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HIGH-TEMPERATURE, LOW-CYCLE FATIGUE OF COPPER-BASE ALLOYS FOR ROCKET NOZZLES; PART I - DATA SUMMARY FOR MATERIALS TESTED IN PRIOR PROGRAMS.

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MAR-TEST INC.
Cincinnati, Ohio
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G.R.Halford, Project Manager

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16. Abstract

A more detailed analysis of the results obtained in 188 previously reported low-cycle fatigue tests of various candidate materials for regeneratively-cooled, reusable rocket nozzle liners is reported. Plots of load range versus cycles are reported for each test along with a stress-strain hysteresis loop near half-life. In addition, a summary table is provided to compare N_5 (cycles to a five percent load range drop) and N_f (cycles to complete specimen separation) values for each test.

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I - SUMMARY

Five recent NASA Contractor Reports were written and published by Mar-Test Inc. to describe short-term tensile and low-cycle fatigue evaluations of eighteen (18) candidate materials (17 copper-base alloys along with pure silver) for regeneratively-cooled, reusable rocket nozzle liners. Test temperatures ranged from room temperature to 593°C with all the elevated temperature tests being performed in high purity argon. All low-cycle fatigue tests were performed in axial strain control with strain ranges being selected to define the fatigue life to about 3000 cycles. A limited evaluation of strain-rate and hold-time effects was also included for selected alloys.

Following the formal publication of the results of these tests it was decided that a more detailed analysis should be made of each test to furnish a more comprehensive description of the low-cycle behavior of each material. This re-analysis focused on the 188 previously reported low-cycle fatigue tests and led to a plot of load range versus cycles for each test. It also yielded a typical hysteresis loop for each test chosen near the region of half-life. And, finally, this re-analysis led to a summary table to allow the values of N_5 (cycles to a five percent load range drop) and N_f (cycles to complete specimen separation) to be compared for each test.

In many of these tests a cyclic softening behavior was exhibited and it was not possible to identify a stabilized load range value for use in calculating N_5. For these instances, the interpretation adopted was based on a five percent reduction from the load range value obtained at the point where a decided change in curvature was noted in the semi-logarithmic plot of load range versus cycles in the regime near fracture.

II - INTRODUCTION

In recent NASA programs, NAS3-16753 and NAS3-17777, a detailed evaluation was made of the short-term tensile and low-cycle fatigue behavior of numerous candidate materials for regeneratively-cooled, reusable rocket nozzle liners such as found in the engines of the Space Shuttle, Orbit-to-Orbit Shuttle, Space Tug, etc. The results obtained in these studies have been described in the following series of NASA Contractor Reports:

NASA CR-121259 --	High Temperature, Low-cycle Fatigue of Copper-base Alloys in Argon; Part I - Preliminary Results for 12 Alloys at 1000°F (538°C).
NASA CR-121260 --	High Temperature, Low-cycle Fatigue of Copper-base Alloys in Argon; Part II - Zirconium-copper at 482°C,538°C and 593°C.
NASA CR-121261 --	High Temperature, Low-cycle Fatigue of Copper-base Alloys in Argon; Part III - Zirconium-copper; Thermal-mechanical Strain Cycling, Hold-time and Notch Fatigue Results.
NASA CR-134627 --	High Temperature,Low-cycle Fatigue of Advanced Copper-base Alloys for Rocket Nozzles; Part I - Narloy Z.
NASA CR-134628 --	High Temperature, Low-cycle Fatigue of Advanced Copper-base Alloys for Rocket Nozzles; Part II-NASA 1.1, Glidcop, and Sputtered Copper Alloys.

Subsequent assessments by NASA personnel of the material property data presented in the above reports indicated that from a design point of view a more detailed evaluation of the stress-strain information recorded in the low-cycle fatigue tests was desirable. It was decided, therefore, that in Task I of this program a more comprehensive analysis would be made of each low-cycle fatigue test performed during the last two NASA-sponsored programs performed by Mar-Test Inc. The strip chart records for each fatigue test were subjected to additional analysis so that a plot of load versus cycles could be prepared. In addition, it was decided that a typical hysteresis loop, selected near half-life, would be presented for each test. And finally, this Task I effort was to present a tabular summary for all the fatigue tests to compare the values of N_5 (cycles corresponding to a five percent load range drop) and N_f (cycles to complete specimen separation) for each test condition and material.

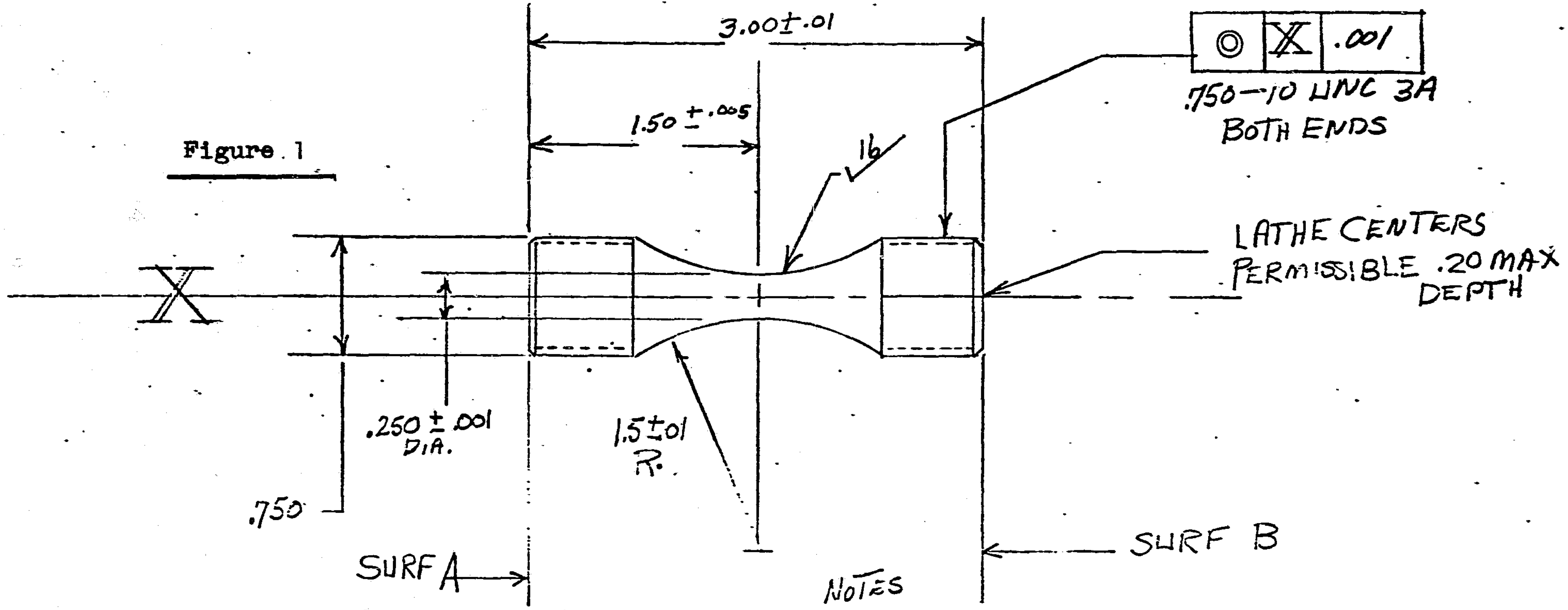
III - MATERIALS AND SPECIMENS

A total of nineteen (19) alloy designations was involved throughout the course of the material evaluations performed by Mar-Test Inc. on NASA Contracts NAS3-16753 and NAS3-17777. These designations together with a brief alloy definition are as follows:

R-0	Zirconium-copper, annealed
R-1	Zirconium-copper, ¼ hard
R-2	Zirconium-copper, ½ hard
R-3	Tellurium-copper, ½ hard
R-4	Chromium-copper, solution annealed and aged
R-5	OFHC copper, hard
R-6	OFHC copper, ¼ hard
R-7	OFHC copper, annealed
R-8	Silver, as-drawn
R-9	Zr-Cr-Mg copper, solution annealed, cold worked and aged
R-10	Electroformed copper, 30-35 ksi
R-13	Co-Be-Zr copper, solution annealed and aged
R-20	A second lot of zirconium-copper, ½ hard
R-21	NASA 1-1A copper alloy, aged
R-22	NASA 1-1B copper alloy, as-received
R-23	Glidcop AL-10
R-24	Narloy Z, centrifugally cast, hot-rolled, solution annealed and aged
R-25	Sputtered zirconium-copper, annealed
R-26	Sputtered zirconium-copper, as-sputtered

All these materials were supplied by NASA-Lewis Research Center to Mar-Test Inc. and test specimens were then fabricated in accordance with the design shown in Figure 1. Special storage procedures were observed for the as-fabricated and post-test specimens and these are described in the contractor reports covering the test programs mentioned above.

Figure 1



NOTES

1- SURFACES A, & B TO BE PARALLEL WITHIN .001
2- SURFACES A, & B TO BE PERPENDICULAR TO CENTER LINE OF SPECIMEN WITHIN .0005 TIR
3- CONTOURED PORTION OF SPECIMEN TO HAVE A $\sqrt{}^{16}$ FINISH OR BETTER. FINISHING SHOULD BE IN THE AXIAL DIRECTION USING LOW STRESS LAPPING OR POLISHING OPERATION
4- ALL DIA'S TO BE CONCENTRIC WITHIN .001 TI.
5- SCREW THREADS TO BE AS LISTED IN NBS HANDBOOK H 28

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
±	±	±

ALL SURFACES $\sqrt{}^{32}$

MATERIAL
GOVT. OR COML. TO BE SPECIFIED

DRAWN
DATE
APPD
ISSUED

APPROVED	DATE
ENGR QtC	1-12-71
MFG	
MATL	

SPECIMEN
LOW CYCLE FATIGUE

Mar-Test inc.
CINCINNATI, OHIO

SIZE MTI-1002

SCALE 1/1
WT CALC ACTUAL
CONT ON SHEET
SH NO.

IV - DISCUSSION OF DATA

A review of all the low-cycle fatigue tests performed on the two previous NASA-sponsored programs at Mar-Test Inc. led to the summary presented in Table 1. Each task of each program is treated individually to indicate the number of low-cycle fatigue tests performed for each material. This sequencing was also used in the presentation of the data plots and summary tables for this report. In other words, the data for the R-0 tests are presented first, followed by the data for the R-1 tests, etc. It will be noted that there are 188 tests involved in this data reporting activity.

For each test the load traces were reviewed first and a plot was made of the load range as a function of the number of cycles. In general, the first and second cycle information was read from the x-y traces (stress-strain hysteresis loops) and these points were plotted. Then this plotting was continued for subsequent cycles using load range information as read from the strip-chart recordings. A sufficient number of data points was selected throughout the fatigue life to define a fairly smooth pattern for the plot of load range versus cycles. Such plots for the 188 tests involved in this evaluation are presented in Figures 2 through 189. Each figure identifies alloy code number (see Table 1), specimen number, test temperature, strain range, strain rate and cycles to failure.

A typical hysteresis loop for each test is presented in Figures 190 through 288. It was the intent here to show the cyclic stress-strain behavior near half-life but in many cases no hysteresis loops were recorded in the immediate vicinity of $N_f/2$. In these instances the hysteresis loop selected for reporting was the one closest to half-life and usually in the region prior to $N_f/2$. The particular cycle used in such plots is recorded in the figure along with the temperature, strain range and cycles to failure.

A final data summary prepared for this report is presented in Table 2. For each test, values of N_5, the cycles to a five percent load range drop, and N_f, cycles to complete specimen separation, are compared. Some interpretation of N_5 had to be made in those instances where cyclic softening was exhibited. In these situations the plot of load range versus cycles on semi-logarithmic coordinates indicated a gradual decrease in the load range as cycling progressed and it was not possible to identify a stabilized load range for calculating a five percent reduction. The special interpretation adopted for these cases involved the selection of that point on the load range plot where a change in curvature first began to appear as the load range began to decrease rapidly as failure approached. A five percent drop from this load range value was then used to establish the value for N_5. In a few cases no value of N_5 is reported (in Table 2) due either to the fact that the specimen failed before a five percent load range reduction was reached or, because of the orientation of the crack with respect to the extensometer tips, the load range actually increased slightly near the failure point.

Table 1 - Summary of Low-Cycle Fatigue Tests Performed by Mar-Test Inc. in Two Previous Programs

CONTRACT NAS3-16753; initation date: June 29, 1972

Alloy Designation	Material	Number of Tests
	Task I ********	
R-0	Zirconium-copper,annealed	6
R-1	Zirconium-copper, ¾ hard	6
R-2	Zirconium-copper, ½ hard	8
R-3	Tellurium-copper, ½ hard	6
R-4	Chromium-copper, SA and aged	6
R-5	OFHC copper, hard	6
R-6	OFHC copper, ¼ hard	7
R-7	OFHC copper, annealed	6
R-8	Silver, as-drawn	6
R-9	Zr-Cr-Mg copper,SA,CW and aged	7
R-10	Electroformed copper, 30-35 ksi	6
R-13	Co-Be-Zr copper, SA and aged	6
	Task II *********	
R-2	Zirconium-copper, ½ hard	25
	Task III **********	
R-2	Zirconium-copper, ½ hard	17
R-20	Zirconium-copper, ½ hard	6

Table 1 continued - Summary of Low-Cycle Fatigue Tests Performed by Mar-Test Inc. in Two Previous Programs

CONTRACT NAS3-17777; initiation date: June 28, 1973

Alloy Designation	Material	Number of Tests
	Task I ********	
R-24	Narloy Z, HR, SA and aged	29
R-2	Zirconium-copper, ½ hard	2
	Task II *********	
R-21	NASA 1-1A copper alloy, aged	4
R-22	NASA 1-1B copper alloy, as-received	20
R-23	Glidcop AL-10	4
R-25	Sputtered zirconium-copper, annealed	4
R-26	Sputtered zirconium-copper, as-sputtered	1
	Overall Total:	188 tests

a) LOAD RANGE PLOTS

Figures 2 through 189

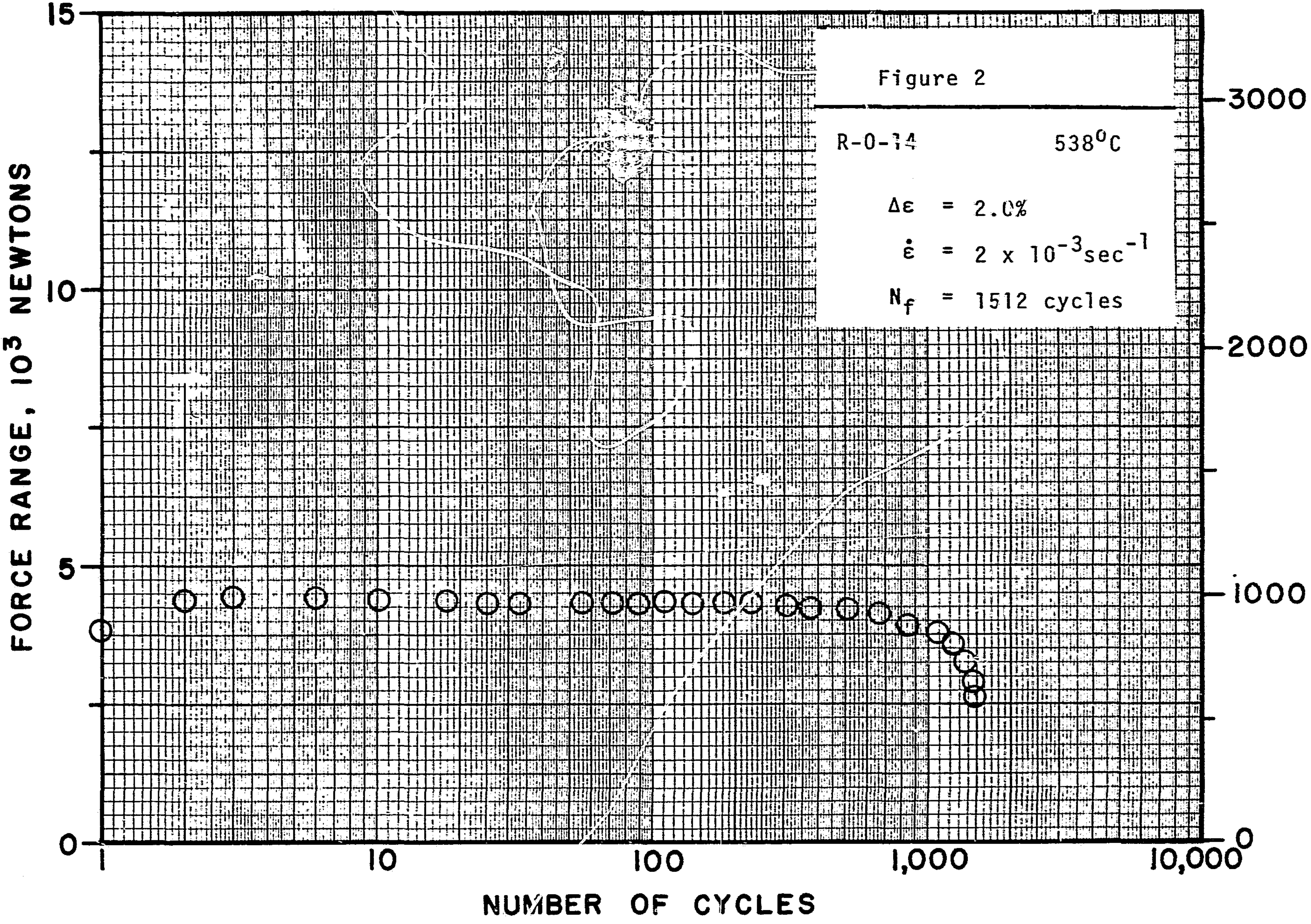


Figure 2

R-0-14
538^{0}C
$\Delta\varepsilon$ = 2.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 1512 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
NUMBER OF CYCLES
1
10
100
1,000
10,000

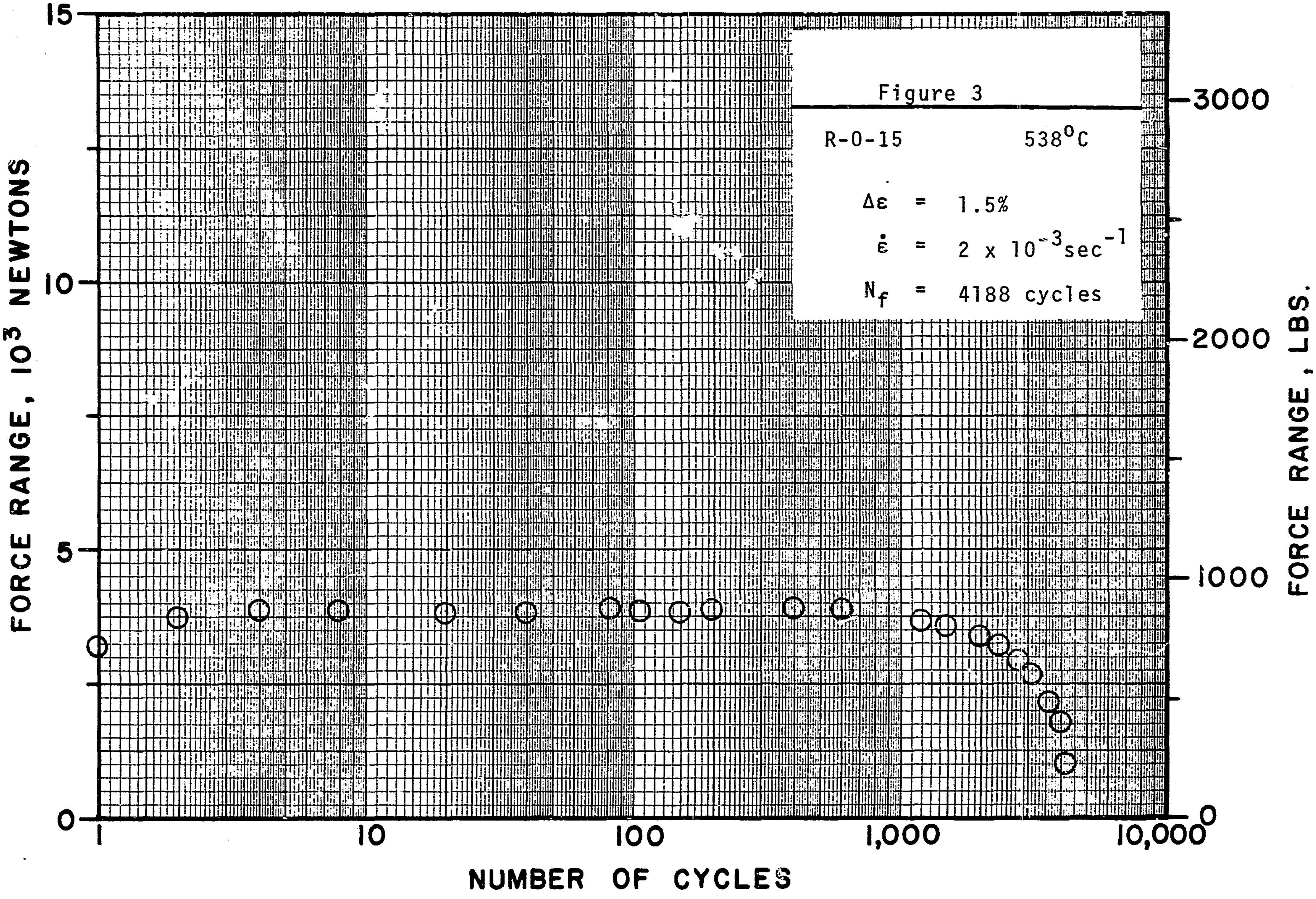


Figure 3

R-0-15
538°C
Δε = 1.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 4188 cycles
FORCE RANGE, 10³ NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

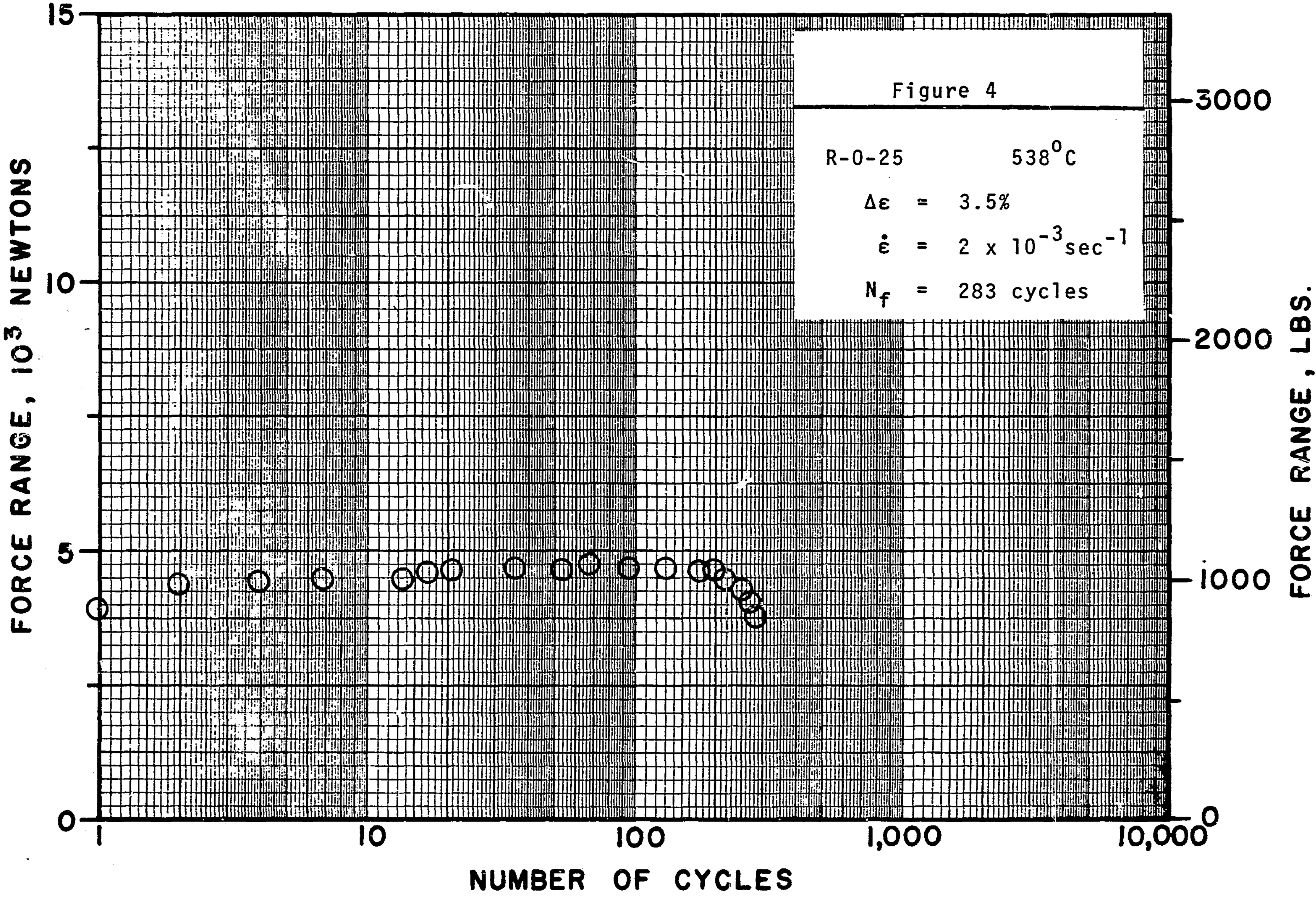


Figure 4
R-0-25
538°C
Δε = 3.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 283 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
1
10
100
1,000
10,000
NUMBER OF CYCLES

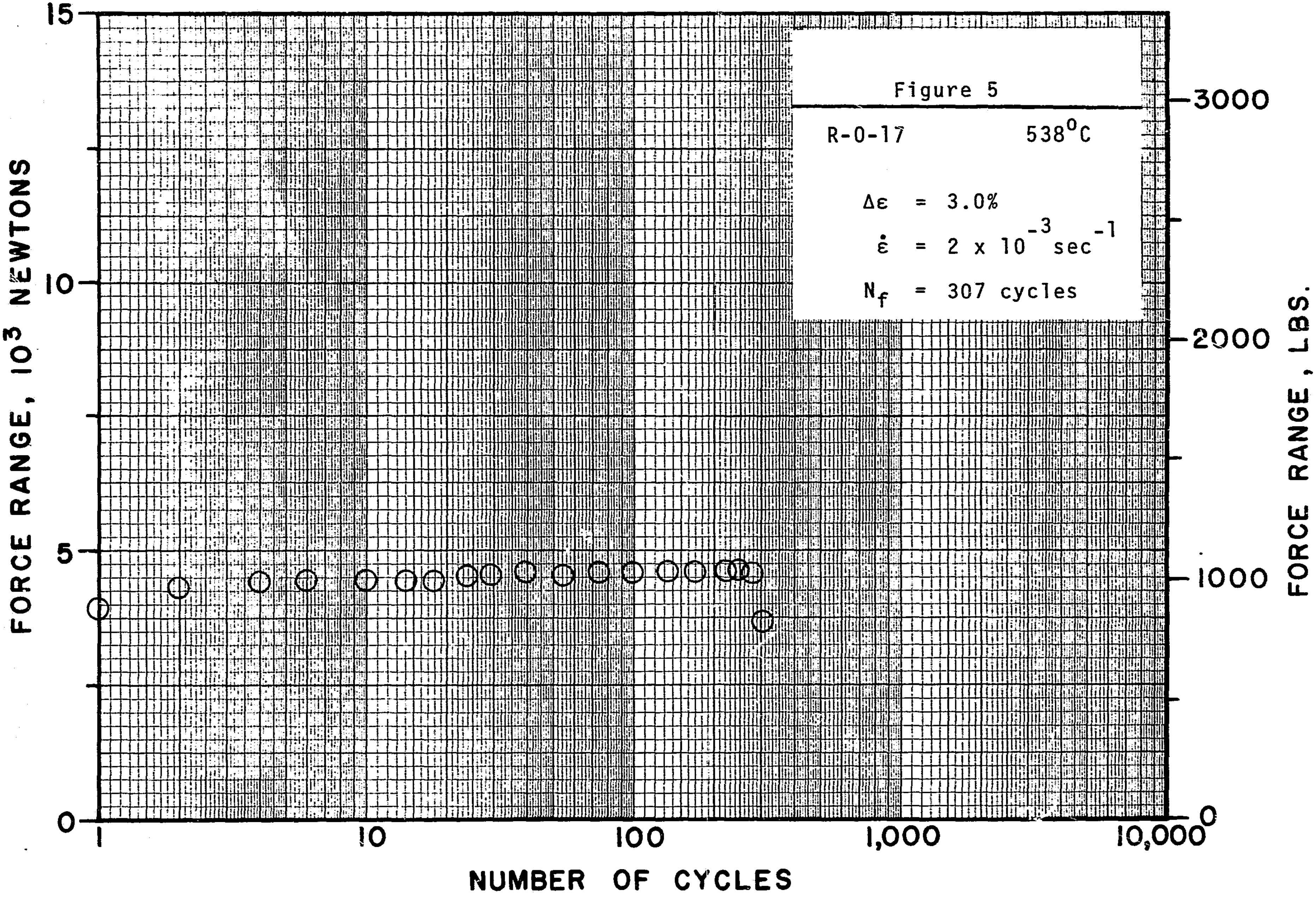


Figure 5

R-0-17 538°C

$\Delta\varepsilon = 3.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3}\ \mathrm{sec}^{-1}$

$N_f = 307$ cycles

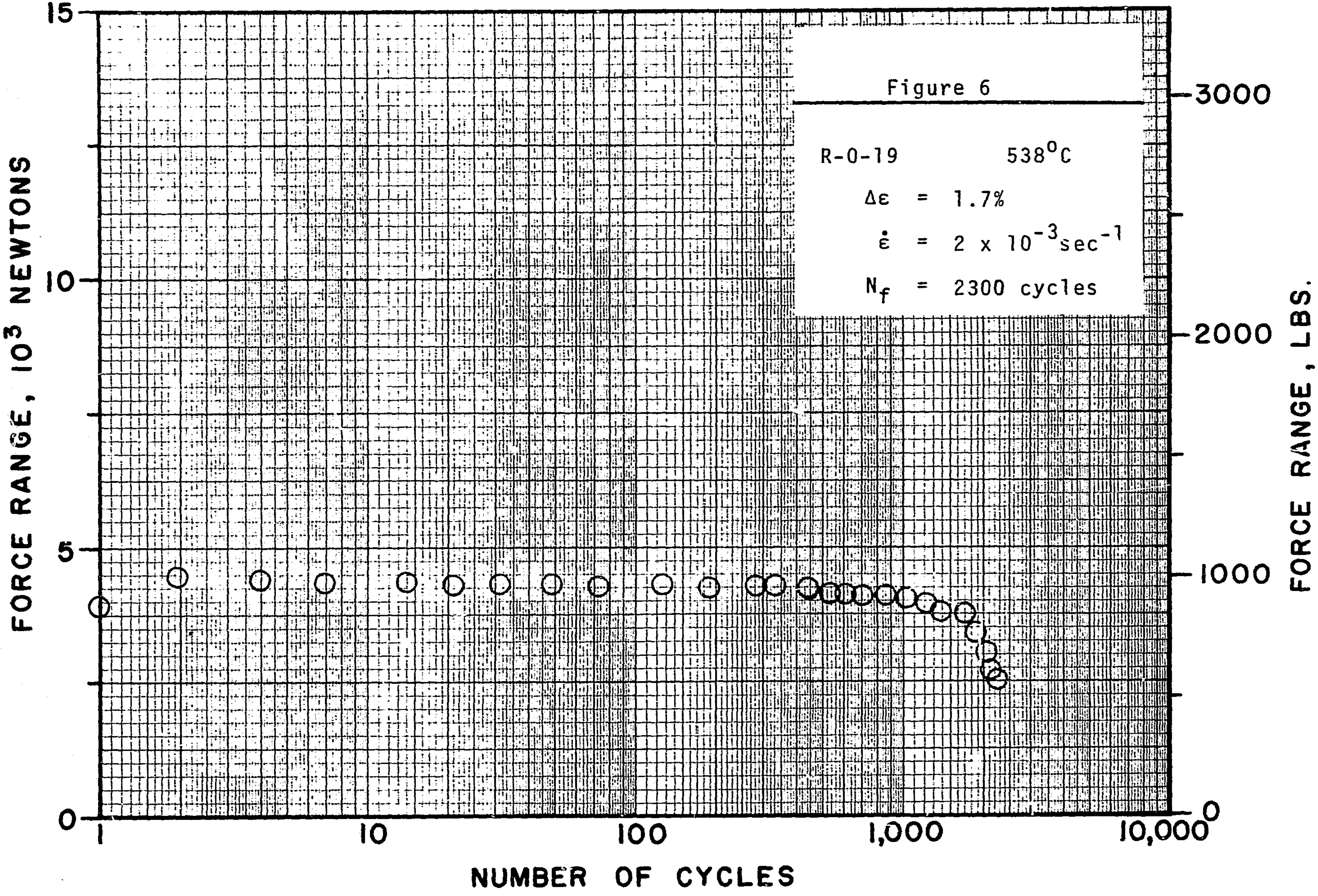


Figure 6

R-0-19
538°C
Δε = 1.7%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 2300 cycles
FORCE RANGE, 10³ NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

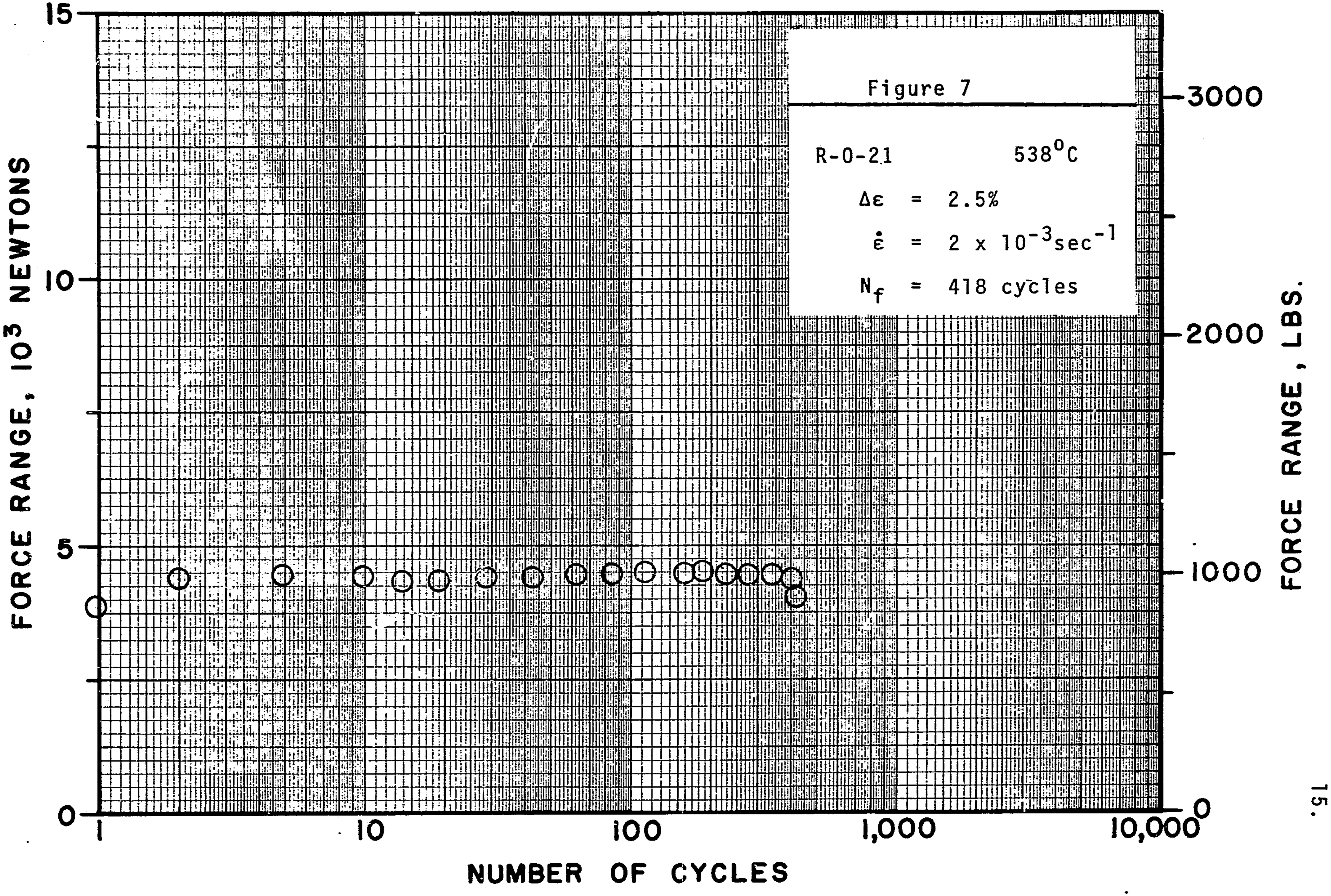


Figure 7

R-0-21 538°C
Δε = 2.5%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 418 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

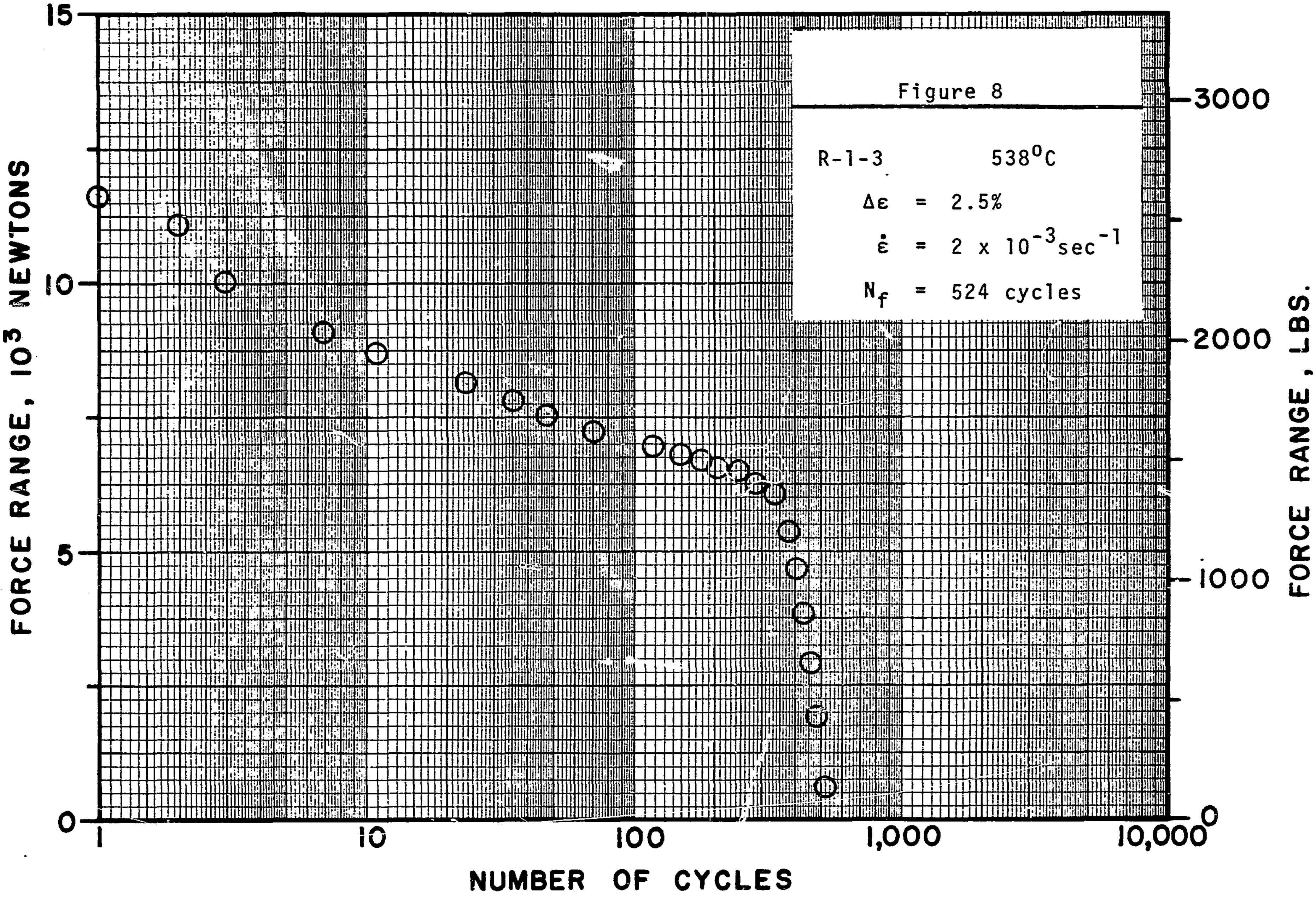


Figure 8

R-1-3 538^{0}C

$\Delta\varepsilon$ = 2.5%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 524 cycles

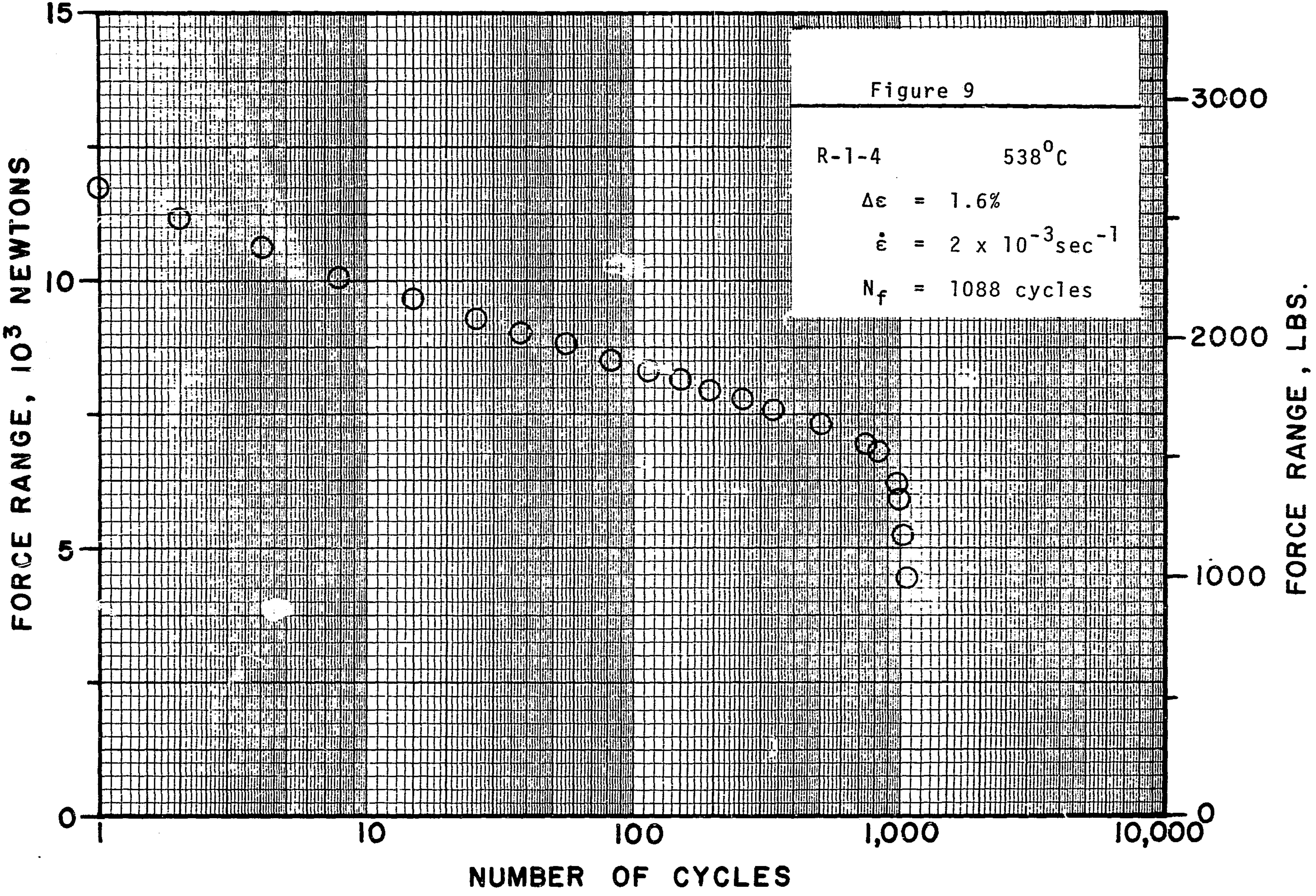


Figure 9

R-1-4 538°C

$\Delta\varepsilon = 1.6\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 1088$ cycles

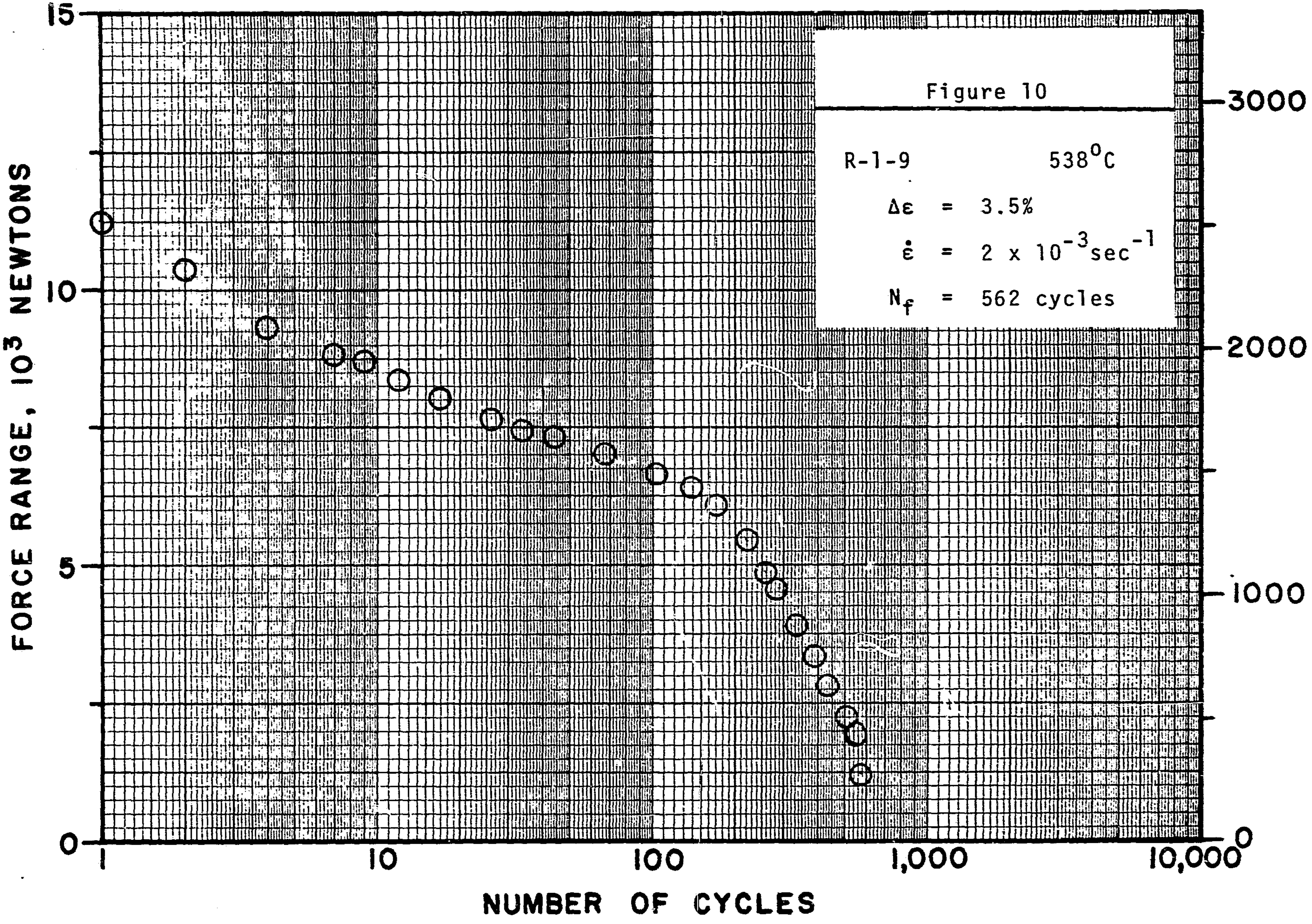


Figure 10

R-1-9
538°C
Δε = 3.5%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 562 cycles
FORCE RANGE, 10³ NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

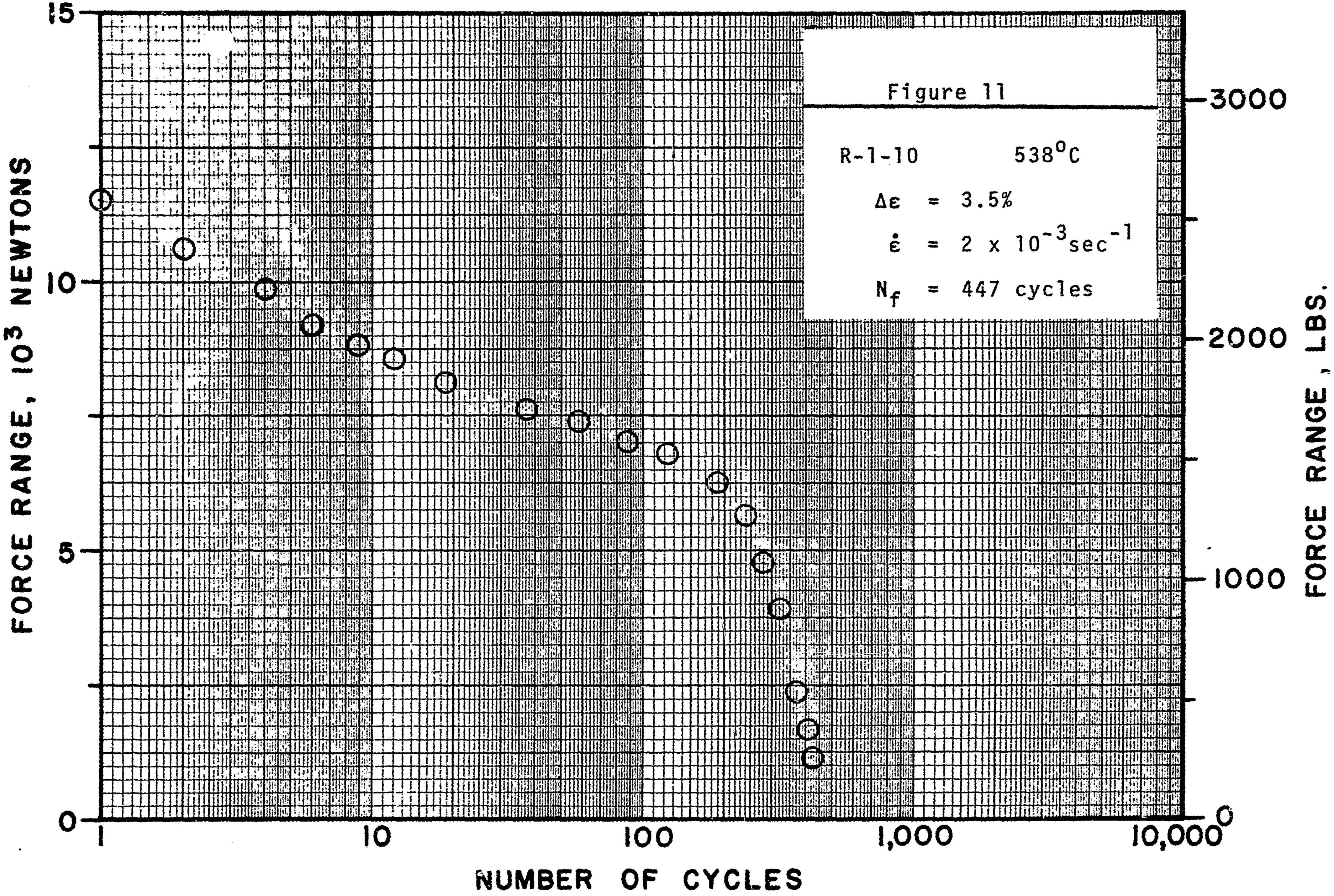


Figure 11

R-1-10 538°C
$\Delta\varepsilon$ = 3.5%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 447 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

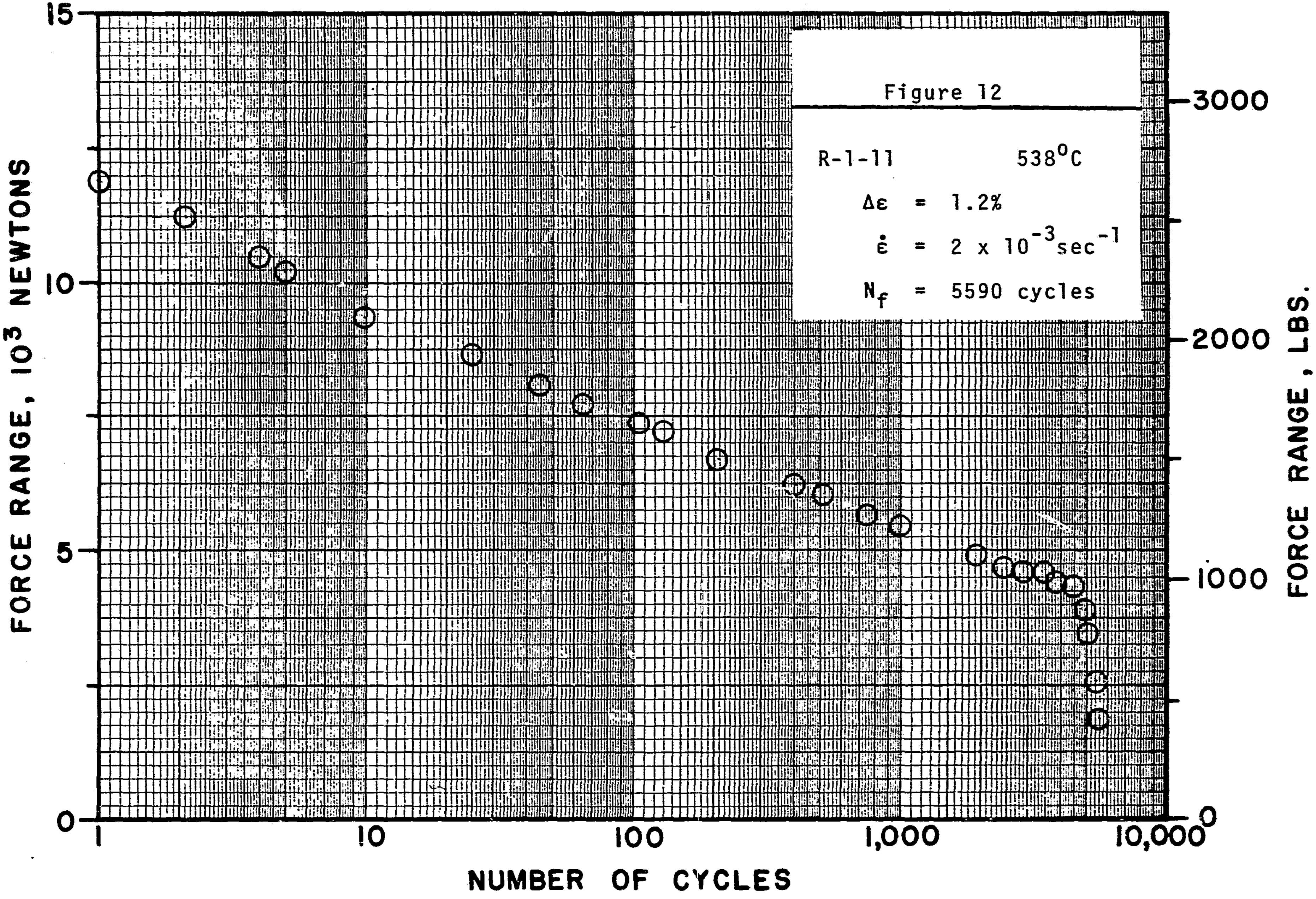


Figure 12

R-1-11 538^{0}C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 5590 cycles

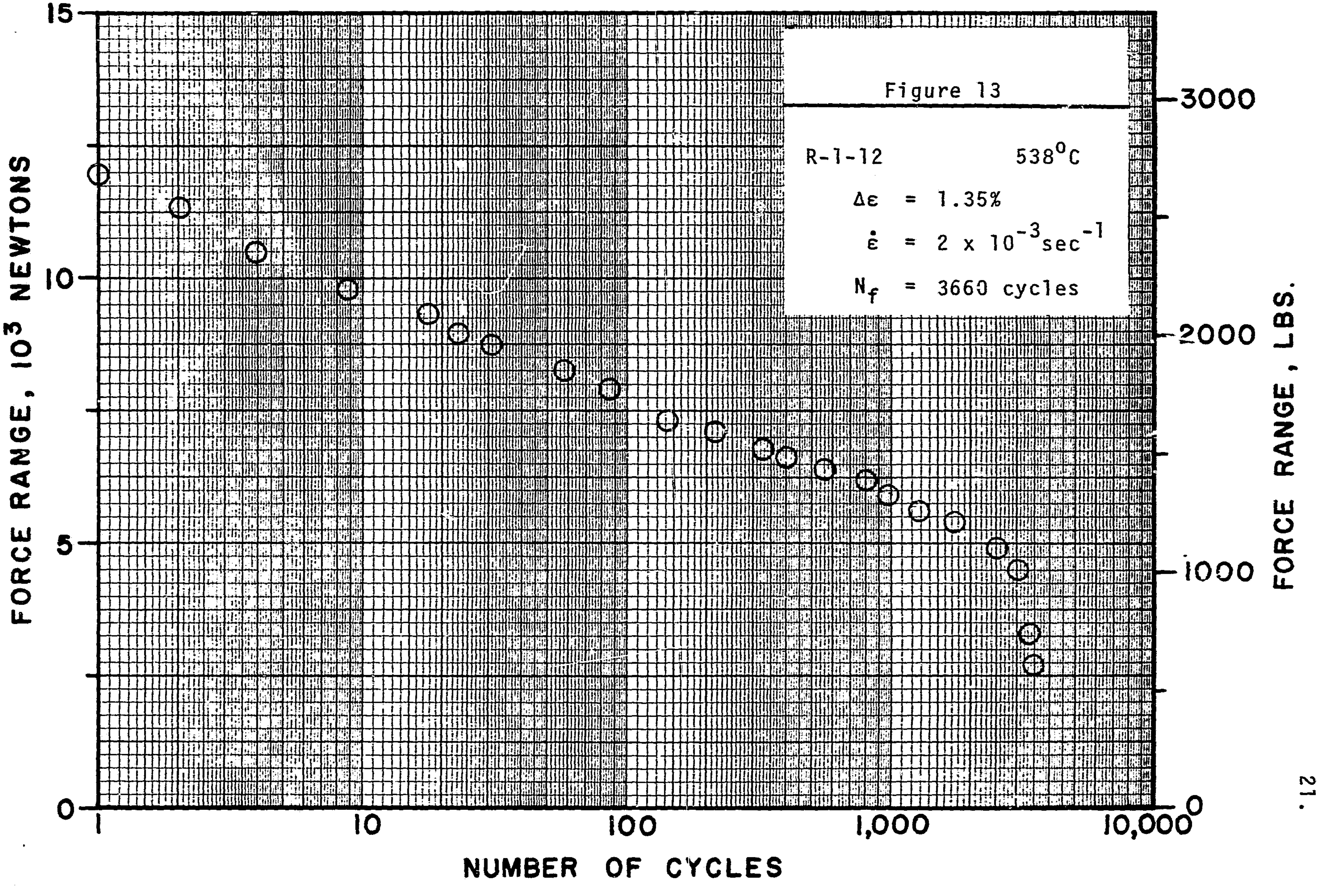


Figure 13

R-1-12 538°C

$\Delta\varepsilon = 1.35\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 3660$ cycles

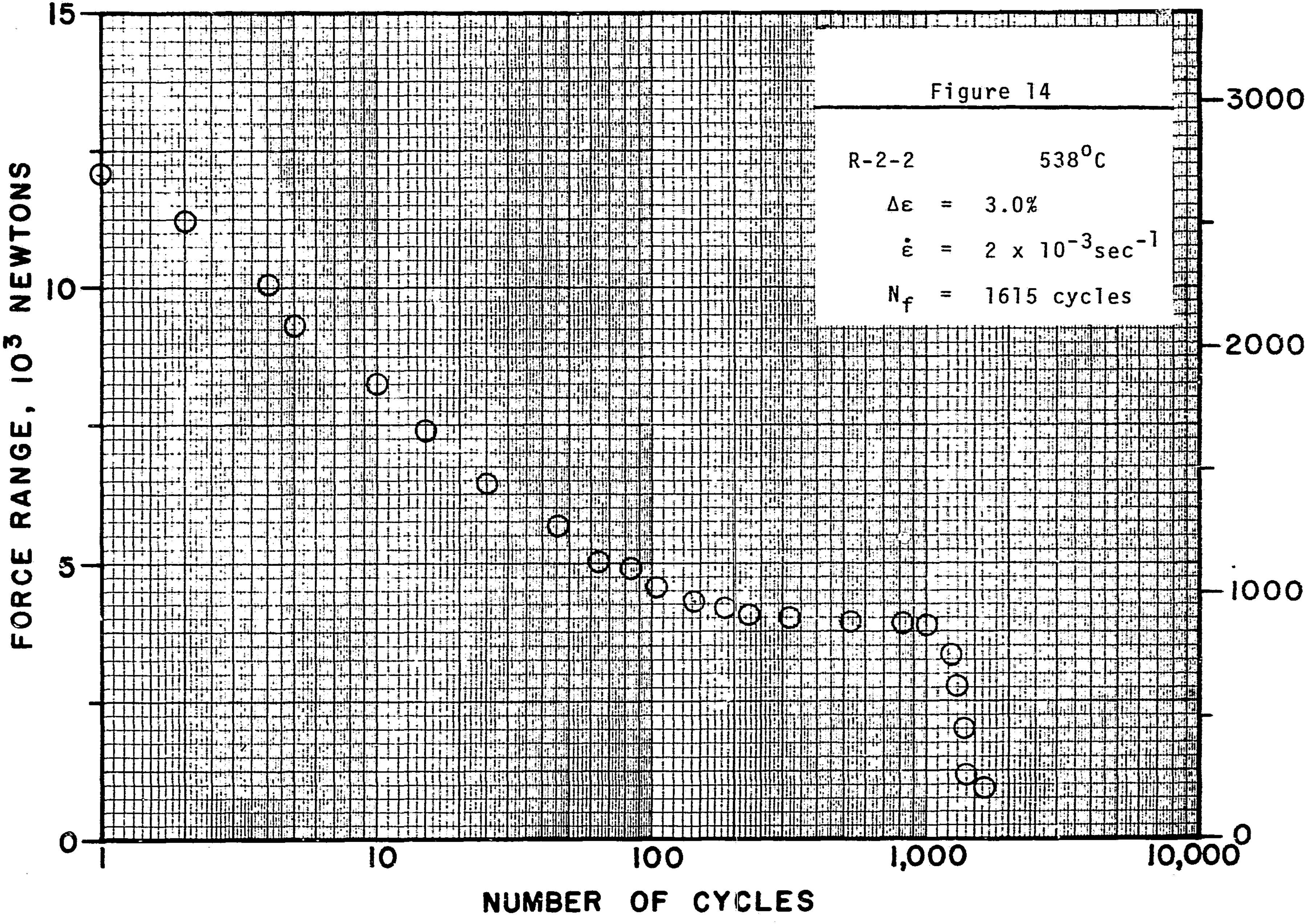


Figure 14

R-2-2 538^{0}C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1615 cycles

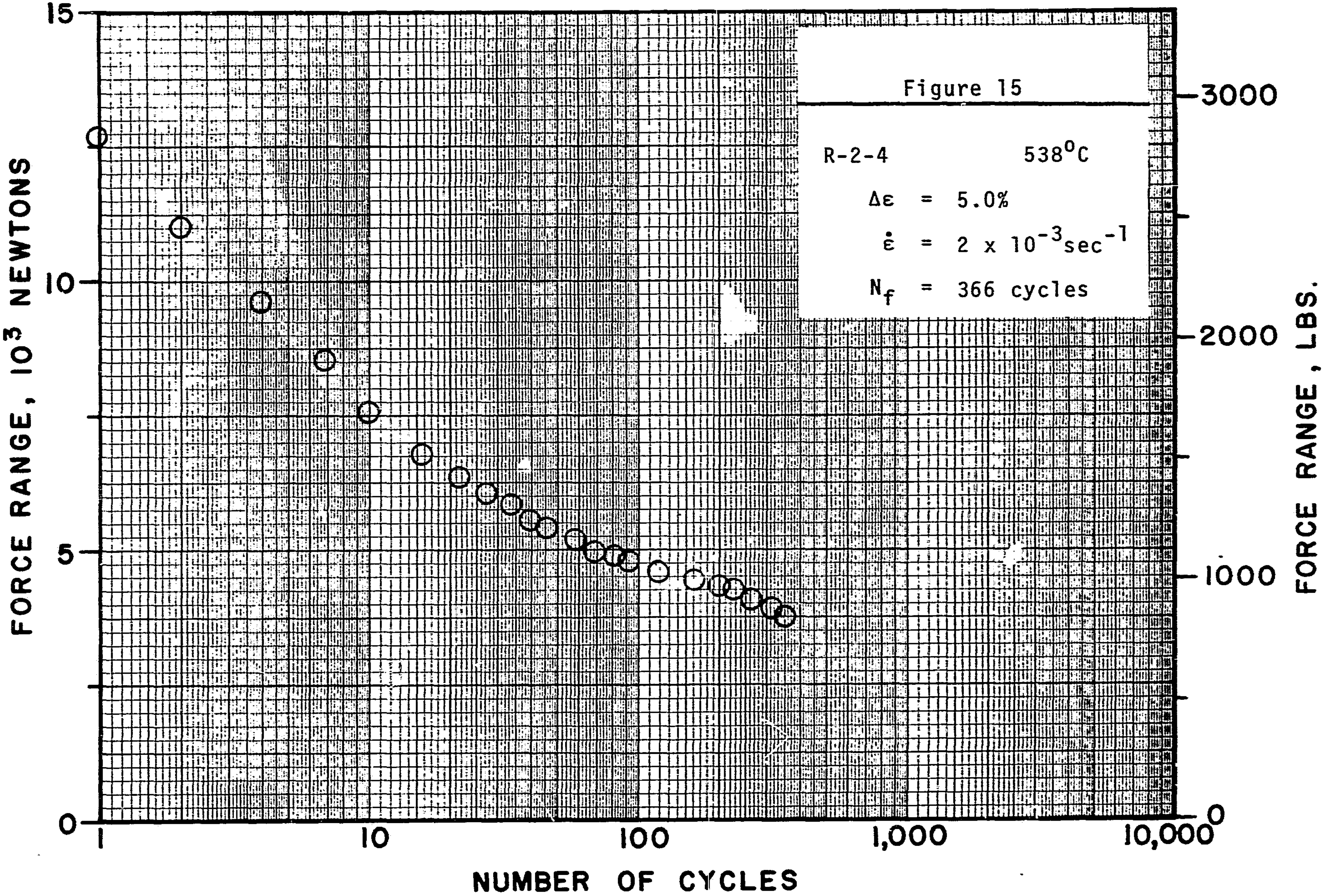


Figure 15

R-2-4 538°C

$\Delta\varepsilon = 5.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \mathrm{sec}^{-1}$

N_f = 366 cycles

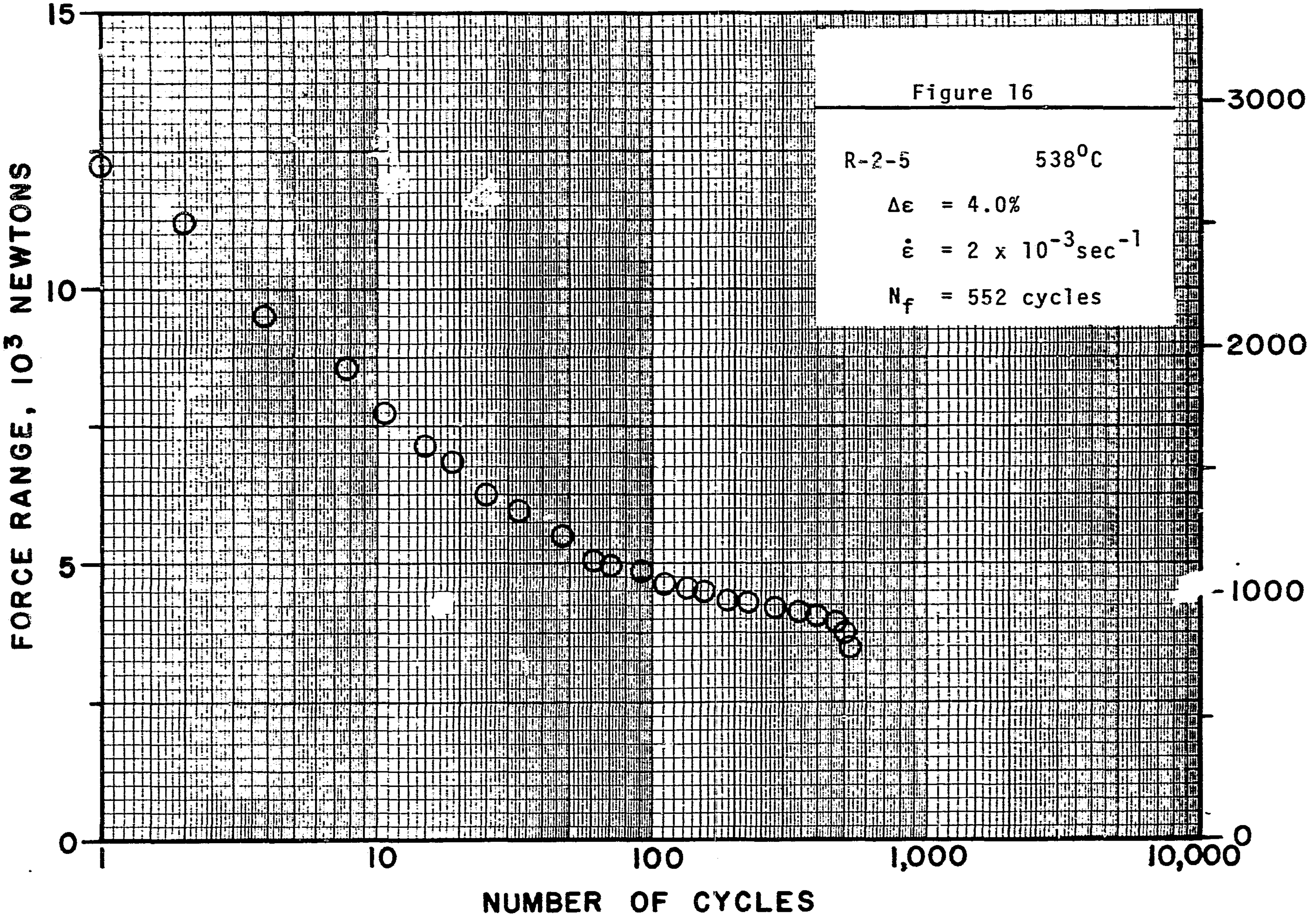


Figure 16

R-2-5 538°C

$\Delta\varepsilon$ = 4.0%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 552 cycles

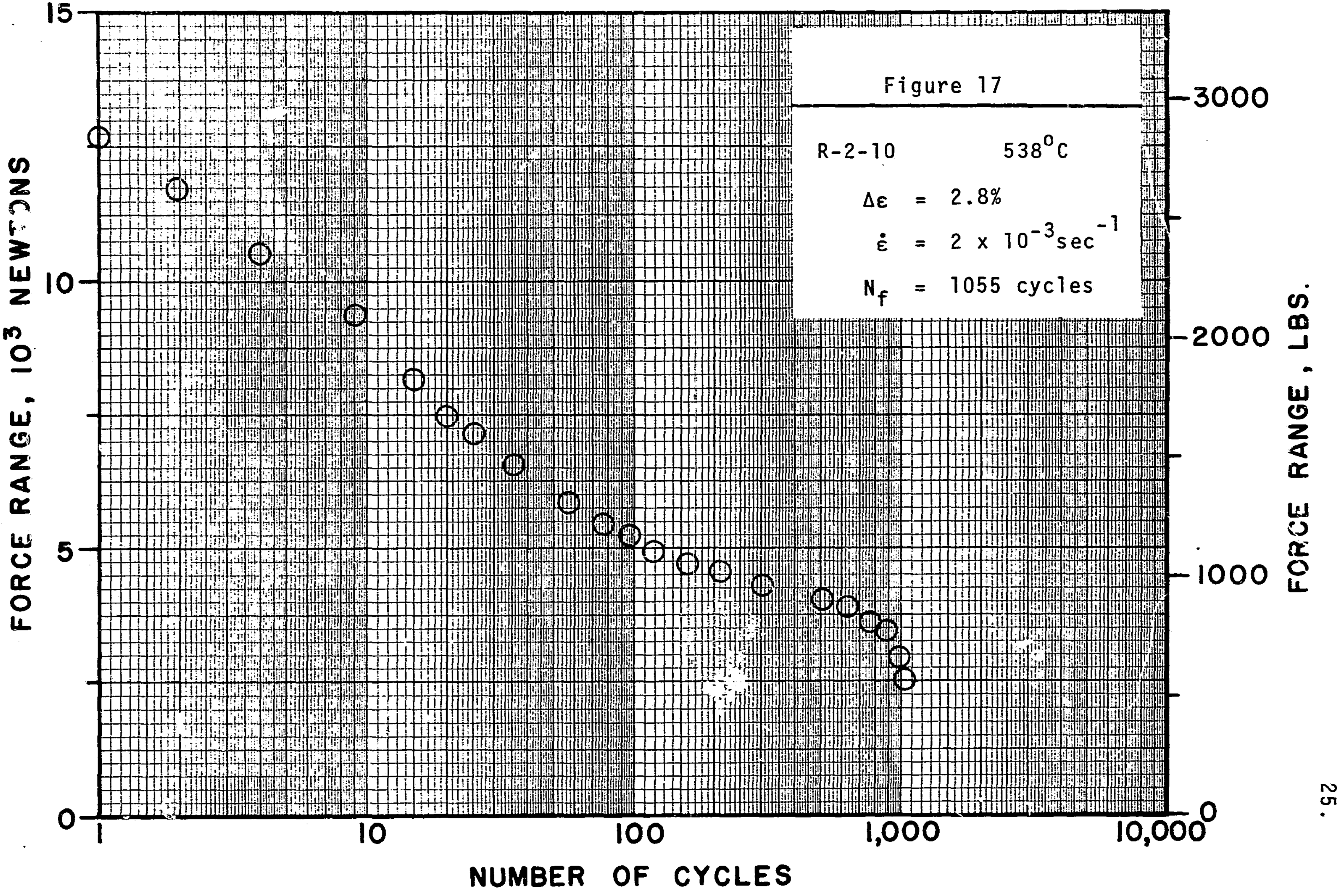


Figure 17
R-2-10 538°C
Δε = 2.8%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1055 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

