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HIGH-TEMPERATURE REVERSE-BEND FATIGUE STRENGTH OF INCONEL ALLOY 625*

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SUMMARY

Inconel 625 has been selected as the clad material for Upgraded Transient Reactor Test Facility (TREAT Upgrade or TU) fuel assemblies. A general description of the expected clad temperature history has been given elsewhere in these proceedings.[1] In brief, the range of temperatures investigated is 900-1100 °C. A reverse bend fatigue test program was selected as the most effective method of determining the fatigue characteristics of Inconel alloy 625 sheet metal.

The TU is an air-cooled reactor; its fuel consists of dispersed UO_2 in a graphite-carbon matrix. During the lifetime of the clad oxidation/nitridation (outside surface) and carburization (inside surface) are expected to occur. Hence, for a proper design of the clad, the effect of these phenomena on the thermomechanical properties -- including fatigue strength -- had to be evaluated. The present work describes the reverse bend fatigue experiments, the results obtained, and the analysis of data. No comparable study has been ound in the technical literature.

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All the specimens were prepared from the Inconel 625 sheet material specified for the fabrication of the TU fuel assemblies (Huntington Alloys Heat #NX1626A). Nominal sheet thickness was 0.635 mm (0.025 in).

The specimen geometry is schematically shown in the inset of Figure 1. The specimen is clamped at the two ends, in neutral position; the shorter end is clamped fixed, the longer end is flexed uniformly by a cam assembly attached to a motor with variable speed. By this method average strain rates from a value of 0.123 s^{-1} to 1.8 s^{-1} were obtained. The specimen was resistively heated; the temperature controlled by a closed-loop infrared detector and controller, a system which resulted in an accuracy of ± 10 °C. The strain rates selected were high enough to minimize creep damage during the fatigue cycling. In all, five types of specimens were tested during this work: 1) mill annealed (average grain diameter, 0.03 mm), 2) solution-annealed (average grain diameter, 0.1 mm), 3) nitrided-solutionized, 4) resolutionized, and 5) carburized-oxidized.

Mill annealing was performed at 950 ± 25 °C by Huntington Alloys, Inc.; all the remaining heat treatments were done by Argonne National Laboratory. The solution-annealed condition was achieved by heating the specimens in an argon environment for one hour at 1100 ± 10 °C. Nitriding-solutionizing was effected in an ammonia-rich atmosphere at 1100 ± 20 °C for 45 minutes. Nitrided layer thickness was measured as ~7.6 x 10^{-2} mm. Some of the nitrided-solutionzed specimens were reheated in argon atmosphere at 1100 ± 10 °C for one hour; these are referred to as the "resolutionized" specimens. The carburized-oxidized specimens were so prepared as to reflect the end-of-life microstructure of the TU fuel clad. The carburized layer depth was measured as 0.114 mm, and the oxide layer as ~5.1 x 10^{-3} mm.

The carburization-oxidation and the nitridation was performed on mill-annealed material. Hence, in these specimens, the grain distribution is a "duplex" type. The near-surface regions are mill-annealed grain type, with nitrides or carbides precipitated at the grain boundaries, whereas the region not affected by carburization or nitridation has large solution-annealed grains.

Typical examples of results from fatigue tests are depicted in Figure 1. The effect of temperature on the solution-annealed specimen is shown in Figure 1a. Higher temperature tends to decrease the fatigue life for a given strain range. The 900 °C fatigue data presented in Figure 1b, demonstrates small differences because of thermophysical treatments with the nitrided surface treatment indicating a slight improvement in fatigue life. The effect, however, is small and will be considered of second order in this discussion. Similarly, it was found that the strain rate in the range of 0.123 s^{-1} to 1.8 s^{-1} had no significant effect on the fatigue strength. However, it was observed that, compared with the fatigue data obtained by push-pull type tests[1] conducted at strain rates $\leq 5.0 \times 10^{-3}$ s^{-1}, the value of the ratio ($N_{f\ \mathrm{Reverse\ Bend}}$) to ($N_{f\ \mathrm{Push\text{-}Pull}}$), ratio D, monotonically decreased from 25.0 at 900 °C to 1.0 at 1100 °C. Based on the experimentally-derived observations and the detailed calculations[1] of creep damage for the push-pull type fatigue tests, it is reasonable to state that, for 900 °C, the strain rate of 0.18 s^{-1} is rapid enough to preclude any significant creep damage. However, at 1100 °C, creep deformation is still the predominant element of the total damage sustained by the test specimen. On the basis of these findings, it is reasonable to state that (design) analyses based on push-pull test data generally over calculate the severity of fatigue damage. Finally, it is concluded that processes of carburization, oxidation, and nitridation will not have significant effect on the fatigue properties of the TU fuel assembly cladding.

