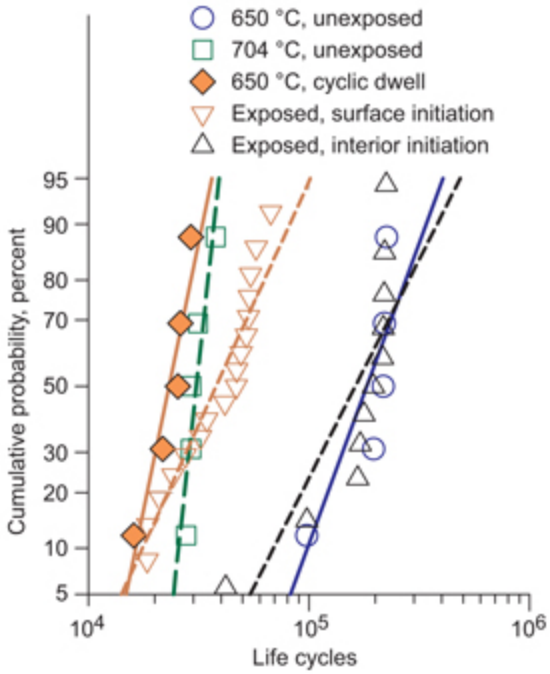
Effects of High-Temperature Exposures on the Fatigue Life of Disk Superalloys Examined

Tests used to characterize the low-cycle-fatigue resistance of disk superalloys are usually performed at cyclic frequencies of 0.33 Hz or faster. However, service conditions for disks in some aerospace and land-based gas turbine engines can produce major cycle periods extending from minutes to hours and days.

Over a service life, this can produce total service times near the maximum temperature that exceed 100 hr for aerospace applications and 100,000 hr for land-based applications. Such time-dependent effects of realistic mission cycles on fatigue resistance can be significant in superalloy disks, and need to be considered for accurate disk life prediction.

The purpose of this study at the NASA Glenn Research Center was to examine the effects of extended exposures and extended cycle periods on the fatigue resistance of two disk superalloys. Current alloy Udimet 720 (Special Metals Corporation, Huntington, WV) disk material was provided by Solar Turbines/Caterpillar Co., and advanced alloy ME3 was provided by the NASA Ultra-Efficient Engine Technologies (UEET) Project, in powder-metallurgy-processed, supersolvus heat-treated form. Fatigue specimens were fully machined and exposed in air at temperatures of 650 to 704 °C for extended times. Then, they were tested using conventional fatigue tests with a total strain range of 0.70 percent and a minimum-to-maximum strain ratio of zero to determine the effects of prior exposure on fatigue resistance. Subsequent tests with extended dwells at minimum strain in each fatigue cycle were performed to determine cyclic exposure effects.

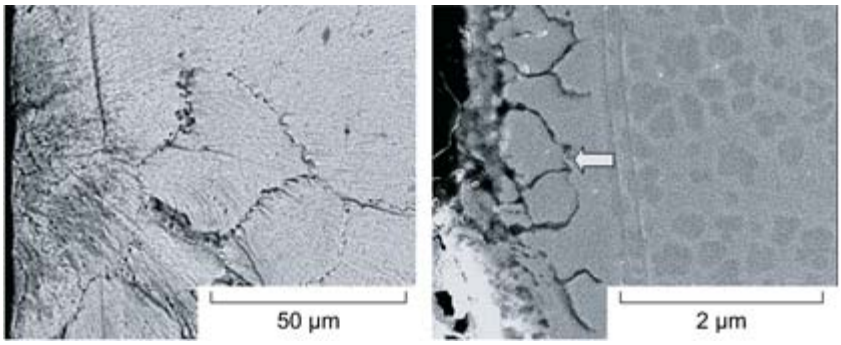


Udimet 720 fatigue lives for 0.70-percent strain range at 650 °C--including prior exposed, unexposed, and cyclic dwell lives--could be generally grouped by failure initiation sites.

Long description of figure 1. Graph of cumulative probability in percent versus life cycles for 650 °C unexposed, 704 °C unexposed, 650 °C cyclic dwell, exposed surface initiation, and exposed interior initiation.

