Benchmark Notch Test For Life Prediction

P. A. Domas and J. Yau
General Electric Co.
Cincinnati, Ohio

W. N. Sharpe and M. Ward
Louisiana State University
Baton Rouge, Louisiana

ABSTRACT

Aircraft gas turbine engine components are subjected to severe stress, temperature, and environmental conditions. In these components, local stress raisers (e.g., notches, boltholes, welds, fillet radii) are very often life limiting areas in that low cycle fatigue failures generally initiate in these critical regions. Economic and reliability demands have prompted inordinate effort in development of analytic methods to first predict stresses and strains in these complex geometry regions and, ultimately, predict the low cycle fatigue life for components containing these necessary design features. These analytical developments have apparently been successful since numerous techniques (most notably in the form of finite-element computer models) have evolved. There remains, however, the need to check or verify these analytical methodologies against actual experimental data measurements. This is not a simple task. Most stress concentration regions in gas turbine engines are geometrically very small, eliminating many conventional extensometry methods for strain measurement. Further, conditions of interest include long times at elevated temperatures (near 649° C), eliminating conventional strain gage measurement methods. The laser Interferometric Strain Displacement Gage was recognized as having the potential to accomplish this demanding task and was employed in this program.

The overall objective of this program was the generation, measurement, and documentation of the actual strains incurred at the root of a discontinuity in cyclically loaded test samples subjected to inelastic deformation at high temperature where creep deformations readily occur. A secondary objective was to perform an analysis of the steady-state cyclic stress-strain response at the root of the discontinuity in the tested samples for comparison to the measured results.

A comprehensive set of local notch root strain measurements for a variety of load patterns in an Inconel 718 notch specimen at 649° C (1200° F) was obtained and documented using the laser Interferometric Strain Displacement

Gage (ISDG). The ISDG was successfully adapted to the high-temperature measurements in this typical Ni-base superalloy and was shown to have a relative uncertainty of $\pm$ 3% of the measured strain with an additional uncertainty of $\pm$ 150 microstrain.

Measurements were made for six load patterns including continuous cyclic, creep and cyclic with tensile and comprehensive hold periods on flat, double-notch bars with an elastic stress concentration factor of 1.9.

Pedigree tensile and cyclic stress-strain data were also generated at 649° C and employed in a simple Neuber analysis to obtain analytic predictions for comparisons to test results. A modified Neuber approach and a limited finite-element study were also compared to the data.

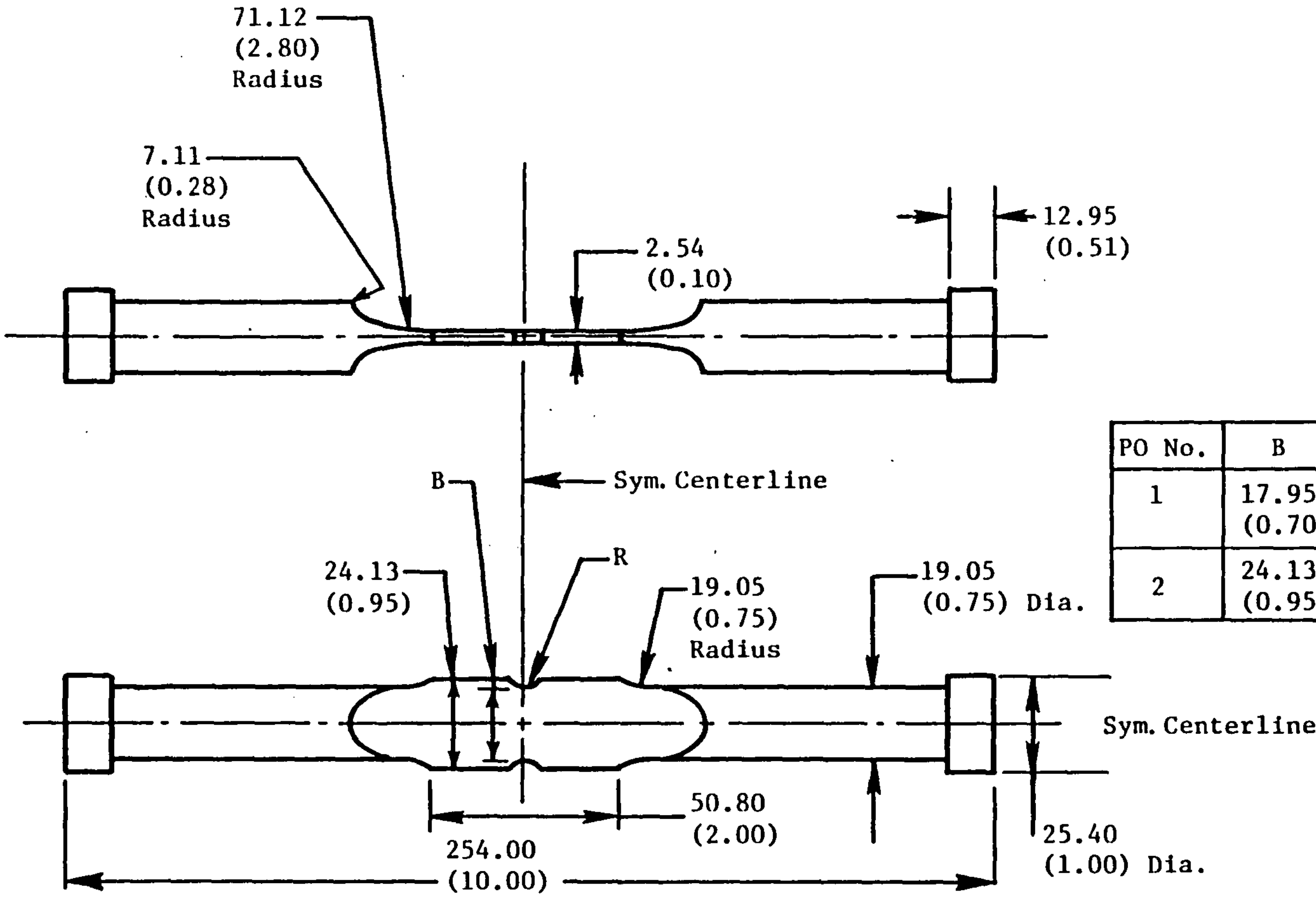
A smooth bar specimen subjected to the notch root strain history recorded from a continuously cycled notch bar was also used to obtain stress behavior data for comparison to the predictions.

