FCP Report No. 25

# MATERIAL CHARACTERIZATION OF SAE 950XK; 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 SAE 950XK at 183HB are reported. The material exhibits a monotonic yield strength of 63 ksi, while the cyclic yield strength is approximately 75 ksi. Periodic incremental overstraining of specimens which did not fail in approximately $10^7$ reversals reduces life by a factor of about 10.

A Report of the
FRACTURE CONTROL PROGRAM

College of Engineering, University of Illinois
Urbana, Illinois 61801
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## ACKNOWLEDGMENTS

Mr. E. C. Sheets and Ms. E. A. Williams generated much of the test results, while Messrs. R. B. Zweigoron and P. Kurath accomplished the data reduction. Mrs. Darlene Mathine typed the manuscript. They are gratefully thanked.

## FOREWORD

This is the fourth in a series of reports of materials of interest to sponsors of the Fracture Control Program. Characterization of an SAE 950XK* at 183HB, supplied by A. O. Smith Corporation, is contained in this report. As in previous reports, the format includes reduced material characterization sheets as well as original laboratory records. However, in order to conserve paper, energy, etc., only selected records are shown.

## PROCEDURE

Specimens removed from 0.25 in. plate of the design shown in Fig. 1 were supplied ready for testing. All monotonic and cyclic tests were accomplished using a ±20 kip closed loop test machine. 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 the results from the monotonic stress-strain tests. Comparison of these results for the 183HB samples of SAE 950XK to similar results for SAE 950X at 150HB (1), given in Table 1, illustrate the following:

(1) There are differences in the yield, ultimate, and true fracture strengths of these steels, but they are in keeping with the hardness variation.

(2) Ductilities are similar which is not anticipated from the hardness difference.

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*High strength, low alloy steel

[1]Watson, P and Topper, T. H., "An Evaluation of the Fatigue Performance of Automotive Steels," SAE Preprint #710597, Society of Automotive Engineers, 1971.

It is felt that the higher ductility in the SAE 950XK is due to full-killing of the ingot while the SAE 950X is semi-killed. Being fully killed, the SAE 950XK would have fewer and smaller voids and inclusions which have been shown to drastically affect ductility of steels.

The cyclic stress-strain behavior of the SAE 950XK is also shown on the data sheet. Cyclic strain hardening is apparent at all strain levels. In comparison, the SAE 950X, shown in Fig. 2, exhibits mixed behavior (i.e., softening at strains less than approximately 0.004 and hardening at higher strain amplitudes).

## Strain-Life Resistance

At the request of the sponsor supplying the SAE 950XK, the samples were not overstrain precycled prior to constant strain amplitude testing. The results of five constant strain amplitude tests are shown at the back of the report. Two additional specimens (Nos. 6 and 7) were periodically overstrained by 1% every $10^5$ cycles. In comparison to the non-overstrained results, a decrease in life of approximately an order of magnitude is noted.

## Conclusions

From monotonic and cyclic stress-strain results, it is concluded that the SAE 950XK, being a fully killed steel, is apparently superior to SAE 950X. It should be noted that no statistical scatter is included in these limited data and, in fact, the scatter in mechanical properties may overlap. Improved short life fatigue resistance of the SAE 950XK is apparent due to its higher ductility. Particular attention is called to the order of magnitude decrease in life from periodic overstraining, since this is a common occurrence in many ground vehicle components.

TABLE 1

MECHANICAL PROPERTIES OF SAE 950X AT 150HB

Monotonic Properties:

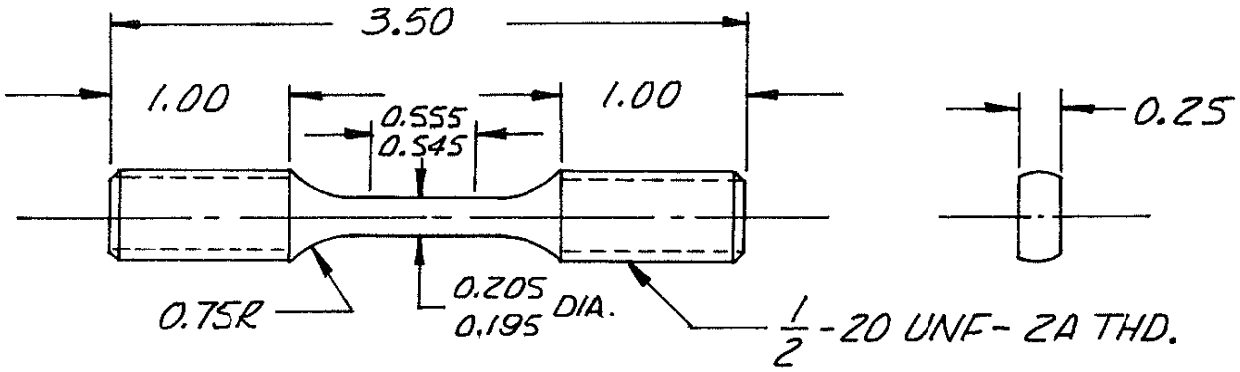
| | |
|---|---|
| Modulus of Elasticity, E | $30 \times 10^3$ ksi |
| Yield Strength, 0.2% $S_y$ | 50 ksi |
| Ultimate Strength, $S_u$ | 64 ksi |
| Red. in Area, %RA | 65.0 |
| True Fracture Strength, $\sigma_f$ | 109 ksi |
| True Fracture Ductility, $\varepsilon_f$ | 1.06 |
| Strain Hardening Exponent, n | 0.16 |
| Strength Coefficient, K | 98 ksi |
| True Toughness, $U_p$ | 100 ksi |

Cyclic Properties:

| | |
|---|---|
| Yield Strength, 0.2% $S_y'$ | 49 ksi |
| Strain Hardening Exponent, n' | 0.134 |
| Strength Coefficient, K' | 115 ksi |
| Fatigue Strength Coefficient, $\sigma_f'$ | 91 ksi |
| Fatigue Ductility Coefficient, $\varepsilon_f'$ | 0.35 |
| Fatigue Strength Exponent, b | -0.075 |
| Fatigue Ductility Exponent, c | -0.54 |
| Transition Fatigue Life, $2N_t$ | $2.6 \times 10^4$ rev |

Chemistry w/o

| C | Mn | P | S | Si | Cu | Ni | Cr | Al | Mo | Cb |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.12 | 0.65 | 0.006 | 0.023 | 0.046 | 0.093 | 0.05 | 0.035 | 0.003 | 0.013 | 0.03 |




DIMS. IN INCHES

FIGURE 1 – SPECIMEN DESIGN
(1/4 INCH PLATE)

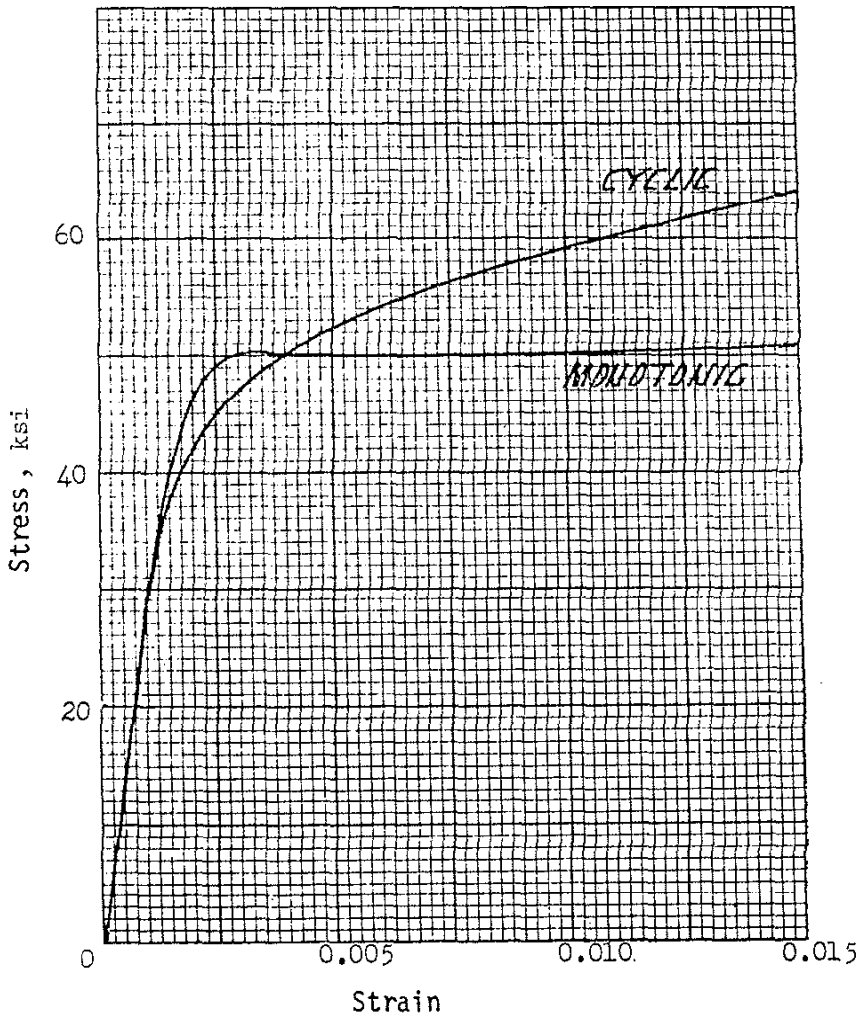



FIGURE 2 - MONOTONIC AND CYCLIC STRESS-STRAIN CURVES FOR SAE 950X @ 150 HB

# MATERIAL CHARACTERIZATION SHEETS

# DATA SHEET FOR MATERIAL CHARACTERIZATION

Material: SAE 950XK

Condition: as received

Matrix Hardness: 183 BHN

Converted from: Rockwell (B-Scale)

## Monotonic Properties:

| | |
|---|---|
| Modulus of Elasticity, E | $31.5 \times 10^3$ ksi |
| Yield Strength, 0.2% $S_y$ | 63.0 ksi |
| Ultimate Strength, $S_u$ | 82.0 ksi |
| Red. in Area, % RA | 67.7% |
| True Fracture Strength, $\sigma_f$ | 207.8 ksi<br>corrected to 174.5 ksi |
| True Fracture Ductility, $\epsilon_f$ | 1.13 |
| Strain Hardening Exponent, n | 0.156 |
| Strength Coefficient, K | 146.4 ksi |
| True Toughness, $U_p$ | 170.9 ksi |
| Poisson's Ratio | --- |

All monotonic values from average of two tests.

## Cyclic Properties:

| | |
|---|---|
| Yield Strength, 0.2% $S_y'$ | 73 ksi$^+$/77* ksi |
| Strain Hardening Exponent, n' | 0.11$^+$/0.12* |
| Strength Coefficient, K' | 141.0$^+$ ksi 156.0* ksi |
| Fatigue Strength Coefficient, $\sigma_f'$ | 162.3** ksi |
| Fatigue Ductility Coefficient, $\epsilon_f'$ | 0.48** |
| Fatigue Strength Exponent, b | -0.088** |
| Fatigue Ductility Exponent, c | -0.53** |
| Transition Fatigue Life, $2N_t$ | 26,580 rev |

\+ - from LCF data
* - from incremental data

## Composition:

| | | | |
|---|---|---|---|
| w/o C | = 0.09 | w/o Mo | = |
| w/o Si | = 0.016 | w/o Cu | = 0.042 |
| w/o P | = 0.009 | w/o Ni | = 0.04 |
| w/o S | = 0.013 | w/o Va | = 0.009 |
| w/o Mn | = 0.46 | w/o Al | = 0.042 |
| w/o Cr | = 0.016 | w/o B | = |
| | | w/o Ti | = 0.14 |

Grain Size:

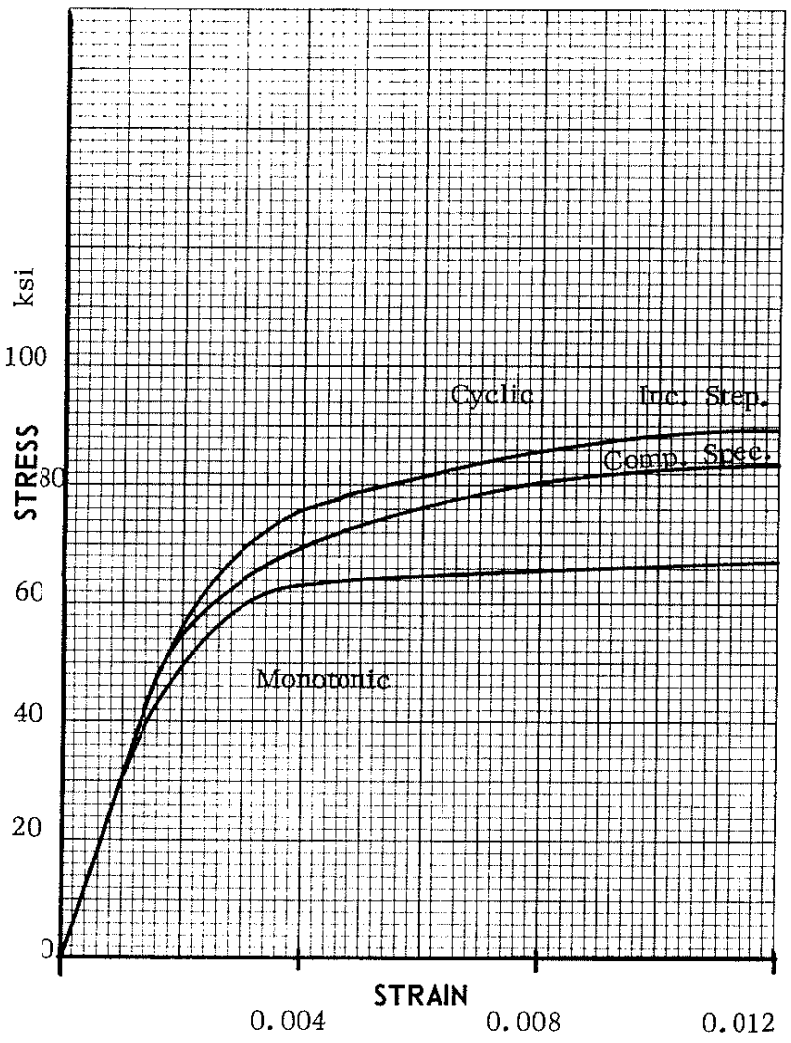
Eutectic Cell Size (Cast irons):

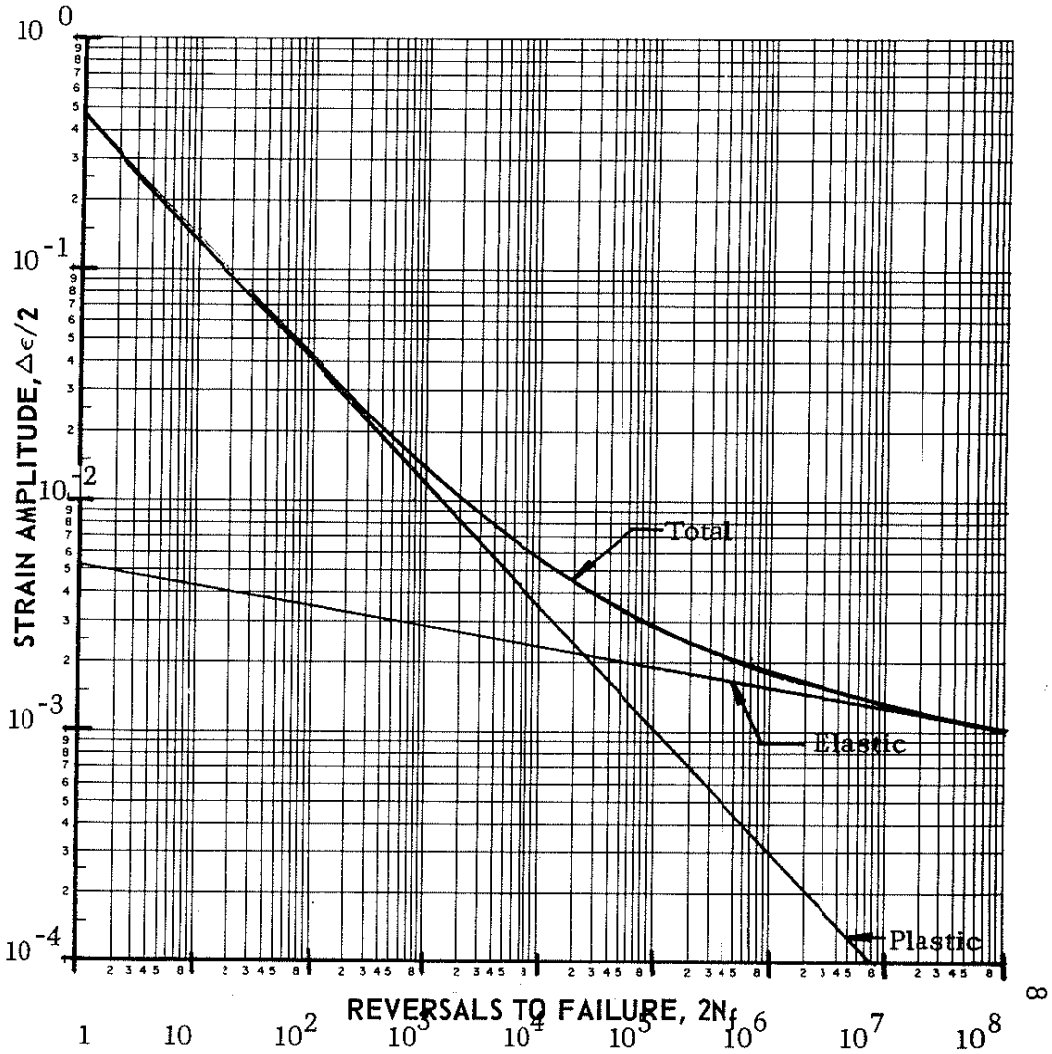
Comments: Periodic overstraining of a specimen run at a constant strain amplitude of 0.0014 results in failure at $1.5 \times 10^6$ reversals whereas runout occurs at a constant amplitude. Similar overstraining of a specimen run at a constant strain amplitude of 0.0017 results in failure at $7 \times 10^5$ reversals whereas a specimen run without overstraining at the same strain amplitude results in failure at $5 \times 10^6$ reversals.

