

Directionally Solidified NiAl-Based Alloys Studied for Improved Elevated-Temperature Strength and Room-Temperature Fracture Toughness

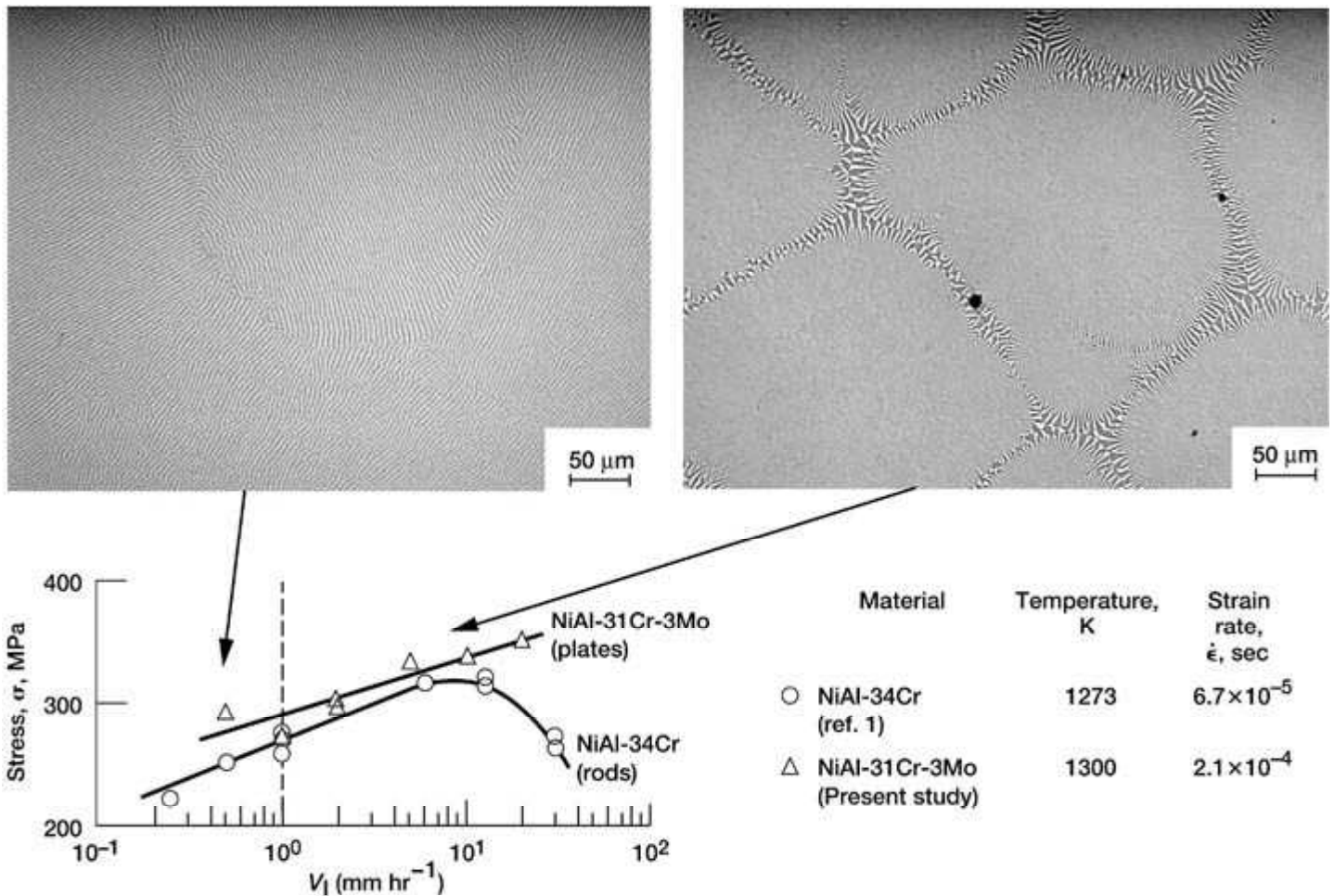
Efforts are underway to replace superalloys used in the hot sections of gas turbine engines with materials possessing better mechanical and physical properties. Alloys based on the intermetallic NiAl have demonstrated potential; however, they generally suffer from low fracture resistance (toughness) at room temperature and from poor strength at elevated temperatures. Directional solidification of NiAl alloyed with both Cr and Mo has yielded materials with useful toughness and elevated-temperature strength values.