The Neuber analysis predicted the first cycle notch root behavior very well on the basis of hysteresis loop comparison when the notch root strain rate stress-strain response curve was used. The stabilized cyclic loops were not well predicted even when cyclic softening had stabilized. The modified Neuber equation (corrected for stress redistribution due to plasticity) and the finite-element analysis improved the cyclic correlation but did not totally resolve the problem.

The smooth bar test using the notch root strain history control shed additional light on this in that the maximum monotonic and stable cyclic stresses were well predicted by Neuber (as was the minimum stable cyclic stress) while the minimum monotonic (first cycle unload) was not. This suggests that kinematic-hardening assumptions may be incorrect for the early cyclic transition period.

The utility of the computerized data acquisition and storage system associated with the ISDG was demonstrated by examining cyclic history dependent parameters (e.g., loop area) on a cycle-by-cycle basis. These parameters were used to assess data quality as well as behavioral trends, and have potential for extension to life prediction application. The hysteresis loop elastic loading slope was used to predict notch root crack initiation which was confirmed by posttest microscopy.

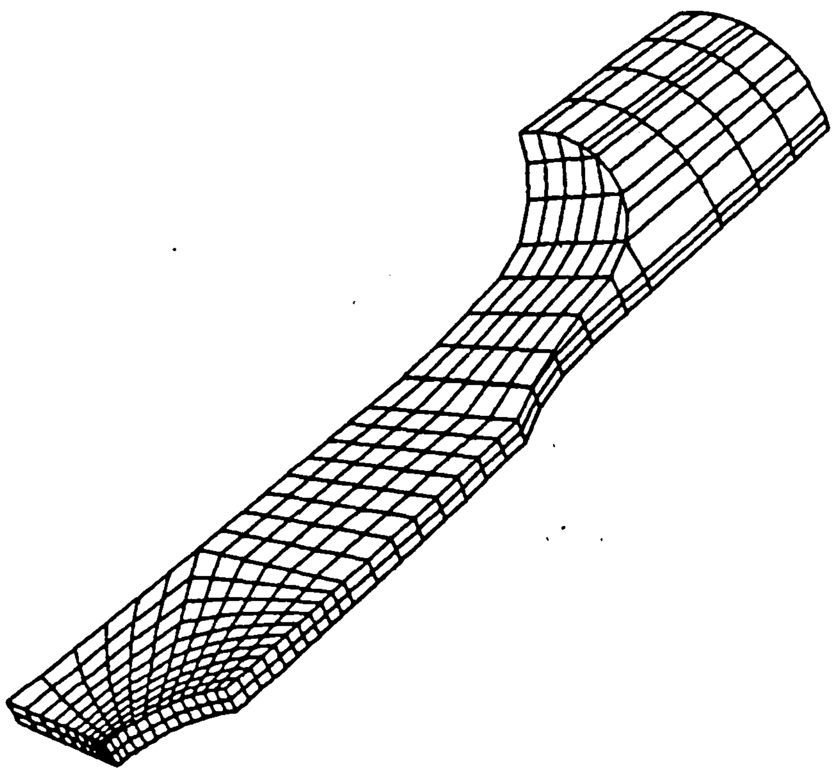
The program objectives of generation of benchmark notch data in a turbine disk alloy at elevated temperature and comparison to a Neuber analysis were met. Significant implications for future model development were determined.



