MATERIAL CHARACTERIZATION OF A 1% NICKEL STEEL; MONOTONIC AND CYCLIC STRESS-STRAIN BEHAVIOR AND STRAIN-LIFE RESPONSE

by

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Abstract

Monotonic and cyclic stress-strain behavior and strain-life resistance of a 1% nickel steel at 188HB are reported. The material cyclically hardens and exhibits a behavior comparable to most high strength low alloy steels of similar hardness. Periodic incremental overstraining reduces life by approximately an order of magnitude.

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A Report of the
FRACTURE CONTROL PROGRAM

College of Engineering, University of Illinois
Urbana, Illinois 61801
September, 1977
FOREWORD

This is the fifth in a series of reports on materials of interest to sponsors of the Fracture Control Program. A 1% nickel steel at 188HB supplied by Clark Equipment Company, which will be referred to herein as IN-787*, is characterized in this report. As in previous reports, the format includes reduced material characterization sheets as well as original laboratory records. However, all data acquisition and reduction were accomplished via a computerized material test facility with a ±10 metric ton load capacity. Only selected records are presented.

PROCEDURE

Specimens of the design shown in Fig. 1 were supplied ready for testing. Specimens used for the constant strain cycling were not precycled prior to testing.

RESULTS

Stress-Strain Behavior

On the data sheet for material characterization are listed results from the monotonic stress-strain tests. Comparison of these results from the 188HB samples of IN-787 to results of SAE 950XK at 183HB given in FCP Report No. 25 illustrate a marked similarity with the exception of the true toughness. As a general trend, a steel having a greater true toughness would exhibit superior impact resistance and notch fatigue resistance.

*IN-787 is a trade name of International Nickel Corporation.
The cyclic stress-strain behavior of IN-787 is also shown on the data sheet. Cyclic strain hardening is apparent at all strain levels on the companion specimen and incremental step strain curves. The precycled tension test shows slight cyclic softening at all strain levels. To avoid confusion, it is recommended that the precycled tension test be ignored and the cyclic stress-strain curve from companion specimen data be employed to interpret cyclic properties.

Strain-Life Resistance

Results of the constant strain amplitude tests are given near the back of the report. Three specimens each were tested at four different strain levels to ascertain any scatter in the life results. Three additional specimens were periodically overstrained by 1% every $10^5$ reversals. Comparison of these overstrained results to those tested at a comparable constant amplitude of 0.0018 shows a decrease in life of approximately an order of magnitude.

Conclusions

From monotonic and cyclic stress-strain results, it is concluded that IN-787 is similar to most high strength low alloy steels of comparable hardness and cleanliness. Because of greater true toughness, IN-787 may exhibit superior impact and notched fatigue resistance but further testing would be necessary to support this assertion.

Attention is called to the order of magnitude decrease in life due to periodic overstraining since this is a common occurrence in ground vehicle components.
### DATA SHEET FOR MATERIAL CHARACTERIZATION

**Material:** In-787†  
**Condition:** Hot rolled

**Monotonic Properties:**
- Modulus of Elasticity, E: \(29.8 \times 10^3\) ksi
- Yield Strength, 0.2% \(S_y\): 65.7 ksi
- Ultimate Strength, \(S_u\): 90.2
- Red. in Area, \(\%\) RA: 76.4
- True Fracture Strength, \(\sigma_f\): 178.0 ksi
- True Fracture Ductility, \(\epsilon_f\): 1.45
- Strain Hardening Exponent, \(n\): 0.14
- Strength Coefficient, \(K\): 138.7 ksi
- True Toughness, \(U_p\): 232.0 in-lb/in²

**Cyclic Properties:**
- Yield Strength, 0.2% \(S_y'\): 72* ksi
- Strain Hardening Exponent, \(n'\): 0.13*
- Strength Coefficient, \(K'\): 163* ksi
- Fatigue Strength Coefficient, \(\sigma_f'\): 191** ksi
- Fatigue Ductility Coefficient, \(\epsilon_f'\): 1.4**
- Fatigue Strength Exponent, \(b\): -0.10
- Fatigue Ductility Exponent, \(c\): -0.68
- Transition Fatigue Life, \(2N_t\): \(10^4\) rev

*From companion specimen results.  
**Intercept values of best-fit line to companion specimen results.

**Composition:**
- w/o C = 0.04  
- w/o Si = 0.25  
- w/o P = 0.007  
- w/o S = 0.016  
- w/o Mn = 0.51  
- w/o Cr = 0.67  
- w/o Mo = 0.25  
- w/o Cu = ---  
- w/o Ni = 1.02  
- w/o Va = ---  
- w/o Al = 0.32  
- w/o B = 0.3013

†Trade name of International Nickel Corporation.