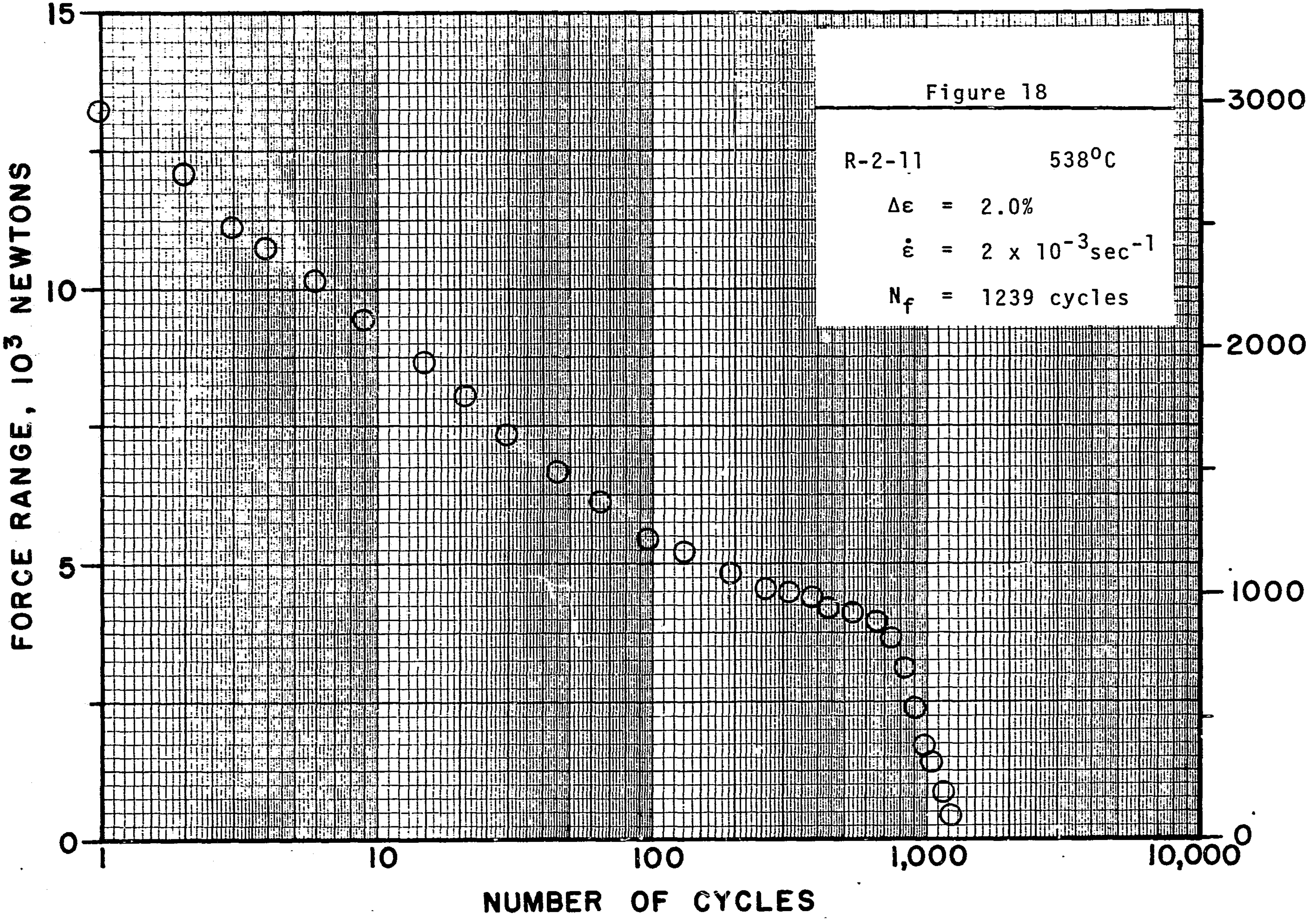


Figure 18

R-2-11 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x $10^{-3}sec^{-1}$

N_f = 1239 cycles

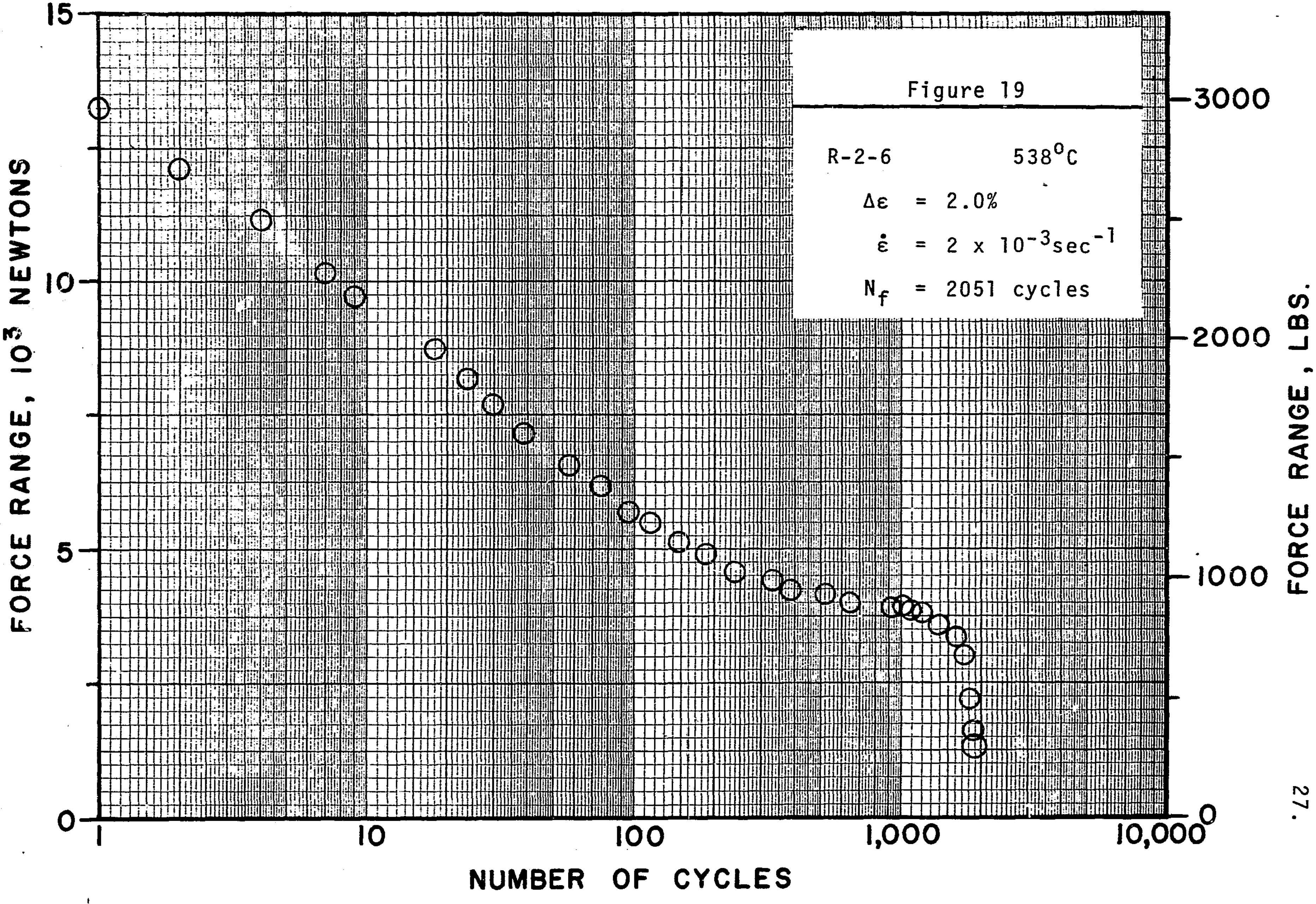


Figure 19

R-2-6 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \mathrm{sec}^{-1}$

N_f = 2051 cycles

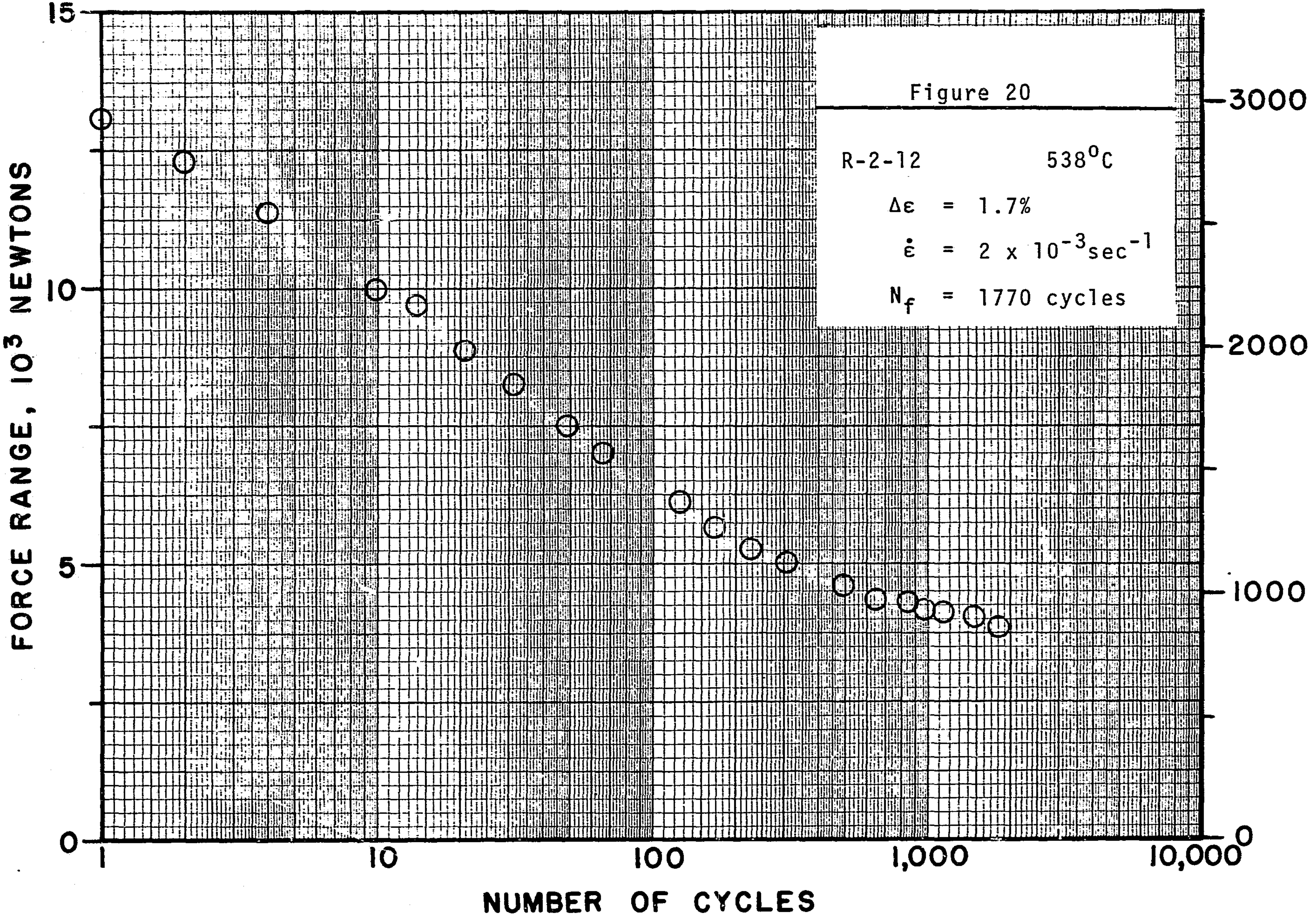


Figure 20

R-2-12 538^{0}C

$\Delta\varepsilon$ = 1.7%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1770 cycles

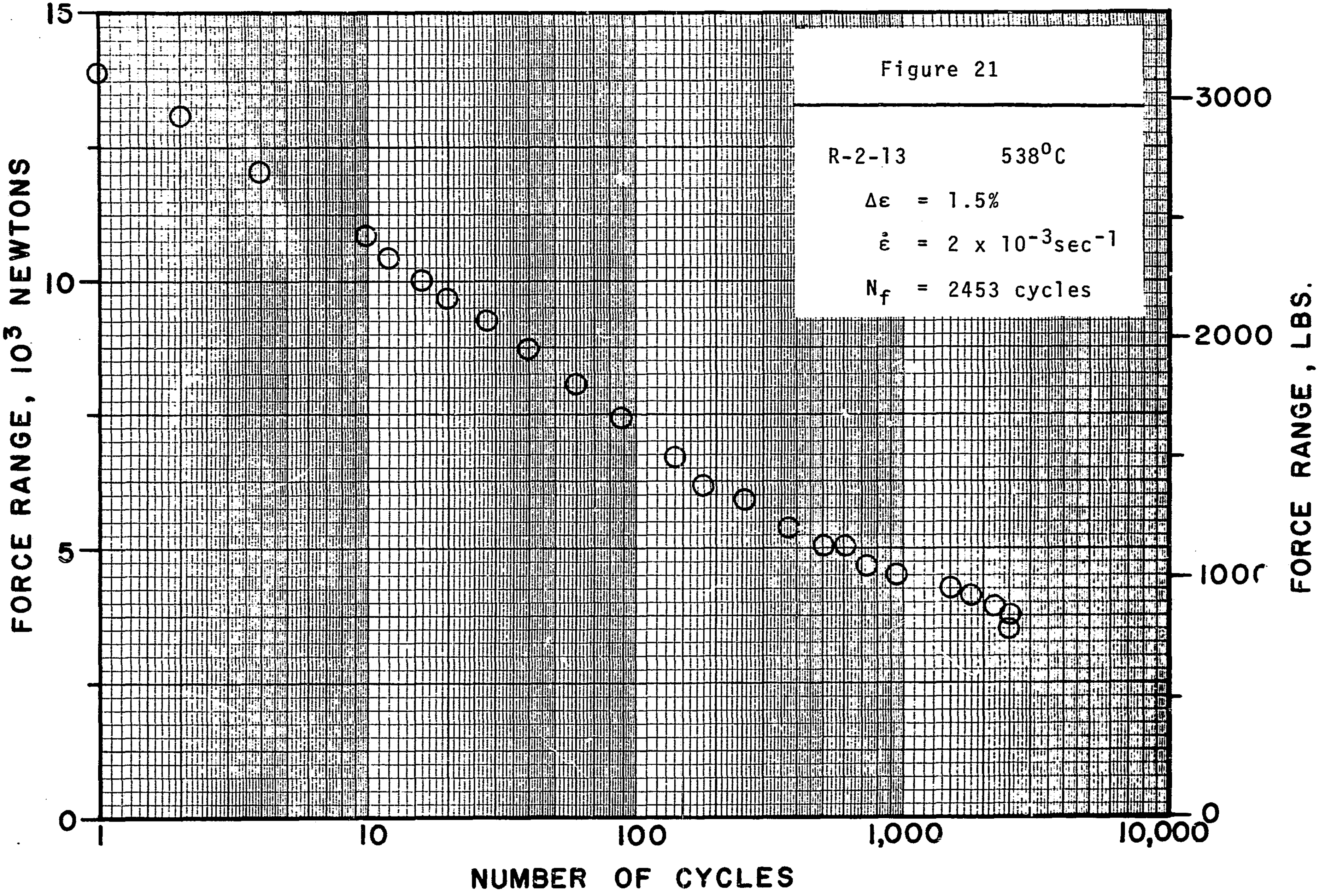


Figure 21

R-2-13 538°C

$\Delta\varepsilon = 1.5\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 2453$ cycles

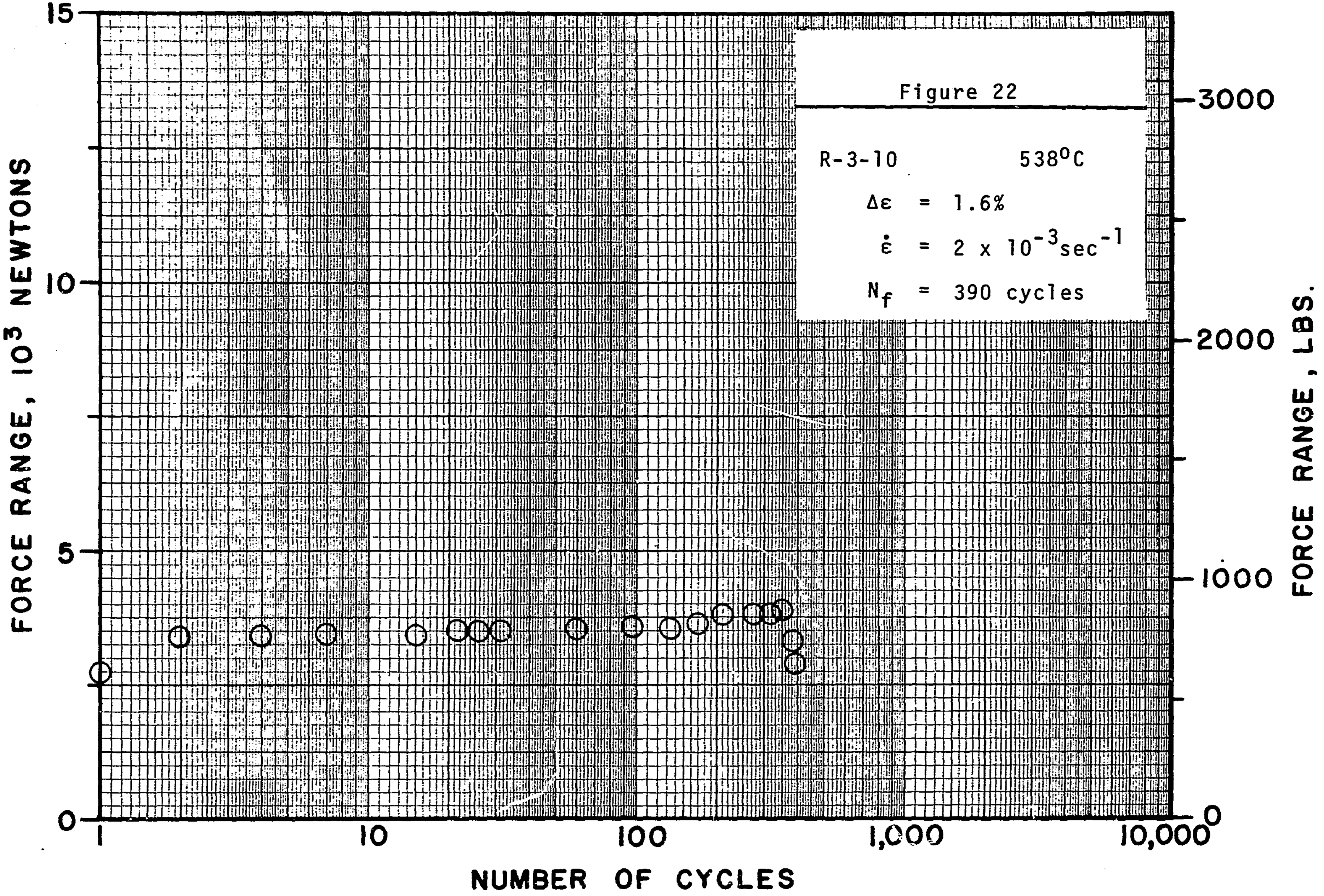


Figure 22

R-3-10 538°C

$\Delta\varepsilon$ = 1.6%

$\dot{\varepsilon}$ = $2 \times 10^{-3}\,\mathrm{sec}^{-1}$

N_f = 390 cycles

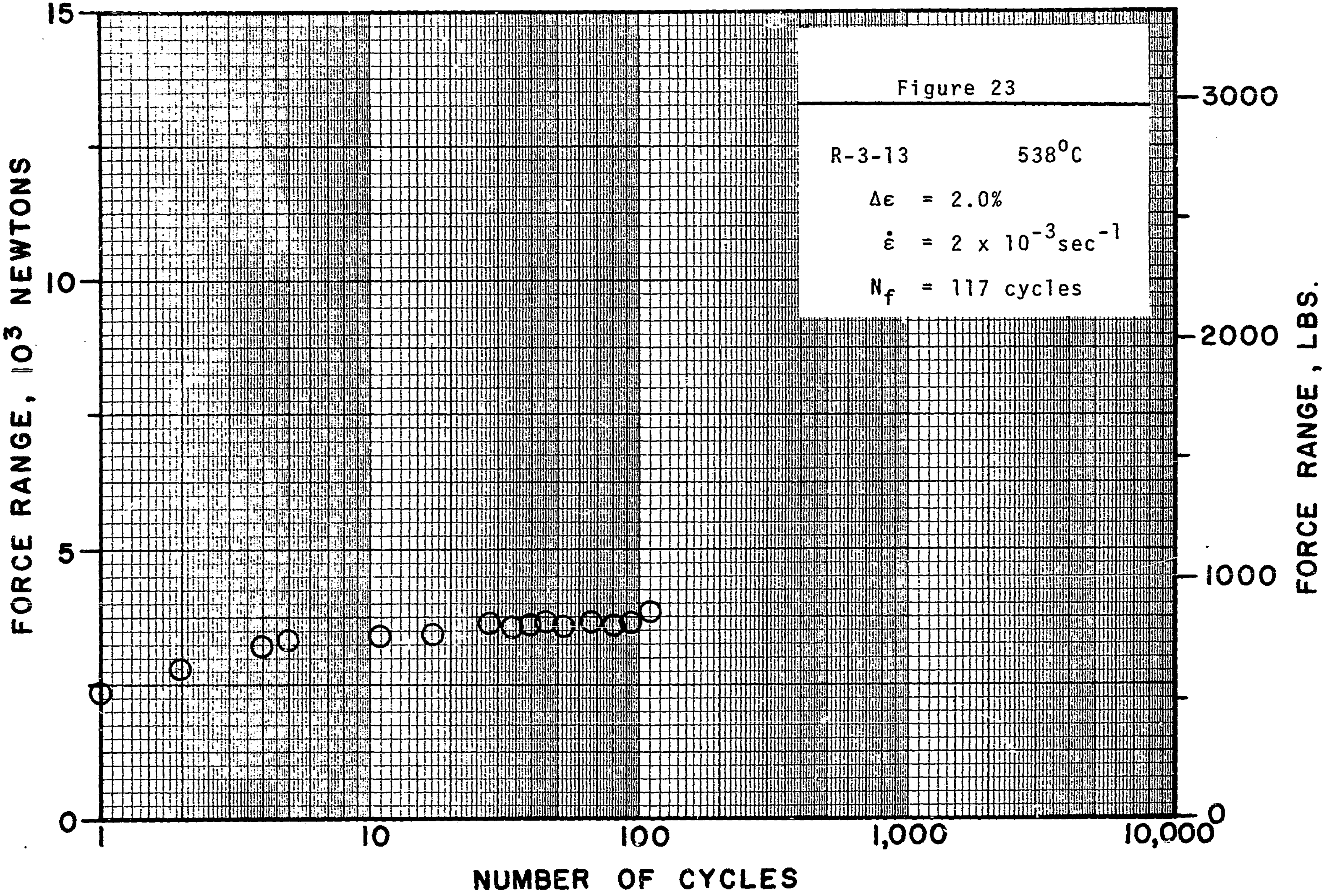

R-3-13 538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 117 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 23

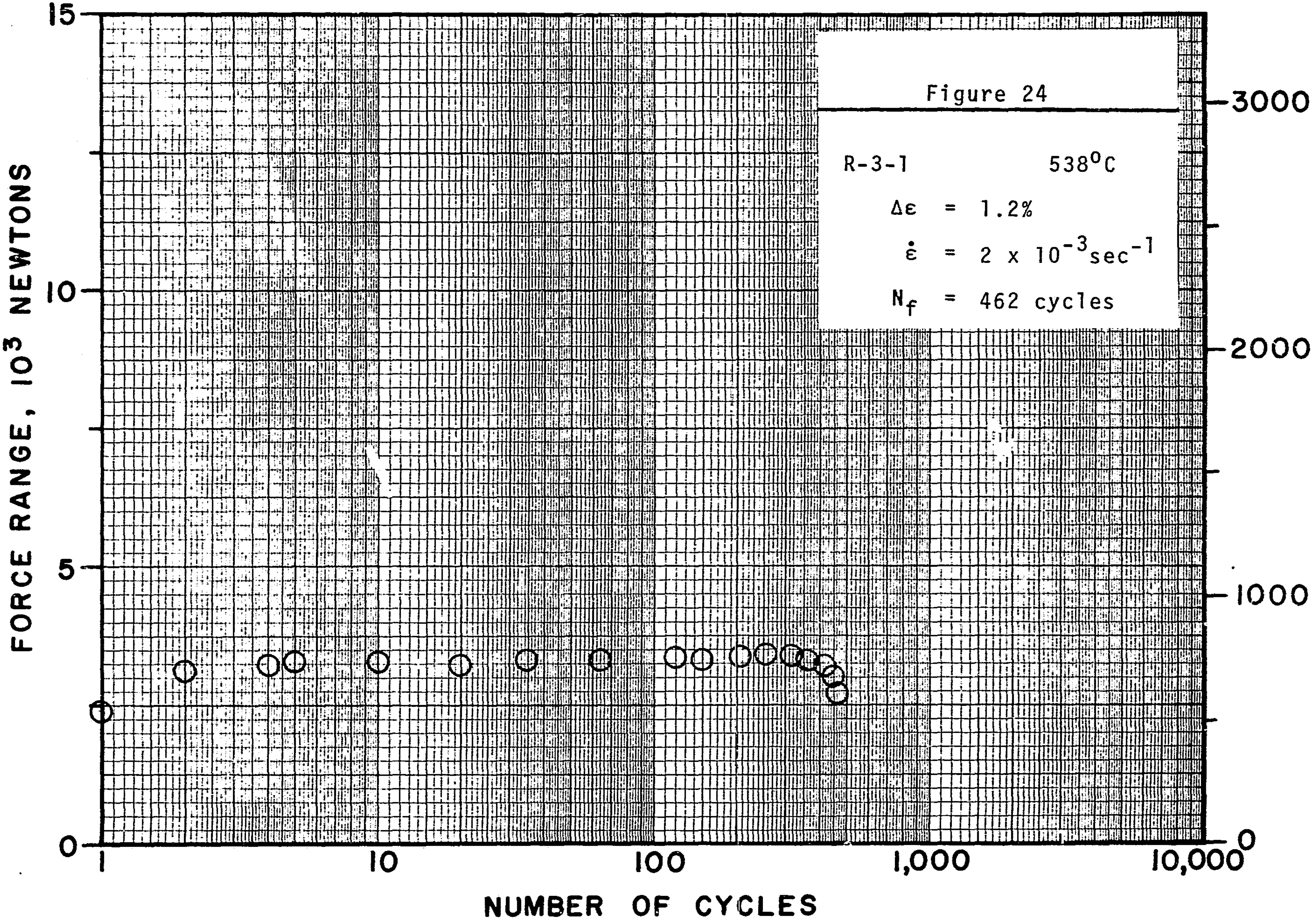


Figure 24

R-3-1 538°C

$\Delta\varepsilon = 1.2\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 462$ cycles

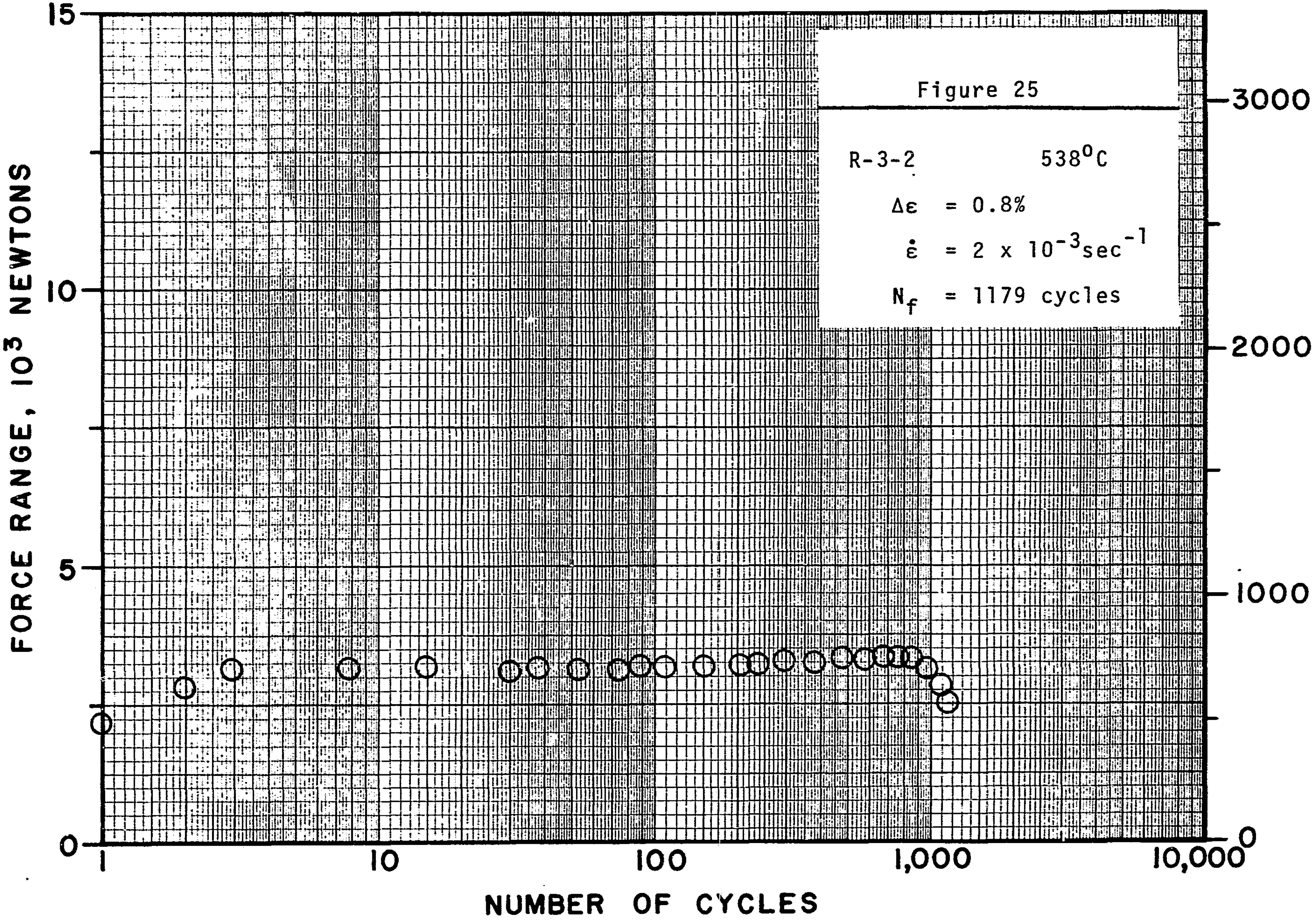


Figure 25

R-3-2 538^{0}C
$\Delta\varepsilon$ = 0.8%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 1179 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

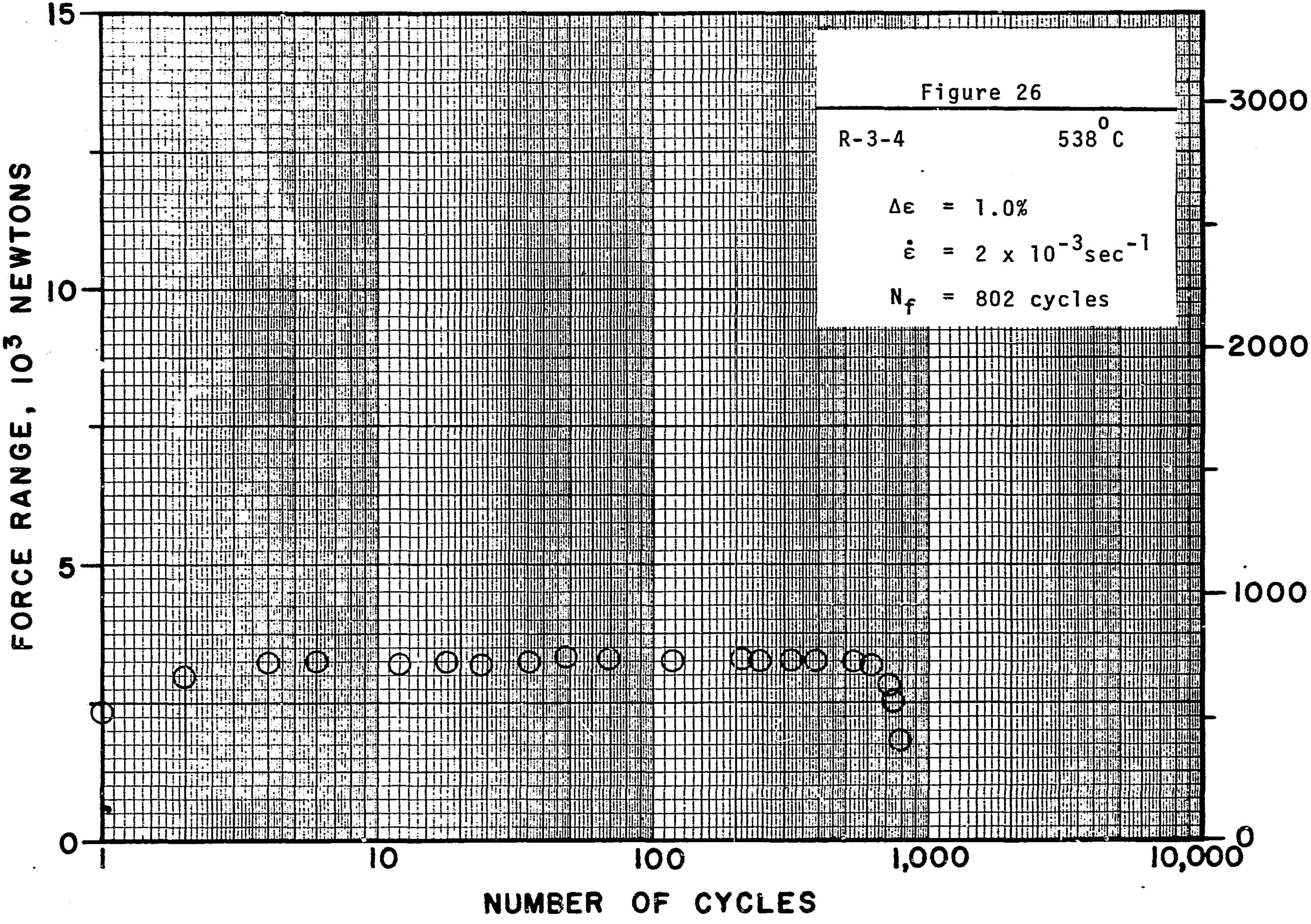


Figure 26
R-3-4
538°C
Δε = 1.0%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 802 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
NUMBER OF CYCLES
1
10
100
1,000
10,000

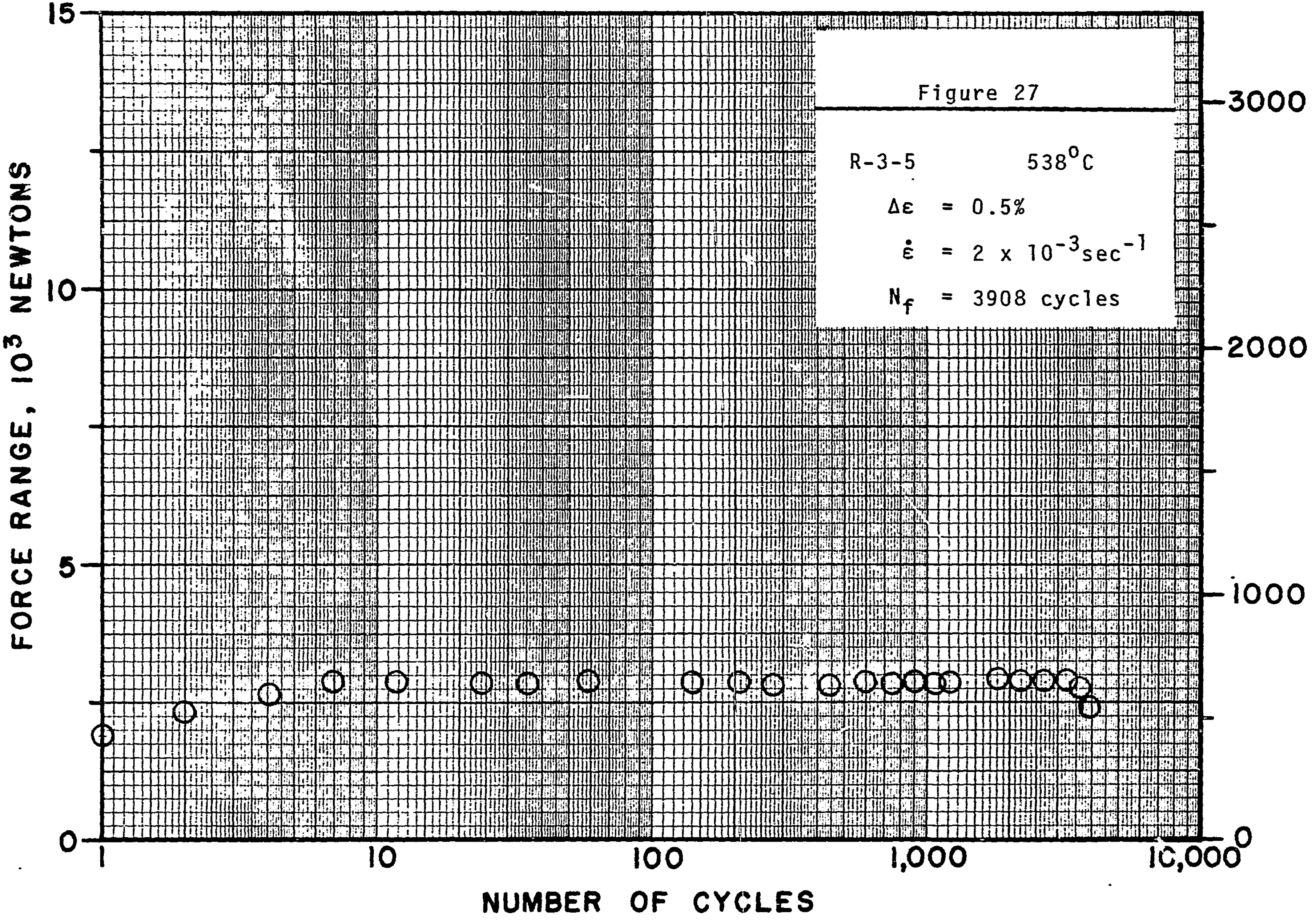


Figure 27

R-3-5 538^{0}C
$\Delta\varepsilon$ = 0.5%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 3908 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

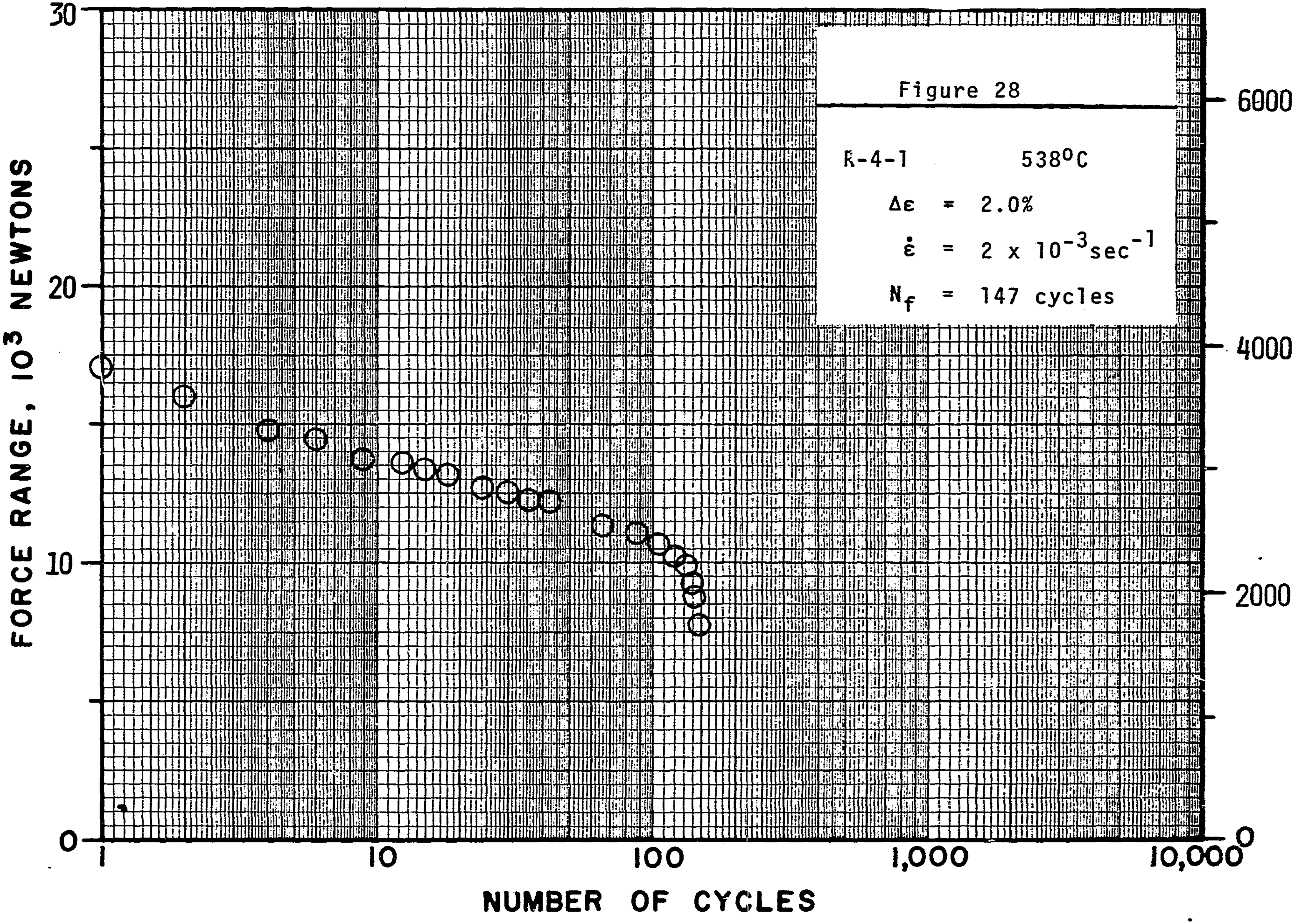


Figure 28

R-4-1 538^{0}C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 147 cycles

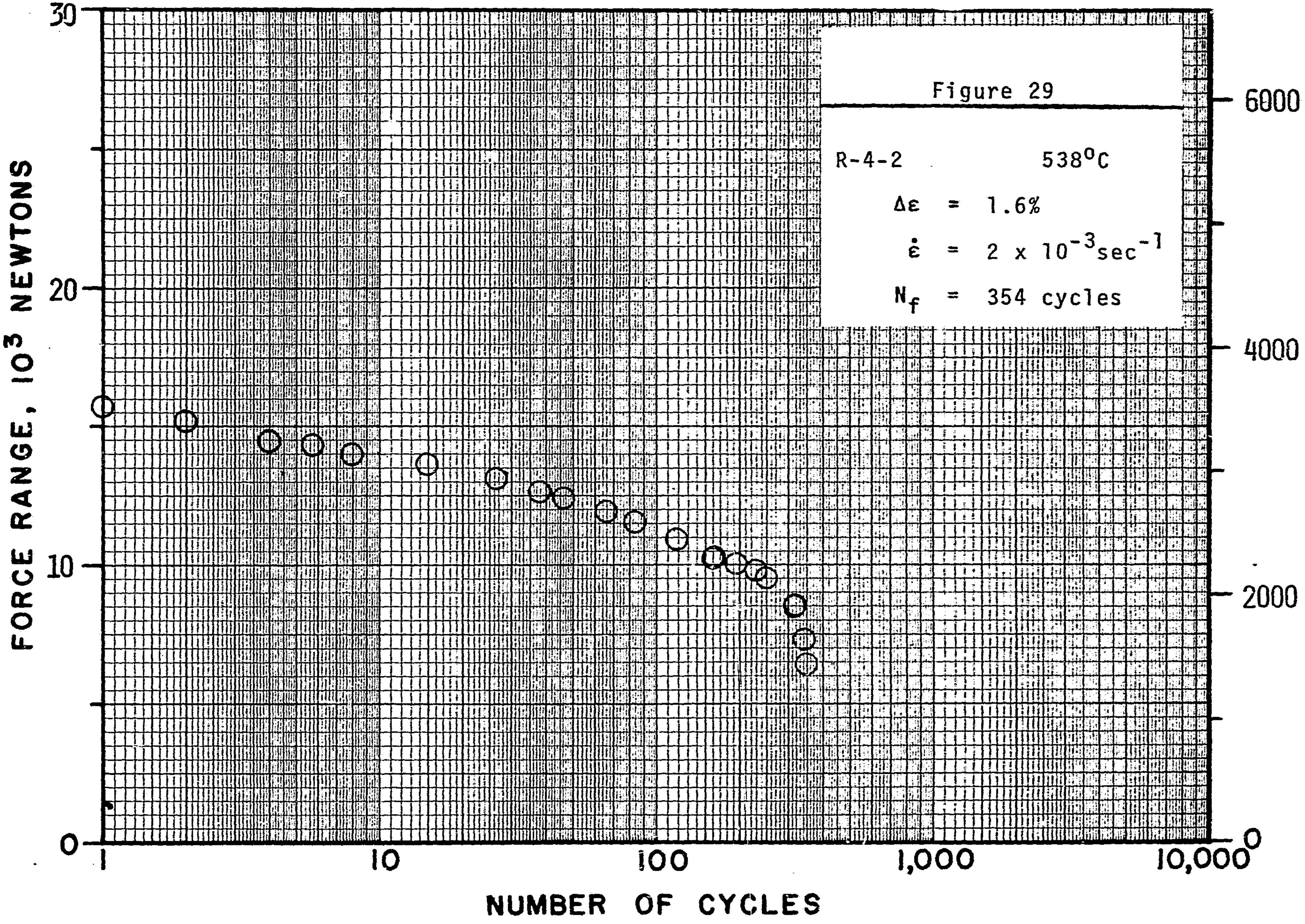


Figure 29

R-4-2 538°C
Δε = 1.6%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 354 cycles
FORCE RANGE, 10³ NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

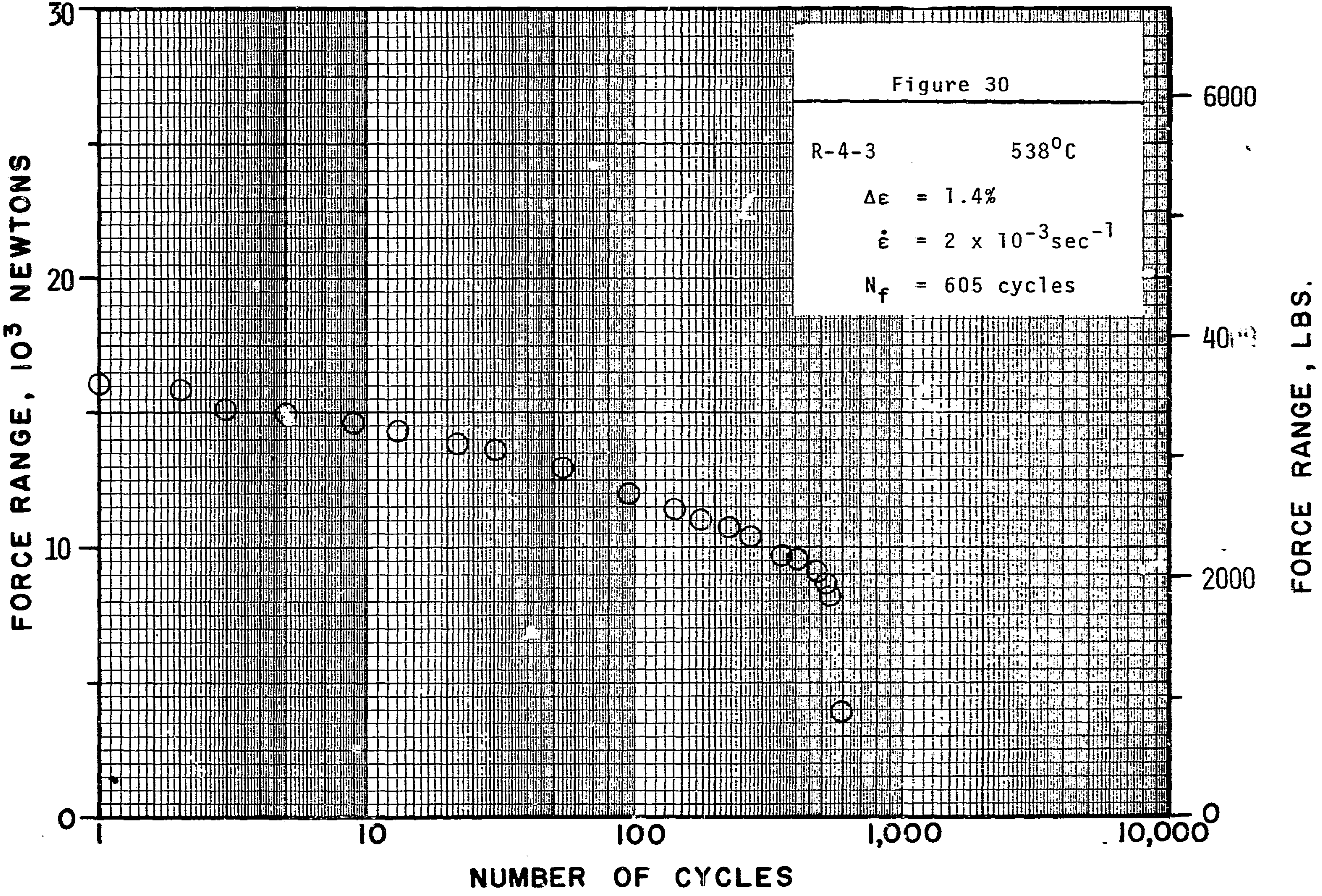


Figure 30

R-4-3 538^{0}C

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = 2×10^{-3}sec^{-1}

N_f = 605 cycles

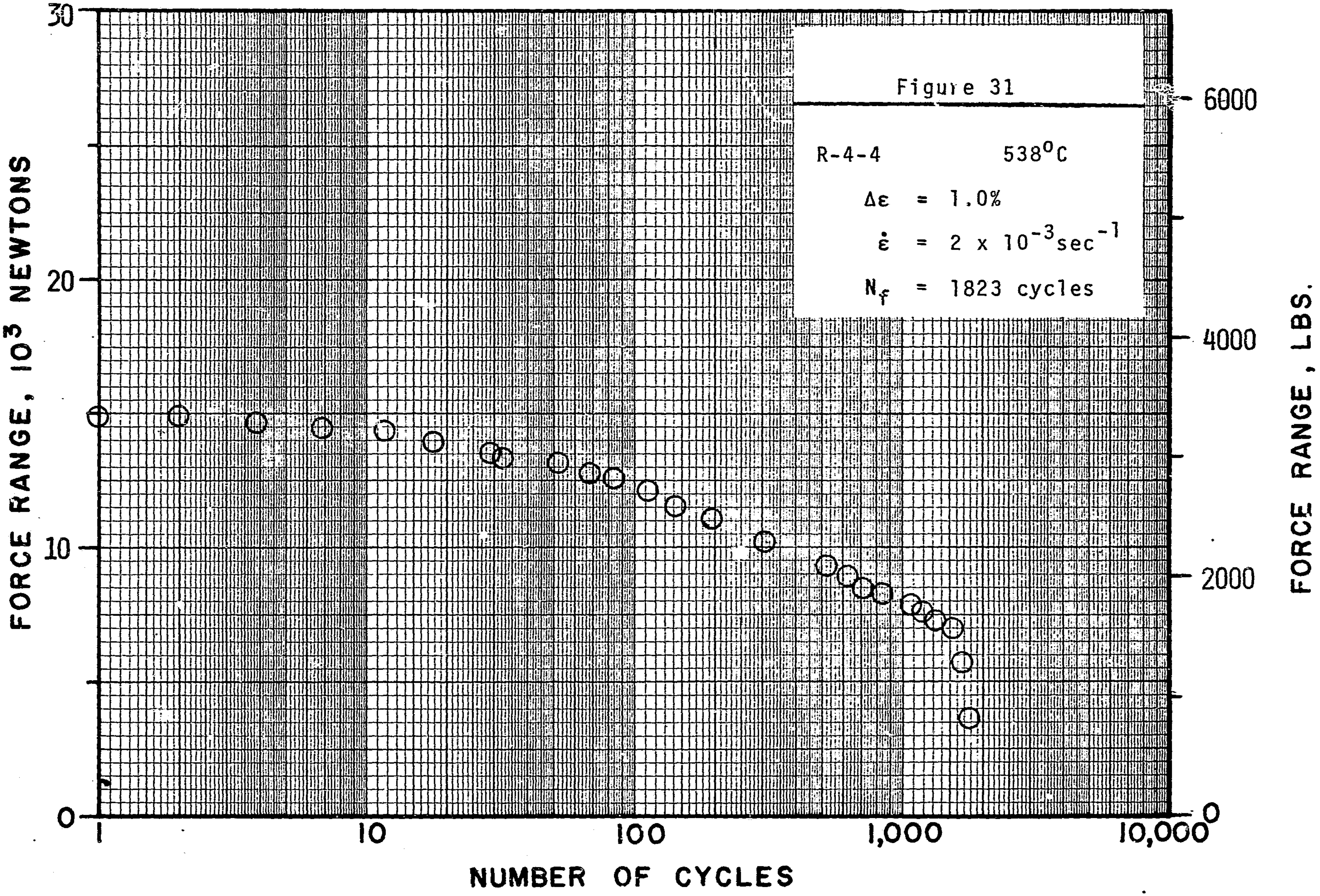


Figure 31

R-4-4 538°C
Δε = 1.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N$_f$ = 1823 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

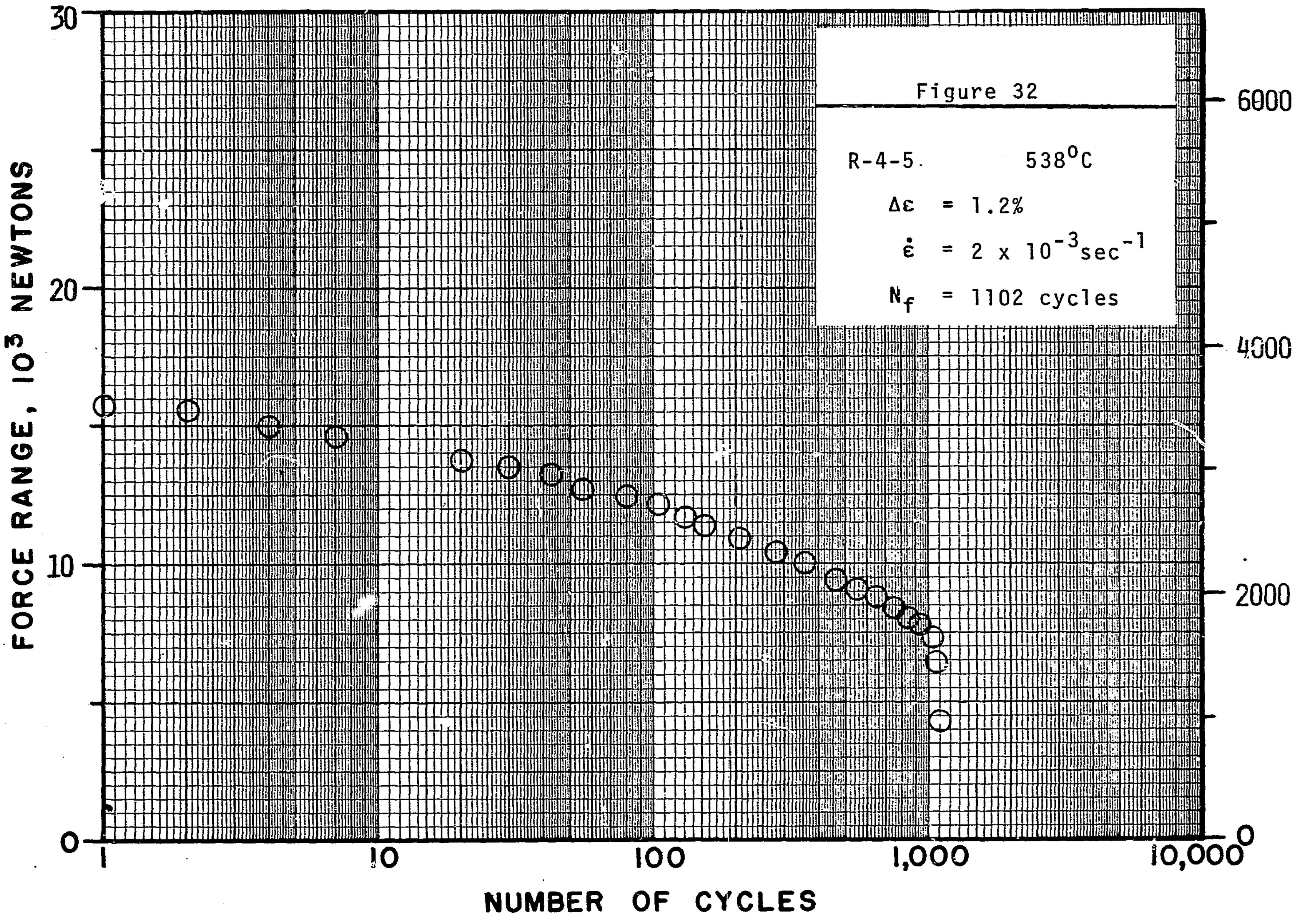


Figure 32

R-4-5. 538^{0}C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1102 cycles

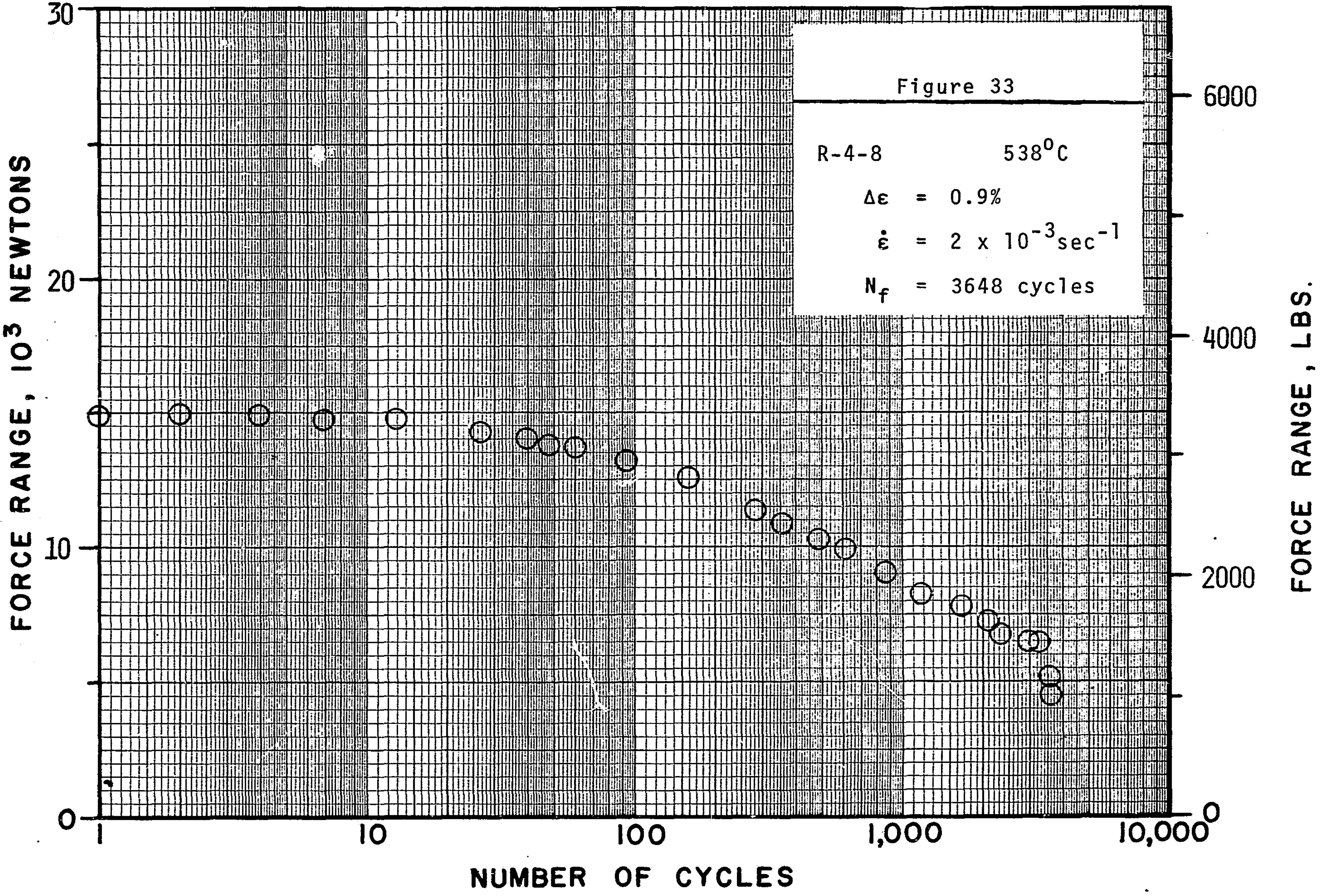


Figure 33

R-4-8 538°C

$\Delta\varepsilon = 0.9\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 3648 cycles

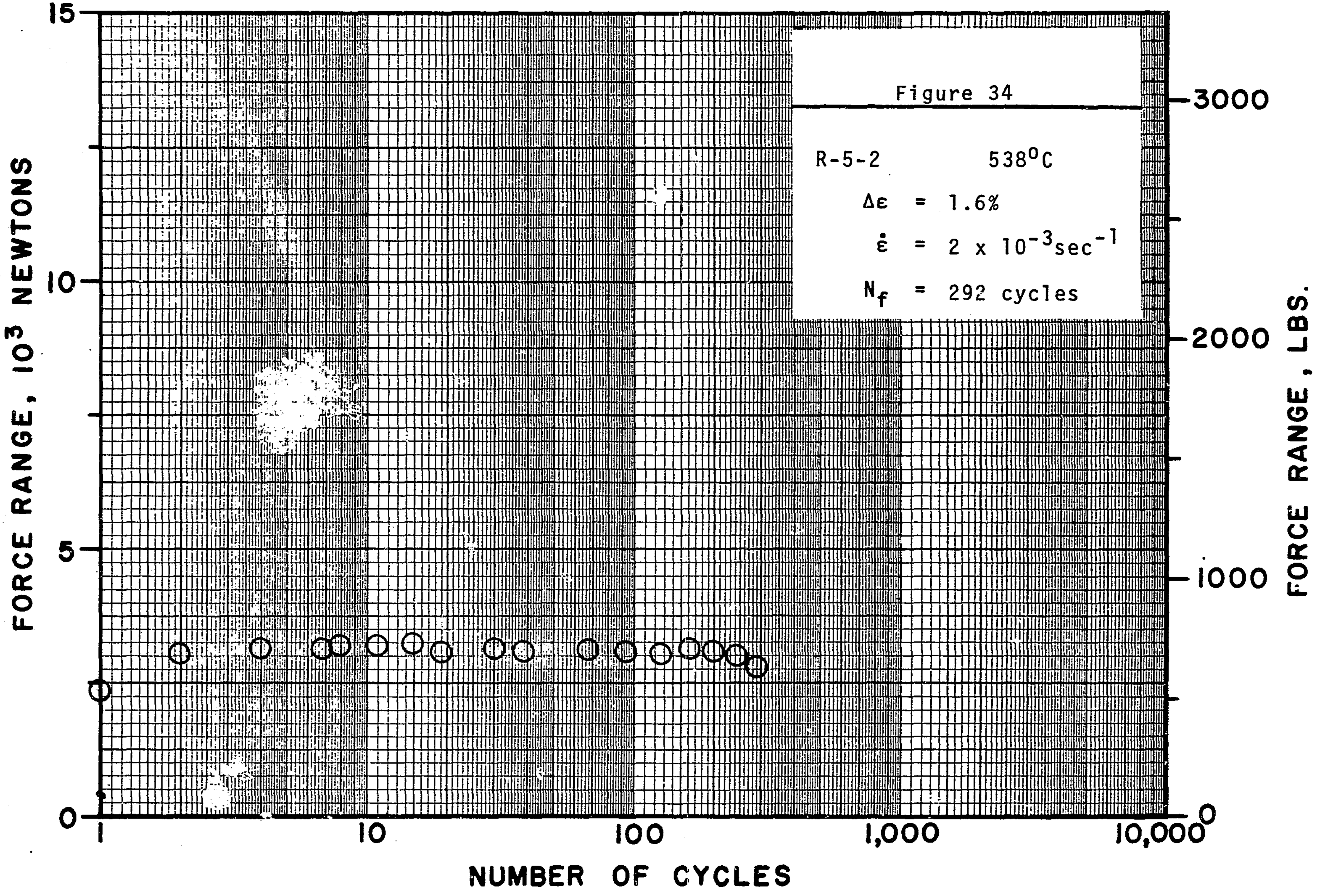


Figure 34

R-5-2 538°C

$\Delta\varepsilon$ = 1.6%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 292 cycles

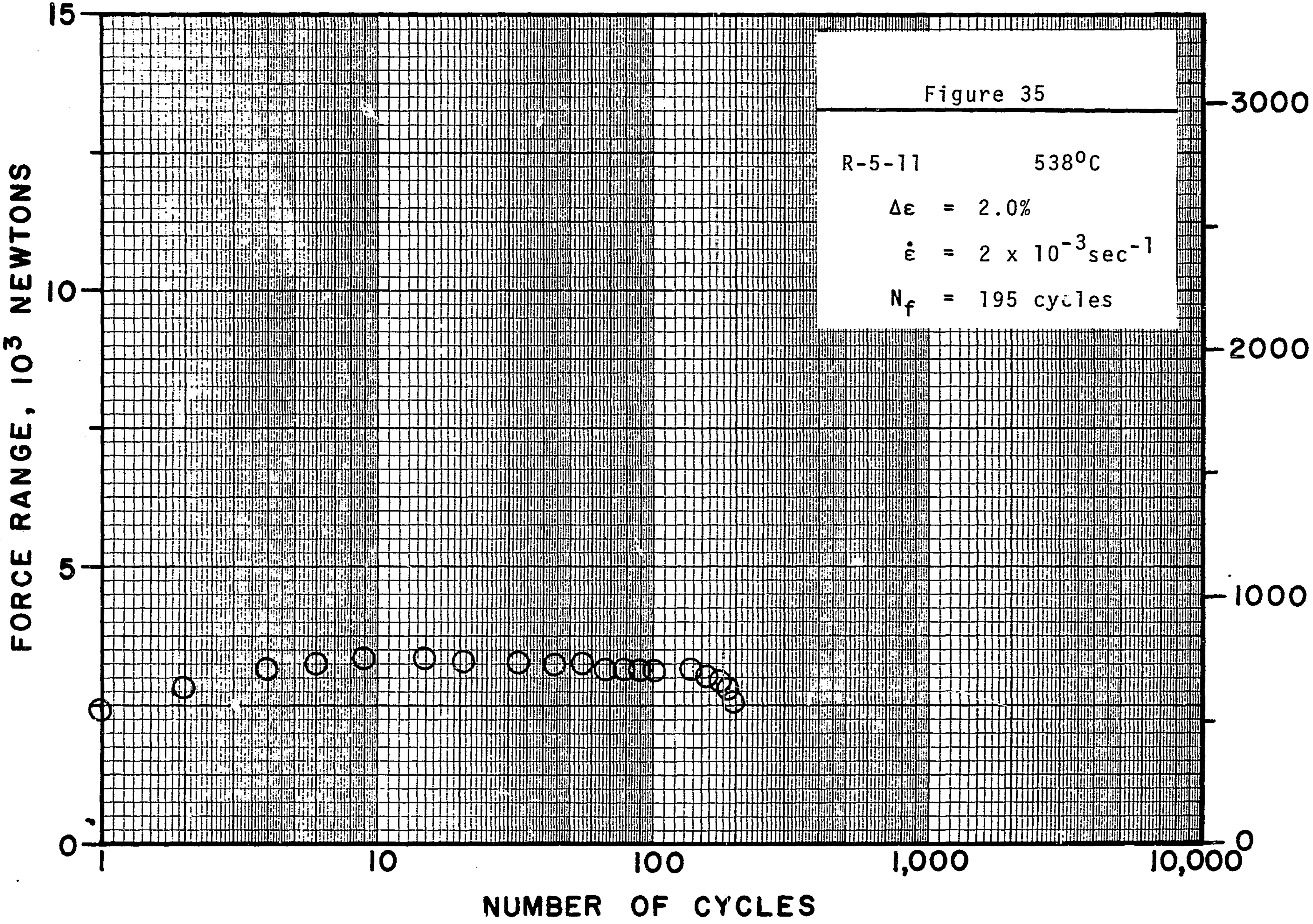


Figure 35

R-5-11 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 195 cycles

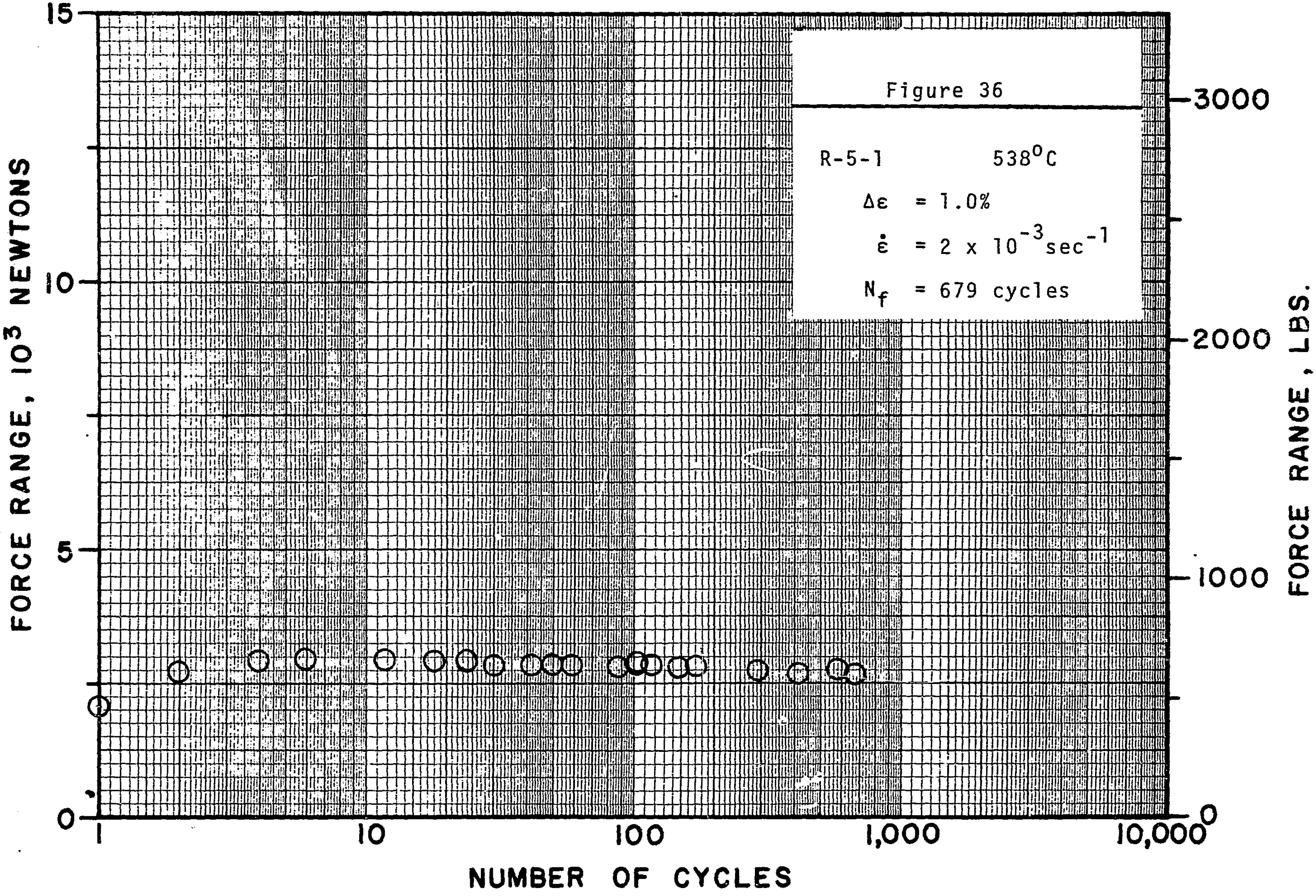


Figure 36

R-5-1 538^{0}C

$\Delta\varepsilon = 1.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 679 cycles

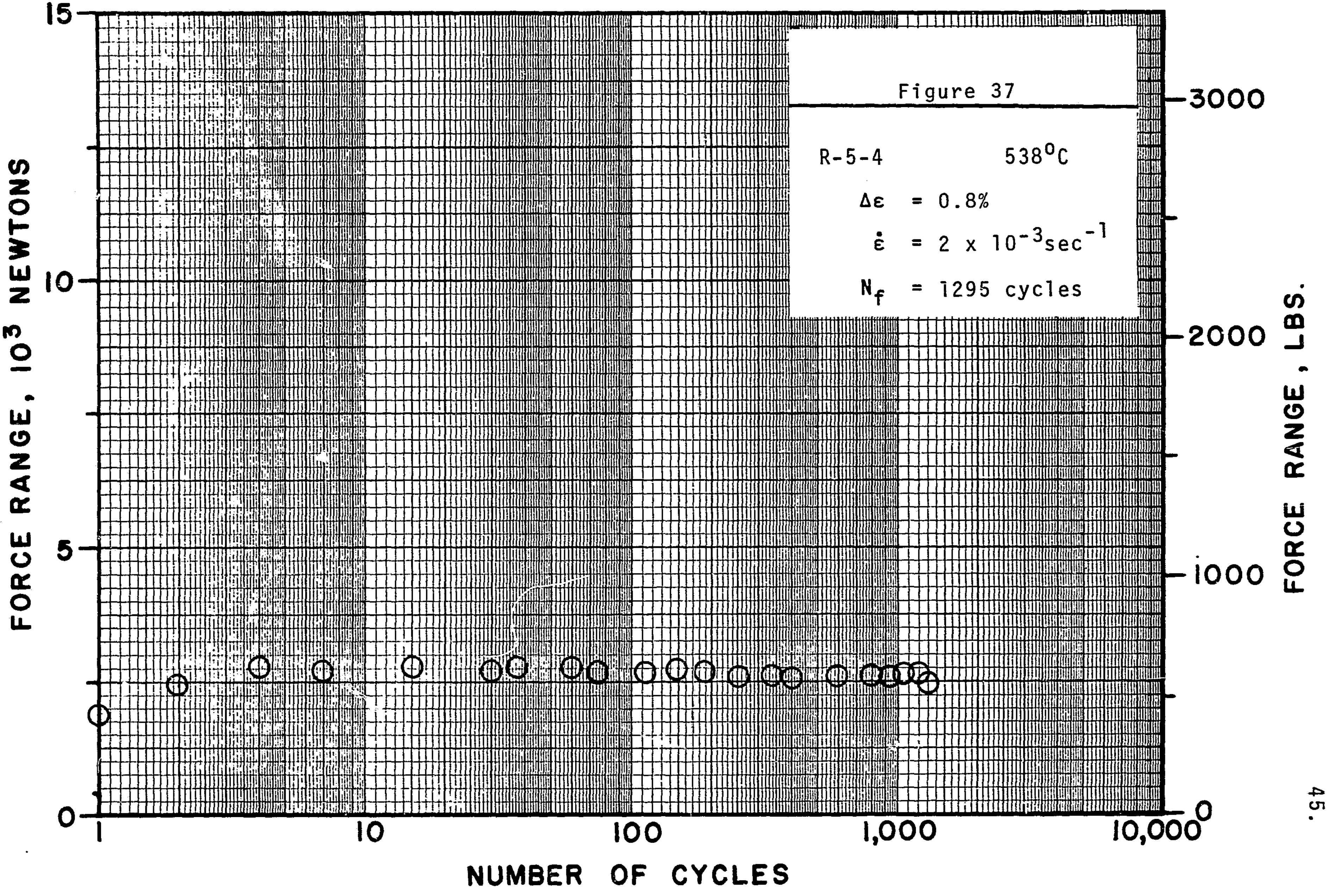


Figure 37
R-5-4
538°C
Δε = 0.8%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N$_f$ = 1295 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

