Microstructural and Mechanical Properties of Extremely Long-Term Thermal Exposed Superalloy Mar-M247After Rejuvenation Heat Treatment

Song Wu[1,2],Xiufang Gong[1,2], Zhenhuan Gao[1,2], Nieliping[1,2], Changshuai Wang[1,2], Lexin Yang[1,2], Chao Luo[1,2]

1. State key Laboratory of Clean and Efficient Turbomachniery Power Equipment, Deyang 618000, Sichuan, China;
2. Donfang Electric Corporation Dongfang Turbine Co., Ltd. Deyang 618000, China)

*Corresponding address: e-mail:Song Wu, Tel/ 086+18782014700, song.wu2022@outlook.com

Abstract： Superalloy Mar-M247 is a polycrystalline nickel-based high-temperature alloy utilized for the hot section blades of heavy-duty gas turbines. However, the degradation of the microstructural and mechanical properties of Mar-M247 occurred after ultra-long-term thermal exposure. In this paper, rejuvenation heat treatments were first performed on alloy samples after 16,000 and 24,000 equivalate operating hour thermal exposures. The differences in microstructural and mechanical properties of the above-rejuvenated alloys were investigated.

Meanwhile, different heat treatment procedures and their re-service stability have been further discussed. The results have shown that when the solution temperature is low, the rejuvenated alloy has more eutectic/carbide, and the size of the γ' phase gets larger; but after the solution temperature is high, the γ' film gets wider, and the hardness value is higher. The above conclusions indicate that the proper choice of rejuvenation heat treatment can restore the damaged alloys. The rejuvenated alloy has the same mechanical properties as the original alloy; meanwhile, it also has a higher stability.

Keywords: Long-term thermal exposure; rejuvenation heat treatment; gas turbine blade; microstructural and mechanical properties; stability.

1 Introduction

Gas turbine blades operate in high-temperature and high-stress environments and withstand temperatures reaching 800℃-1000℃ for a total service life of up to 50,000 hours. It is reported that the proper examining and repairing interval of blades is 16000 and 24000 EOH due to different maintenance plans. Between each repair interval, the blade's metallurgical organization and performance degradation are inevitably caused by the long-term thermal exposure of the blade. Microstructure degradation includes the strengthened phase getting γ' dissolved, coarsening growing, and volume fraction reducing. The microstructure changes ultimately seriously affect the alloy's high-temperature mechanical properties, significantly shortening the operation life of the gas turbine.

Steven and Flewitt [1] have investigated the effect of heat treatments on the morphology of superalloy IN738. The distribution and area fraction of γ' phases have been analyzed and related to changes in the hardness.

Yao et al. [2] have discussed the microstructural degradation of Ni-superalloy CMSX-4 material after high temperatures and a series of rejuvenation heat treatments. The observed microstructures have been investigated for the effectiveness of the heat treatment procedures and their effect on the subsequent mechanical performance. The tensile test results showed that, when the degraded CMSX-4 material was restored using the RHT, these were subject to more rapid decline than those of the as-received alloy during further subsequent degradation treatment. However, the process parameters affecting microstructure and mechanical properties during RHT have not been discussed in detail.

This paper aims to provide a greater understanding of the suitability of rejuvenation heat treatments and their role in extending component life in power plant applications. It focuses on the recovery of microstructure and mechanical properties after ultra-long service damage and discusses in detail the effect of solid solution temperature in the rejuvenation heat treatment procedure on the stability of microstructure and properties after re-service.

2 Experimental procedure

The material used in this work was a conventional polycrystalline nickel-based superalloy Mar-M247. Experimental samples had a diameter of 5 mm and a thickness of 4 mm and were machined by EDM from an unserved turbine blade. These samples were first exposed to high temperature and long-term thermal exposure and then restored through rejuvenation heat treatment. The detailed experimental conditions are listed in Table 1.

Table 1. Damaged alloys and their RHT procedures.

Thermal Exposure Temperature/℃-Time/h	RHT No.	Solid Solution Treatment Condition
1000℃/16000h-24000h	RHT-1	1190˚C/4h/AC
	RHT-2	1220˚C/4h/AC
	RHT-3	1250˚C/4h/AC

3 Result and discussion

To investigate the effect of solid solution temperature on the microstructure of thermally exposed alloys, rejuvenated alloys with different thermal exposure periods from 16000h to 24000h are compared and analyzed from the aspects of precipitation-strengthened phases γ' and mechanical properties in Fig. 1-Fig. 2.