**$\sigma_f'$ & $\epsilon_f'$ are intercept values for the elastic strain-life line. As with the values of b & c, $\sigma_f'$ & $\epsilon_f'$ were determined from least square fits of data from five strain controlled fatigue tests (including one runout) and the true fracture strength and ductility from the monotonic results.

**Material:** SAE 950 XK **Hardness:** 183 BHN

**Condition:** as received




FRACTURE CONTROL PROGRAM
UNIVERSITY OF ILLINOIS

# MONOTONIC STRESS-STRAIN RESULTS

SUMMARY OF MONOTONIC TENSION PROPERTIES

A O SMITH SAE 950XK

SPECIMEN # 7  8-JUN-76

TRUE FRACTURE STRESS = 225.191 KSI CORRECTED TO 189.161 KSI

TRUE FRACTURE STRAIN = 1.14028

REDUCTION IN AREA = 68.0272 %

N= .158377

K= 150.819

TRUE FRACTURE TOUGHNESS = 186.206 KSI

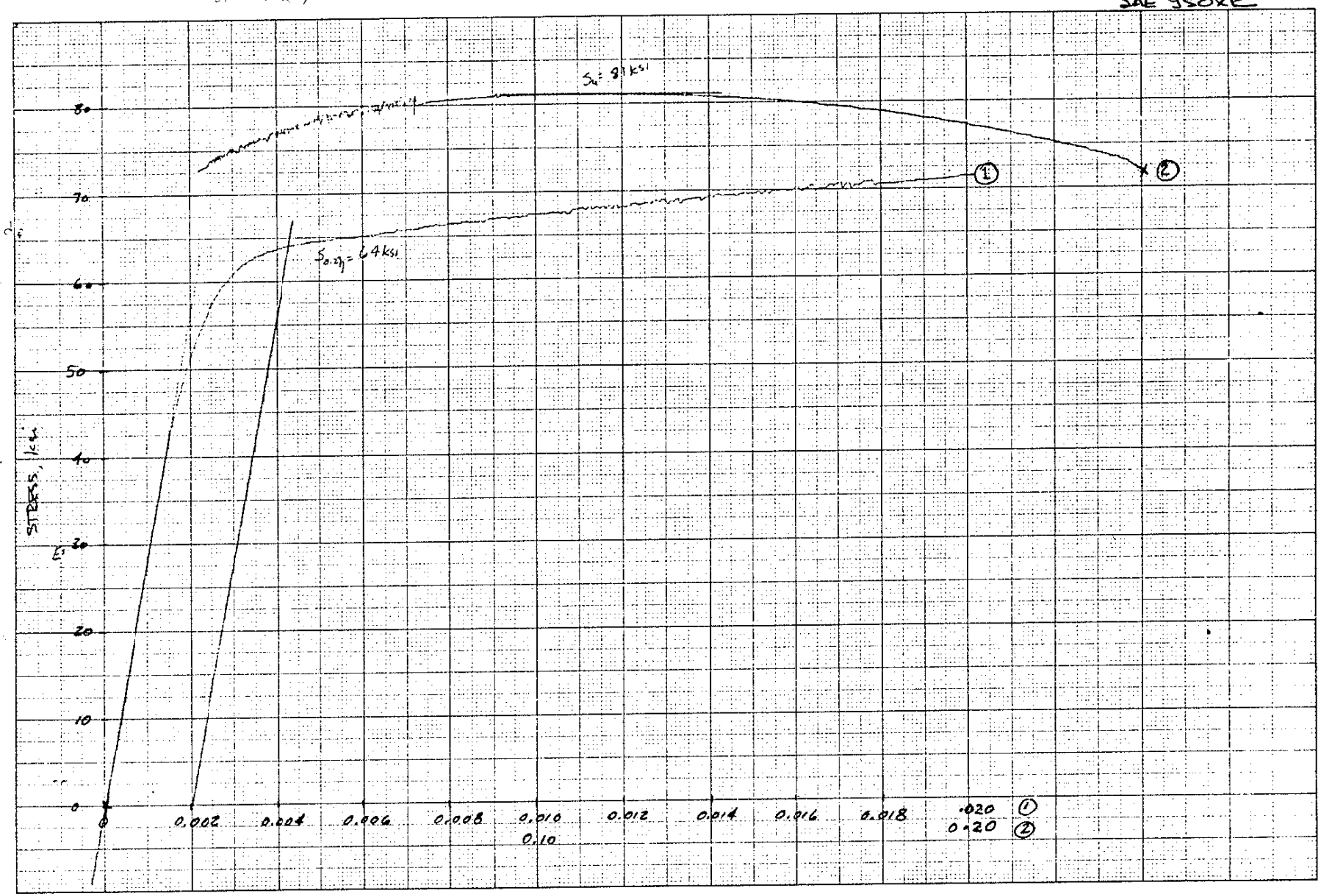
$S_u = 81$ ksi

$S_{.002} = 64$ ksi

$E = 30$ E03

Specimen 7

SAE 950X-T

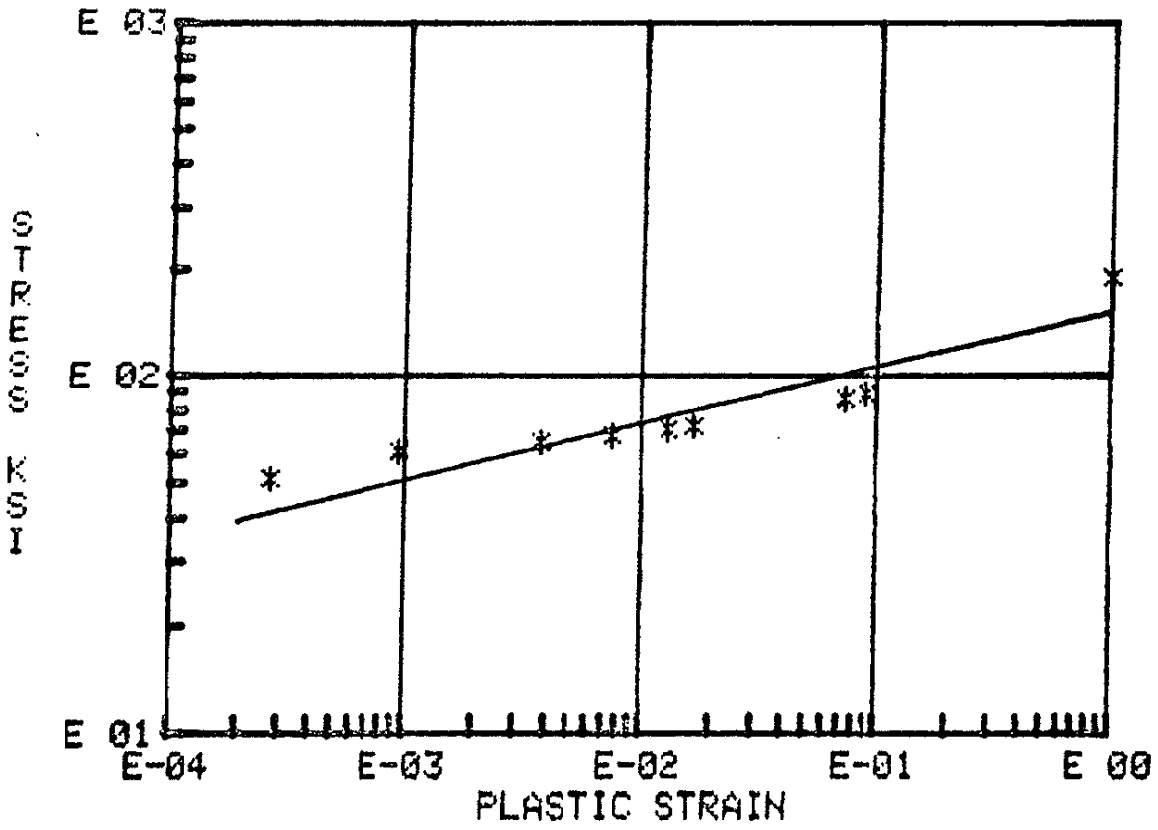


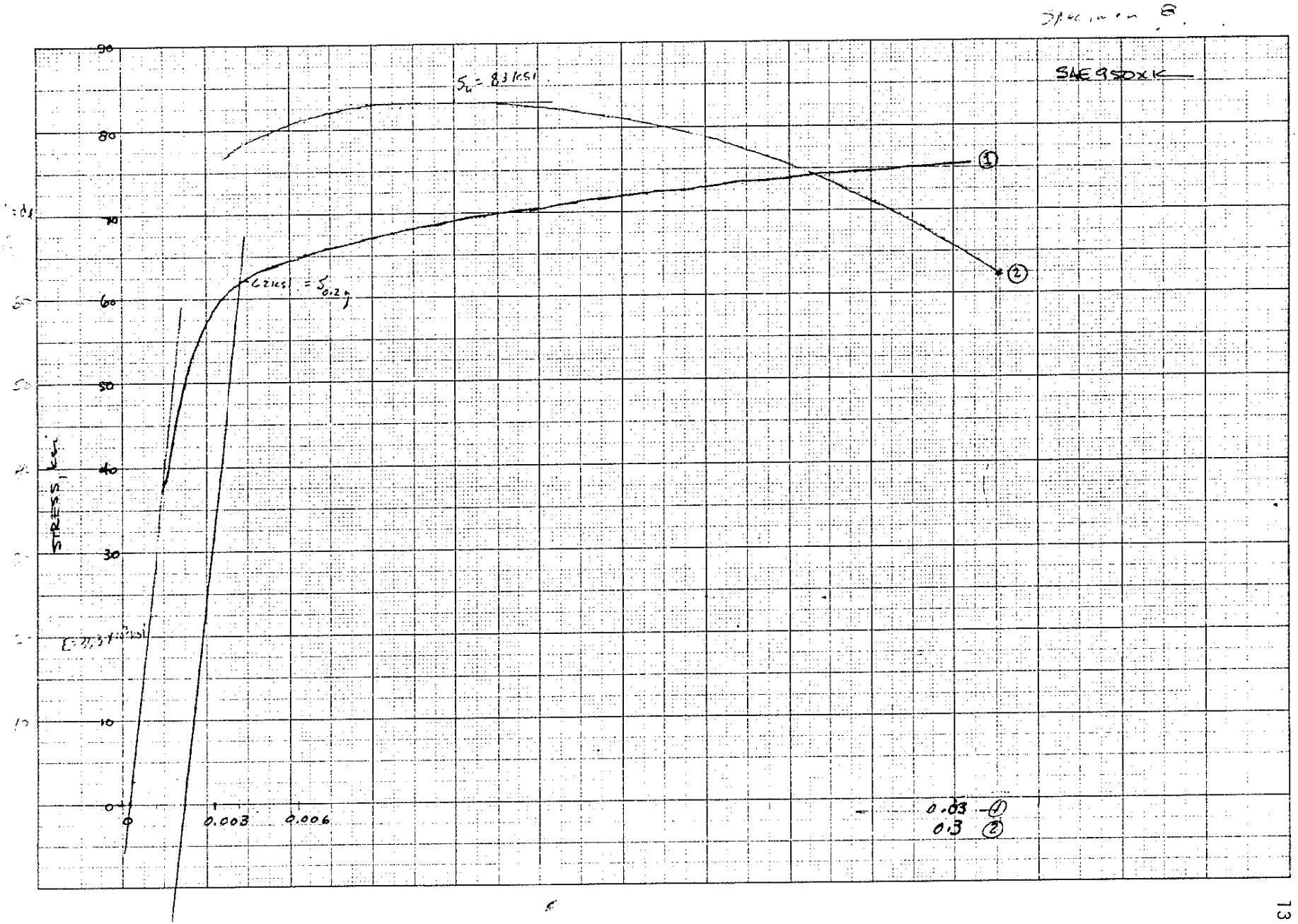
MONOTONIC STRESS-STRAIN

A O SMITH SAE 950XK

SPECIMEN # 7  8-JUN-76

N = .158377  K = 150.819




Specimen B
SAE 950X
$S_u$ = 83 ksi
$S_{0.2\%}$ = 63 ksi
STRESS, ksi
90
80
70
60
50
40
30
20
10
0
0
0.003
0.006
0.03 ①
0.3 ②
①
②