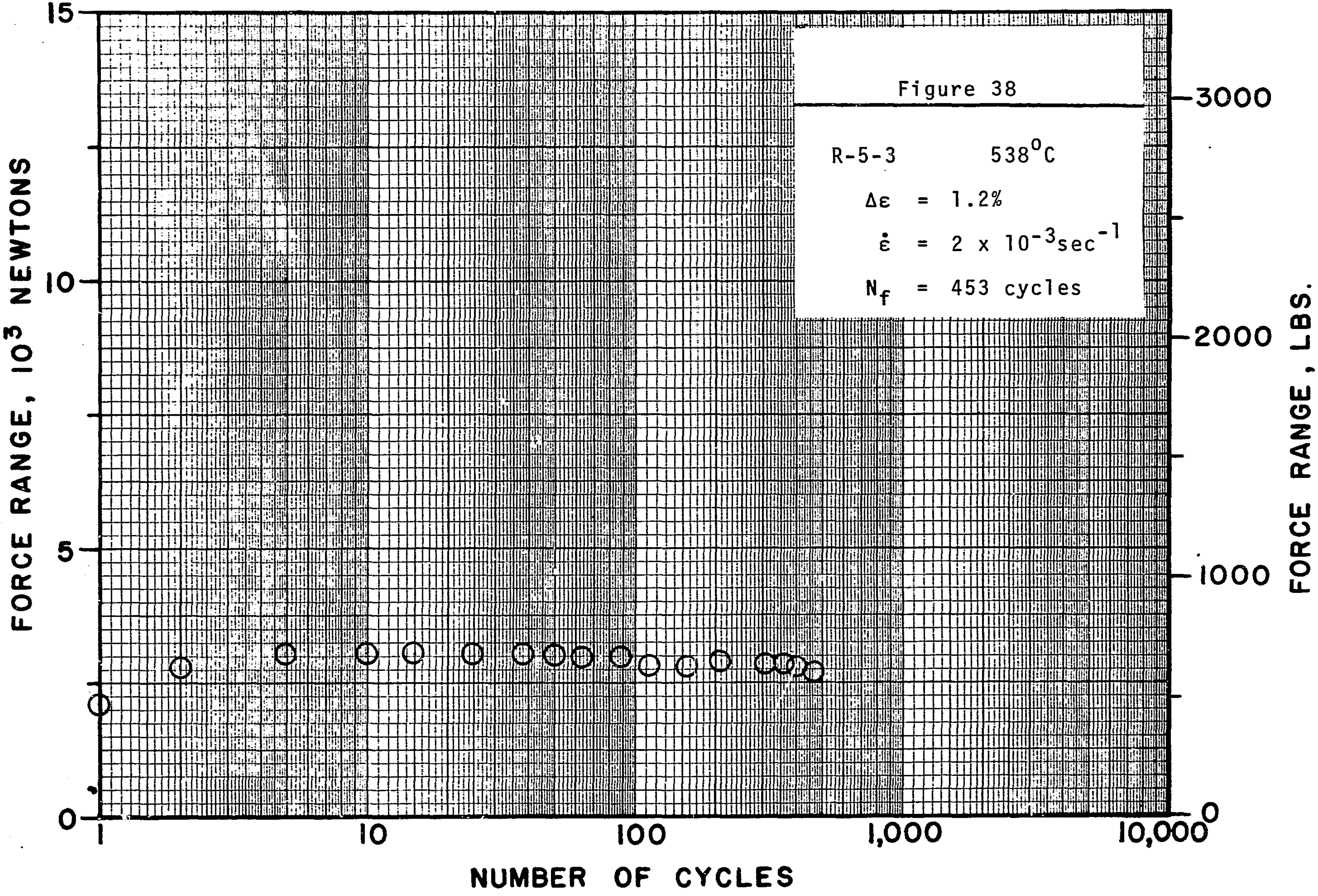


Figure 38

R-5-3 538°C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 453 cycles

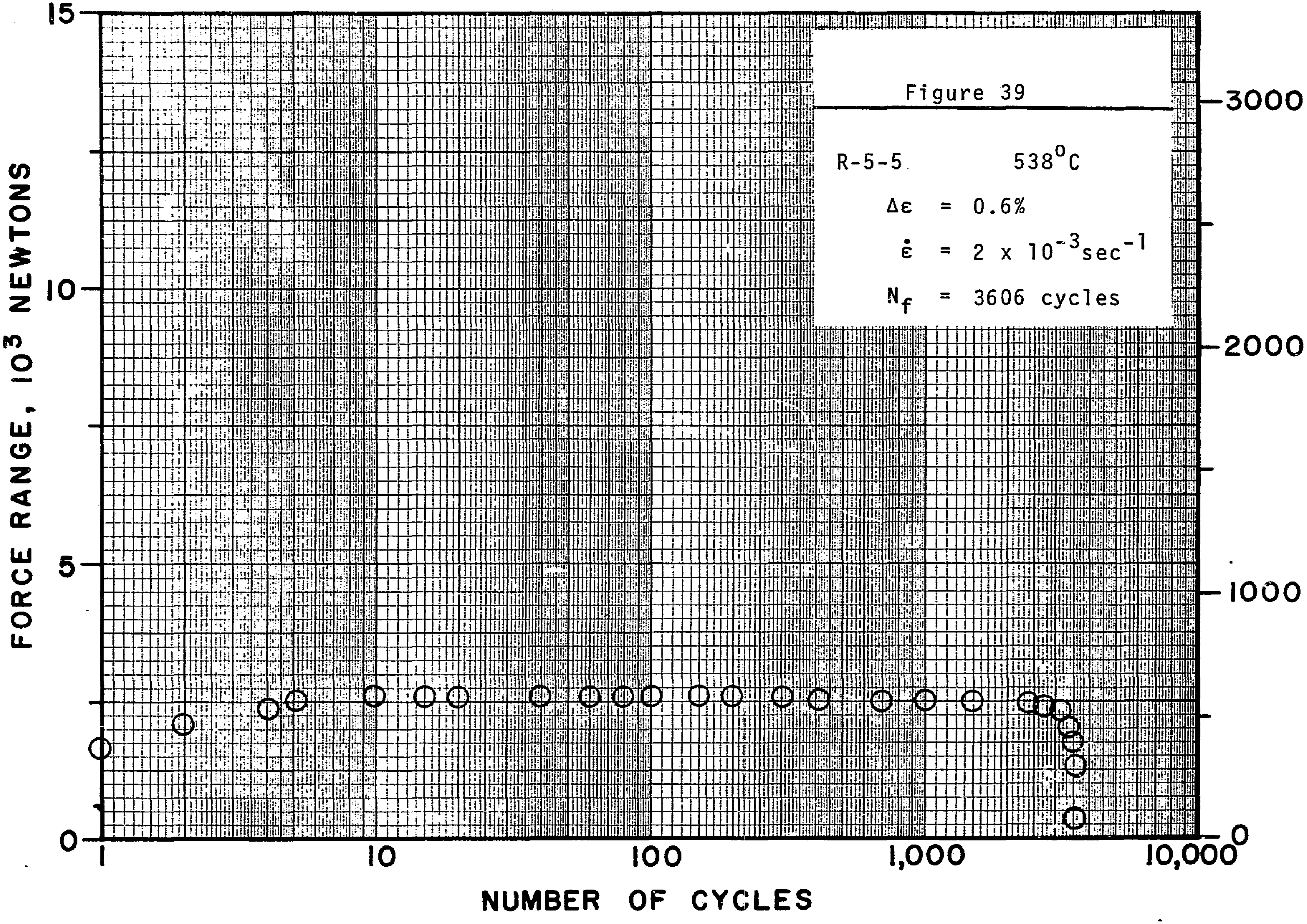


Figure 39

R-5-5 538°C

$\Delta\varepsilon$ = 0.6%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 3606 cycles

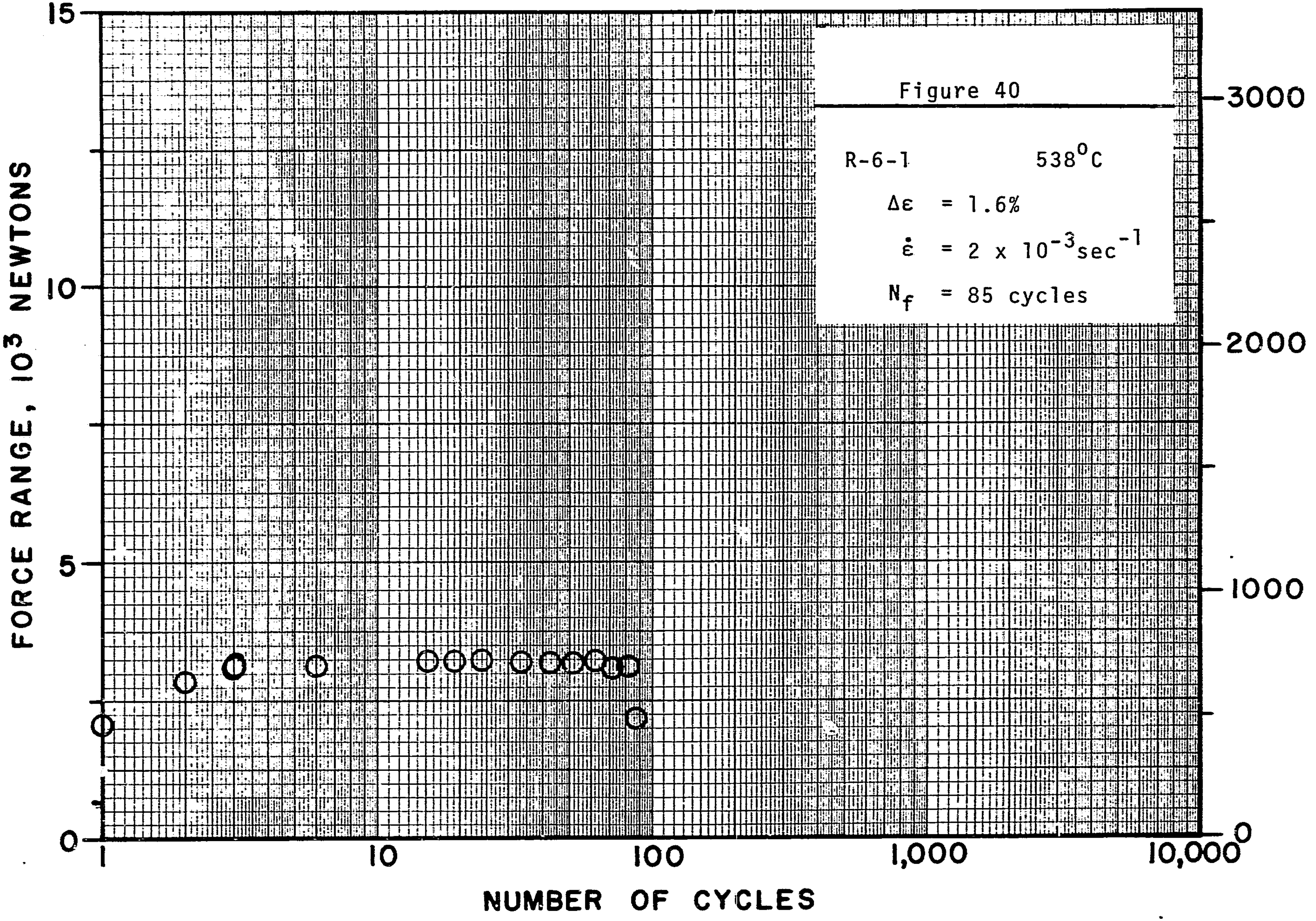


Figure 40

R-6-1 538^{0}C

$\Delta\varepsilon$ = 1.6%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 85 cycles

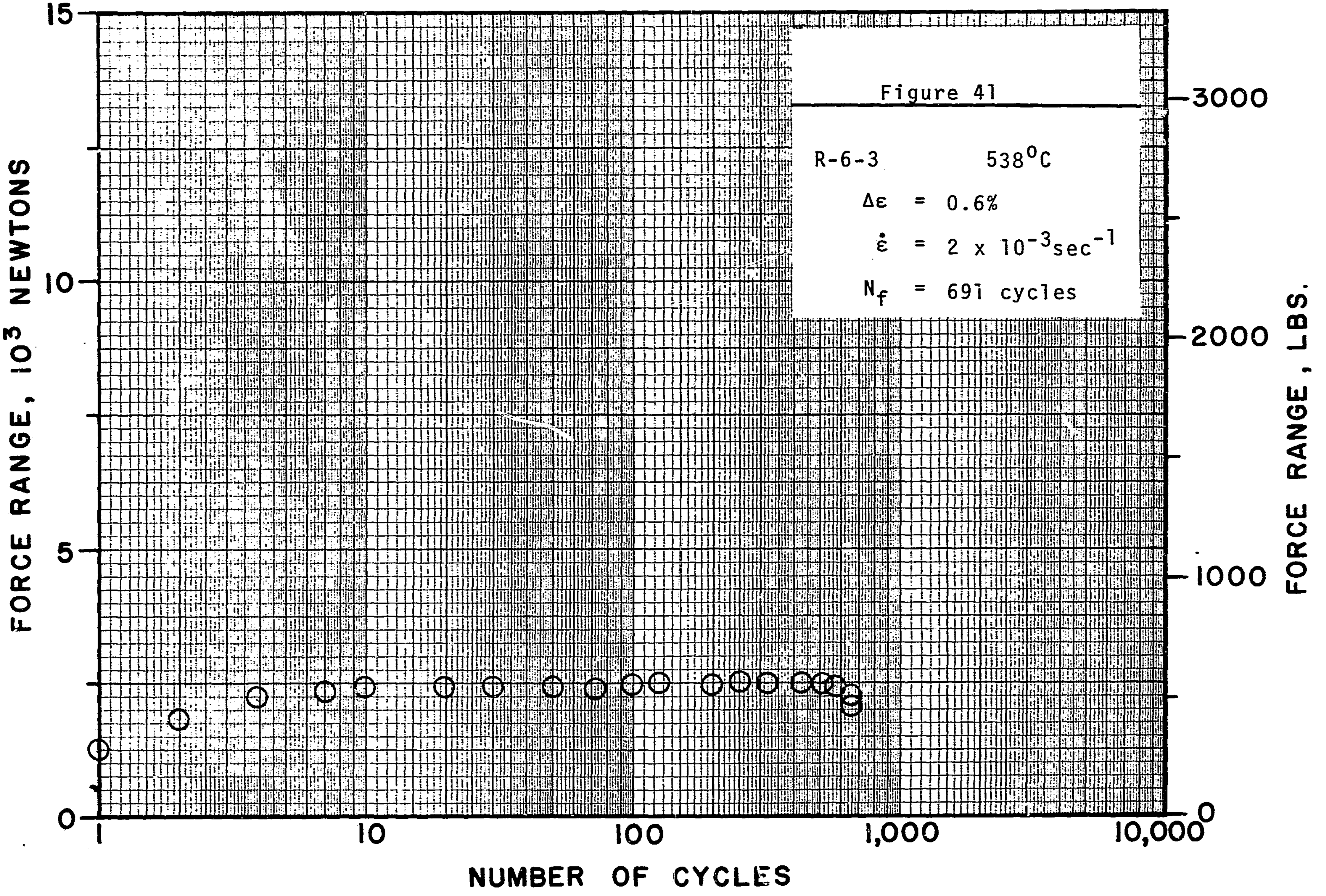


Figure 41

R-6-3 538°C
Δε = 0.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 691 cycles
FORCE RANGE, 10³ NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

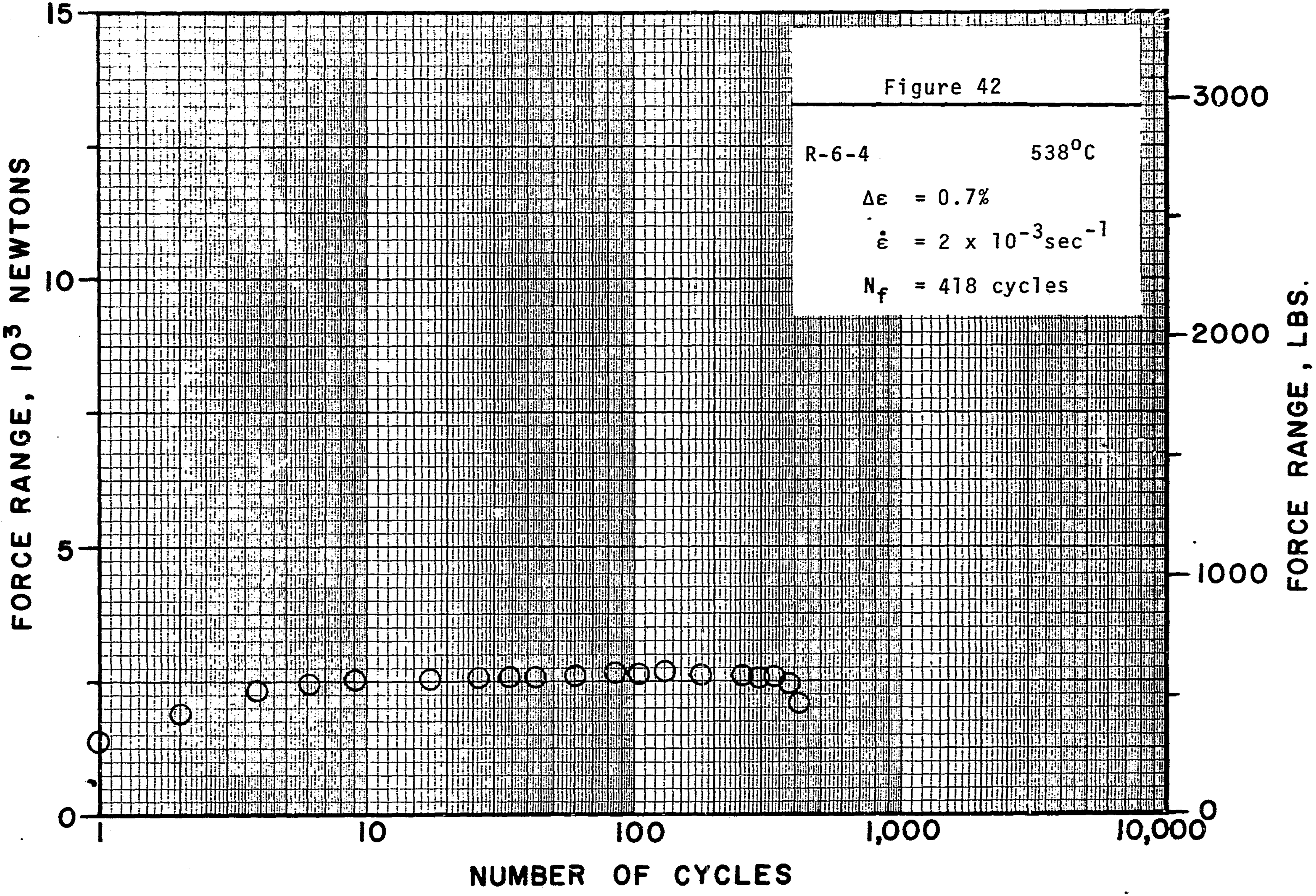


Figure 42

R-6-4 538°C

$\Delta\varepsilon = 0.7\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 418 cycles

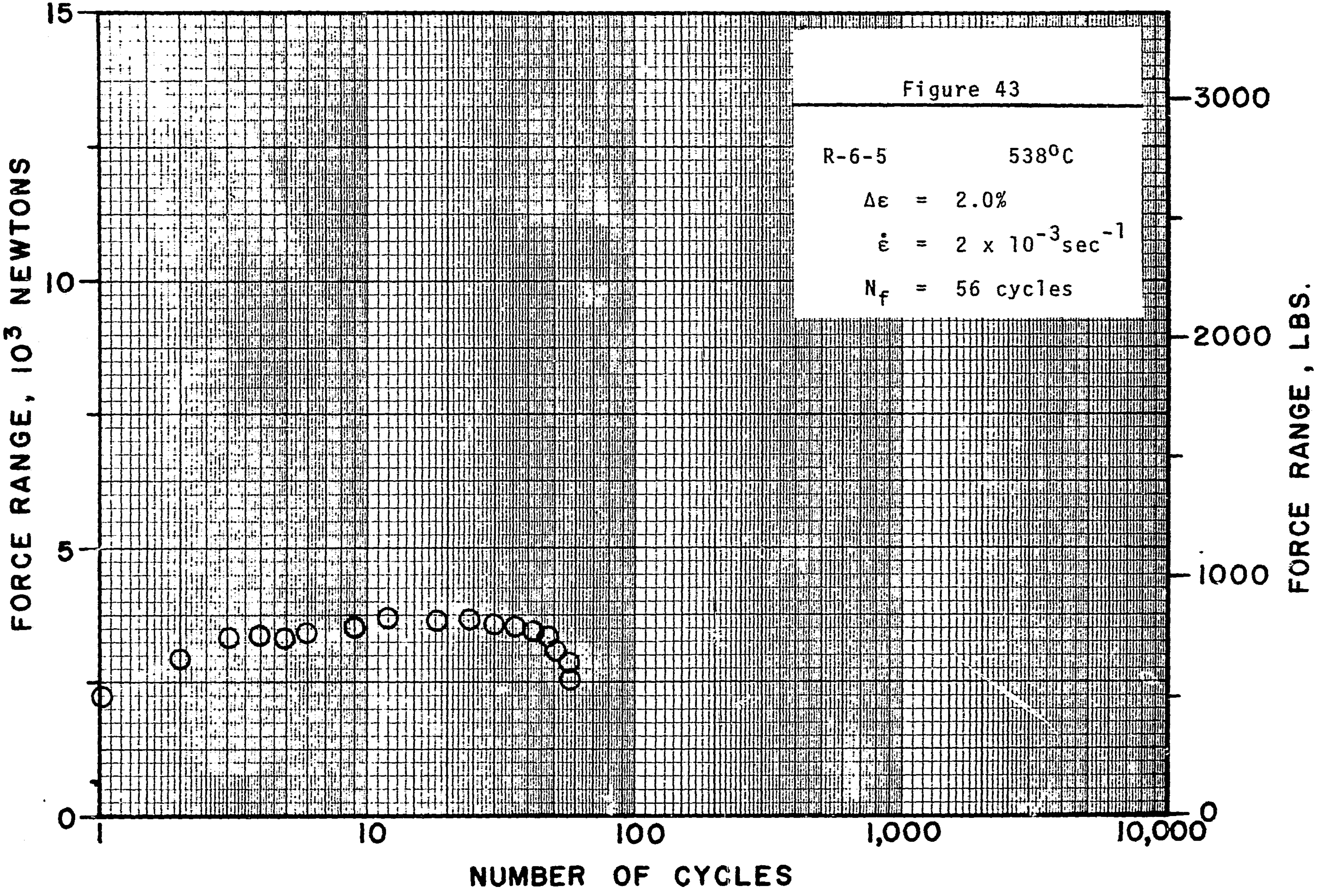


Figure 43

R-6-5 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 56 cycles

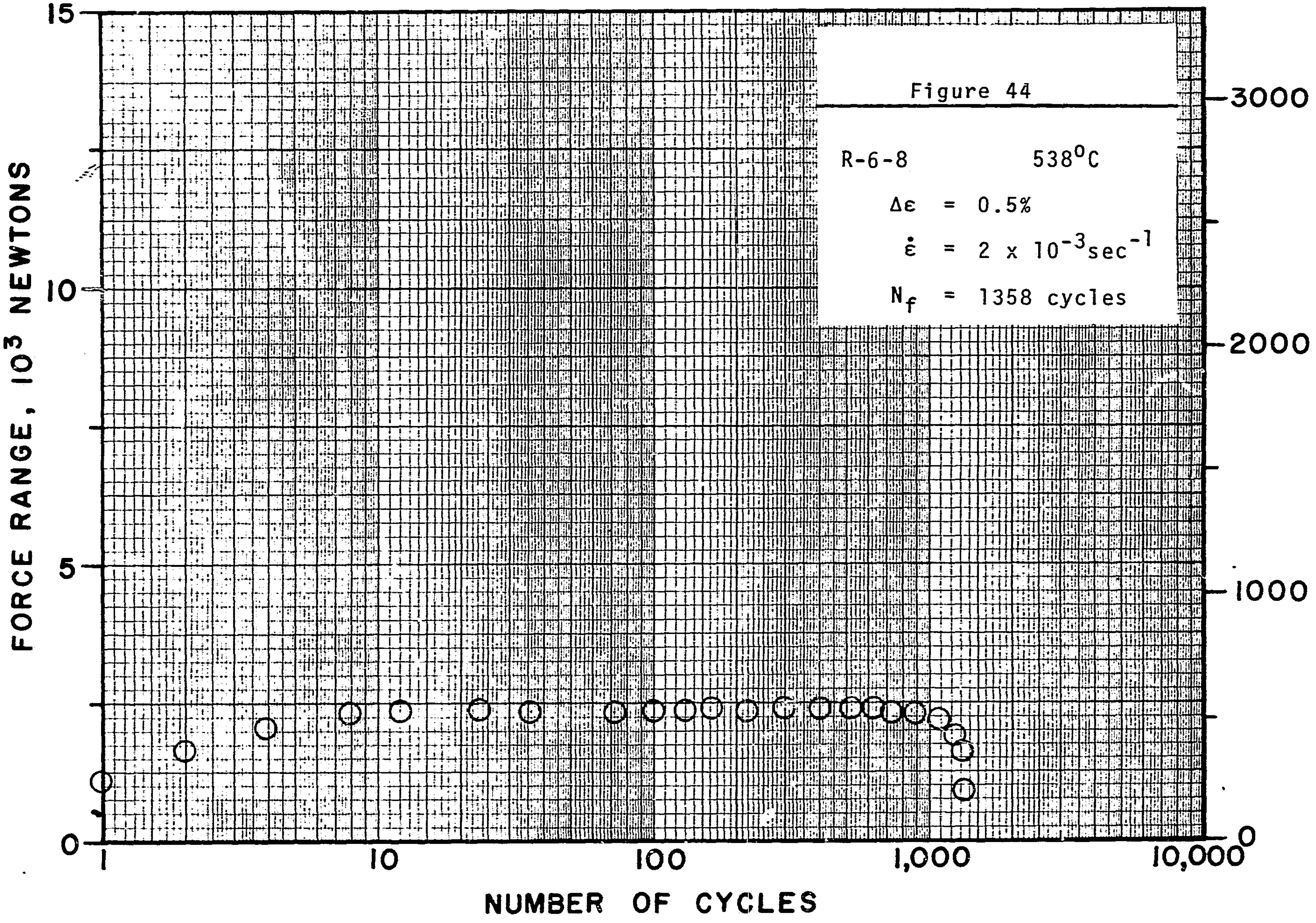


Figure 44

R-6-8 538^{o}C

$\Delta\varepsilon$ = 0.5%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1358 cycles

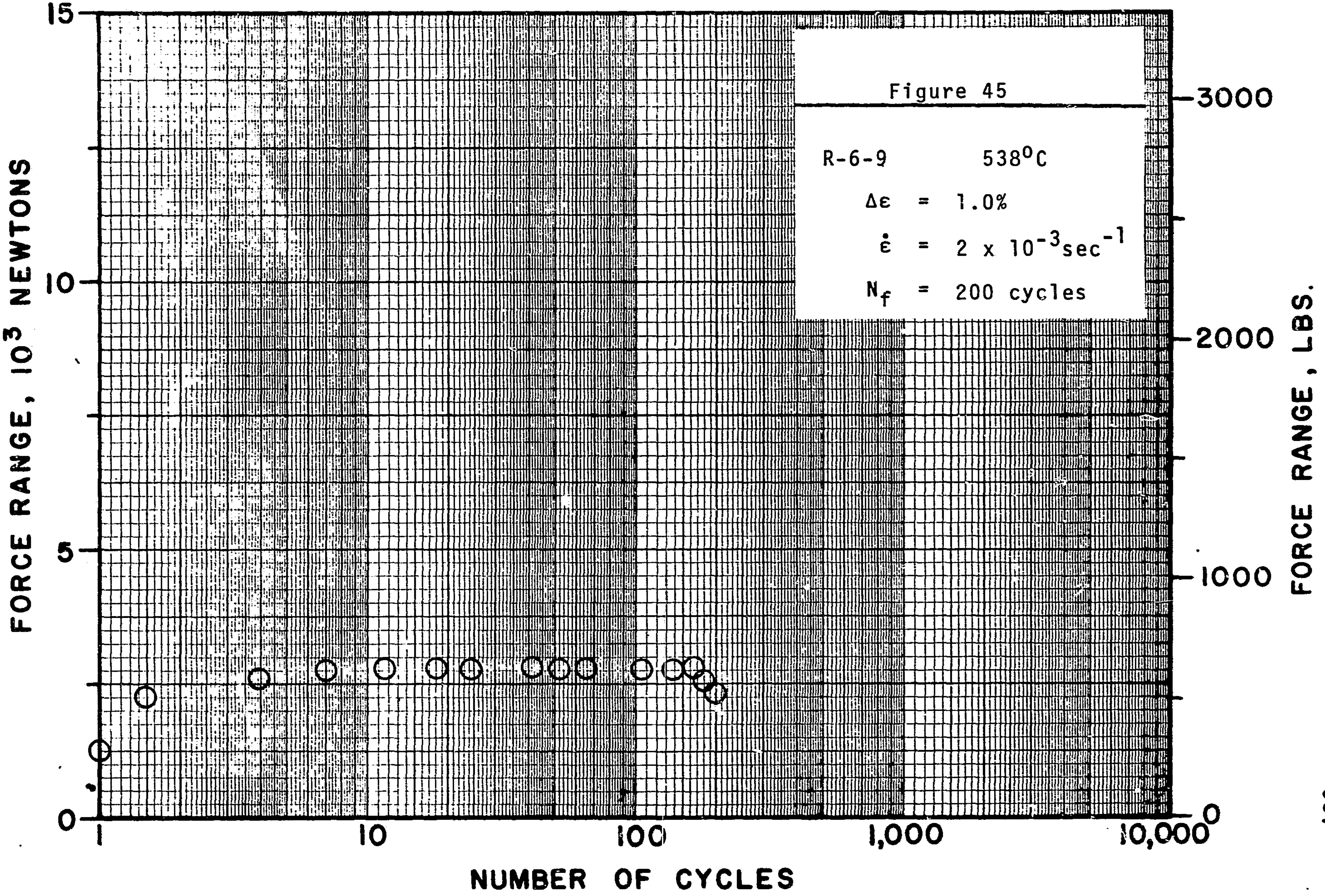


Figure 45
R-6-9 538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 200 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

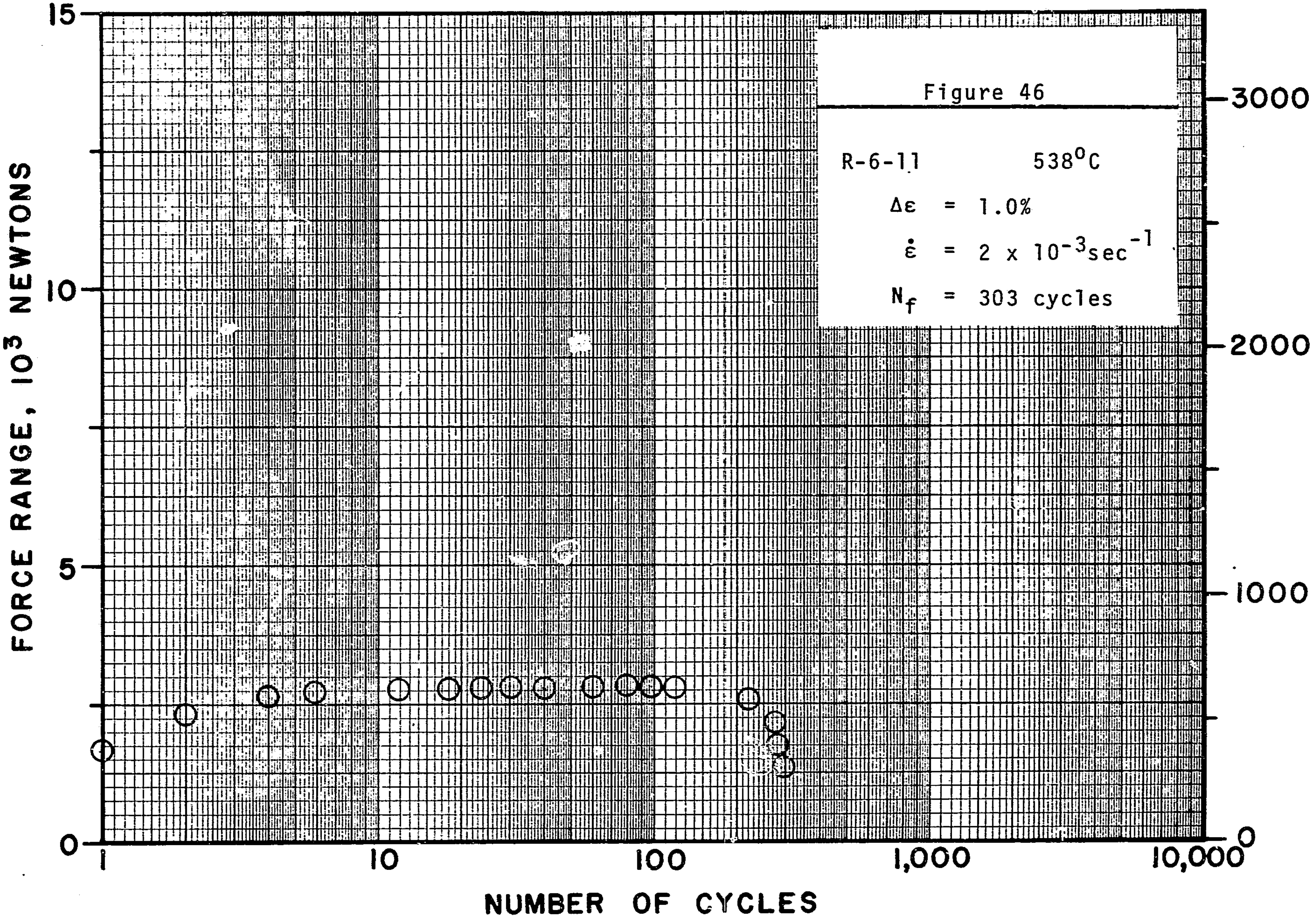


Figure 46

R-6-11 538°C

$\Delta\varepsilon$ = 1.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 303 cycles

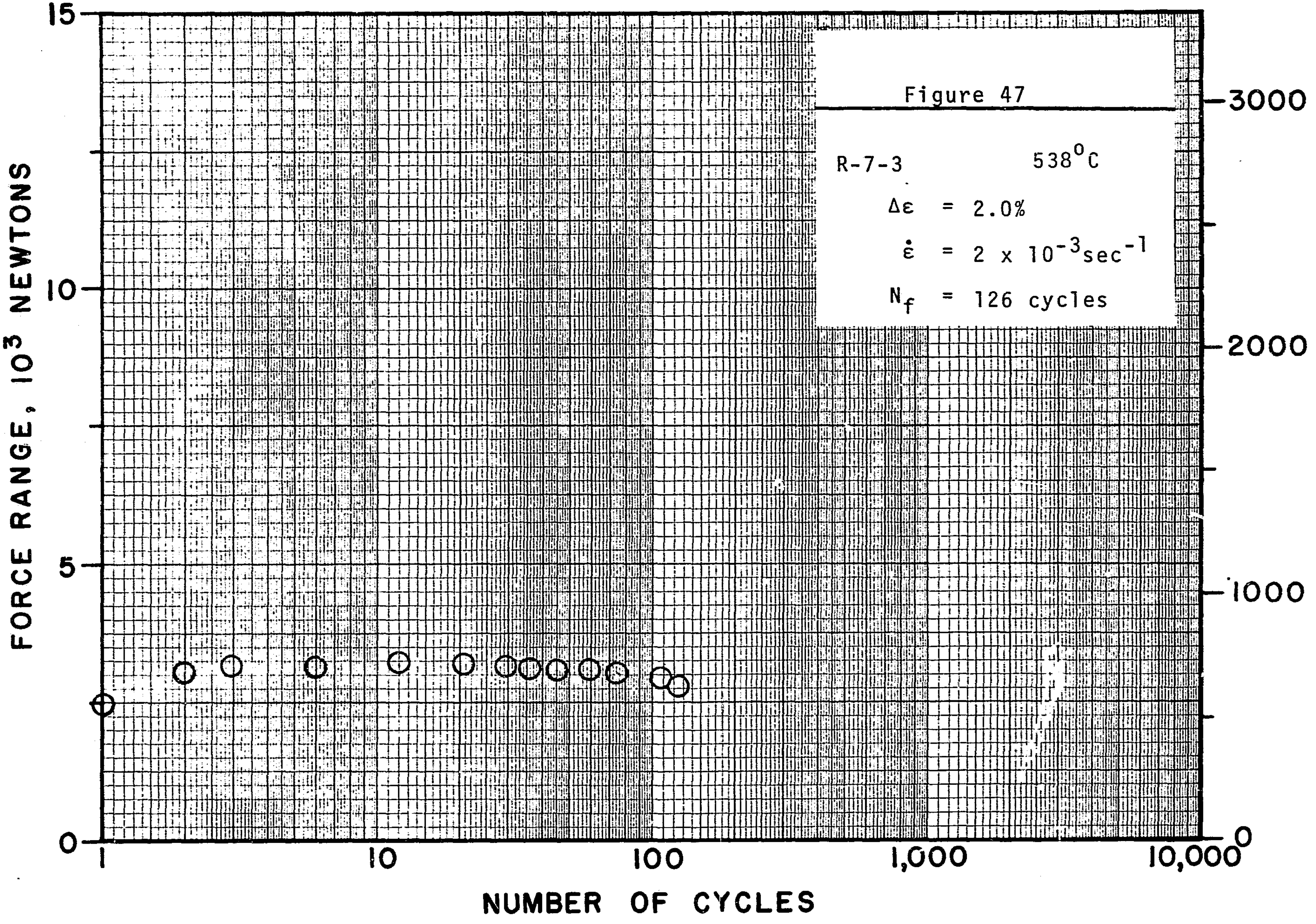


Figure 47

R-7-3
538°C
Δε = 2.0%
$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$
N_f = 126 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

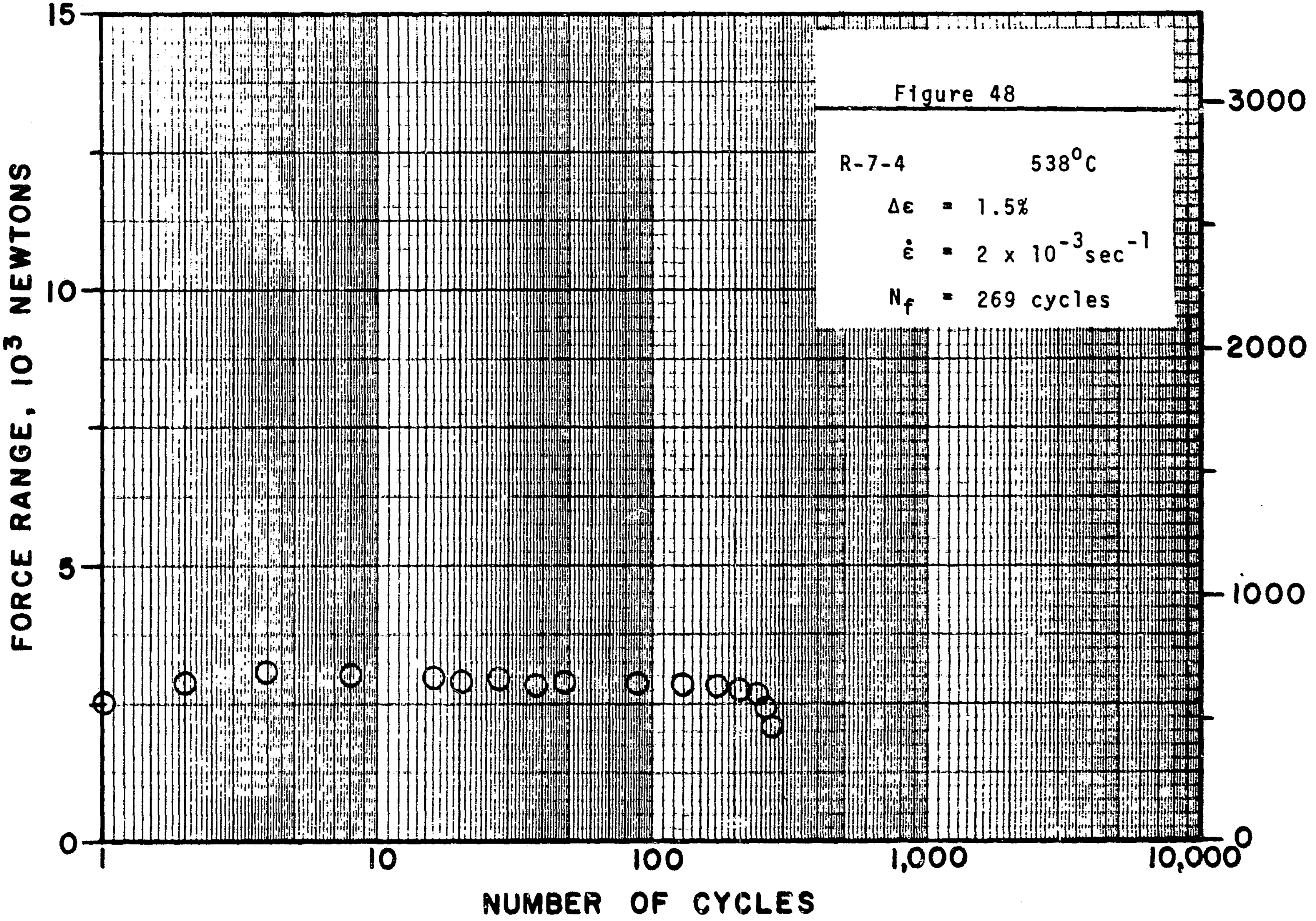


Figure 48

R-7-4 538°C

$\Delta\varepsilon$ = 1.5%

$\dot{\varepsilon}$ = $2 \times 10^{-3}\,\text{sec}^{-1}$

N_f = 269 cycles

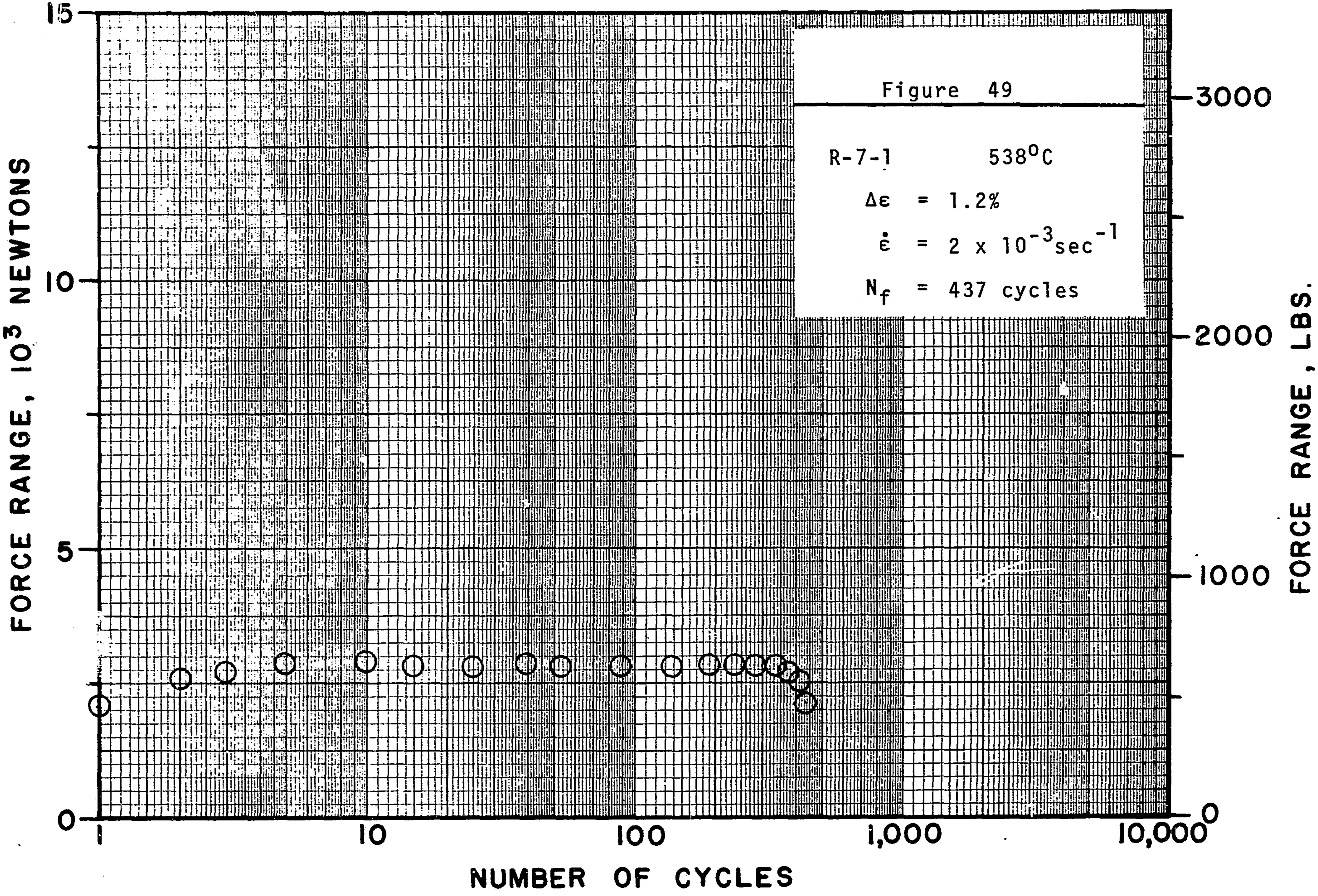


Figure 49
R-7-1 538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 437 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

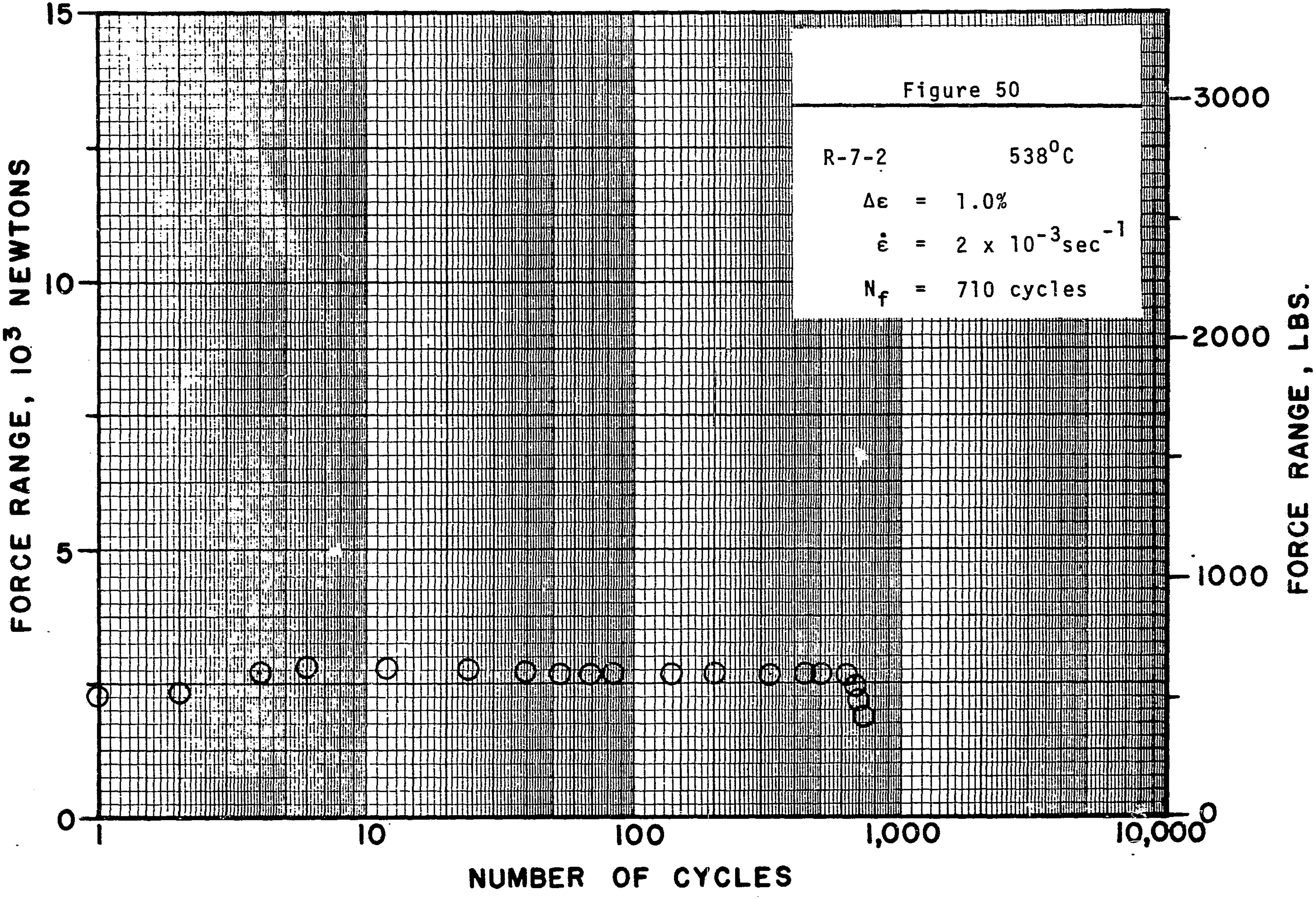


Figure 50

R-7-2 538°C

$\Delta\varepsilon$ = 1.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 710 cycles

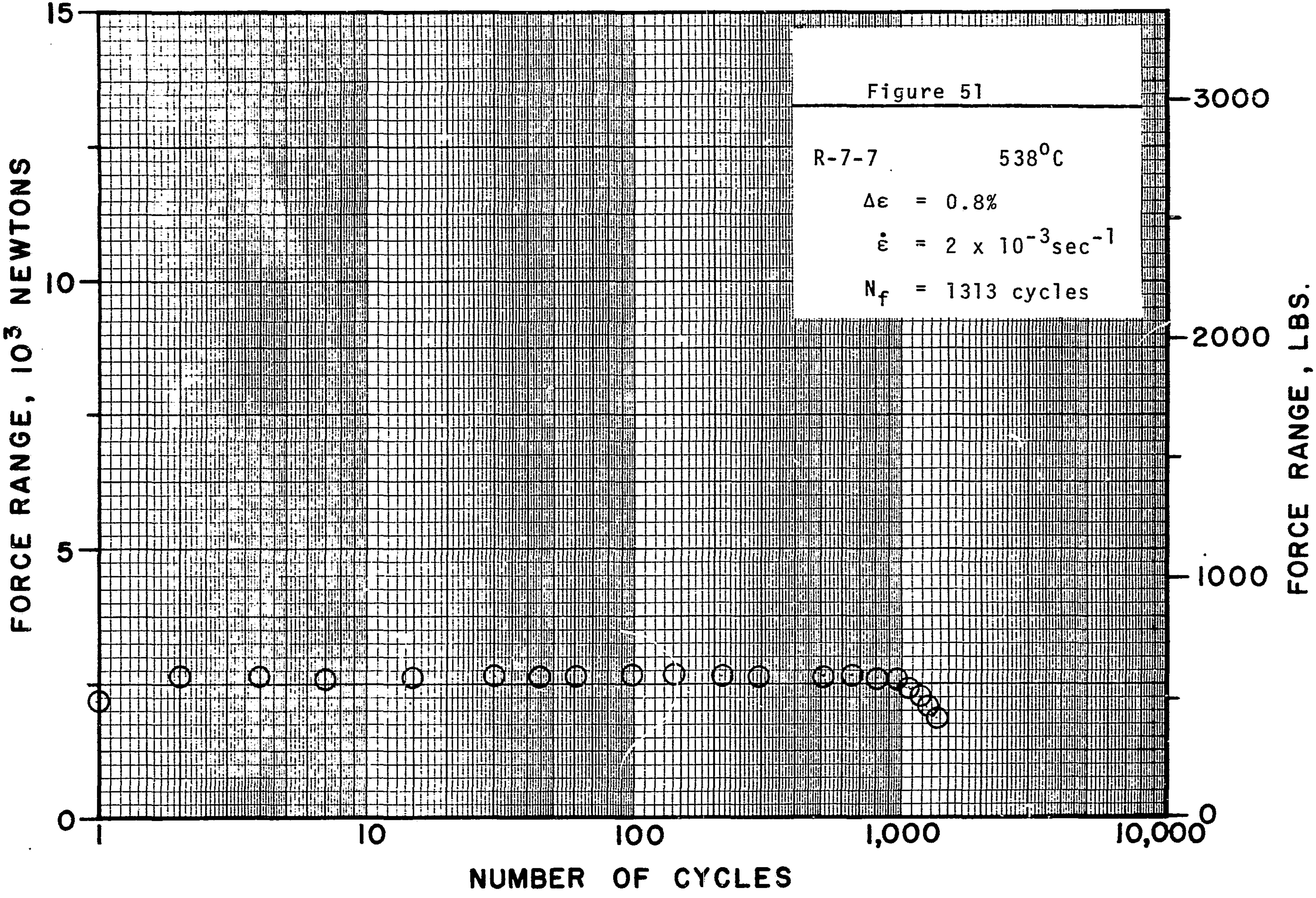


Figure 51

R-7-7 538^{0}C

$\Delta\varepsilon$ = 0.8%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 1313 cycles

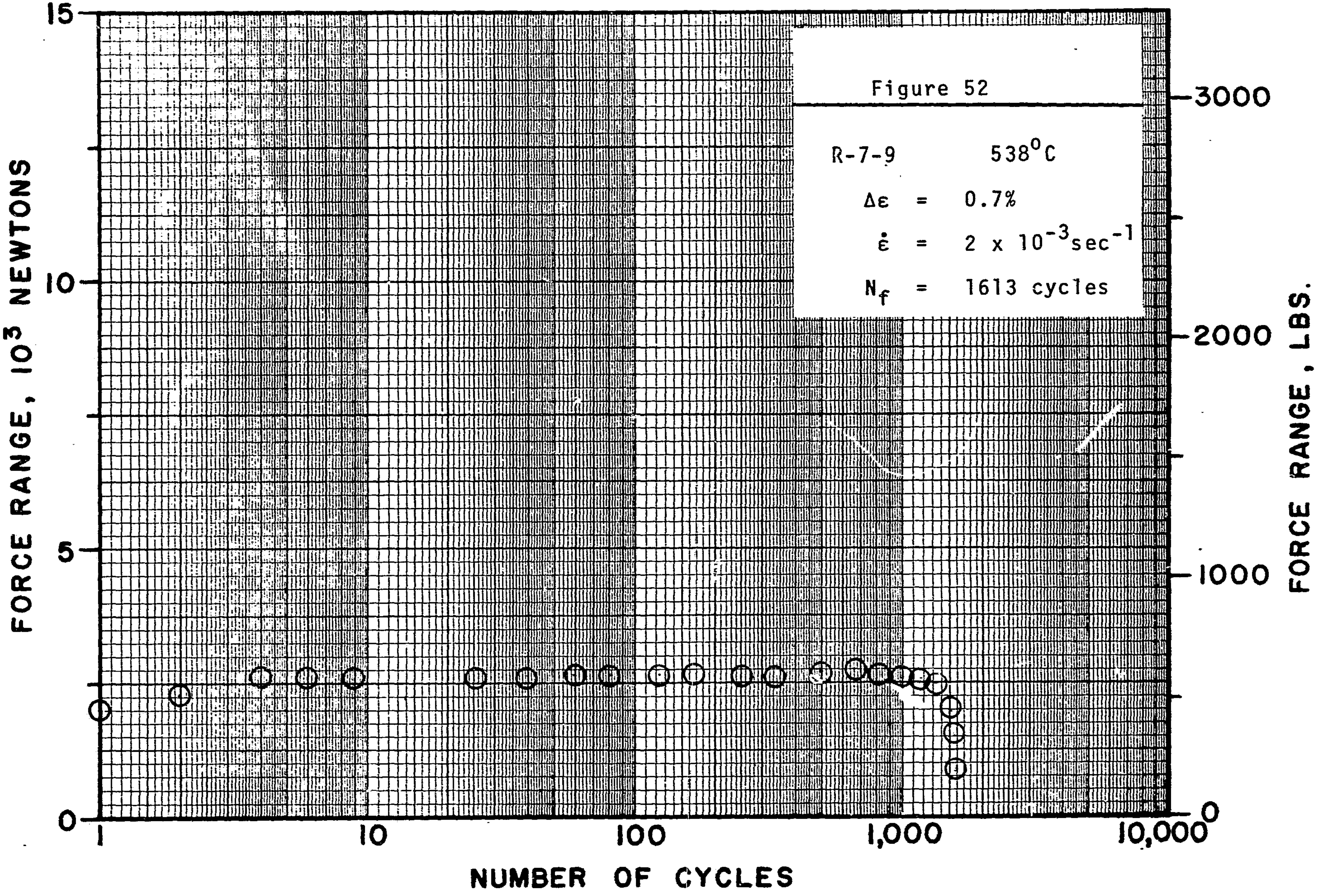


Figure 52

R-7-9 538°C

$\Delta\varepsilon$ = 0.7%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 1613 cycles

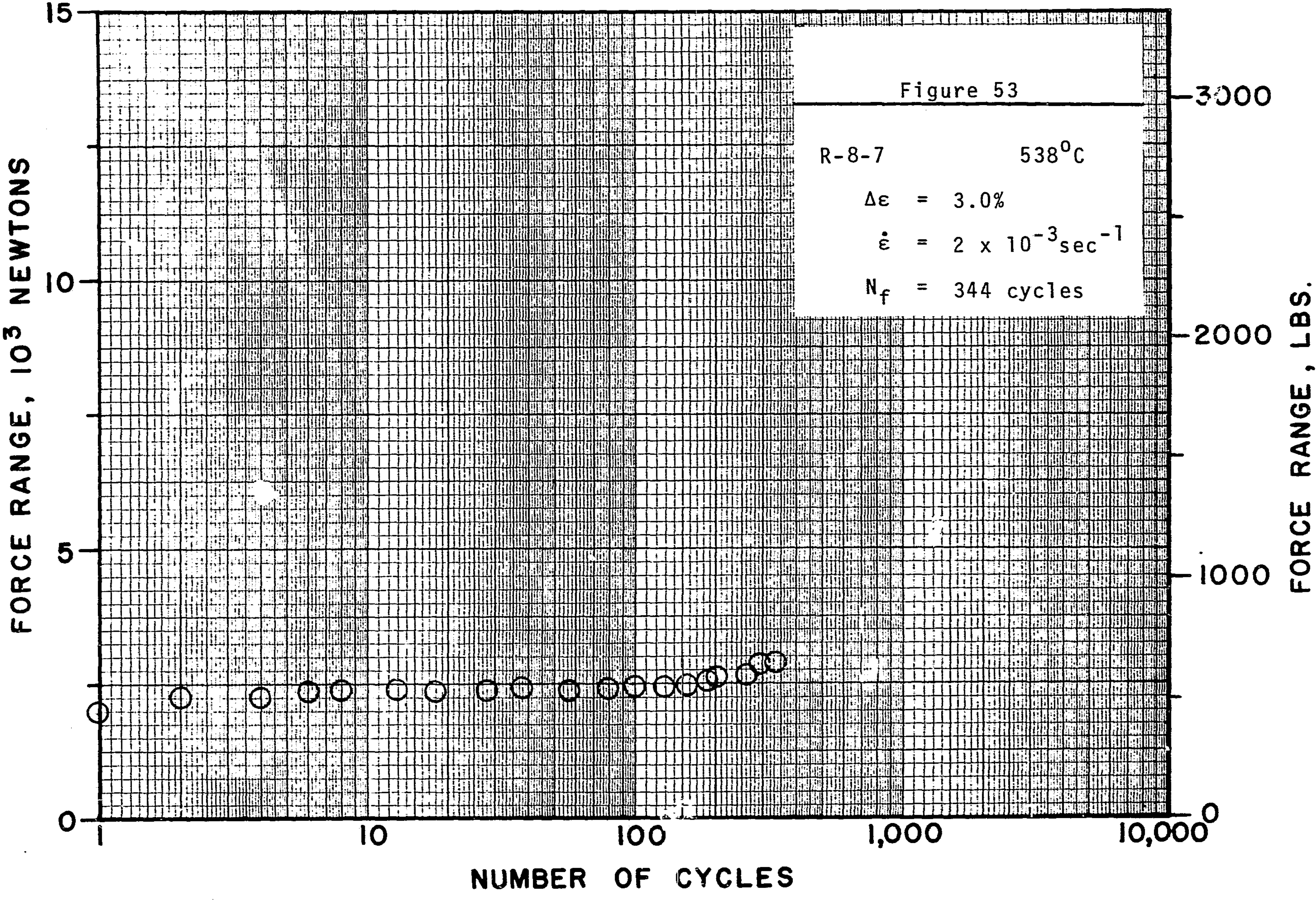


Figure 53

R-8-7 538°C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 344 cycles

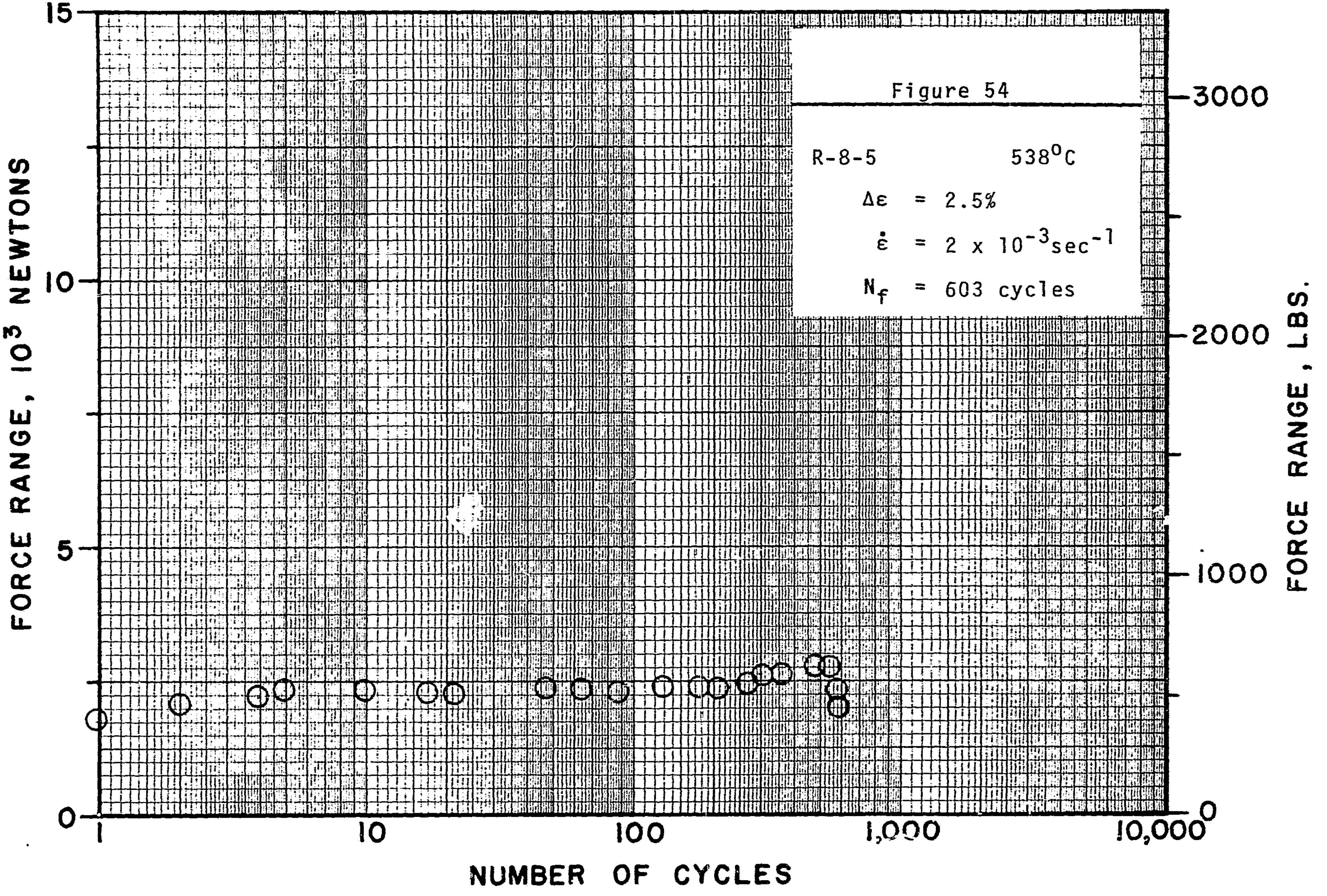


Figure 54

R-8-5 538^{0}C

$\Delta\varepsilon = 2.5\%$

$\dot{\varepsilon} = 2 \times 10^{-3} sec^{-1}$

$N_f = 603$ cycles

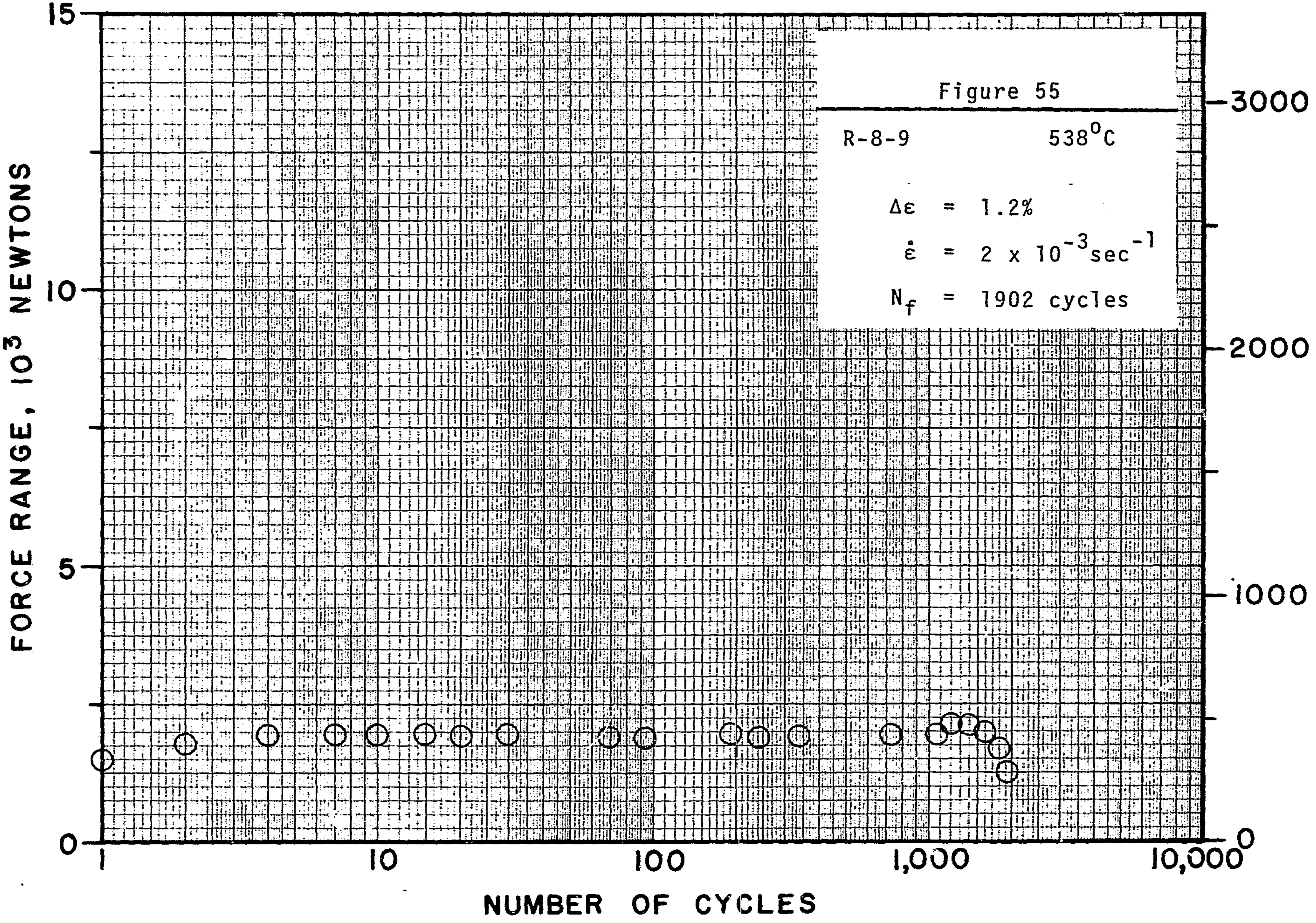


Figure 55

R-8-9 538°C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 1902 cycles

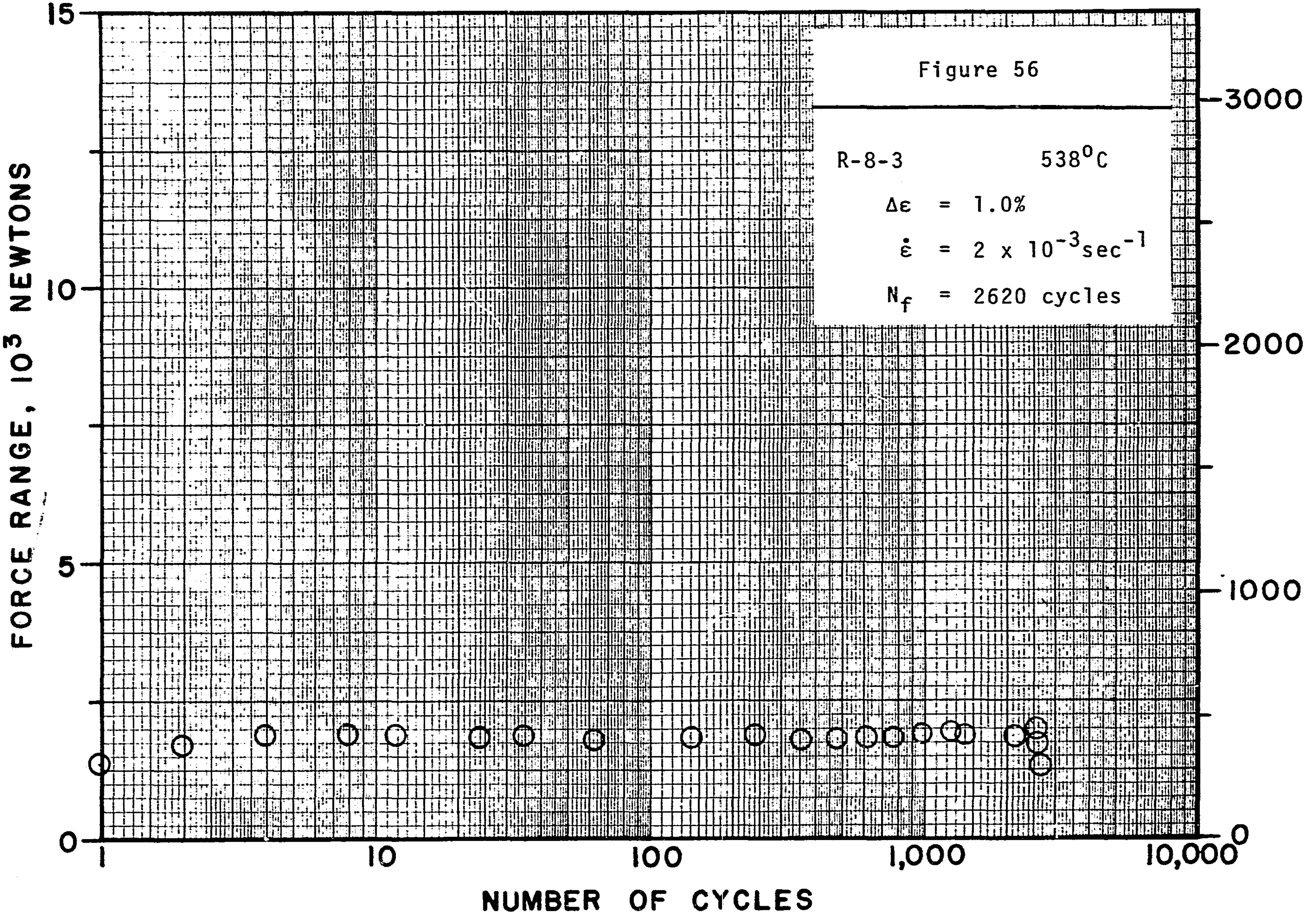


Figure 56

R-8-3
538^{0}C
$\Delta\varepsilon$ = 1.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 2620 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

