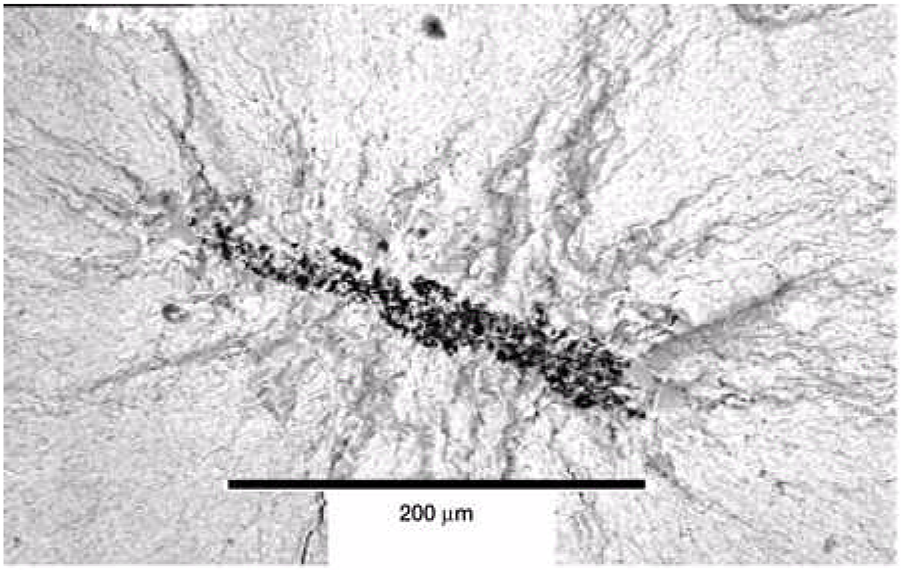
Major Effects of Nonmetallic Inclusions on the Fatigue Life of Disk Superalloy Demonstrated

The fatigue properties of modern powder metallurgy disk alloys can vary because of the different steps of materials and component processing and machining. Among these variables, the effects of nonmetallic inclusions introduced during the powder atomization and handling processes have been shown to significantly degrade low-cycle fatigue life. The levels of inclusion contamination have, therefore, been reduced to less than 1 part per million in state-of-the-art nickel disk powder-processing facilities. Yet the large quantities of compressor and turbine disks weighing from 100 to over 1000 lb have enough total volume and surface area for these rare inclusions to still be present and limit fatigue life. The objective of this study was to investigate the effects on fatigue life of these inclusions, as part of the Crack Resistant Disk Materials task within the Ultra Safe Propulsion Project. Inclusions were carefully introduced at elevated levels in a nickel-base disk superalloy, U720, produced using powder metallurgy processing. Multiple strain-controlled fatigue tests were then performed on extracted test specimens at 650 °C. Analyses were performed to compare the low-cycle fatigue lives and failure initiation sites as functions of inclusion content and fatigue conditions.

