf mechanism, which locks dislocations at high temperatures.The Co-Ni-Al-W alloy has better mechanical properties at high temperatures than other recently developed W-free/ Cr-containing γ/γ′ Co-based superalloys.

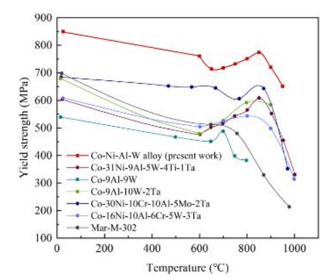

Fig. 5 The temperature dependence of compression yield strength of the Co-Ni-Al-W alloy and other Co-based superalloys.

6 Conclusion

1) The Co-Ni-Al-W alloy has a high γ′ solvus temperature of 1221 ℃ and a low density of 8.7 g/cm³.

2) The Co-Ni-Al-W alloy ages at 800-900 ℃, with γ′ phase morphology changing from spherical to cubic. Its size grows with higher aging temperatures and longer time. The γ′ phase volume fraction decreases with increasing temperature while increases with longer aging time.

3) The coarsening behavior of γ′ phase in the Co-Ni-Al-W alloy follows the diffusion-controlled LSW coarsening mode. The γ′ phase coarsening rates were increased from 1.30×10^{-27} m³/s at 800 ℃ to 9.56×10^{-27} m³/s at 900 ℃.

4) The compression yield strength curve of the Co–Ni-Al-W alloy comprises threestages. From 650 to 850℃, theyield strength exhibits a positive temperature dependence and reaches a maximum of 774 MPa at 850℃.