SUMMARY OF MONOTONIC TENSION PROPERTIES

A O SMITH SAE 950XK

SPECIMEN # 8  8-JUN-76

TRUE FRACTURE STRESS = 190.373 KSI CORRECTED TO 159.913 KSI

TRUE FRACTURE STRAIN = 1.12135

REDUCTION IN AREA = 67.4324 %

N= .153647

K= 142.068

TRUE FRACTURE TOUGHNESS = 155.506 KSI

$S_u$ = 93 KSI

$S_{.002}$ = 62 KSI

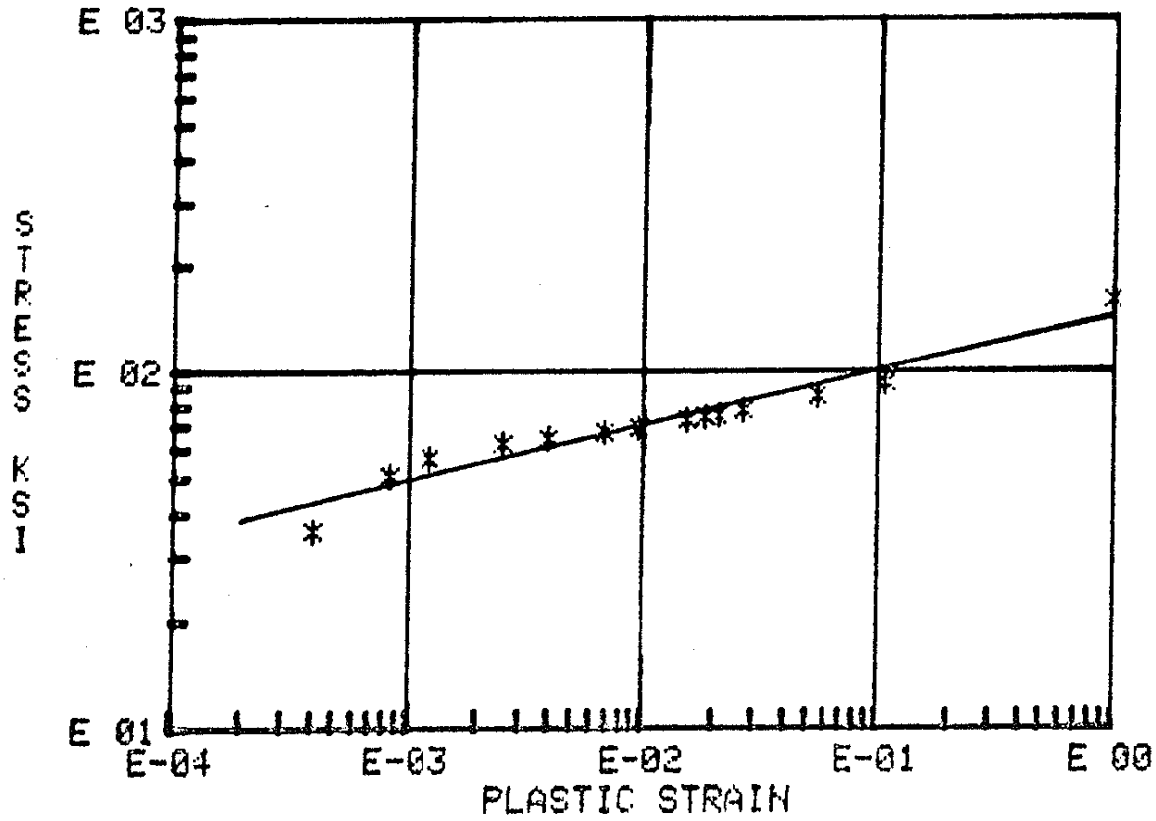
$E$ = 33 E03

MONOTONIC STRESS-STRAIN

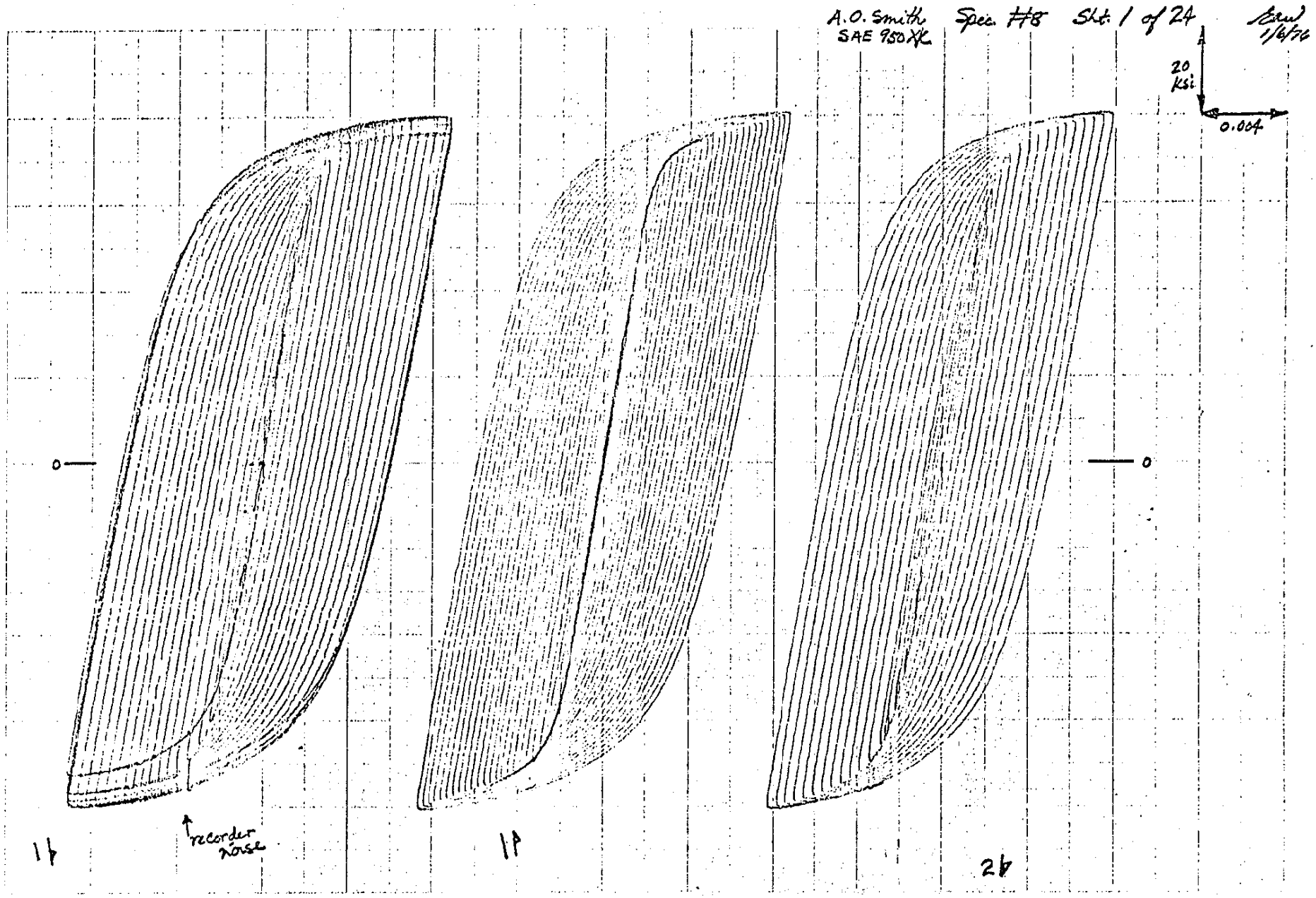
A O SMITH SAE 950XK

SPECIMEN # 8  8-JUN:76

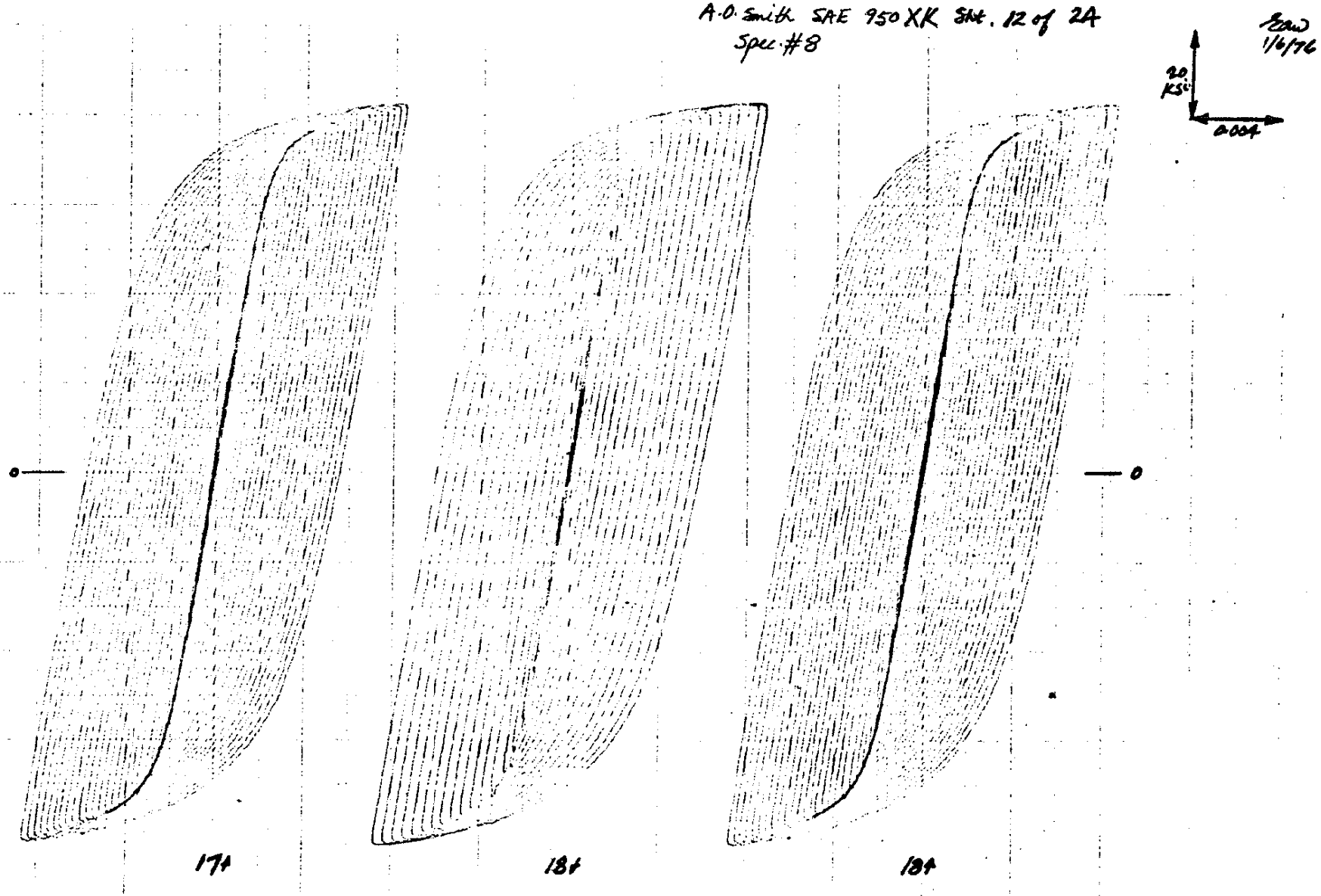
N = .153647  K = 142.068

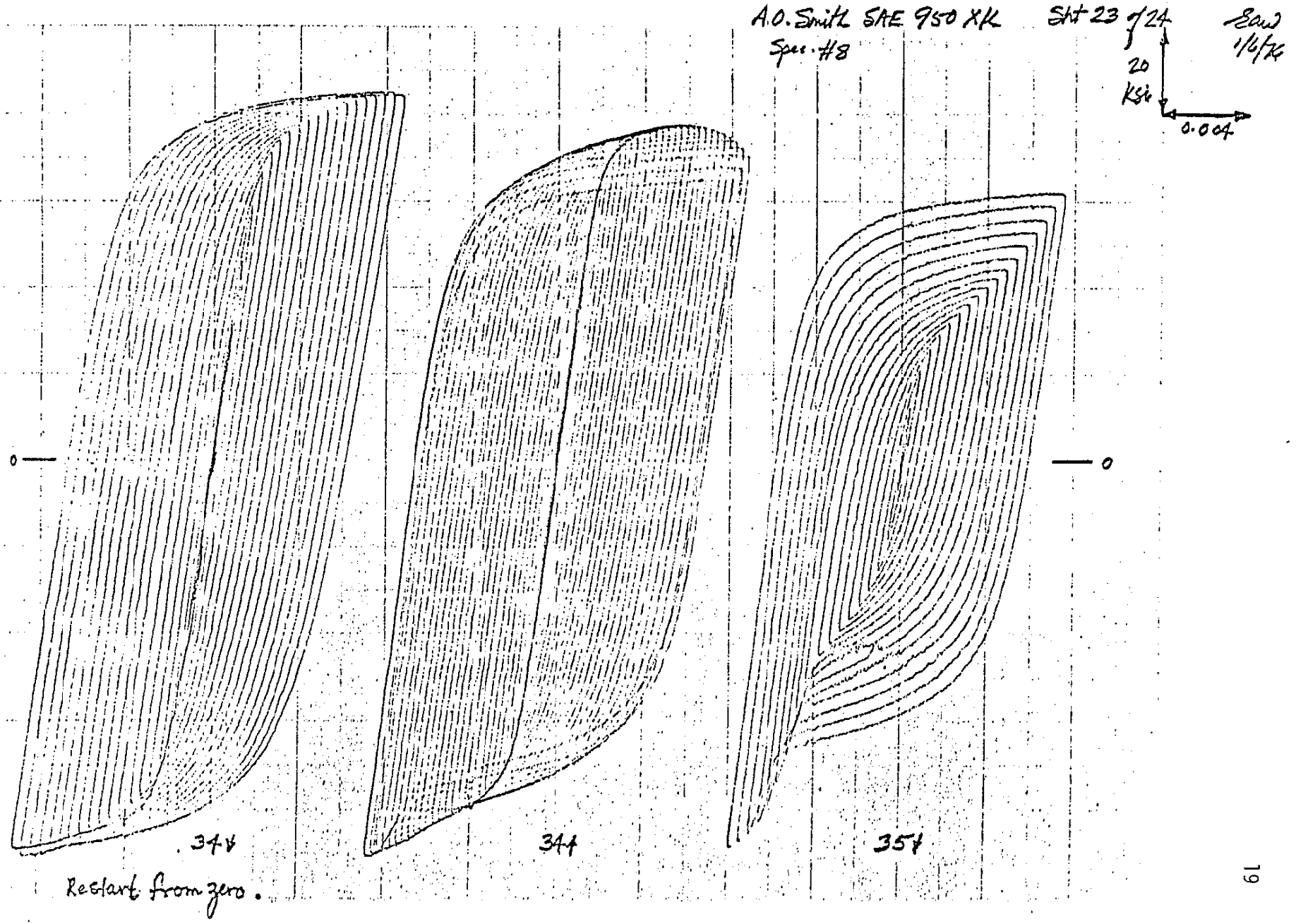


# CYCLIC STRESS-STRAIN RESULTS


A.O. Smith
SAE 950XL
Spec. #8
Sht. 1 of 24
Rev 1/16/76
20 ksi
0.004
0
0
recorder noise
1A
1P
2P

A.O. Smith SAE 950XK Sht. 12 of 24
Spec #8




A.O. Smith SAE 950 XK
Spec. #8
Sht 23 of 24
Saw 1/6/74
20 Ksi
0.004
0
0
34V
34H
35H
Restart from zero.

