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Thermomechanical testing of nickel base superalloy single crystals

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D. Thermomechanical Testing Of Nickel Base Superalloy Single Crystals

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Introduction

Thermomechanical response of single crystal superalloys during weld heating and cooling will affect cracking behavior in the heat-affected-zone (HAZ) and weld-metal (WM) regions. Thermomechanical response of these superalloys will depend on the phase fractions of ordered am ma-prime precipitates in the am ma matrix. During weld heating, the am ma-prime precipitates will dissolve as they approach the solvus temperature and some liquation may occur in the interdendritic regions. On cooling, the single-phase gamma matrix will decompose to a mixture of am ma and am ma-prime phases. In this work we evaluated the strength, ductility and reduction in area as a function of temperature during on heating and on cooling conditions to evaluate weldability.

Procedure

In this research we evaluated three commercial single crystal nickel-base superalloys (Rene N5, PWA 1483, and CMSX4) after a standard heat treatment. Tensile samples were machined with a gauge length of 0.5" (12.7 mm) and the major axis of the specimen was oriented approximately along [001] direction. For on-heating tests, the samples were heated to different peak temperatures (600 to 1300°C) at a rate of 10°C/s. After reaching the peak temperature, the samples were deformed with a displacement rate of 13 mm/s. For on-cooling tests, the samples were heated to 1300°C at a rate of 10°C/s and then held for 2 seconds and then cooled at a rate of 130°C/s to different temperatures (600 to 1200°C) and were deformed with a displacement rate of 13 mm/s.

Results and Discussion

Room temperature tensile testing of the samples showed typical single-crystal stress-strain behavior with three distinct regimes. Due to stress-concentration and crystal twisting, the failures were very near the grips. Interestingly, the stress to failure and failure locations during on-heating tests did not change with increase in temperature during on-heating tests. The measured reduction in area and elongation were very small.

However, when the peak temperature of the sample was higher than 1000°C, the softening of the sample occurred and the failure locations were very close to the center of the gauge length. In addition, the extent of ductility and reduction in area increased. This softening is related to rapid dissolution of gamma prime precipitates above 1000°C.

In contrast to these results, during on-cooling tests showed no recovery of reduction in area at similar temperatures in the range of 1000 to 1200°C. In addition, the strength of these samples was also not high. With continued cooling below 1000°C, the samples recovered some ductility and strength. The slow recovery of strength in these alloys during heating is related to slow transformation kinetics of gamma phase to a mixture of gamma + gamma-prime phases. Subtle differences in on-heating and on-cooling results were observed between the alloys used in the current experiments.

Computational thermodynamic kinetic modeling results were in agreement with the rapid solution and delayed kinetics for precipitation during cooling. Results also indicate the possibility of nonequilibrium phase transformation that may affect thermomechanical response. These results are important to evaluate the cracking tendency in the weld metal and heat-affectedzones..

Conclusions

Thermomechanical responses of three commercial single-crystal superalloys were evaluated during on heating to different isothermal temperatures. Below 1000°C, the stress-tofailure, reduction in area and ductility did not vary with temperature. Most of the failures occurred with a knife-edge indicating a typical single crystal stress-strain behavior. However, on heating above 1000°C, rapid softening occurred due to dissolution of gamma-prime precipitates. Thermomechanical responses of these alloys were also evaluated during on cooling to different temperatures with a peak temperature of 1300°C. Interestingly, the samples did not recover any reduction area, however moderate ductility improvement was noticed. The stress-to-failure recovered only by super cooling to a low temperature below 1000°C due to slow transformation kinetic of gamma prime precipitates.

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