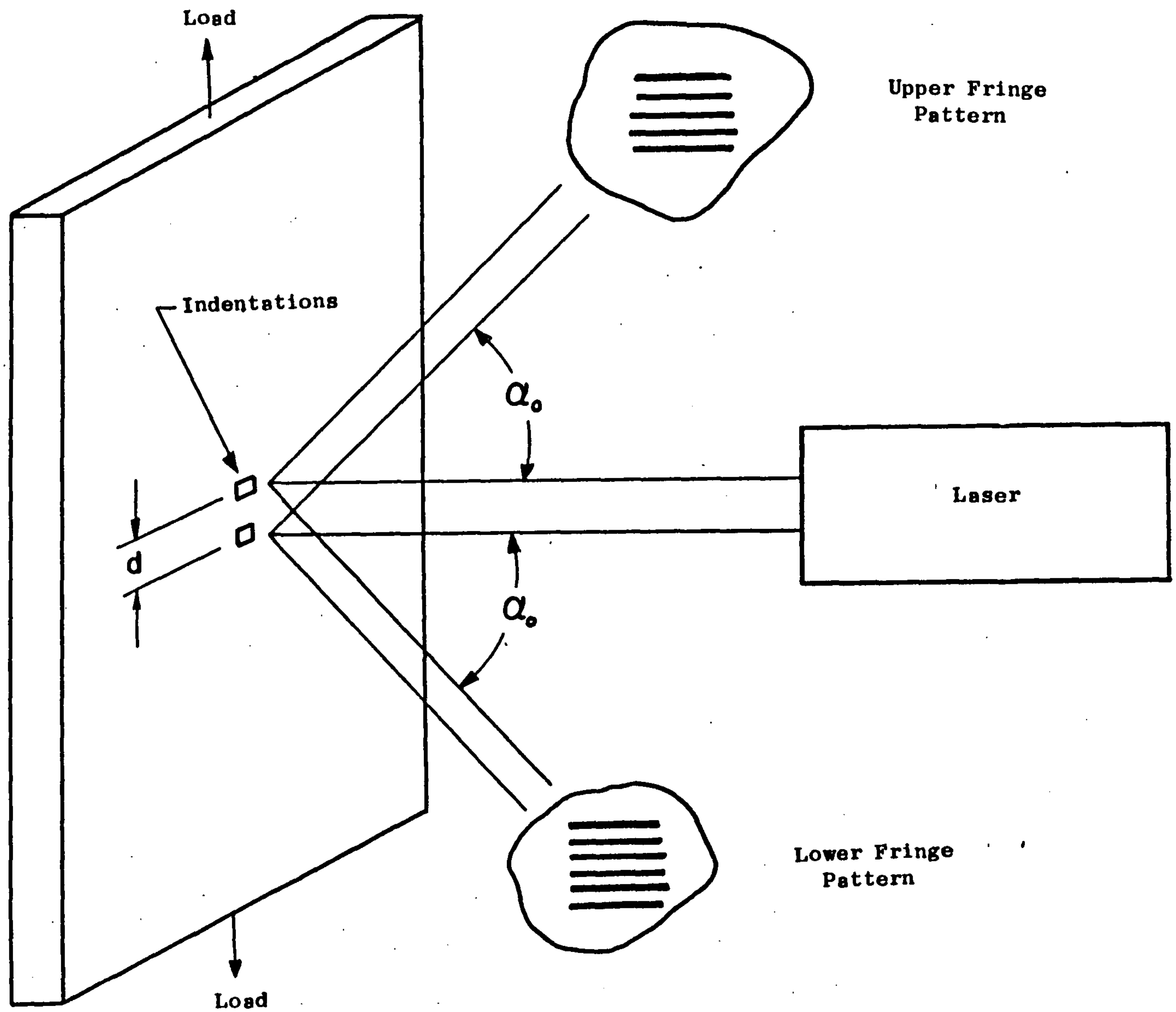
PO No.	B	R
1	17.958 (0.707)	4.902 (0.193)
2	24.13 (0.95)	-

- Dimensions in mm (inches)