Comments:
1. Specimens machined from material parallel to rolling direction.  
2. Periodic incremental overstraining every \(10^5\) rev by \(\pm 1\%\) of samples tested at \(\pm 0.0018\) strain, reduced life by approximately an order of magnitude when compared to samples tested at the same strain amplitude without overstraining (i.e. \(2N_t = 8.6 \times 10^5\) rev compared to \(10^7\) rev runouts).

FRACTURE CONTROL PROGRAM  
UNIVERSITY OF ILLINOIS
FIG. 1 - SPECIMEN DESIGN
(All dimensions in inches)
MONOTONIC TENSION TESTS
MONOTONIC TENSION TEST OF NICURGE SPECIMEN # 04
STRAIN RATE = 5.00000E-04 18-NOV-76 RONZ

TEST IN STRAIN CONTROL
MONOTONIC TENSION TEST OF MICUAGE SPECIMEN # 04

STRAIN RATE = 5.00000E-04 18-NOV-76  RUNZ

TEST IN STROKE CONTROL
MONOTONIC TENSION TEST OF NICUAGE SPECIMEN # 04
STRAIN RATE = 5 00000E-04 16-NOV-76 P092

INPUT LOWER STRESS FOR MODULUS FIT? 10
INPUT UPPER STRESS FOR MODULUS FIT? 45

ELASTIC MODULUS = 30072.5 KSI (10 POINTS)
IS THIS OK? Y

---

![Stress-Strain Curve Graph](image)

- L
- U
MONOTONIC TENSION TEST OF NICUAGE SPECIMEN # 04
STRAIN RATE = 5.00000E-04 13-NOV-76 RONZ

PLACE CURSORS ON FINAL FRACTURE POINT

IS THIS OK? Y

-FRACTURE STRESS = 50.3371 KSI
MONOTONIC TENSION TEST OF NICOUGE SPECIMEN # 04
STRAIN RATE = 5.0000 *E-04 18-NOV-76 RUN2

INPUT LOWER PL. STRAIN FOR N/K FIT? .02
INPUT UPPER PL. STRAIN FOR N/K FIT? .08

N = .140595  K = 140.157 KSI

IS THIS OK? Y

[Graph showing stress-strain relationship]
MONOTONIC TENSION TEST OF NICEUAGUE SPECIMEN # 04
STRAIN RATE = 5.00000E-04 18-NOV-76 RONZ

SUMMARY OF MONOTONIC TENSION PROPERTIES

ELASTIC MODULUS = 30072.5 KSI

0.002 YIELD STRESS @ STRAIN = 66.3124 KSI

ULTIMATE STRENGTH @ STRAIN = 90.7909 KSI

FRACUTURE STRESS = 50.3371 KSI

INITIAL SPECIMEN AREA = .0486655 SQ IN

FINAL SPECIMEN AREA = 9.5633E-03 SQ IN

% REDUCTION IN AREA = 80.4842 %

TRUE FRACUTURE STRAIN = 1.63395

TRUE FRACUTURE STRENGTH CORRECTED TO = 257.93 KSI

STRAIN HARDENING EXPONENT = .148595

STRENGTH COEFFICIENT = 140.157 KSI
### MONOTONIC TENSION TEST OF NUCAGE SPECIMEN # 15

**Strain Rate = 5.00000E-04 16-NOV-76**  

**Rohn**

**SUMMARY OF MONOTONIC TENSION PROPERTIES**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
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<td>72.3433</td>
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<td>True Fracture Strain</td>
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<td>True Fracture Strength Corrected to</td>
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<td>Strain Hardening Exponent</td>
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<td>Strength Coefficient</td>
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INCREMENTAL STEEP-STRAIN TESTS
INCREMENTAL STEP TEST OF SPECIMEN # 01 OF NICRAVE PONZ
23-NOV-75

STRAIN RATE= 5 0000000E-03 MAX STRAIN= .015
ELASTIC MODULUS= 29879.5 KSI BLOCK .5
INCREMENTAL STEP TEST OF SPECIMEN # 01 OF NICUA GE
RONZ  23-NOV-76

STRAIN RATE= 5.00000E-03 MAX STRAIN= .015

ELASTIC MODULUS= 29879.5 KSI

BLOCK  8

N' = .0996847
K' = 123.506 KSI
INCREMENTAL STEP TEST OF SPECIMEN # 01 OF NICOUGE
RONZ 23-NOV-76

STRAIN RATE= 5.00000E-03 MAX STRAIN= .015
ELASTIC MODULUS= 29879.5 KSI

BLOK &

**** STRESS IN KSI UNITS

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<tr>
<th>CYC</th>
<th>STRAIN</th>
<th>AMPLITUDE</th>
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<th>MEANS</th>
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<td>79.9562</td>
<td>1.0198E-04</td>
<td>1.1724E-04</td>
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</table>
PRECYCLED TENSION TEST
INCREMENTAL STEP TEST OF SPECIMEN # 02 OF NICOUGE
ROHZ  19-NOV-76

