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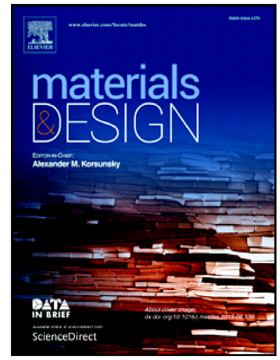

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New type of γ' phase in Ni based single crystal superalloys: its formation mechanism and strengthening effect

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Abstract

New type of γ'-precipitate in Ni-(6-8)Al-(7-12)Mo-4.5Ta-1.5Re (weight%) single-crystal superalloys and its effect on mechanical properties have been investigated. The phase exhibits a rattan form from cross-sectional observation while a curved thin film in stereoscopic structure. Its density is strongly linked to Al and Mo contents and holding time of solid solution. Its formation arises as a result of i) the overlap of γ'-precipitate and ii) the subsequent interface migration; the former is caused by the mismatch of γ-γ' periodicity, which is inherited from the congruent ordering and spinodal decomposition independently occurring in different regions; the latter is driven from the chemical potential difference between γ-ribbon and γ'-precipitate induced by interface curvature and misfit stress. The γ'-rattan improves room temperature tensile properties through changing the slip lines and inhibiting the crack growth, which is ascribed to the change in the stress field of γ-γ' structure.

Key words: Single crystal; Superalloy; Precipitate; Mechanical property; Finite-element calculation

1. Introduction

Ni based single-crystal (SC) superalloys have been used widely in manufacturing turbine blades of advanced aero- and gas engines[1-5]. Decade research has focused on improvement of high temperature properties by alloying design and generally, more and more refractory elements Re and Ru have been applied to strengthen γ-matrix [6-8]. However, high level of Re and Ru leads to the extensively high density and excessive cost, which limits the development of superalloys [9]. Thus a γ'-rich SC alloy IC21 is recently developed, at which a good high temperature creep resistance is achieved with lower density and cost [10]; it produces a decreased fraction of γ-matrix, which requires less Re and Ru for strengthening. However, the γ'-rich alloying (i.e. extra Al addition) predominantly leads to a substantial change in γ/γ' microstructure, in particular the interconnected γ'-phase which exhibits a length of usually higher than 100 μm in the cross section (as illustrated in **Figure 4a** of Zhang's work [10]).

Different kinds of abnormal-shaped γ'-particles of the size 0.5~1 μm have been investigated in superalloys, such as flower-like [11], butterfly-shaped [12-15] and irregular-shaped γ'-phases [16]. The flower-like structure where the spherical particle accompanies with many protrusions was firstly investigated by Mullins and Sekerka [17]; they ascribed this morphological instability to the point effect of diffusion: the potential for interfacial instability arises as the γ'-particles precipitates in diffusion controlled manner. It is found that the stabilizing factors include surface energy [17, 18], surface diffusion [19, 20] and anisotropy of surface tension. Yoo YS et al. [11, 21, 22] has confirmed this theory by experiments of alloys with low or high lattice misfit; it demonstrated that the morphological instability is strongly related to the super-saturation of matrix.