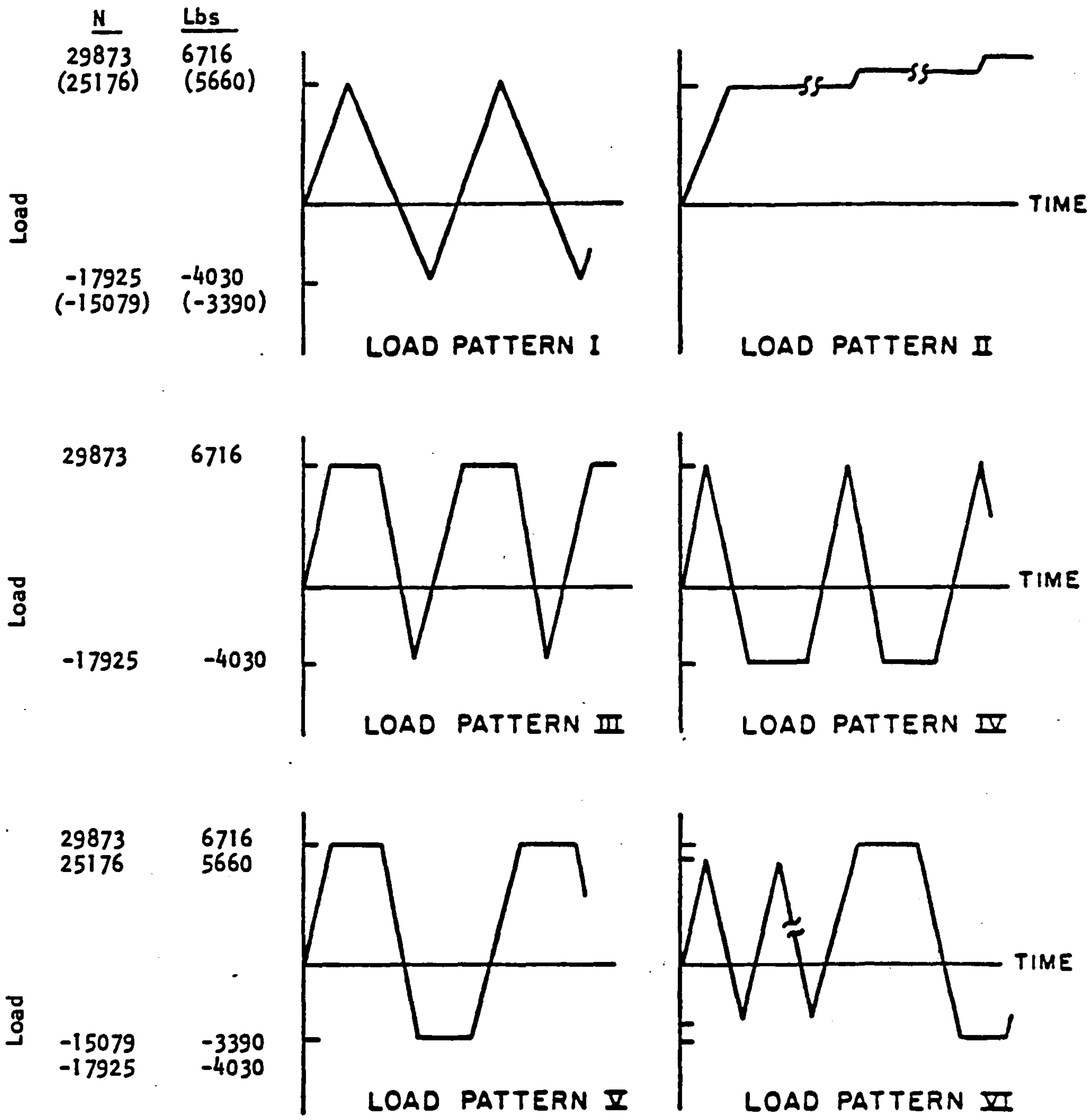
Benchmark Notch Specimen CAP111280 (K_t = 1.9).



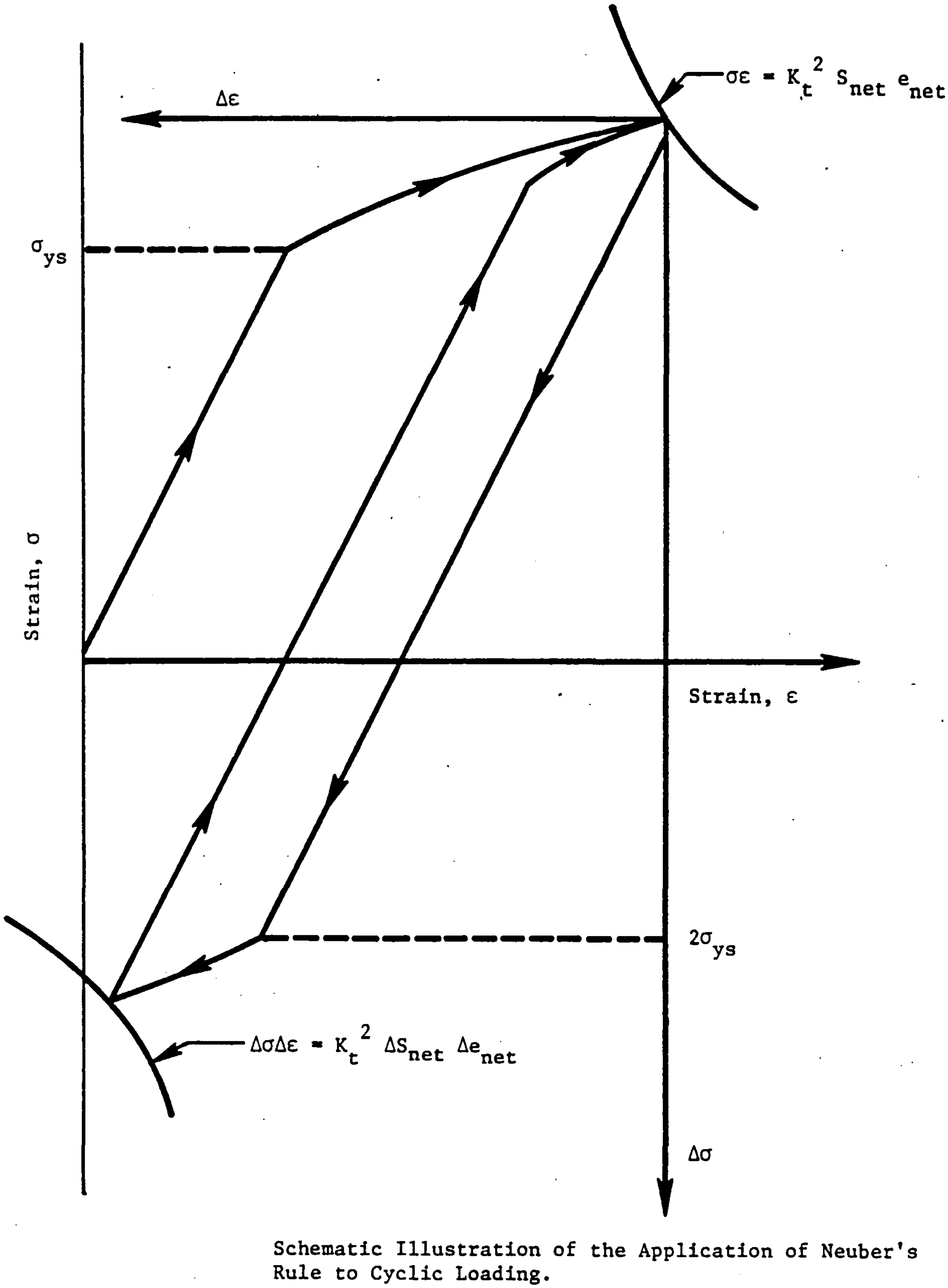
Three-Dimensional Finite-Element Mesh Pattern
of 1/8 of the Benchmark Notch Fatigue Specimen.