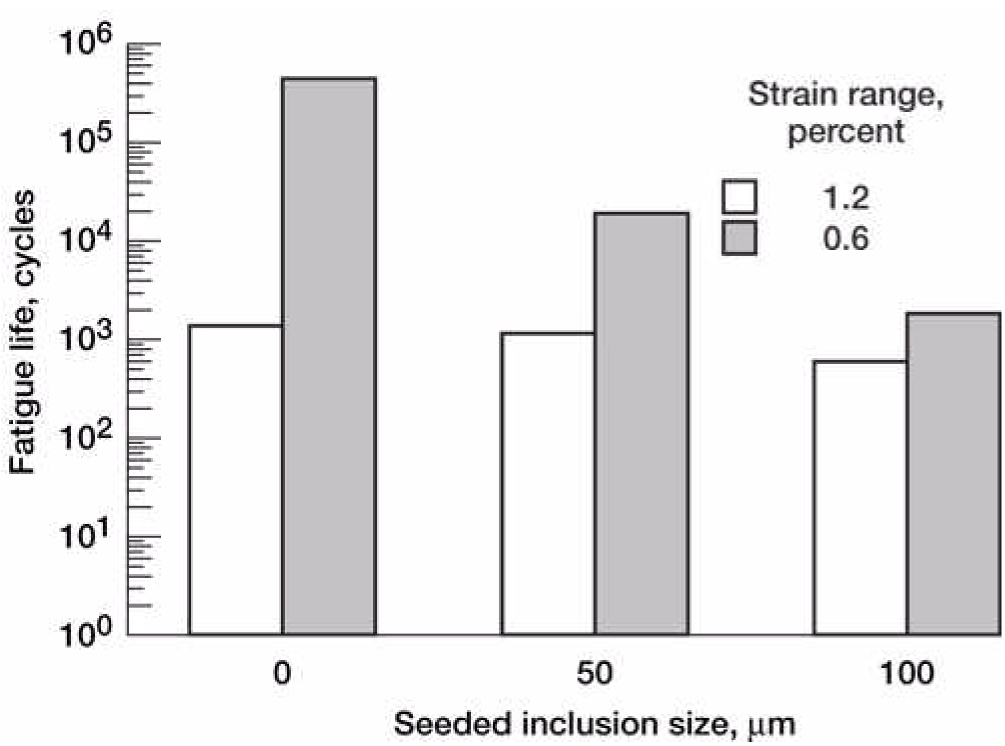


Inherent alumina nonmetallic inclusion that initiated a crack within a U720 fatigue specimen to cause failure (ref. 1). Specimen tested at 538 °C, a strain range of 0.75 percent, and a strain ratio of 0.

Powder of the nickel-base superalloy U720 was atomized in argon at Special Metals Corporation, Inc., using production-scale high-cleanliness powder-processing facilities and handling practices. The powder was then passed through a 270-mesh screen. One portion of this powder was set aside for subsequent consolidation without introduced inclusions.

Two other portions of this powder were seeded with alumina inclusions. Small, polycrystalline soft (Type 2) inclusions of about 50 μm diameter were carefully prepared and blended into one powder lot, and larger hard (Type 1) inclusions of about 150 μm mean diameter were introduced into the other seeded portion of powder. All three portions of powder were then sealed in separate containers, hot isostatically pressurized, extruded, forged into subscale disks, and heat treated. Low-cycle-fatigue specimens were then extracted, machined, and tested. Fatigue tests were performed at 650 °C in closed-loop servohydraulic testing machines using induction heating and axial extensometers. All tests were continued to failure, and fractographic evaluations were performed on all specimens to determine the crack initiation sites.

A large majority of the failures in specimens with introduced inclusions occurred at cracks initiating from inclusions at the specimen surface, as shown for each type of inclusion in the following bar chart. The inclusions significantly reduced fatigue life from unseeded material levels, as shown in the bar chart. These effects were found to depend on the strain range, strain ratio, and inclusion size. Tests at lower strain ranges and higher strain ratios resulted in larger effects of inclusions on life. Inclusion effects on life were thereby maximized in tests at the lowest strain range of 0.6 percent and the most positive strain ratio of 0.5. Under these conditions, small Type 2 inclusions reduced life substantially--about 20 times, whereas large Type 1 inclusions dramatically reduced life 100 times. These results clearly demonstrate that it is essential to include the effects of inclusions for realistic predictions of disk fatigue life. Important issues, including temperature dependence, crack initiation versus propagation, surface treatments, realistic disk features and machining, and realistic disk spin testing will be addressed to accurately model inclusion effects on disk fatigue life.



The larger seeded inclusions reduced fatigue life over 100 times in tests at a lowest strain range of 0.6 percent, a highest strain ratio of 0.5, and a temperature of 650 °C.
Long description

Fatigue life varied from well over 105 cycles for no inclusions to a little over 103 cycles for 100-micrometer inclusions. A single crack initiating at a surface-connected seeded inclusion caused failure in each case.

Reference

1. Gabb, T.P., et al.: Assessments of Low Cycle Fatigue Behavior of Powder Metallurgy Alloy U720. The Thirty-First National Symposium on Fatigue and Fracture Mechanics. ASTM STP-1389, G.R. Halford and J.P. Gallagher, eds., 2000, pp. 110-127. (reprints available)

Glenn contacts: Tim Gabb, 216-433-3272, Timothy.P.Gabb@grc.nasa.gov; and Jack Telesman, 216-433-3310, Jack.Telesman@grc.nasa.gov
OAI contact:
U.S. Army Research Laboratory, Vehicle Technology Directorate at Glenn contacts: Peter Bonacuse, 216-433-3309, Peter.J.Bonacuse@grc.nasa.gov; and Robert L. Barrie, 216-433-5090, Robert.L.Barrie@grc.nasa.gov
Authors: Timothy P. Gabb, Jack Telesman, Peter T. Kantzos, Peter J. Bonacuse, and Robert L. Barrie
Headquarters program office: OAT
Programs/Projects: Ultra Safe