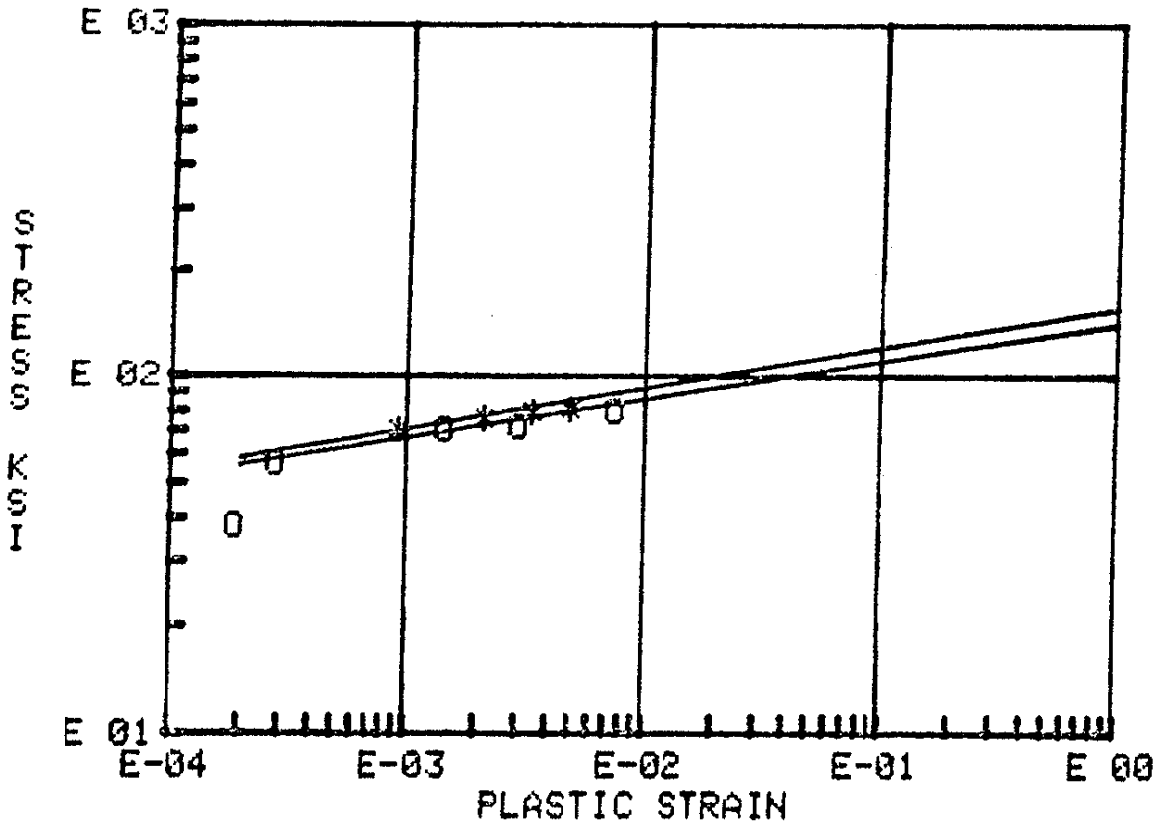
CYCLIC STRESS-STRAIN

O--LCF TESTS  *--INCREM TESTS

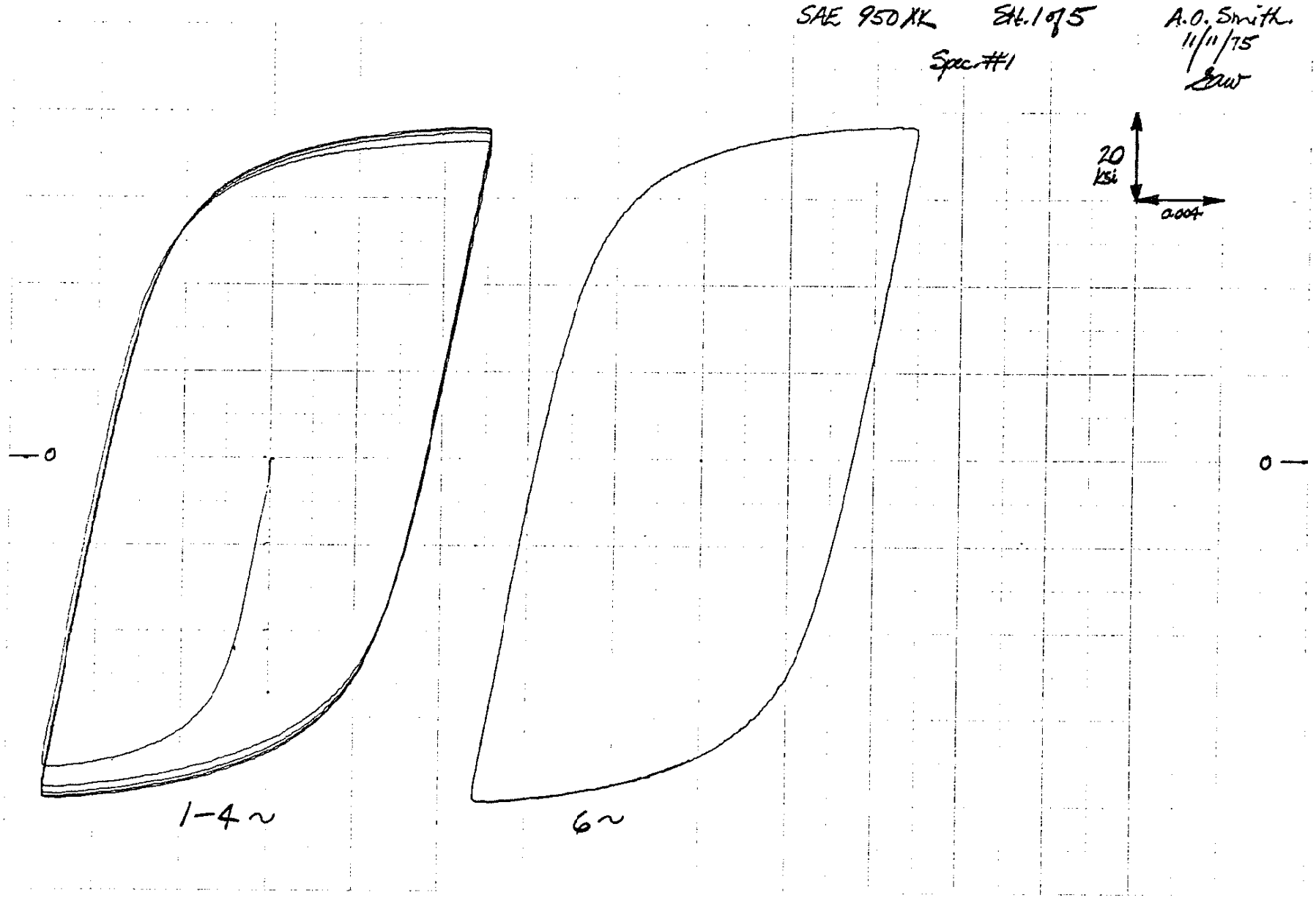
A O SMITH SAE 950XK

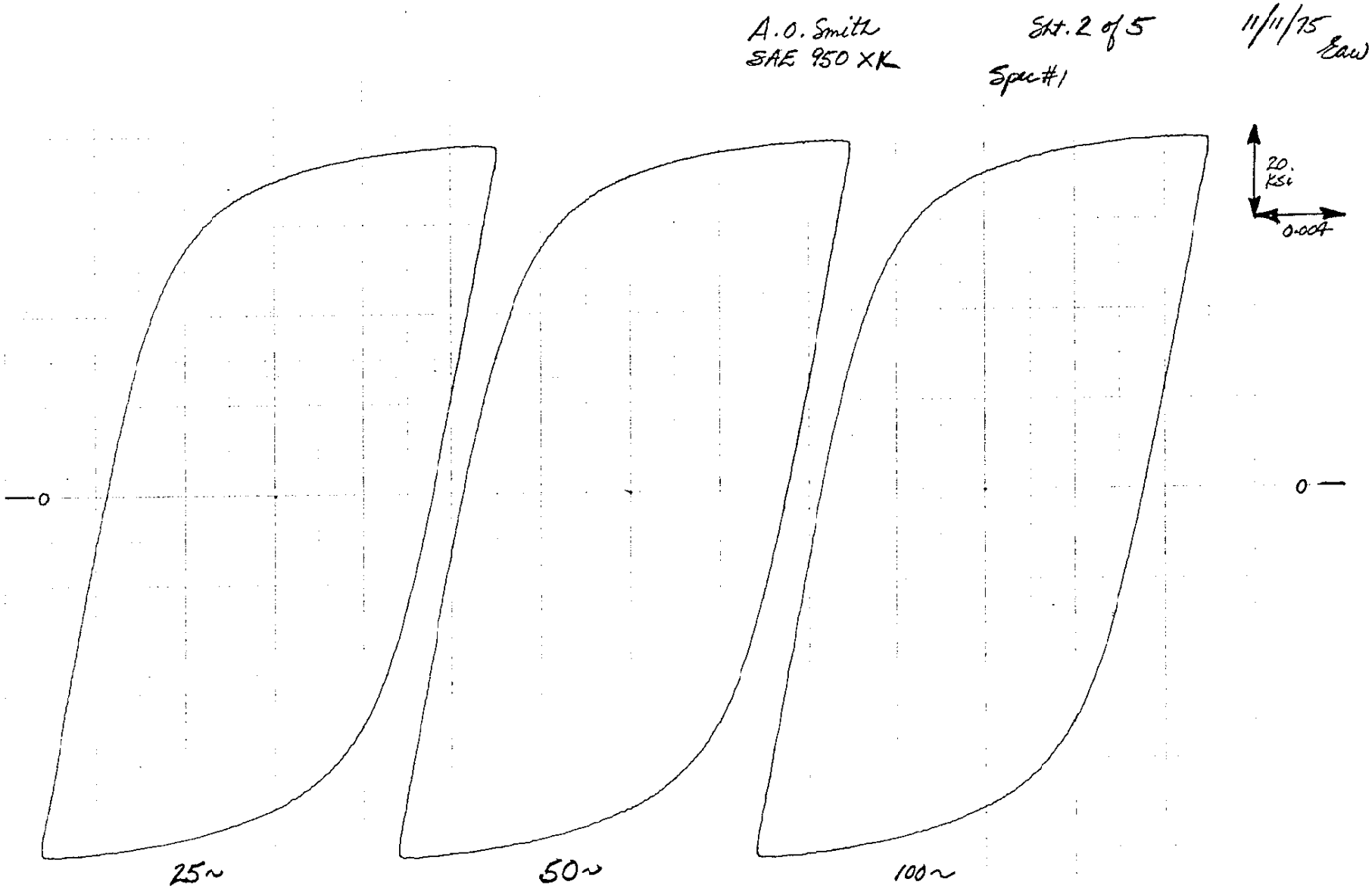
N' = .103198  K' = 141.01 FOR LCF TESTS

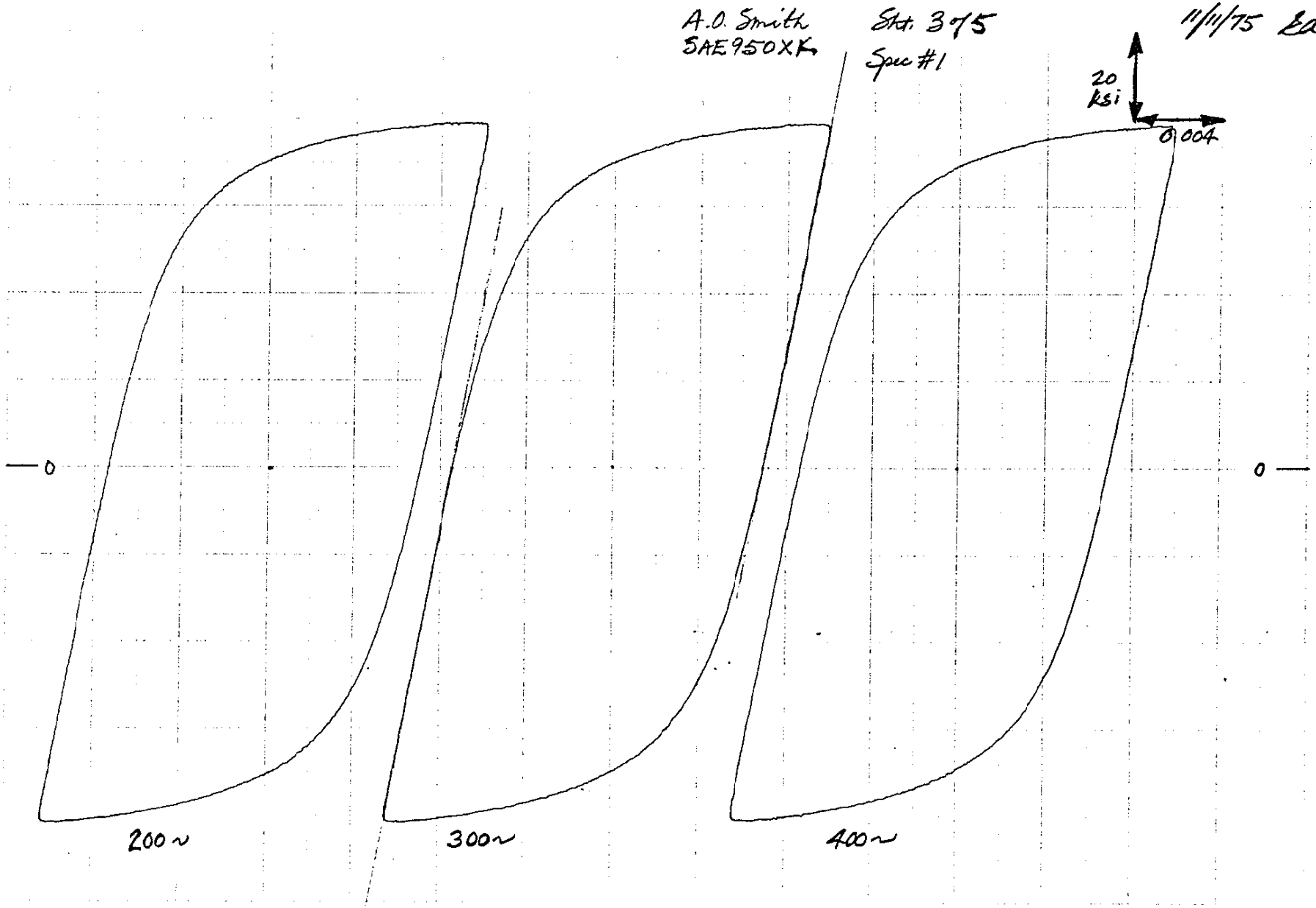
N' = .114891  K' = 156.009 FOR INCREM TESTS



STRESS-STRAIN HYSTERESIS LOOPS FROM CONTROLLED STRAIN FATIGUE TESTS

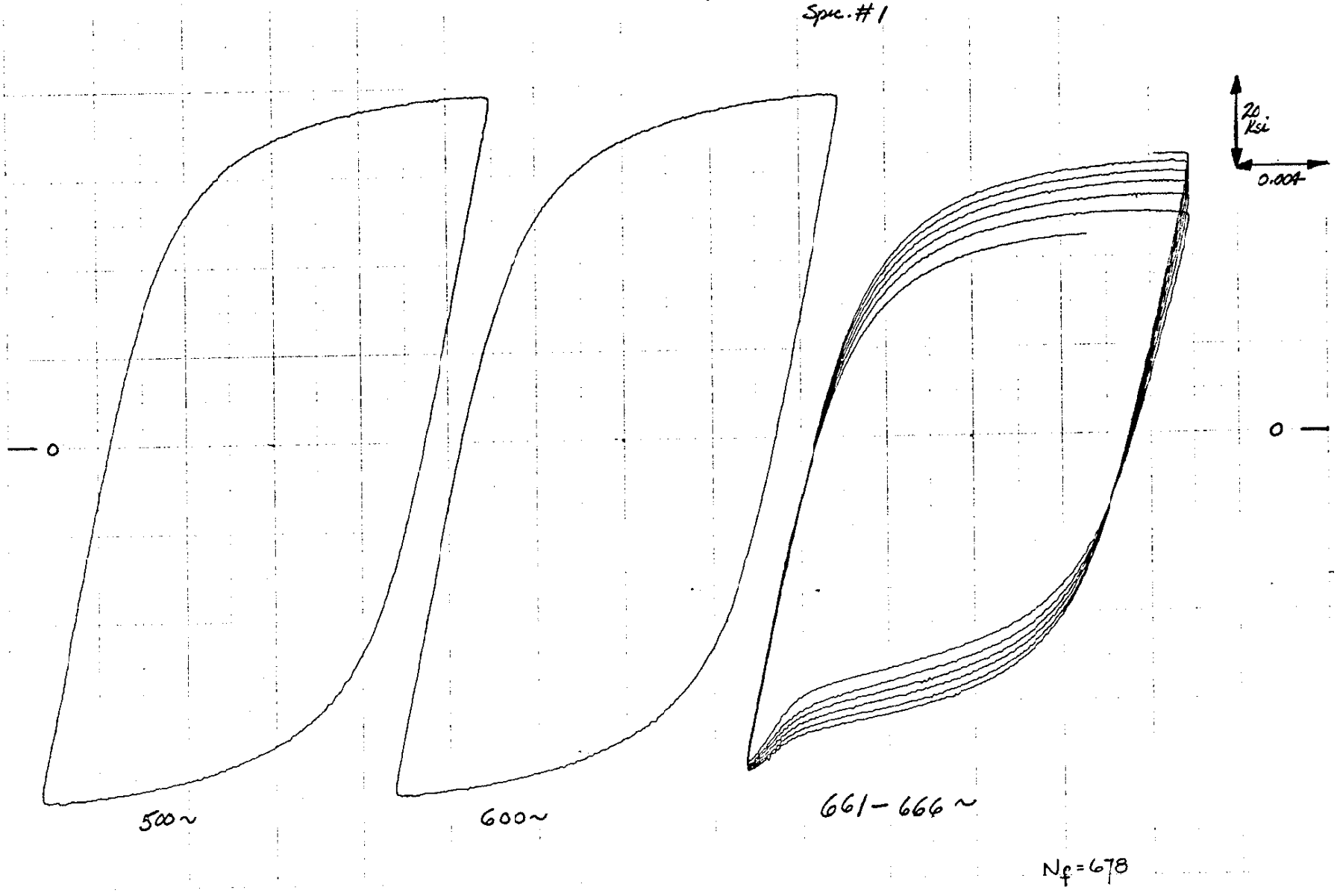

SAE 950XK Ht. 1075 A.O. Smith.
11/11/75
Spec #1
20 ksi
0.004
0
0
1-4~
6~


A.O. Smith
SAE 950 XK
Sht. 2 of 5
Spec #1
11/11/75
Eaw
20 KSi
0.004
0
0
25~
50~
100~

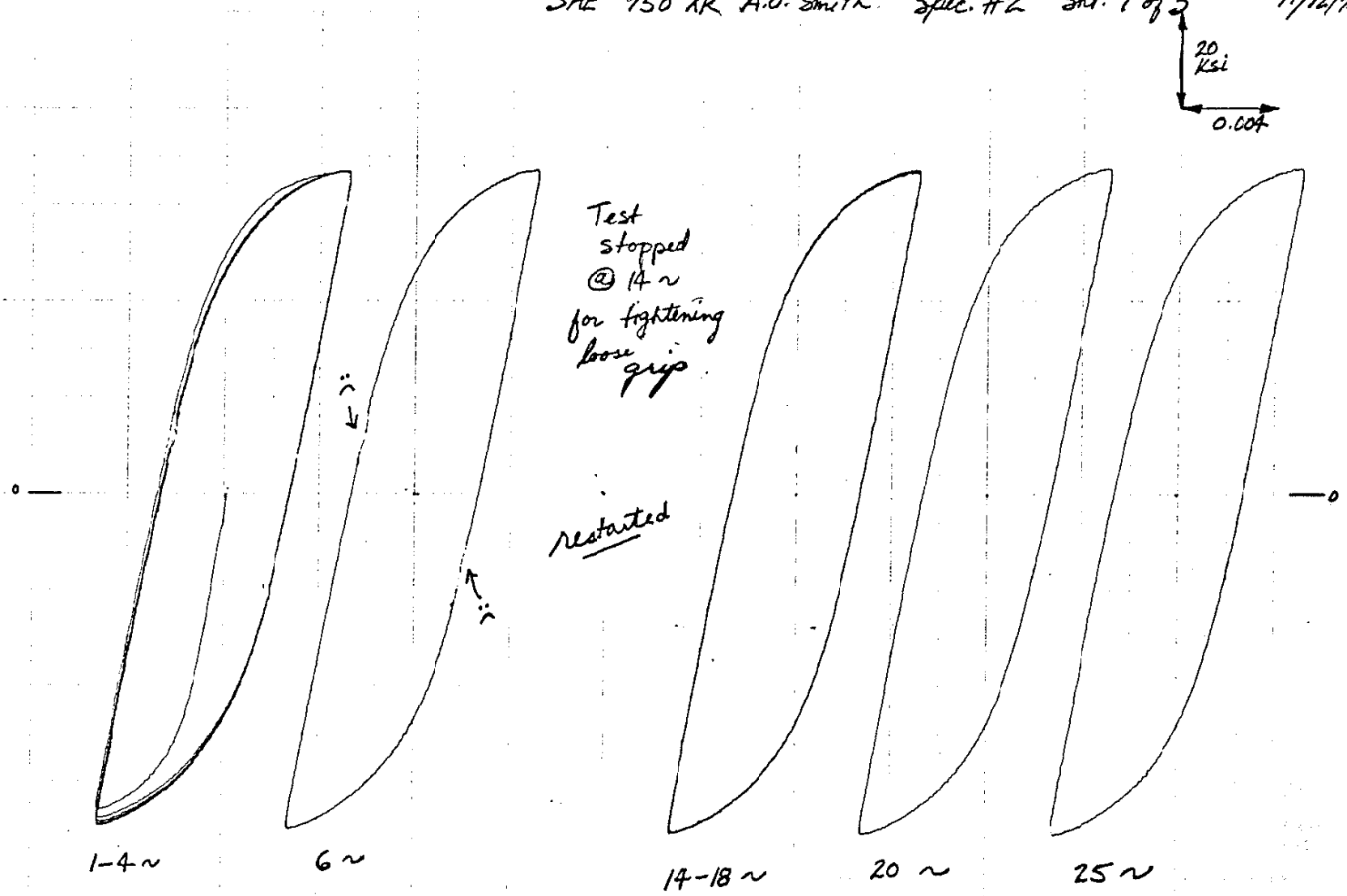

A.O. Smith
SAE950XK
Std. 375
Spec #1
11/11/75 Eaw
20 ksi
0.004
0
0
200~
300~
400~

