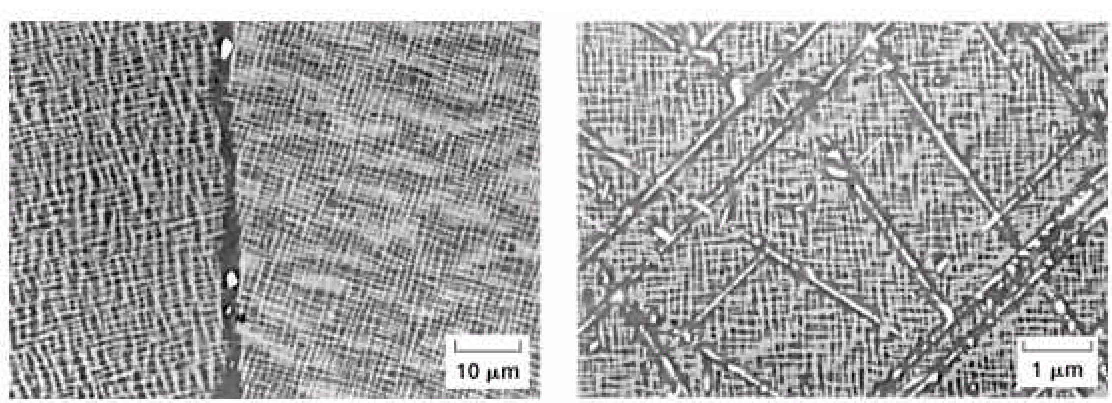
Deleterious Phase Formation in Next-Generation Nickel-Base Superalloys Predicted

Nickel- (Ni-) base superalloy single crystals represent the state-of-the-art for turbine engine airfoil applications because they offer the best balance of properties under the high operating temperatures required for efficient engine operation. Current trends in alloy design take advantage of improved creep rupture strength with the addition of higher levels of refractory elements. In particular, the addition of significantly higher levels of rhenium in third-generation superalloys is key for both microstructural stability and creep rupture strength. Although refractories provide strength benefits, alloys tend to be unstable when their refractory content is high because of topologically close-packed (TCP) phases. The formation of these phases in sufficient amount is detrimental to the performance of these alloys because of their brittle nature and because they deplete the Ni-rich matrix of potent solid-solution strengthening elements.

TCP phase formation in modern single-crystal superalloys is being investigated in-house at the NASA Lewis Research Center, where particular attention is being paid to the potential synergistic effects of alloying elements. The approach chosen in this investigation was to develop a model based on a design-of-experiments methodology. A design of experiments consisting of 44 alloys was set up to quantify both the linear and pairwise interactive effects of aluminum (Al), cobalt (Co), chromium (Cr), molybdenum (Mo), rhenium (Re), tantalum (Ta), and tungsten (W) in a third-generation Ni-base superalloy according to the resultant amount of TCP phase in the microstructure.

All alloys were produced by vacuum induction melting and were cast using high-purity melting stock. This was followed by a homogenization heat treatment and a simulated long-duration engine exposure.



Third-generation, Ni-base, superalloy aged microstructures. Left: Group 2. Right: Group 3.

After alloys were aged at 1093 °C for 400 hours, an examination of all microstructures showed that the alloys fell into three groups on the basis of the TCP distribution. Group 1 alloys contained no TCP phase. Group 2 contained less than 3 vol % TCP, which formed exclusively at the grain boundaries. Group 3 contained between 3 and 17 vol % TCP, which formed within grains as well as at grain boundaries.

A regression model was developed to describe the presence of TCP phase in the microstructures of a polycrystalline third-generation superalloy on the basis of chemical content. The result of this analysis, in terms of atomic percent, follows:

$$(\text{vol \% TCP})^{1/2} = 16.344782 - 1.019587(\text{Al}) - 2.624322(\text{Cr}) - 3.821997(\text{Mo}) + 1.109575(\text{Re}) - 3.207295(\text{Ta}) + 6.462984(\text{W}) - 2.271803(\text{Co}) + 0.052884(\text{Al})(\text{Co}) + 0.214059(\text{Al})(\text{Cr}) + 0.300698(\text{Al})(\text{Mo}) + 0.80011(\text{Co})(\text{Re}) + 0.257108(\text{Cr})(\text{Mo}) - 5.081598(\text{Re})(\text{W}) + 1.824441(\text{Ta})(\text{W})$$

This relationship has been shown to explain 95 percent of the TCP variations seen in the experiments. It is also useful for identifying principal elemental effects as well as interactive effects toward TCP phase instability and for providing insight for stable alloy development. Additional efforts are underway to further refine these results.

Bibliography

Ritzert, F., et al.: The Effect of Alloying on Topologically Close Packed Phase Instability in Advanced Nickel-Based Superalloy Rene N6. NASA TM-1998-206622, 1998.

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