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Creep Properties of NiAl-1Hf Single Crystals Re-Investigated

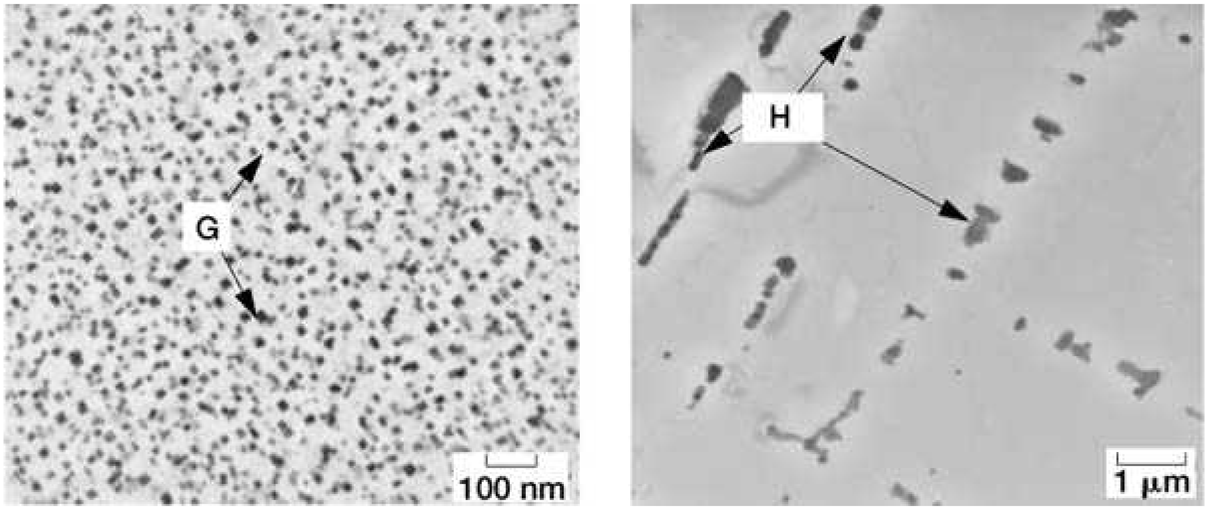
NiAl-1Hf single crystals have been shown to be quite strong at 1027 °C, with strength levels approaching those of advanced Ni-based superalloys. Initial testing, however, indicated that the properties might not be reproducible. Study of the 1027 °C creep behavior of four different NiAl-1Hf single-crystal ingots subjected to several different heat treatments indicated that strength lies in a narrow band. Thus, we concluded that the mechanical properties are reproducible.

Recent investigations (ref. 1) of the intermetallic NiAl have confirmed that minor alloying additions combined with single-crystal growth technology can produce elevated-temperature strength levels approaching those of Ni-based superalloys. For example, General Electric alloy AFN–12 {Ni-48.5(at.%) Al-0.5Hf-1Ti-0.05Ga} has a creep rupture strength equivalent to Rene’80 combined with a ~30-percent lower density, a fourfold improvement in thermal conductivity, and the ability to form a self-protective alumina scale in aggressive environments.

Although the compositions of strong NiAl single crystals are relatively simple, the microstructures are complex and vary with the heat treatment and with small ingot-to-ingot variations in the alloy chemistry (ref. 2). In addition, initial testing (ref. 3) suggested a strong dependence between microstructure and creep strength. If these observations were true, the ability to utilize NiAl single-crystal rotating components in turbine machinery could be severely limited.

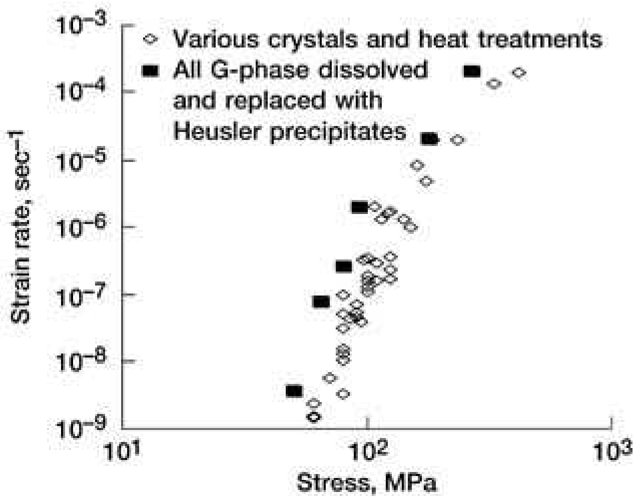
To investigate the possible limitations in the creep response of high-strength NiAl single crystals, the NASA Glenn Research Center at Lewis Field initiated an indepth investigation (ref. 4) of the effect of heat treatment on the microstructure and subsequent 1027 °C creep behavior of [001]-oriented NiAl-1Hf with a nominal chemistry of Ni-47.5Al-1Hf-0.5Si. This alloy was selected since four ingots, grown over a number of years and possessing slightly different compositions, were available for study. Specimens taken from the ingots were subjected to several heat treatment schedules, examined by transmission electron microscopy, and tested in both compression and tension.

An example of the microstructure found in a [001]-oriented NiAl-1Hf specimen after a solution treatment at 1317 °C for 50 hr followed by air cooling is illustrated in the image on the left, where the NiAl matrix contains a uniform distribution of nanometer-scale G-phase ($Ni_{16}Hf_6Si_7$) precipitates. Other heat treating schedules produced microstructures with nanometer-sized G-phase cubes and plates or, in an extreme case, produced a microstructure with all the G-phase converted to Heusler (Ni_2AlHf) particles (indicated by "H" in the right image).



Bright field transmission electron microscopy images of phases observed in [001]-oriented single crystal NiAl-1Hf alloys. Left: Solution treated and air cooled. Right: Solution treated, furnace cooled, plus aged at 1127 °C for 20 hr.

The results of 1027 °C creep strength and strain rate testing are illustrated in the following graph, which summarizes data from tensile and compressive testing of samples cut from all four NiAl-1Hf ingots and subjected to a variety of heat treatment schedules. With one exception, all the strength values lie in a narrow band that spans six orders of magnitude in strain rate. The only factor that produced results outside of this band was the heat treatment schedule that dissolved all the G-phase and replaced it with Heusler precipitates.



Comparison of 1027 °C creep properties for [001]-oriented NiAl-1Hf crystals taken from several ingots and subjected to different heat treatments.

The results portrayed in this figure lead to the important practical conclusion that the elevated-temperature creep properties of NiAl-1Hf single crystals are reproducible and are not affected by small variations in alloy chemistry from ingot to ingot or by different initial distributions of G-phase in the heat-treated alloy. The only variable in this study that produced a significant and deleterious effect on mechanical strength was a post-solution heat treatment that lead to the complete disappearance of the G-phase in favor of Heusler precipitates.

References

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