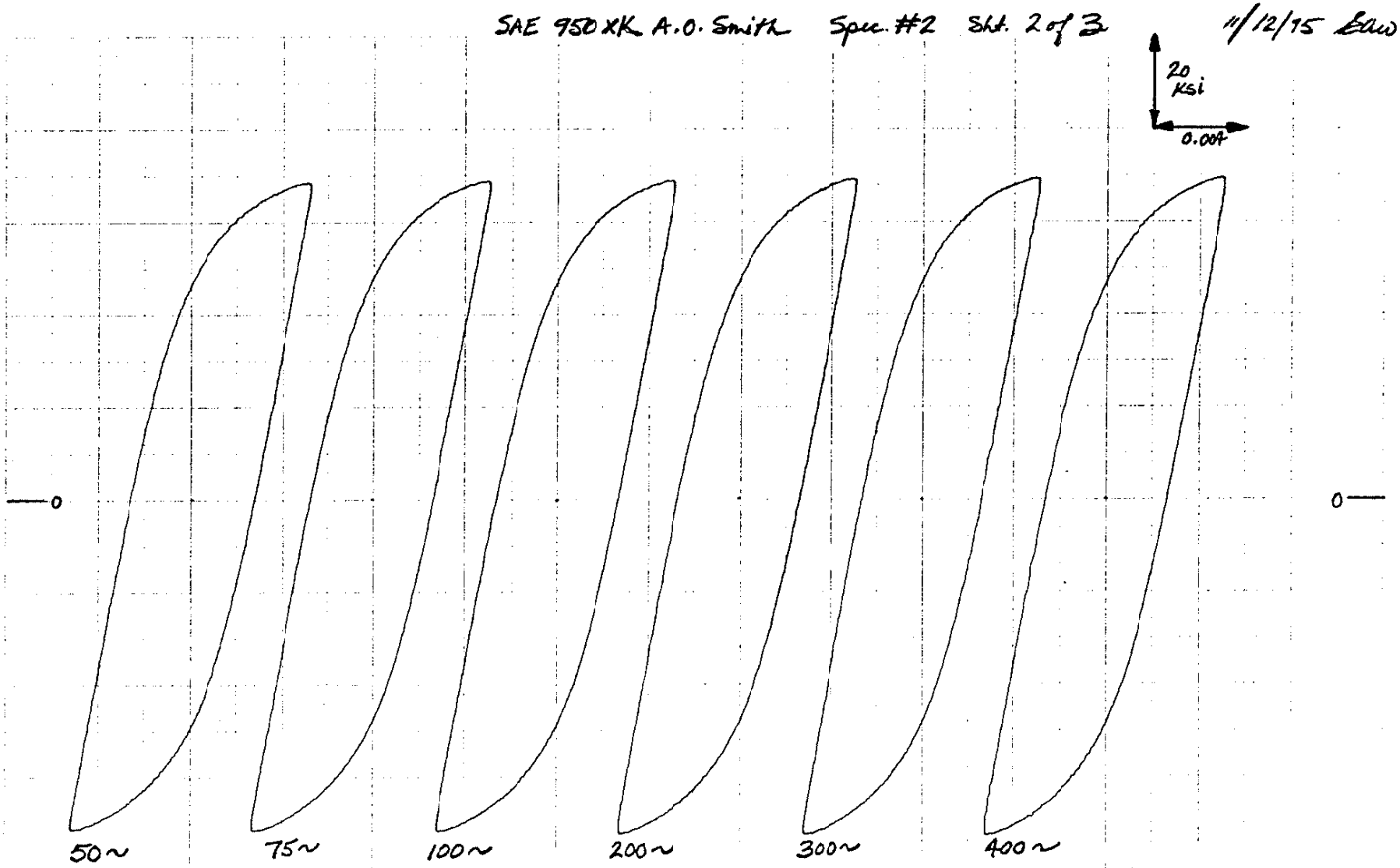
SAE 950 XK A.O. Smith Sht. 4 of 5 11/11/75 SRW.

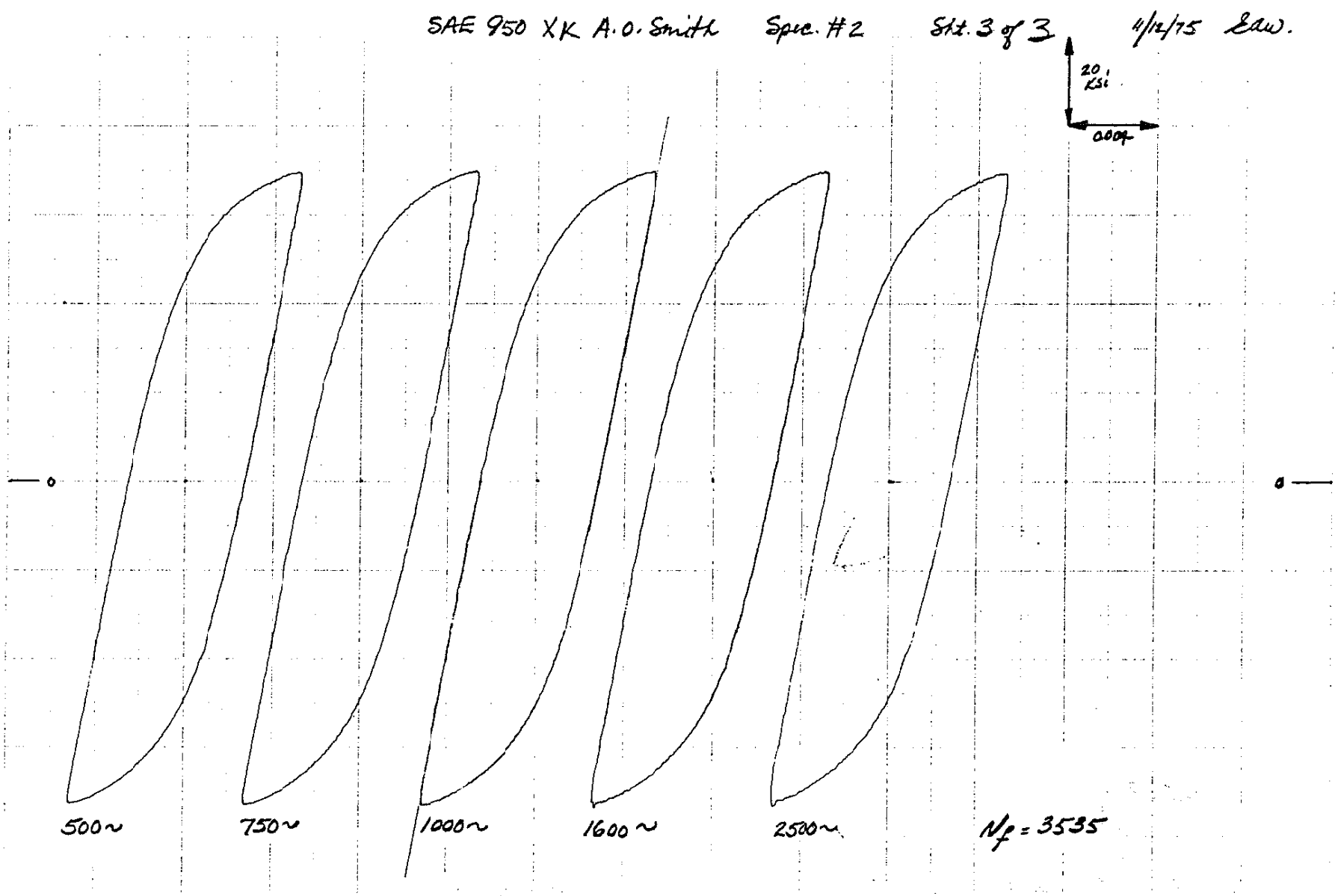
Spec. #1

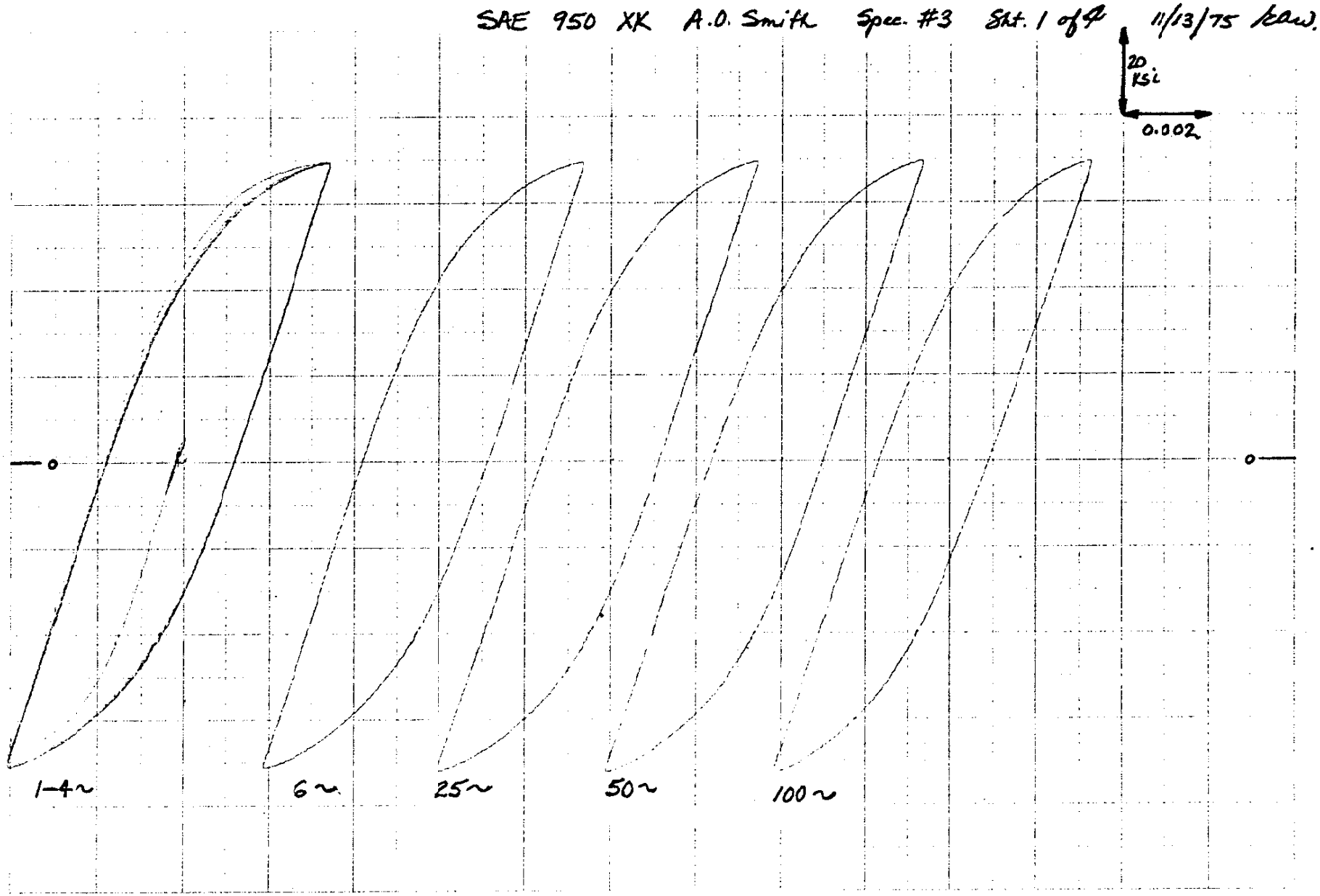


SAE 950 XK A.O. Smith Spec. #2 Sht. 1 of 3 11/12/75 Eaw.

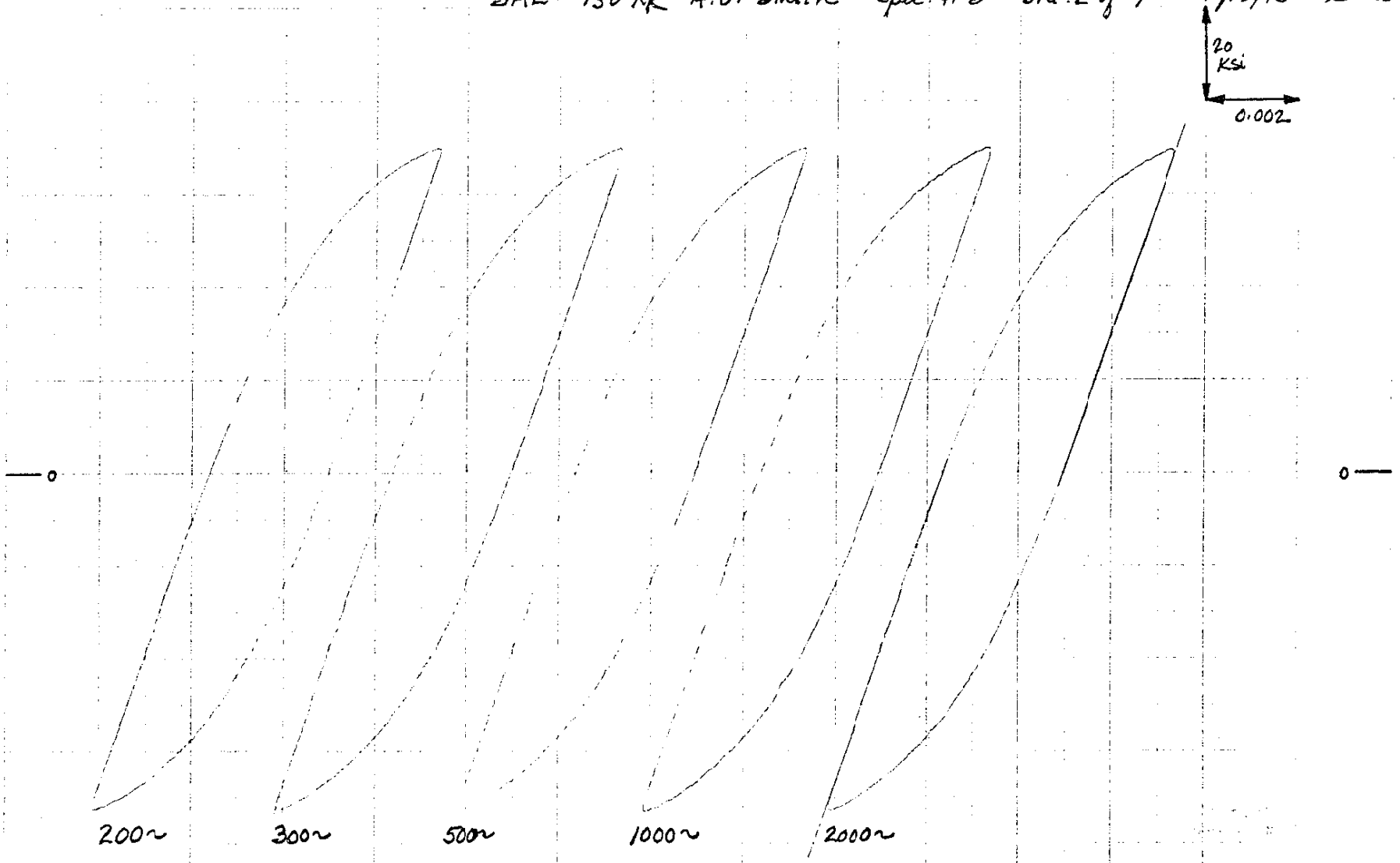


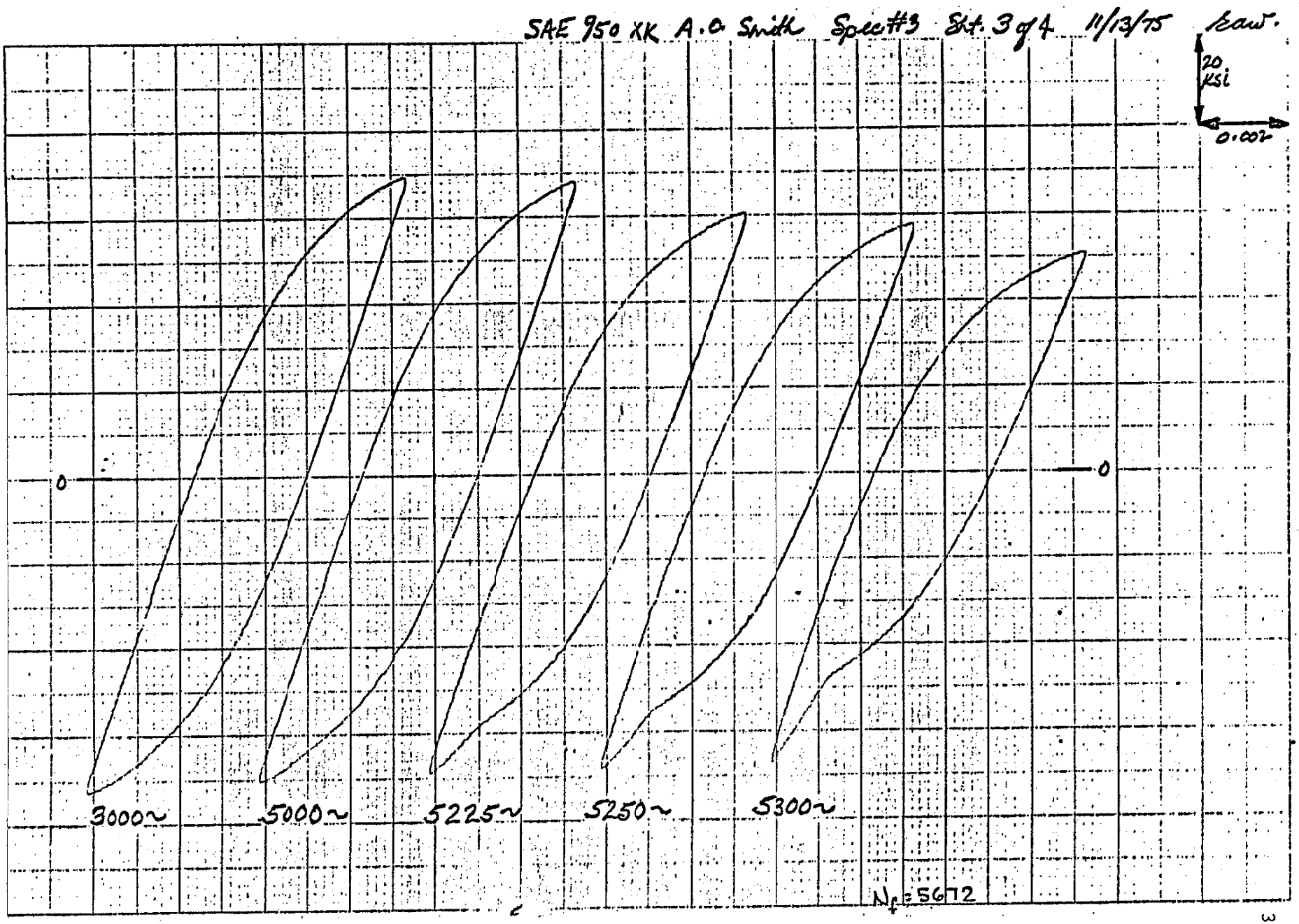

SAE 950 XK A.O. Smith Spec. #2 Sht. 2 of 3
11/12/15 Ellw
20 ksi
0.004
0
0
50~
75~
100~
200~
300~
400~