STRAIN RATE= 5.00000E-03 MAX STRAIN= .01
ELASTIC MODULUS= 38134.1 KSI
BLOCK .5
INCREMENTAL STEP TEST OF SPECIMEN # 02 OF NICUAG
FONZ  13-NOV-76

STRAIN RATE= 5.00000E-03   MAX STRAIN= .01

ELASTIC MODULUS= 30134.1  KSI

BLOCK  16
MONOTONIC TENSION TEST OF PRE-CYCLED SIGUAGE SPECIMEN # 02

TEST IN STRAIN CONTROL

NOTE: COMPUTER MALFUNCTION
AFTER BLOCK 16 -
SPECIMEN PULLED IN TENSION AFTER PRECYCLING.
### MONOTONIC TENSION TEST OF PRE-CYCLED NICUAGUE SPECIMEN # 02

**STRAIN RATE = 0.000000E+00 19-NOV-76 RUNZ**

**SUMMARY OF MONOTONIC TENSION PROPERTIES**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Elastic Modulus</td>
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<td>0.002 Yield Stress @ Strain</td>
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<td>Ultimate Strength @ Strain</td>
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<td>Fracture Stress</td>
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<td>KSI</td>
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<td>Initial Specimen Area</td>
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<td>Final Specimen Area</td>
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<td>% Reduction in Area</td>
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<td>Strength Coefficient</td>
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STRESS-STRAIN HYSTERESIS LOOPS STRESS-LIFE RESPONSE AND PLASTIC STRAIN-LIFE RESPONSE FROM CONTROLLED STRAIN FATIGUE TESTS
IN-787

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Strain Amplitude $\frac{\Delta \varepsilon}{2}$</th>
<th>Reverse to Failure $2N_f$</th>
<th>Plastic Strain Amplitude $\frac{\Delta \varepsilon_p}{2}$</th>
<th>Stabilized Stress Amplitude $\frac{\Delta \sigma}{2}$, ksi</th>
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<td>08</td>
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<td>U</td>
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<td>82,158</td>
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<td>16</td>
<td>0.0018</td>
<td>&gt;10$^7$</td>
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<tr>
<td>18</td>
<td>0.0018</td>
<td>&gt;10$^7$</td>
<td>runouts</td>
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<tr>
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<td>&gt;10$^7$</td>
<td></td>
<td>50.0</td>
</tr>
<tr>
<td>21**</td>
<td>0.0018</td>
<td>800,500</td>
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<td>24**</td>
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<td>22**</td>
<td>0.0018</td>
<td>883,104</td>
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</table>

*Measured at 50% of life to failure.

**Specimens overstrained every $10^5$ reversals to a strain of $\pm 1\%$ which was incrementally decreased to 0-0 in 40 reversals.
FATIGUE TEST OF SPECIMEN #02 OF NIOUAGE
RONZ 6-DEC-76

STRAIN RATE = .02 STRAIN LIMIT = .01

***** STRESS IN KSI UNITS
***** LOOPS RECORDED @ 0.1 Hz
FATIGUE TEST OF SPECIMEN #08 OF NICUAGE
ROHZ 6-DEC-76

STRAIN RATE = 0.02 STRAIN LIMIT = 0.01
ELASTIC MODULUS = 23523.4 KSI
**** STRESS IN KSI UNITS

'*' - AMPLITUDES @ 0.1 HZ (LOOPS)
'+' - AMPLITUDES @ THE SPECIFIED STRAIN RATE
'X' - TENSILE PEAKS (FAILURE)
FATIGUE TEST OF SPECIMEN #98 OF NITUPE

E-01  E-02  E-03  E-04  E-05  E-06  E-07
Cycles

E-01  E-02  E-03  E-04  E-05  E-06  E-07
Strain

Elastic modulus = 235 GPa
Strain rate = 0.1 strain limit = 0.1

** Stress in < SI Units

"*" = Amplitudes @ 0.1 Hz (Loops)
"++" = Amplitudes @ Specified Strain Rate
FATIGUE TEST OF SPECIMEN #97 OF NIOUGE
MONZ  07-DEC-76