Reference

1. Ankur Purohit, Ulrich Thiele and John E. O'Donnell, "Fatigue Strength and Evaluation of Creep Damage During Fatigue Cycling of Inconel Alloy 625" (published elsewhere in these proceedings).

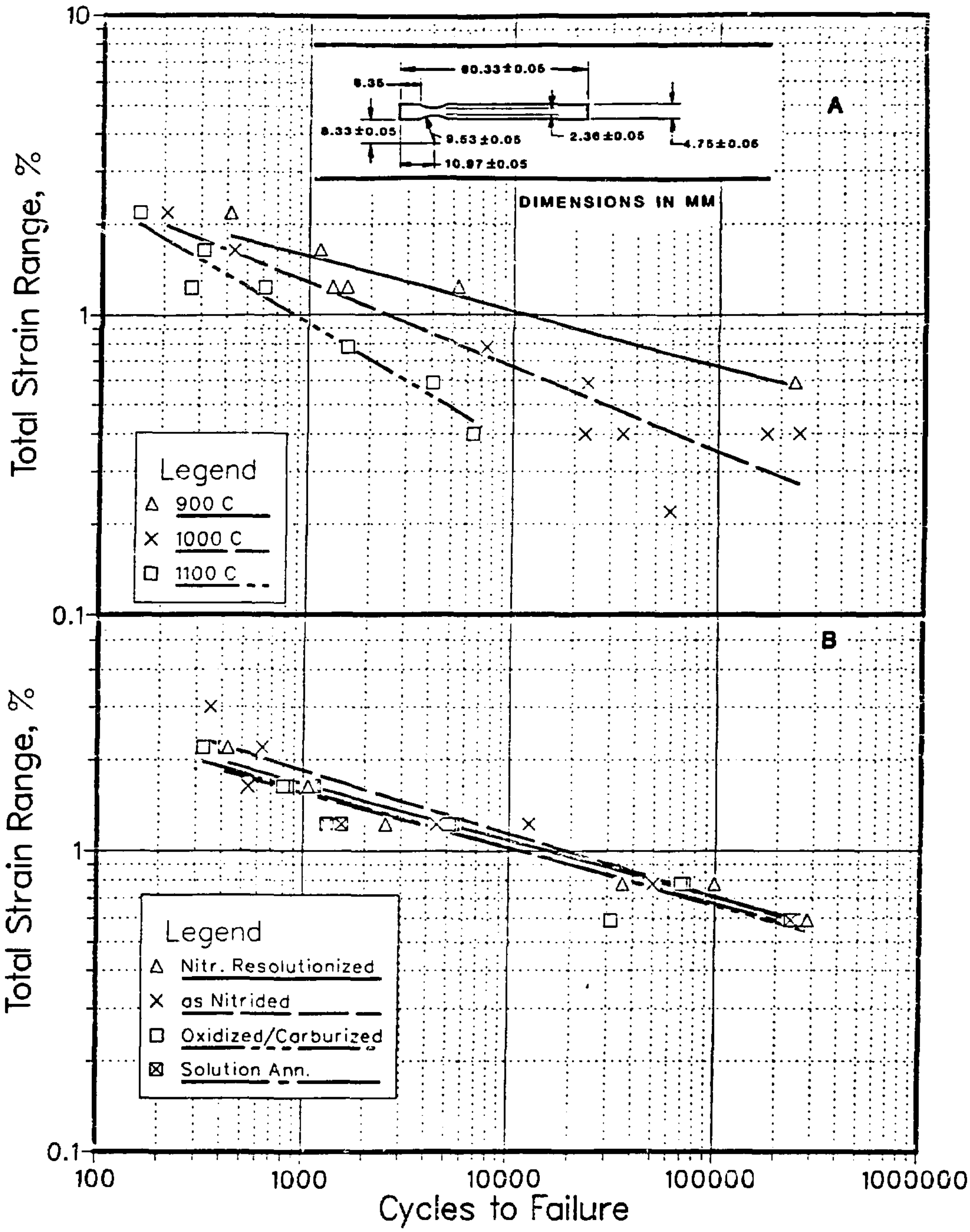

Figure 1. Reverse Bend Fatigue Test Results, for Inconel Alloy 625:

(A) Solution-annealed specimens for 900-1100 °C and
(B) Various thermophysical pretreatments for test temperature of 900 °C