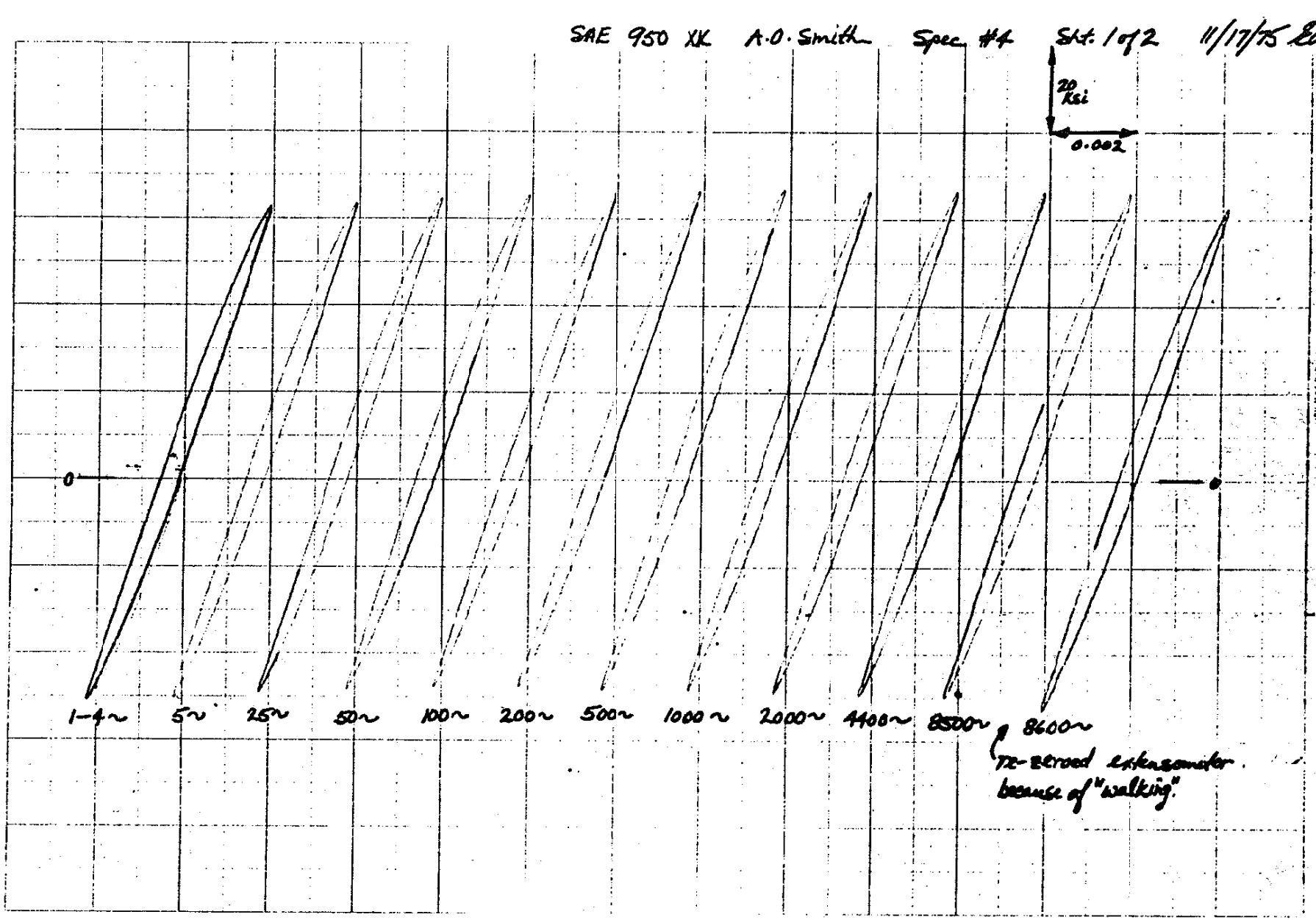

SAE 950 XK A.O. Smith Spec. #2 Sht. 3 of 3 4/12/75 Saw.
20 KSI
.004
500~
750~
1000~
1600~
2500~
$N_f$ = 3535

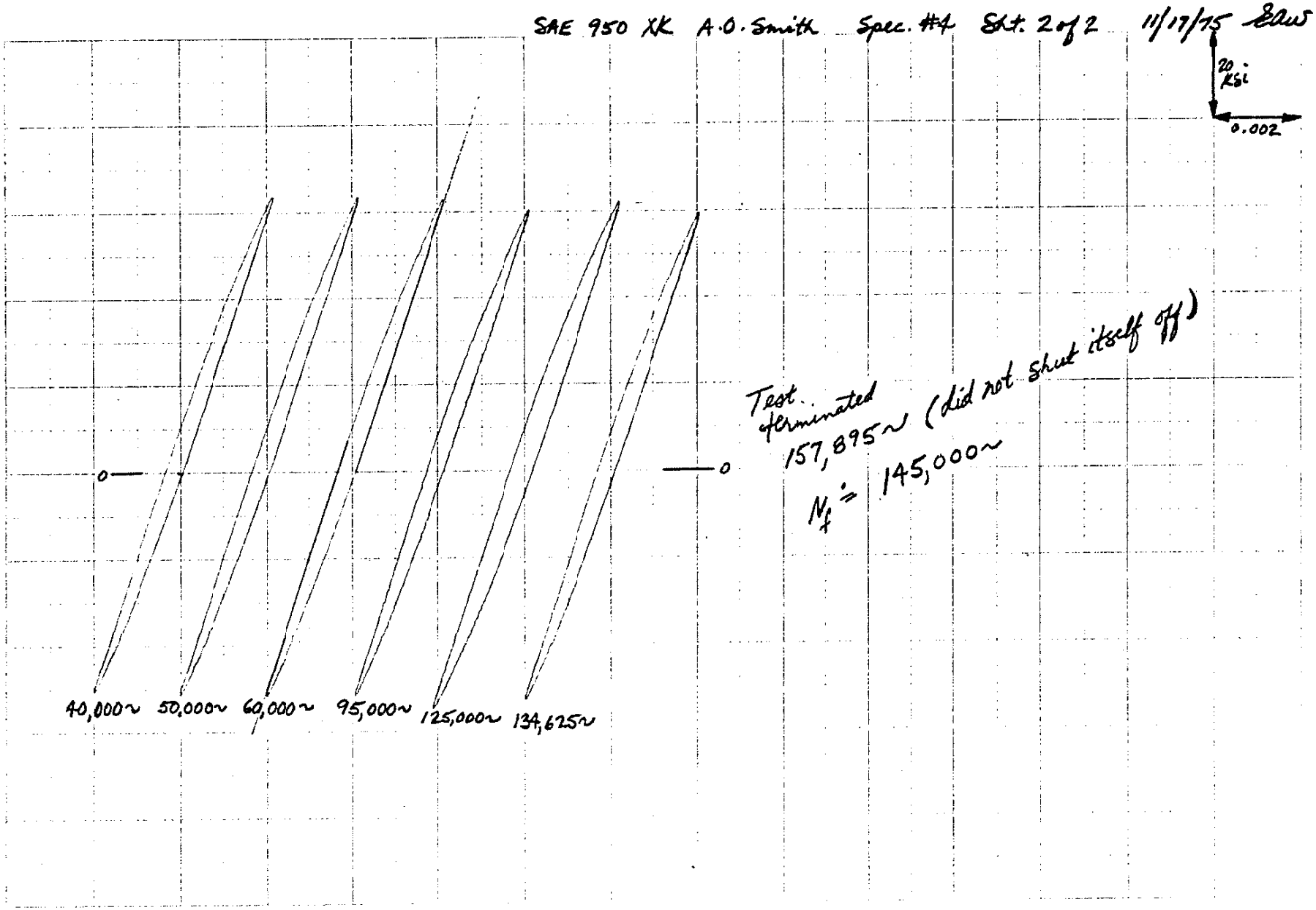

SAE 950 XK A.O. Smith Spec. #3 Sht. 1 of 4 11/13/75 kaw.
20 ksi
0.002
0
0
1-4~
6~
25~
50~
100~

SAE 950 XK A.O. Smith Spec. #3 Sht. 2 of 4 11/13/75 Saw

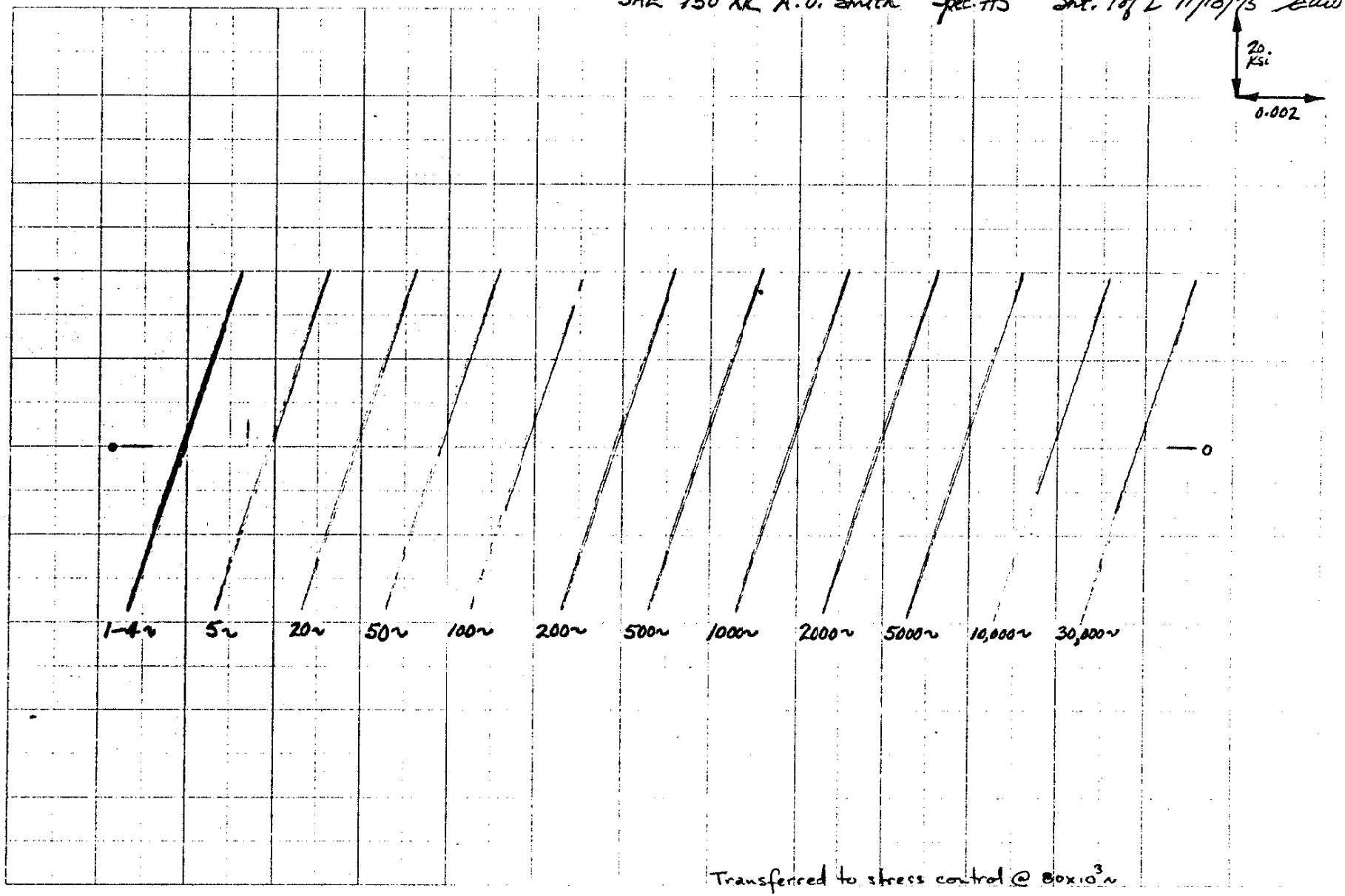



SAE 950 XK A.O Smith Spec#3 Spt. 3 of 4 11/13/75 Room.
20 KSI
0.002
0
0
3000~
5000~
5225~
5250~
5300~
$N_f$ = 5672


SAE 950 XK A.O. Smith Spec #4 Sht. 1 of 2 11/17/75 Edw.
20 Ksi
0.002
0
1-4~
5~
25~
50~
100~
200~
500~
1000~
2000~
4400~
8500~
8600~
re-zeroed extensometer because of "walking"

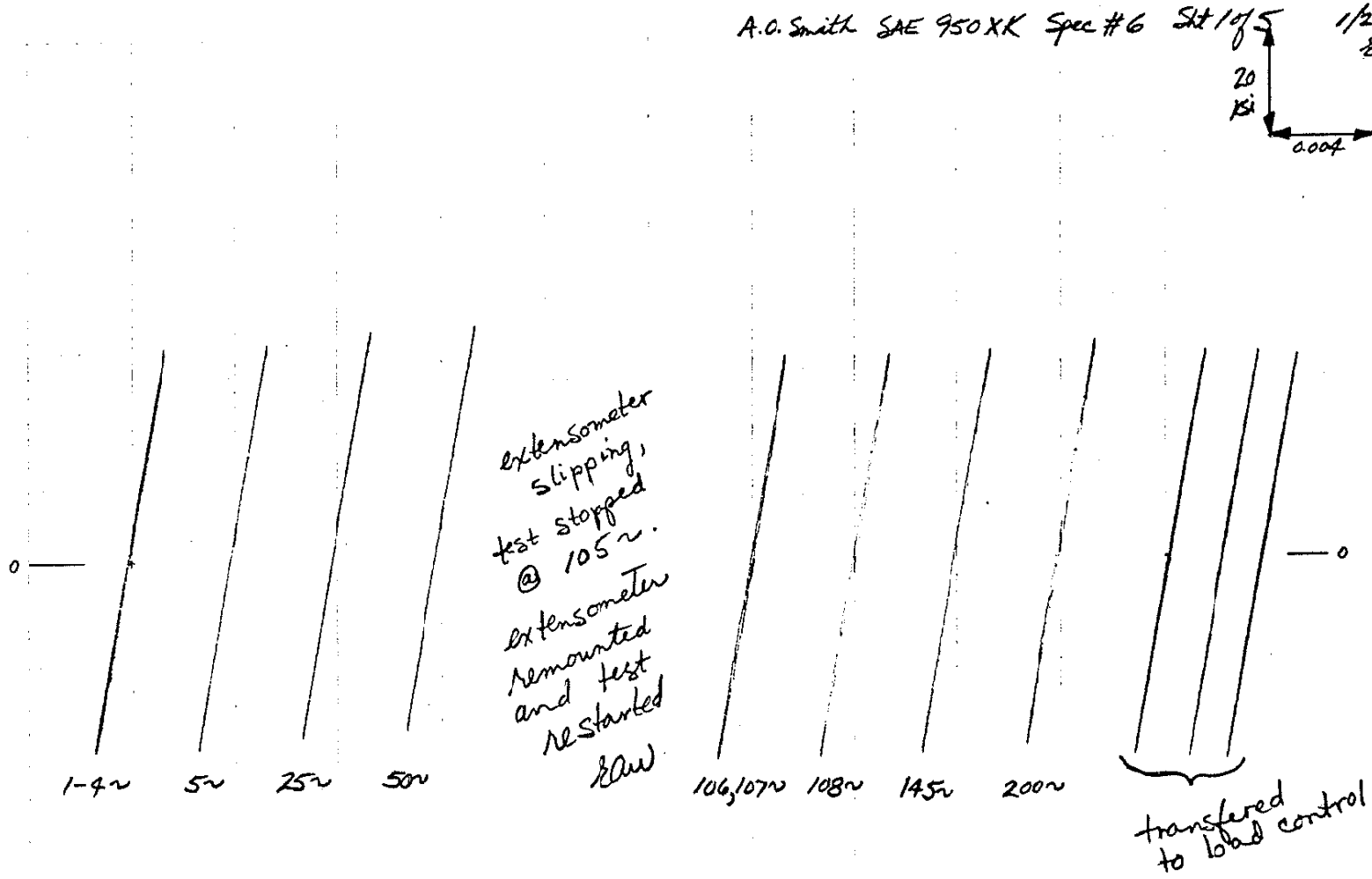

SAE 950 XK A.O. Smith Spec. #4 Sht. 2 of 2 11/17/75 BAW
20 KSi
0.002
0
0
Test terminated
157,895~ (did not shut itself off)
$N_f$ ≈ 145,000~
40,000~ 50,000~ 60,000~ 95,000~ 125,000~ 134,625~

SAE 950 XK A.O. Smith Spec. #5 Sht. 1 of 2 11/18/75 &aw.