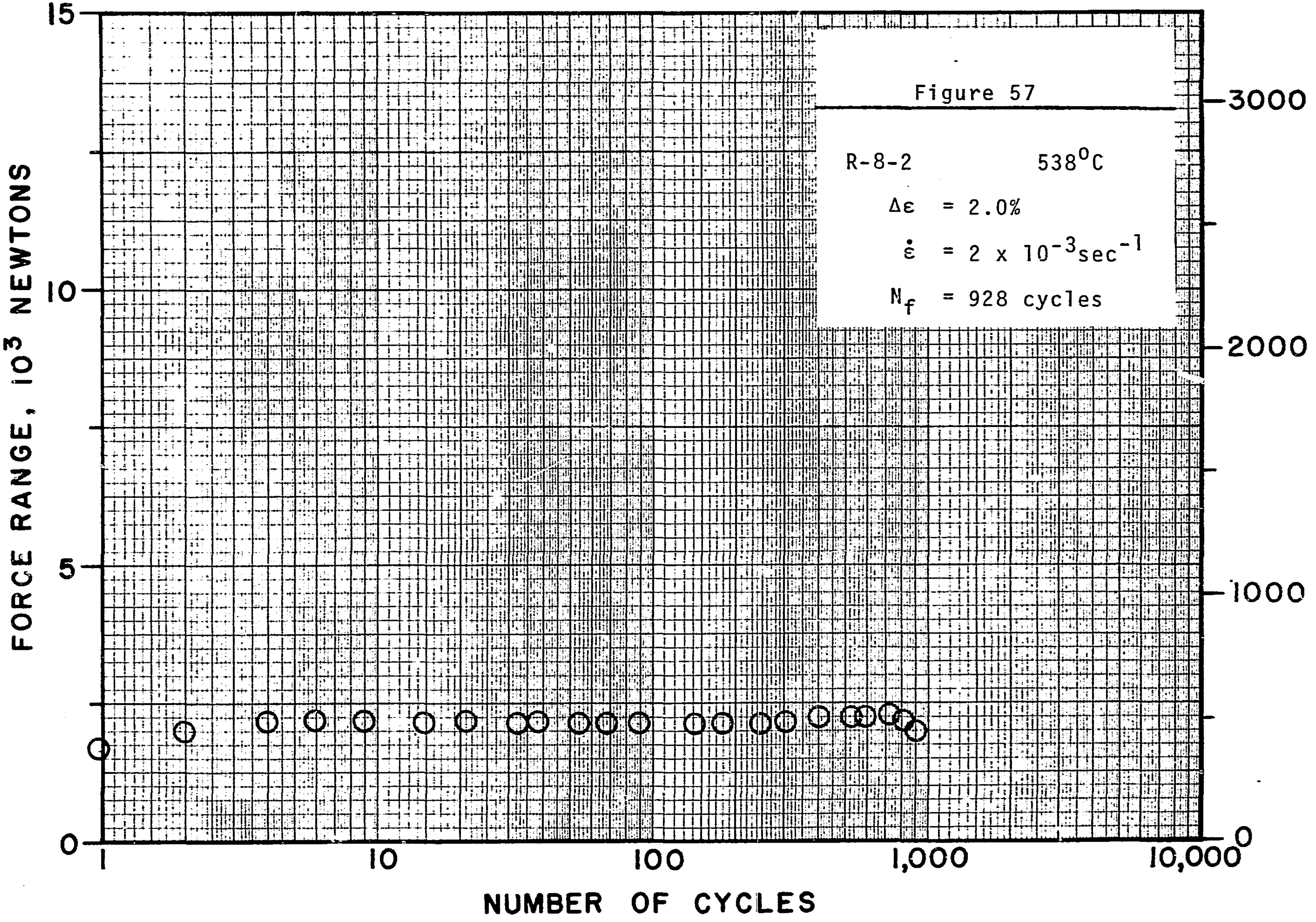


Figure 57

R-8-2 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 928 cycles

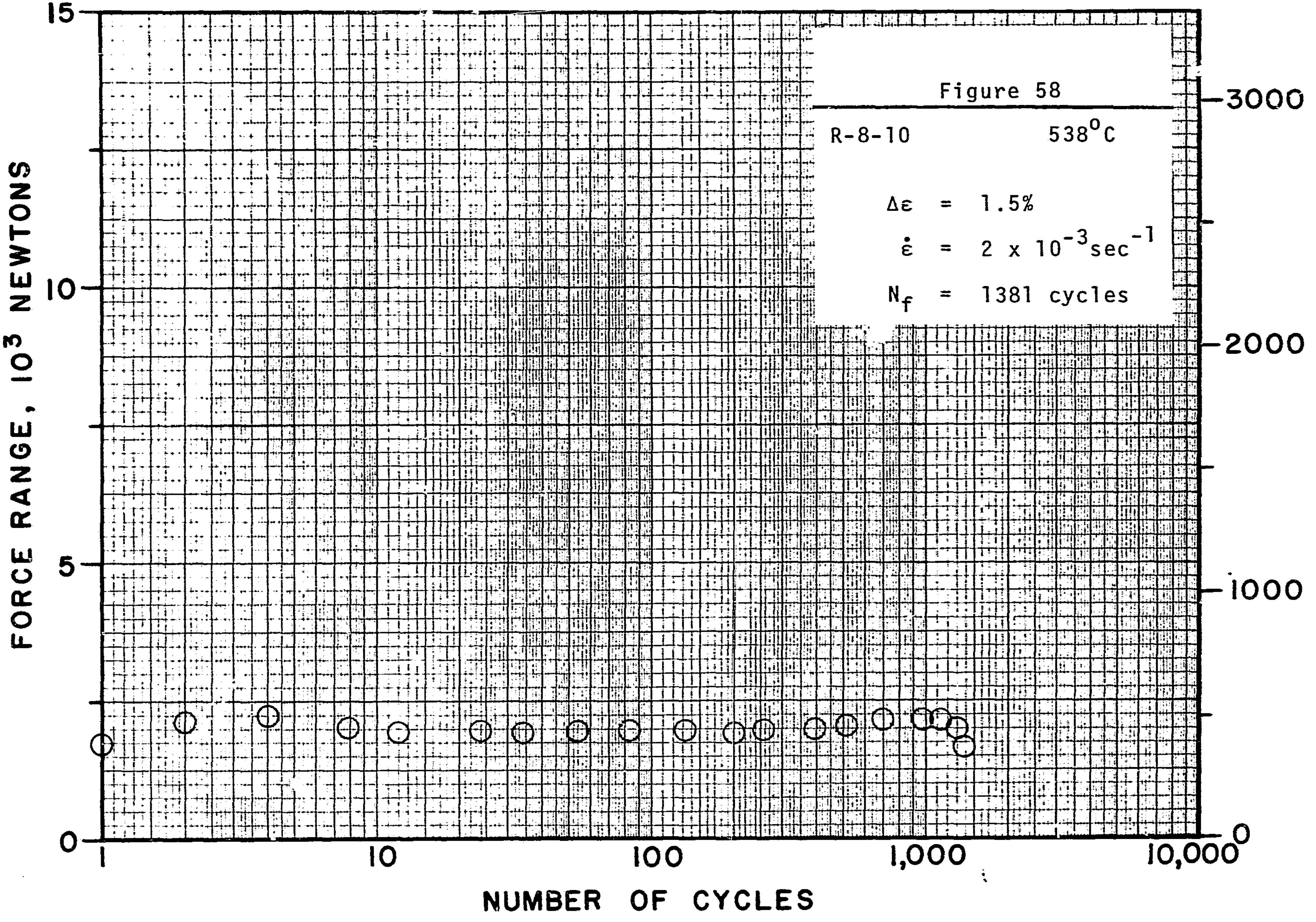


Figure 58

R-8-10 538°C

$\Delta\varepsilon$ = 1.5%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 1381 cycles

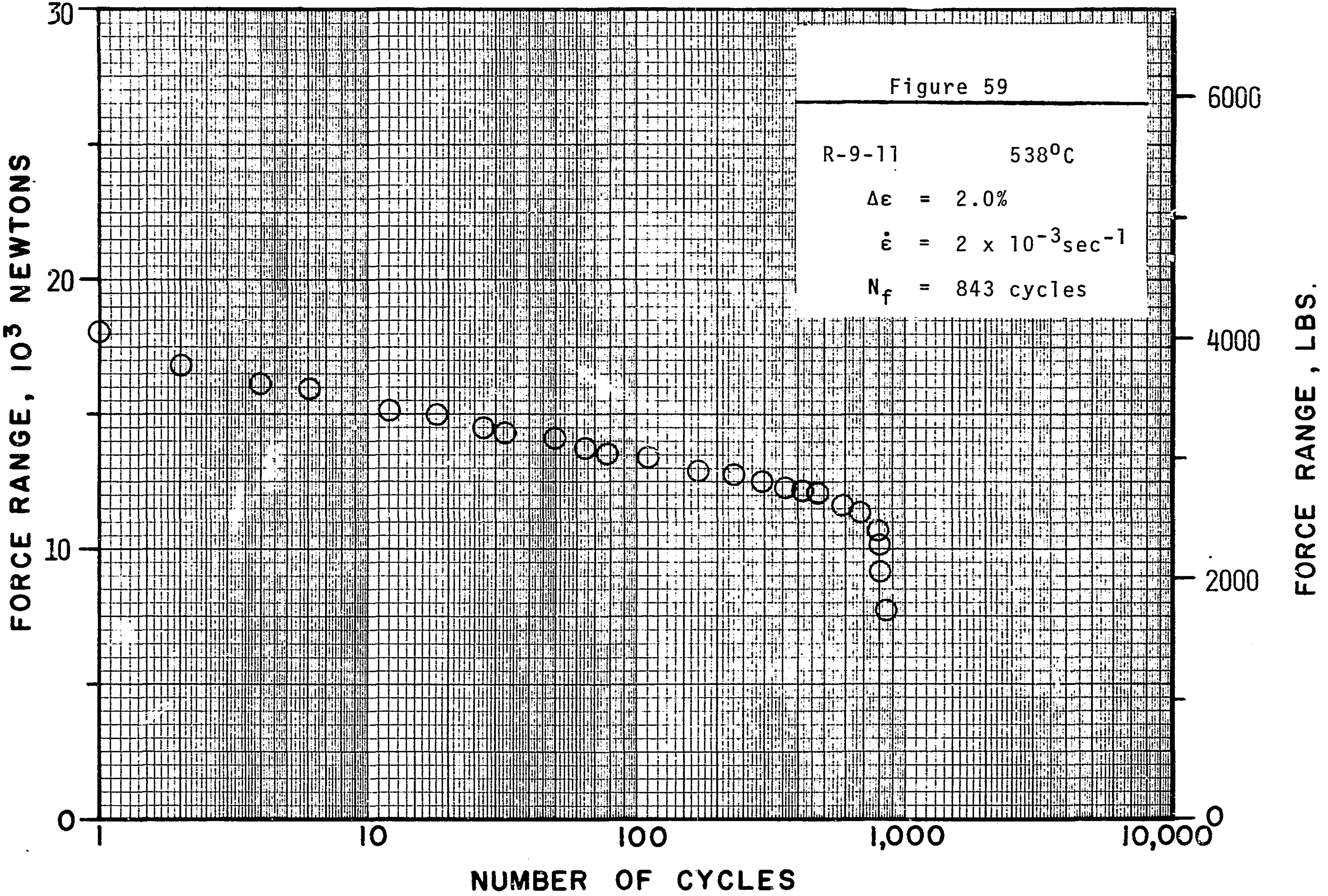


Figure 59

R-9-11 538^{o}C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 843 cycles

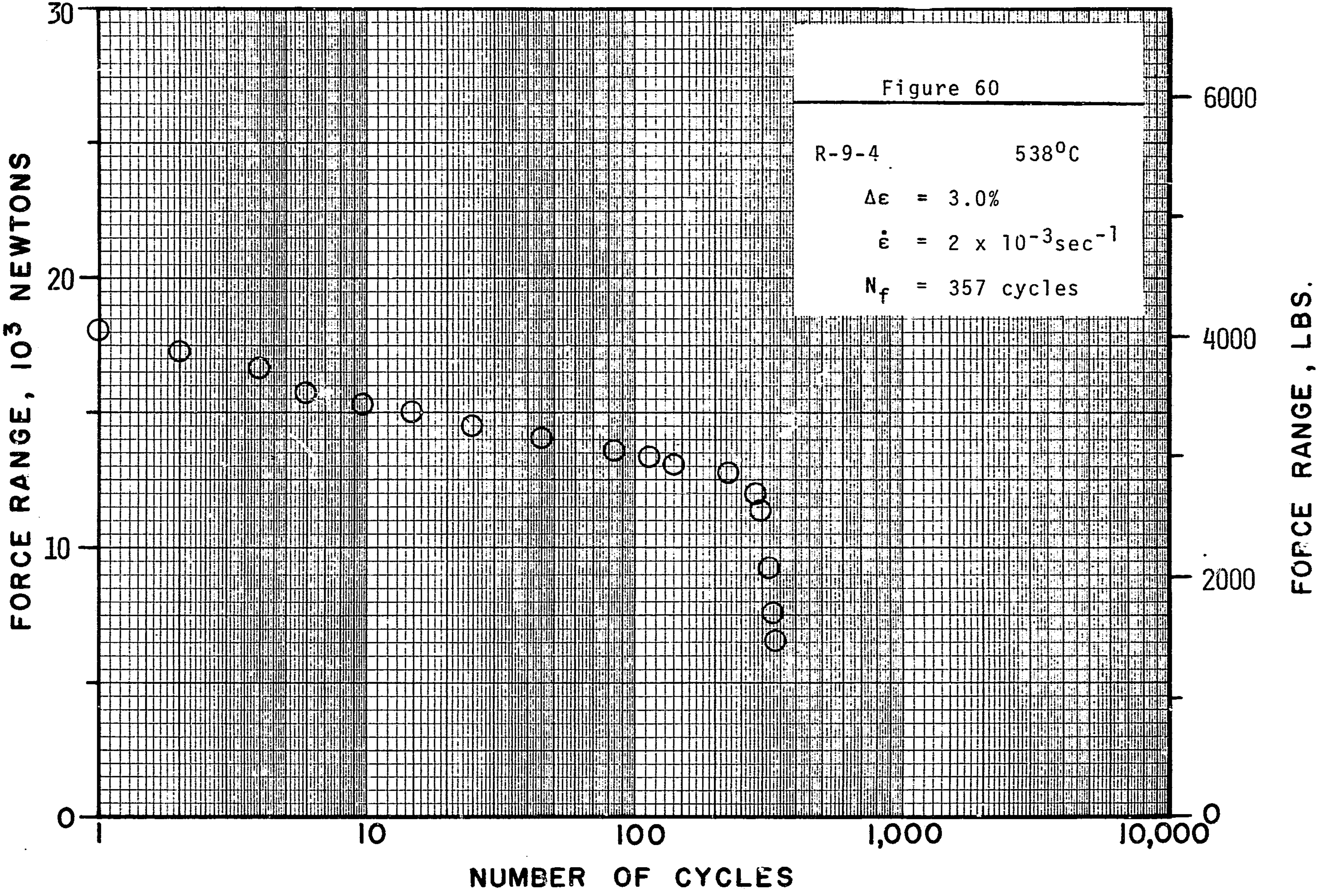


Figure 60

R-9-4 538°C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 357 cycles

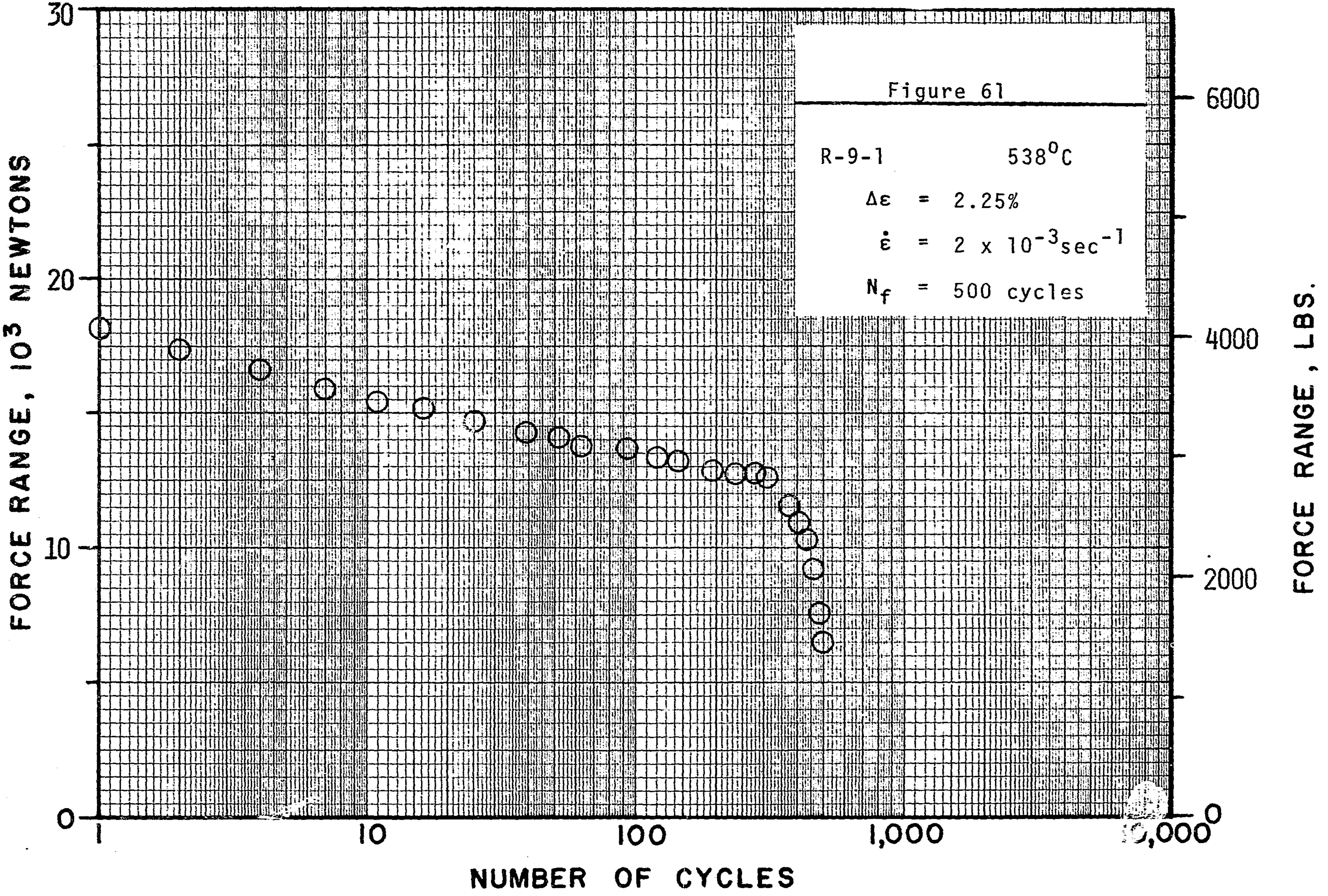


Figure 61
R-9-1 538°C
Δε = 2.25%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 500 cycles
FORCE RANGE, 10³ NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

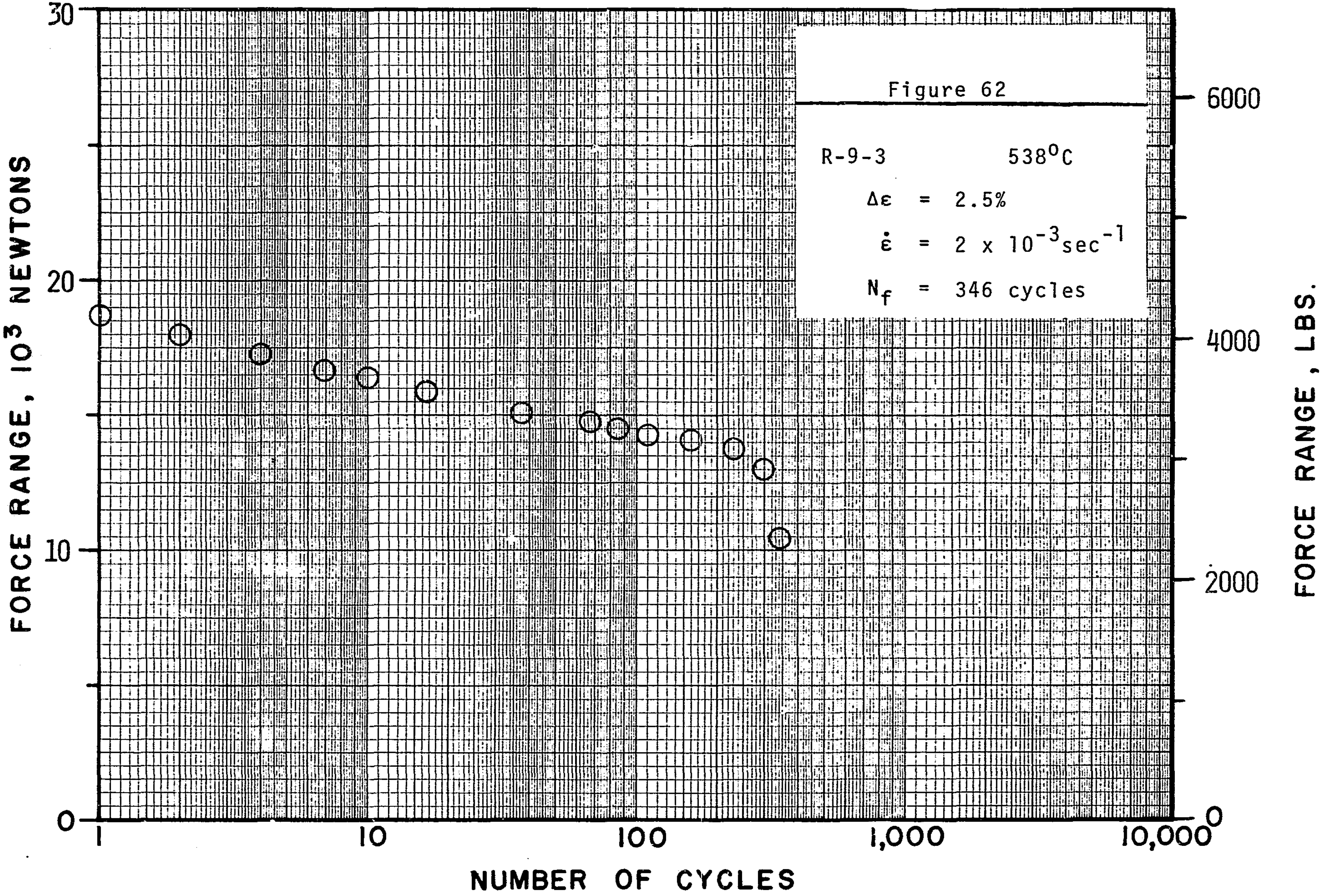


Figure 62

R-9-3 538°C

$\Delta\varepsilon$ = 2.5%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 346 cycles

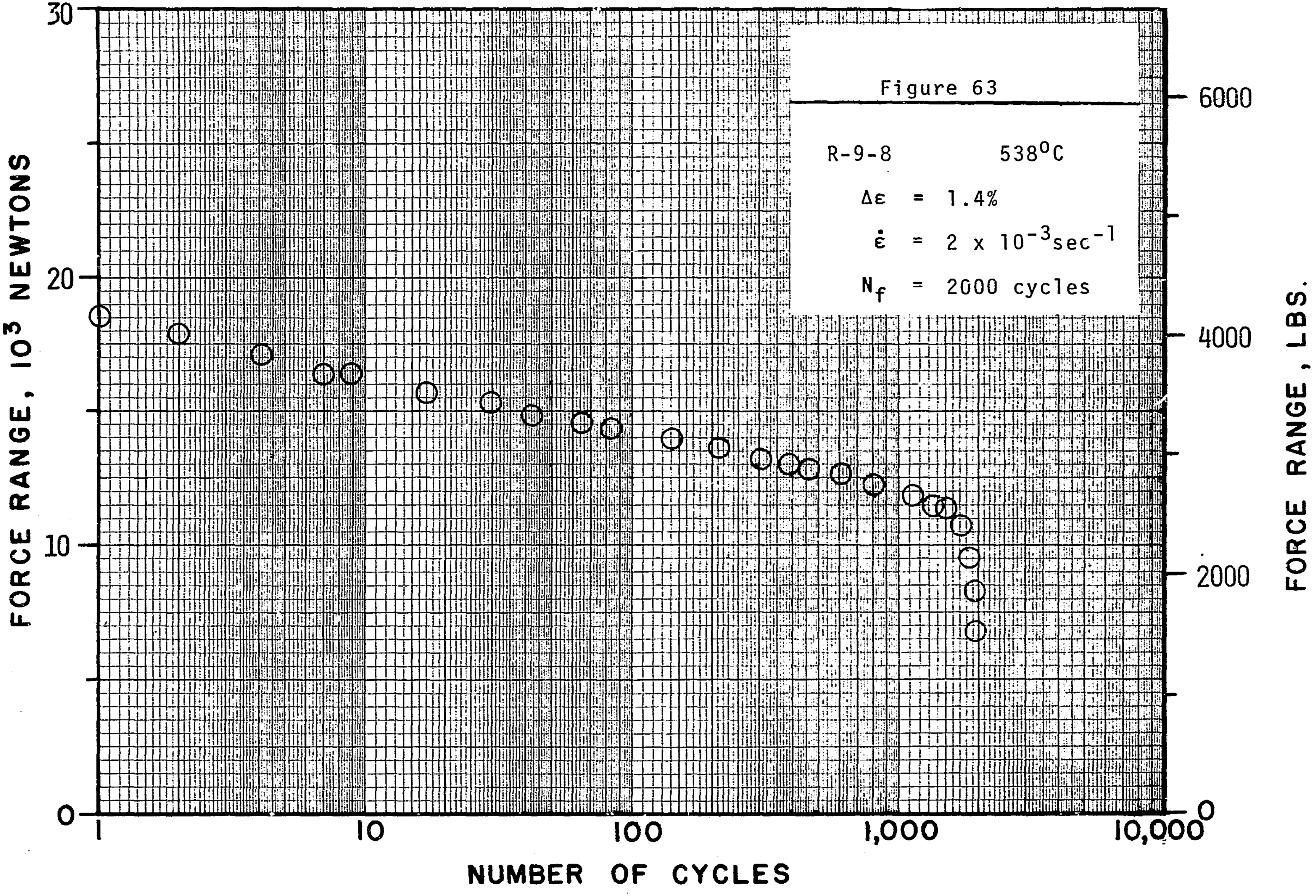


Figure 63

R-9-8 538°C
Δε = 1.4%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 2000 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000

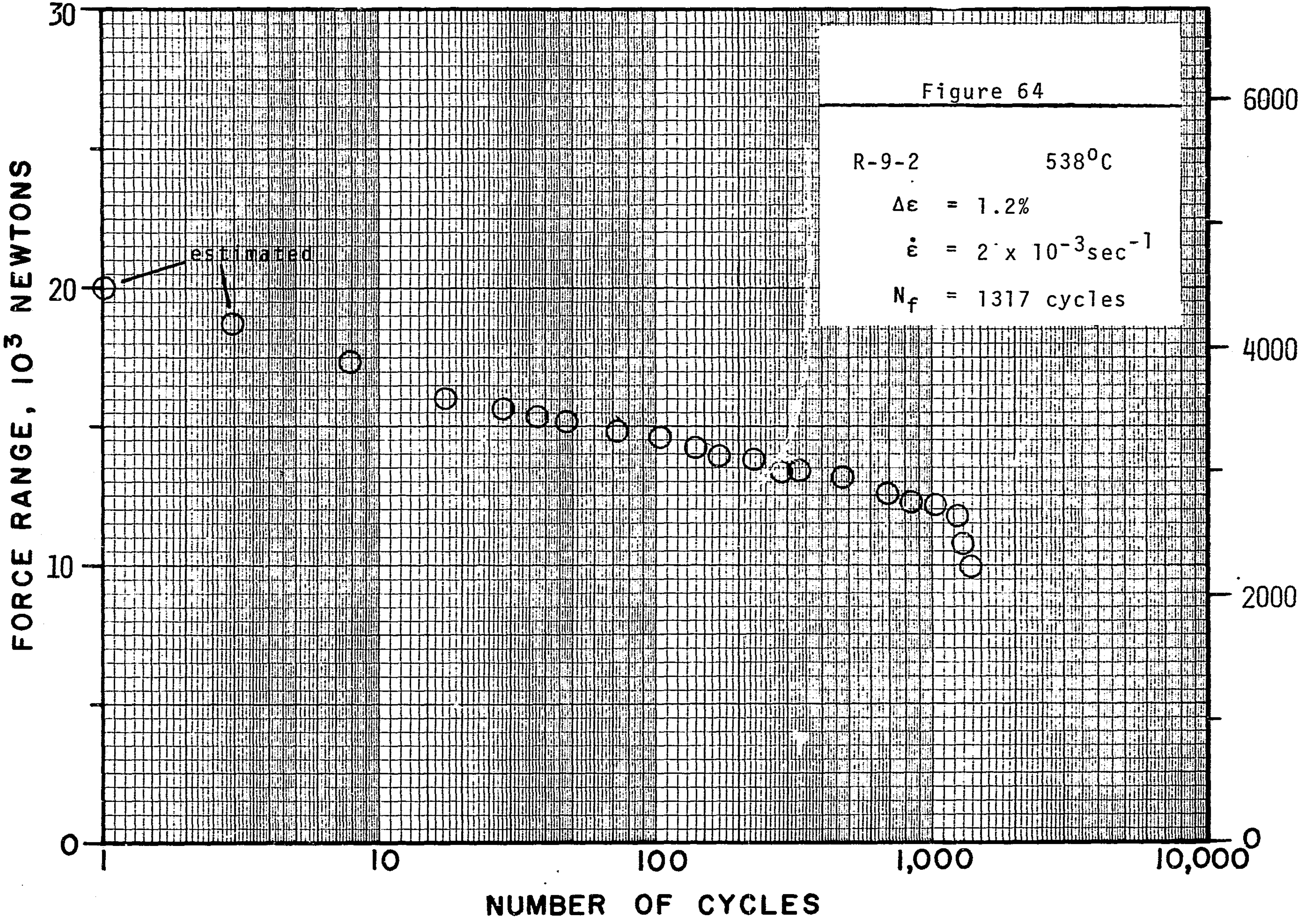


Figure 64

R-9-2 538^{0}C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1317 cycles

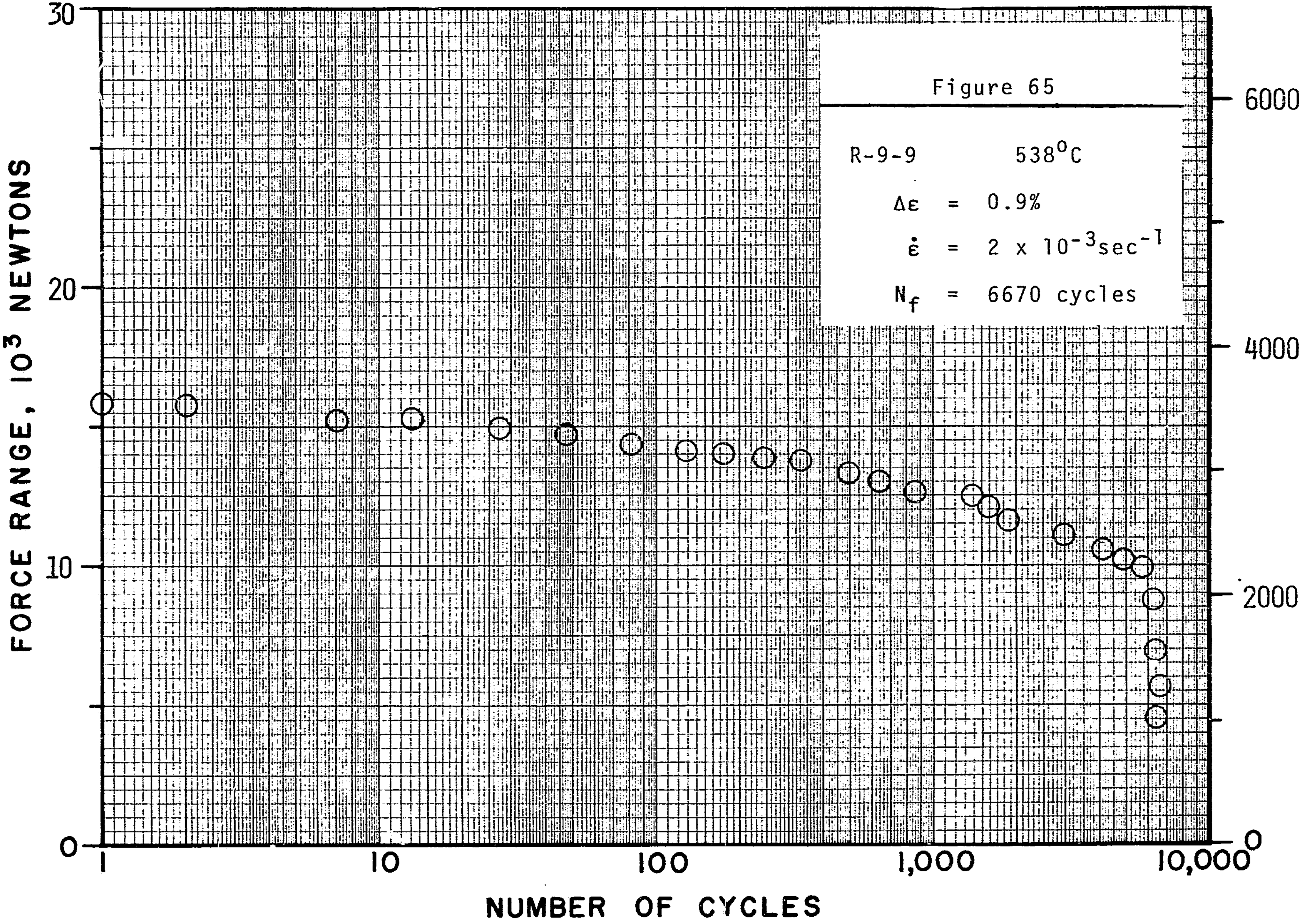


Figure 65

R-9-9 538°C

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 6670 cycles

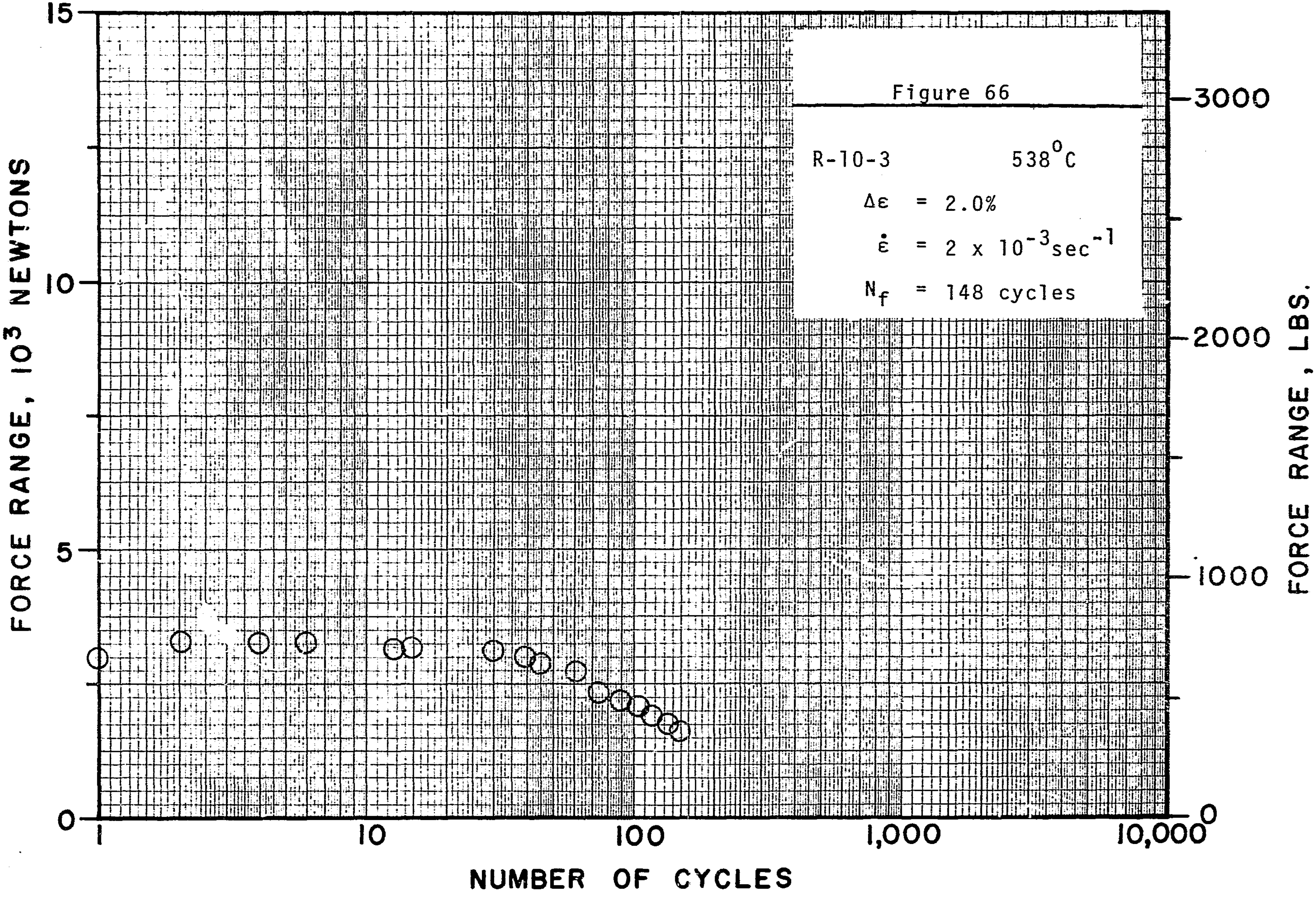


Figure 66
R-10-3
538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 148 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

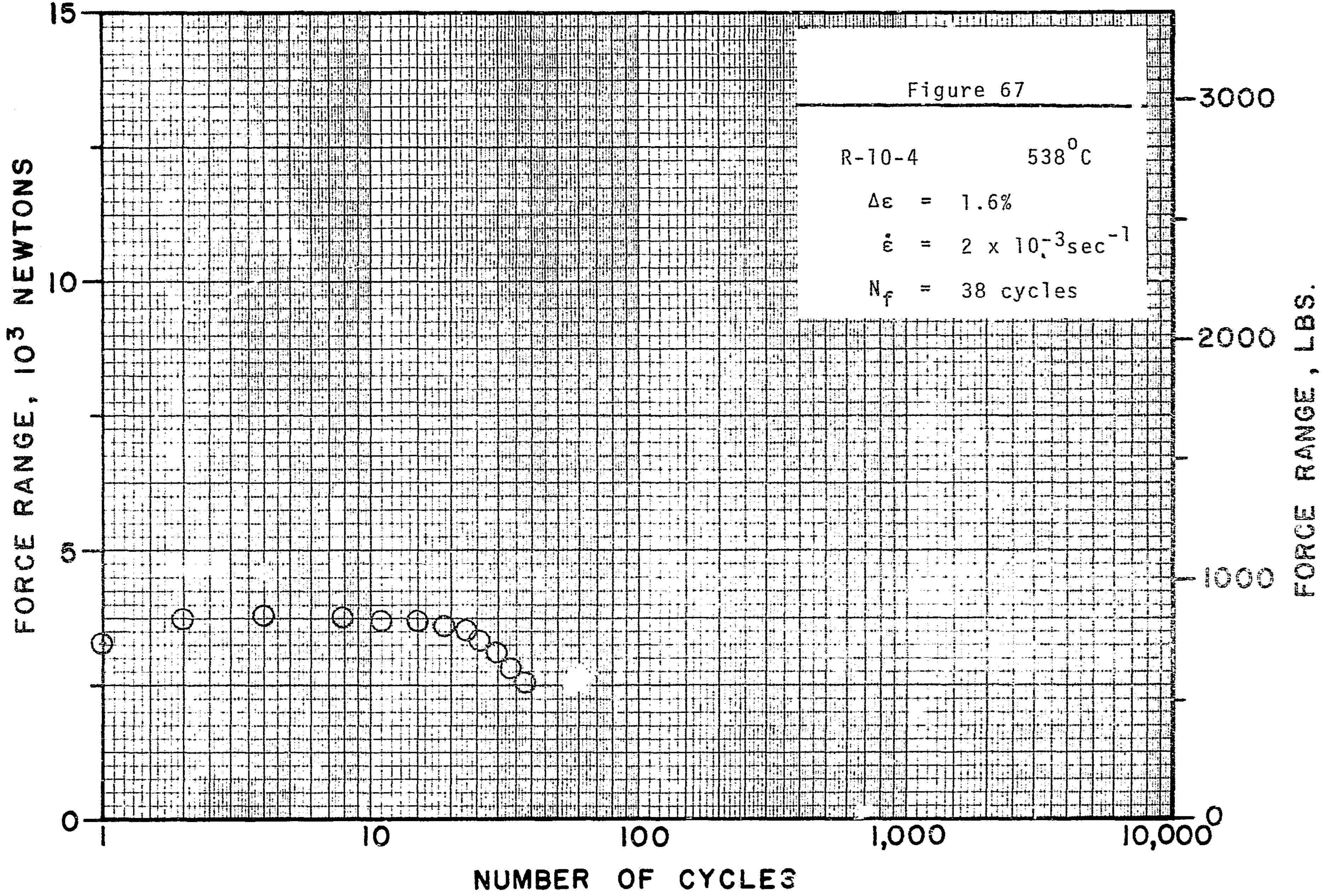


Figure 67

R-10-4 538°C

$\Delta\varepsilon$ = 1.6%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 38 cycles

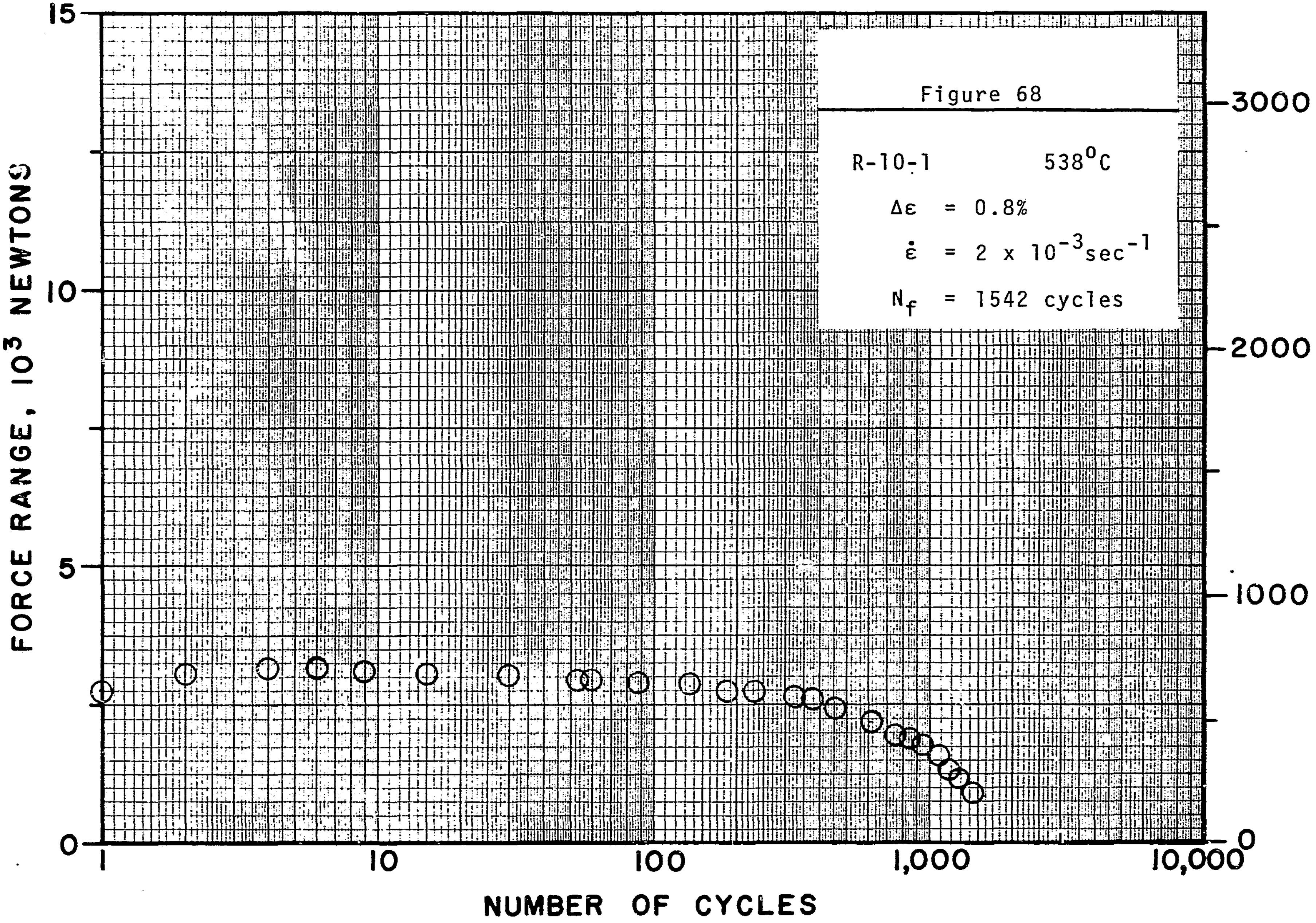


Figure 68

R-10-1 538^{0}C

$\Delta\varepsilon$ = 0.8%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1542 cycles

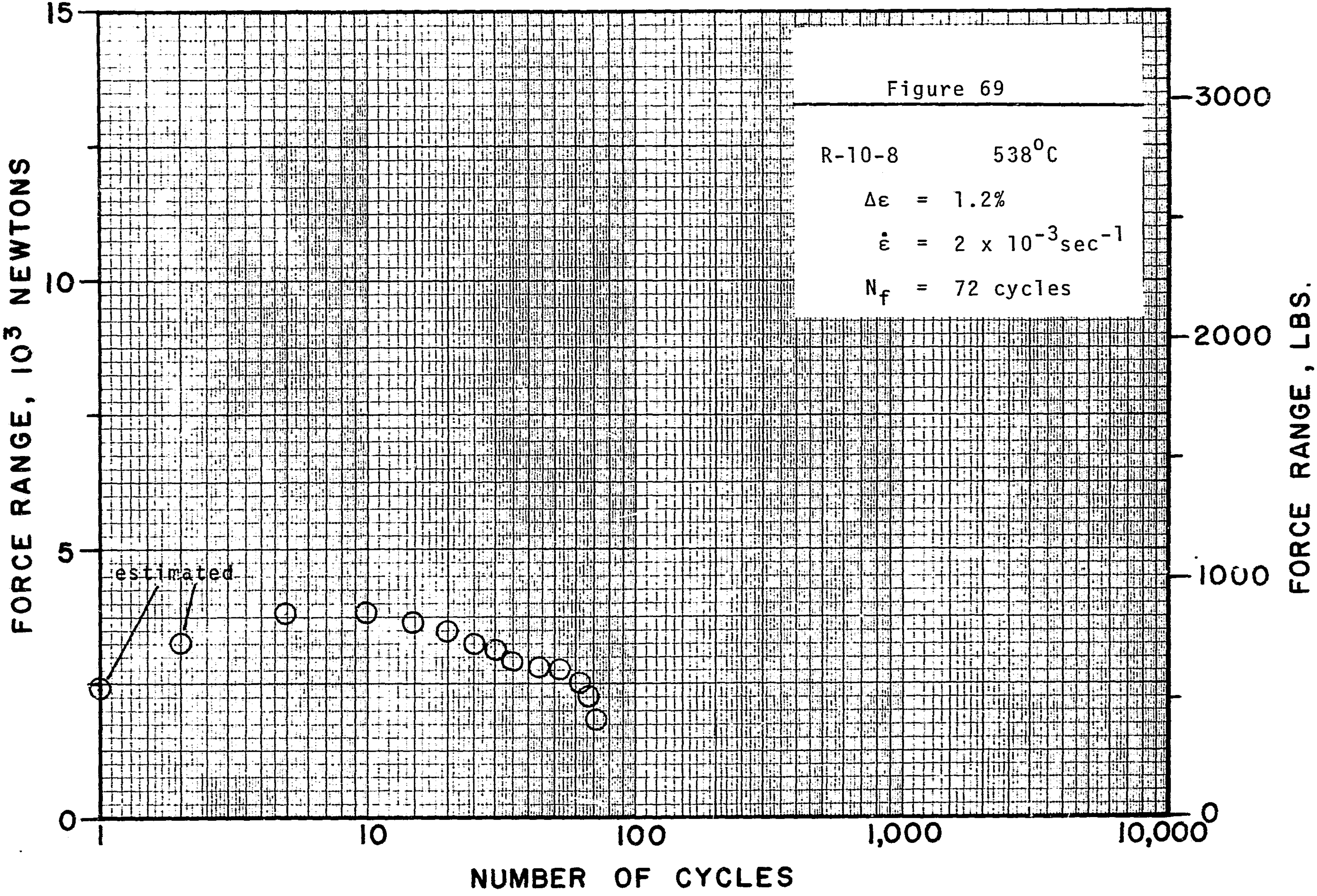


Figure 69
R-10-8
538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 72 cycles
estimated
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

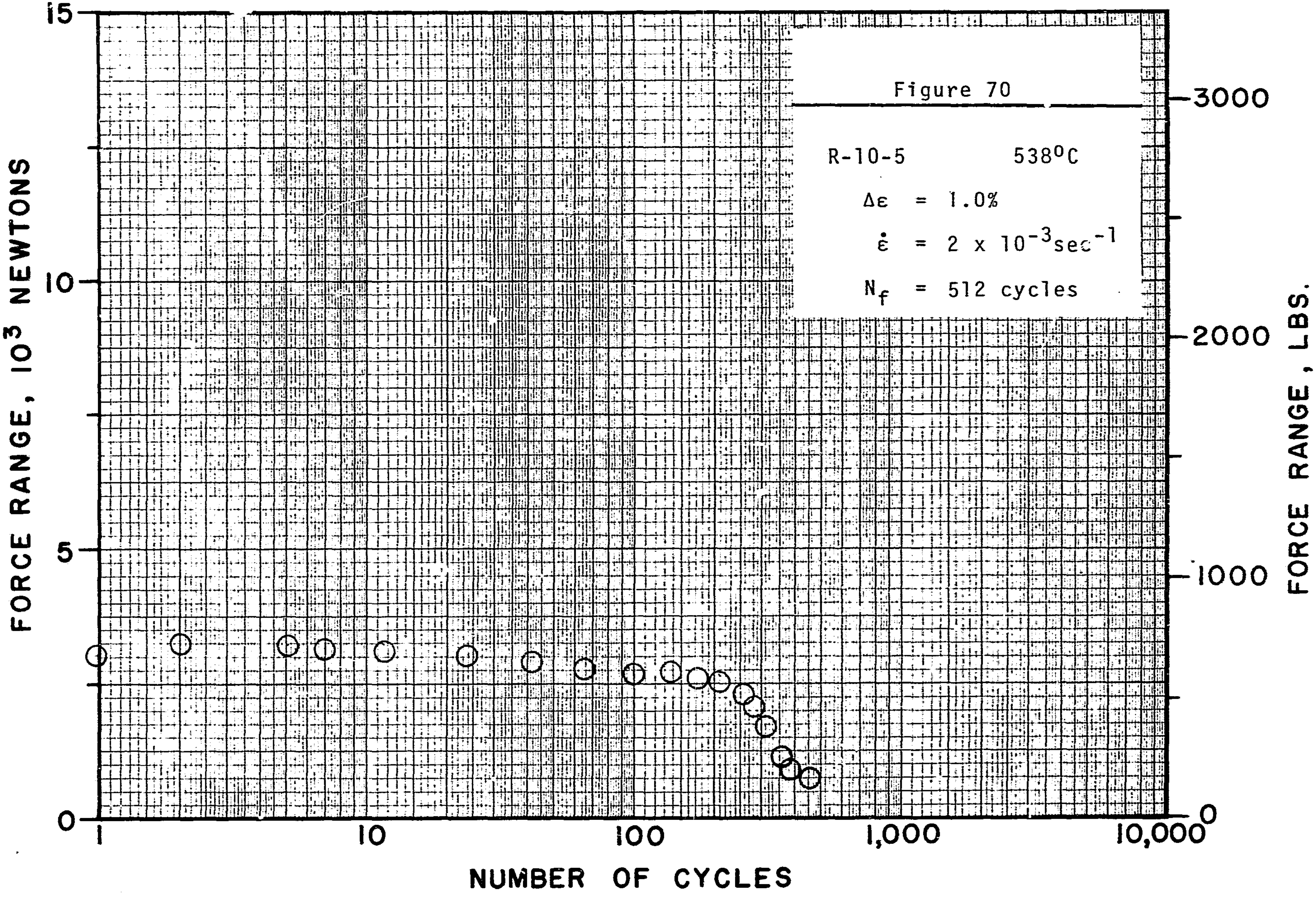


Figure 70

R-10-5 538^{o}C

$\Delta\varepsilon$ = 1.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 512 cycles

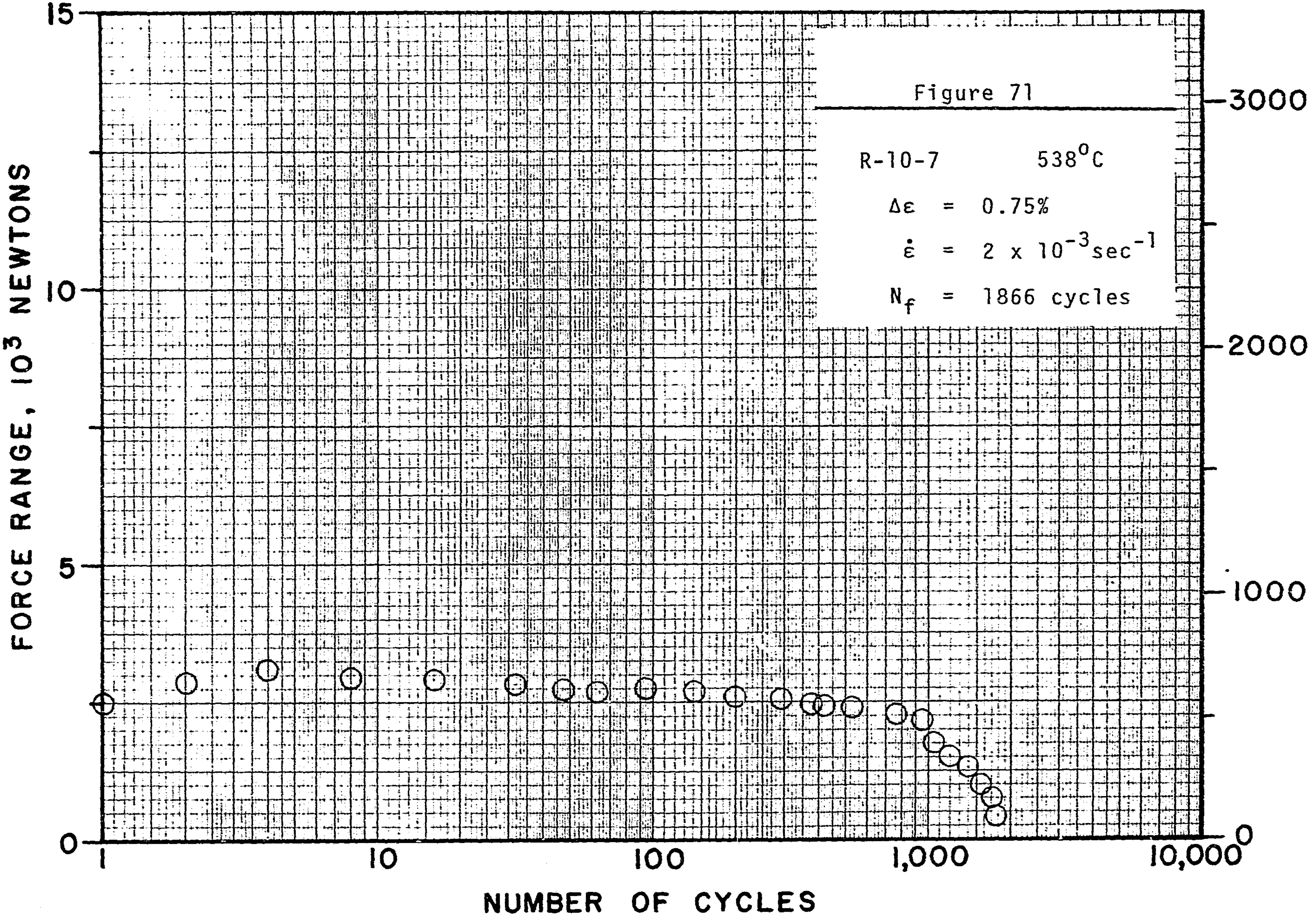


Figure 71

R-10-7 538^{0}C

$\Delta\varepsilon$ = 0.75%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1866 cycles

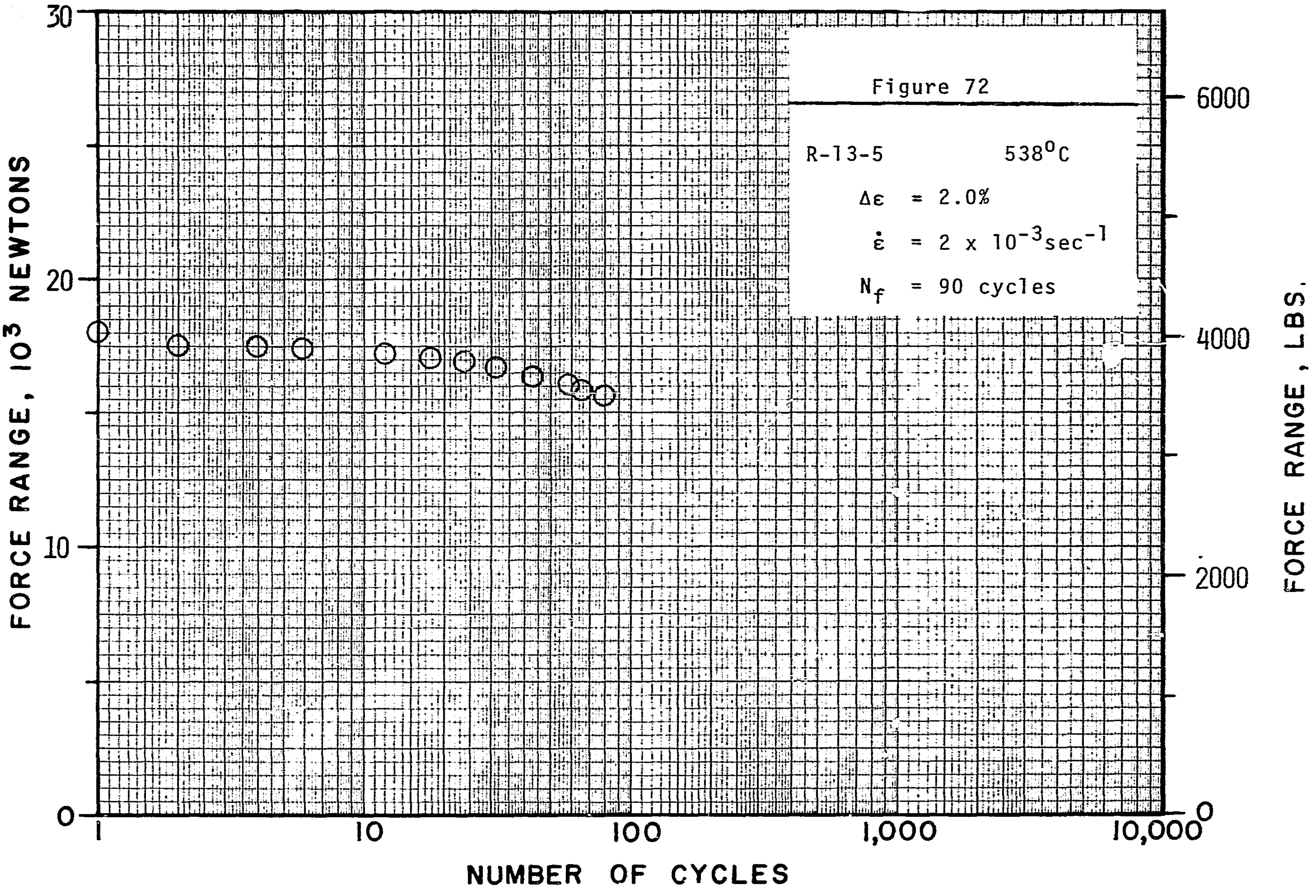


Figure 72

R-13-5 538^{0}C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 90 cycles

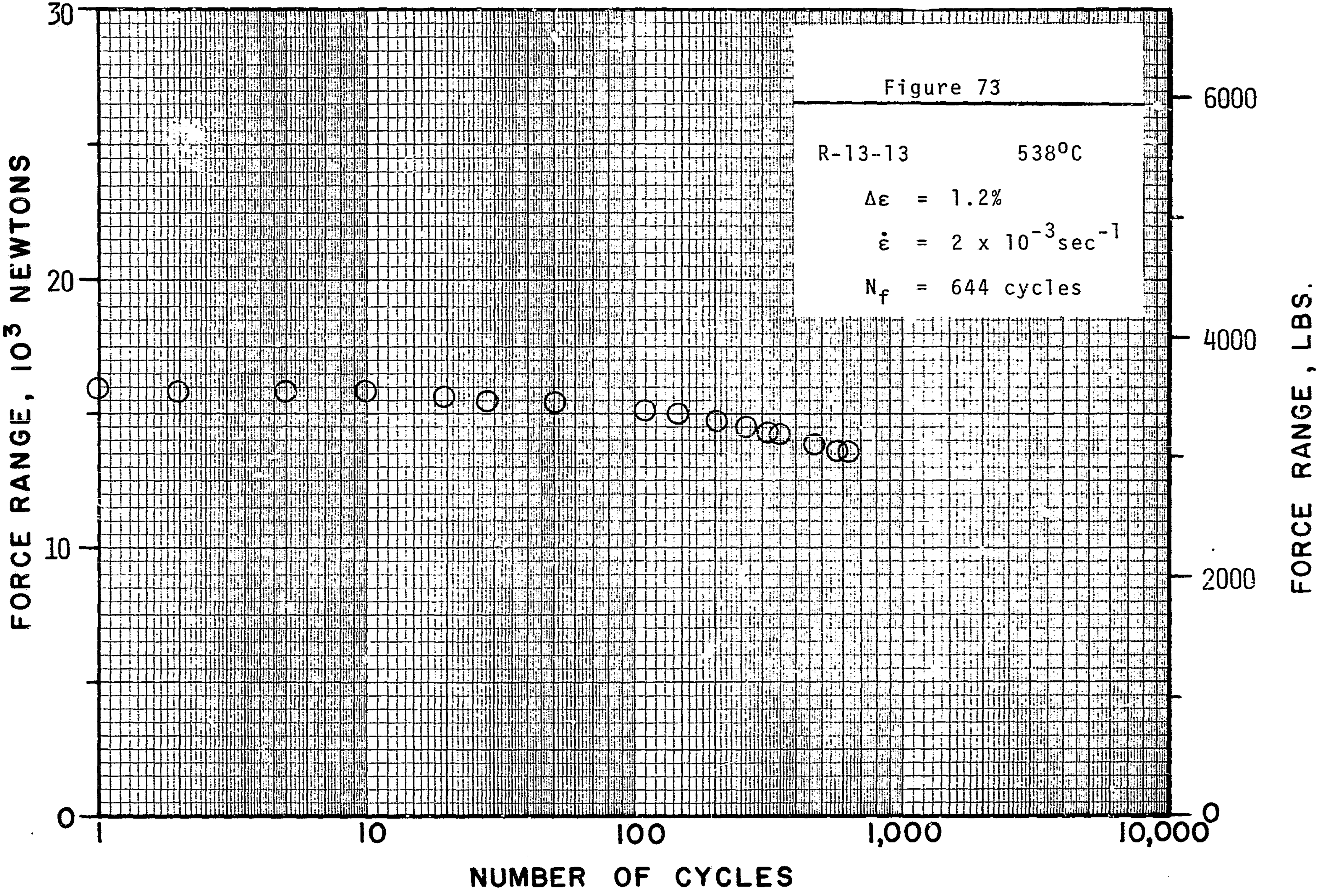


Figure 73

R-13-13 538°C

$\Delta\varepsilon = 1.2\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \mathrm{sec}^{-1}$

N_f = 644 cycles

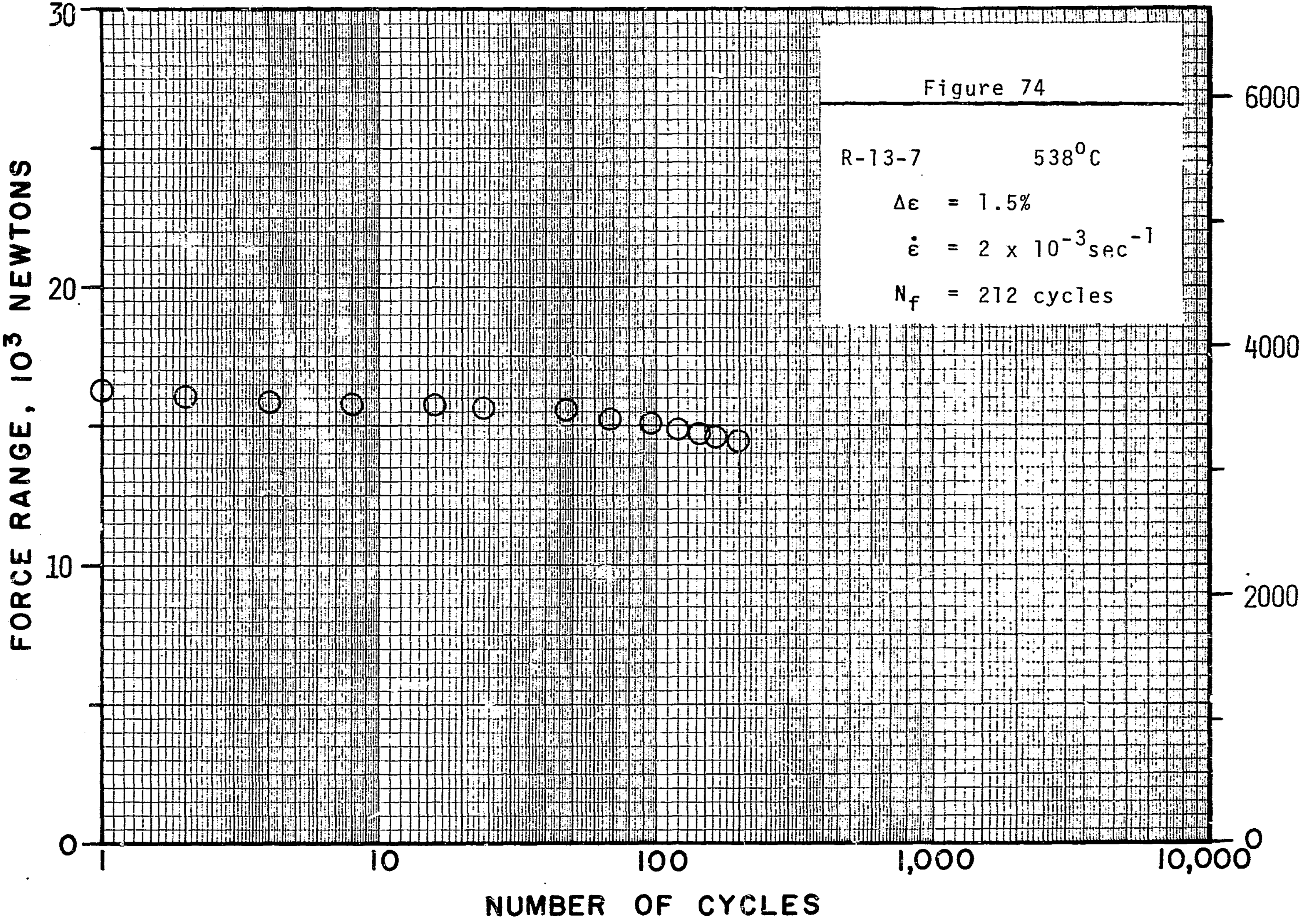


Figure 74

R-13-7 538°C

$\Delta\varepsilon$ = 1.5%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 212 cycles

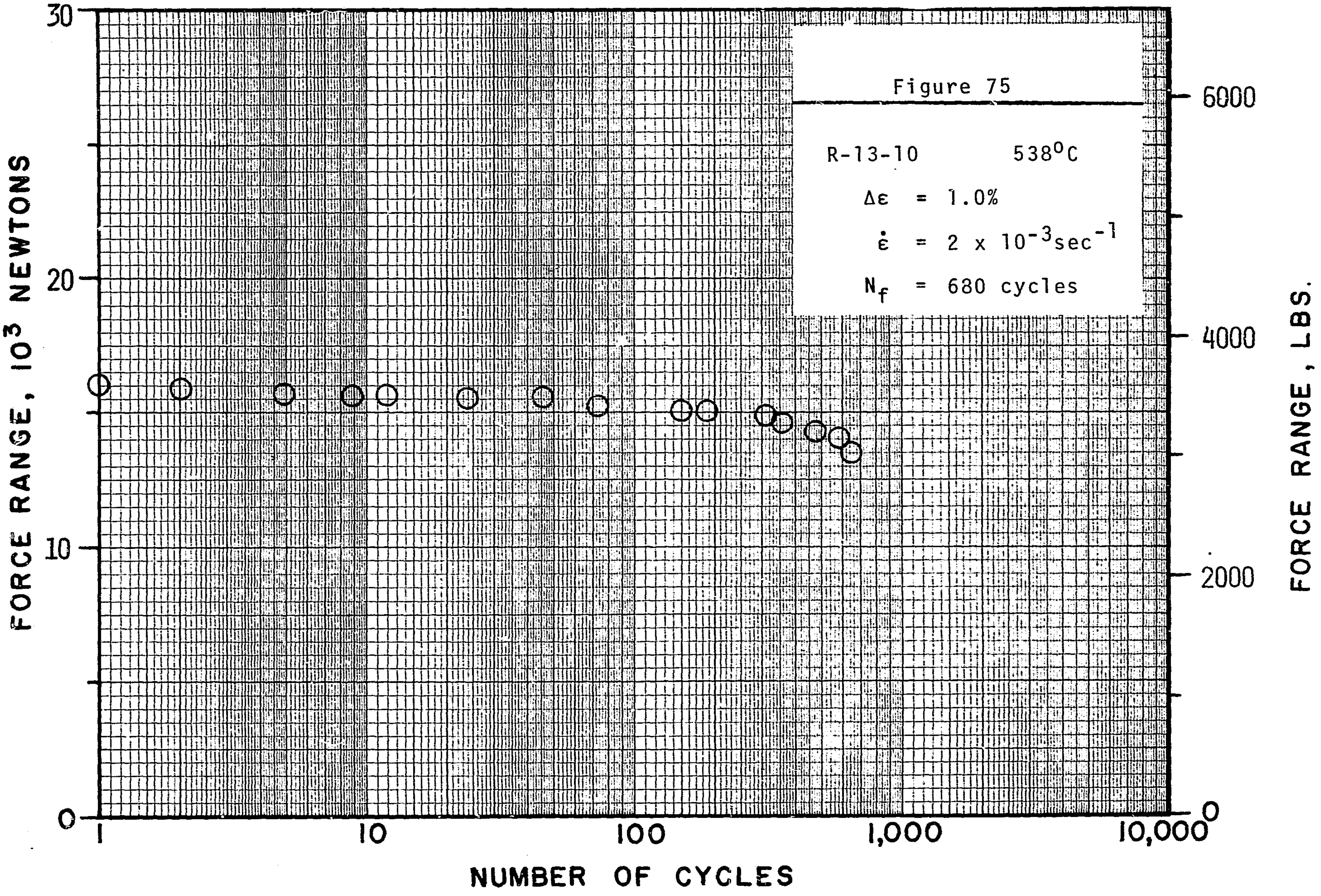


Figure 75

R-13-10
538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 680 cycles
FORCE RANGE, 10³ NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
1
10
100
1,000
10,000
NUMBER OF CYCLES

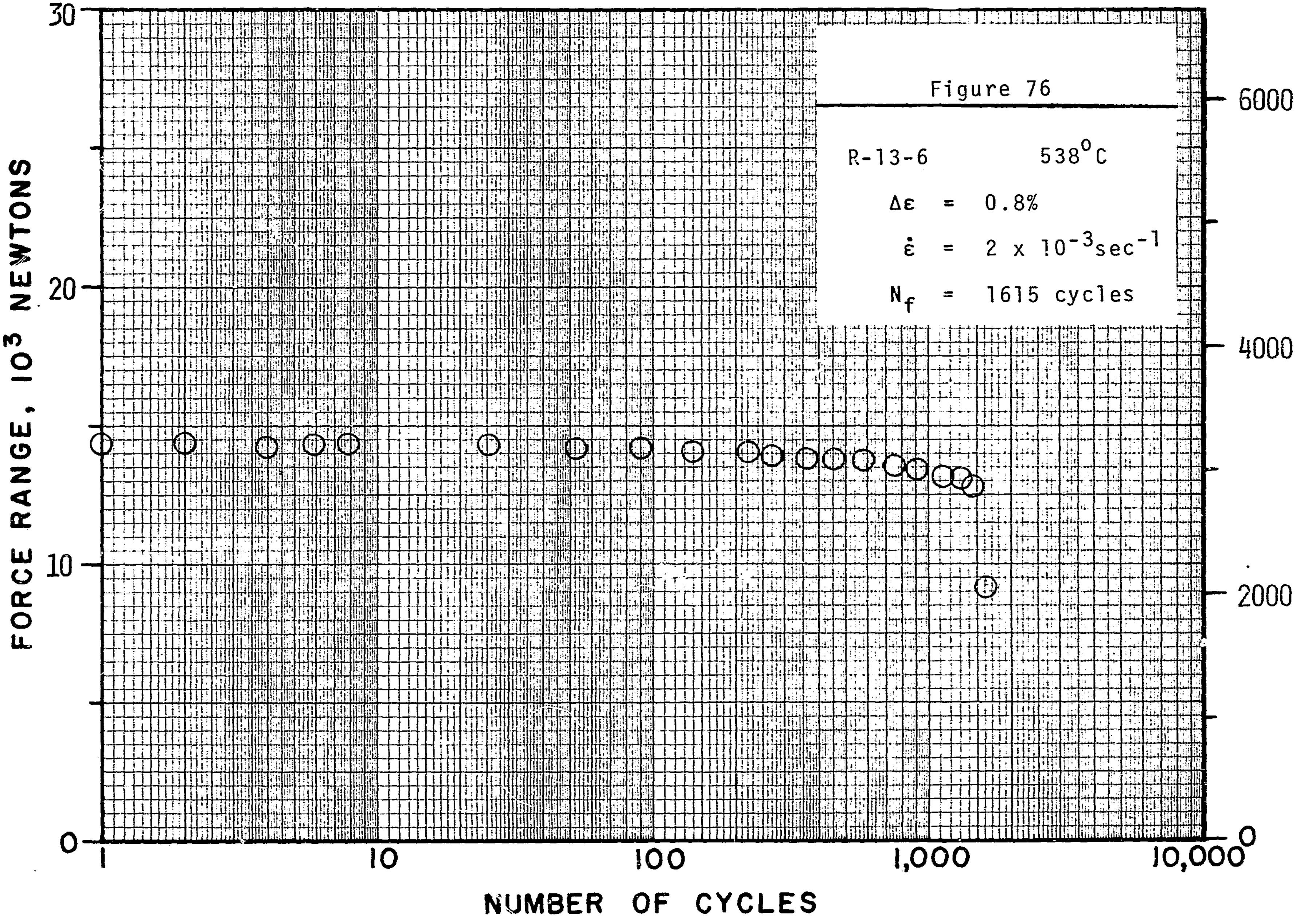

30
20
10
0
1
10
100
1,000
10,000
6000
4000
2000
0
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
R-13-6 538°C
$\Delta\varepsilon$ = 0.8%
$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$
N_f = 1615 cycles