STRAIN RATE = .02  STRAIN LIMIT = 5.00000E-03

***** STRESS IN KSI UNITS
***** LOOPS RECORDED @ 0.1 HZ

E 0.02  CYCLES 1-8
1.00

STRESS

0.50

0.00

-0.50

-1.00

-2.00 -1.00 0.00 1.00 2.00
STRAIN  E-02

E 0.02  CYCLE 16
1.00

STRESS

0.50

0.00

-0.50

-1.00

-2.00 -1.00 0.00 1.00 2.00
STRAIN  E-02

E 0.02  CYCLE 32
1.00

STRESS

0.50

0.00

-0.50

-1.00

-2.00 -1.00 0.00 1.00 2.00
STRAIN  E-02

E 0.02  CYCLE 64
1.00

STRESS

0.50

0.00

-0.50

-1.00

-2.00 -1.00 0.00 1.00 2.00
STRAIN  E-02
FATIGUE TEST OF SPECIMEN #07 OF NICJAGE
RONZ 37-DEC-76

STRAIN RATE = 0.2 STRAIN LIMIT = 5.00000E-03
ELASTIC MODULUS = 30297.7 KSI
***** STRESS IN KSI UNITS

'*' - AMPLITUDES @ 0.1 HZ (LOOPS)
'+ ' - AMPLITUDES @ THE SPECIFIED STRAIN RATE
'X' - TEAYSILE PEAKS (FAILURE)
FATIGUE TEST OF SPECIMEN #07 OF NIDUAGE
RONZ 07-DEC-76

STRAIN RATE = 02 STRAIN LIMIT = 5.0000E-03
ELASTIC MODULUS = 30297.7 KSI
***** STRESS IN KSI UNITS

'*'- AMPLITUDES @ 0.1 HZ (LOOPS)
'+'- AMPLITUDES @ SPECIFIED STRAIN RATE

Diagram showing data points and cycles.
FATIGUE TEST OF SPECIMEN #12 OF NICONAGE
RONZ 18-JAN-77

STRAIN RATE = .05 STRAIN LIMIT = 3.000E-03

***** STRESS IN KSI UNITS
***** LOOPS RECORDED @ 0.1 Hz

![Graphs showing stress-strain cycles for cycle 1-8, cycle 16, cycle 32, and cycle 64.](image-url)
FATIGUE TEST OF SPECIMEN #12 OF NICURGE
FONZ       18-JAN-77

STRAIN RATE = .05 STRAIN LIMIT = 3.00000E-03
ELASTIC MODULUS = 29772.8 KSI
**** STRESS IN KSI UNITS

'*' - AMPLITUDES @ 0.1 HZ (LOOPS)
'*' - AMPLITUDES @ THE SPECIFIED STRAIN RATE
'*' - TENSILE PEAKS (FAILURE)
FATIGUE TEST OF SPECIMEN #12 OF NIOUAGE
RONZ  18-JAN-77

STRAIN RATE = .05  STRAIN LIMIT = 3.000000E-03
ELASTIC MODULUS = 29772.8  KSI
***** STRESS IN KSI UNITS

'.'- AMPLITUDES @ 0.1 HZ (LOOPS)
'*'- AMPLITUDES @ SPECIFIED STRAIN RATE

[Graph showing strain versus cycles with markers and annotations]

E-01  E-02  E-03  E-04  E-05
P  L

E-03
STRAIN
AMPL

E-04
E-05

Cycles 00  01  02  03  04  05  06  07
FATIGUE TEST OF SPECIMEN #23 OF NICOUGE
ROHZ  19-MAR-77

STRAIN RATE = 7 20000E-03 STRAIN LIMIT = 1.60000E-03

**** STRESS IN KSI UNITS
**** LOOPS RECORDED 0 0 1 Hz

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**CYCLES 1-8**

**CYCLE 16**

**CYCLE 32**

**CYCLE 64**
FATIGUE TEST OF SPECIMEN #23 OF NICOUGE
RONZ 19-MAR-77

STRAIN RATE = 7.20000E-03 STRAIN LIMIT = 1.80000E-03
ELASTIC MODULUS = 29098.2 KSI
***** STRESS IN KSI UNITS
***** LOOPS RECORDED @ 0.1 HZ

'*' - AMPLITUDES @ 0.1 HZ (LOOPS)
'+' - AMPLITUDES @ THE SPECIFIED STRAIN RATE
'X' - TENSILE PEAKS (FAILURE)
FATIGUE TEST OF SPECIMEN #23 OF NICUAG
RONZ 19-MAR-77

STRAIN RATE = 7.20030E-03 STRAIN LIMIT = .80000E-03
ELASTIC MODULUS = 29038.2 KSI
**** STRESS IN KSI UNITS
**** LOOPS RECORDED @ 0.1 HZ

'*' - AMPLITUDES @ 0.1 HZ (LOOPS)
'+' - AMPLITUDES @ SPECIFIED STRAIN RATE

Diagram showing cycles vs. strain with plotted data points.