The intermetallic alloy NiAl has been proposed as an advanced material to extend the maximum operational temperature of gas turbine engines by several hundred degrees centigrade. This intermetallic alloy displays a lower density (~30-percent less) and a higher thermal conductivity (4 to 8 times greater) than conventional superalloys as well as good high-temperature oxidation resistance. Unfortunately, unalloyed NiAl has poor elevated-temperature strength (~50 MPa at 1027 °C) and low room-temperature fracture toughness (about 5 MPa $\sqrt{\text{cm}}$).

Directionally solidified NiAl eutectic alloys are known to possess a combination of high elevated-temperature strength and good room-temperature fracture toughness. Research (refs. 1 and 2) has demonstrated that a NiAl matrix containing a uniform distribution of very thin Cr plates alloyed with Mo possessed both increased fracture toughness and elevated-temperature creep strength. Although attractive properties were obtained, these alloys were formed at low growth rates (≥ 19 mm/hr), which are considered to be economically unviable. Hence, an investigation was warranted of the strength and toughness behavior of NiAl-(Cr,Mo) directionally solidified at faster growth rates. If the mechanical properties did not deteriorate with increased growth rates, directional solidification could offer an economical means to produce NiAl-based alloys commercially for gas turbine engines.

An investigation at the NASA Glenn Research Center at Lewis Field was undertaken to study the effect of the directional solidification growth rate on the microstructure, room-temperature fracture toughness, and strength at 1027 °C of a Ni-33Al-31Cr-3Mo eutectic alloy. The directionally solidified rates varied between 7.6 and 508 mm/hr (ref. 3). Essentially fault-free, alternating (Cr, Mo)/NiAl lamellar plate microstructures (left photograph) were formed during growth at and below 12.7 mm/hr, whereas cellular microstructures (right photograph) with the (Cr, Mo) phase in a radial spokelike pattern were developed at faster growth rates. The compressive strength at 1027 °C continuously increased with increasing growth rate and did not indicate a maxima as was reported for directionally solidified Ni-33Al-34Cr (see the graph). Surprisingly, samples with the

lamellar plate microstructure (left photograph) possessed a room-temperature fracture toughness of $\sim 12 \text{ MPa}\sqrt{\text{m}}$, whereas all the alloys with a cellular microstructure had a toughness of about $17 \text{ MPa}\sqrt{\text{m}}$. These results are significant since they clearly demonstrate that Ni-33Al-31Cr-3Mo can be directionally solidified at much faster growth rates without any observable deterioration in its mechanical properties. Thus, the potential to produce strong, tough NiAl-based eutectics at commercially acceptable growth rates exists. Additional testing and alloy optimization studies are underway.



Top: Unetched optical microstructure perpendicular to the growth direction of Ni-33Al-31Cr-3Mo. Left: Directional solidification at 12.7 mm/hr results in planar eutectic grains. Right: Directional solidification at 127 mm/hr results in radial eutectic cells. Bottom: Elevated-temperature flow strength of directionally solidified NiAl-based eutectic alloys as a function of growth rate for tests conducted at $\sim 1027^\circ\text{C}$ and a strain rate of $\sim 10^{-4} \text{ sec}^{-1}$.

References

1. Cline, H.E.; and Walter, J.L.: The Effect of Alloy Additions on the Rod-Plate Transition in the Eutectic NiAl-Cr. Metall. Trans., vol. 1, 1970, pp. 2907–2917.

2. Johnson, D.R., et al.: Processing and Mechanical Properties of In-Situ Composites From the NiAl-Cr and NiAl-(Cr,Mo) Eutectic Systems. *Intermetallics*, vol. 3, issue 2, 1995, pp. 99–113.
3. Whittenberger, J.D., et al.: Effect of Growth Rate on Elevated Temperature Plastic Flow and Room Temperature Fracture Toughness of Directionally Solidified NiAl-31Cr-3Mo. *Intermetallics*, vol. 7, issue 10, 1999, pp. 1159–1168.

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