Figure 76

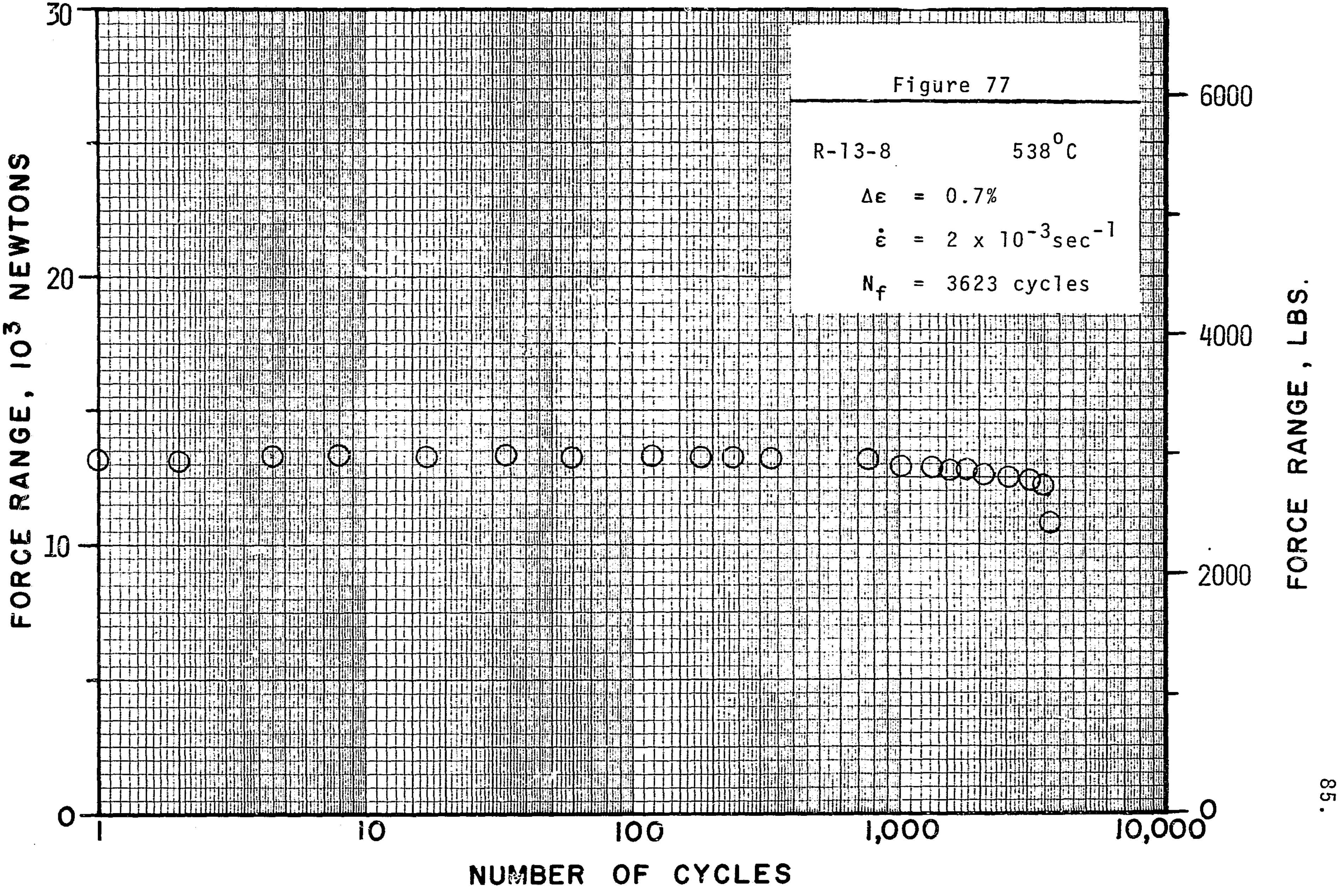


Figure 77

R-13-8
538°C
$\Delta\varepsilon$ = 0.7%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 3623 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

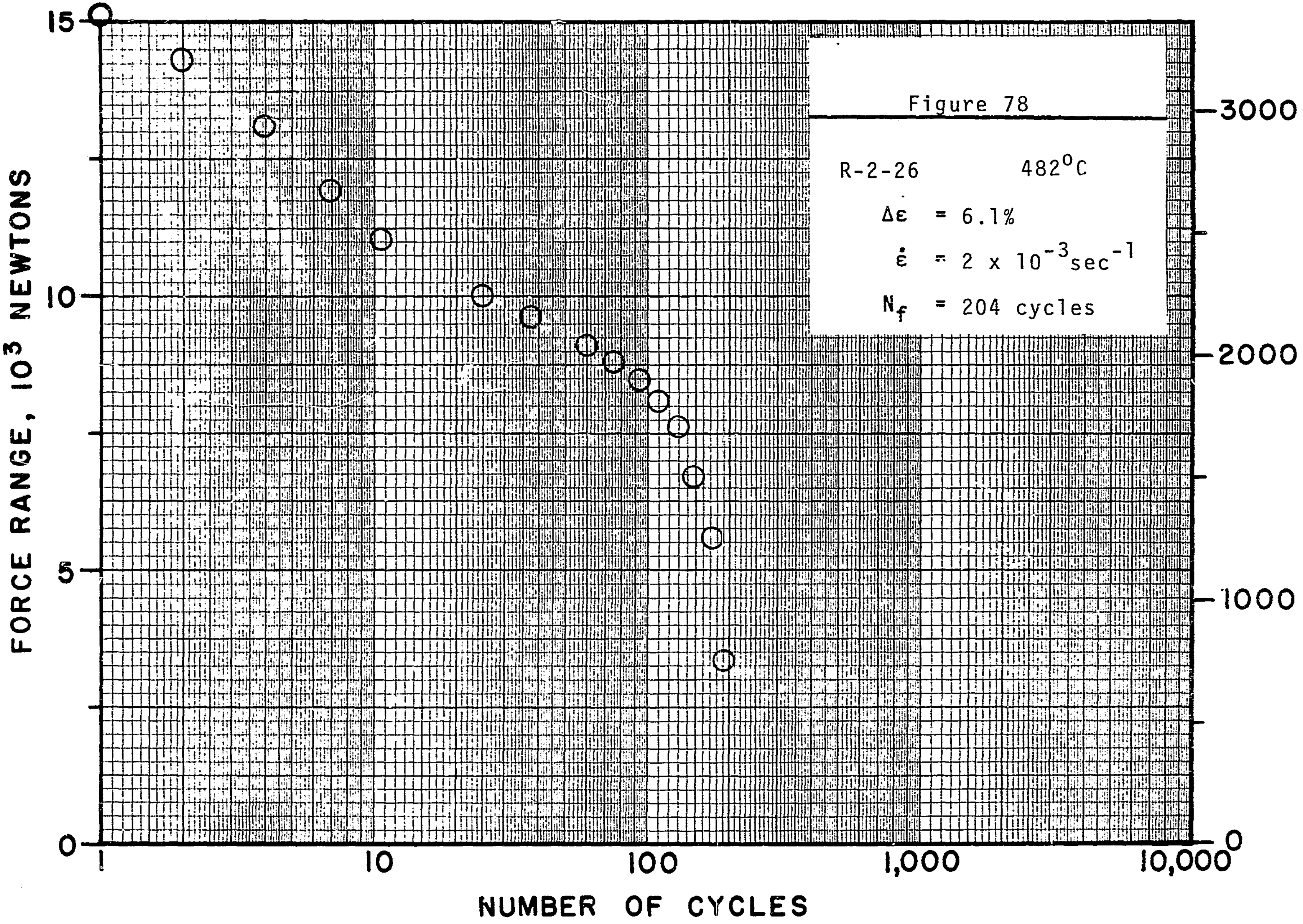


Figure 78
R-2-26
482°C
Δε = 6.1%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 204 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

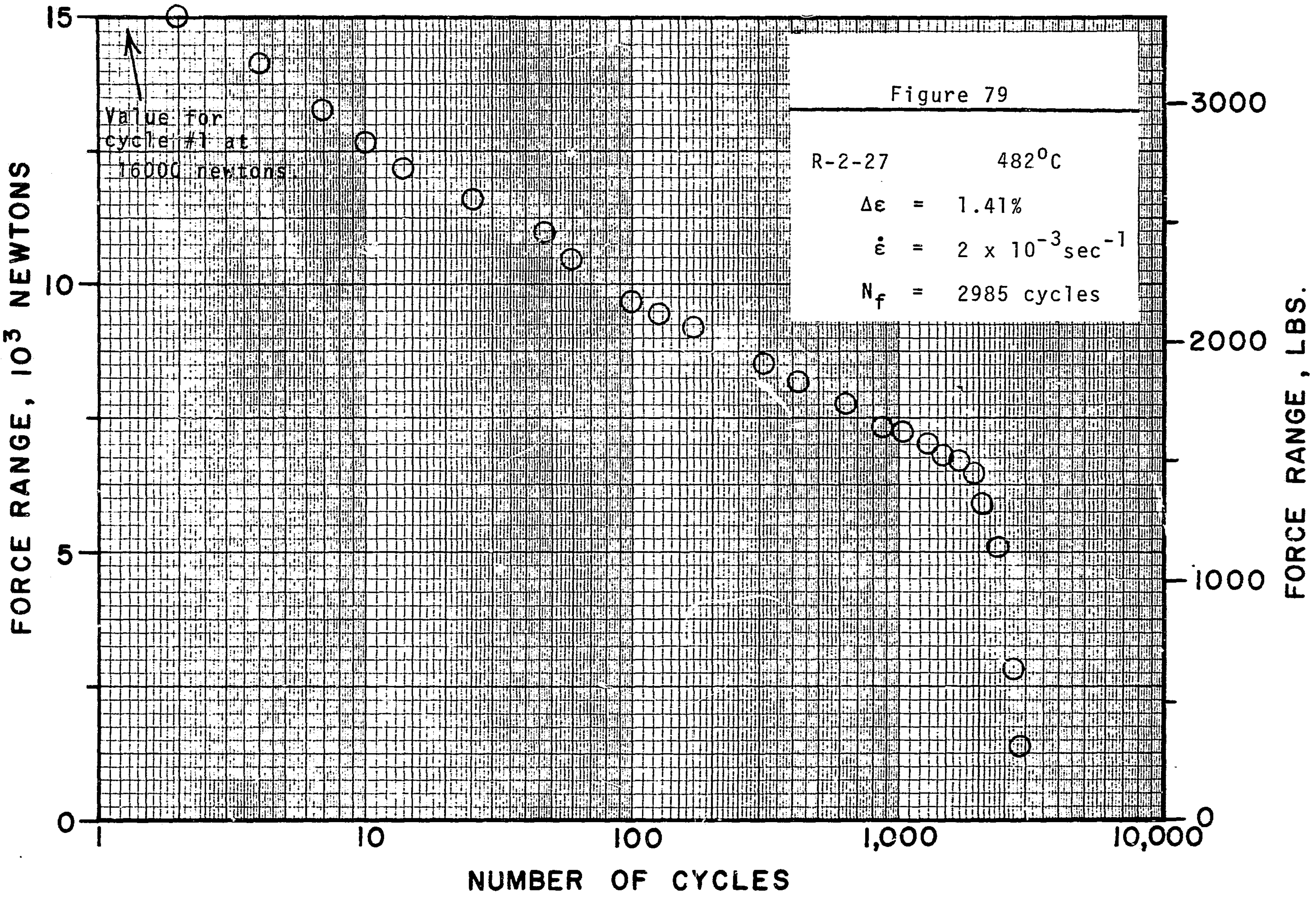


Figure 79

R-2-27 482°C

$\Delta\varepsilon$ = 1.41%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \mathrm{sec}^{-1}$

N_f = 2985 cycles

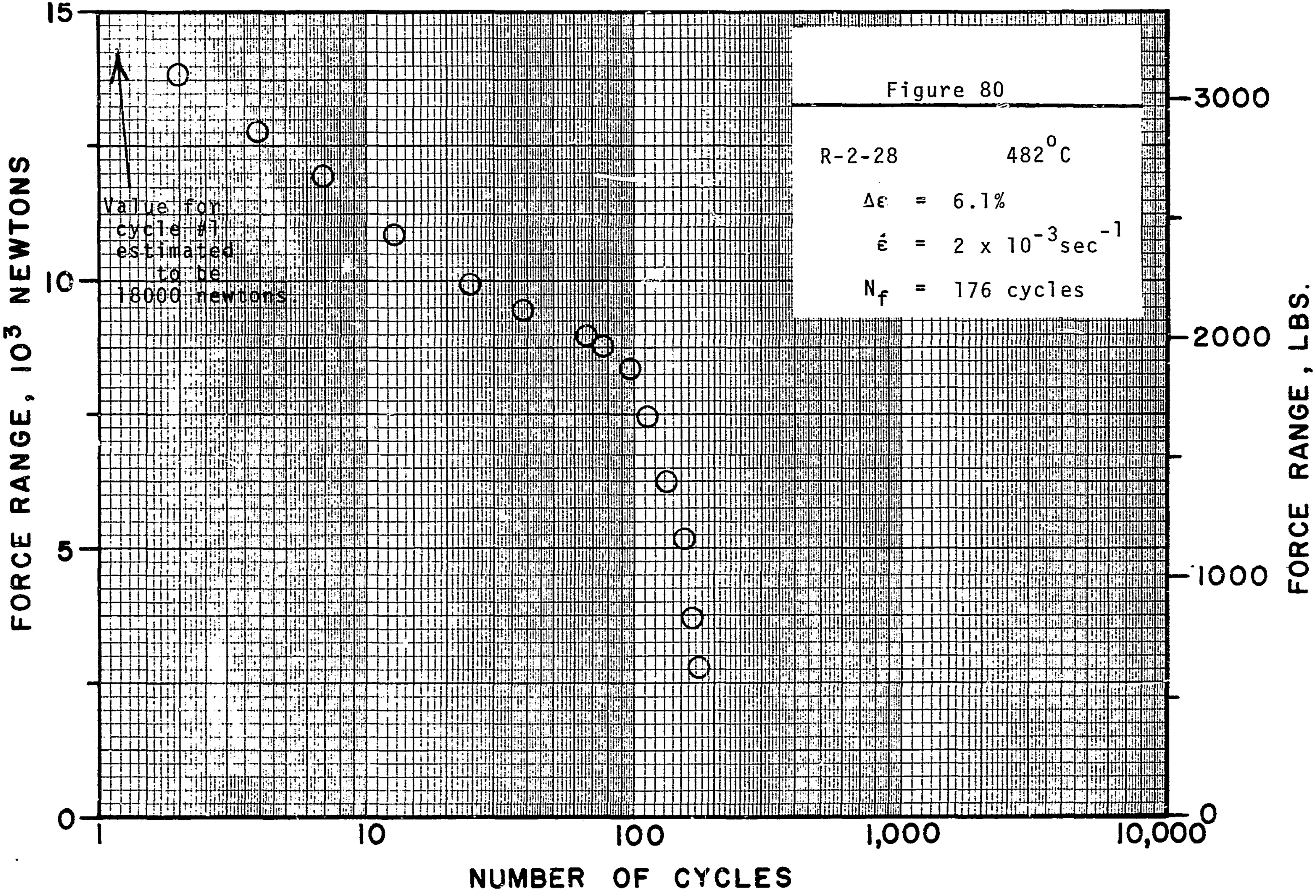


Figure 80

R-2-28 482°C

$\Delta\epsilon = 6.1\%$

$\dot{\epsilon} = 2 \times 10^{-3} \mathrm{sec}^{-1}$

$N_f = 176$ cycles

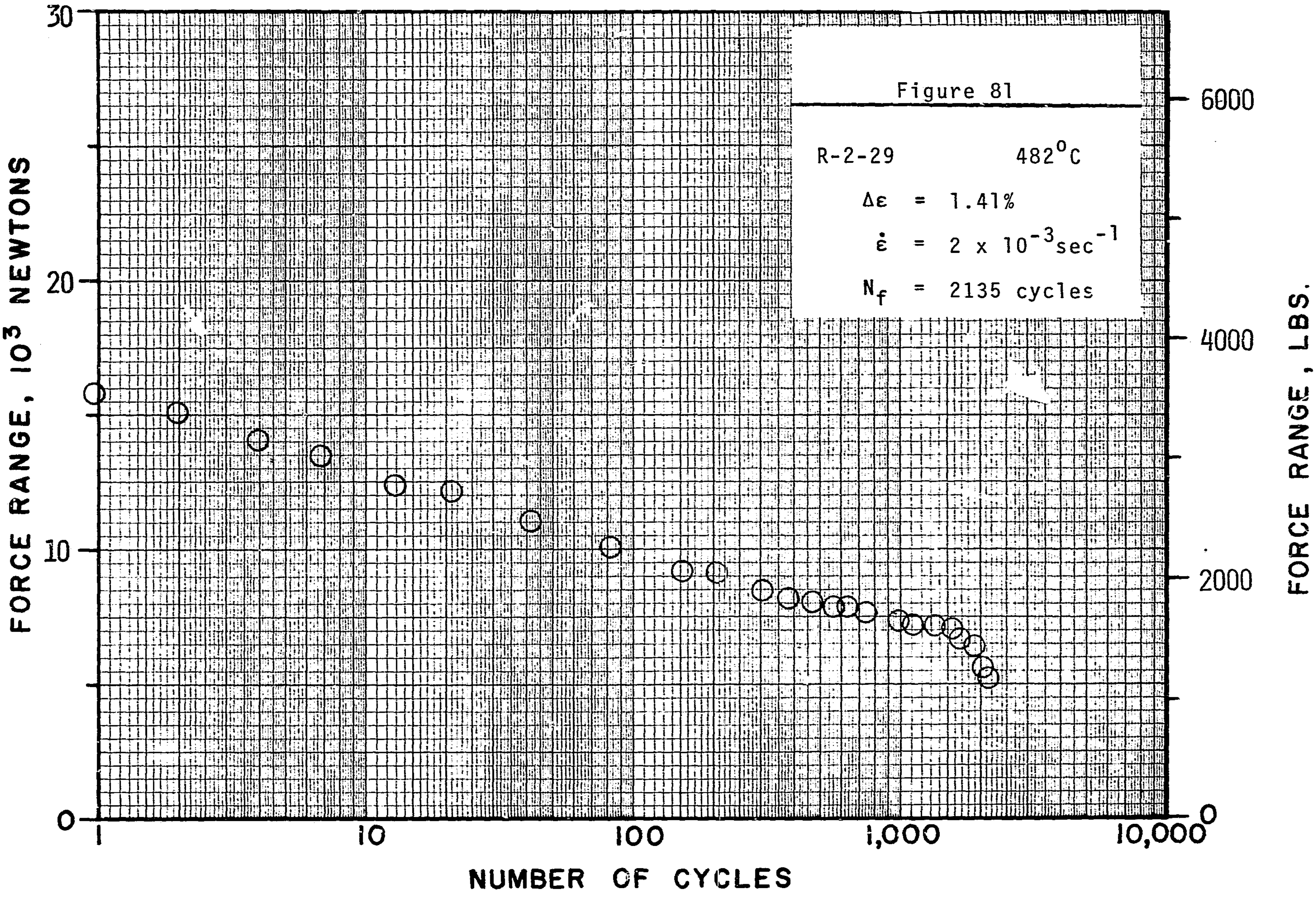


Figure 81

R-2-29 482°C

$\Delta\varepsilon = 1.41\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 2135 cycles

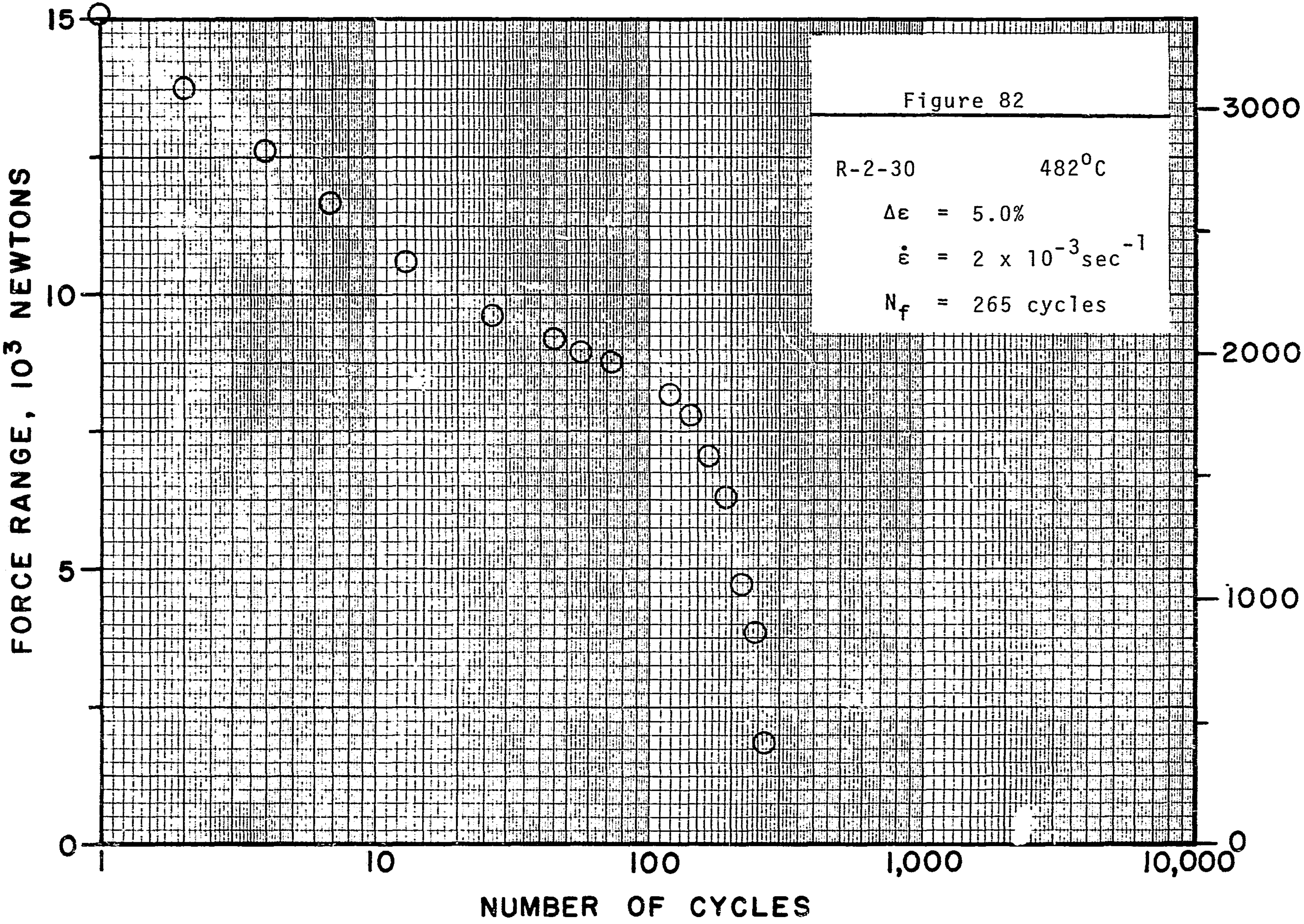


Figure 82

R-2-30 482^{0}C

$\Delta\varepsilon$ = 5.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 265 cycles

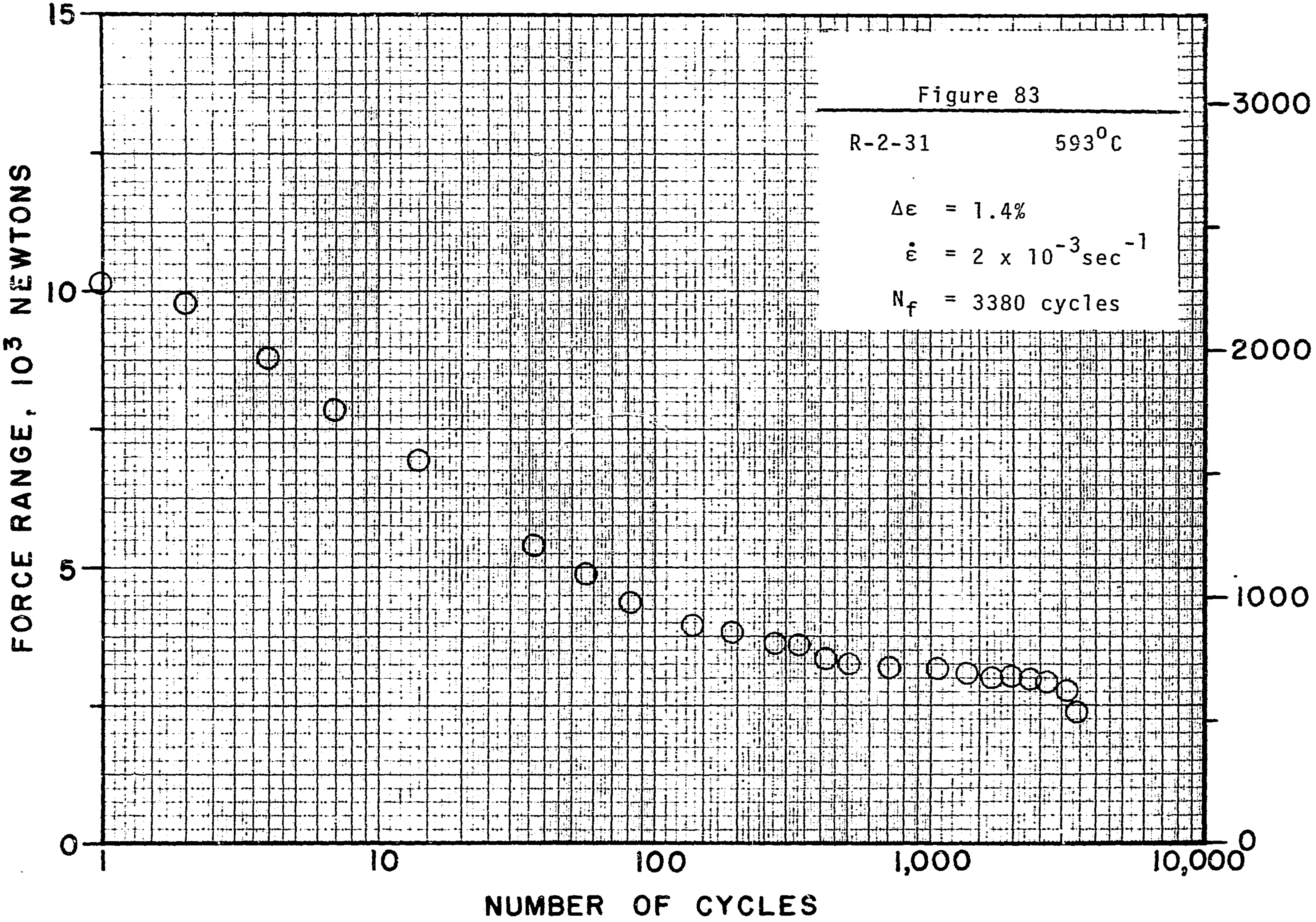


Figure 83

R-2-31
593°C
$\Delta\varepsilon$ = 1.4%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 3380 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
1
10
100
1,000
10,000
NUMBER OF CYCLES

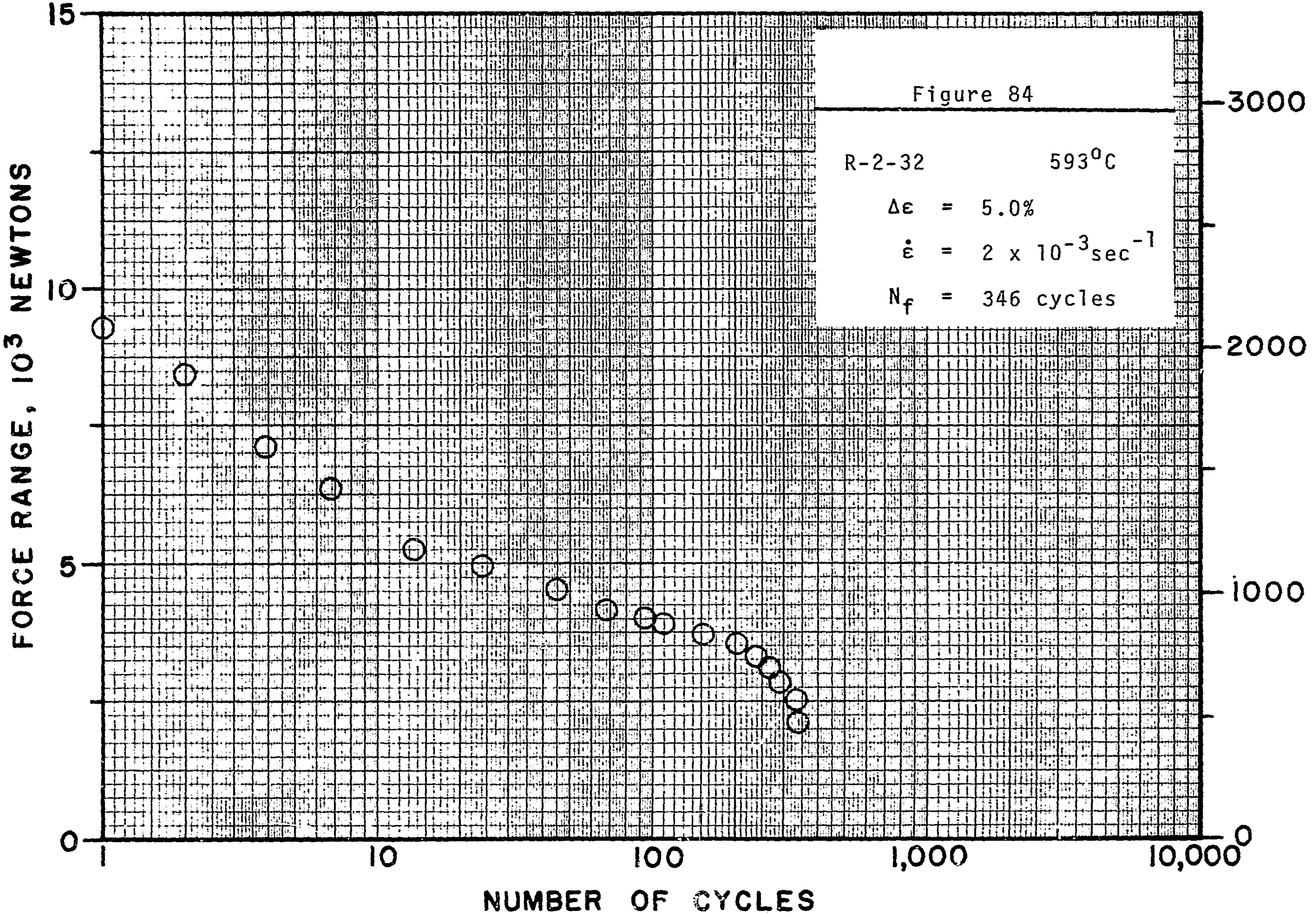


Figure 84

R-2-32
593^{o}C
$\Delta\varepsilon$ = 5.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 346 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

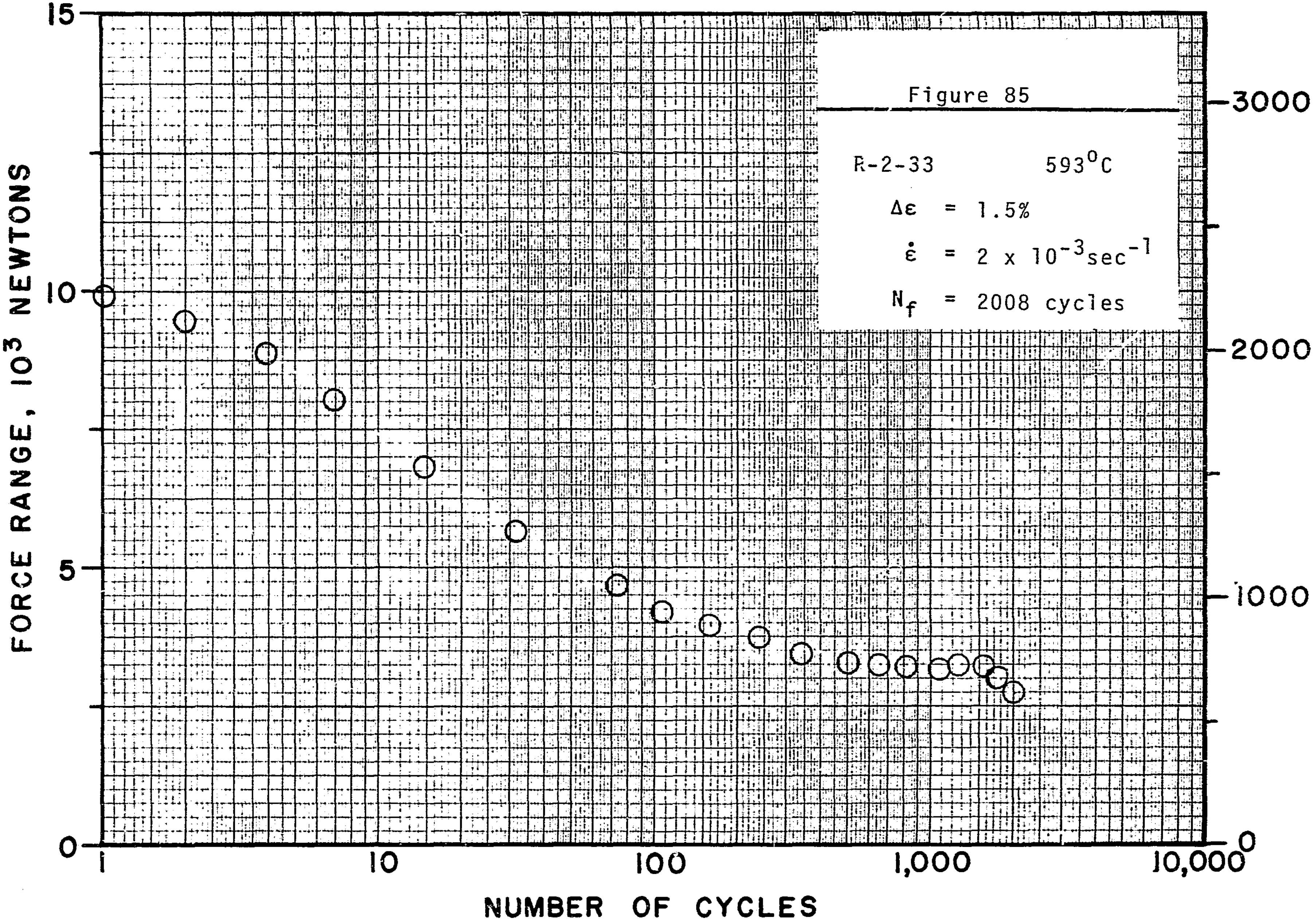


Figure 85

R-2-33
593°C
Δε = 1.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 2008 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

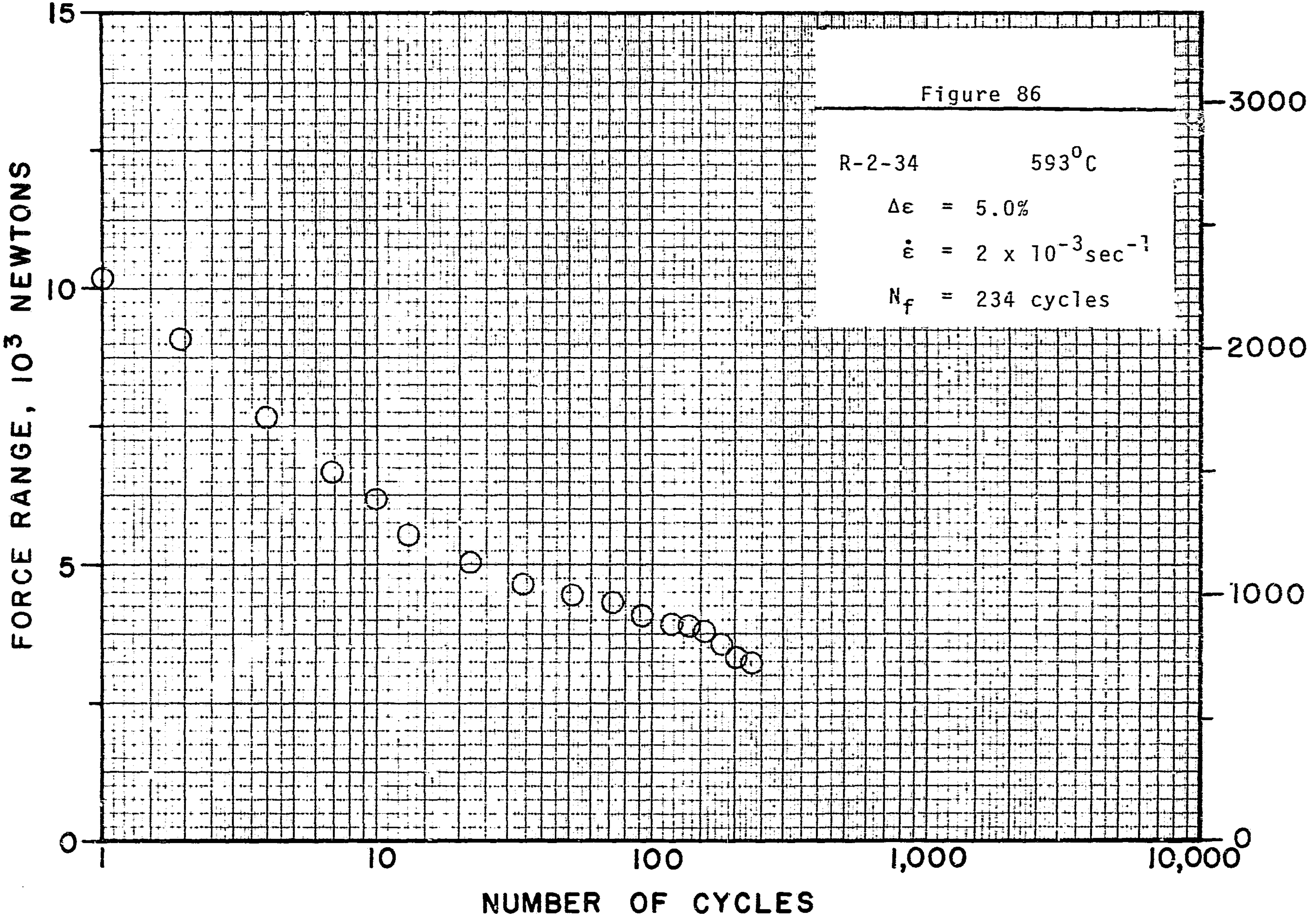


Figure 86

R-2-34 593^{0}C

$\Delta\varepsilon$ = 5.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 234 cycles

C-2

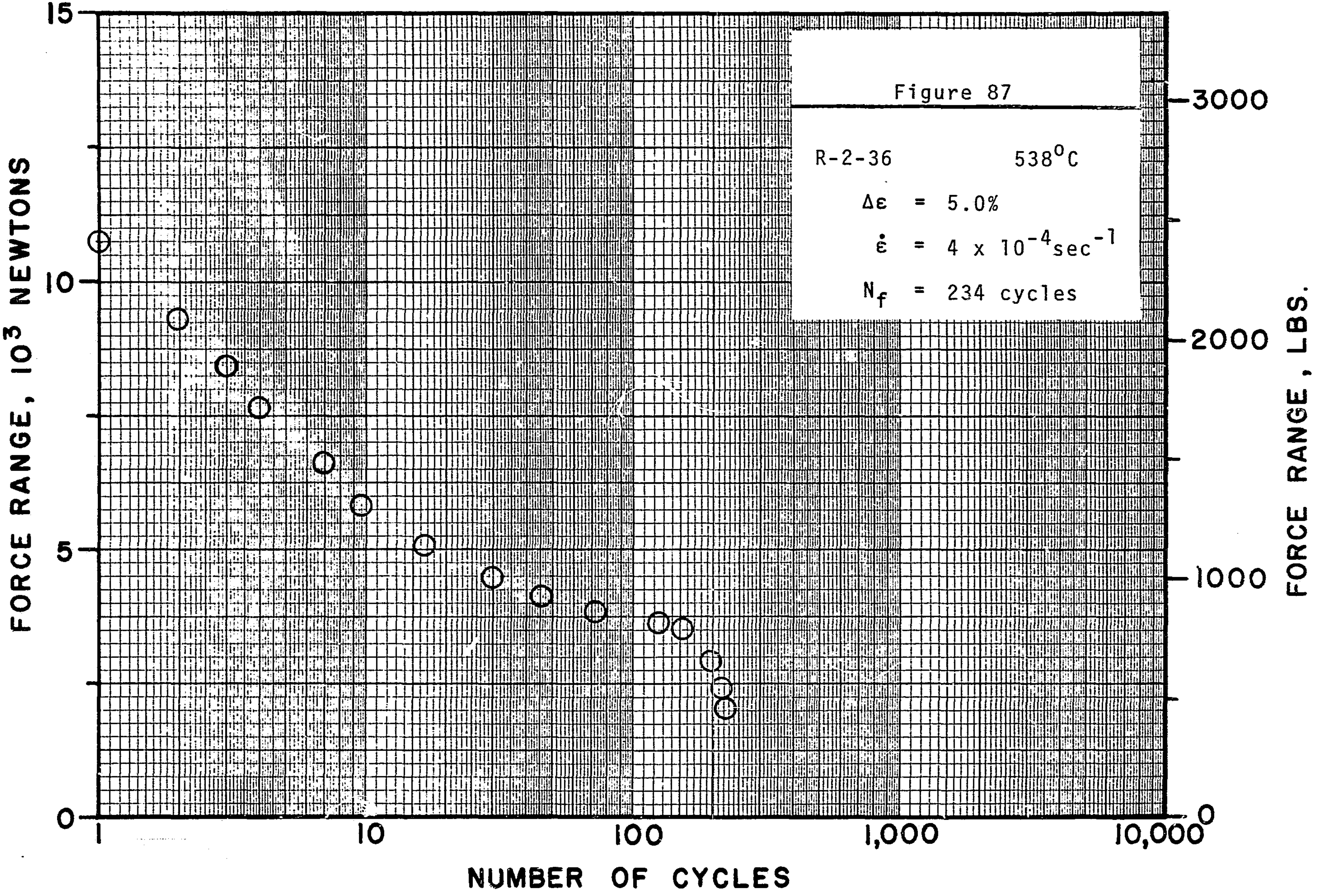


Figure 87

R-2-36 538^{0}C

$\Delta\varepsilon = 5.0\%$

$\dot{\varepsilon} = 4 \times 10^{-4} \text{sec}^{-1}$

$N_f = 234$ cycles

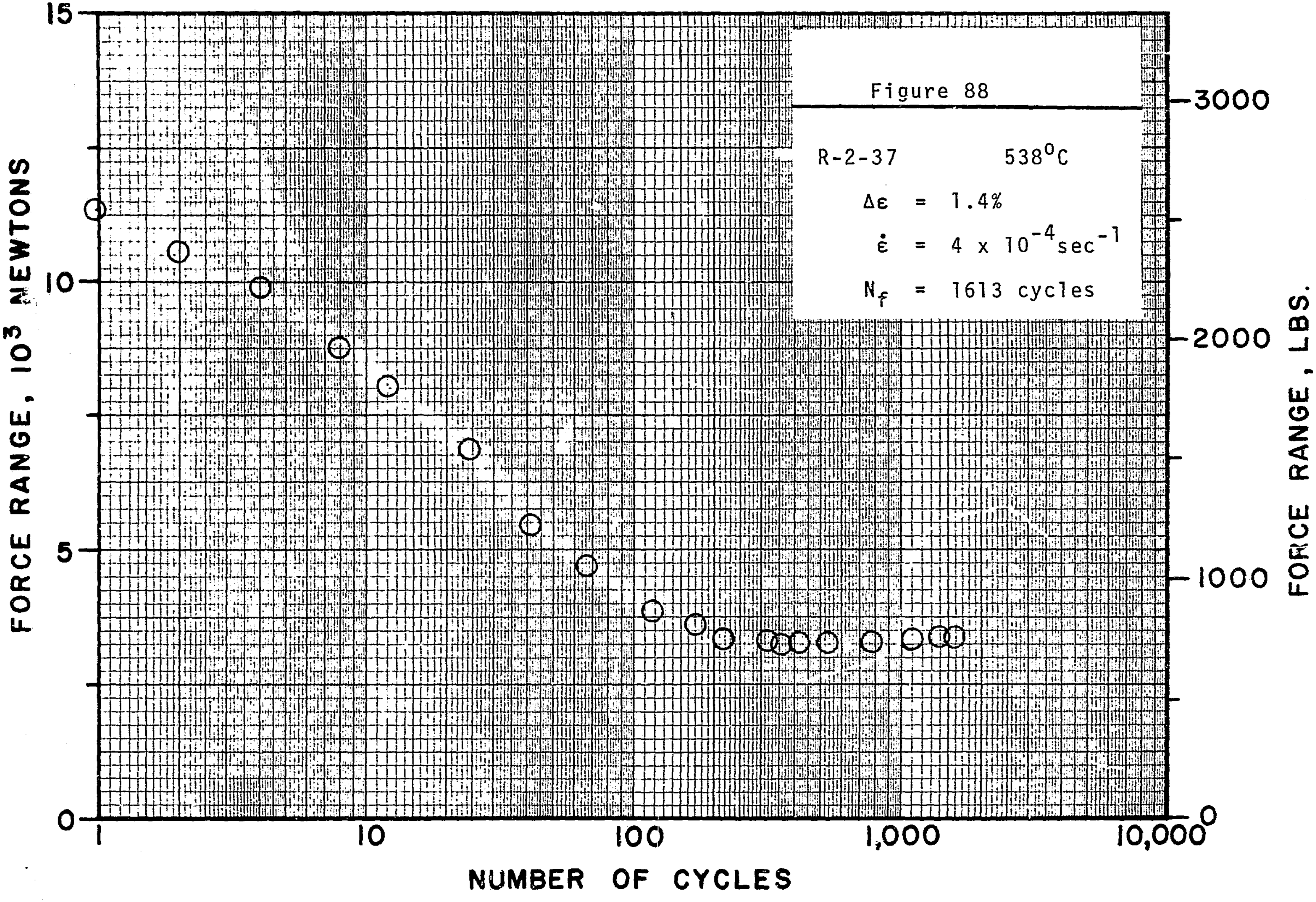


Figure 88

R-2-37 538^0C

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = $4 \times 10^{-4} sec^{-1}$

N_f = 1613 cycles

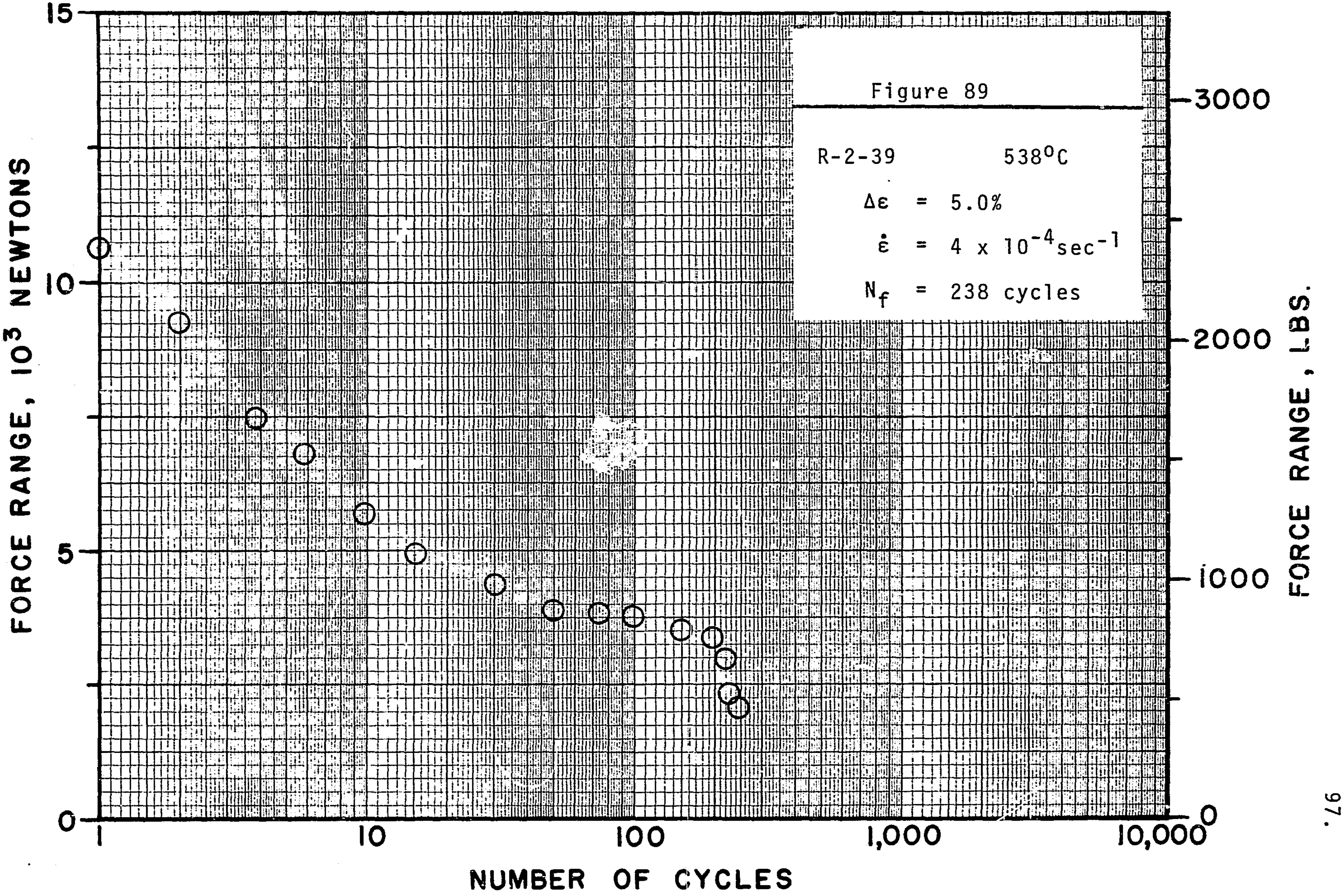


Figure 89
R-2-39 538°C
Δε = 5.0%
ε̇ = 4 x 10⁻⁴sec⁻¹
N_f = 238 cycles
FORCE RANGE, 10³ NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
1
10
100
1,000
10,000
NUMBER OF CYCLES

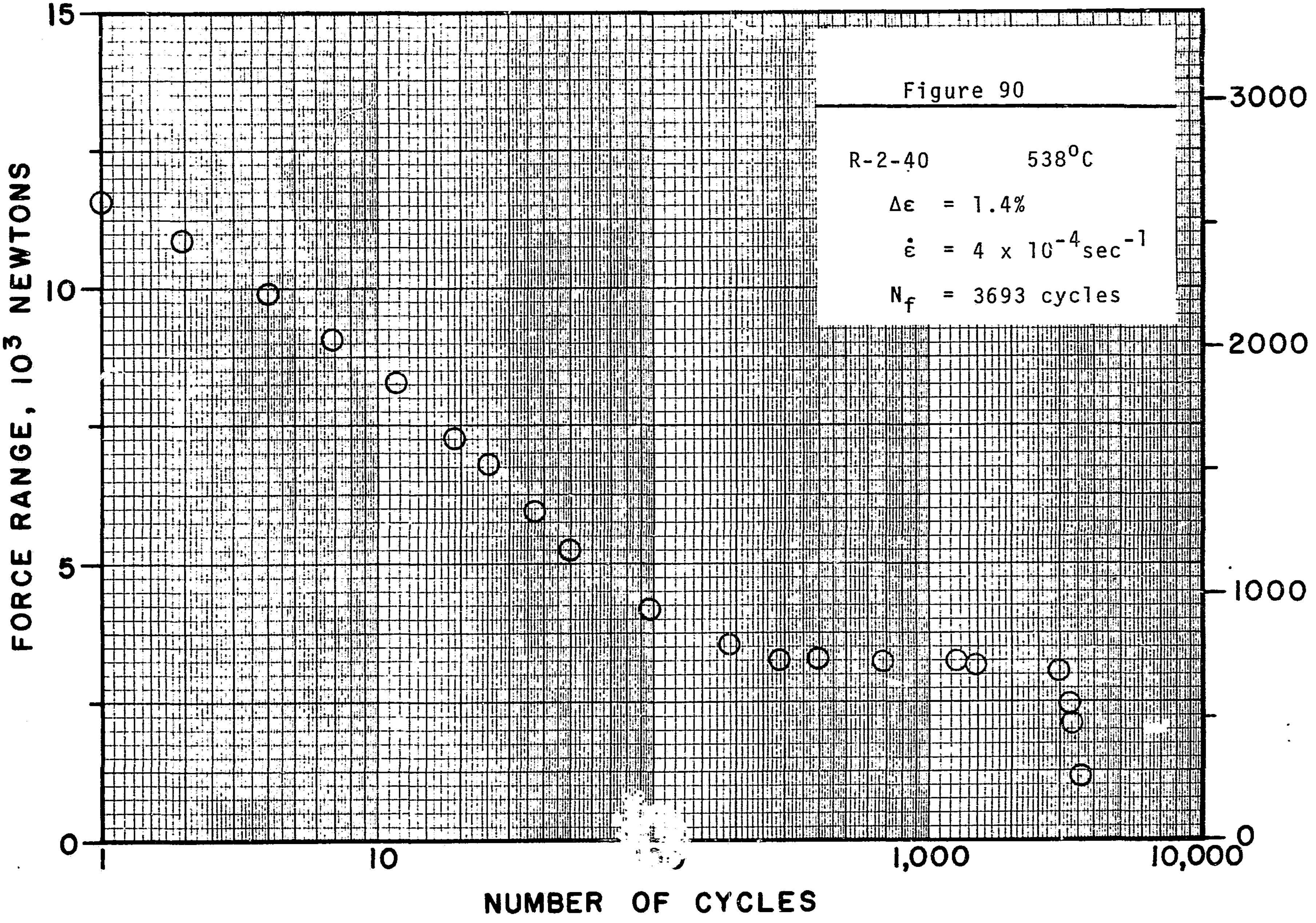


Figure 90

R-2-40 538°C

$\Delta\varepsilon = 1.4\%$

$\dot{\varepsilon} = 4 \times 10^{-4} \mathrm{sec}^{-1}$

$N_f = 3693$ cycles

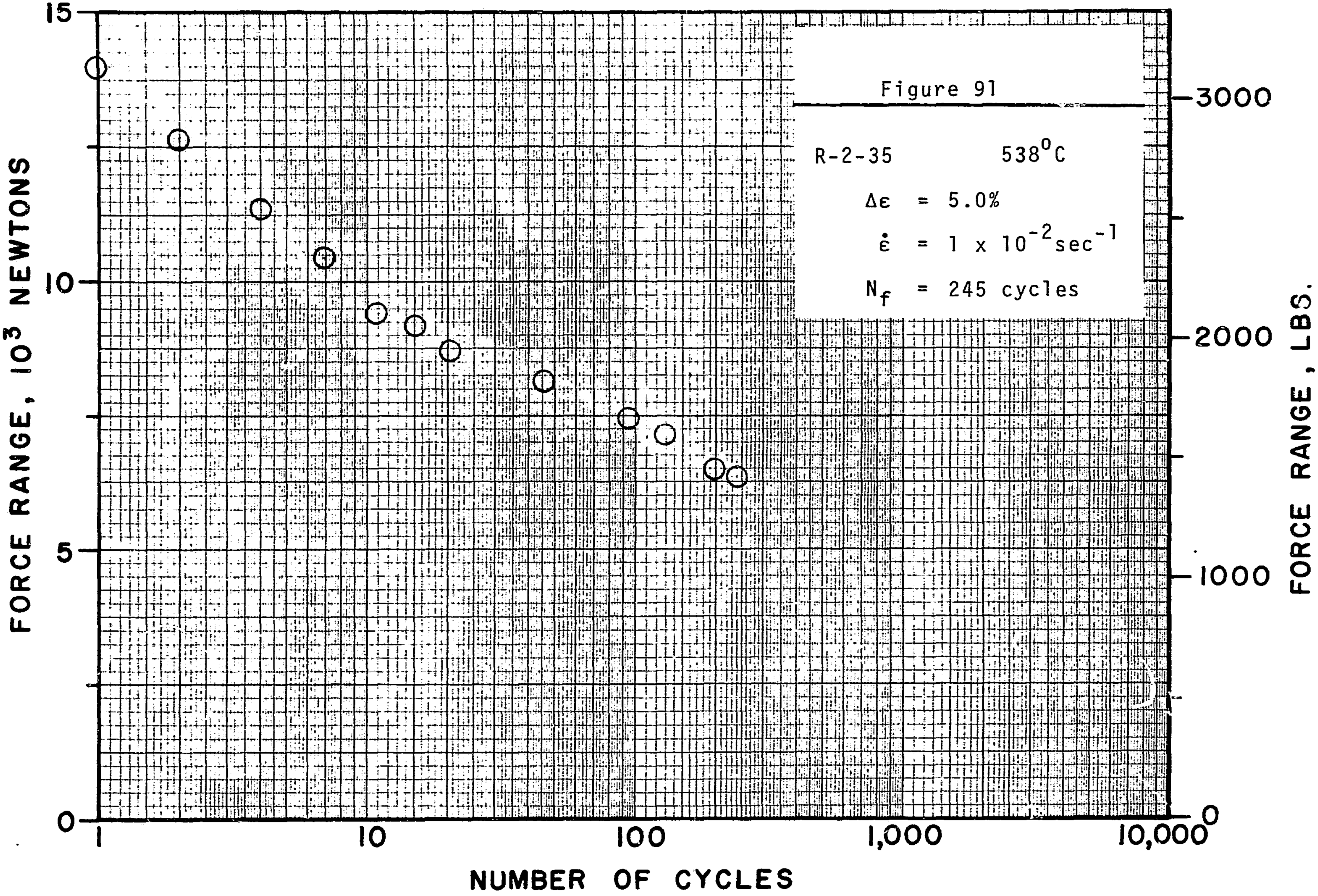


Figure 91

R-2-35
538°C
Δε = 5.0%
$\dot{\varepsilon}$ = 1 x 10^{-2} sec^{-1}
N_f = 245 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

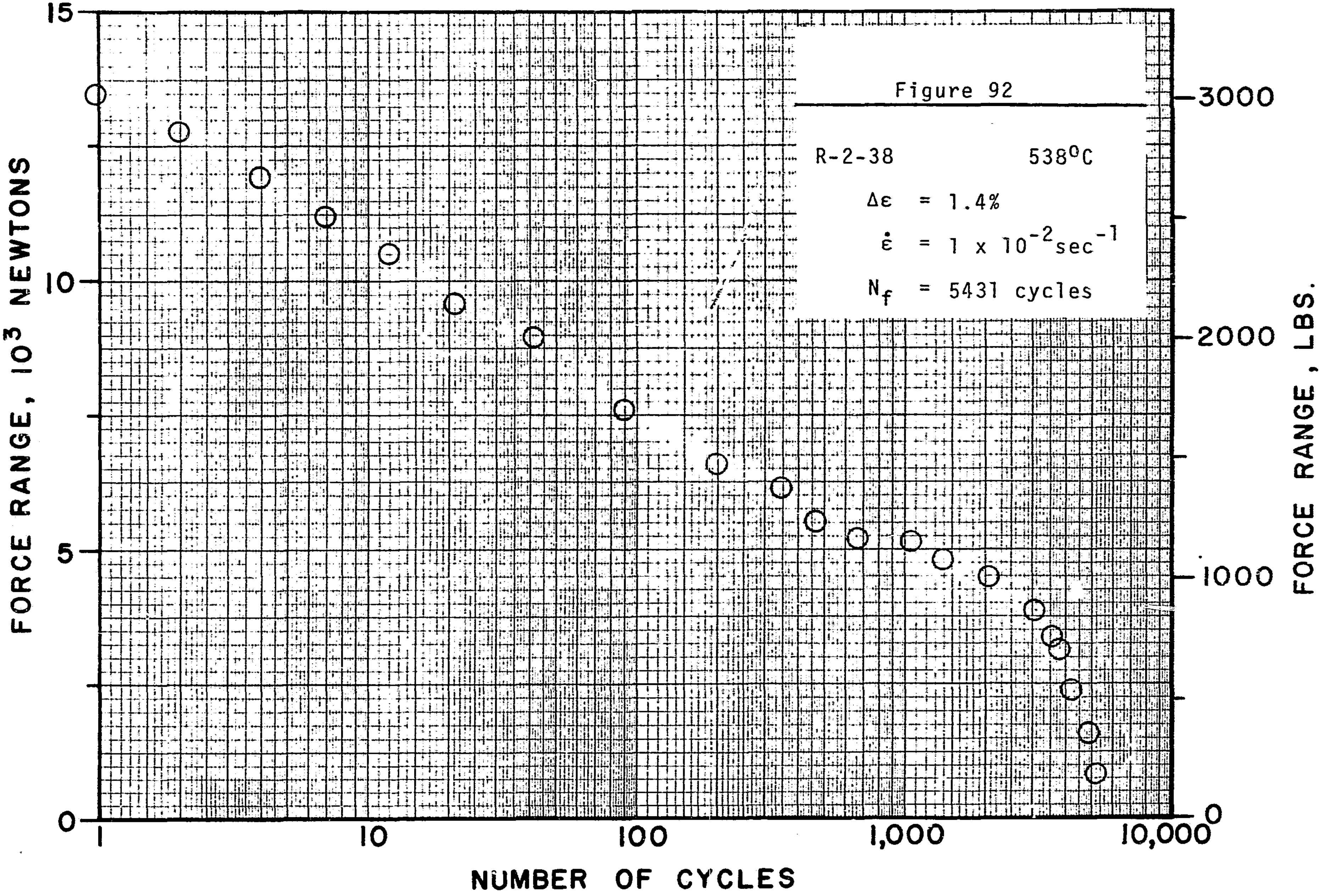


Figure 92

R-2-38 538°C

$\Delta\varepsilon = 1.4\%$

$\dot{\varepsilon} = 1 \times 10^{-2} sec^{-1}$

$N_f = 5431$ cycles

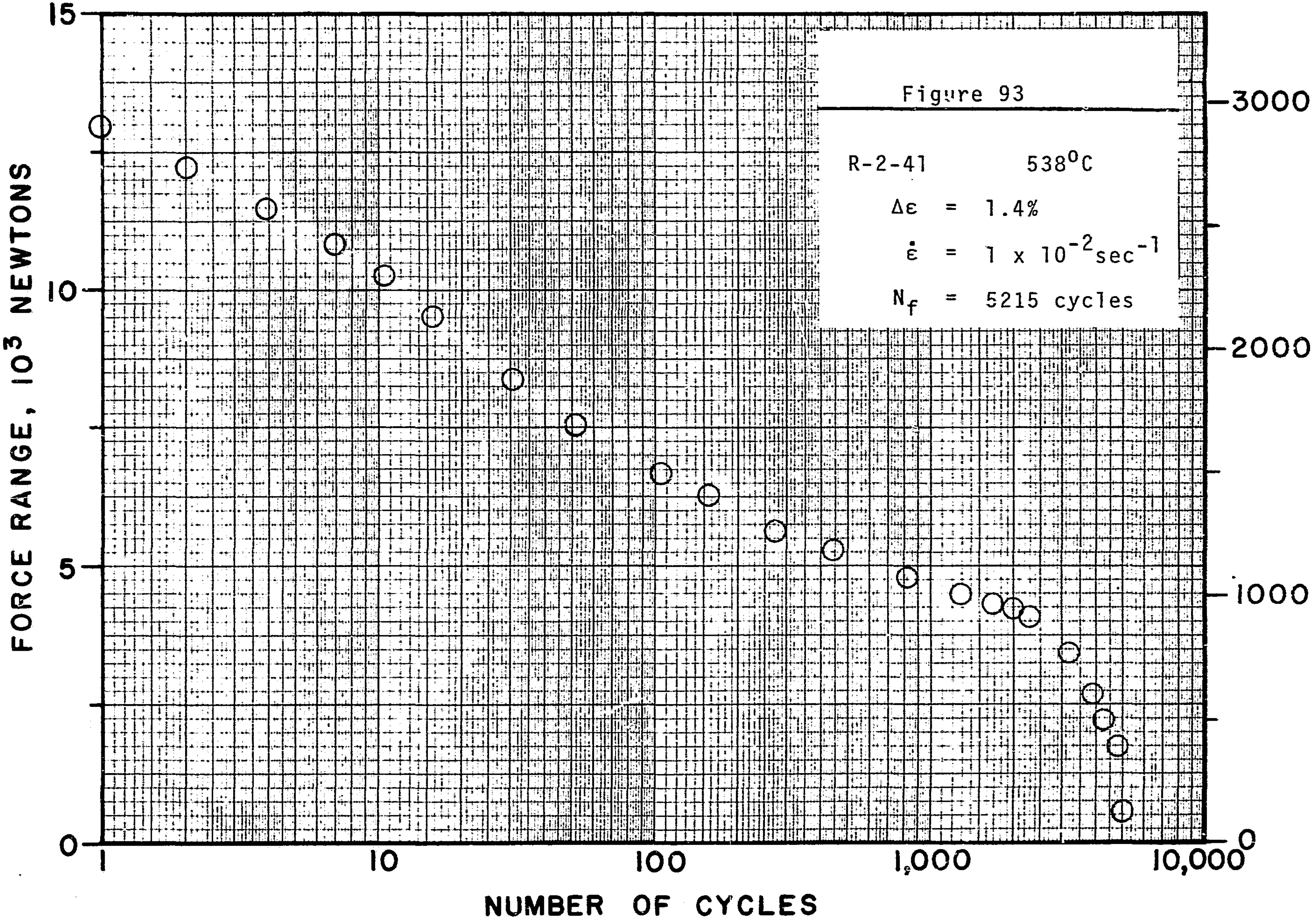


Figure 93

R-2-41 538^{0}C
$\Delta\varepsilon$ = 1.4%
$\dot{\varepsilon}$ = 1 x 10^{-2} sec^{-1}
N_f = 5215 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

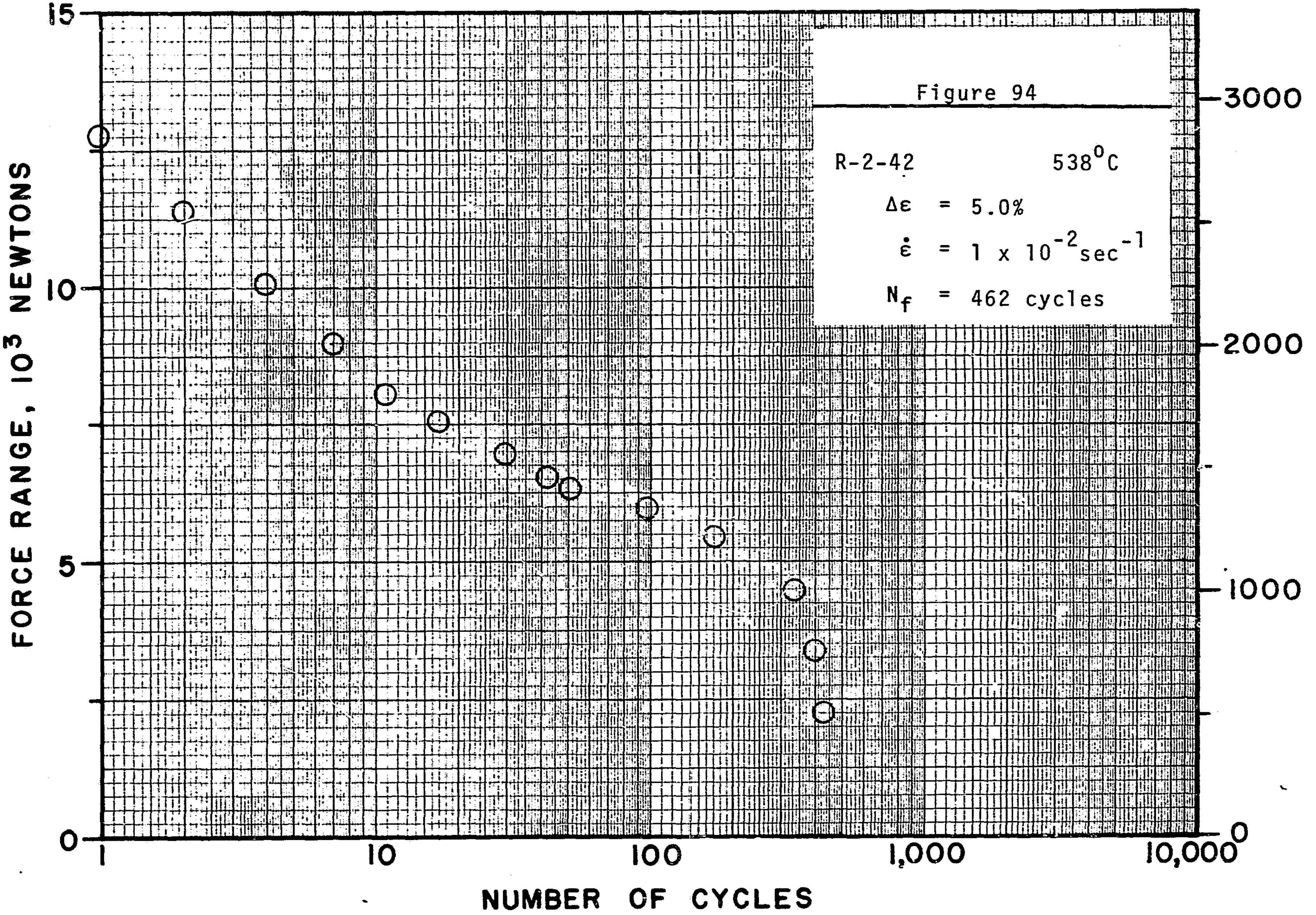

FORCE RANGE, 10^3 NEWTONS
15
10
5
0
1
10
100
1,000
10,000
NUMBER OF CYCLES
FORCE RANGE, LBS.
3000
2000
1000
0
R-2-42
538°C
$\Delta\varepsilon = 5.0\%$
$\dot{\varepsilon} = 1 \times 10^{-2} \text{sec}^{-1}$
$N_f = 462$ cycles

Figure 94

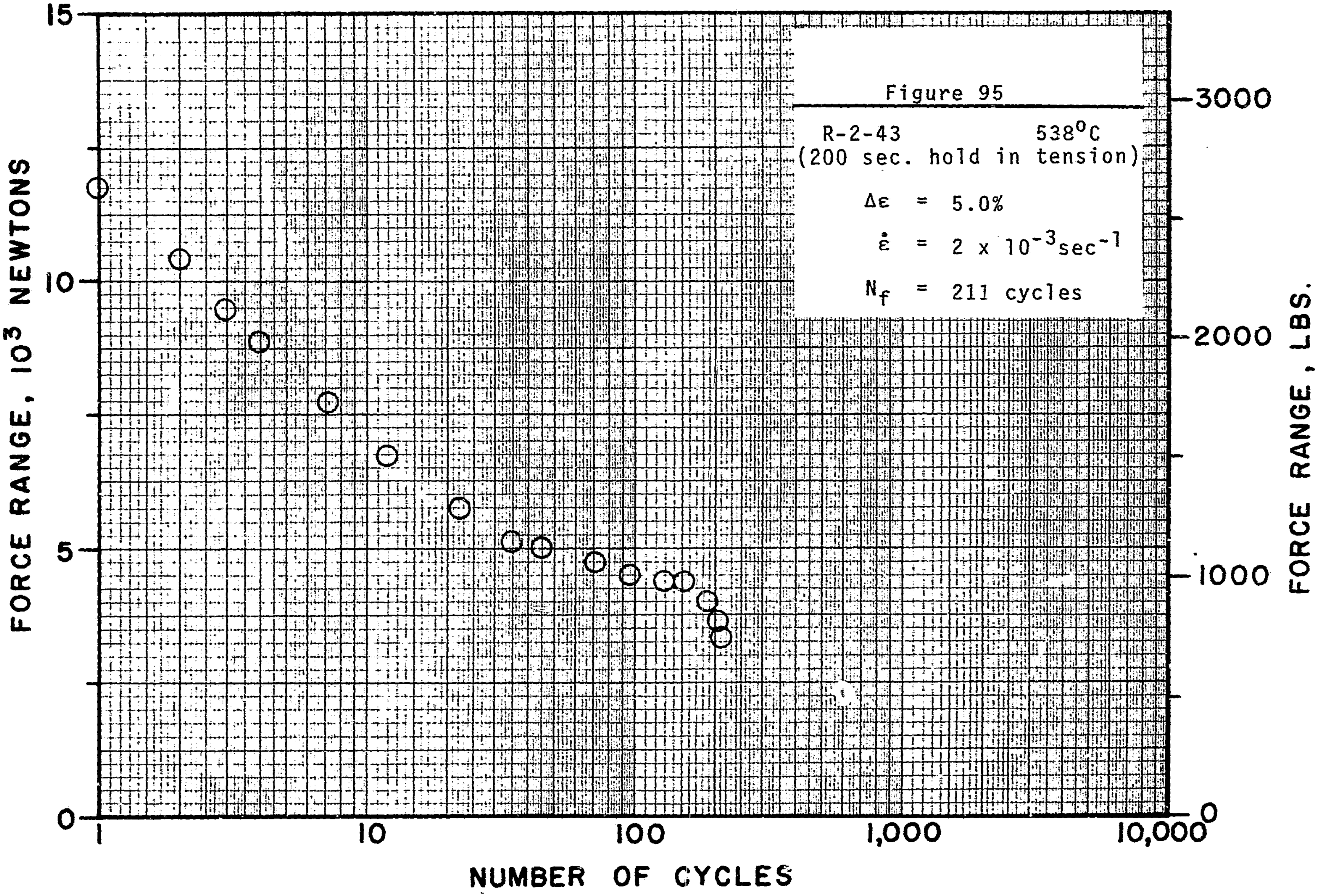


Figure 95

R-2-43 538°C
(200 sec. hold in tension)

$\Delta\varepsilon$ = 5.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 211 cycles

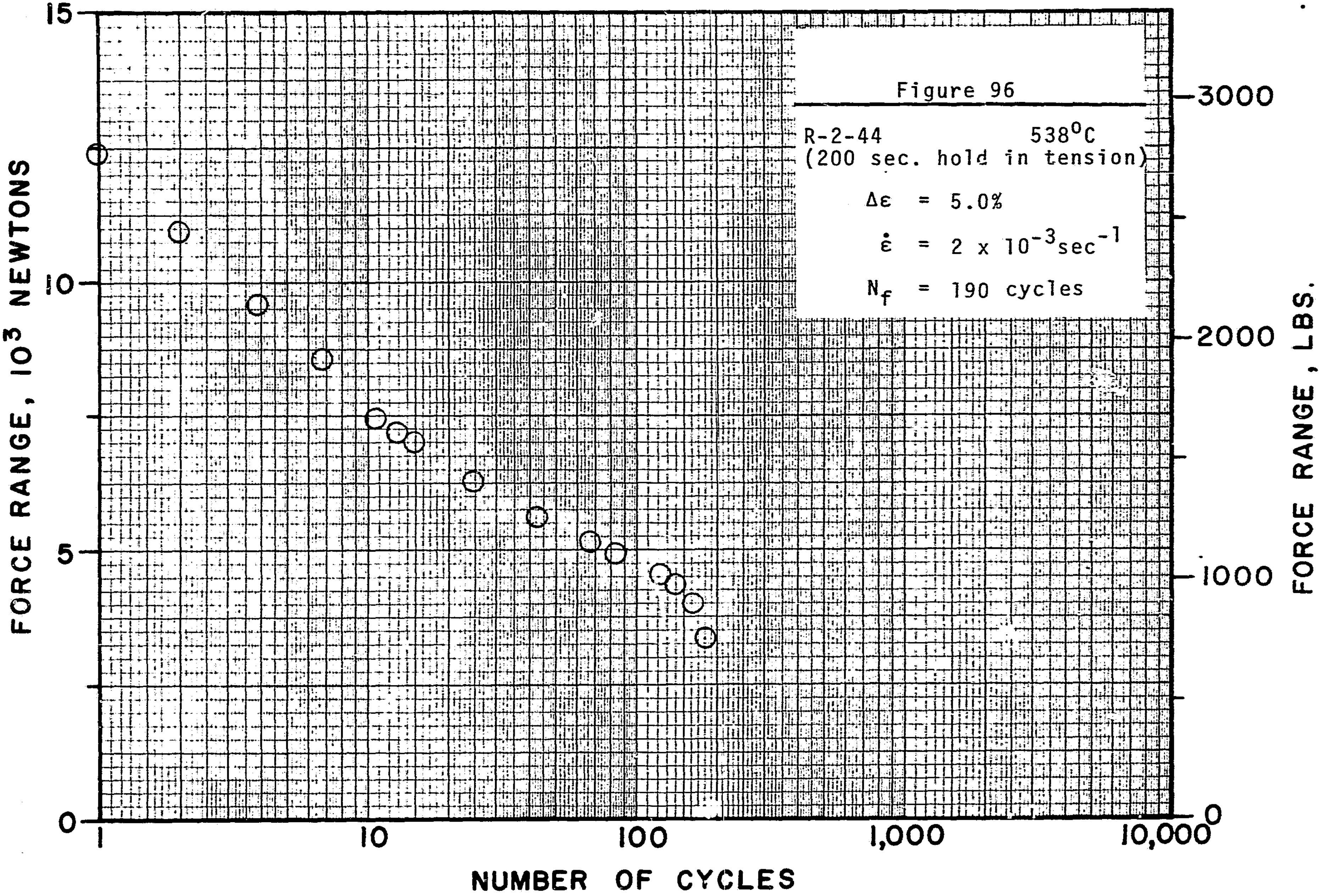

R-2-44
538^{0}C
(200 sec. hold in tension)
$\Delta\varepsilon$ = 5.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 190 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 96

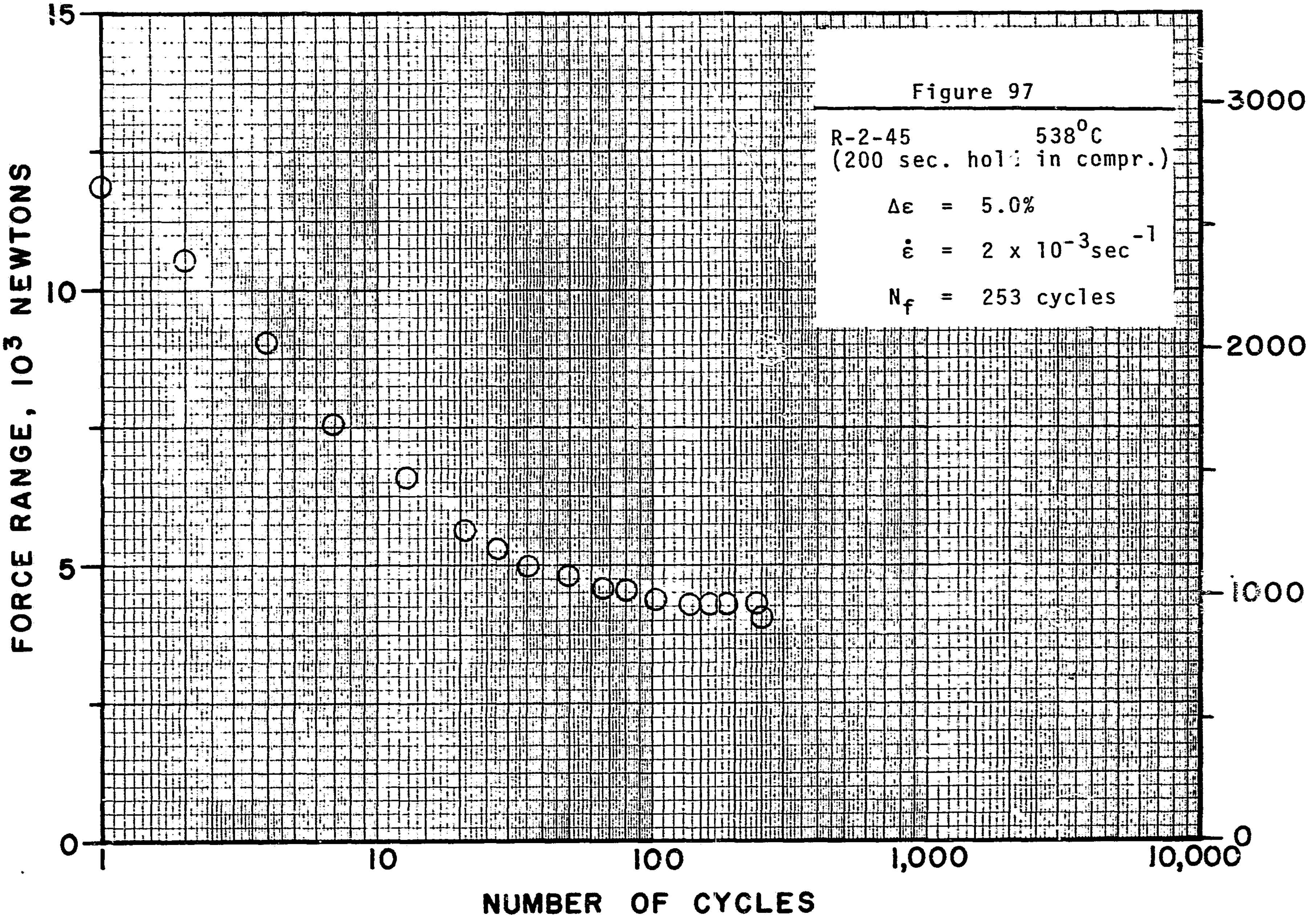


Figure 97

R-2-45 538°C
(200 sec. hold in compr.)
Δε = 5.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 253 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

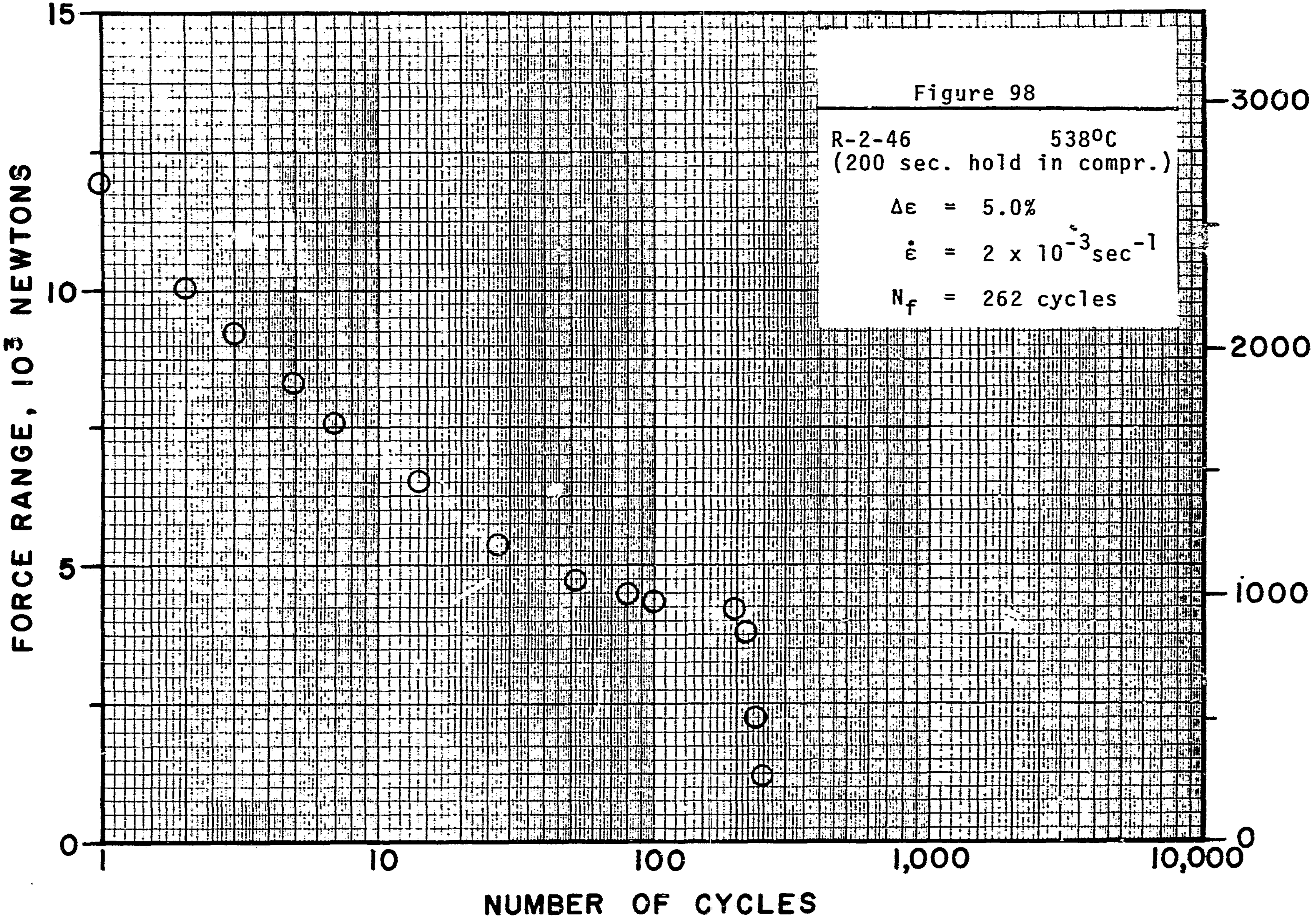


Figure 98

R-2-46 538°C
(200 sec. hold in compr.)

