Effect of Mo Addition on the Microstructure and Creep Property of Ni-Based Single Crystal Superalloys

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Abstract: A self-developed 4th generation Ni-based single crystal superalloy with different Mo contents has been developed to investigate the microstructure and creep property. The Mo addition did not change the dendrite spacings significantly. The segregation of refractory elements, such as W and Re, was significantly restrained. With the relief of segregation, the content of eutectic islands was decreased by Mo addition. After heat treatments, Mo addition decreased the size of γ' phase and γ channel width. Mo addition mainly affected the creep life by influencing the formation of creep pores, dislocation networks, elemental inhomogeneity, TCP phases and γ channel widening. a suitable Mo content range was proposed.

Keywords: Mo addition, superalloys, solidification characteristics, microstructure

1 Introduction

As a key strengthening element in Ni-based single crystal superalloys (SCs), Mo has attracted much attention in recent yearsdue to its low-cost and low-density[1-3]. Previous studies have researched the effects of Mo addition on the microstructures and creep properties of SCs[2, 4]. However, previous studies on the effects of Mo were carried out mainly in low-generation alloy systems[1, 2]. The behavior of Mo might act differently in the new-generation SCs due to the complex composition. Therefore, it was crucial to investigate the effects of Mo addition on the microstructure and creep property in new-generation SCs for further alloy design. In this paper, this goal was achieved by developing a 4th generation SC with different Mo content.

2 Experimental procedure

The 4th generation SCs were directionally solidified by the Bridgeman method in our lab. The composition of the investigated alloys was listed in Table 1. The solid solution treatment procedure was set mainly based on the results of incipient tests, the highest temperature of which was set as 1350 ℃. The creep tests were carried out at 1100 ℃ and 137 MPa.

Table 1. Composition of the investigated alloys. (wt.%)

	Al+Ta	W+Re+Cr+Co	Ru	Hf	Mo	Ni
2Mo	12	19.8	2.5	0.1	2	Bal.
3Mo	12	19.8	2.5	0.1	3	Bal.
4Mo	12	19.8	2.5	0.1	4	Bal.

The images of microstructure were mainly gained by scanning electron microscope (SEM). The samples were mechanically grinded and polished. The polished samples were then etched by a solution consisted of HF, HNO3 and glycerin with the volume ratio of 1: 2: 3.

3 Result and discussion

The as-cast structure

The primary and secondary dendrite structure of the as-cast sample was exhibited in Fig.1a and 1b. Mo addition did not significantly influence the dendrite arm spacings. Fig. 1c showed a typical eutectic morphology, which could be classified as the fine γ/γ' structure and coarse γ' phase. Fig. 1d indicated that Mo addition significantly decreased the segregation ratio of refractory elements. Such alleviation of segregation behavior led to the decrease of the eutectic content, as the statistical results in Fig.1e showed.

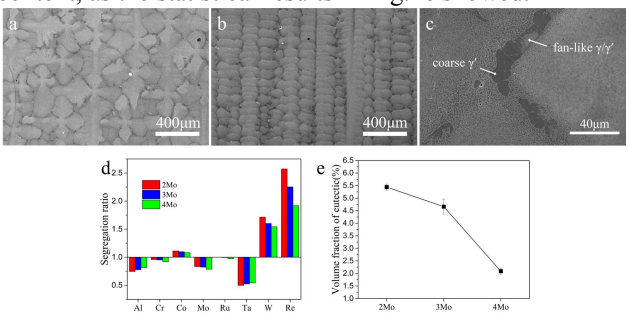

Fig.1 The as-cast microstructure of 3Mo SC, including (a) the primary dendrite, (b) the secondary dendrite, (c) eutectic island, (d) the elemental segregation ratio and (e) the volume fraction of eutectic islands[3].

Microstructure after heat treatments

To explore the upper limit temperature of the solid solution treatment, the incipient melting tests were carried out. The incipient melting stopped to occur near 1350 ℃, thus the upper limit of solid solution temperature was set as 1350 ℃. During the solid solution treatment procedure, the

temperature rose in multiple steps from 1320 ℃ to 1350 ℃. The samples were held at 1350 ℃ for 10 h, followed by air cooling. The two-step aging treatments were carried out at 1100 ℃ and 870 ℃, respectively. Fig.2 showed the microstructure in the dendrite cores after heat treatments. Due to the residual segregation, the size of γ' in the interdendritic regions was slightly larger than in the dendrite cores. Moreover, Mo addition decreased the size of γ' phase and the width of γ channel.

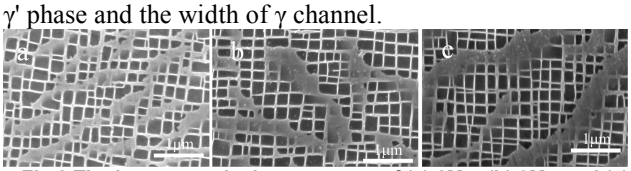

Fig.2 The heat-treated microstructure of (a) 2Mo, (b) 3Mo and (c) 4Mo in the dendrite cores[3].

Creep property at 1100 ℃/137 MPa

The creep life at 1100 ℃/137 MPa was exhibited in Fig.3. 2Mo and 3Mo alloy possessed similar creep life reaching 500 h. However, the creep life of 4Mo alloy decreased to less than 300 h. The influence mechanisms of Mo addition on the creep properties were analyzed. Mo influenced the creep property in both positive and negative ways, which were summarized in Fig.3. Mo addition inhibited the formation of creep pores, delayed the elemental inhomogeneity and promoted the formation of dense interfacial dislocations, which were beneficial factors enhancing creep resistance. However, Mo also promoted the precipitation of topologically close-packed phases (TCP phases) and accelerated the widening of the γ channel, which weakened the creep strength. Based on the analysis of the creep property and microstructure, the suitable range of Mo content in the 4th generation Ni-based SCs was proposed.

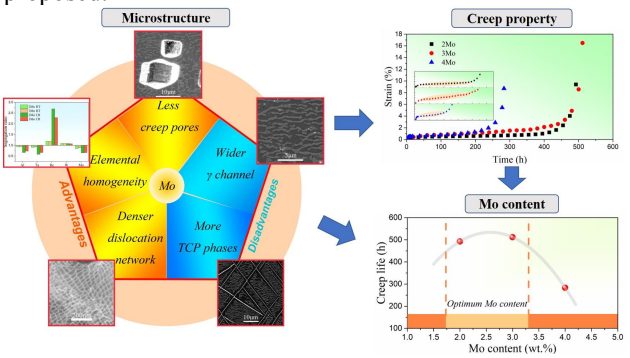

Fig.3 The creep property of the investigated alloys and the effect mechanisms of Mo addition[5]. The suitable range of Mo content was proposed based on the analysis.

4 Conclusion

(1)Mo decreased the segregation ratio of refractory elements, decreasing the content of eutectic islands.

(2)After heat treatments, the γ/γ' became typical cubic patterns. Mo addition slightly decreased the size of γ' phase and the width of γ channel.

(3)Mo enhanced the creep property by affecting the formation of creep pores, interfacial dislocation networks and elemental inhomogeneity. Meanwhile, the γ channel widening and TCP phase induced by Mo addition weakened the creep strength.

5 Acknowledgments

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