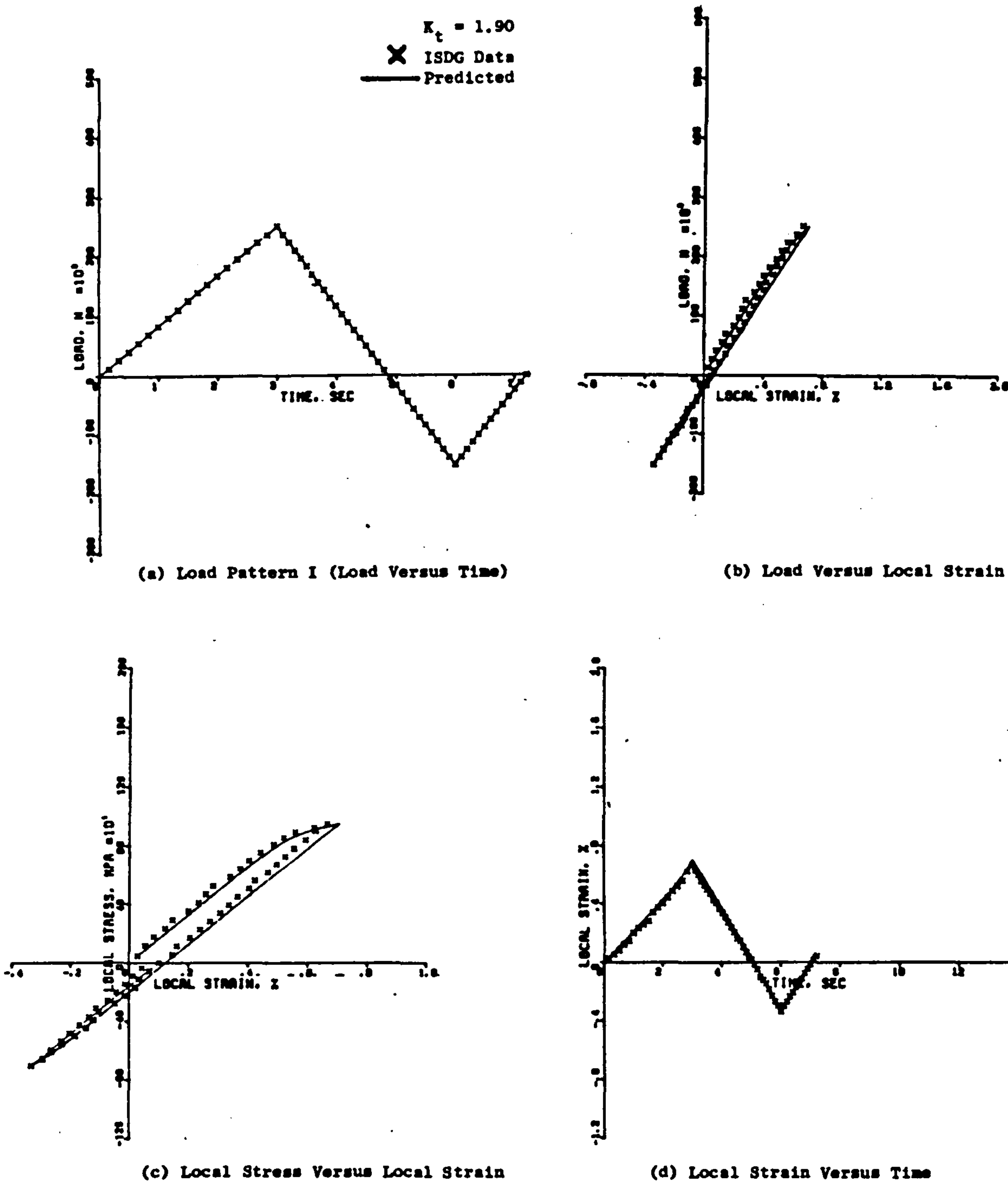
Schematic of the ISDG.