$\Delta\varepsilon = 5.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3} sec^{-1}$

$N_f = 262$ cycles

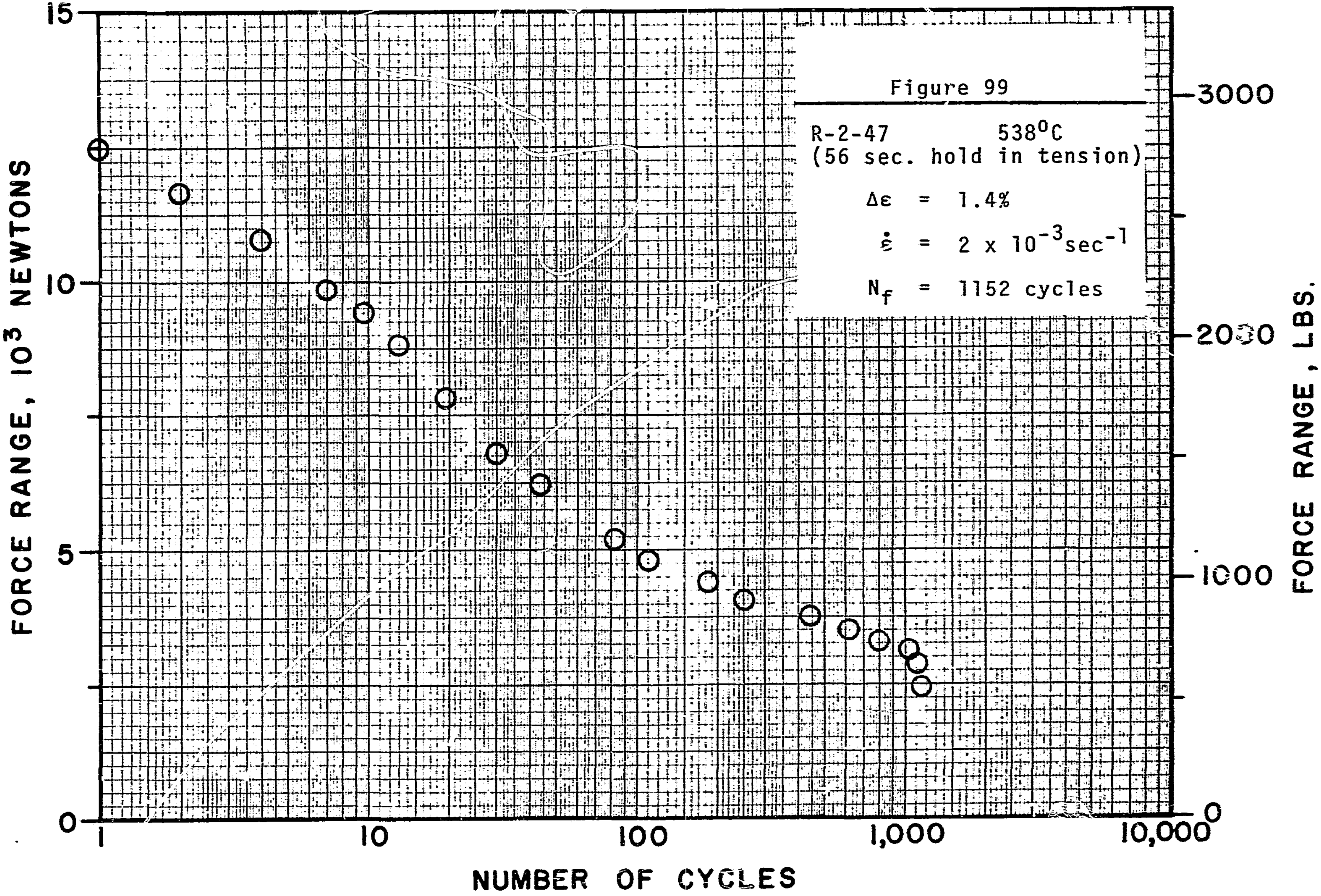


Figure 99

R-2-47 538^{o}C
(56 sec. hold in tension)

$\Delta\varepsilon = 1.4\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 1152$ cycles

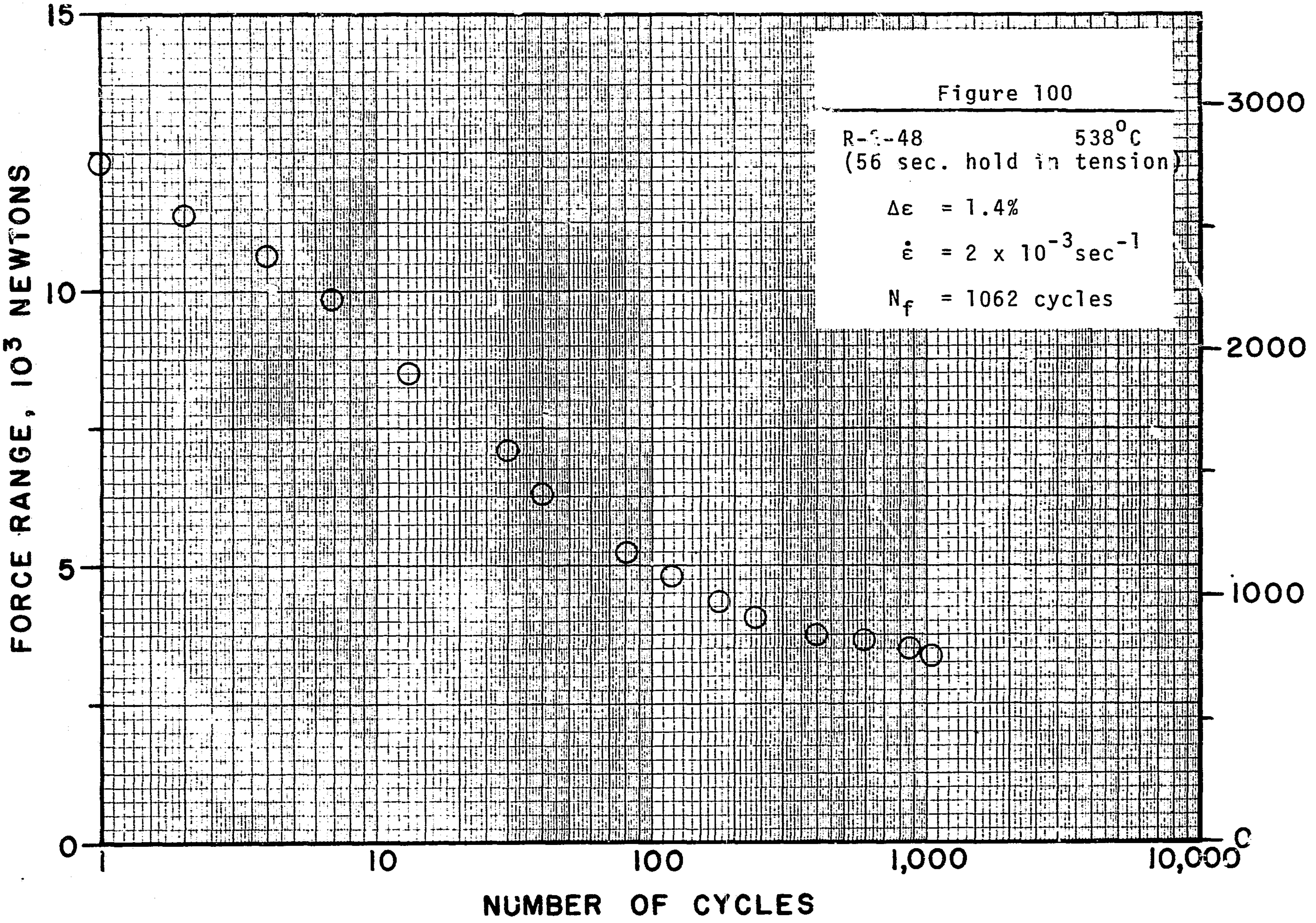


Figure 100

R-[illegible]-48
538°C
(56 sec. hold in tension)
Δε = 1.4%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 1062 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
NUMBER OF CYCLES
1
10
100
1,000
10,000

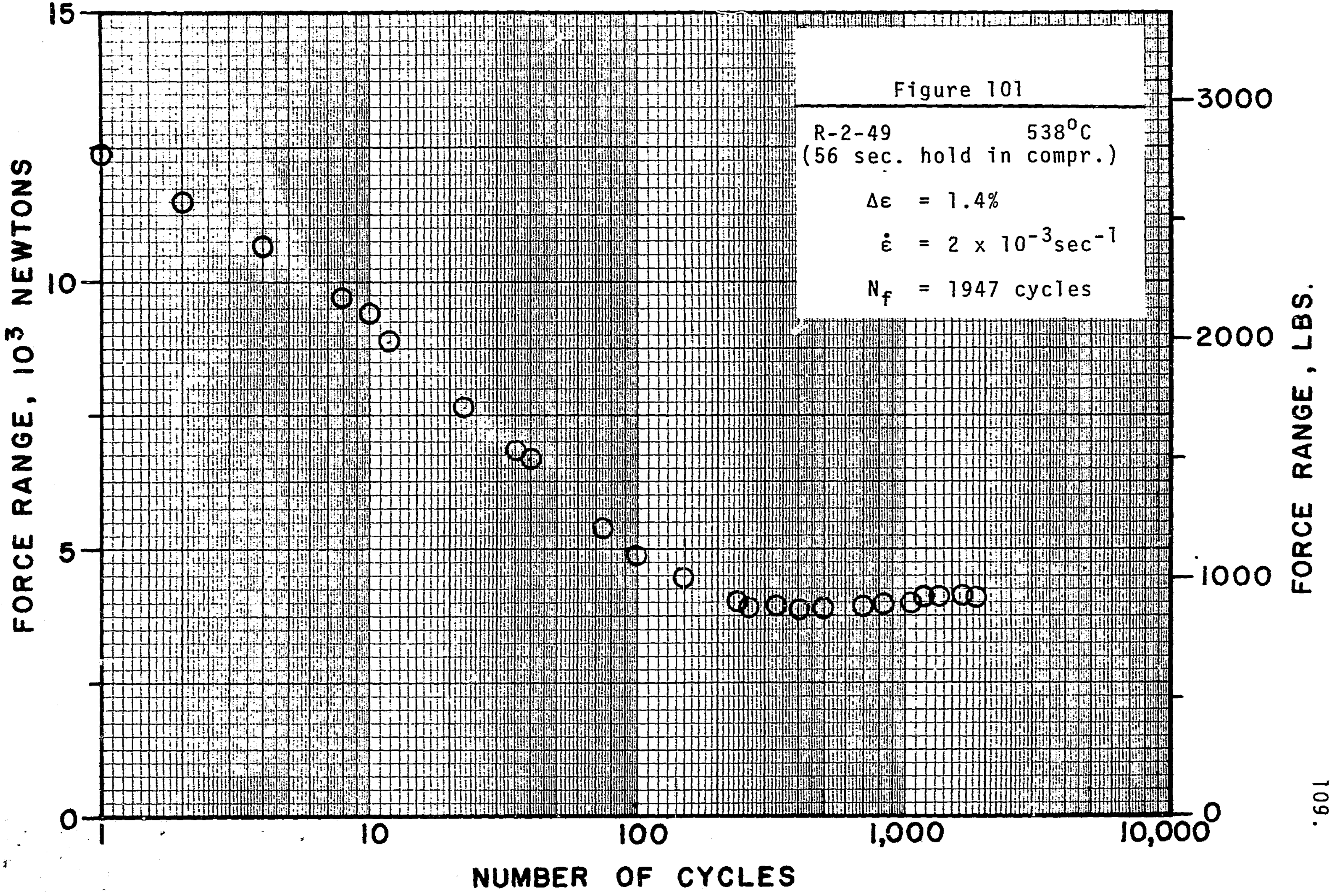


Figure 101

R-2-49 538°C
(56 sec. hold in compr.)

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 1947 cycles

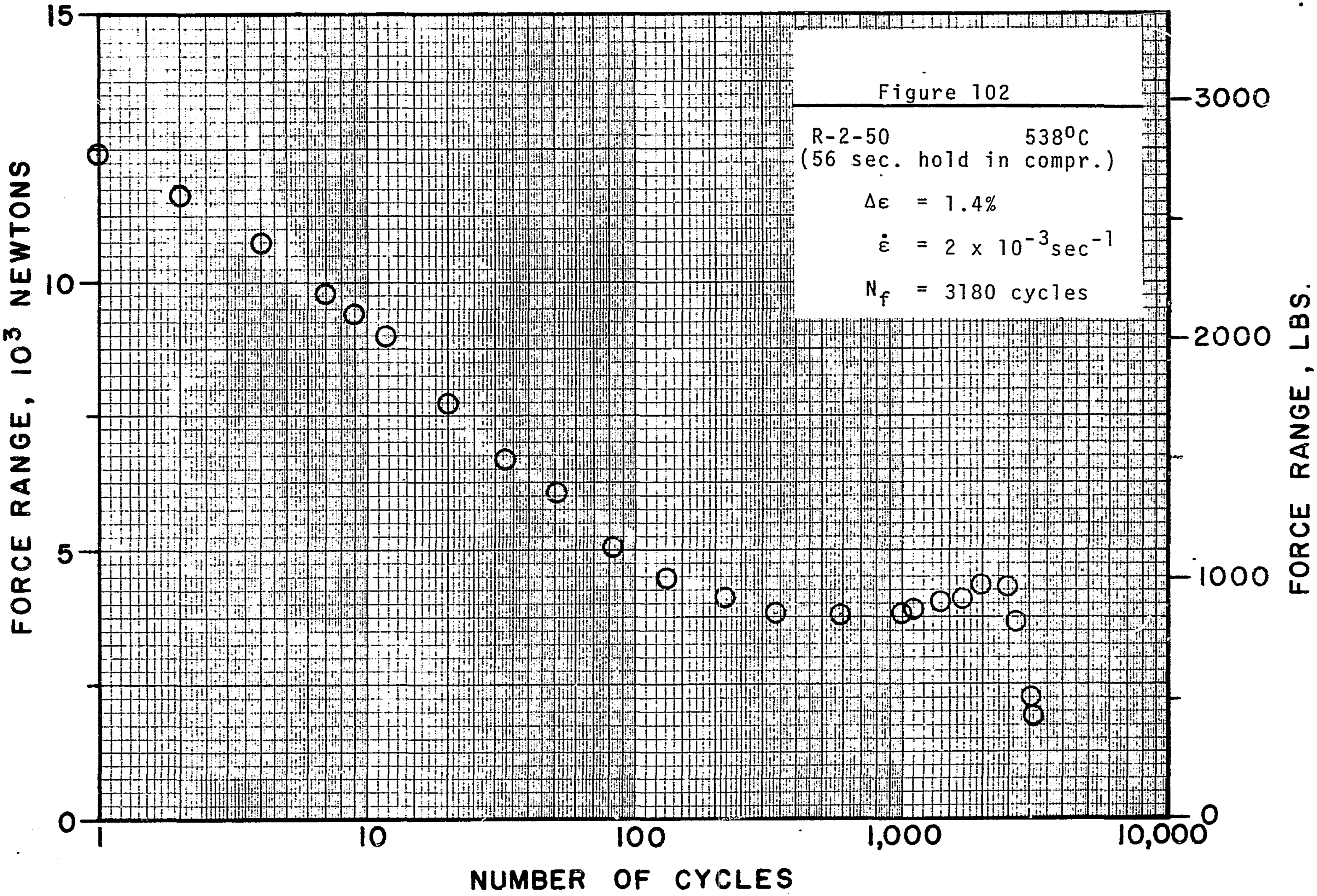


Figure 102

R-2-50 538°C
(56 sec. hold in compr.)

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon} = 2 \times 10^{-3} sec^{-1}$

N_f = 3180 cycles

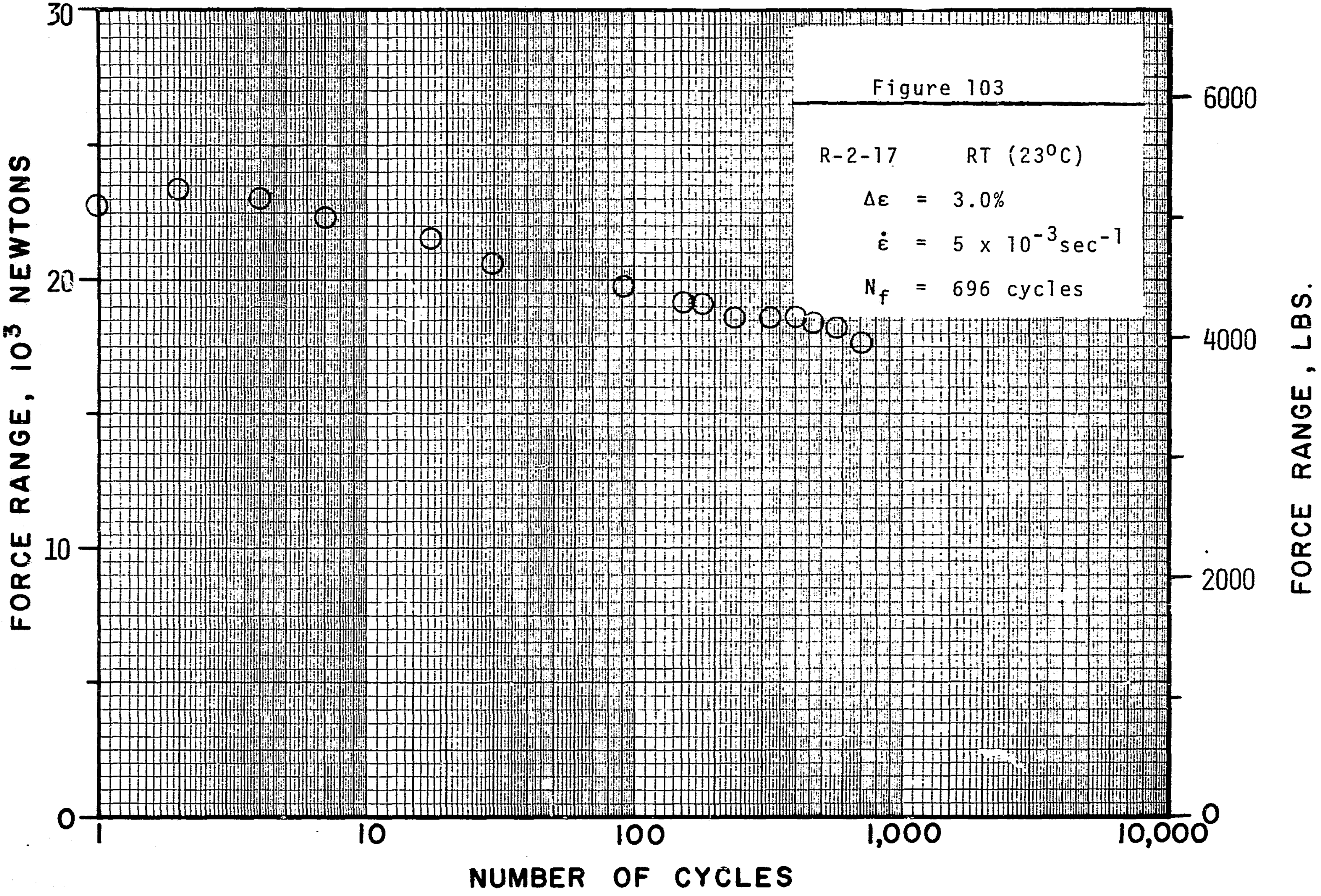


Figure 103

R-2-17 RT (23^{o}C)

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $5 \times 10^{-3} \text{sec}^{-1}$

N_f = 696 cycles

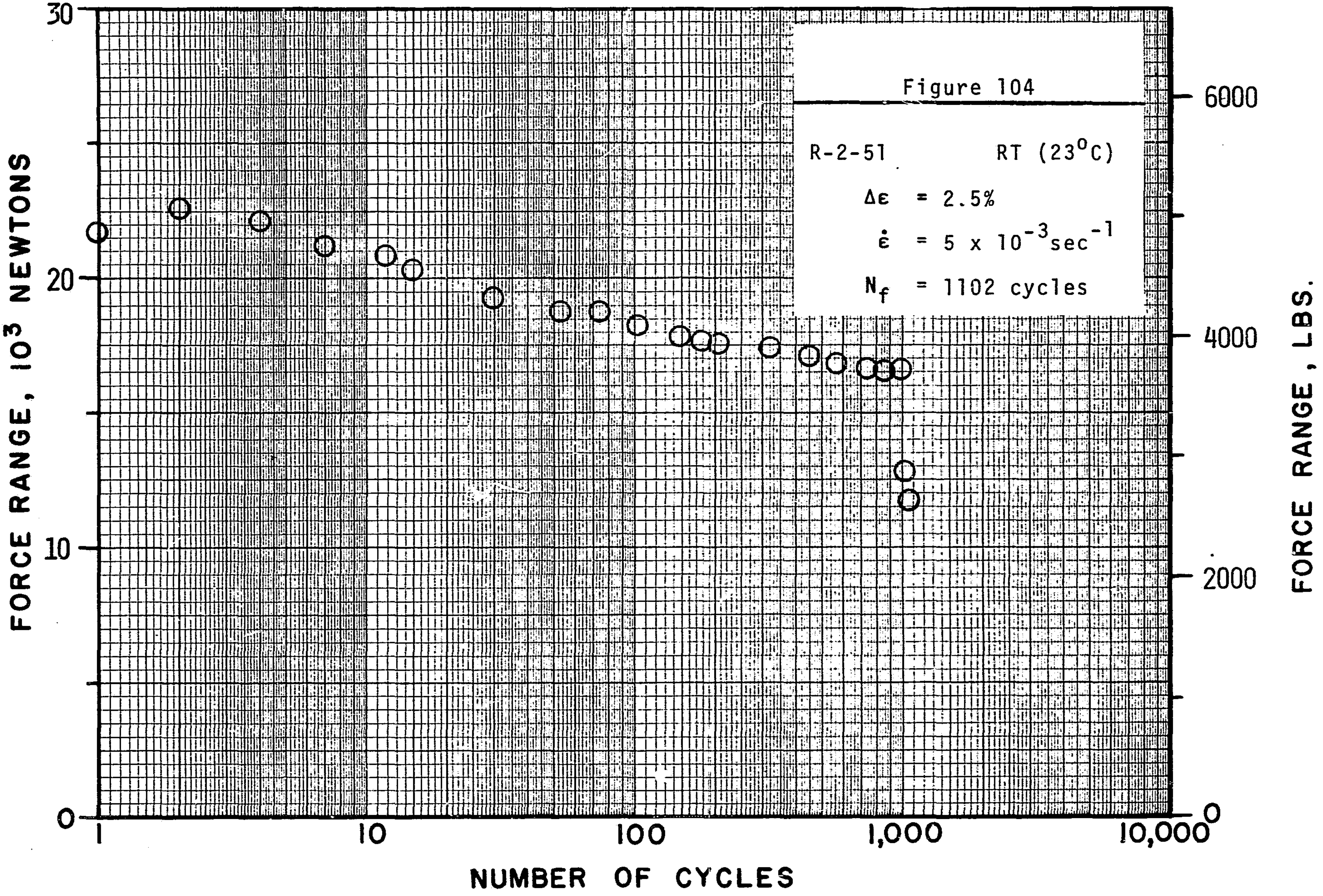


Figure 104
R-2-51
RT (23^oC)
$\Delta\varepsilon$ = 2.5%
$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$
N_f = 1102 cycles
FORCE RANGE, 10^3 NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
NUMBER OF CYCLES
1
10
100
1,000
10,000

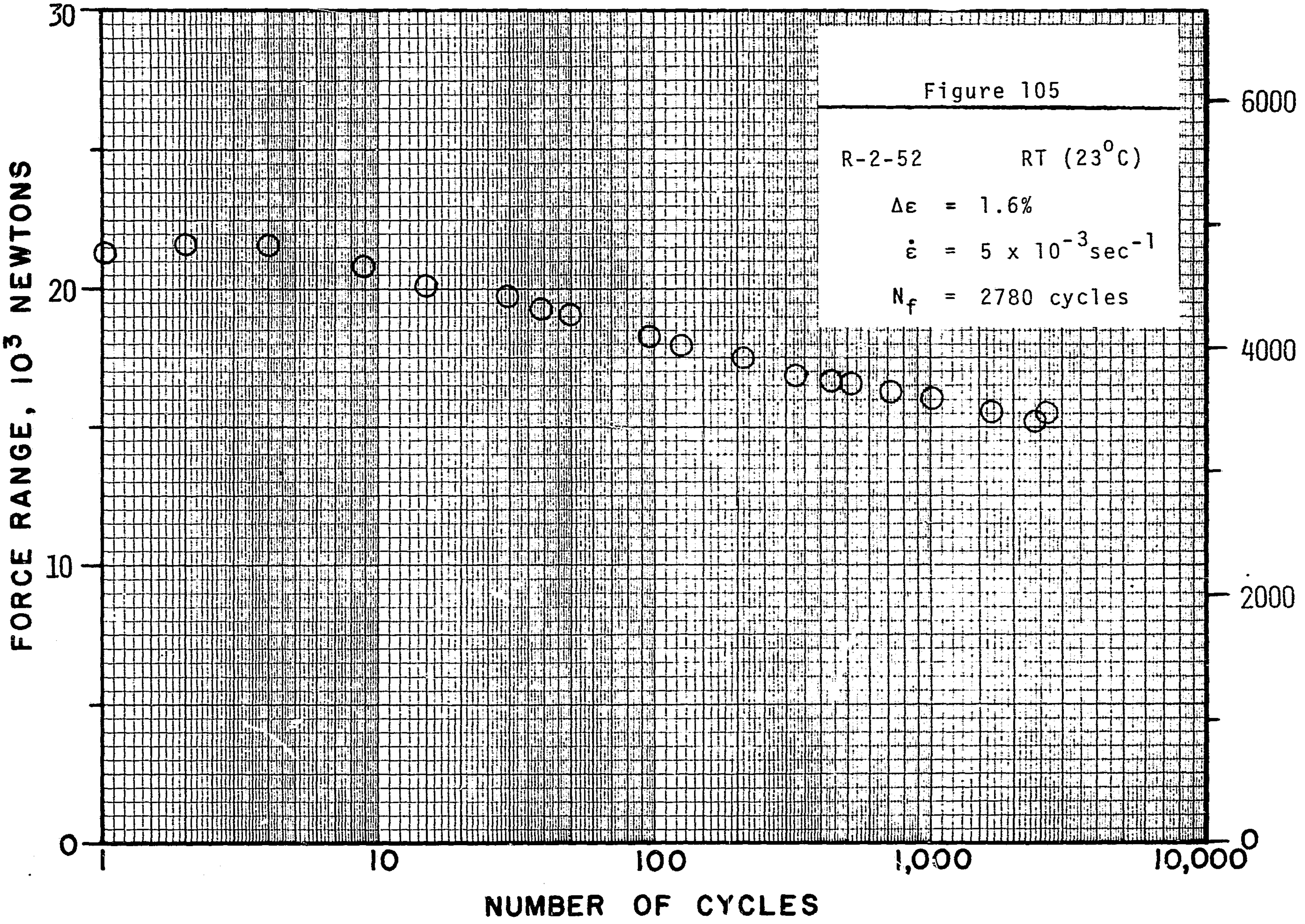


Figure 105

R-2-52
RT (23°C)
Δε = 1.6%
$\dot{\varepsilon} = 5 \times 10^{-3} \mathrm{sec}^{-1}$
N_f = 2780 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

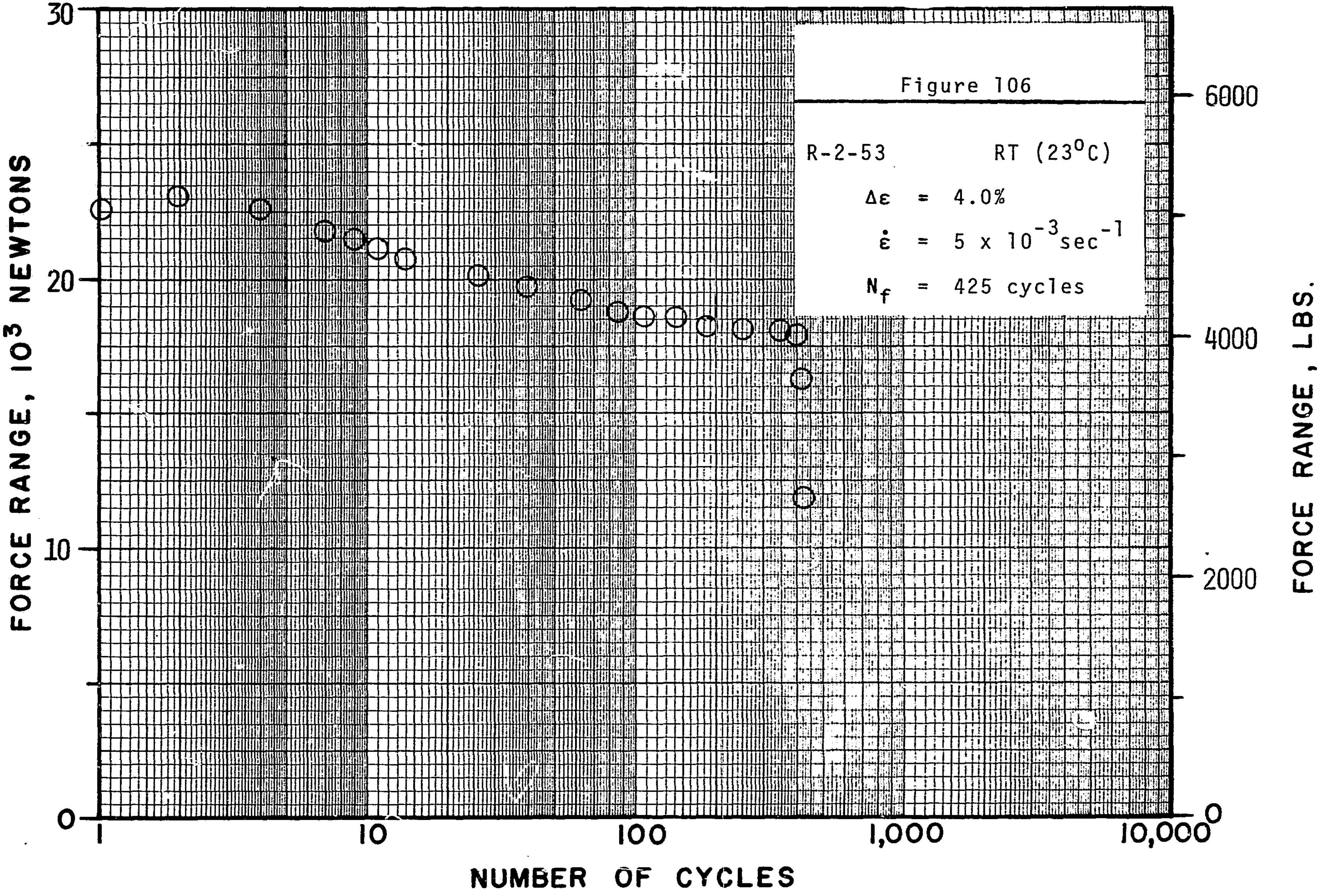


Figure 106

R-2-53
RT (23°C)
$\Delta\varepsilon$ = 4.0%
$\dot{\varepsilon}$ = 5 x 10^{-3} sec^{-1}
N_f = 425 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

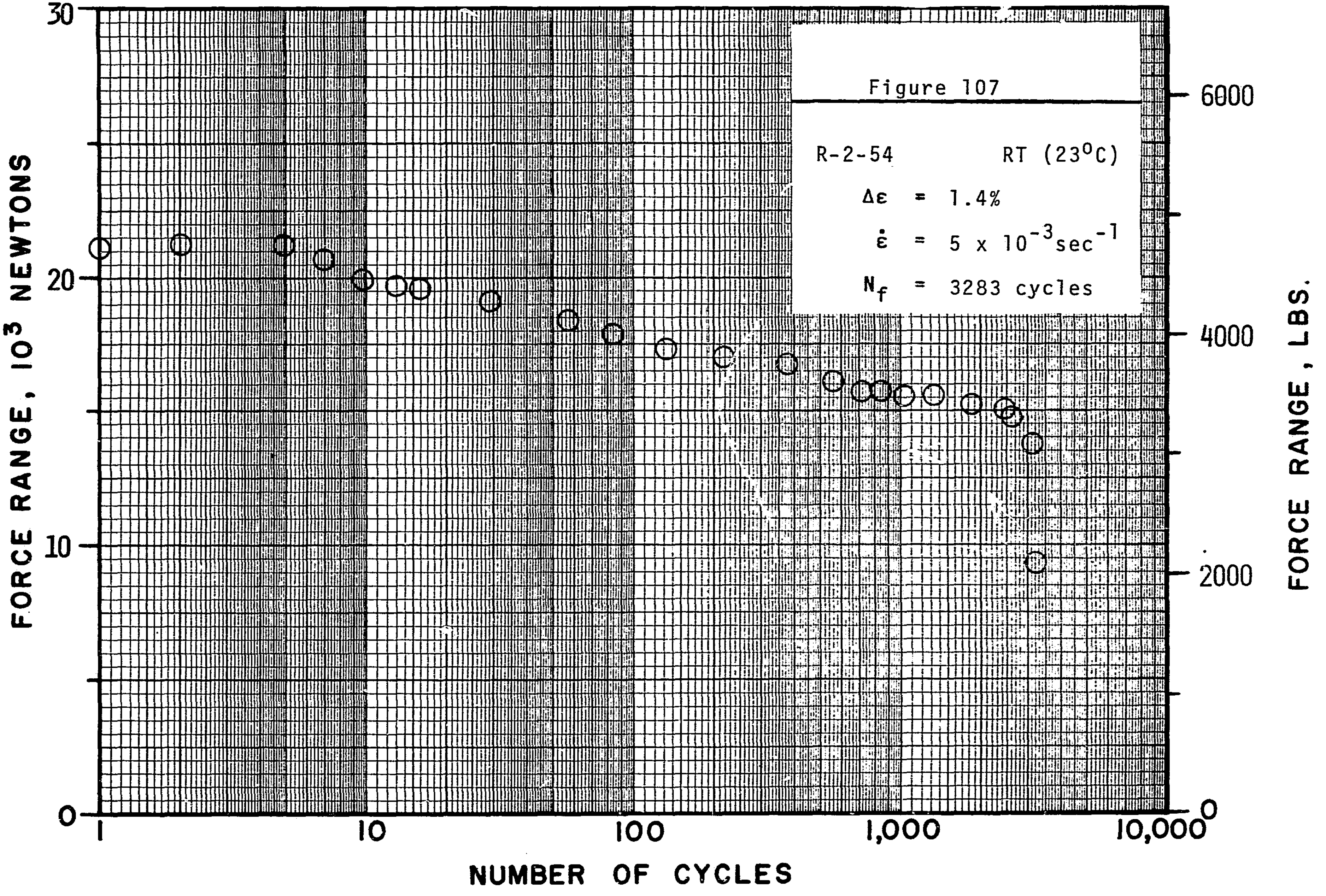


Figure 107

R-2-54
RT (23^oC)
$\Delta\varepsilon$ = 1.4%
$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$
N_f = 3283 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

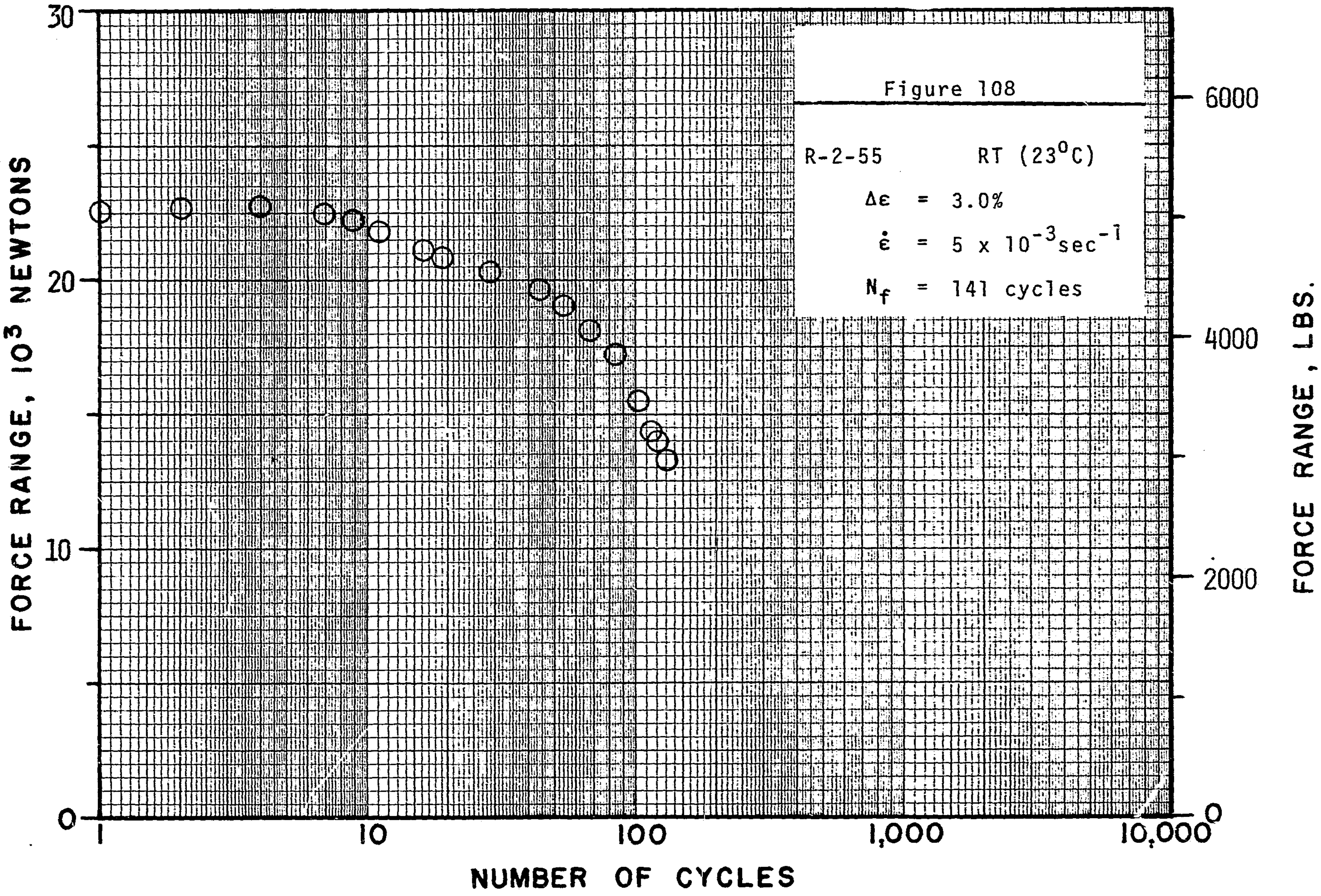


Figure 108

R-2-55 RT (23°C)

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$

N_f = 141 cycles

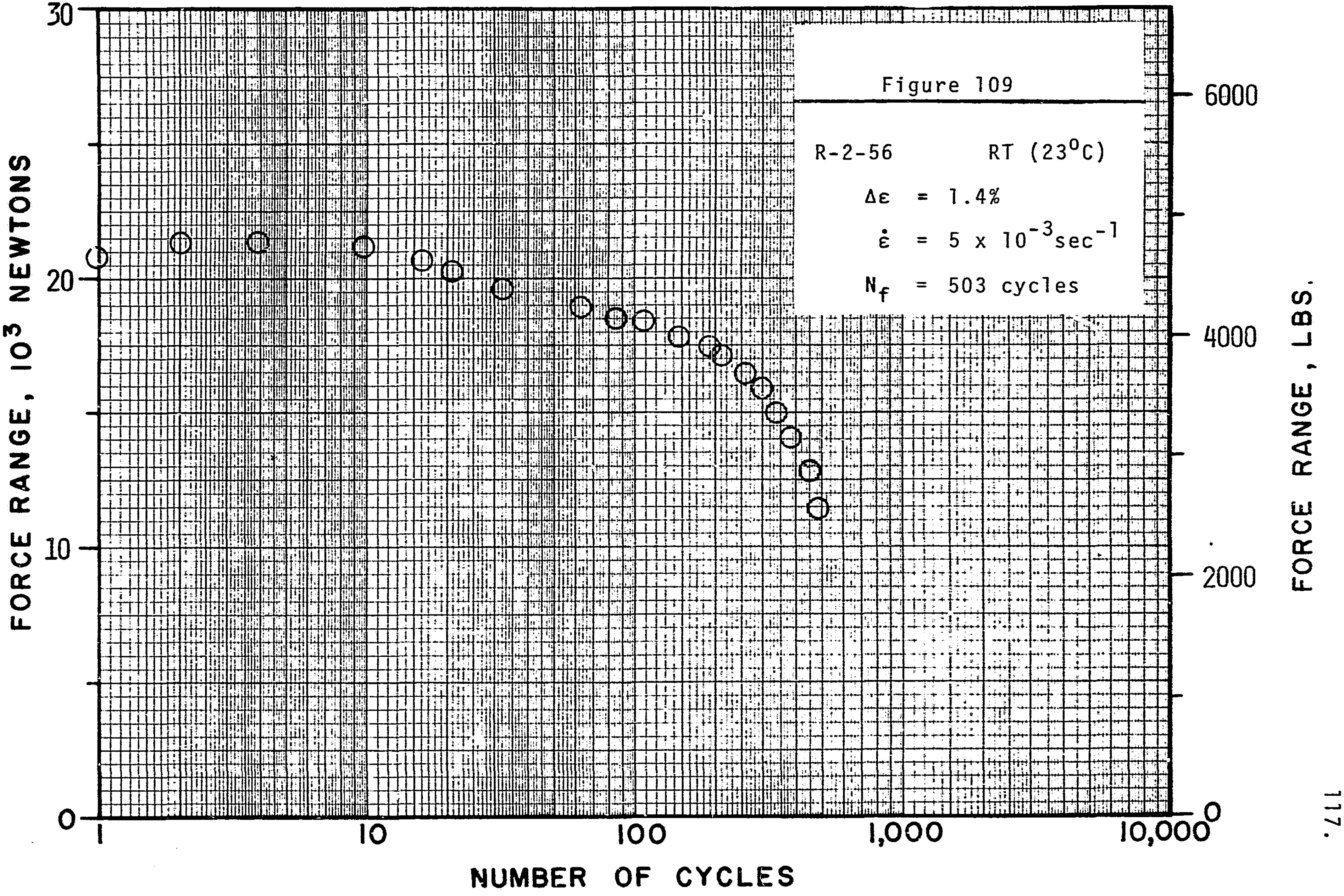


Figure 109

R-2-56 RT (23^oC)

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$

N_f = 503 cycles

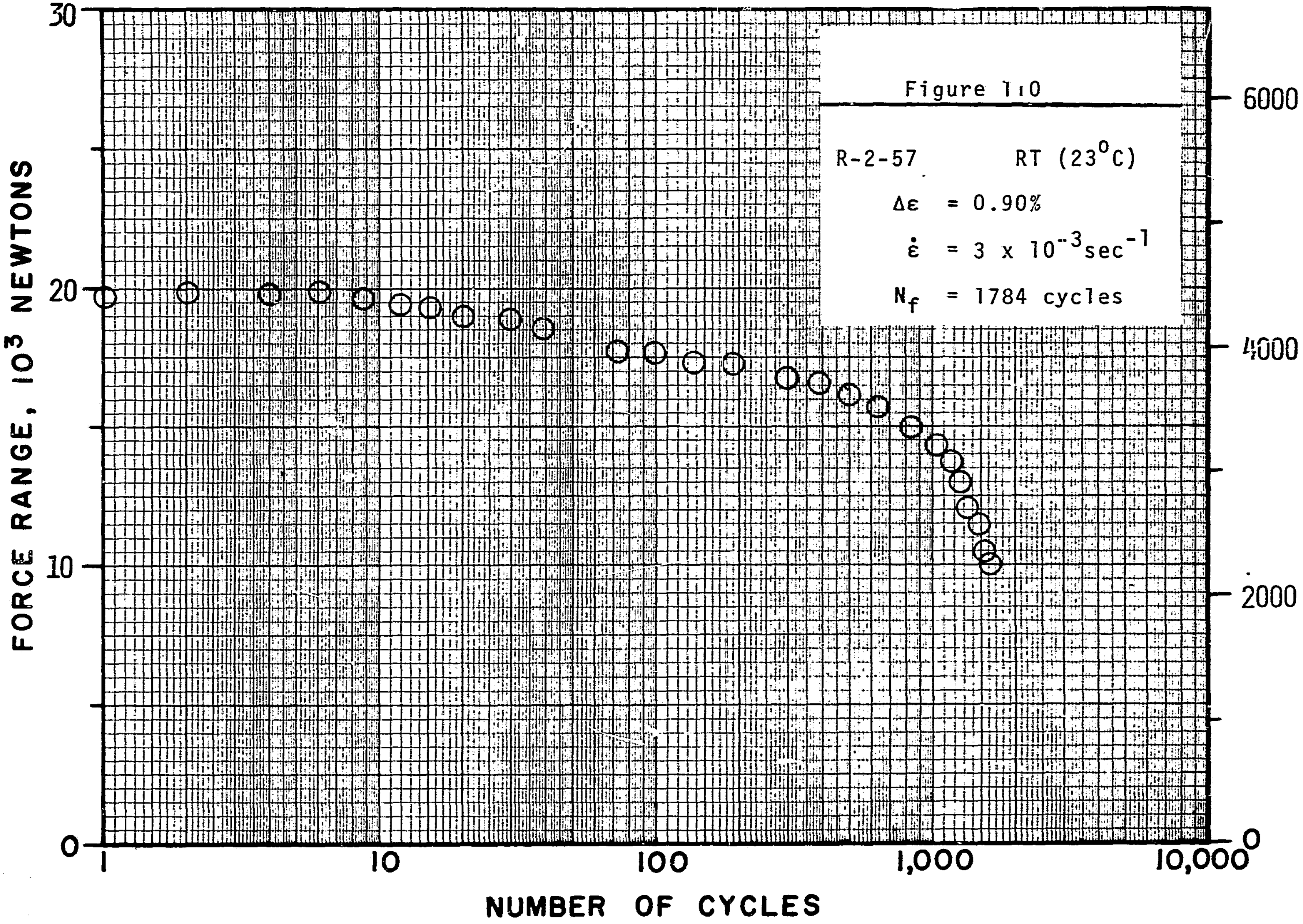


Figure 110

R-2-57 RT (23^{0}C)

$\Delta\varepsilon = 0.90\%$

$\dot{\varepsilon} = 3 \times 10^{-3} sec^{-1}$

$N_f = 1784$ cycles

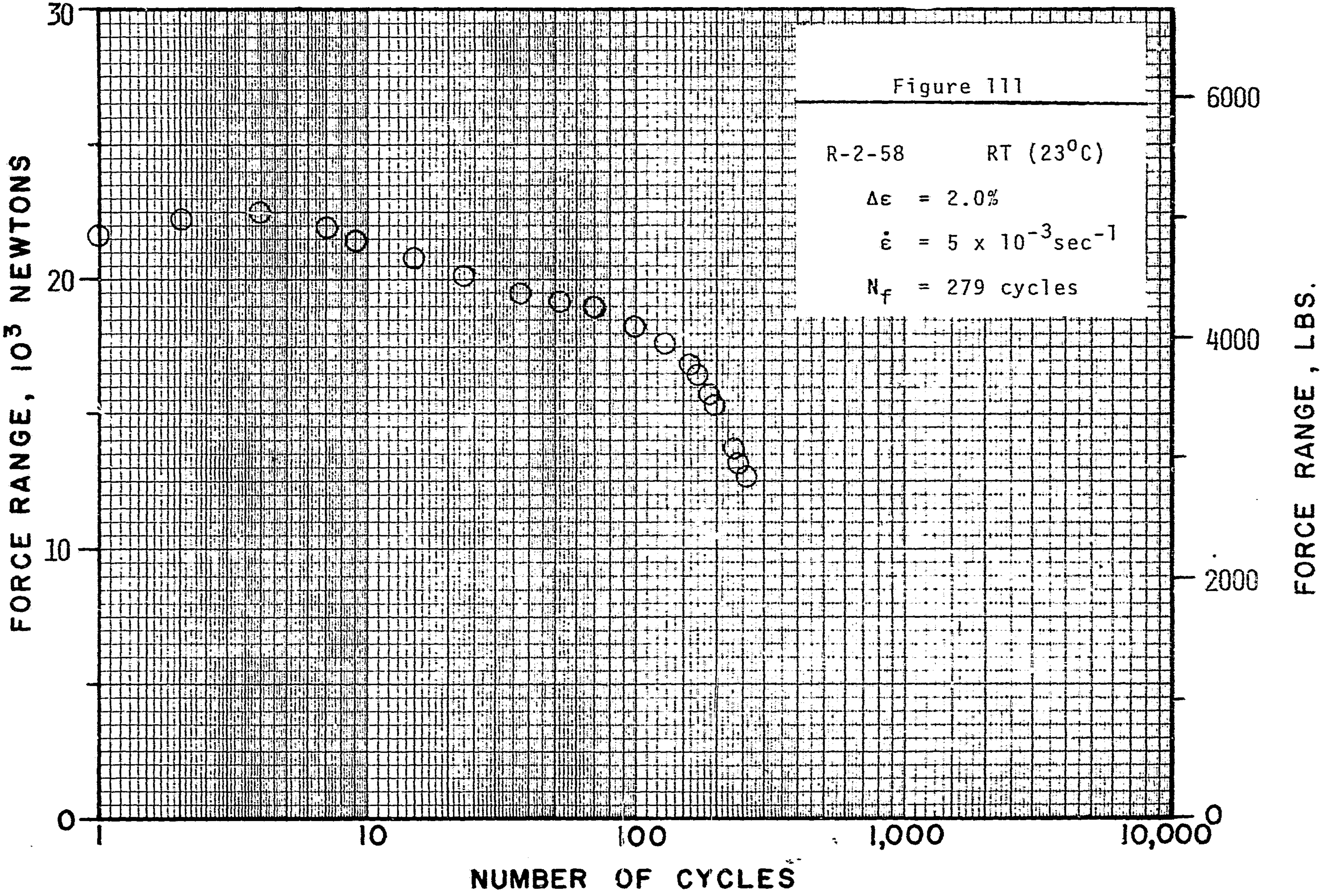


Figure 111

R-2-58 RT (23^oC)

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$

N_f = 279 cycles

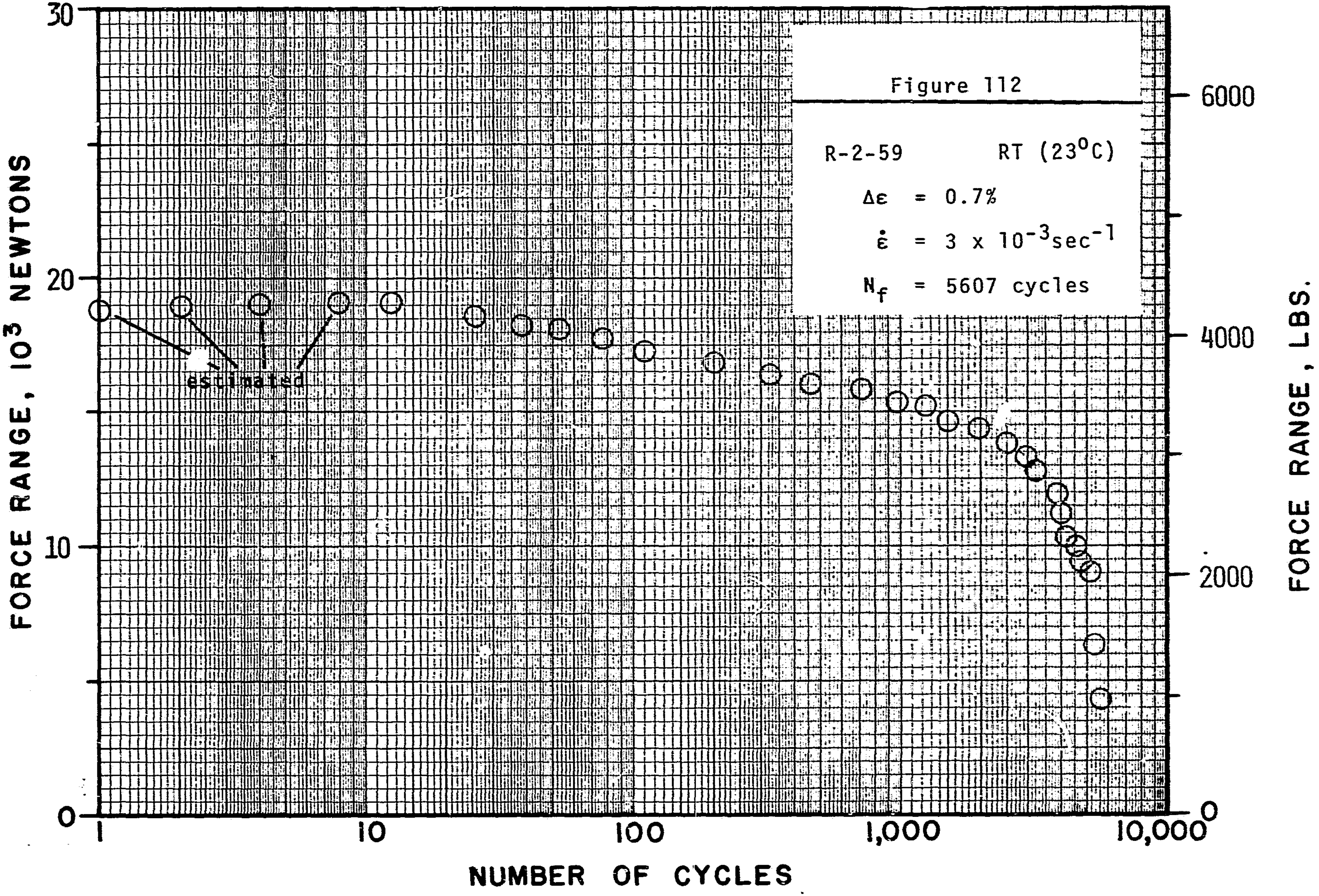


Figure 112

R-2-59 RT (23^0C)

$\Delta\varepsilon = 0.7\%$

$\dot{\varepsilon} = 3 \times 10^{-3} sec^{-1}$

$N_f = 5607$ cycles

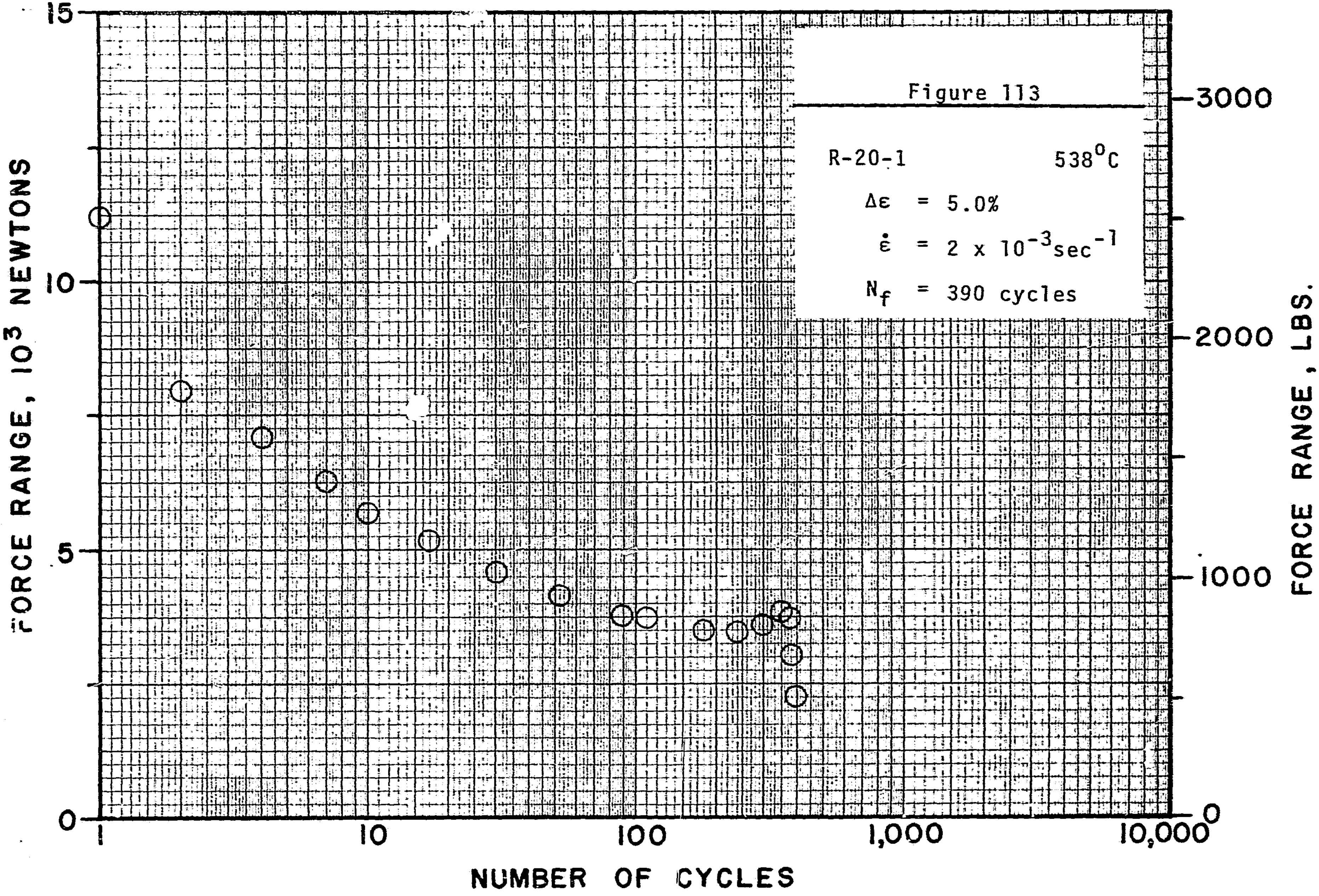


Figure 113

R-20-1
538°C
Δε = 5.0%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 390 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

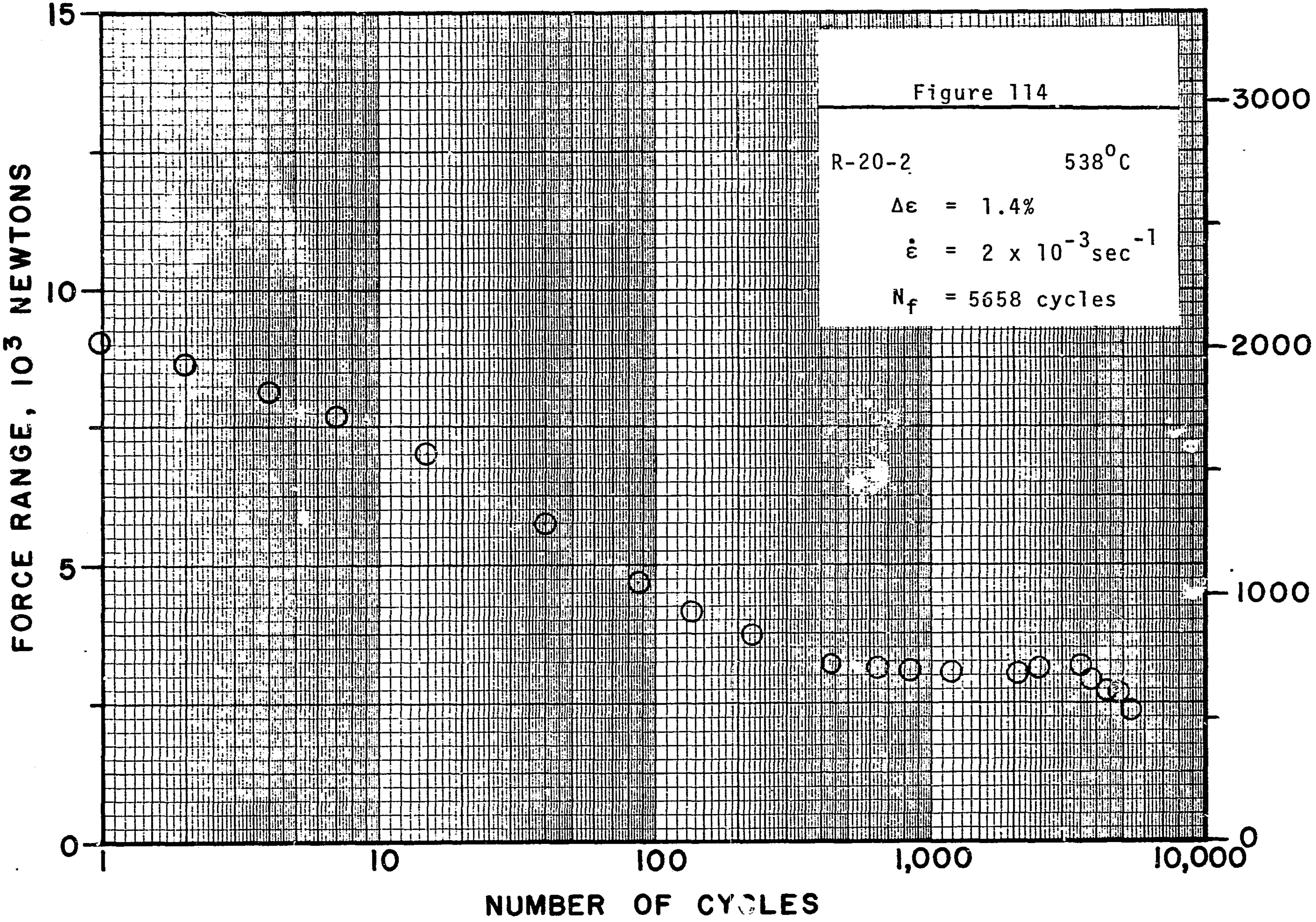


Figure 114

R-20-2 538°C

$\Delta\varepsilon = 1.4\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 5658 cycles

