Microstructure and Room-Temperature Fracture Toughness of Nb-Si Alloy with Addition of Mn

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Abstract: The effect of Mn element on the microstructure and mechanical properties of Nb-Si based alloys is studied, and the investigated alloys compositions are Nb-16Si-22Ti-xMn (x = 0, 2, 4, 8 at.%). Solubility of Mn in Nbss phase is higher than that in silicide. This dissolution of Mn in Nbss phase and silicide causes solid solution strengthening. Tiss phase and Mn2Ti phase eutectic structure precipitates between dendrites of 8Mn alloy, which affect room-temperature fracture toughness adversely.

Keywords: Nb-Si alloy; Mn; Fracture toughness; Microstructure

1 Introduction

Nb-Si alloys have attracted many attentions due to their high melting temperature (~1800 ºC), relatively small density (6.6~7.2 g/cm^3) and excellent mechanical performance in high-temperature environments [1-4]. However, the room-temperature fracture toughness and oxidation resistance of Nb-Si alloys at high temperature is poor, these shortcomings limit its application greatly.

2 Experimental procedure

All the alloys mentioned above were prepared by a vacuum non-comsumable electric arc furnace under an argon atmosphere of 0.05 MPa below standard atmospheric pressure, equipped with a water-cooled copper crucible. Each ingot was melted 5 times repeatedly to ensure that the composition of alloys was uniform. Phase composition was analyzed by XRD. Observation of microstructure morphology adopt Quanta 200FEG scanning electron microscope with backscatter mode. Chemical composition of constituent phases was test by the energy disperse spectroscopy which based on the SEM. Electron diffraction image and the analysis of distribution of chemical elements used transmission electron microscope (Talos F200X). As shown in the Fig. 1. The room-temperature fracture toughness test adopted the electronic universal mechanical testing machine (Instron5569). The room-temperature fracture toughness was characterized by K_Q, which can be obtained from the formula shown below:

$$\boldsymbol{K_Q=(P\cdot S/B\cdot W^{3/2})\cdot F(A/W)}\ (1)$$

$$F(A/W)=3(\alpha/W)^{1/2}\cdot\frac{1.99-(\alpha/W)(1-\alpha/W)[2.15-3.93(\alpha/W)+2.7(\alpha/W)^2]}{2(1+/2\alpha W)(1-\alpha/W)^{3/2}}\ (2)$$

where P is the corresponding load at the 95% slope of the linear elastic part of the load-displacement curve, S stands for the load span (S = 4W), W stands for the width of sample, B is the thickness and a is the length including the slit notch of the pre-crack.

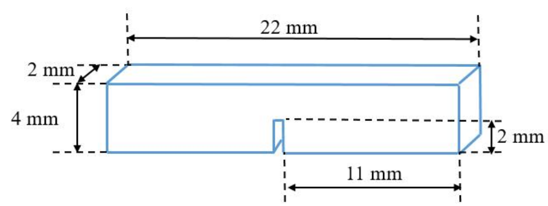

Fig. 1. The size of sample for fracture toughness testing

3 Result and discussion

Phase constitutions and microstructure of Nb-Si based alloys

Fig. 2 shows the microstructure of as-cast Nb-16Si-22Ti-*x*Mn (*x* = 0, 2, 4, 8 at.%), and the microstructure of the alloys is identified. All the alloys maintain microstructure characteristics of hypoeutectic because of the primary Nbss phase distributed in (Nb, Ti)$_3$Si matrix. Primary Nbss phase exhibits dendritic feature and Nbss phase in eutectic structure remains the morphology of fine block, as shown in Fig. 3(a)~(d). Previous studies have pointed out that the intensity (I_j) of the diffraction peak is proportional to the weight percentage of phase content (ω_j, wt.%).

When atomic ratio of Mn reaches 8 at.%, a fine eutectic structure appears between dendrites as shown in Fig. 2(d). XRD analysis of phases constituent and previous research, the darker gray phase has a lot of Ti, it can be certain as Tiss phase. The black phase is identified by Mn_2Ti phase.

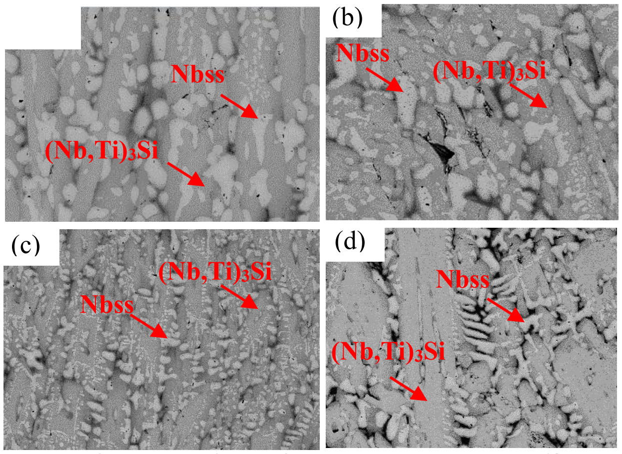

Fig. 2. BSE images of Nb-16Si-22Ti-xMn (x = 0, 2, 4, 8 at.%) alloys: (a) Nb-16Si-22Ti, (b) Nb-16Si-22Ti-2Mn, (c) Nb-16Si-22Ti-4Mn, (d) Nb-16Si-22Ti-8Mn

4 Room temperature mechanical properties

Fig. 6 shows the K_Q value which represents room-temperature fracture toughness of Nb-Si based alloys. As the content of Mn in alloys increases (atomic ratio from 2 to 8), the room-temperature fracture toughness shows a trend of increasing at first and then decreasing. When the atomic ratio of Mn reaches 4 at.%, the fracture toughness of the as-cast alloys get a peak (8.07 MPa • $m^{1/2}$). When the atomic ratio exceeds 4 at.%, the fracture toughness is severely degraded. Compared with Nb-16Si-22Ti alloy, the fracture toughness of the 4 at.% Mn alloy is increased by 17%.

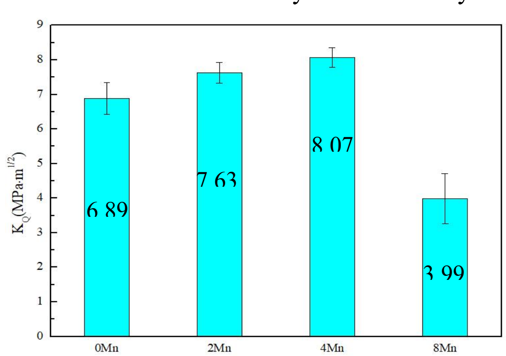

Fig. 6. Average room-temperature fracture toughness K_Q value of Nb-16Si-22Ti-xMn (x = 0, 2, 4, 8) alloys

5 Conclusion

(1)With the increase of Mn, the volume fraction of Nbss decreases. Solubility of Mn in Nbss phase is higher than that in silicide. When the content of Mn reaches 8 at%, Tiss and Mn_2Ti eutectic structure precipitates at the grain boundary.

(2)Solid solution strengthening effect of Mn in Nbss contributes to the improvement of room-temperature fracture toughness greatly. However, the Mn_2Ti at the interface in the 8Mn alloy is harmful to fracture toughness. Due to the increase of Mn content in Nbss, K_Q value of Nb-16Si-22Ti-8Mn alloy has increased by 17% compared to Nb-16Si-22Ti alloy.

6 Acknowledgments

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