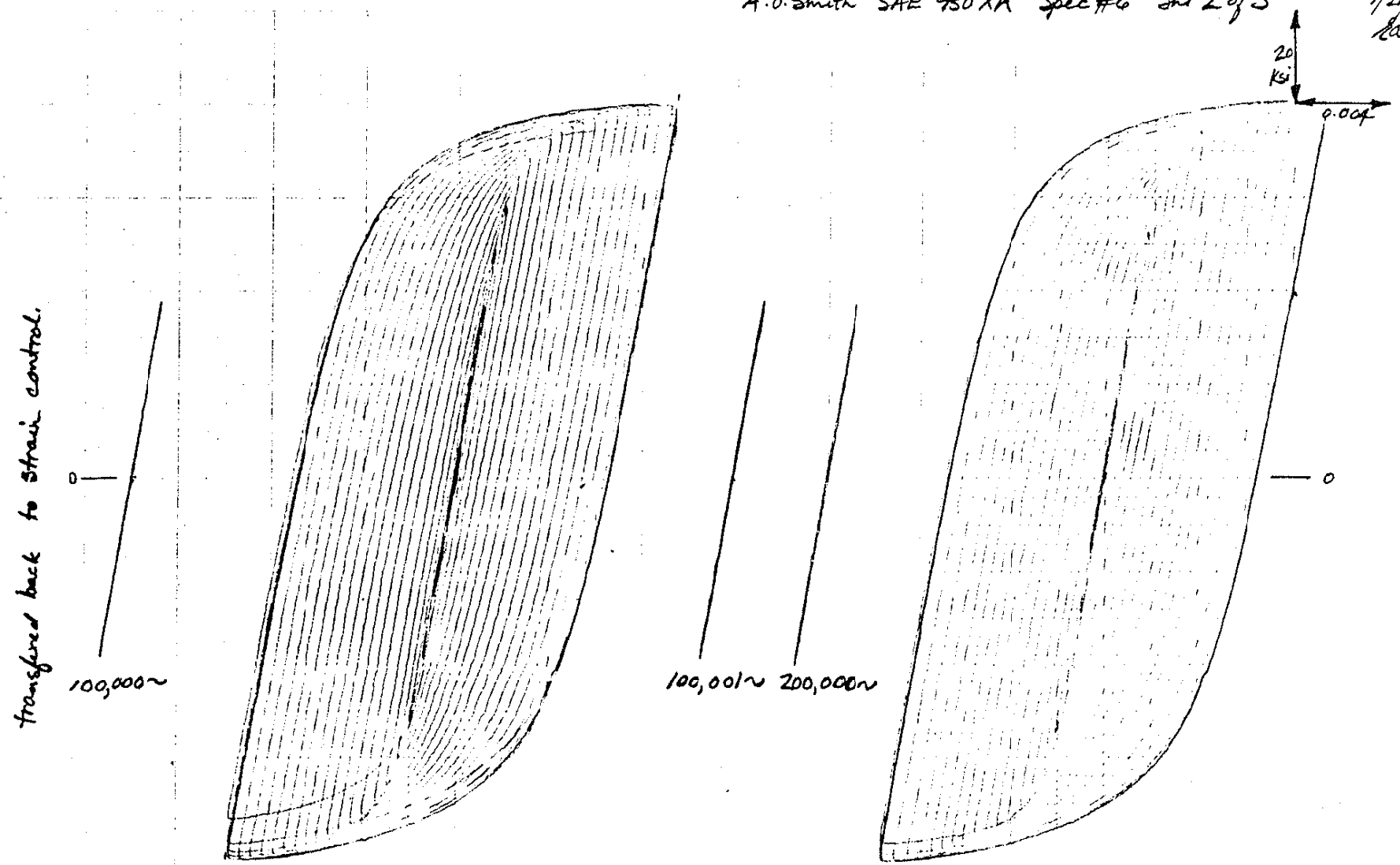



Transferred to stress control @ $80 \times 10^3$~

A.O. Smith SAE 950XK Spec #6 Sht 1 of 5 1/2/76 EAW.

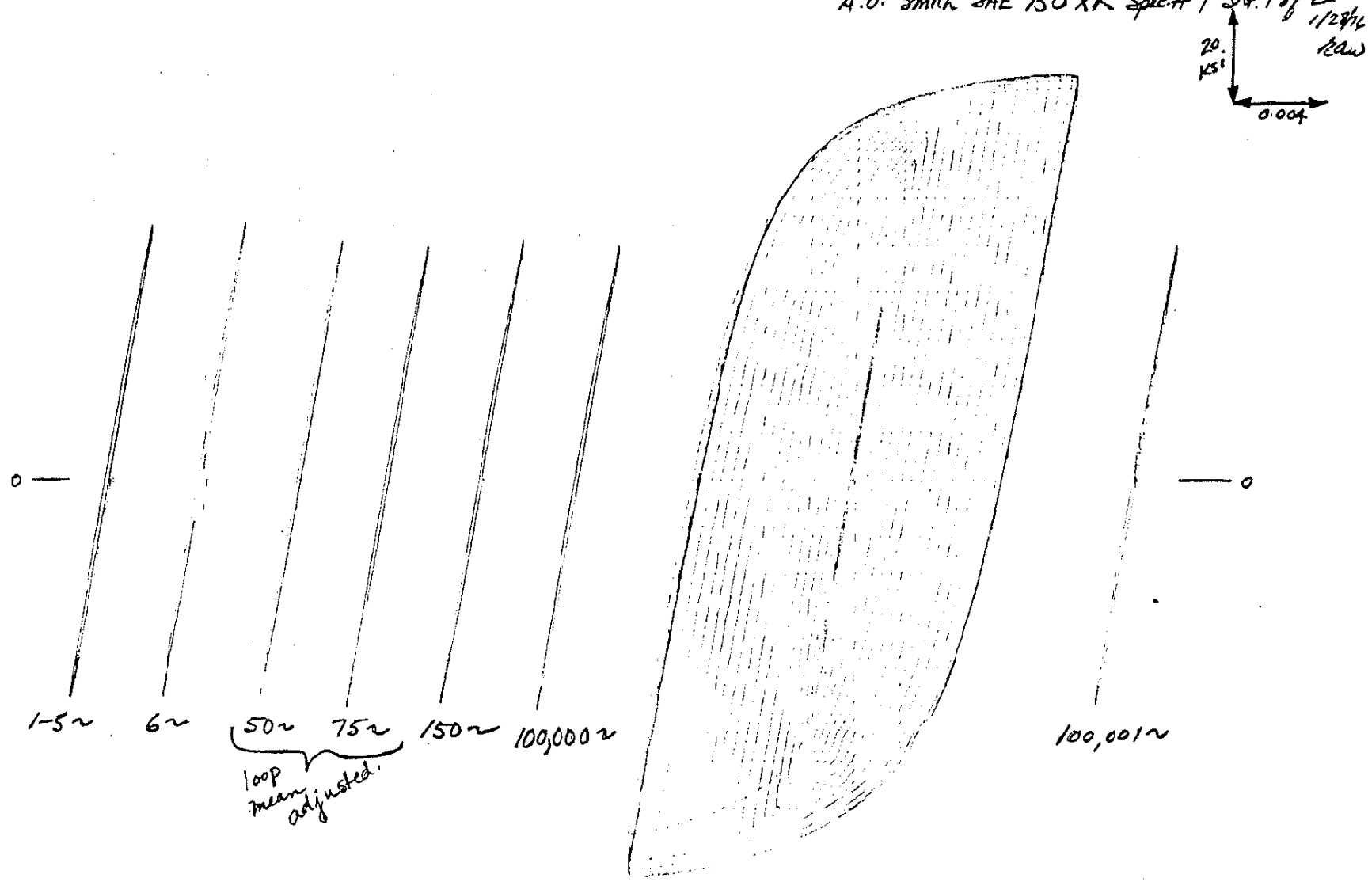


A.O. Smith SAE 950 XK Spec #6 Sht 2 of 5 1/21/16 law.

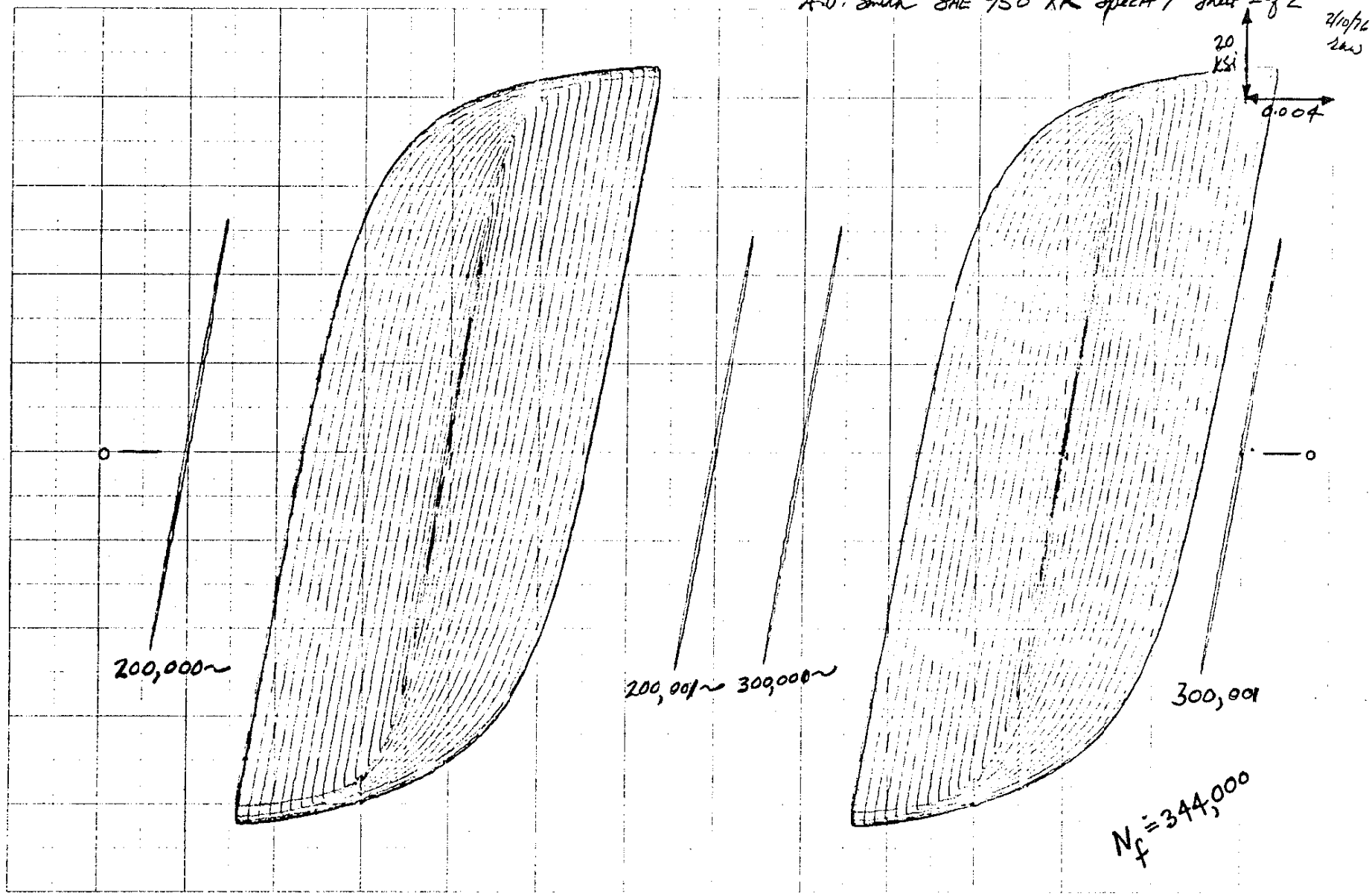



repeat overstraining every $10^5$~
failure @ $7.36 \times 10^5$~

A.O. Smith SAE 950 XK Spec #7 Sht. 1 of 2



A.O. Smith SAE 950 XK Spec#7 Sheet 2 of 2



# STRAIN-LIFE RESULTS

| | Spec. No. | Strain Amplitude, $\Delta\epsilon/2$ | Reversals to Failure, $2N_f$ | Elastic Strain Amplitude, $\Delta\epsilon e/2$ | Plastic Strain Amplitude, $\Delta\epsilon p/2$ | Stabilized* Stress Amplitude $\Delta\sigma/2$, ksi |
|---|---|---|---|---|---|---|
| Non-overstrained | 1 | 0.0102 | 1,356 | 0.0025 | 0.0077 | 80 |
| | 2 | 0.0053 | 7,070 | 0.0023 | 0.0030 | 72 |
| | 3 | 0.0037 | 11,344 | 0.0022 | 0.0015 | 71 |
| | 4 | 0.0021 | $2.9 \times 10^5$ | 0.0018 | 0.0003 | 57 |
| | 5 | 0.0014 | $2.3 \times 10^{7}$** | 0.0012 | 0.0002 | 38 |
| Periodic Overstrained | 6+ | 0.0014 | $1.5 \times 10^6$ | 0.0012 | 0.0002 | 38 |
| | 7+ | 0.0017 | $6.9 \times 10^5$ | 0.0015 | 0.0002 | 48 |

Note - no specimens were initially overstrained.

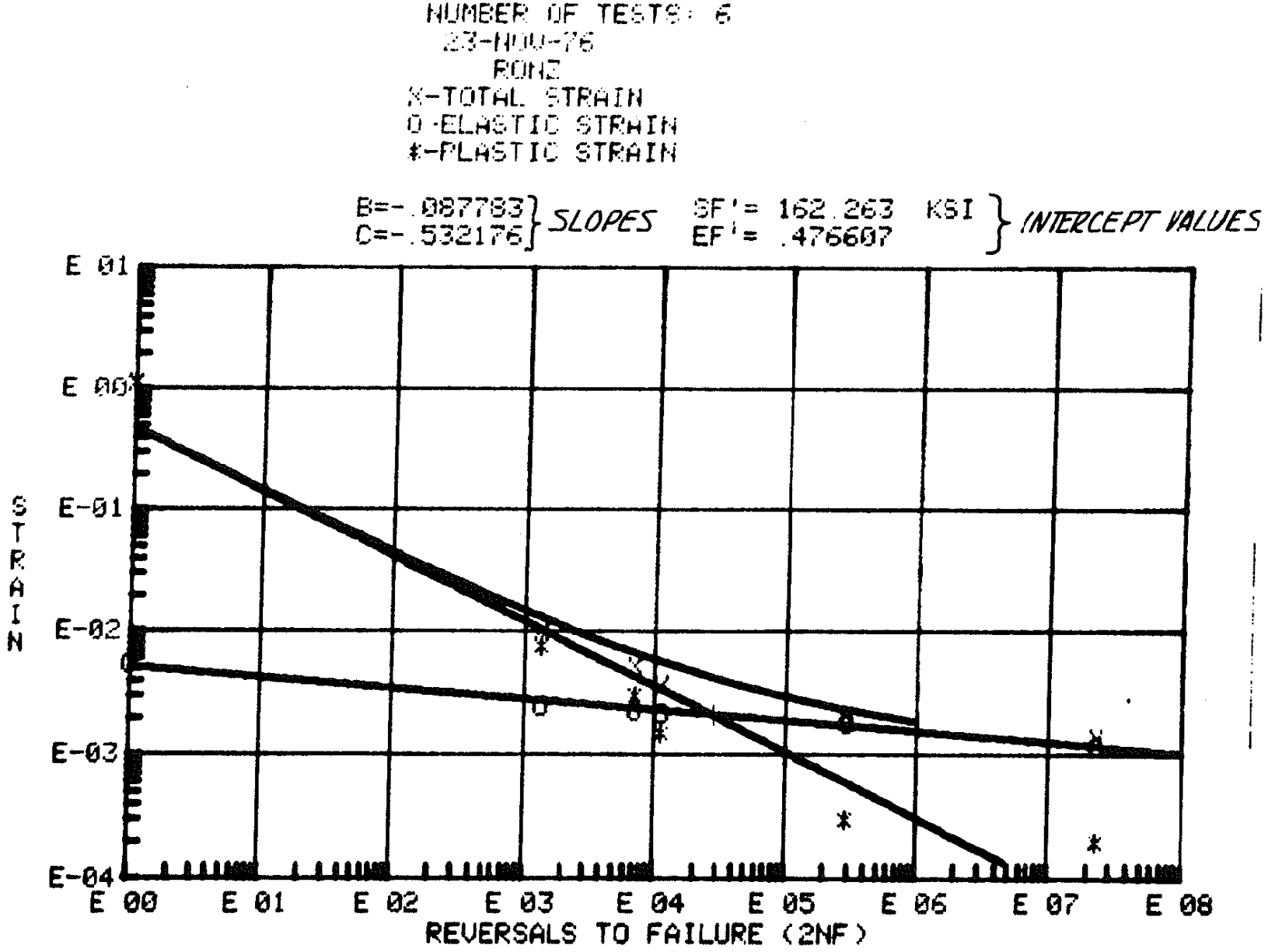
* - measured at 50% of life to failure.