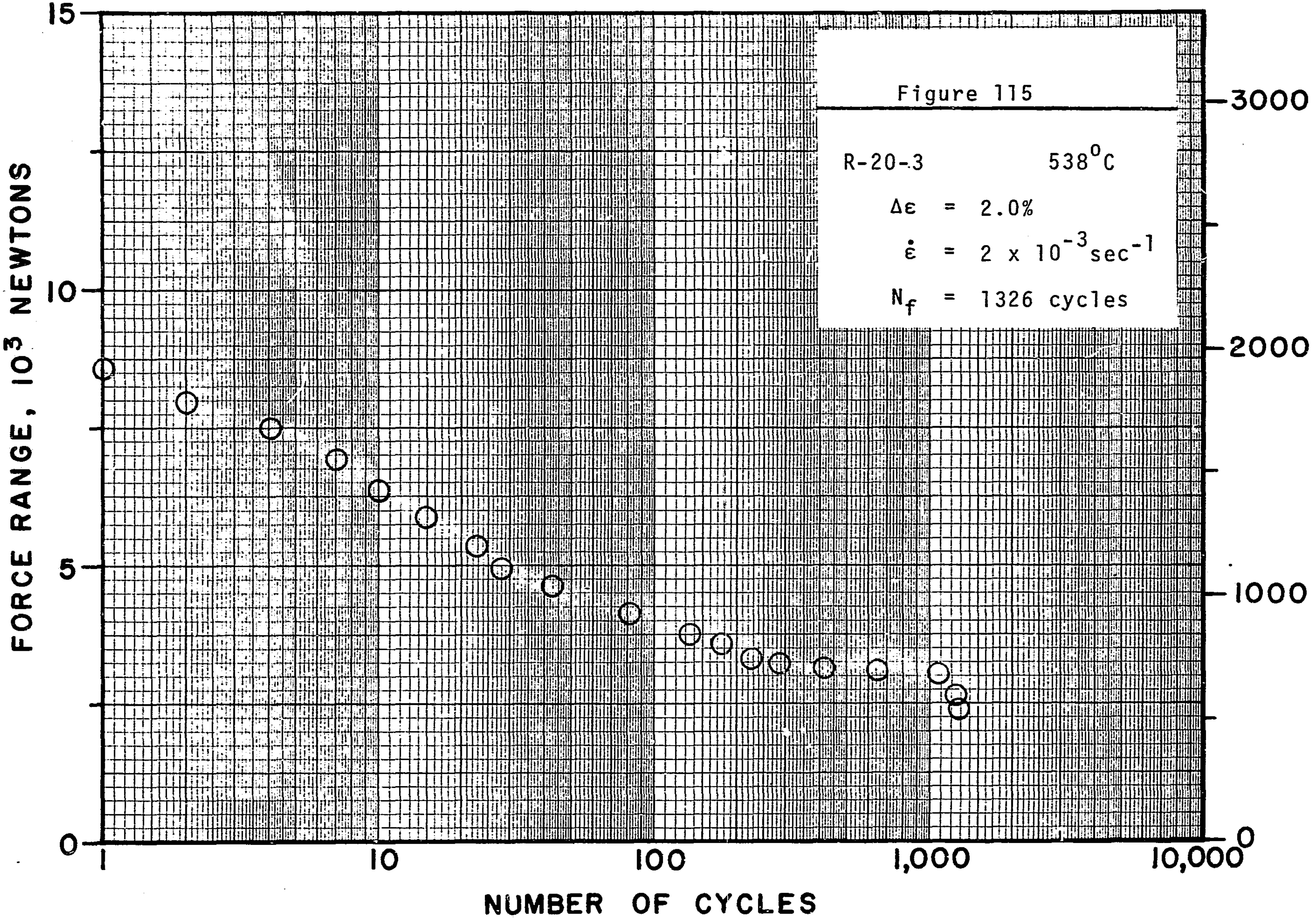


Figure 115

R-20-3 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 1326 cycles

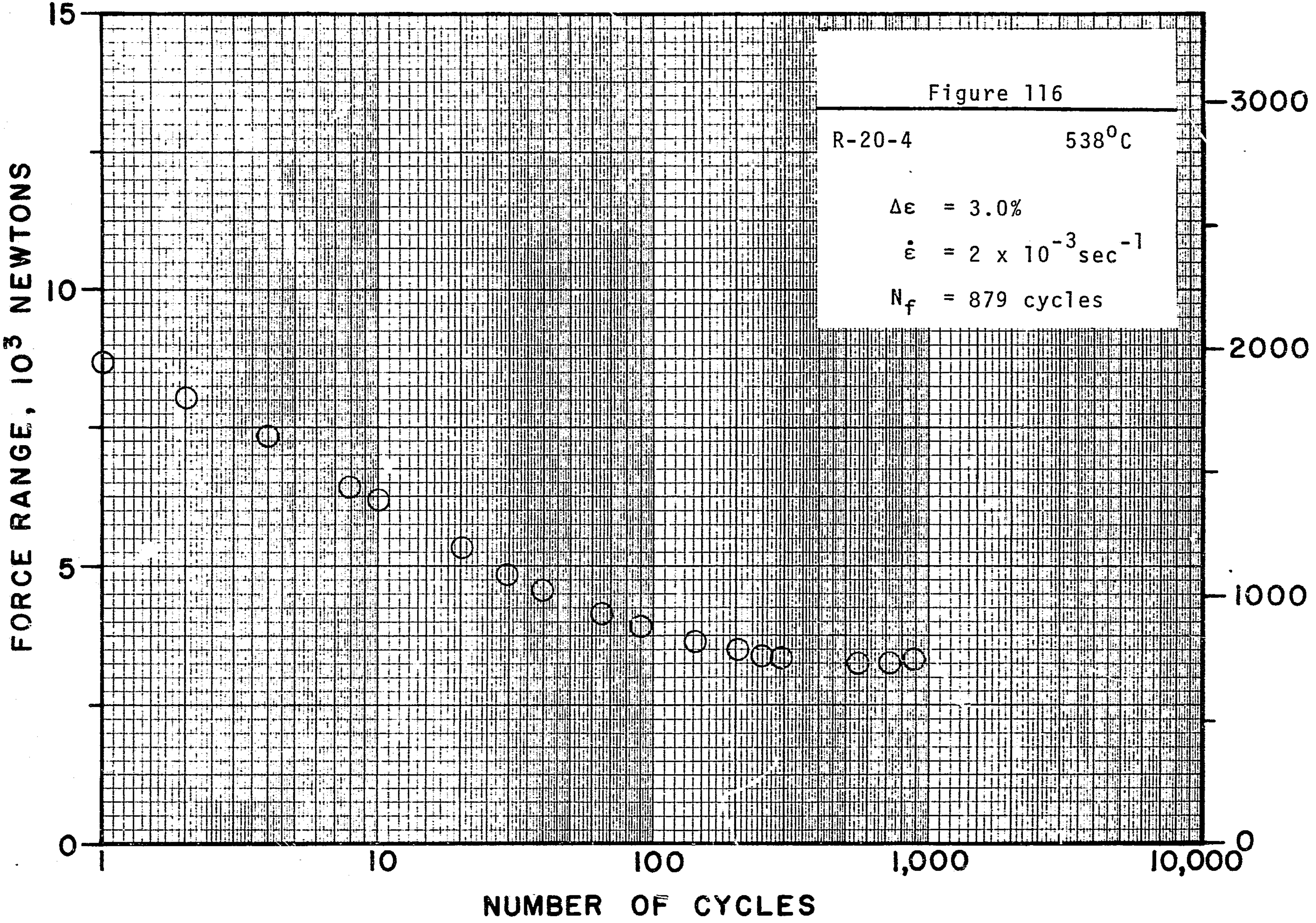


Figure 116

R-20-4 538°C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 879 cycles

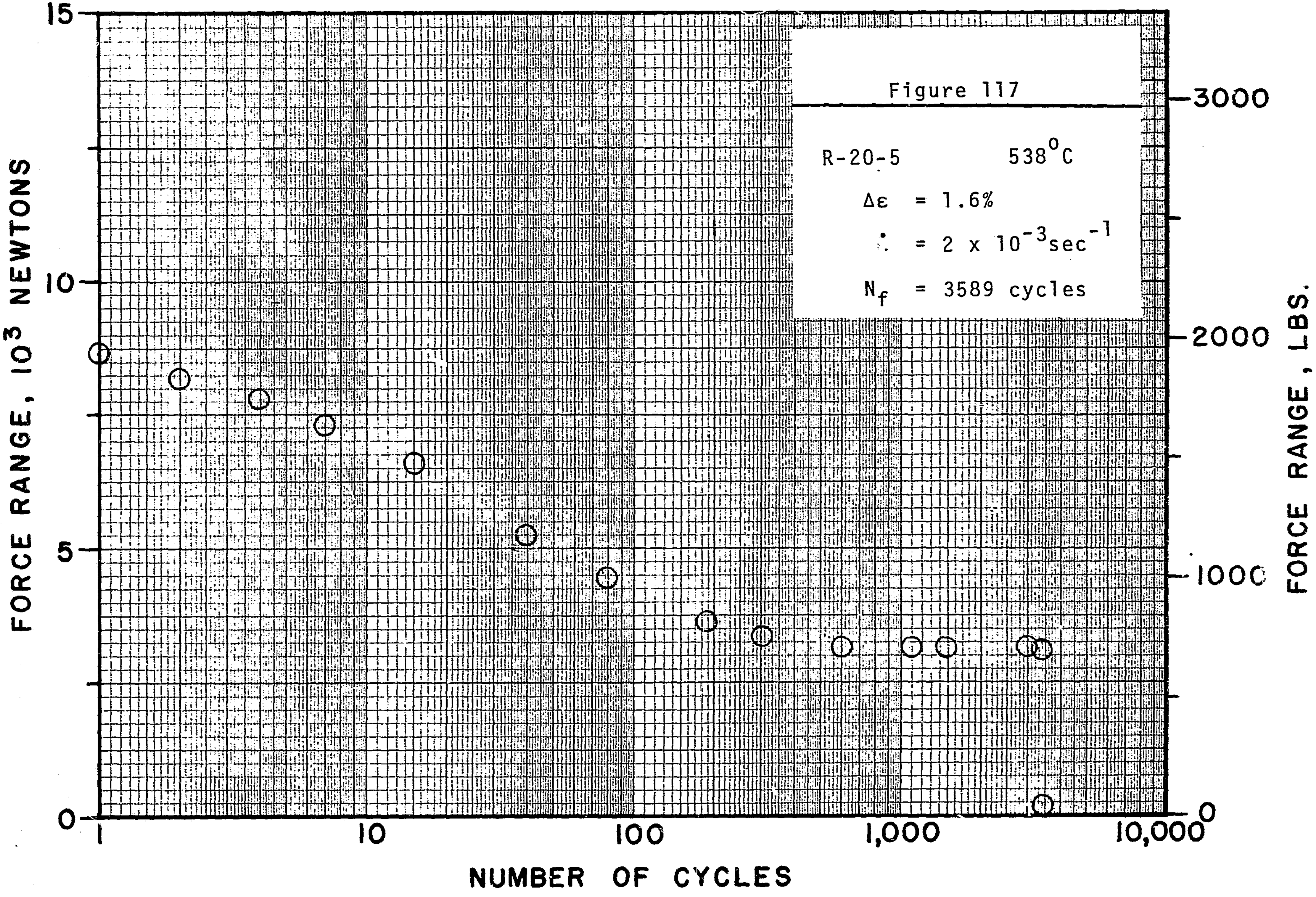


Figure 117

R-20-5 538°C

$\Delta\varepsilon$ = 1.6%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 3589 cycles

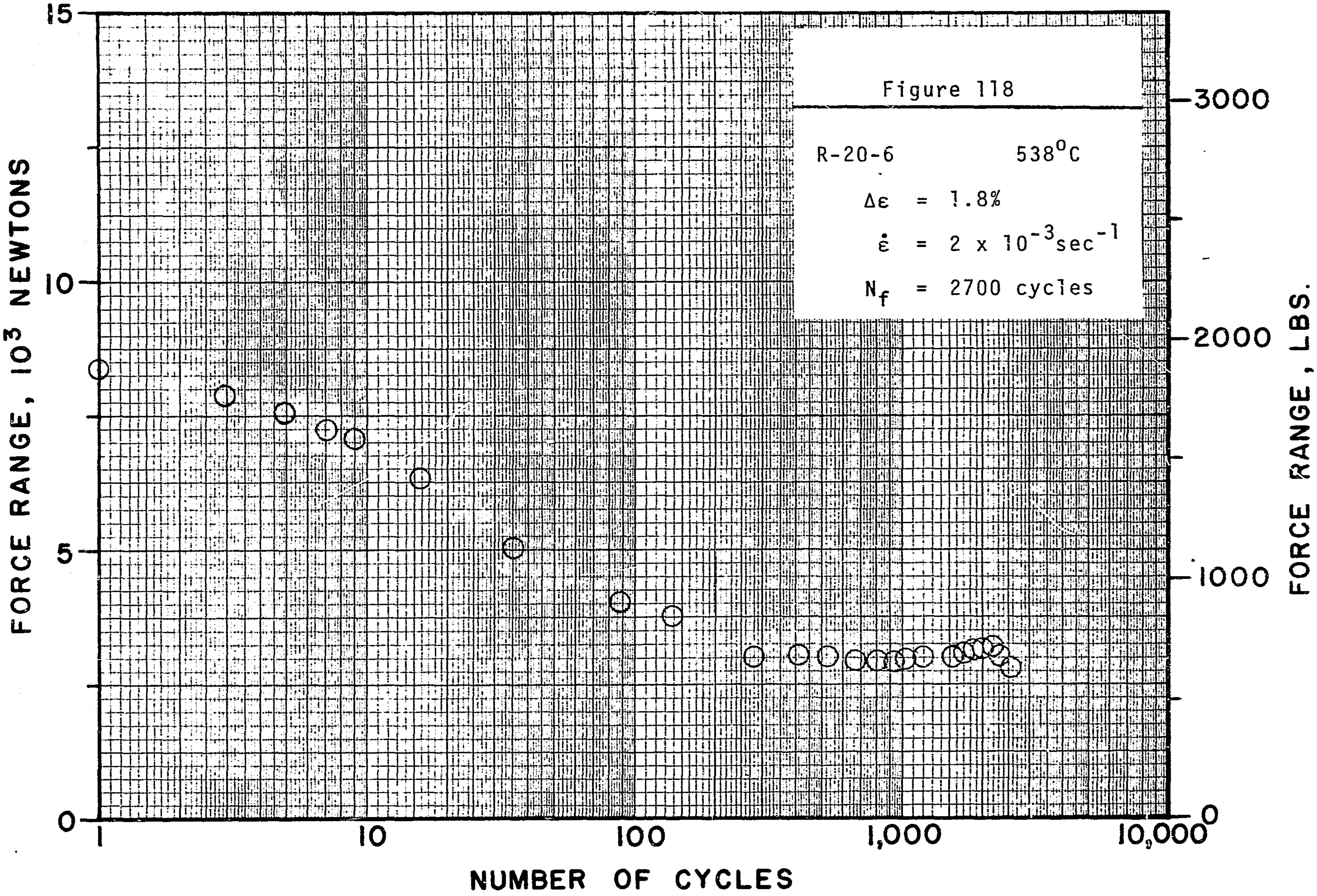


Figure 118

R-20-6 538°C

$\Delta\varepsilon$ = 1.8%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 2700 cycles

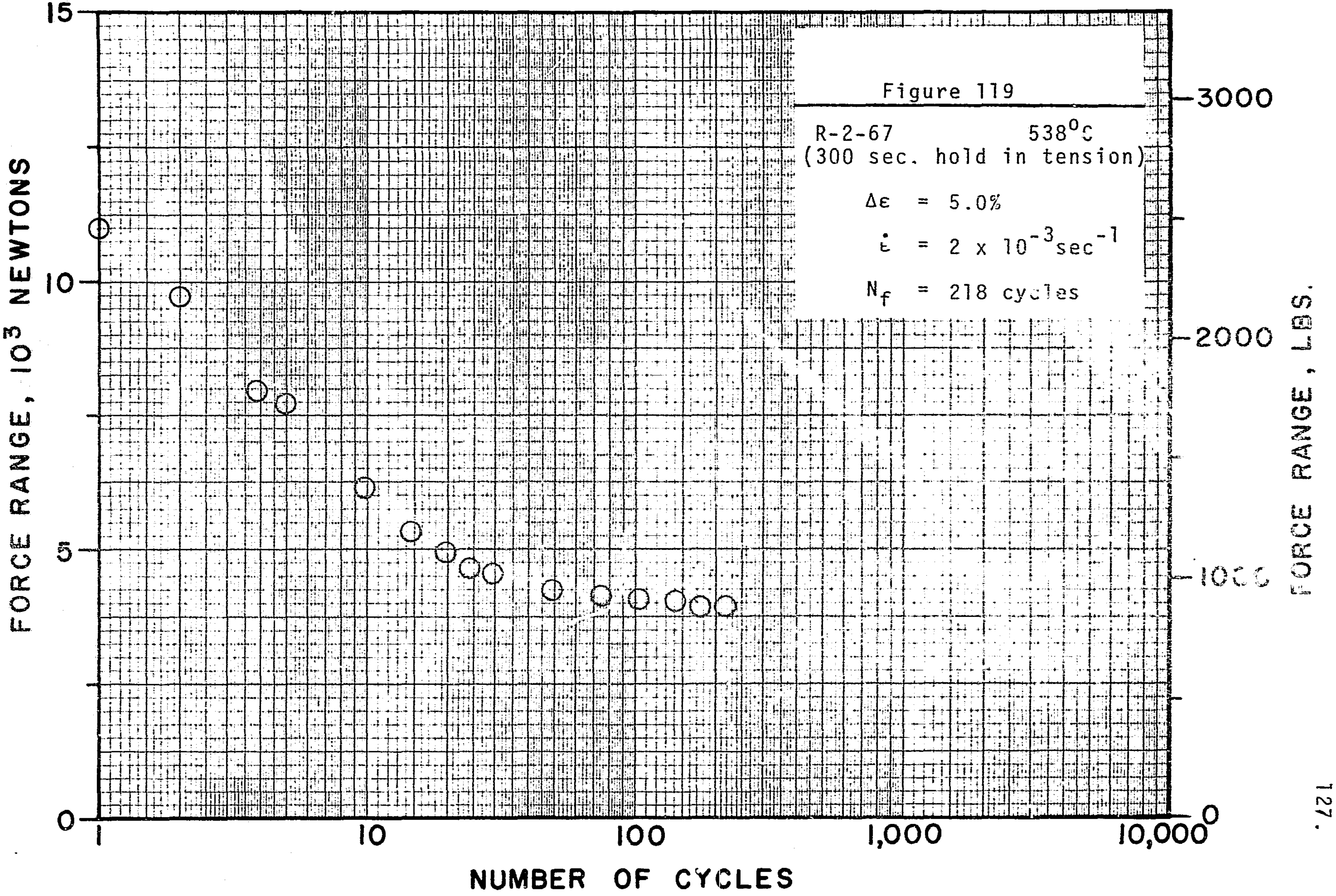


Figure 119

R-2-67 538°C
(300 sec. hold in tension)

$\Delta\varepsilon$ = 5.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 218 cycles

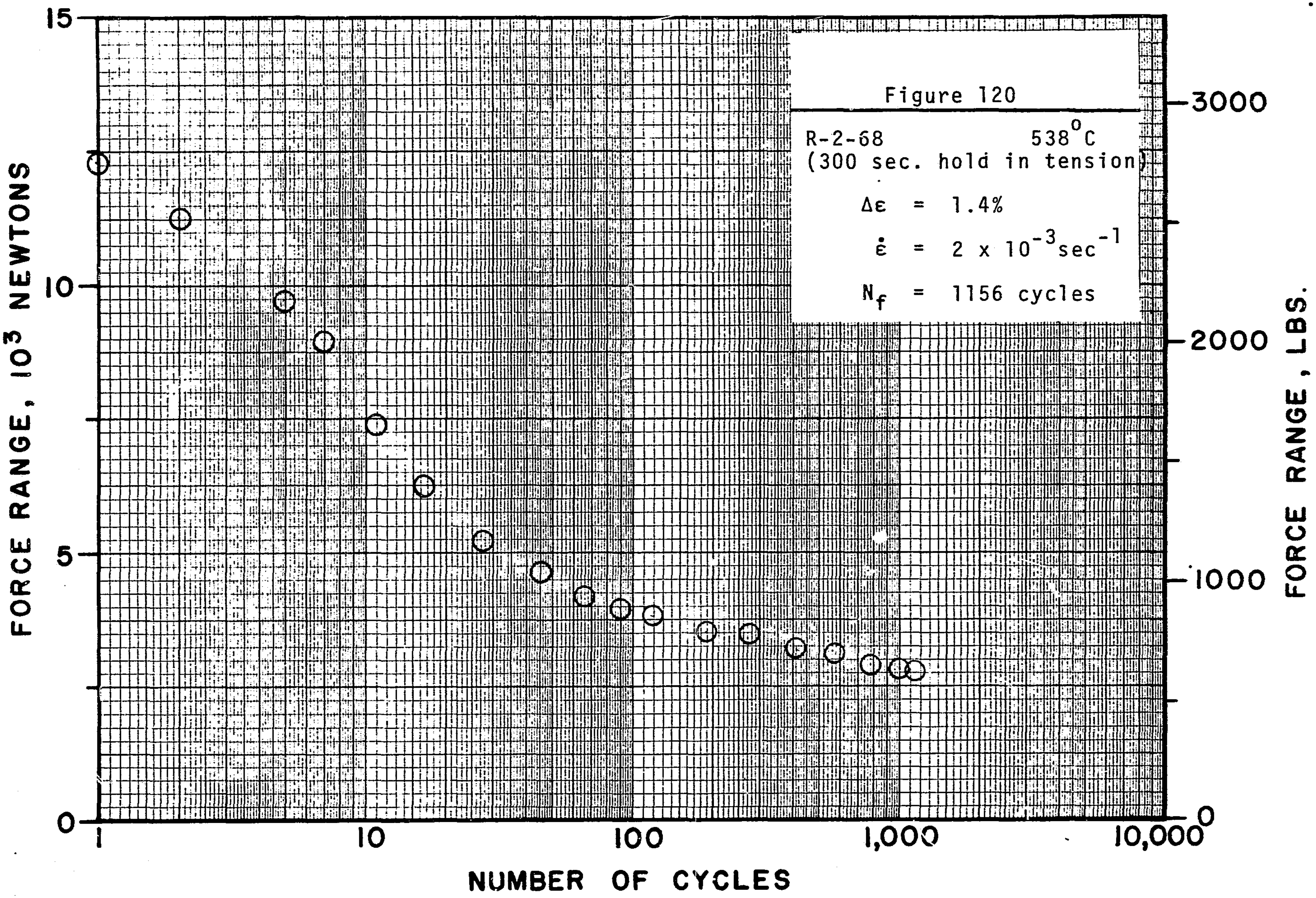


Figure 120

R-2-68 538°C

(300 sec. hold in tension)

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 1156 cycles

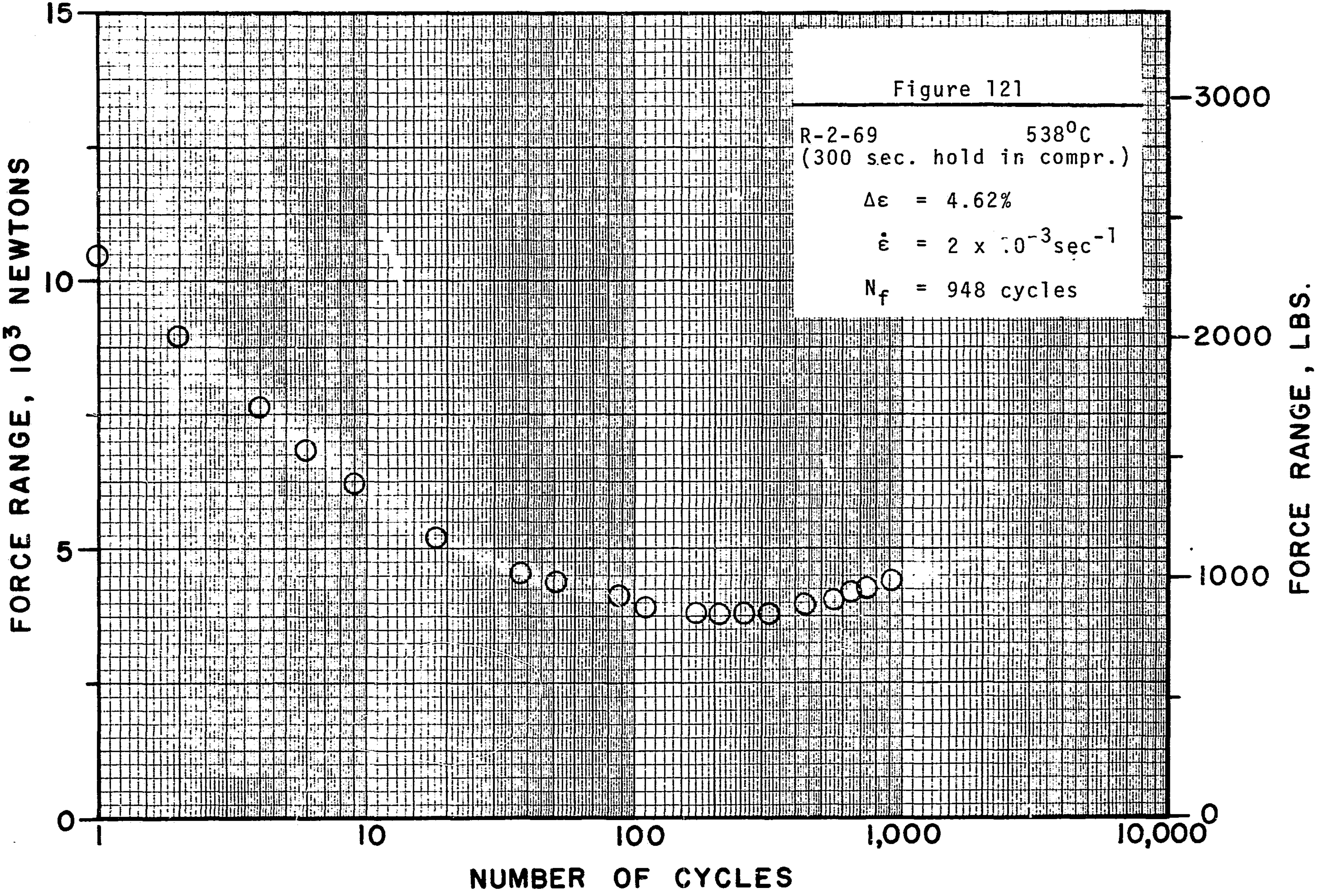


Figure 121

R-2-69 538^{0}C
(300 sec. hold in compr.)

$\Delta\varepsilon = 4.62\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 948$ cycles

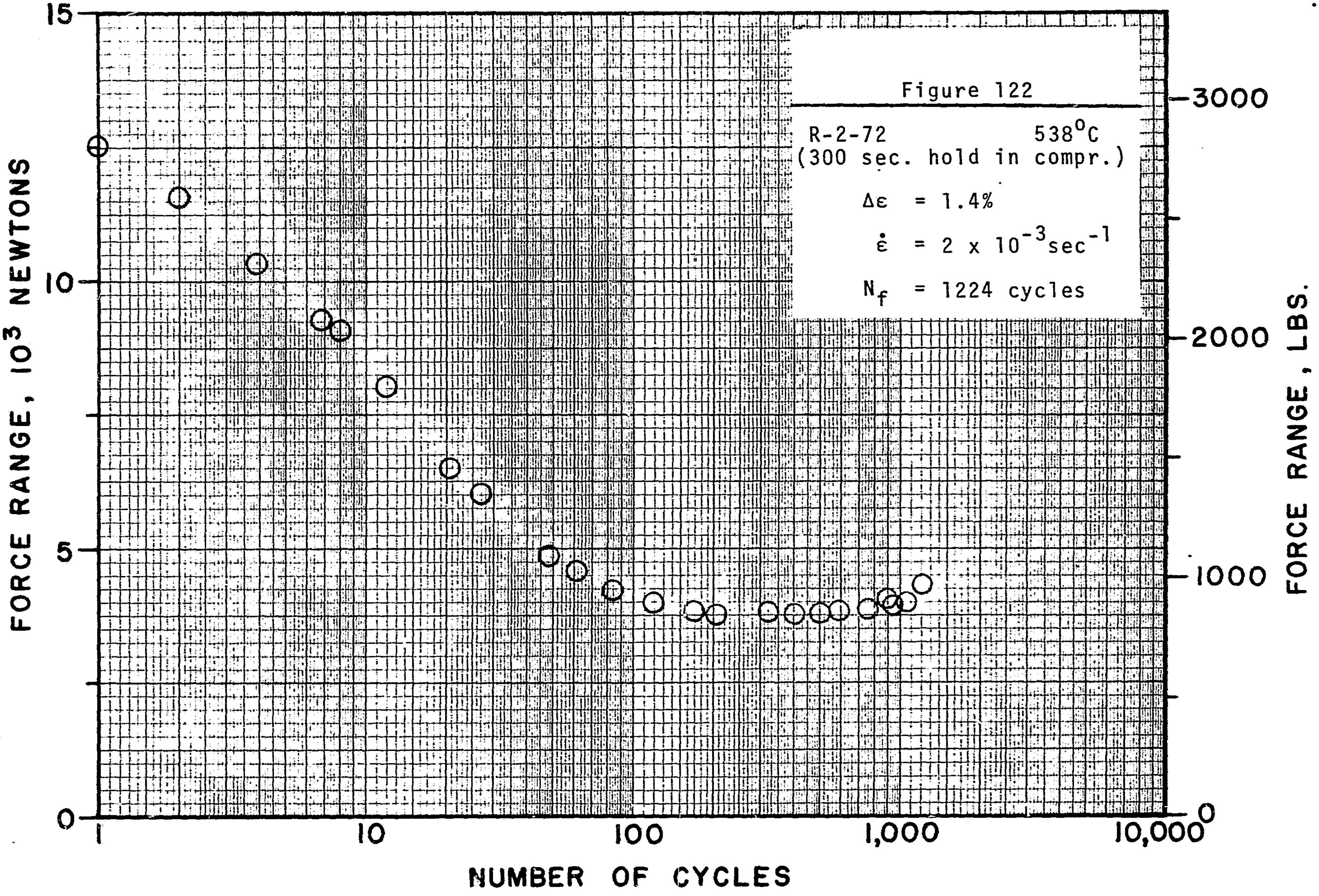


Figure 122

R-2-72 538^0C
(300 sec. hold in compr.)

$\Delta\varepsilon$ = 1.4%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 1224 cycles

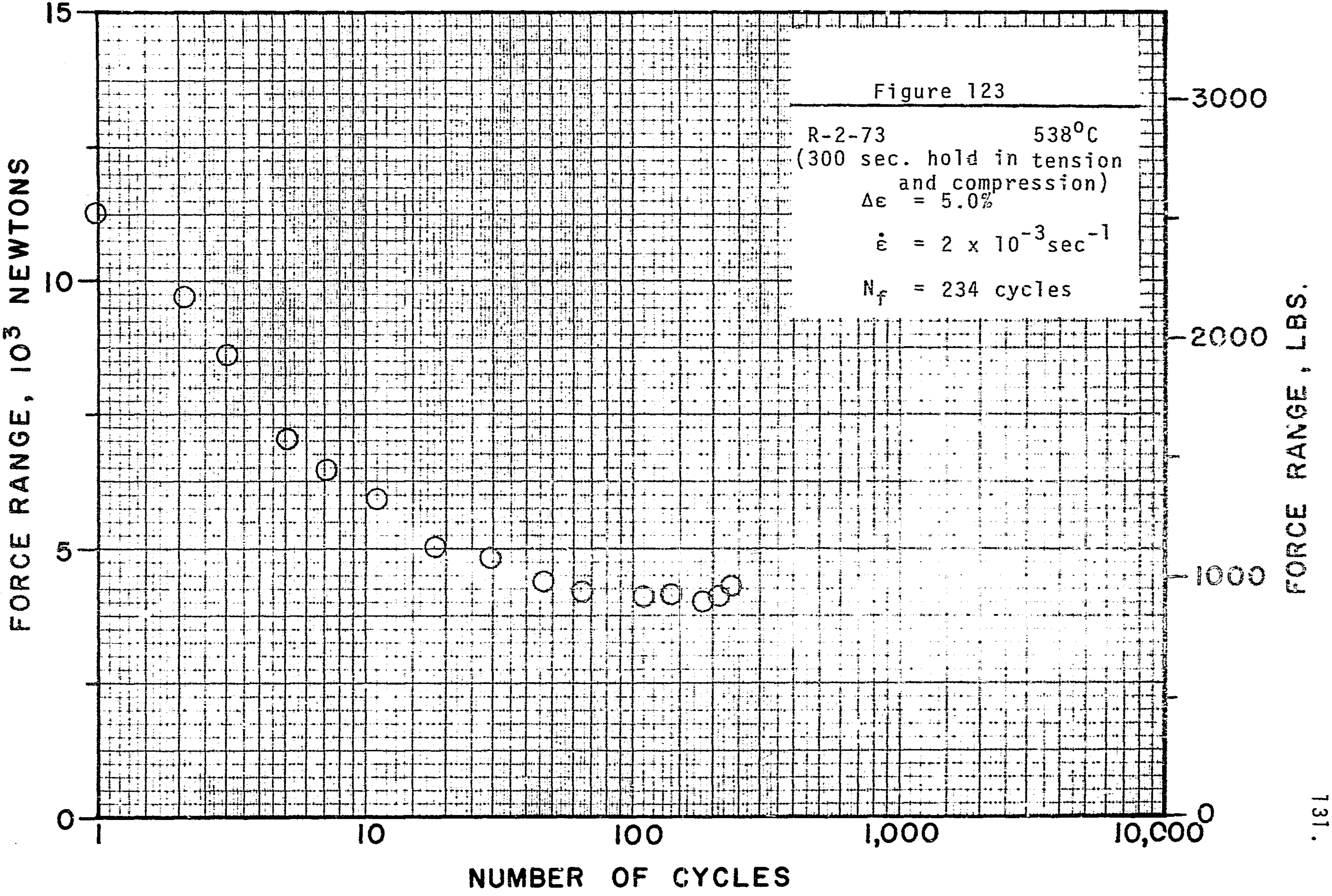


Figure 123

R-2-73 538°C
(300 sec. hold in tension
and compression)

$\Delta\varepsilon = 5.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \mathrm{sec}^{-1}$

$N_f = 234$ cycles

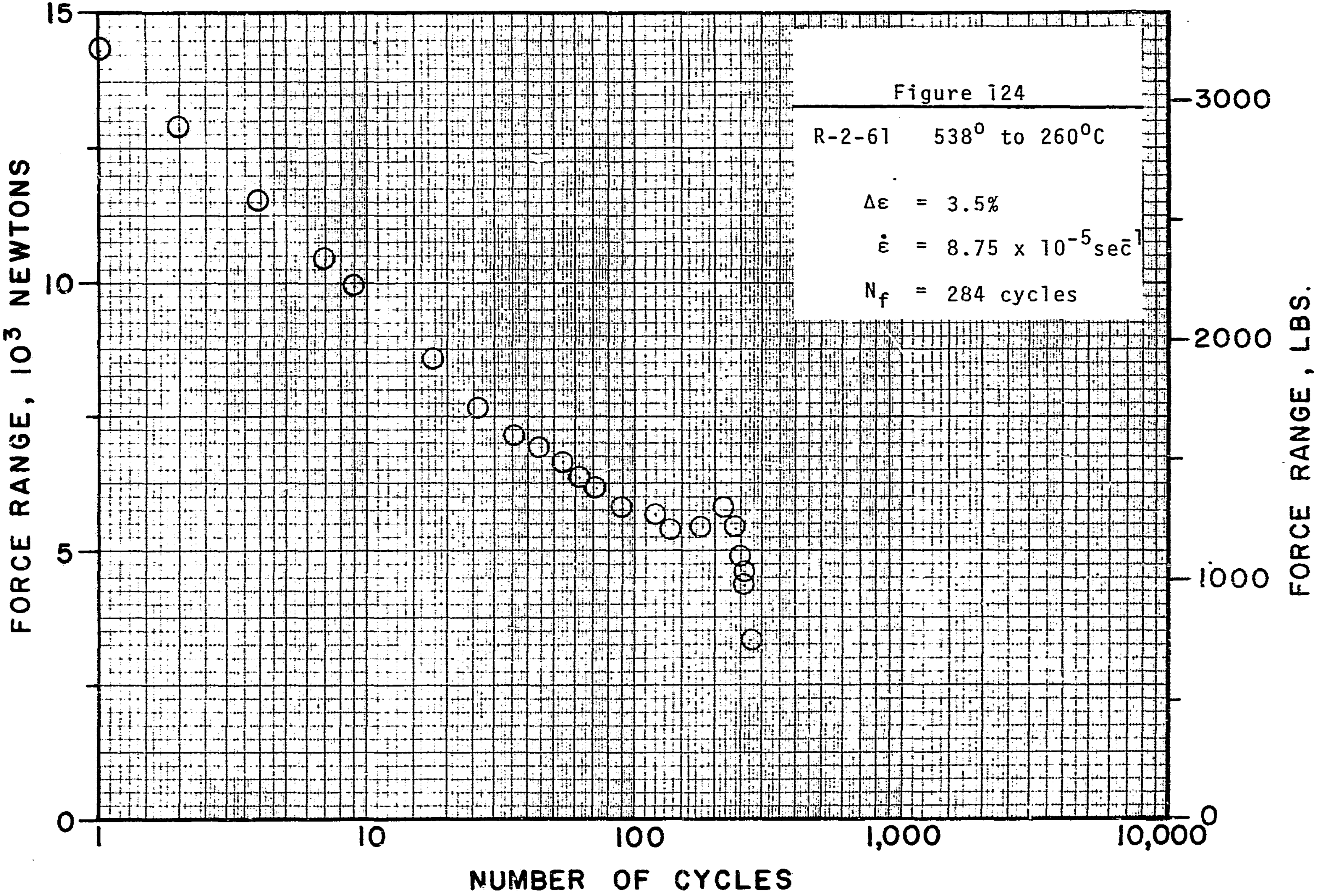


Figure 124

R-2-61 538° to 260°C

$\Delta\varepsilon$ = 3.5%

$\dot{\varepsilon}$ = 8.75×10^{-5} sec^{-1}

N_f = 284 cycles

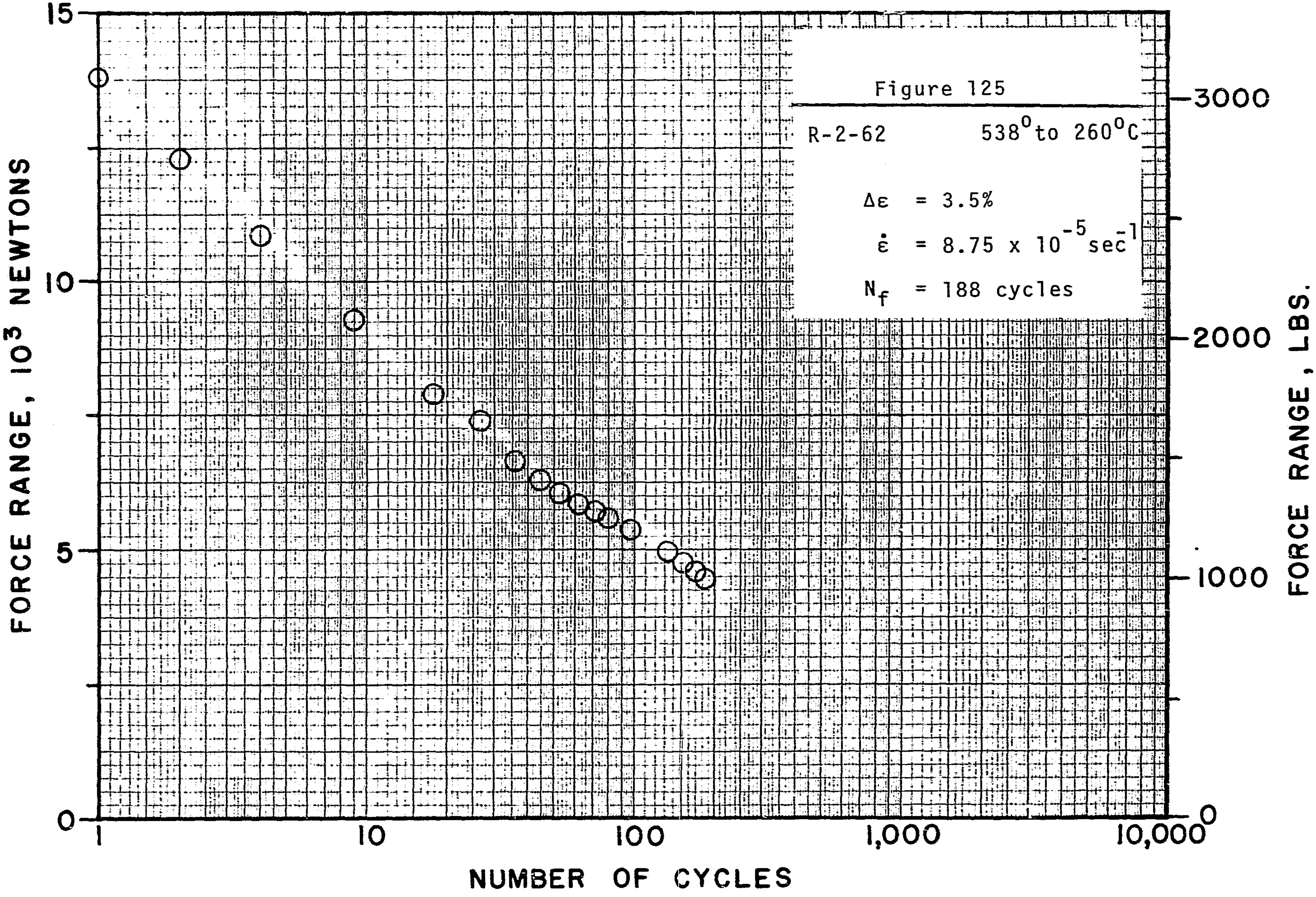


Figure 125

R-2-62 538^0 to 260^{0}C

$\Delta\varepsilon$ = 3.5%

$\dot{\varepsilon}$ = 8.75 x 10^{-5} sec^{-1}

N_f = 188 cycles

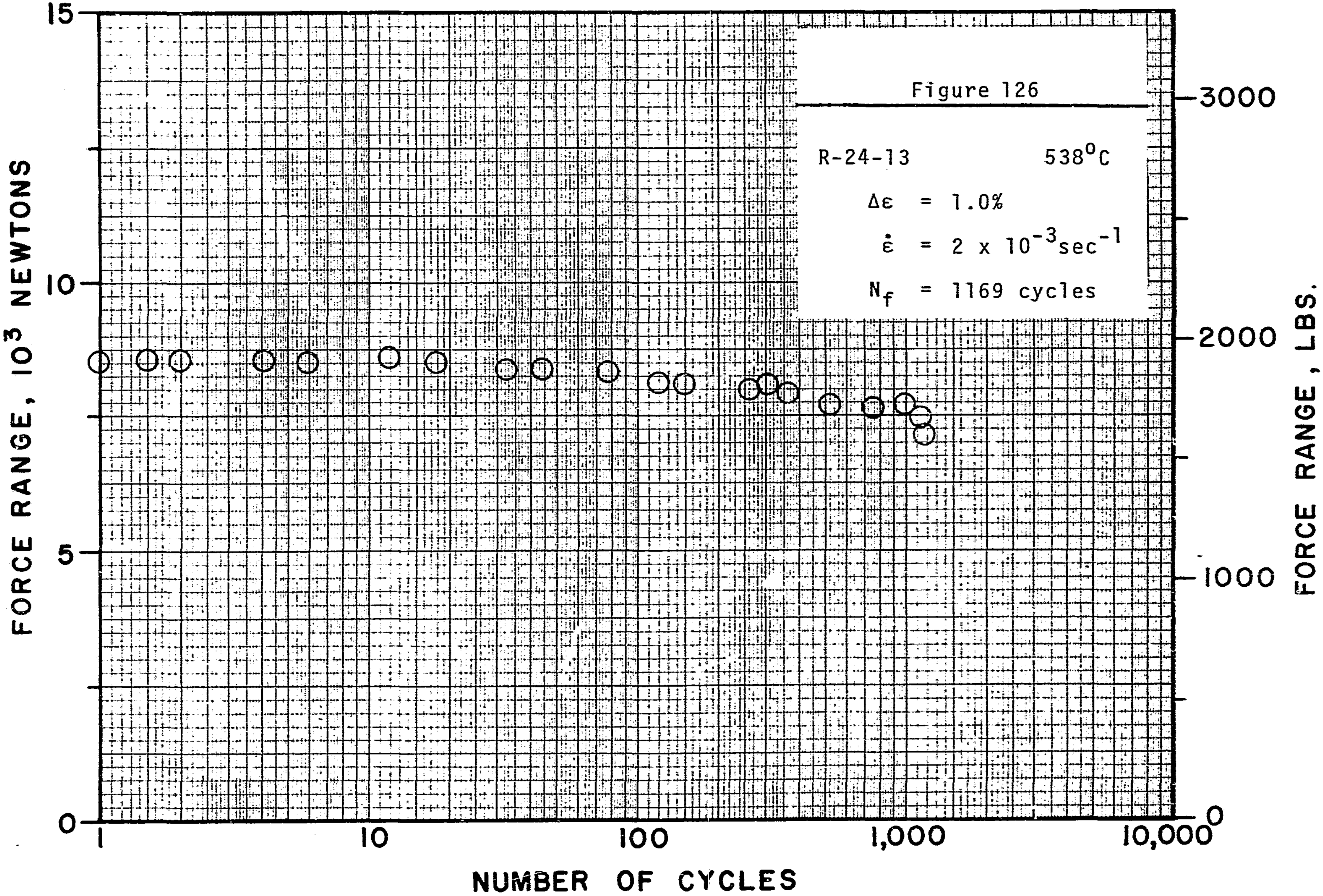


Figure 126

R-24-13 538°C

$\Delta\varepsilon$ = 1.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 1169 cycles

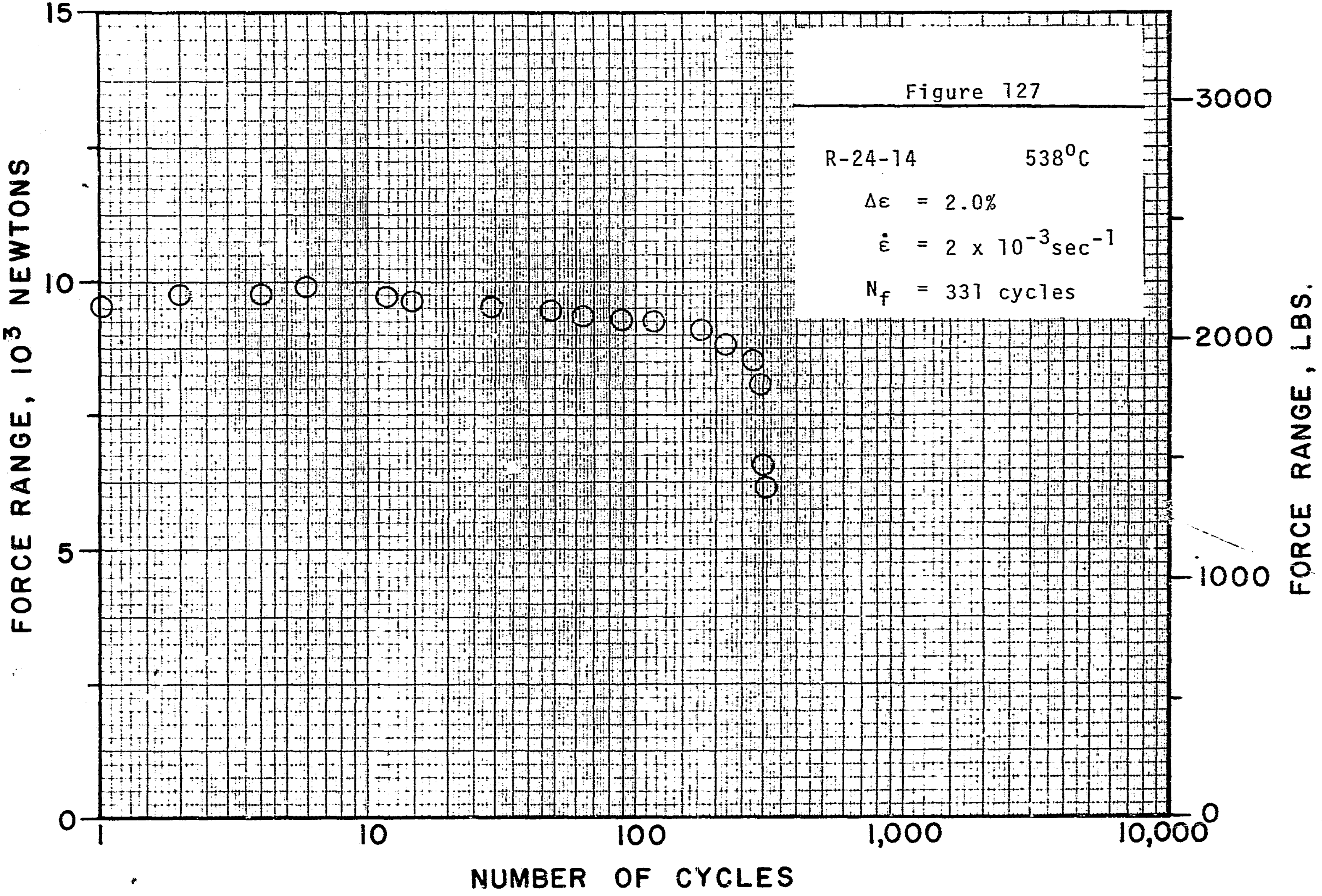


Figure 127

R-24-14 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 331 cycles

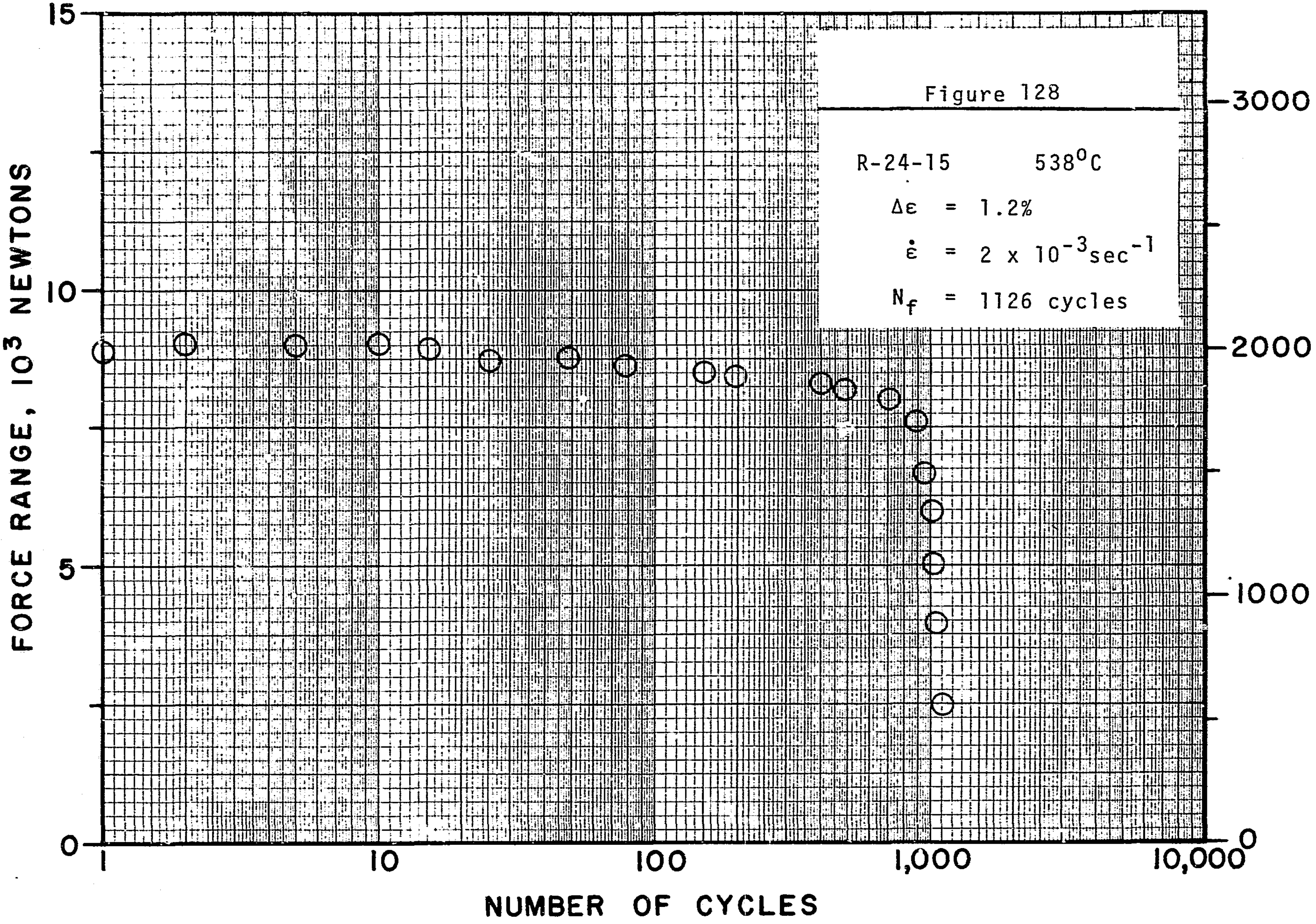


Figure 128

R-24-15 538°C

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 1126 cycles

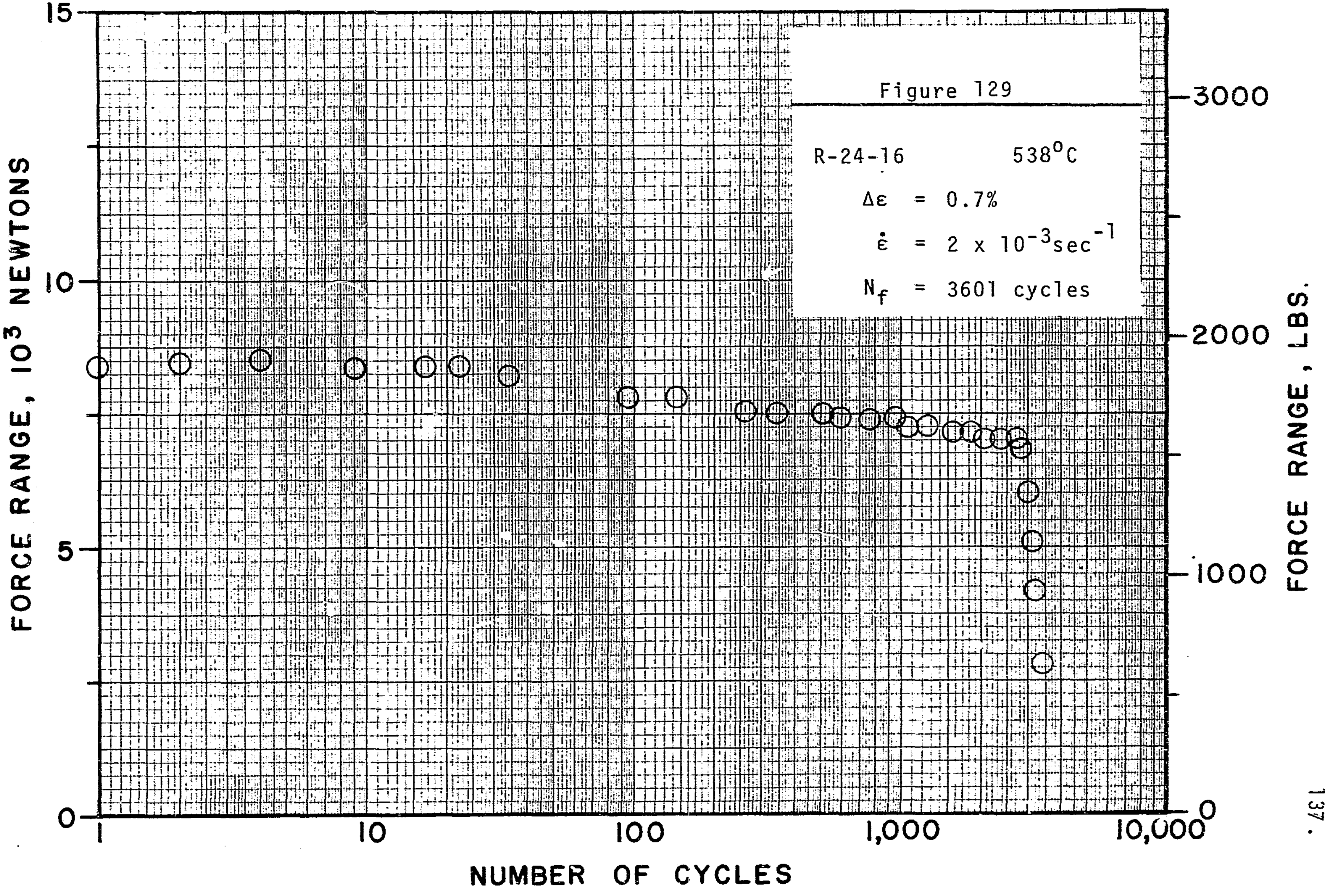


Figure 129

R-24-16 538^{0}C
$\Delta\varepsilon$ = 0.7%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 3601 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
NUMBER OF CYCLES
1
10
100
1,000
10,000

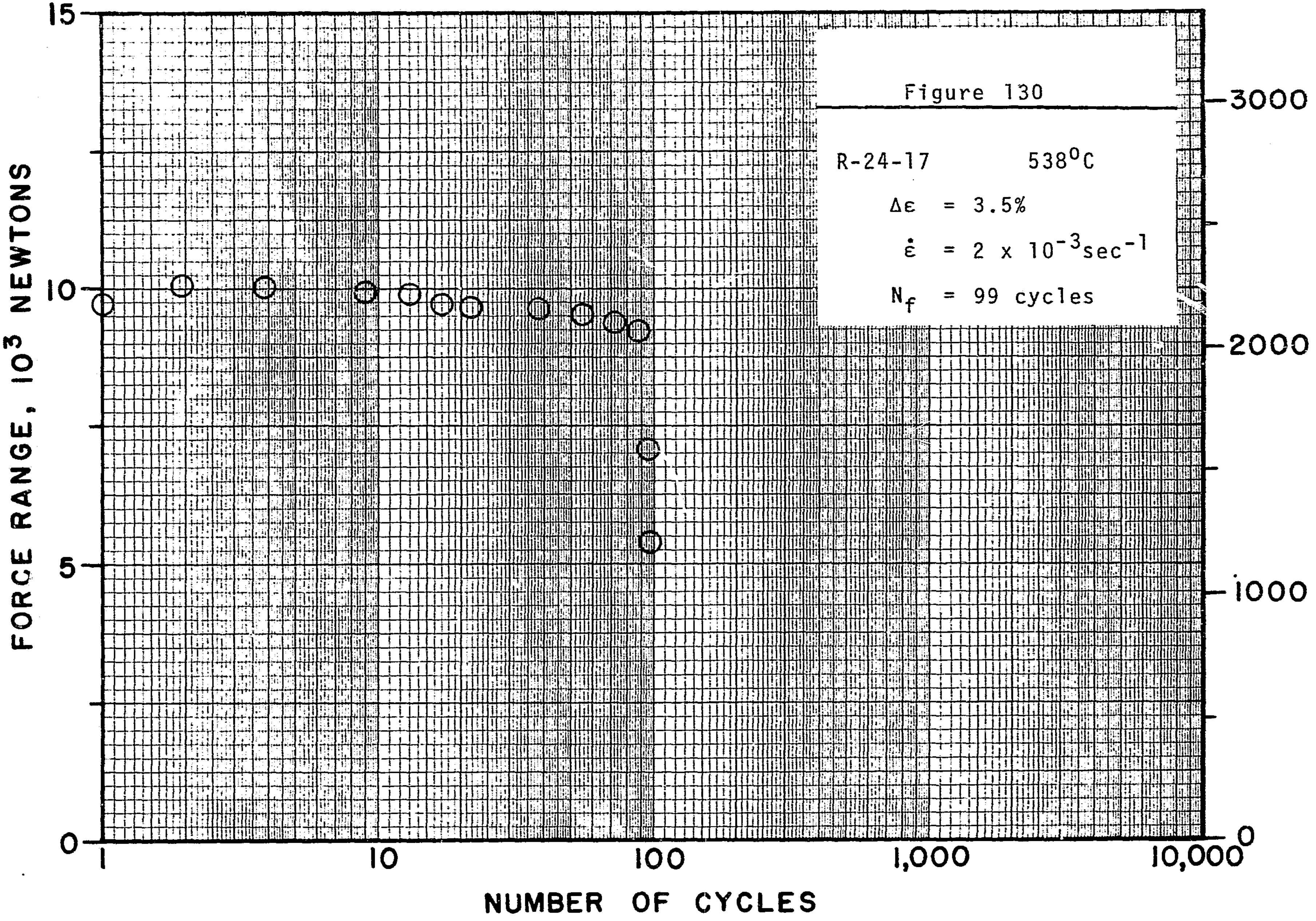


Figure 130
R-24-17
538°C
Δε = 3.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 99 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

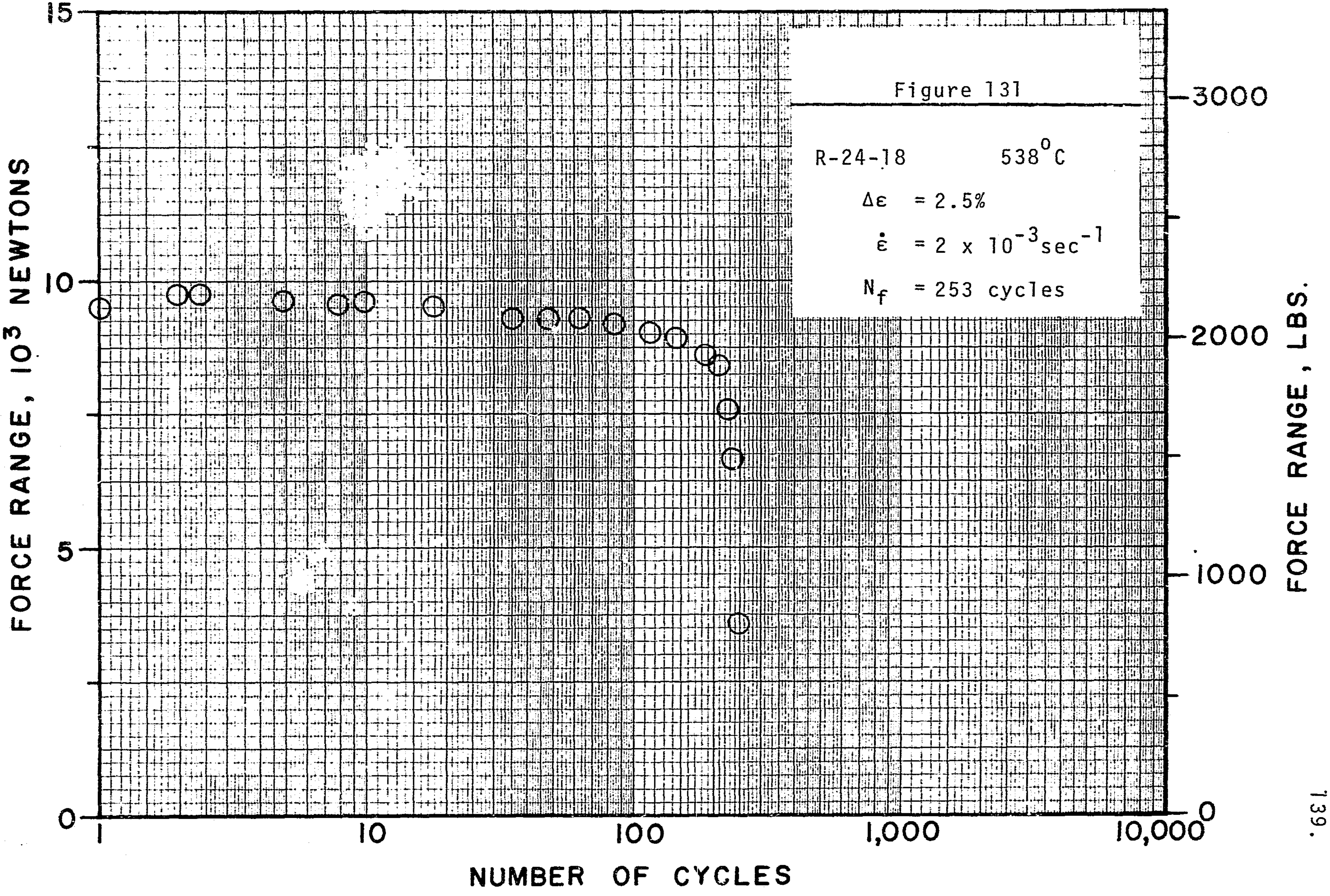


Figure 131

R-24-18 538°C

$\Delta\varepsilon = 2.5\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 253$ cycles

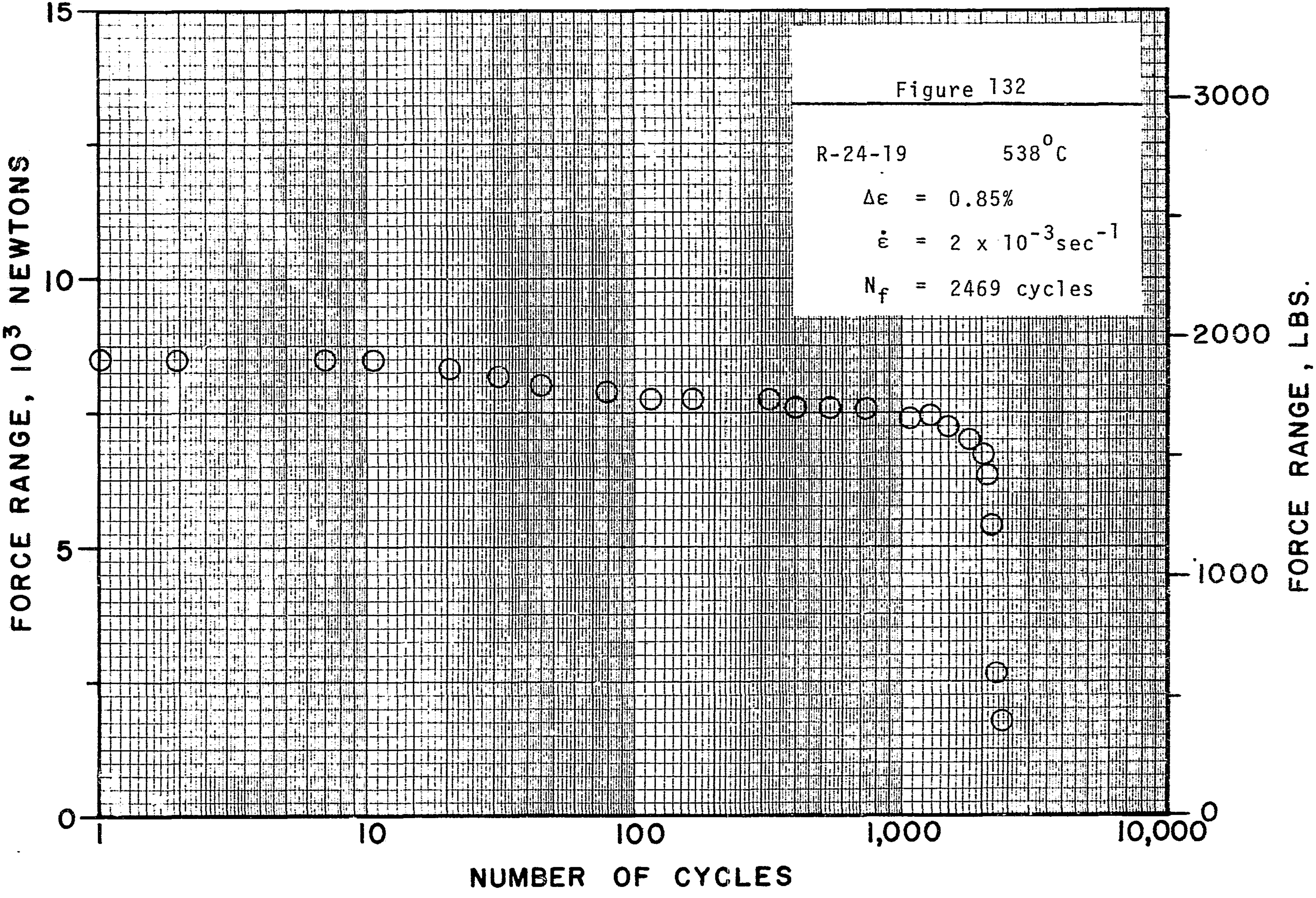


Figure 132

R-24-19 538°C

$\Delta\varepsilon$ = 0.85%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 2469 cycles

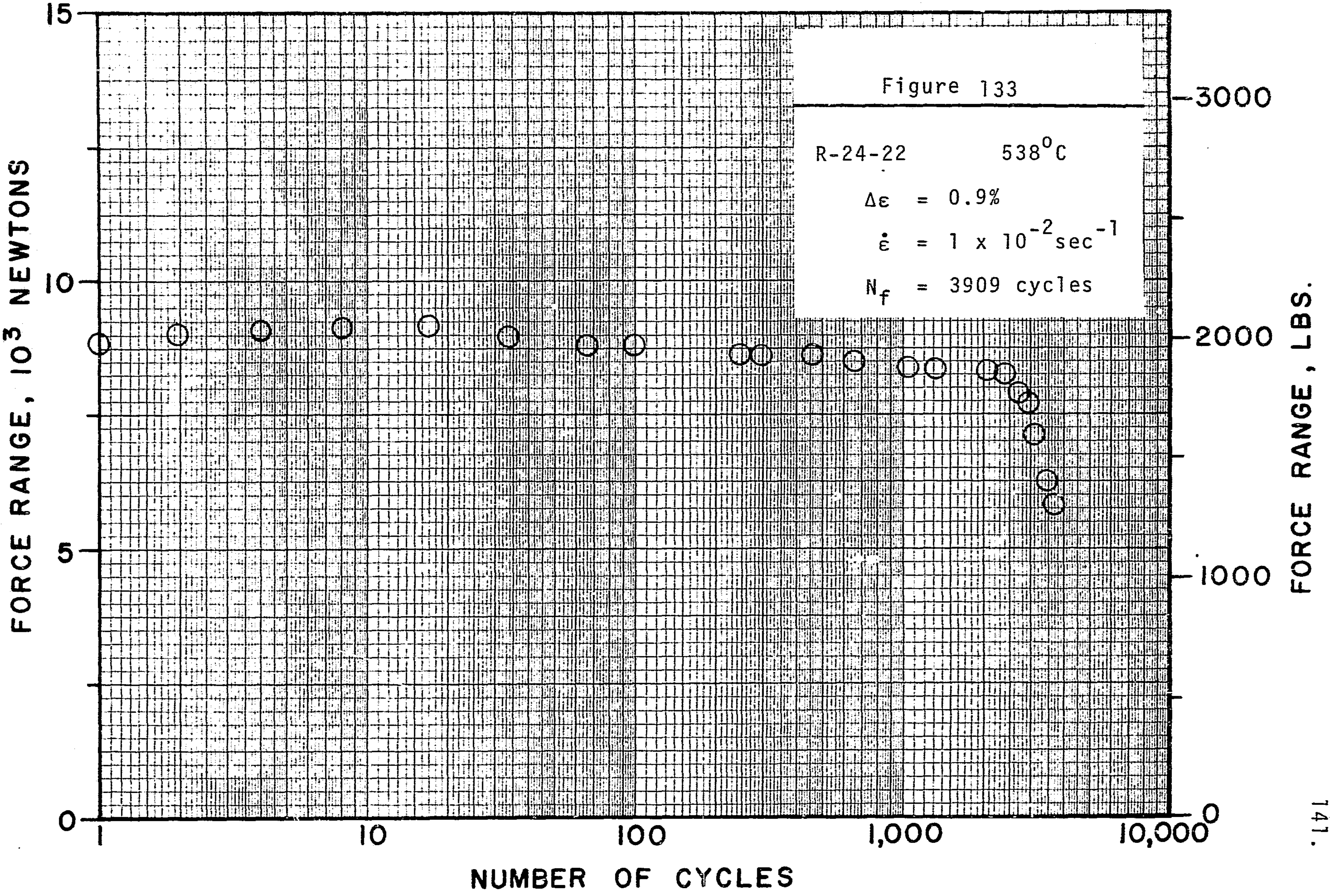


Figure 133

R-24-22 538°C
Δε = 0.9%
$\dot{\varepsilon}$ = 1 x 10^{-2}sec^{-1}
N_f = 3909 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

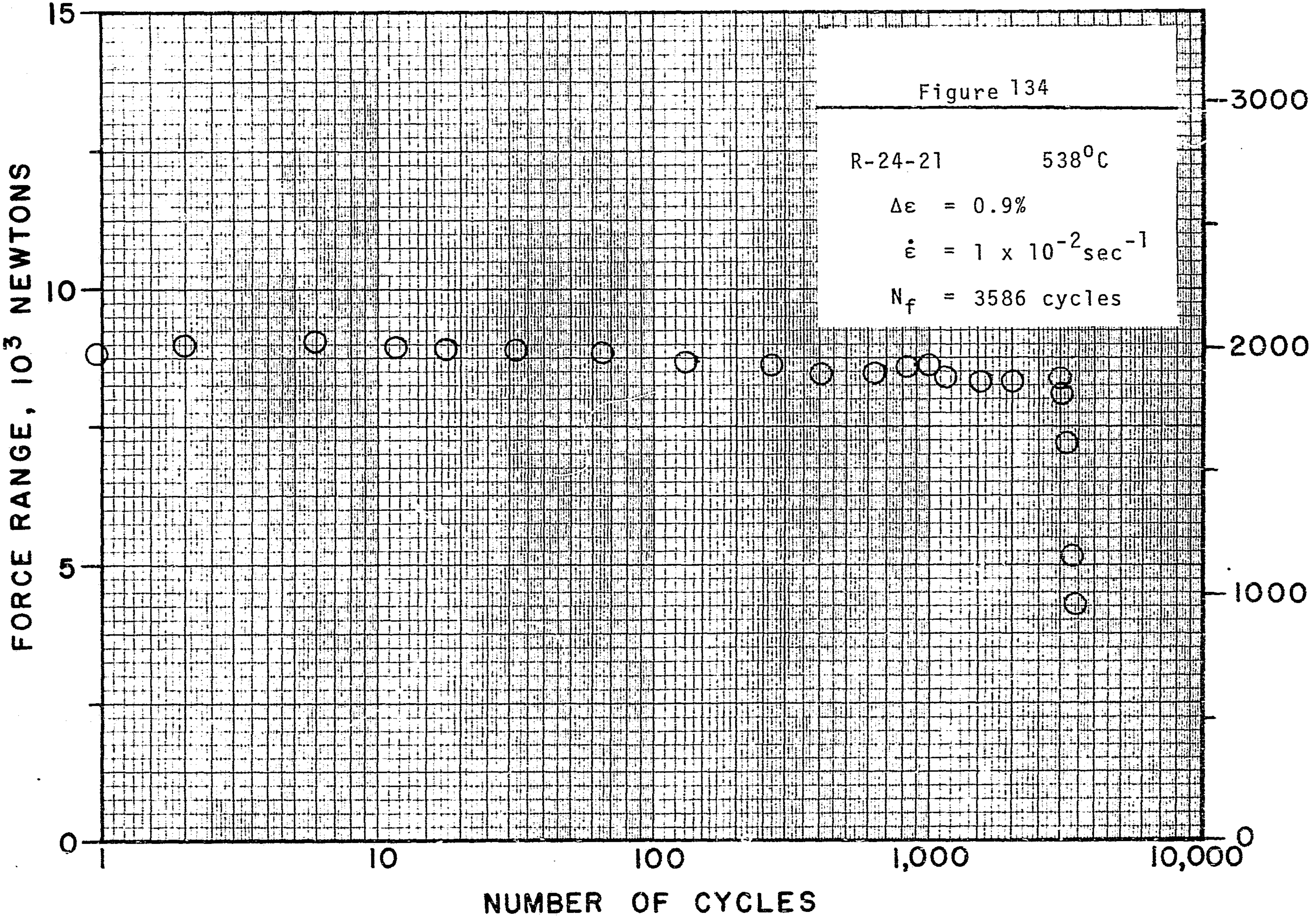


Figure 134
R-24-21
538°C
Δε = 0.9%
ε̇ = 1 x 10⁻² sec⁻¹
N_f = 3586 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

