Microstructure Development in Nickel Base Superalloys during Weld Thermal Cycle*

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Introduction

Welding plays an important role in the economical reuse and reclamation of used and failed nickel base superalloy blades. Previous research on microstructure development during laser beam welding of a single crystal CMSX4 alloy [Ref. 1] showed non-equilibrium γ/γ' microstructure development. In addition, the γ' precipitates were found to be irregular in shape and atom probe field ion microscopy illustrated the presence of diffusional concentration profile within the γ phase in the as welded condition. To understand the above microstructure characteristics, γ' precipitation from γ phase was investigated during continuous cooling from solutionizing temperature.

Experimental Procedure

A directionally solidified superalloy (CM247-DS) of composition Ni – 8% Cr – 9% Co – 5.5% Al – 0.8% Ti – 0.1% Nb – 0.6% Mo – 3.2 Ta – 9.5 W – 0.08 C (wt.%) was used for this investigation. The alloy was machined to produce 6-mm diameter test samples for Gleeble® thermal simulations. The samples were solutionized at 1300 °C for 5 min (above the solvus temperature of γ' phase) and then cooled at different rates (10 °C/min, 1 °C/s, 10 °C/s, 75 °C/s and water quench). The transformation characteristics were followed by dilatometry. The samples after the heat treatments were characterized with transmission electron microscopy

Results and Discussion

The measured dilatometry curves of relative radius change with temperature while cooling from 1300 °C showed some slope changes. This observation may be an indication of decomposition of γ to γ'. The dilatometry measurements were not able to detect a sharp onset of this decomposition. However, the dilatometry curves were different for different cooling rates. The above variation was validated by thermal simulation with pure nickel samples.

Transmission electron micrographs obtained from same zone axis of [001] for all the samples are compared in Fig. 1. The microstructure from the as received condition (Fig. 1*a*) shows regular cuboidal γ' precipitates of size ~600 nm in γ matrix. For slow cooling rate 0.167 °C/s the γ' precipitates (Fig. 1*b*) were coarser (~700 nm) and also exhibit indications of coarsening. With the cooling rate of 1 °C/s (Fig. 1*c*), the size and distribution of γ' were similar to that found in the as received condition. However, the shape of these precipitates shows some differences. There

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are some indications of irregularities compared to that of cuboidal shape in the as-received condition.

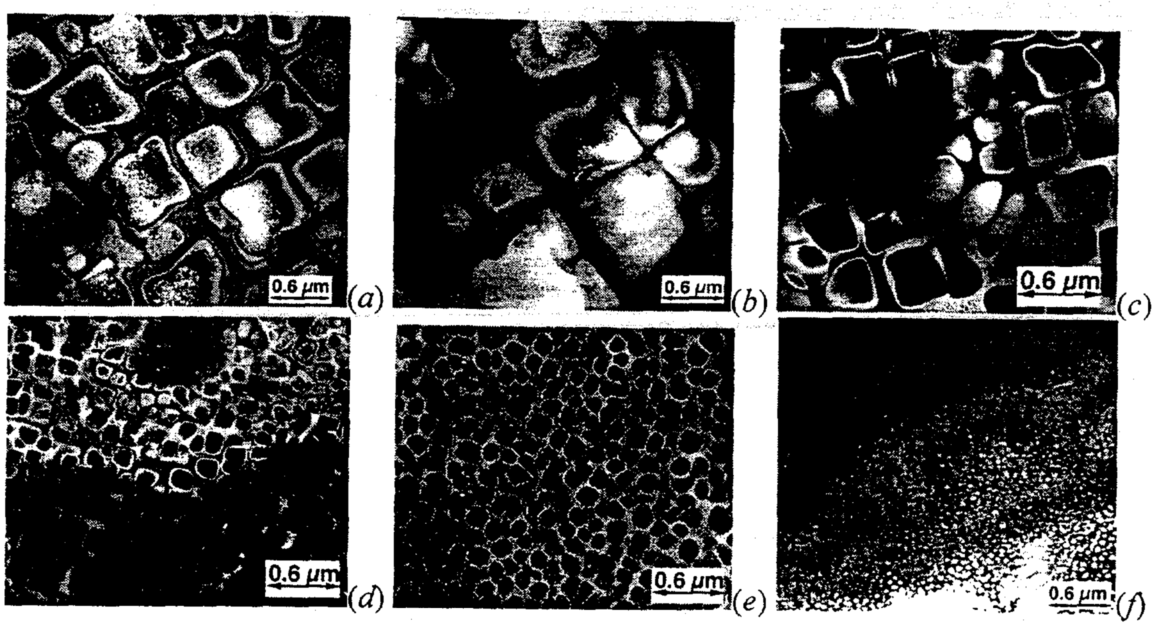

Fig. 2 Transmission electron micrographs from CM247DS after continuous cooling experiments: (*a*) as received; (*b*) 0.167 °C/s; (*c*) 1 °C/s, (*d*) 10 °C/s, and (*e*) 75 °C/s and (*f*) after water quench.

Increasing the cooling rates to 10 °C/s (Fig. 1*d*) and 75 °C/s (Fig. 1*e*) resulted in dramatic changes in γ' precipitation characteristics. With increase in cooling rate, the number density of these precipitates increased, size decreased and shape of the precipitates became more irregular. On water quenching the samples from solutionizing temperature, the number density of γ' increased tremendously and the size of these precipitates were smaller than 60 nm. Further TEM observations indicated that these precipitates were irregular in nature. The above phase transformation characteristics are related to nucleation of γ' at large undercooling. In addition, the present results and thermodynamic calculations [2] indicate that the decomposition of γ into γ' occurs by nucleation and growth and similar microstructure development can be expected in weld metal regions.

Conclusions

Continuous cooling transformation characteristics of CM247DS nickel base superalloy were investigated using thermal simulation and transmission electron microscopy. Dilatometry measurements during continuous cooling showed some differences due to differences in the decomposition of γ to γ'. Transmission electron microscopy showed with an increase in the cooling rate, the number density of γ' precipitates increased, with a corresponding decrease in the size. The above transformation characteristics can be explained based on the nucleation and growth mechanism.

Acknowledgement

This research is supported by the Division of Materials Sciences, U.S. Department of Energy under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corporation. The authors would like to thank Dr. B. Seth of SIMENS-Westinghouse for providing the alloy used in this investigation.

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