** - specimens did not fail and test terminated.

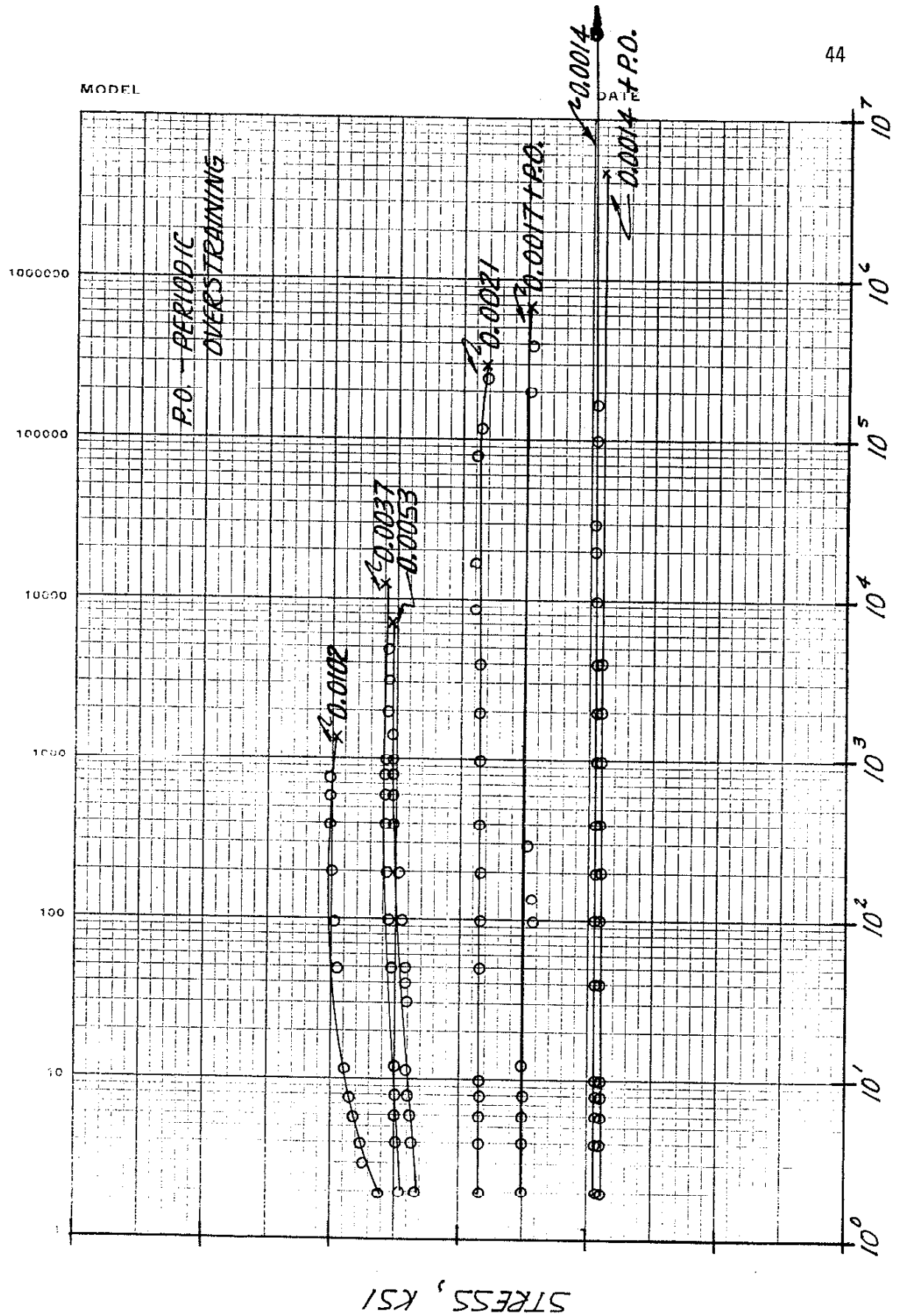
\+ - specimens overstrained each $10^5$ cycles to a strain of 1% which was incrementally decreased to 0 - 0 in 20 cycles.

```
ENTER TYPE OF MATERIAL ? SAE 950 XK
ENTER THE DATE ? 23-NOV-76
ENTER YOUR INTIALS ? RONZ
ENTER ELASTIC MODULUS (KSI) ? 31500
ENTER TITLE ?
ENTER NUMBER OF TESTS ? 6
ENTER-REVS-TOT-PLAS- ? 1,1,1355,1,13
ENTER-REVS-TOT-PLAS- ? 1356,.0102,.0077
ENTER-REVS-TOT-PLAS- ? 7070,.0053,.003
ENTER-REVS-TOT-PLAS- ? 11344,.0037,.0015
ENTER-REVS-TOT-PLAS- ? 290000, 0021, 0003
ENTER-REVS-TOT-PLAS- ? 2.30E07, 0014, 0002
DO YOU WANT TO MARK EXTRA POINTS (Y,N) ? N
```

THESE DATA USED FOR FITTING ELASTIC & PLASTIC STRAIN-LIFE LINES


STRAIN-LIFE CURVE FOR SAE 950 X
NUMBER OF TESTS: 6
23-NOV-76
RONZ
X-TOTAL STRAIN
O-ELASTIC STRAIN
*-PLASTIC STRAIN
B=-.087783
C=-.532176
SLOPES
SF'= 162.263 KSI
EF'= .476607
INTERCEPT VALUES
E 01
E 00
E-01
E-02
E-03
E-04
STRAIN
E 00
E 01
E 02
E 03
E 04
E 05
E 06
E 07
E 08
REVERSALS TO FAILURE (2NF)

# STRESS-TIME RESPONSE TO CONTROLLED STRAIN FATIGUE TESTS


MODEL
DATE
P.O. - PERIODIC OVERSTRAINING
ε 0.0014
ε 0.0014 + P.O.
ε 0.0017 + P.O.
ε 0.0021
ε 0.0037
ε 0.0053
ε 0.0102
1000000
100000
10000
1000
100
10
1
$10^7$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
REVERSALS, 2N
STRESS, KSI

ADDITIONAL MATERIAL CHARACTERIZATION SHEETS

## DATA SHEET FOR MATERIAL CHARACTERIZATION

Material: SAE 950XK

Condition: as received

Matrix Hardness: 183 BHN

Converted from: Rockwell (B-Scale)

### Monotonic Properties:

| | |
|---|---|
| Modulus of Elasticity, E | $31.5 \times 10^3$ ksi |
| Yield Strength, 0.2% $S_y$ | 63.0 ksi |
| Ultimate Strength, $S_u$ | 82.0 ksi |
| Red. in Area, % RA | 67.7% |
| True Fracture Strength, $\sigma_f$ | 207.8 ksi<br>corrected to 174.5 ksi |
| True Fracture Ductility, $\epsilon_f$ | 1.13 |
| Strain Hardening Exponent, n | 0.156 |
| Strength Coefficient, K | 146.4 ksi |
| True Toughness, $U_p$ | 170.9 ksi |
| Poisson's Ratio | --- |

All monotonic values from average of two tests.

### Cyclic Properties:

| | |
|---|---|
| Yield Strength, 0.2% $S_y'$ | 73 ksi$^+$/77* ksi |
| Strain Hardening Exponent, n' | 0.11$^+$/0.12* |
| Strength Coefficient, K' | 141.0$^+$ ksi 156.0* ksi |
| Fatigue Strength Coefficient, $\sigma_f'$ | 162.3** ksi |
| Fatigue Ductility Coefficient, $\epsilon_f'$ | 0.48** |
| Fatigue Strength Exponent, b | -0.088** |
| Fatigue Ductility Exponent, c | -0.53** |
| Transition Fatigue Life, $2N_t$ | 26,580 rev |

+ - from LCF data
* - from incremental data

### Composition:

| | | | |
|---|---|---|---|
| w/o C | = 0.09 | w/o Mo | = |
| w/o Si | = 0.016 | w/o Cu | = 0.042 |
| w/o P | = 0.009 | w/o Ni | = 0.04 |
| w/o S | = 0.013 | w/o Va | = 0.009 |
| w/o Mn | = 0.46 | w/o Al | = 0.042 |
| w/o Cr | = 0.016 | w/o B | = |
| | | w/o Ti | = 0.14 |

Grain Size:

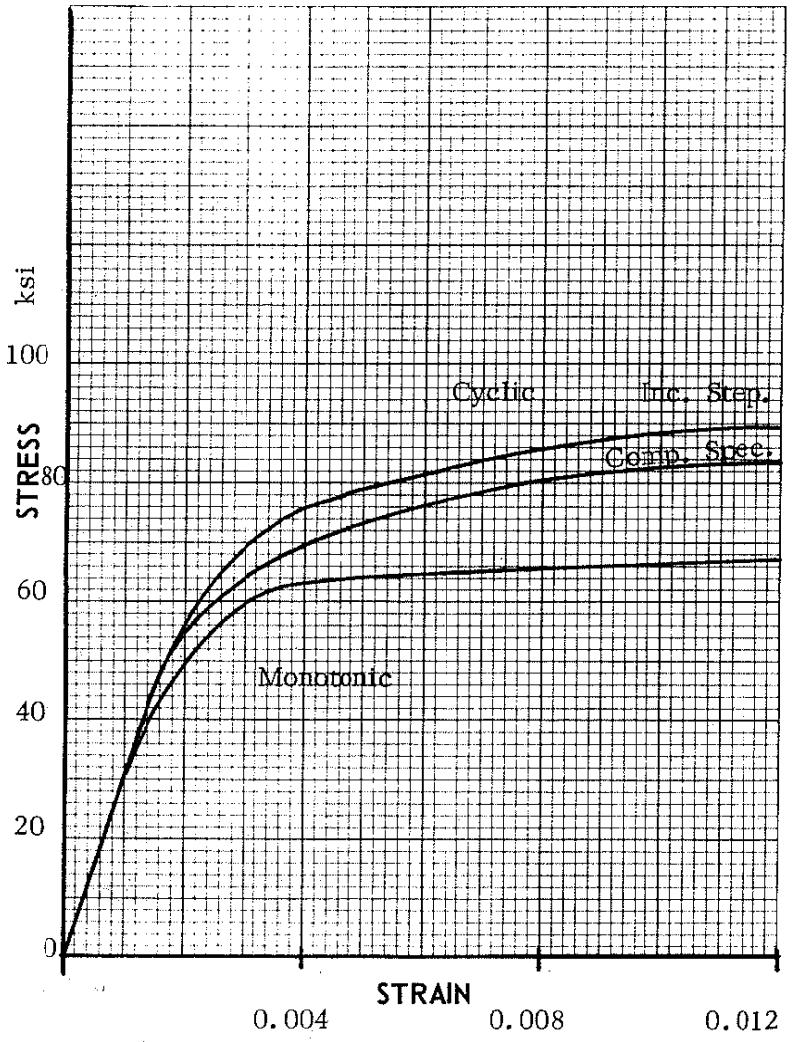
Eutectic Cell Size (Cast irons):

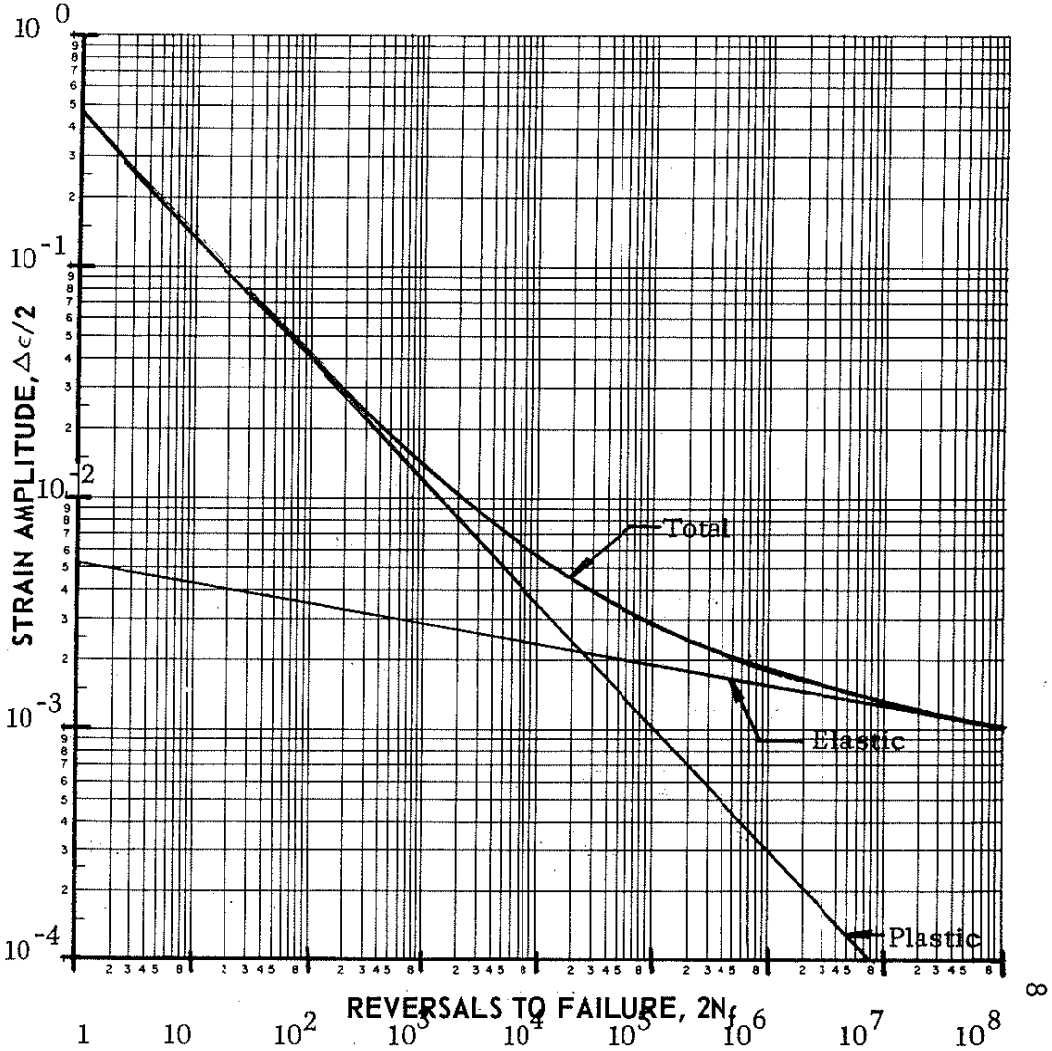
Comments: Periodic overstraining of a specimen run at a constant strain amplitude of 0.0014 results in failure at $1.5 \times 10^6$ reversals whereas runout occurs at a constant amplitude. Similar overstraining of a specimen run at a constant strain amplitude of 0.0017 results in failure at $7 \times 10^5$ reversals whereas a specimen run without overstraining at the same strain amplitude results in failure at $5 \times 10^6$ reversals.

**$\sigma_f'$ & $\epsilon_f'$ are intercept values for the elastic strain-life line. As with the values of b & c, $\sigma_f'$ & $\epsilon_f'$ were determined from least square fits of data from five strain controlled fatigue tests (including one runout) and the true fracture strength and ductility from the monotonic results.

**Material:** SAE 950 XK **Hardness:** 183 BHN

**Condition:** as received




FRACTURE CONTROL PROGRAM
UNIVERSITY OF ILLINOIS