Microstructure Characteristics of the Ni-Si Composites

Chunjuan Cui¹,²,⁎, Chiqiang Ren¹, Lulu Tian¹, Pei Wang¹ and Songyuan Wang¹

¹School of Metallurgical engineering, Xi’an University of Architecture and Technology, Xi’an, China
² Shaanxi Engineering Technology Research Center for Wear-resisting Materials, Xi’an, China

⁎Corresponding author e-mail: cuichunjuan@xauat.edu.cn

Abstract. A hypoeutectic alloy is a metallic alloy which has a composition less the eutectic point, and a hypereutectic alloy is a metallic alloy which has a composition beyond the eutectic point. As the temperature of a non-eutectic composition is lowered, the liquid mixture will precipitate one component of the mixture before the other. In a non-eutectic solution, there will be a proeutectoid phase, so microstructure is of importance to understand the crystal growth mechanism. In the present paper microstructure characteristics of Ni-Si composites were investigated and the crystal growth mechanism was revealed.

1. Introduction

Ni₃Si is an Ll 2 structured (ordered face-centered-cubic) intermetallic compound, possesses anomalous yield strength as a function of temperature, and shows excellent strength at temperatures up to 973K [1]. Ni₃Si has been paid more attentions because of the low density, high melting point, high strength, excellent oxidation resistance and magnificent corrosion resistance in acid environments, particularly in sulfuric acid solutions [2-4]. However, the engineering application of this material is limited by the brittleness at the ambient temperature. Many achievements that tried to improve the brittleness have been obtained [5-7]. Cui prepared Ni-Ni₃Si eutectic with a modified Bridgman directional solidification technology [8] and Electron beam floating zone melting [9], respectively. The Ni-Si hypoeutectic and Ni-Si hypereutectic are prepared with a modified Bridgman directional solidification technique in order to expand the alloy composition range. Microstructures of the Ni-Si eutectic and non-eutectic were systematically compared in the present paper, and the crystal growth mechanisms of the Ni-Si composite were obtained.

2. Experiments

The master alloys were obtained by cutting the middle of the Ni-11wt% Si, Ni-11.5wt%Si and Ni-12wt% Si alloys into Φ6×120mm slices, which were produced with vacuum induction melting technique by homogenously mixing 99.99% purity Ni and 99.99% purity Si together. The Ni-Si composites were prepared by modified Bridgman directional solidification equipment at different solidification rates. The directionally solidified Ni-Si composites were cut along the longitudinal direction and, subsequently ground and mechanically polished, followed by etching in a 5%HCl+H₂O+FeCl₃ solution. Microstructure and phase distributions are observed with OLYMPUS GX51 optical microscope (OM).
3. Results and discussions
Fig.1, Fig.2 and Fig.3 are the microstructures of Ni-Si hypoeutectic, Ni-Si eutectic and Ni-Si hypereutectic, respectively. It can be seen that Ni-Si hypoeutectic is composed of α-Ni phase and Ni$_3$Si phase, which is a kind of pseudo-eutectic structure. While both Ni-Si eutectic and Ni-Si hypereutectic is composed of three phases: α-Ni phase, Ni-Ni$_3$Si eutectic, and metastable Ni$_{31}$Si$_{12}$ phase.

Figure 1. Microstructure of the Ni-11wt% Si hypoeutectic composite at solidification rate of 3μm/s (a) Transverse section; (b) Longitudinal section.

Figure 2. Microstructure of the Ni-11.5wt% Si eutectic composite at solidification rate of 6μm/s (a) Transverse section; (b) Longitudinal section.
Figure 3. Microstructure of the Ni-12wt% Si hypereutectic composite at solidification rate of 9μm/s (a) Transverse section; (b) Longitudinal section.

The Nickel-rich part of Ni-Si equilibrium phase diagram is shown in Fig.4 [10]. It can be seen from Fig.1 that there is no metastable Ni$_3$Si$_{12}$ phase formed in Ni-Si hypoeutectic, and hypoeutectic reaction produced the regular broken-lamellar structure. This is a kind of pseudo eutectic structure. When the temperature drops to $T_E$, the eutectic reaction will continue to occur in the pseudo-eutectic region, and pseudo-eutectic structure is formed.

At the eutectic composition, the eutectic reaction is in thermal equilibrium. Liquid, $\alpha$-Ni phase and $\beta_2$-Ni$_3$Si all coexist at the same time and are in chemical equilibrium. When the temperature is decreased, the $\beta_3$-Ni$_3$Si phase transforms to $\beta_2$-Ni$_3$Si phase. Then the eutectoid decomposition is taken place as Formula (1) shows

$$\beta_2$-Ni$_3$Si $\rightarrow \beta_1$-Ni$_3$Si + $\gamma$$  \tag{1}$$

where $\beta_1$-Ni$_3$Si is a Silicon-rich phase. $\gamma$ has the formula Ni$_{31}$Si$_{12}$ and a complex hexagonal crystal structure. It can be seen from Fig.2 that microstructure of the Ni-Si eutectic is regular broken-lamellar eutectic structure, and the phase interface is at the state of the lowest energy state.

Figure 4. The nickel-rich part of Ni-Si equilibrium phase diagram.
Hypereutectic solutions are characterized as those with a higher composition of species β and a lower composition of species α than the eutectic composition. It can be seen from Fig. 4 that the liquid mixture will precipitate β₃Ni₃Si phase of the mixture before the α-Ni phase. Then the transformation β₃-Ni₃Si phase to β₂-Ni₃Si phase occurs, and the eutectoid decomposition is taken place as Formula (1) shows in the next moment. It can be seen from Fig. 3 that the microstructure of the Ni-Si hypereutectic is also pseudo-eutectic structure.

Moreover, the amount of the Ni₁₃Si₁₂ phase is increased with the increase of the silicon content. Ni₁₃Si₁₂ phase is a kind of metastable phase, and it is not beneficial to the mechanical properties of the Ni-Si alloy. But it can easily transform to stable Ni₃Si phase after annealing [11], thus the comprehensive properties of the Ni-Si composites can be improved as a result.

4. Conclusion
Ni-Si hypoeutectic, eutectic and hypereutectic composites were successfully prepared. The pseudo-eutectic structures are obtained at the pseudo-eutectic region. The microstructure of the Ni-Si composites, which contain both metallic solution matrix and hard intermetallic compounds, indicates a hopeful prospect for the enhancement of the properties of the composites.

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