Fig.1 presented the area(or volume) fractions of precipitation-strengthened phases γ'. It indicated that the γ' phases of thermally exposed alloys for both 16000h and 24000h can be restored into uniformly distributed γ' phases after RHT. However, with a higher solid solution temperature, the area fractions of γ' phases in the rejuvenated alloys in Fig. 1(c) and Fig. 1(f) tend to have a higher fraction value and hardness value (in Fig. 2) as compared to those in Fig. 1(b) and Fig. 1(e).

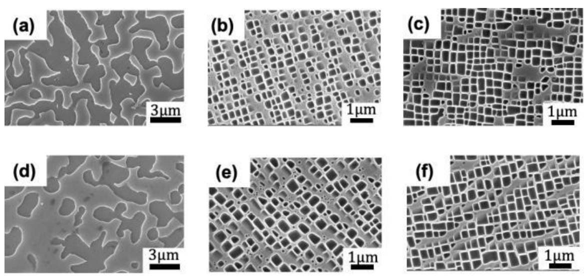

Fig.1 Morphology of γ' phases for thermal exposed alloys after (a)-(c) 16000h and (d)-(f) 24000h. (a), (d) thermal exposed alloys; (b), (e) rejuvenated alloys by RHT-1(1190 ˚C); (c), (f) rejuvenated alloys by RHT-3(1250 ˚C).

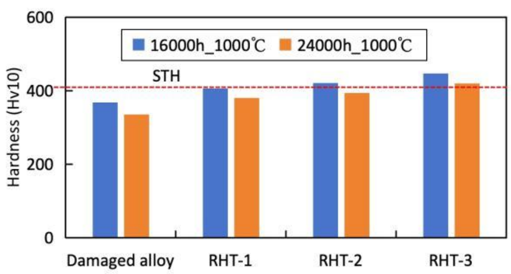

Fig. 2 Mechanical properties comparison between different rejuvenation heat treatments.

Fig. 3 described the coarsening behavior of γ' phases during the short-term re-aging at a temperature of 1000 ℃ using the coarsening equation of Lifshitz-Slyozov-Wagner(LSW) [3]. It is indicated that when the solid solution temperature of RHT is 1250℃, the coarsening rate of γ' phase rejuvenated by high solid solution temperature (the slope value of the coarsening curves) tends to be lower as compared to those of the other RHT procedures, and the SHT alloy.

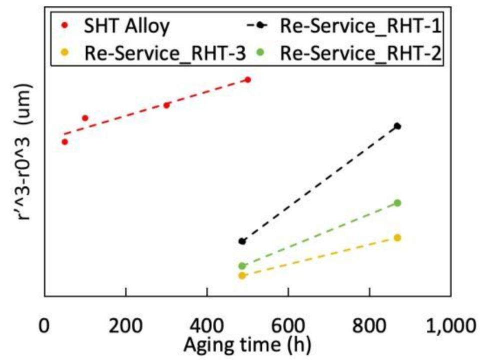

Fig. 3 The coarsening behavior of the γ' phase for the rejuveated alloys at the aging temperature of 1000℃.

4 Conclusion

1) The microstructure of alloy Mar-M247 was significantly degraded after 24,000h of long-time thermal exposure compared to 16,000h, where it showed a more obvious growth of the γ' precipitation-strengthened phases.

2) Appropriate selection of solid solution temperature in RHT can effectively restore the degraded microstructure and properties. The microstructure stability after rejuvenation is high, and the hardness and durability are comparable to the as-received alloy.

References

[1]Steven, R. A., Flewitt, P. E. J. (1978). Microstructural changes which occur during isochronal heat treatment of the nickel-base superalloy IN-738. Journal of Materials Science, 13, 367-376.

[2] Yao, Z., Degnan, C. C., Jepson, M. A. E.,Thomson, R. C. (2013). Effect of rejuvenation heat treatments on gamma prime distributions in a Ni based superalloy for power plant applications. Materials Science and Technology, 29(7), 775-780.

[3]Zhang, J., Liu, L., Huang, T., Chen, J., Cao, K., Liu, X., Fu, H. (2021). Coarsening kinetics of γ' precipitates in a Re-containing Ni-based single crystal superalloy during long-term aging. Journal of Materials Science & Technology, 62, 1-10.