Load Spectra.



Schematic Illustration of the Application of Neuber's Rule to Cyclic Loading.



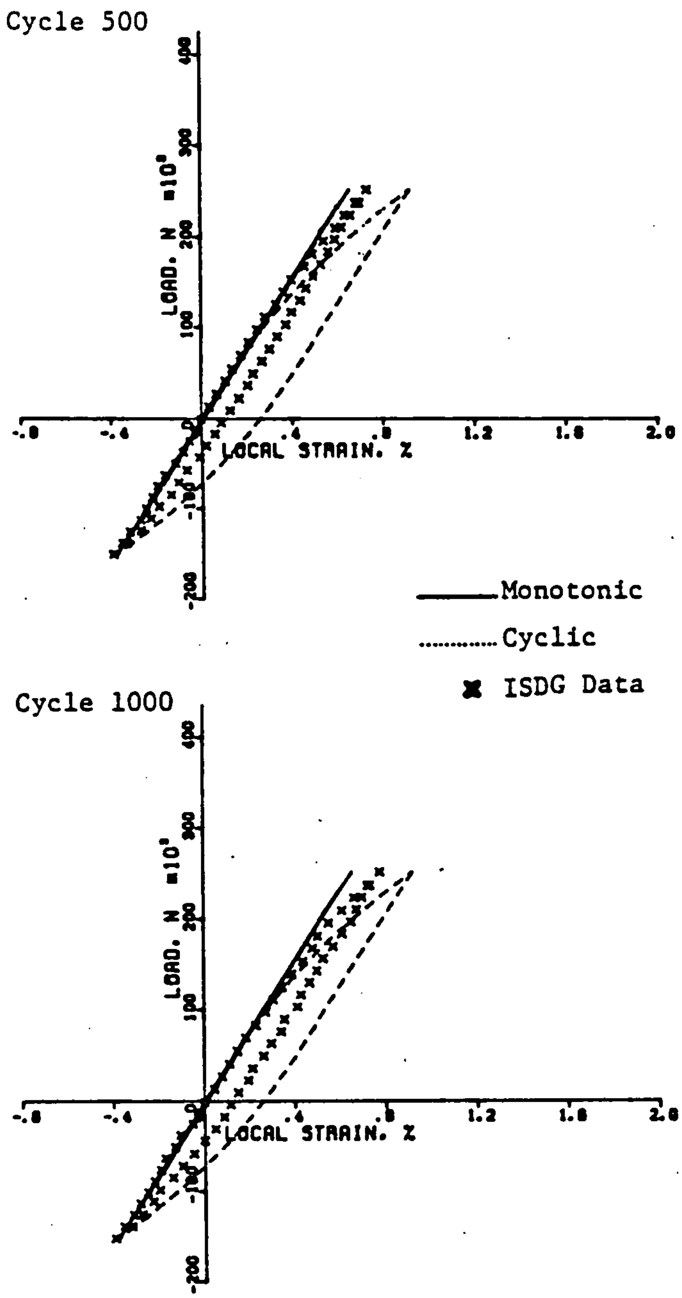
(a) Load Pattern I (Load Versus Time)