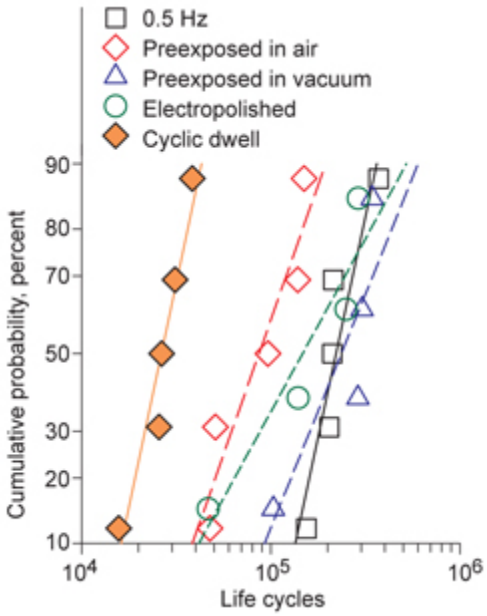
The effects of various prior exposures at 650 to 704 °C for 100 to 1029 hr were first evaluated on Udimet 720 fatigue life and failure modes. Resulting Udimet 720 fatigue lives at 650 °C, including prior exposed and unexposed lives, could be generally grouped according to failure-initiation sites (see the preceding graph). Specimens failing from surface-oxide-initiated cracks had about 80-percent lower lives than those failing from internal cracks at inclusions or grain facets.

Cyclic dwell tests at 650 °C were then performed with a dwell time based on the longest prior exposure time at 650 °C divided by the subsequent log mean cyclic life. These tests reduced mean lives by about 90 percent from unexposed, conventional test lives, and specimens invariably failed from surface-oxide-initiated cracks (see the following photomicrographs). Cyclic dwell lives were lower than the preexposed lives, suggesting that the damage produced by each fatigue cycle and a dwell exposure can interact.



Fractured surfaces (left) and metallographic sections (right) showed failures initiated at surface oxidation for many exposed and all cyclic dwell specimens of Udimet 720 and ME3.

Further discriminating evaluations were performed using disk alloy ME3 with a constant total exposure time. Cyclic dwell tests were first performed on ME3 to get a log mean cyclic life of 26,362 cycles and test duration of 439 hr at the same strain conditions as before (see the following graph). This test duration time was then used as the prior exposure condition. The contribution of environmental attack was isolated by comparing prior exposures of 704 °C/439 hr in air versus vacuum. Prior exposure in air reduced fatigue life about 50 percent from unexposed levels, and induced surface-oxide-initiated failures. Prior exposures in vacuum did not significantly reduce subsequent mean fatigue life from unexposed levels, and did not induce surface failures. This indicated that the air environment was strongly contributing to the damage. Long exposures could also be detrimental by reducing the beneficial compressive residual stresses produced near the specimen surface during machining. These effects were evaluated by electropolishing away the surface layer on several specimens before conventional fatigue testing. The fatigue lives of these specimens showed more scatter than for the unpolished specimens, but fatigue life was not consistently reduced by the electropolishing. This indicated that the relaxation of beneficial compressive residual stresses was not strongly driving the life reductions due to exposure. Cyclic dwell testing was again most damaging, reducing mean fatigue life about 90 percent in comparison to unexposed, conventional fatigue test life.



Controlled experiments on ME3 for 0.70-percent strain range at 704 °C indicated that mixed cycling and exposure in air is life limiting.

Long description of figure 3. Graph of cumulative probability in percent versus life cycles for 0.5 hertz, preexposed in air, preexposed in vacuum, electropolished, and cyclic dwell.

It was concluded that exposure effects can significantly influence disk superalloy fatigue lives by shifting the failure initiation sites from internal defects to environment-affected surface layers. Prior exposures of specimens can be used to help approximate some aspects of the exposure effects that may occur during service by activating, to some degree, a fatigue cracking mechanism at surface oxidation. However, more realistic cyclic dwell tests produced the lowest lives here, and these can give more accurate indications of the effect of cumulative exposure on service lives.

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