The Effect of Sm on the Microstructure and Properties of Nb-Si Based in-Situ Composites

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Abstract： This study examines the microstructure and mechanical properties (with a focus on room-temperature toughness), of Sm-doped Nb-Si based in-situ composites. The base alloy consists of the coarse primary Nb5Si3 phase and the Nb3Si + Nbss (Nb solid solution) eutectic cells. The microstructure significantly refines with increasing Sm content. In addition， Sm forms a stable Sm oxide phase, which alleviates the oxygen contamination problem to some extent. Thus, with 0.2 at% Sm doping, the KQ value is 18.10 MPa·m1/2, which is 31.6% higher than that of the base alloy.

Keywords: Nb-Si based composites; rare earth elements; microstructure; properties

1 Introduction

The TET of the next-generation aero-engines is predicted to be approximately 2400K [2]. The blade material must survive temperatures of 1600 K even with advanced cooling systems and thermal barrier coatings [3]. However, nickel-based single crystal superalloys have a temperature bearing capacity of only 1450 K [4]. Thus, the search for new-generation ultra-high temperature structural materials has begun.

Nb-Si based in-situ composites become the most expected candidate materials because of its low density (7.3–8.6 g/cm^3) and quite high-temperature strength (270–320 MPa at 1673 K) [7]. However, issues with their poor room-temperature toughness and oxidation resistance must be resolved [10].

In this study, the highly active rare-earth element Sm was doped into the classical Nb-Ti-Si-Hf-Cr-Al system. It is expected that some progress will be made in the application of Nb-Si based in-situ composites by Sm doping.

2 Experimental procedure

The base alloy had the standard composition of Nb-24.7Ti-16.0Si-8.2Hf-2.0Cr-1.9Al (MASC alloy, at.%) [29]. The Sm doping amounts used were 0.1, 0.2, 0.4, and 0.8 at%, hereinafter referred to as *x*Sm alloys. Button ingots were prepared using a non-consumable vacuum arc furnace. To ensure the accuracy of the alloy composition, the alloy was melted six times. Electrical discharge machining (EDM) was used to prepare the specimens.

X-ray diffractometry (XRD) was used to examine the phase composition. Field emission scanning electron microscopy equipped with an energy dispersive spectrometer (FE-SEM; Hitachi TM4000) was used to examine the microstructure, fracture morphologies and composition. Wave dispersive spectrometry (WDS), wherein a wave dispersive spectrometer equipped with an electron probe X-ray microanalyzer (EPMA), was used to study the light element O. Quantitative analysis of the phase or microstructure was performed using Image Pro Plus 6.0. In-situ transmission electron microscopy (TEM; Talos F200X) was used to determine the phase structure. An AGXplus electronic universal tensile machine was used to measure the mechanical properties.

3 Result and discussion

Phases and microstructure

The phase compositions of all the alloys are Nbss phase, Nb_3Si phase and γ-Nb_5Si_3 phase. Sm doping causes changes in the number, intensity, and position of the diffraction peaks. The diffraction peak intensity of the Nb_3Si phase decreases with the increasing of Sm content, and the diffraction peaks of the Nb_3Si phase at 39° disappear in the Sm-doping alloys. The phase content is directly related to changes in the number and intensity of the diffraction peaks. This demonstrates that Sm doping results in a a relative decrease in the Nb_3Si phase content.

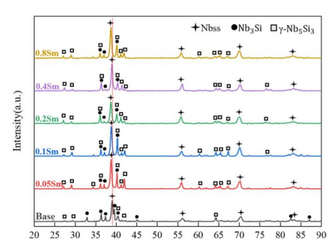


Figure 1 XRD patterns of base-xSm (x = 0, 0.05, 0.1, 0.2, 0.4, and 0.8) alloys

Combined with the XRD results and phase compositions, the dark grey phase is the Nbss phase. The thin hexagonal phase with a darker color is the γ-Nb_5Si_3 phase, which typically forms a eutectic structure with the secondary Nbss phase. The Nb_3Si phase is the light gray phase with a large area percentage. It was discovered that microstructure especially the Nb_3Si phase significantly refined as the Sm content increased.

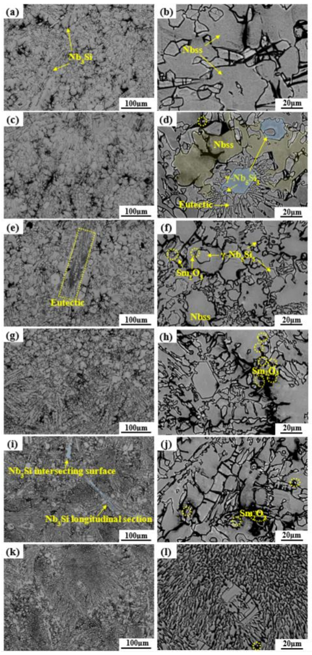
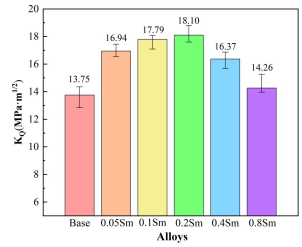


**Figure 2 Microstructure morphology:
(a, b) base alloy; (c, d) 0.05Sm alloy;
(e, f) 0.1Sm alloy;(g, h) 0.2Sm alloy;
(i, j) 0.4Sm alloy; (k, l) 0.8Sm alloy.**

Mechanical properties

The K_Q value of base alloy is 13.75 MPa·m$^{1/2}$, and the K_Q value is greatly increased by the doping of an appropriate amount of Sm. The K_Q value of 0.2Sm alloy reaches 18.10 MPa·m$^{1/2}$, which is 31.6% higher than that of the base alloy. The reduction in the size of brittle silicides is directly responsible for the increase in toughness. In addition, Sm doping with strong oxygenophilicity reduces the oxygen content in the base alloy. However, the microstructure is too fine to resist cracking through when the Sm content exceeds 0.4 at.%.



igure 3 KQ values of base-xSm (x = 0, 0.05, 0.1, 0.2, 0.4, and 0.8) alloys

4 Conclusion

(1) The phase compositions are Nbss phase, Nb_3Si phase and γ-Nb_5Si_3 phase. microstructure especially the Nb_3Si phase significantly refine as the Sm content increased.

(2) With 0.2 at% Sm doping, the KQ value is 18.10 MPa·m$^{1/2,}$ 31.6% higher than that of the base alloy.

Acknowledgments

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References

[1] Zeng Q, Chen X. Combustor technology of high temperature rise for aero engine[J]. Prog Aerosp Sci. 2023, 140: 100927.
[2] Zhang G, Zhu R, Xie G, Li S, Sundén B. Optimization of cooling structures in gas turbines: A review[J]. Chin J Aeronaut. 2022, 35: 18–46.
[3] Unnikrishnan U, Yang V. A review of cooling technologies for high temperature rotating components in gas turbine[J]. Propuls Power Res. 2022, 11: 293–310.
[4] Bewlay BP, Jackson MR. A review of very-high-temperature Nb-silicide-based composites[J]. Metall Mater Trans A. 2003, 34: 2043–52.
[5] Knittel S, Mathieu S, Portebois L, et al. Effect of tin addition on Nb–Si-based in situ composites[J]. Part II: Oxidation behaviour, Intermetallics. 2014, 47: 43-52.
[6] Bewlay BP, Jackson MR, Lipsitt HA. The balance of mechanical and environmental properties of a multielement niobium-niobium silicide-based in situ composite[J]. Metall Mater Trans A,1996, 27: 3801–08.