(b) Load Versus Local Strain

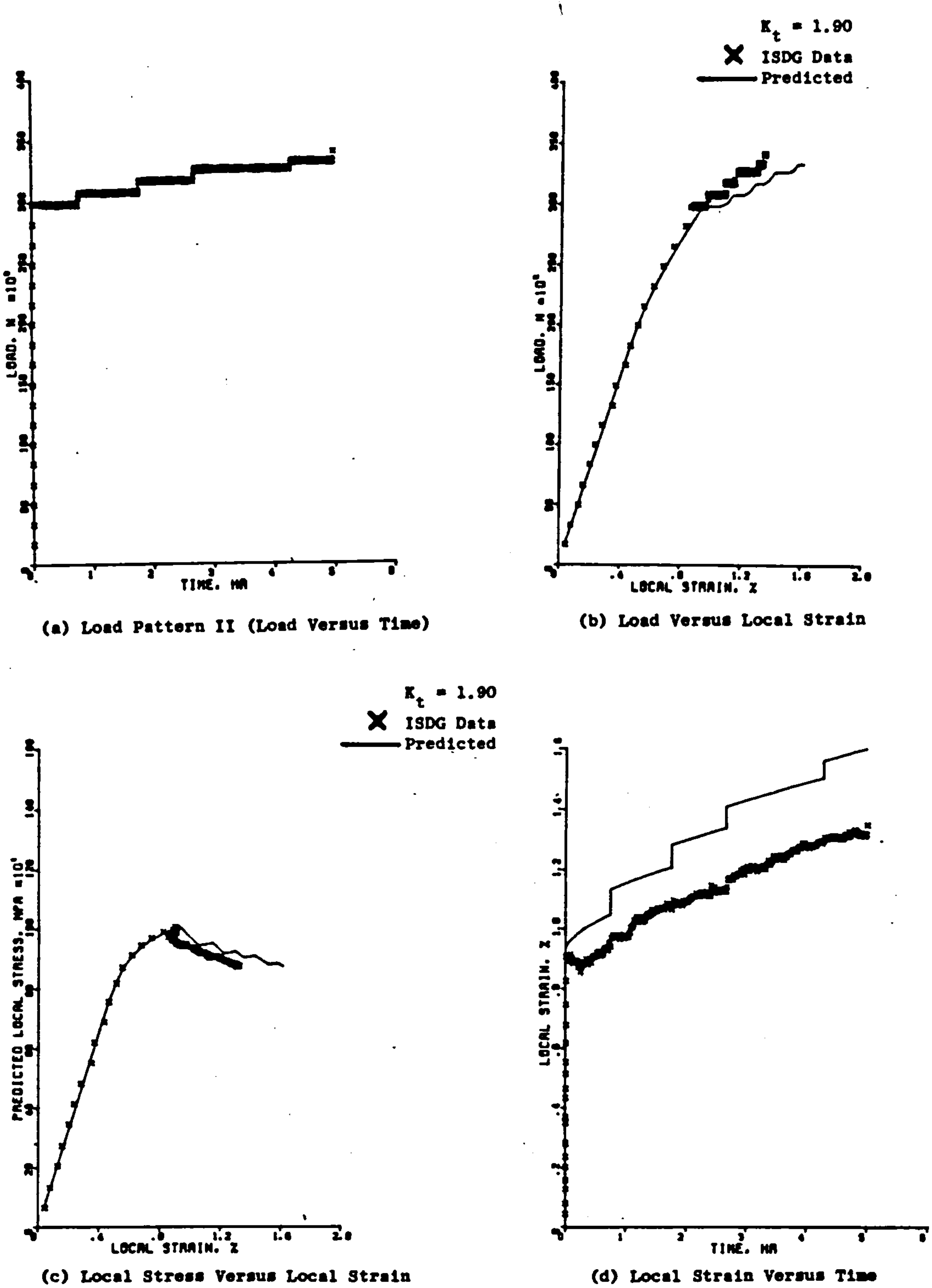
(c) Local Stress Versus Local Strain

(d) Local Strain Versus Time

Comparison of Neuber Predicted and ISDG Measured First Cycle Stress-Strain Behavior for Inconel 718 Notched Bar at 649° C for Load Pattern I (Continuous Cycle), Test 6.



Comparison of Neuber Predictions and ISDG Measured Intermediate Cycle Notch Root Strain Behavior of Test 6 (Continuous Cycle).



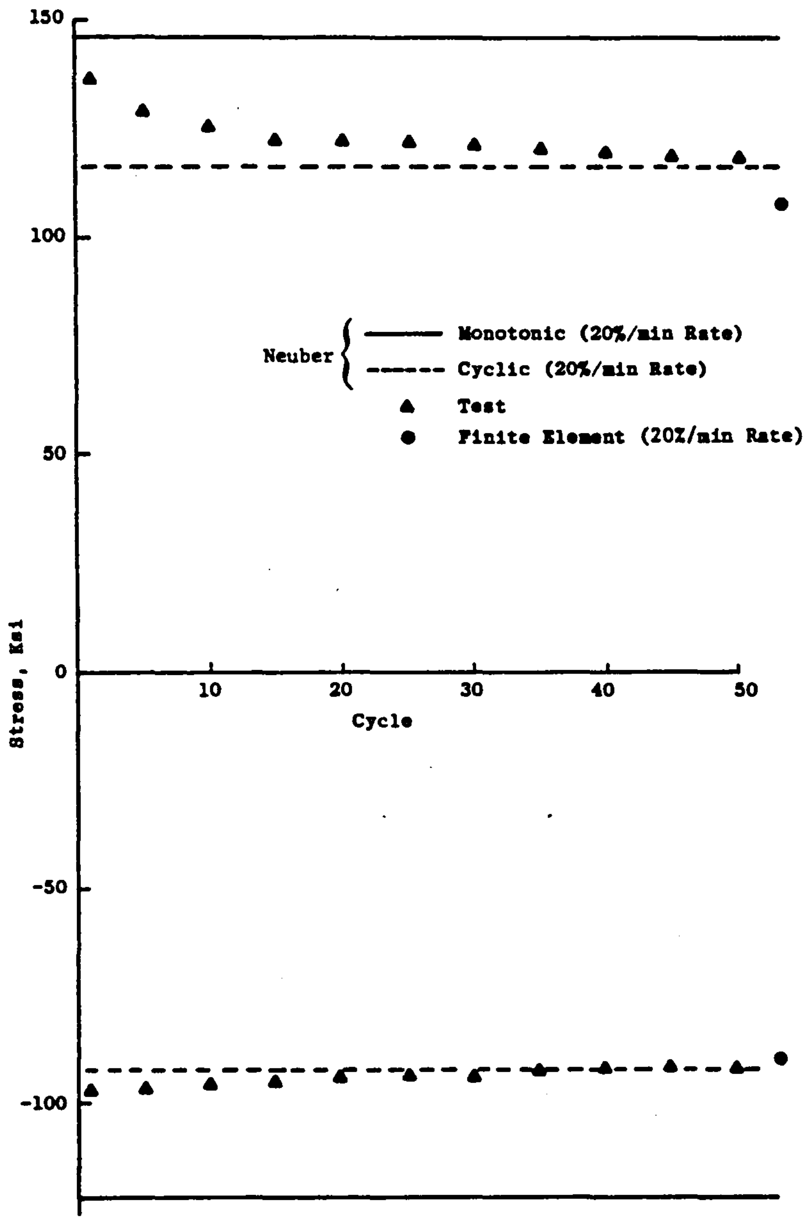
(a) Load Pattern II (Load Versus Time)

(b) Load Versus Local Strain

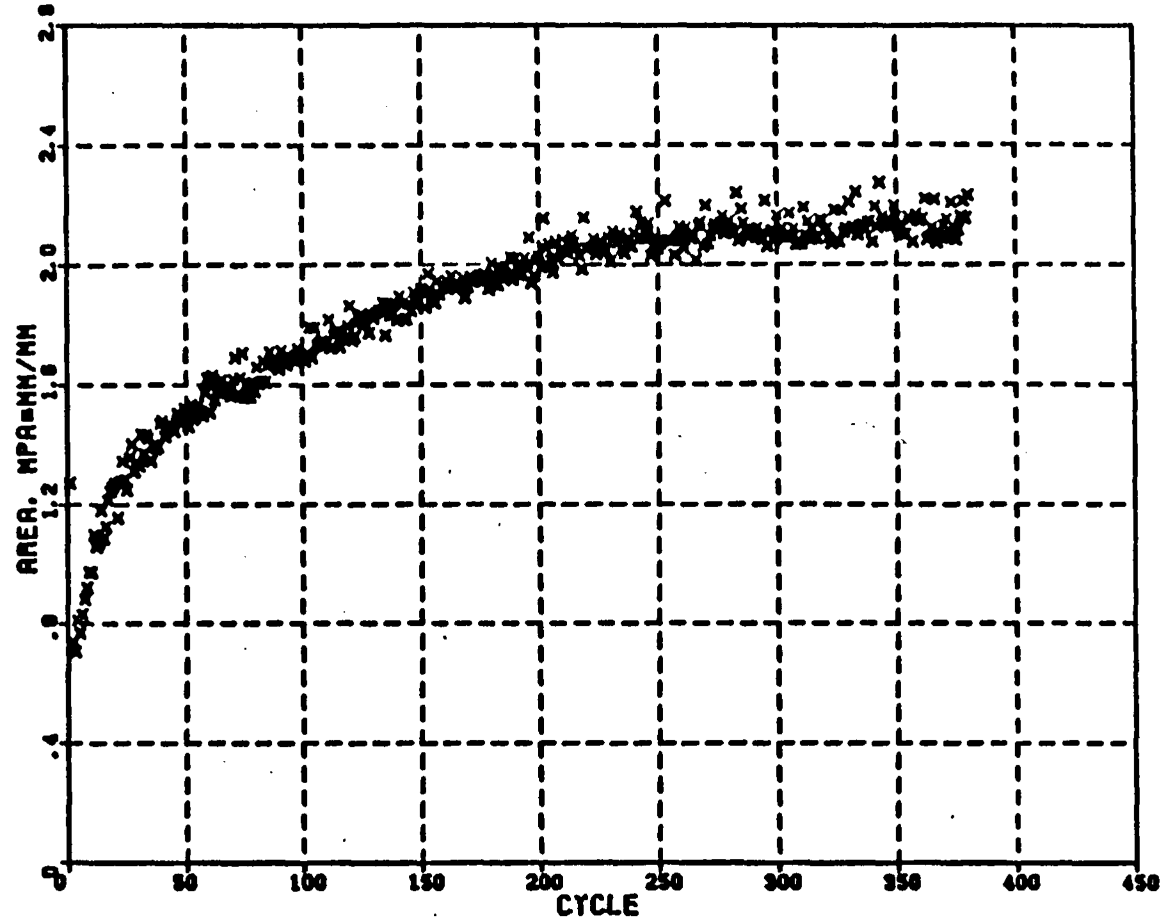
(c) Local Stress Versus Local Strain

(d) Local Strain Versus Time

Comparison of Neuber Predicted and ISDG Measured First Cycle Stress-Strain Behavior for Inconel 718 Notched Bar at 649° C for Load Pattern II (Creep Test), Test 12.



Comparison of Analytical Predictions of Notch Root Stress and the Result of a Strain-Controlled Smooth Bar Test Using the Strain Pattern Recorded in Test No. 6.



Variation of Hysteresis Loop Area in the Cycle History
of Test 10.

Conclusions

- ISDG System Accuracy of ± 3% *or* ± 150 Microstrain.

- When Local Notch Strain Rate Influences were Included, Neuber Provided Excellent Correlation for the Monotonic (Load Up) Case.

- Stabilized Cyclic Behavior was not Well Predicted by Neuber. Finite Element Results Improved Correlation but also in Error.

- Maximum Monotonic and Cyclic Stress and Minimum Cyclic Stress Levels were Well Predicted. Initial Off Loading (Monotonic) Minimum Stress Was Not.

- Computerized Cycle by Cycle Hysteresis Loop Parameter Assessment Useful Tool. The Elastic Slope (Modulus) was Indicator of Notch Root Cracking.