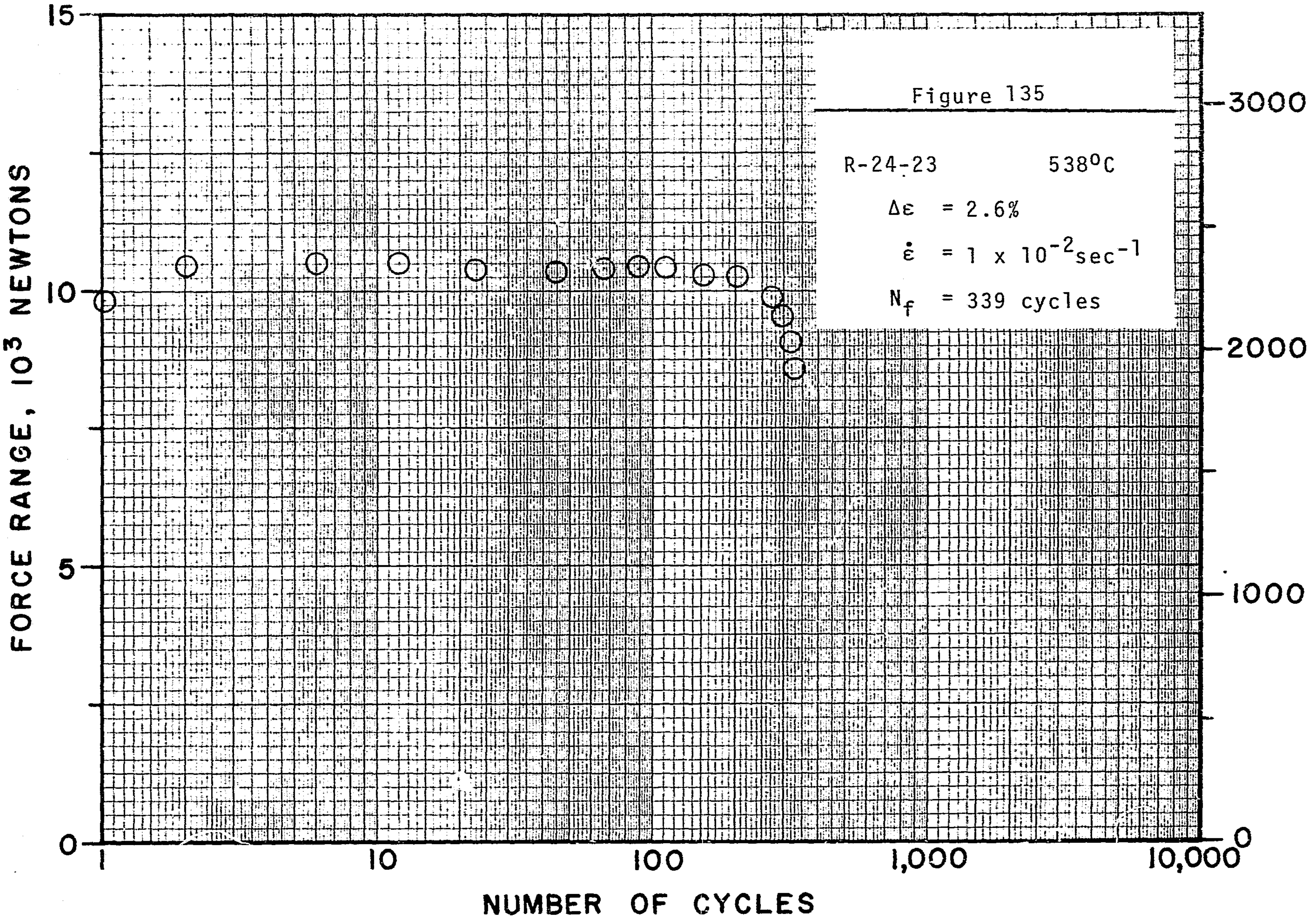


Figure 135

R-24-23 538°C

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = $1 \times 10^{-2} sec^{-1}$

N_f = 339 cycles

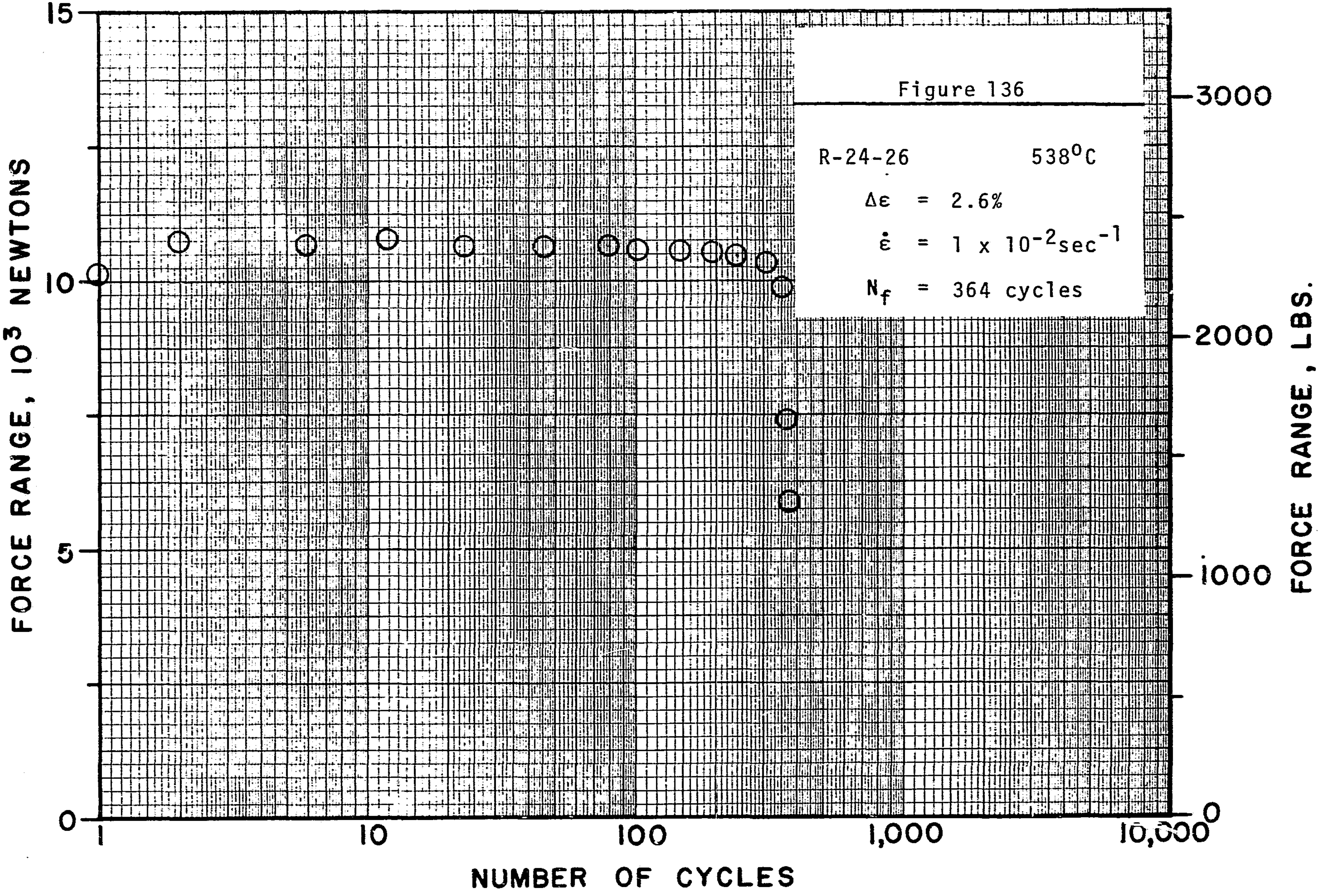


Figure 136

R-24-26 538^{0}C

$\Delta\varepsilon = 2.6\%$

$\dot{\varepsilon} = 1 \times 10^{-2} sec^{-1}$

$N_f = 364$ cycles

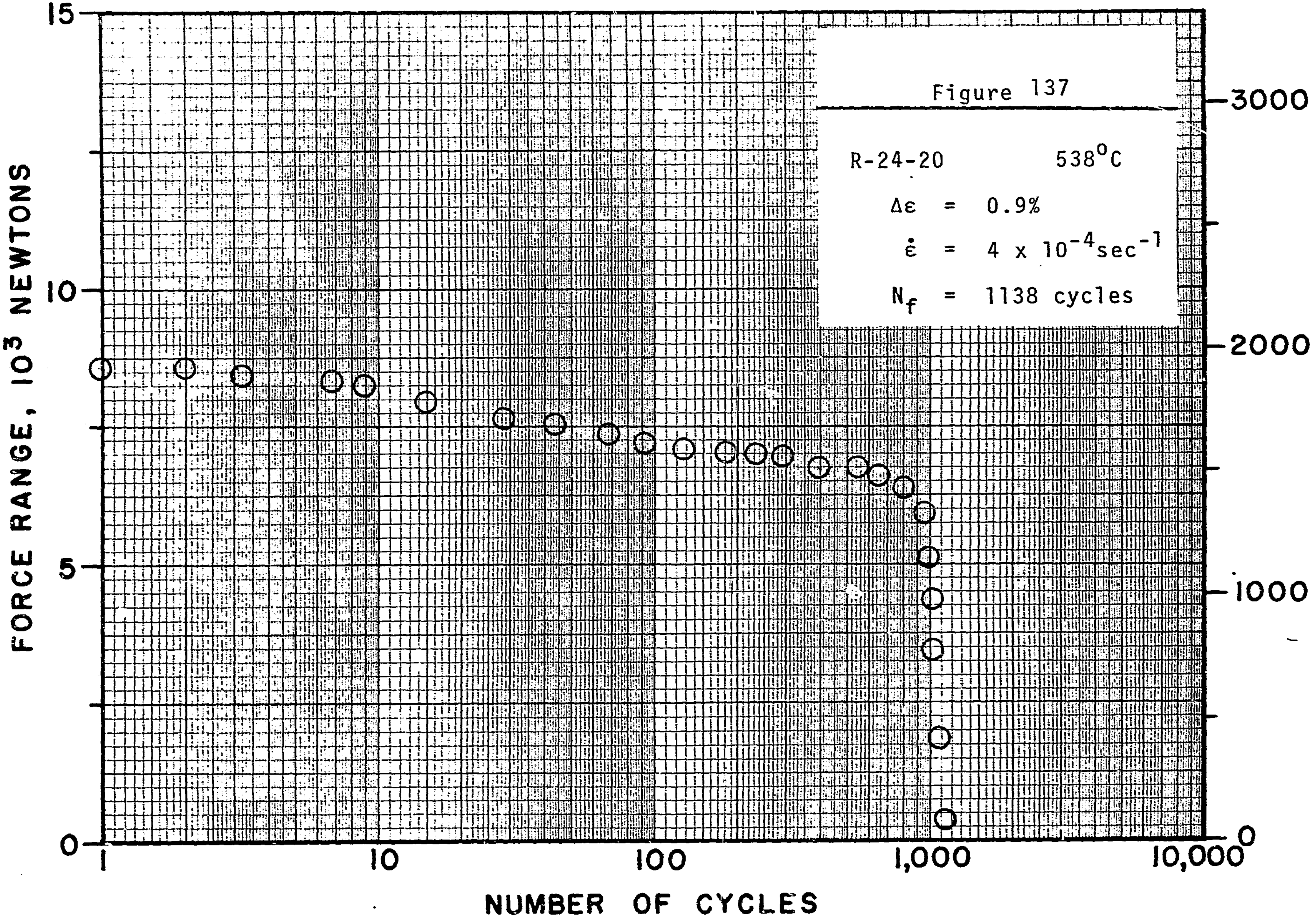


Figure 137

R-24-20 538°C

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = $4 \times 10^{-4} \text{sec}^{-1}$

N_f = 1138 cycles

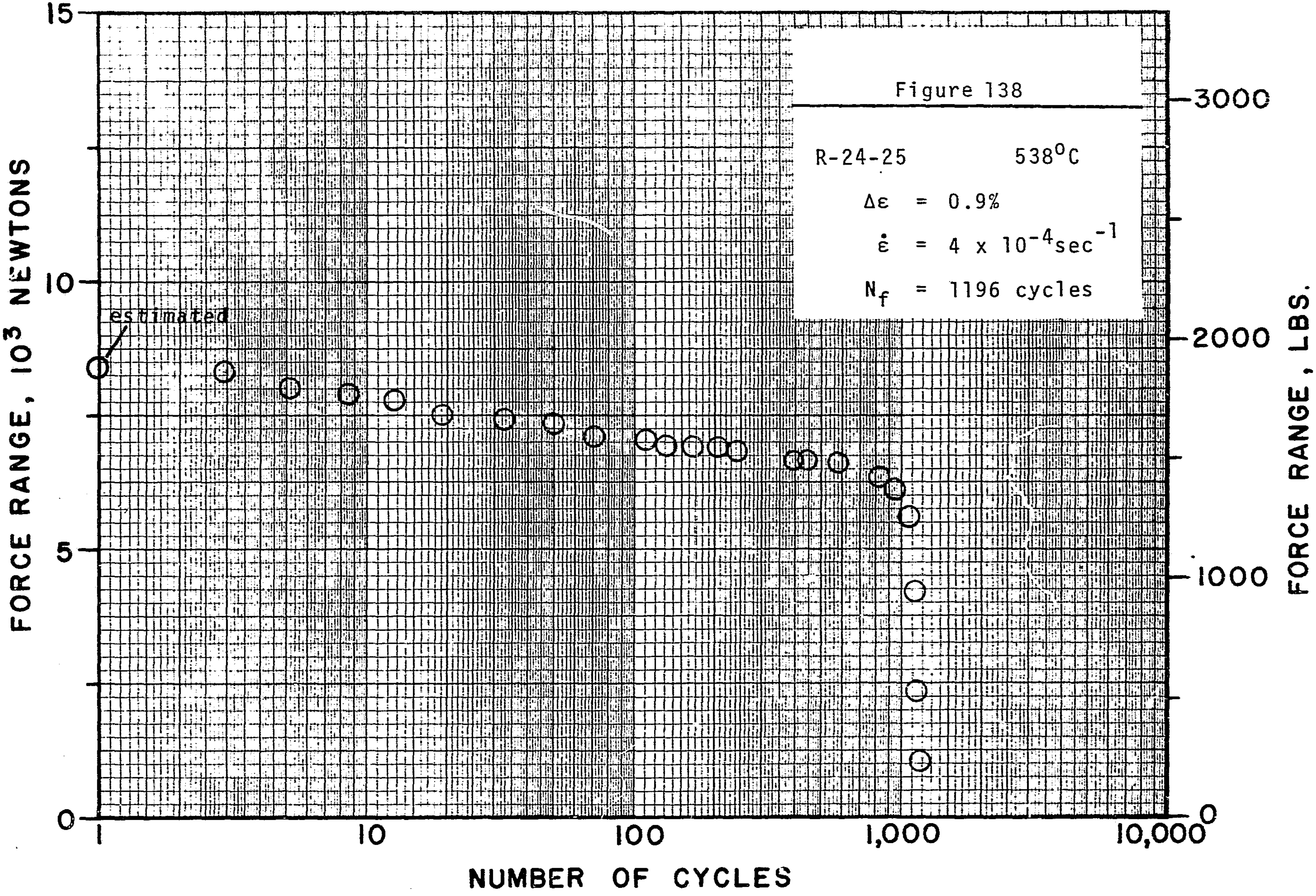


Figure 138

R-24-25 538°C

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = $4 \times 10^{-4} \text{sec}^{-1}$

N_f = 1196 cycles

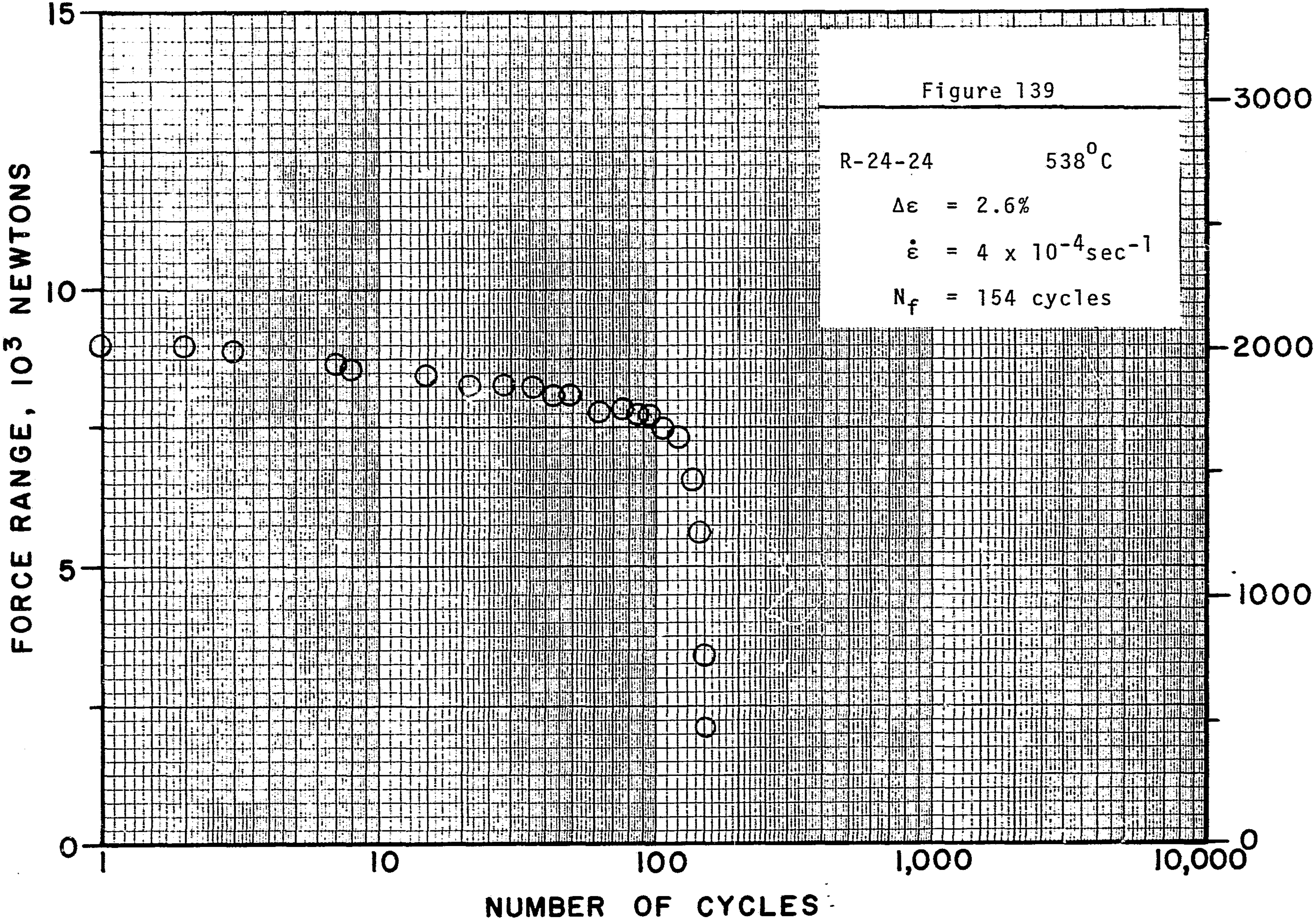


Figure 139

R-24-24 538°C

$\Delta\varepsilon = 2.6\%$

$\dot{\varepsilon} = 4 \times 10^{-4} sec^{-1}$

$N_f = 154$ cycles

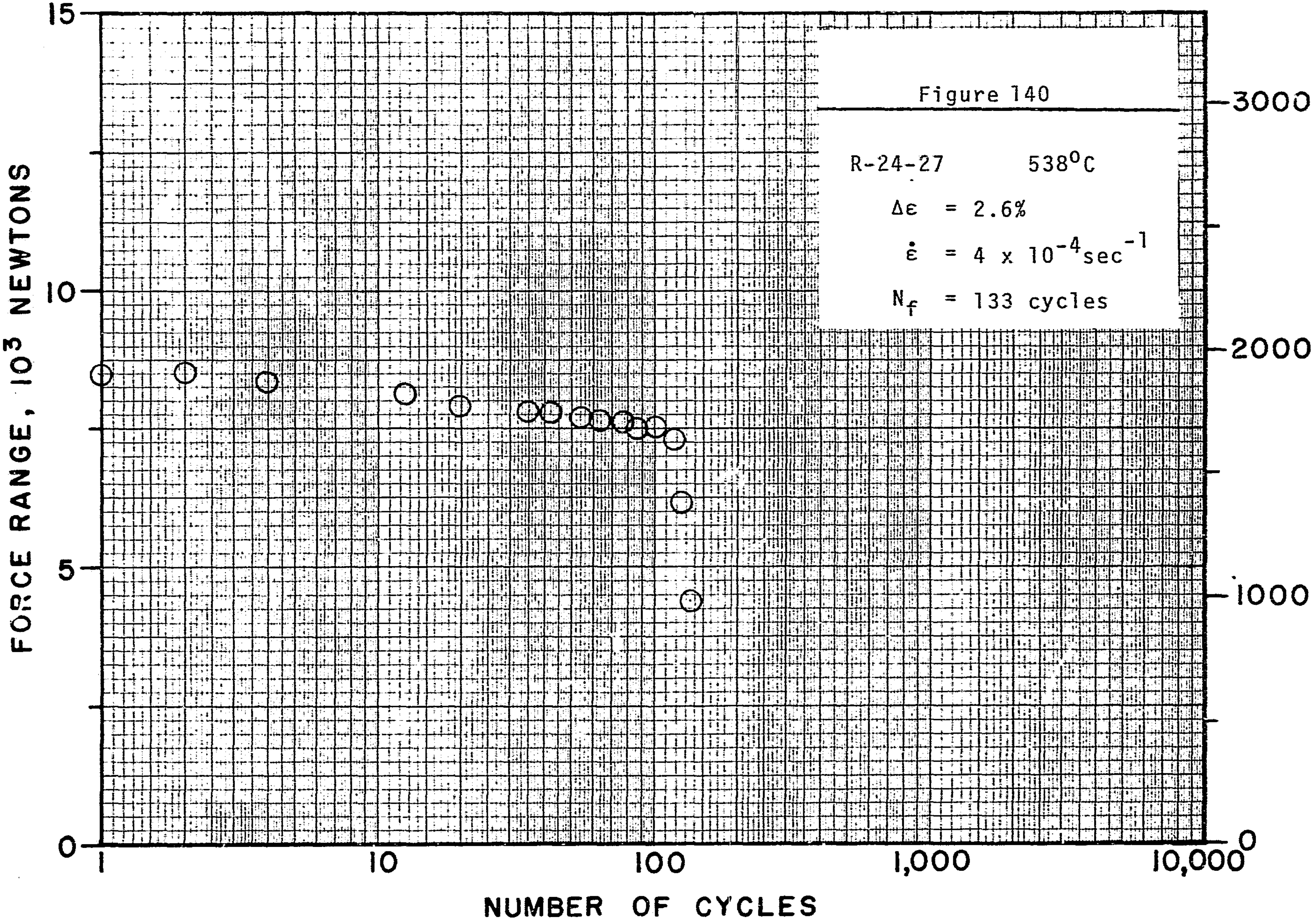


Figure 140

R-24-27 538^{o}C

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 4 x 10^{-4}sec^{-1}

N_f = 133 cycles

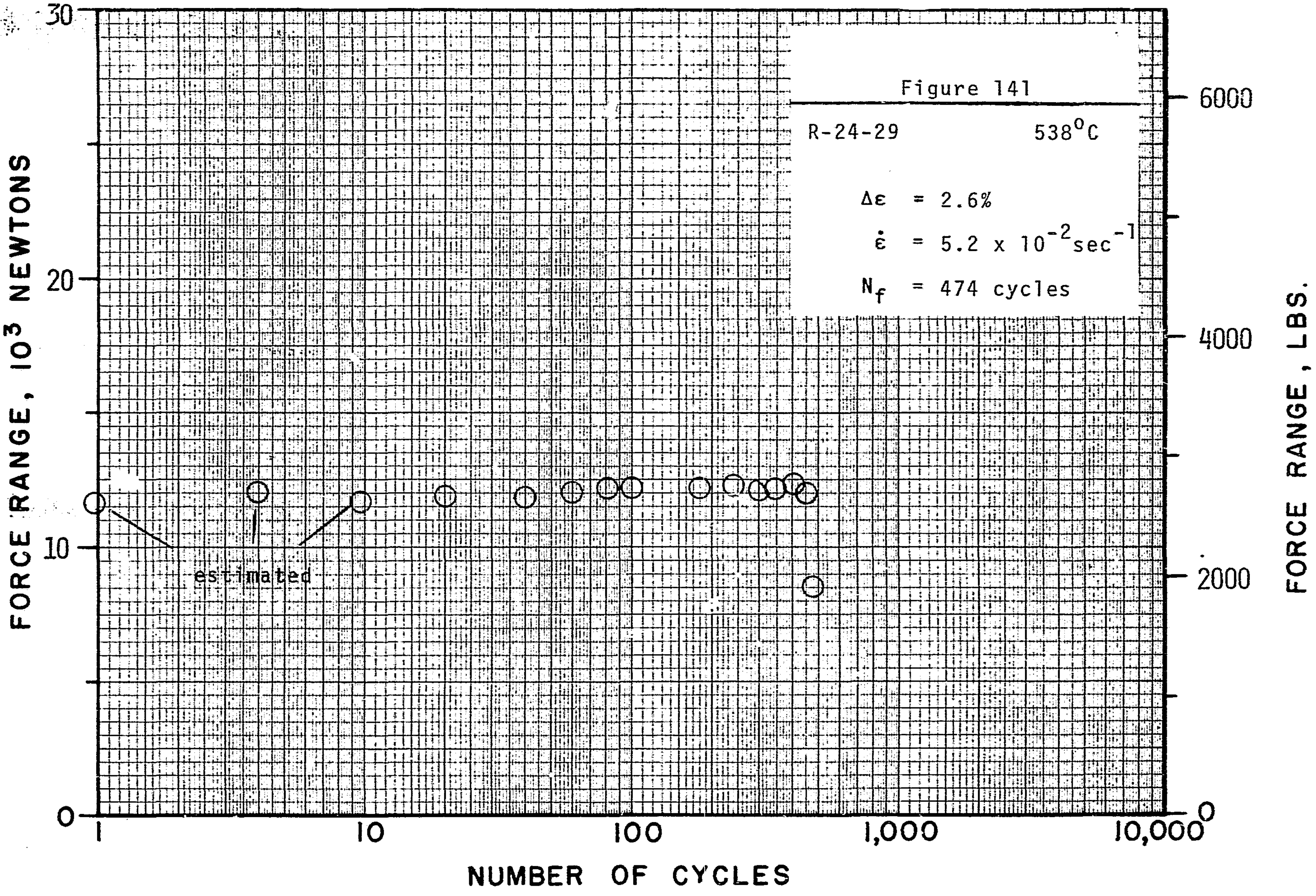


Figure 141

R-24-29 538°C

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 5.2 x 10^{-2} sec^{-1}

N_f = 474 cycles

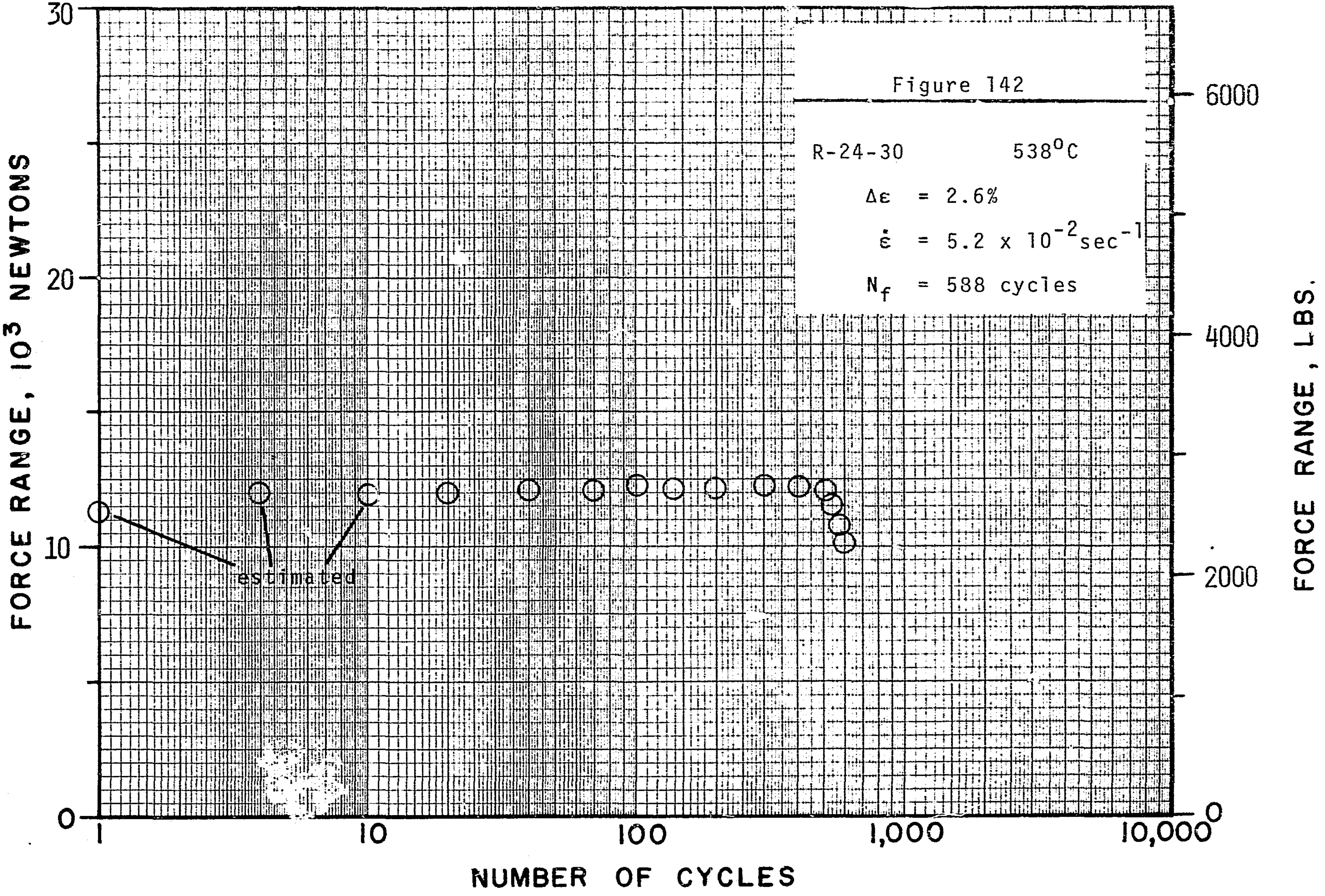


Figure 142

R-24-30 538^{0}C
$\Delta\varepsilon$ = 2.6%
$\dot{\varepsilon}$ = 5.2 x 10^{-2} sec^{-1}
N_f = 588 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
NUMBER OF CYCLES
1
10
100
1,000
10,000

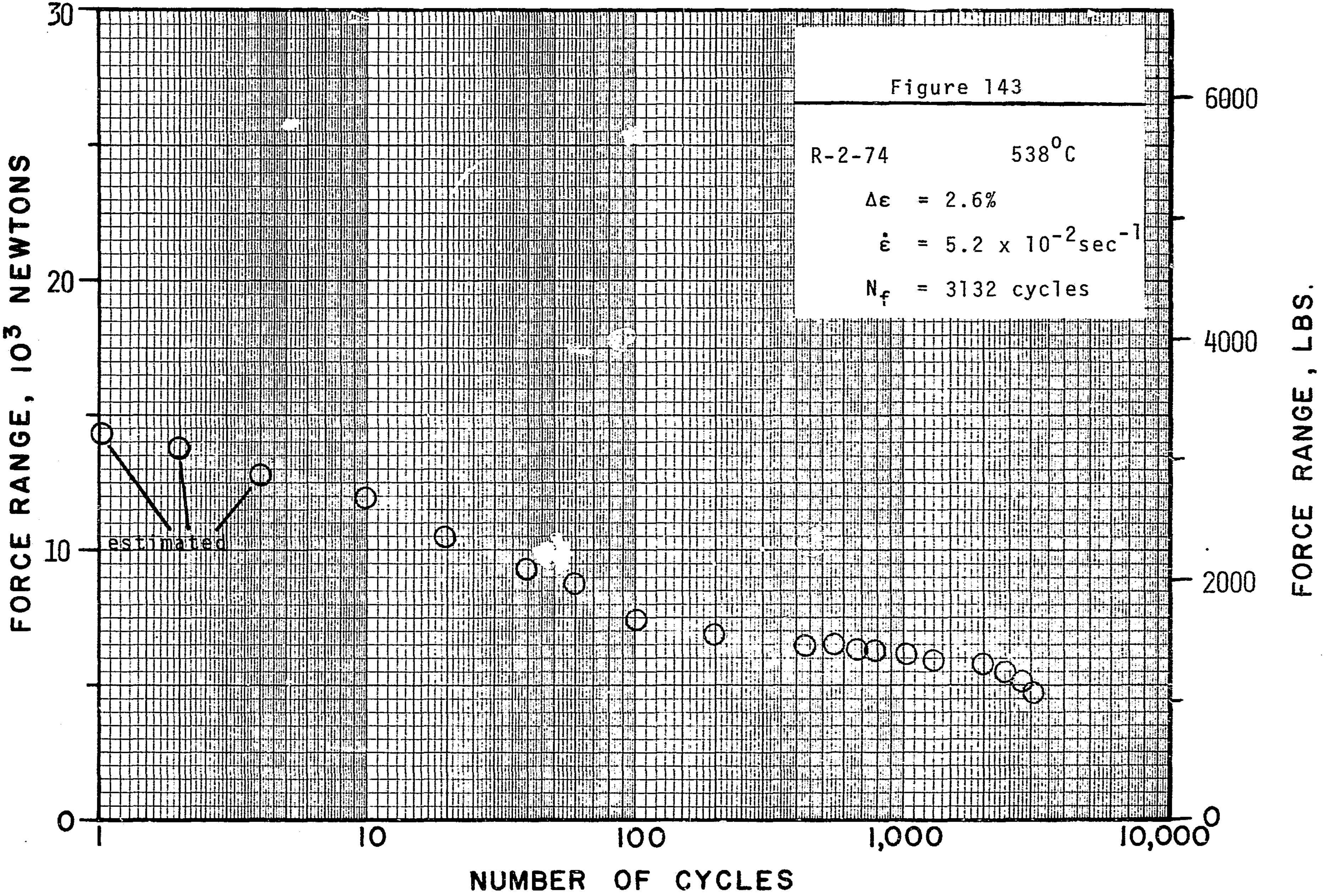


Figure 143

R-2-74
538°C
Δε = 2.6%
$\dot{\varepsilon}$ = 5.2 x 10^{-2} sec^{-1}
N_f = 3132 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
NUMBER OF CYCLES
1
10
100
1,000
10,000

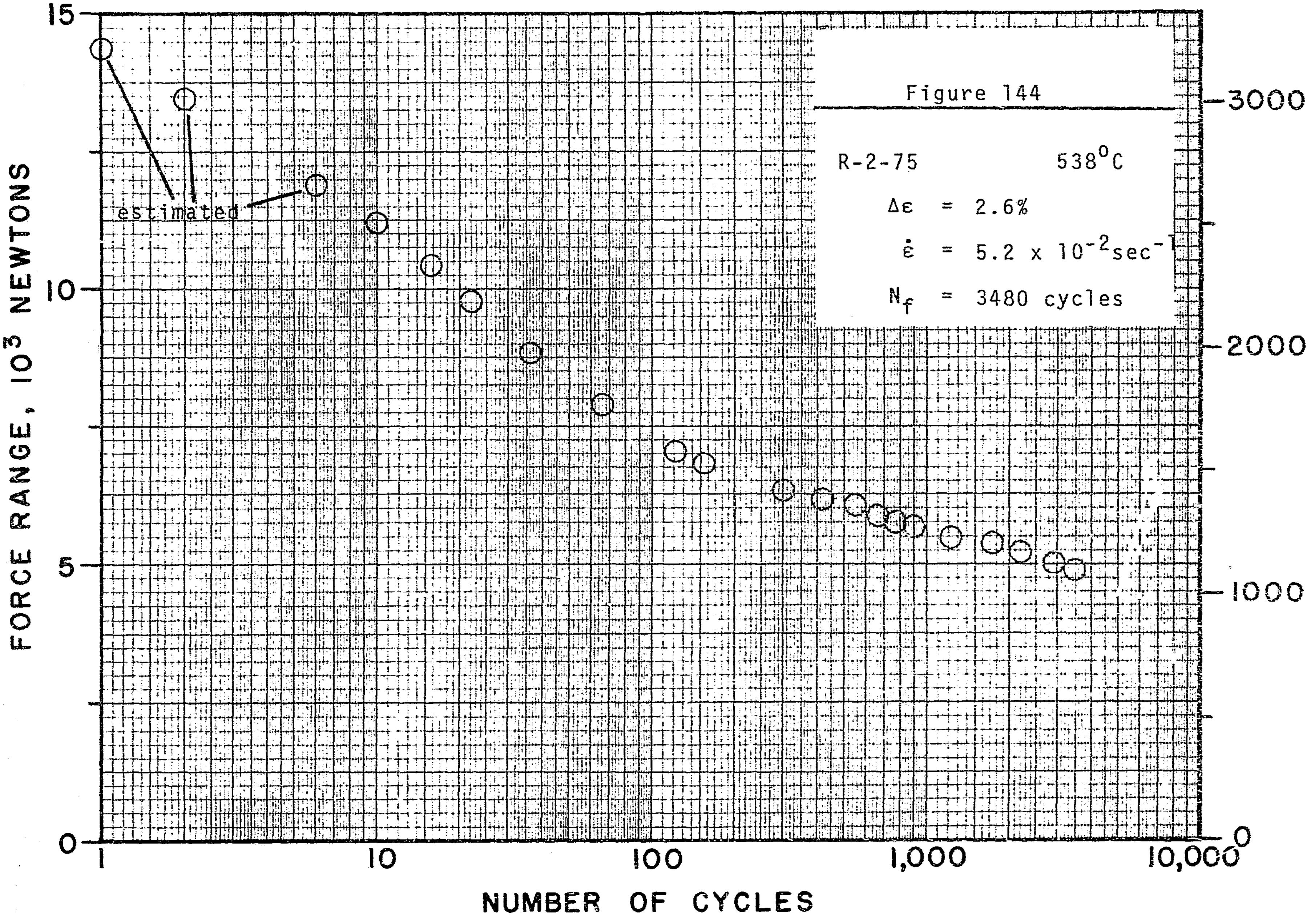


Figure 144

R-2-75 538^{0}C

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 5.2 x 10^{-2}sec^{-1}

N_f = 3480 cycles

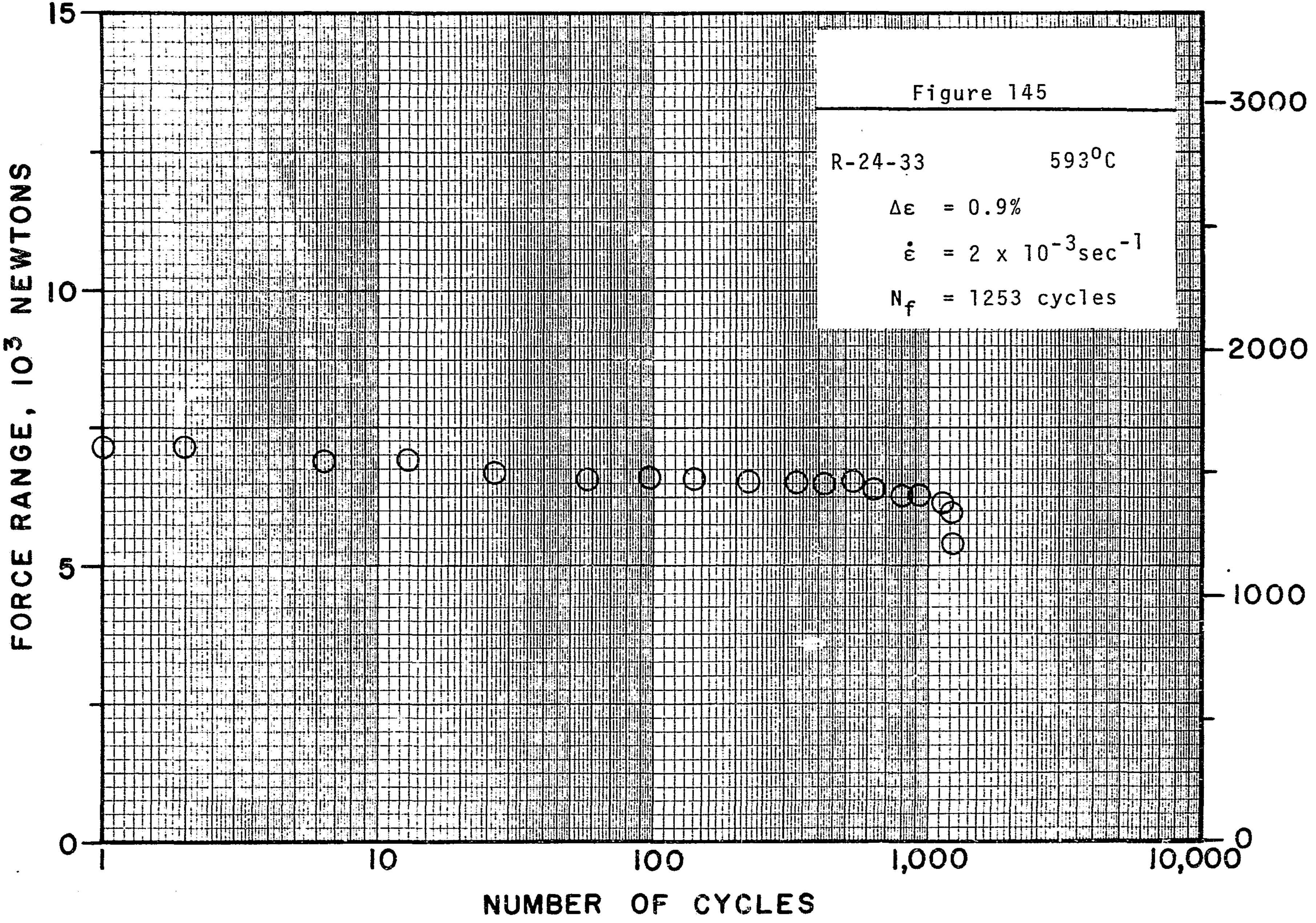


Figure 145

R-24-33 593^{o}C

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 1253 cycles

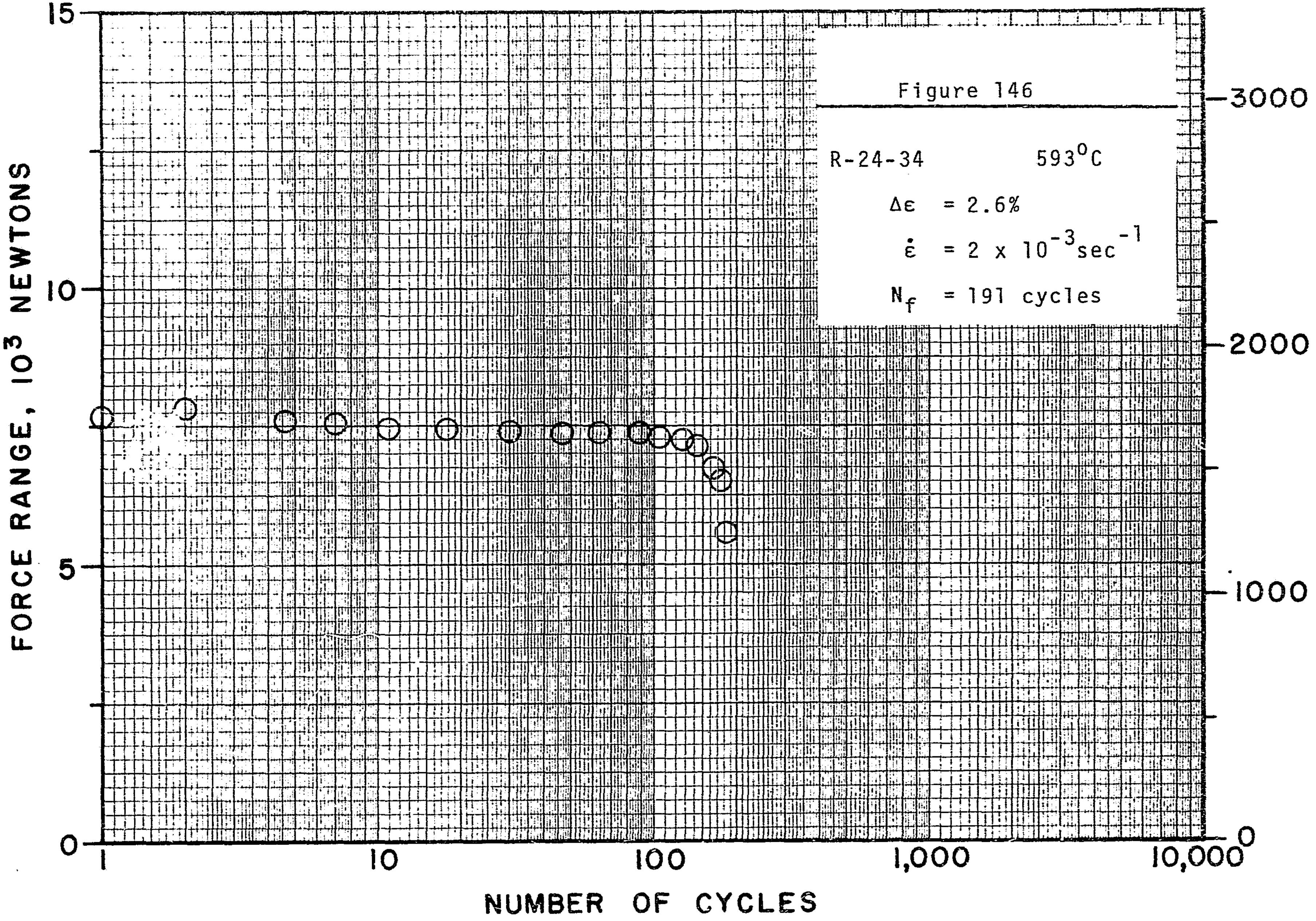


Figure 146

R-24-34 593^{0}C

$\Delta\epsilon$ = 2.6%

$\dot{\epsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 191 cycles

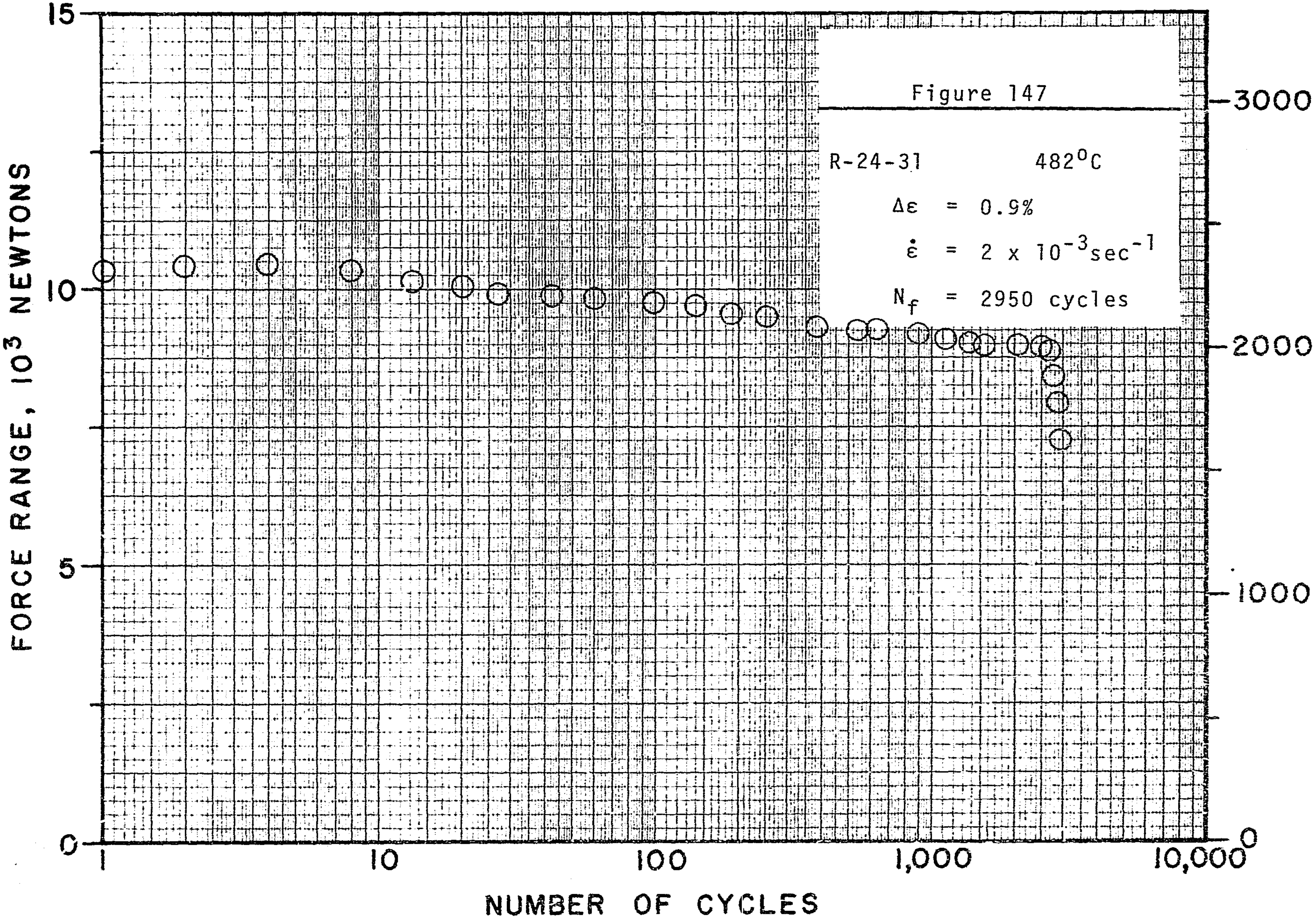


Figure 147

R-24-31 482°C

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 2950 cycles

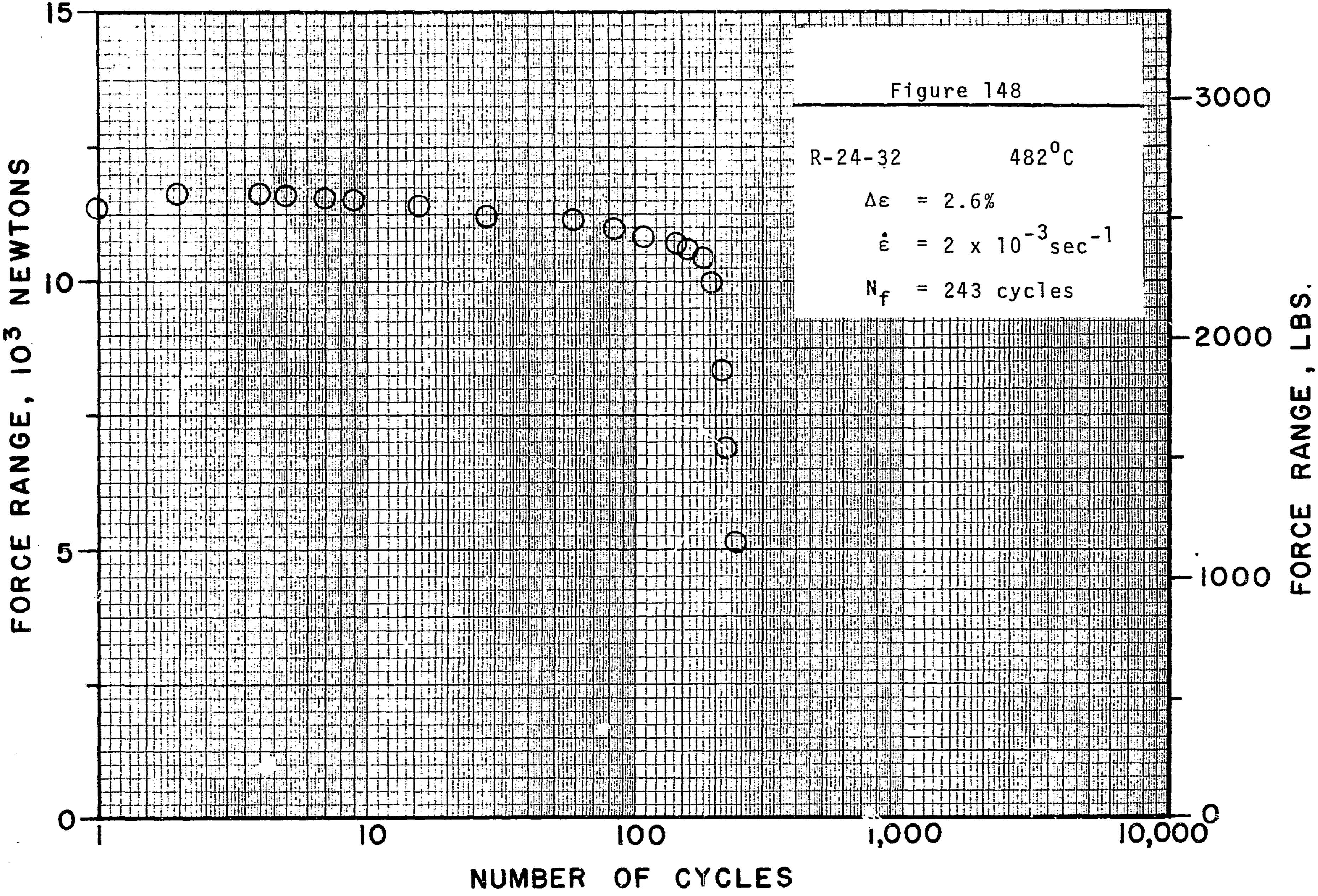


Figure 148

R-24-32 482°C

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 243 cycles

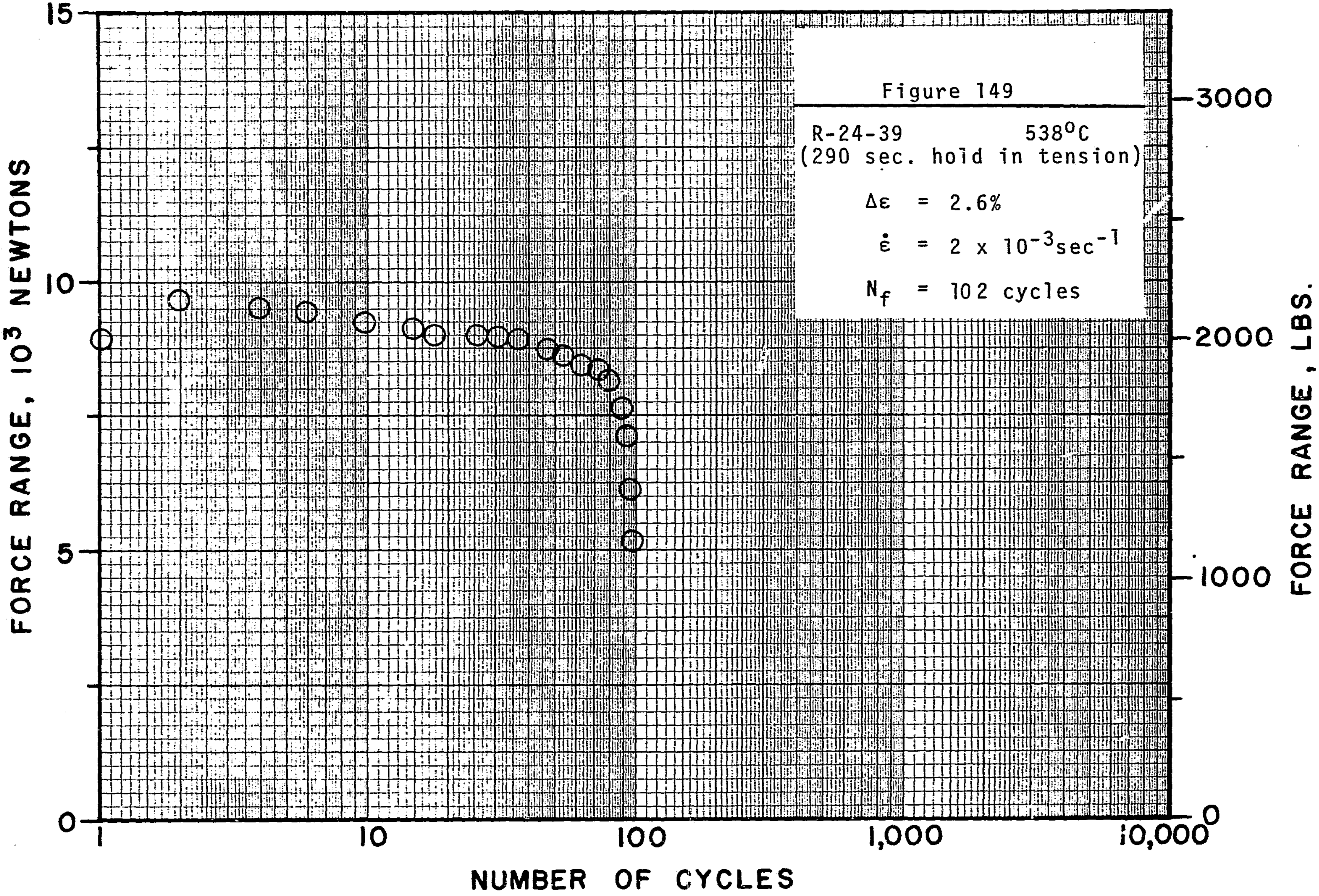


Figure 149

R-24-39 538°C
(290 sec. hold in tension)

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 102 cycles

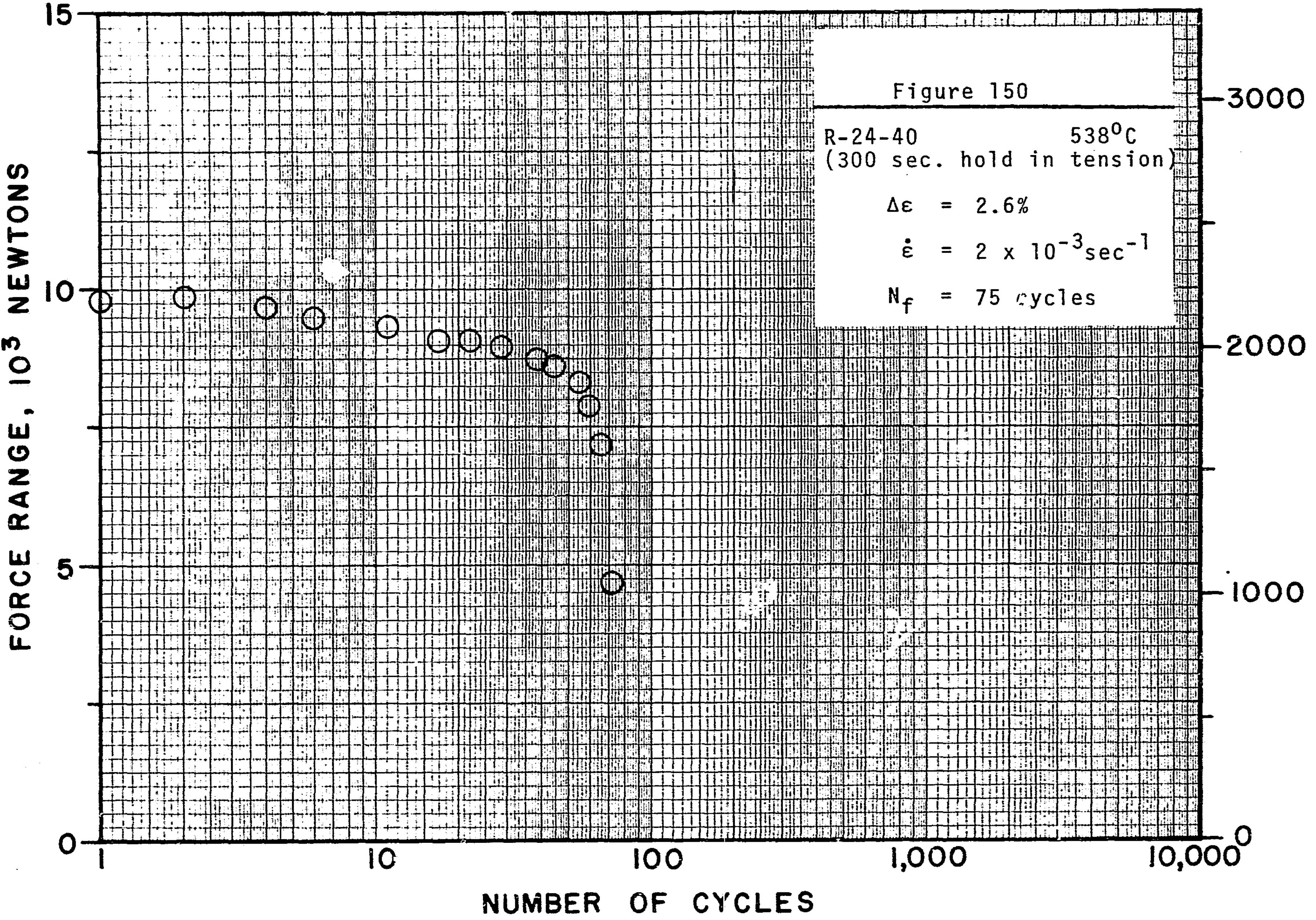


Figure 150

R-24-40 538^{0}C
(300 sec. hold in tension)

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 75 cycles

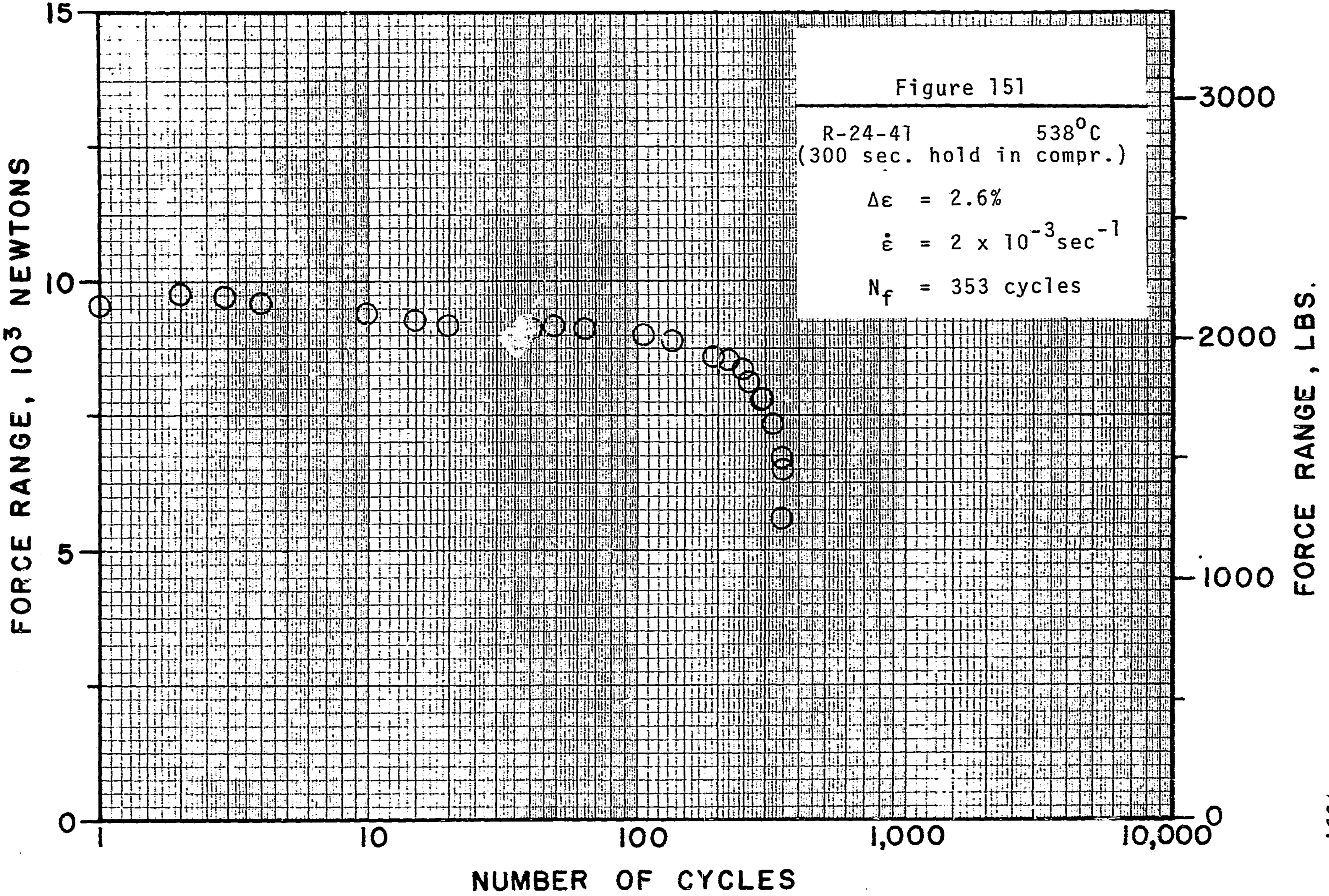


Figure 151
R-24-41 538°C
(300 sec. hold in compr.)
Δε = 2.6%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 353 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

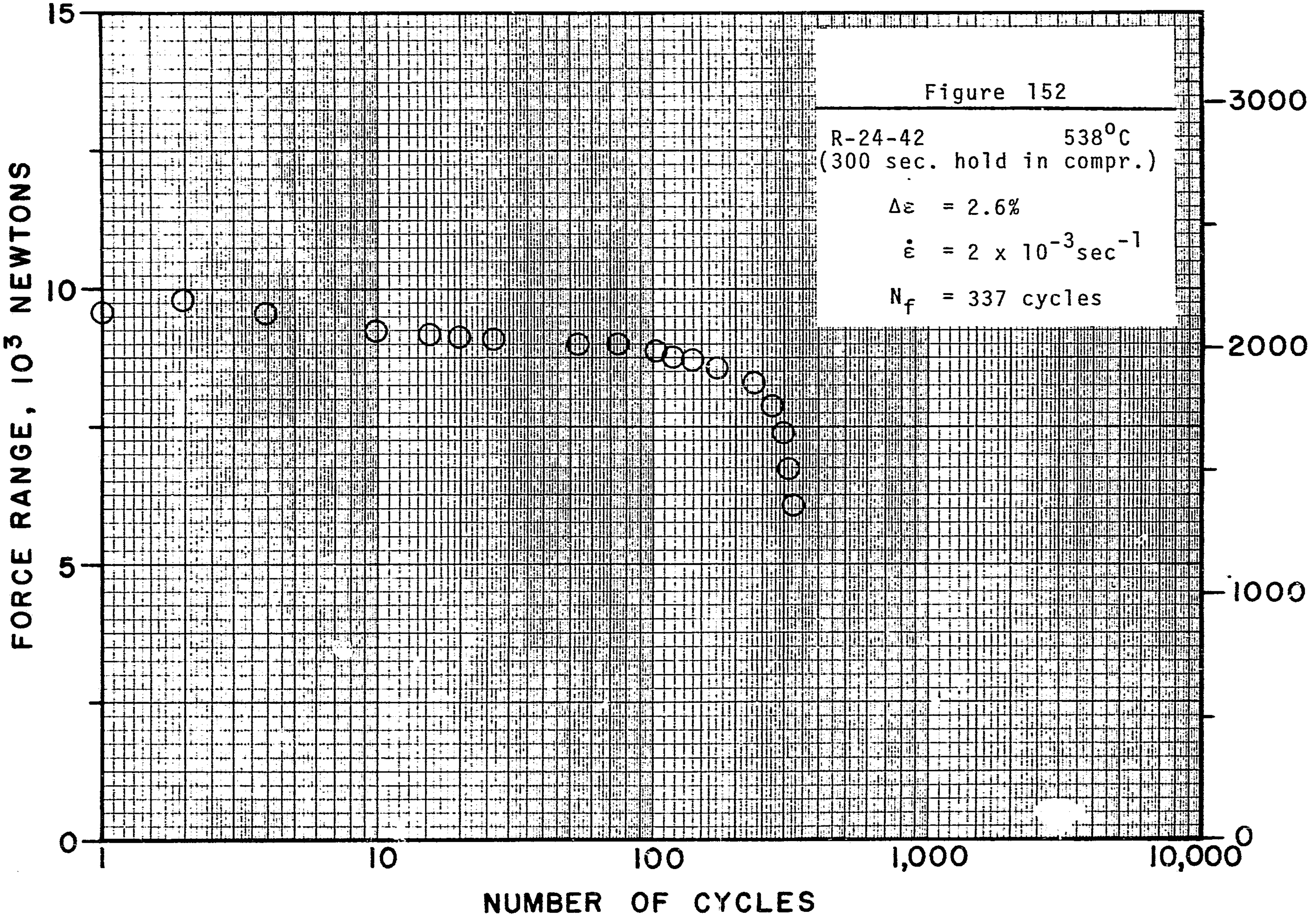


Figure 152

R-24-42 538°C
(300 sec. hold in compr.)

$\Delta\varepsilon$ = 2.6%

$\dot{\varepsilon}$ = 2 x $10^{-3}sec^{-1}$

N_f = 337 cycles

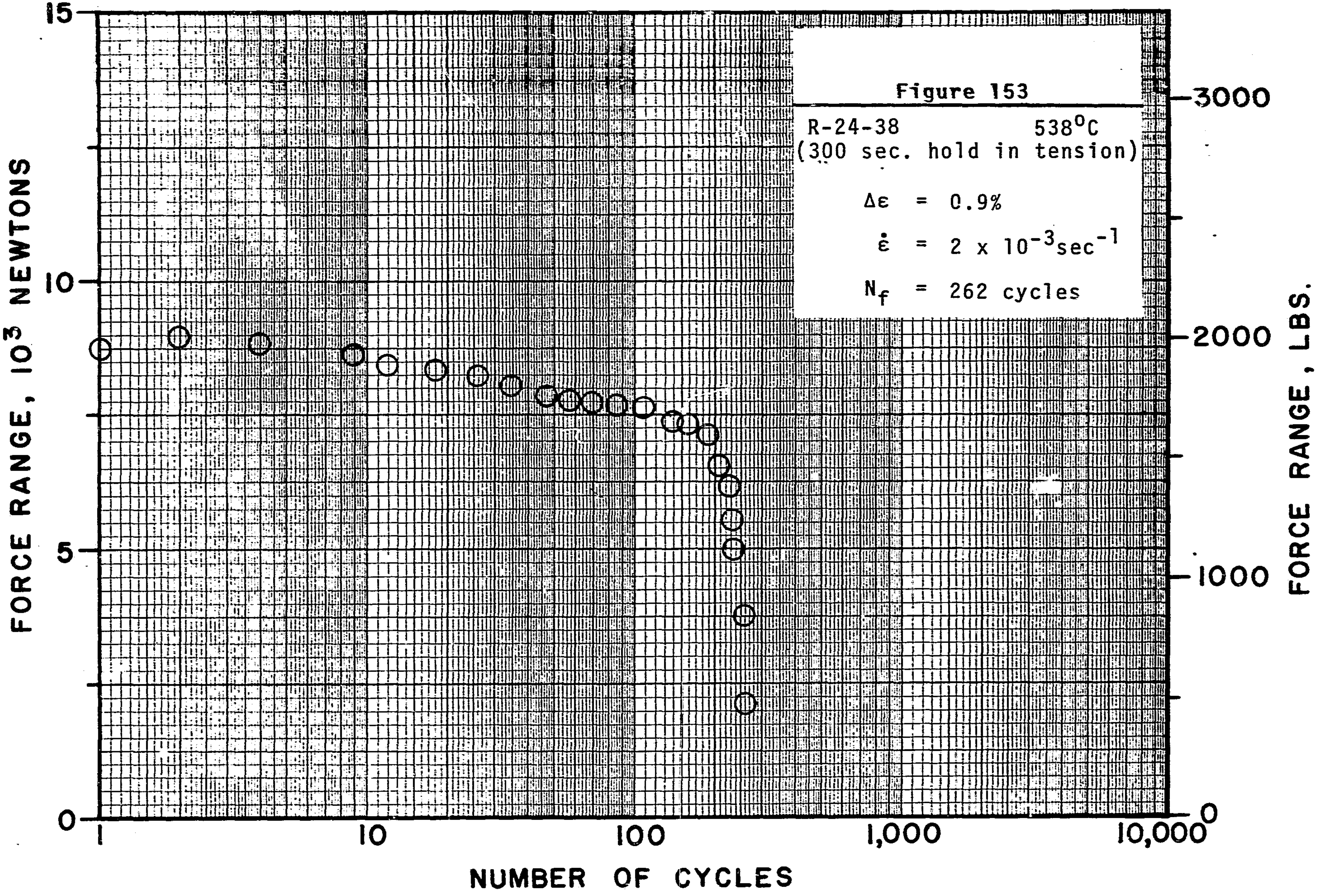


Figure 153

R-24-38 538°C
(300 sec. hold in tension)

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 262 cycles

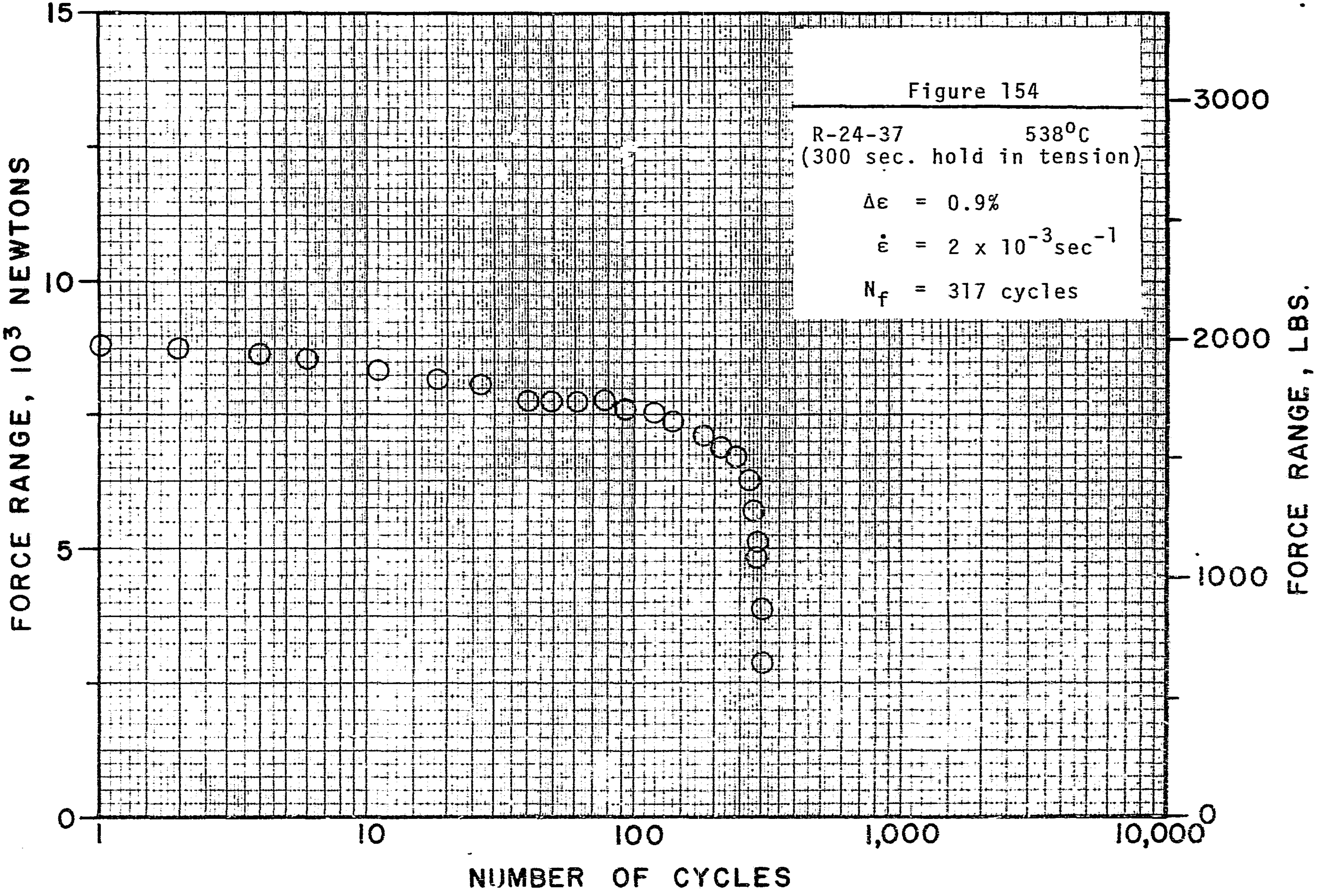


Figure 154

R-24-37 538°C
(300 sec. hold in tension)

$\Delta\varepsilon$ = 0.9%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 317 cycles

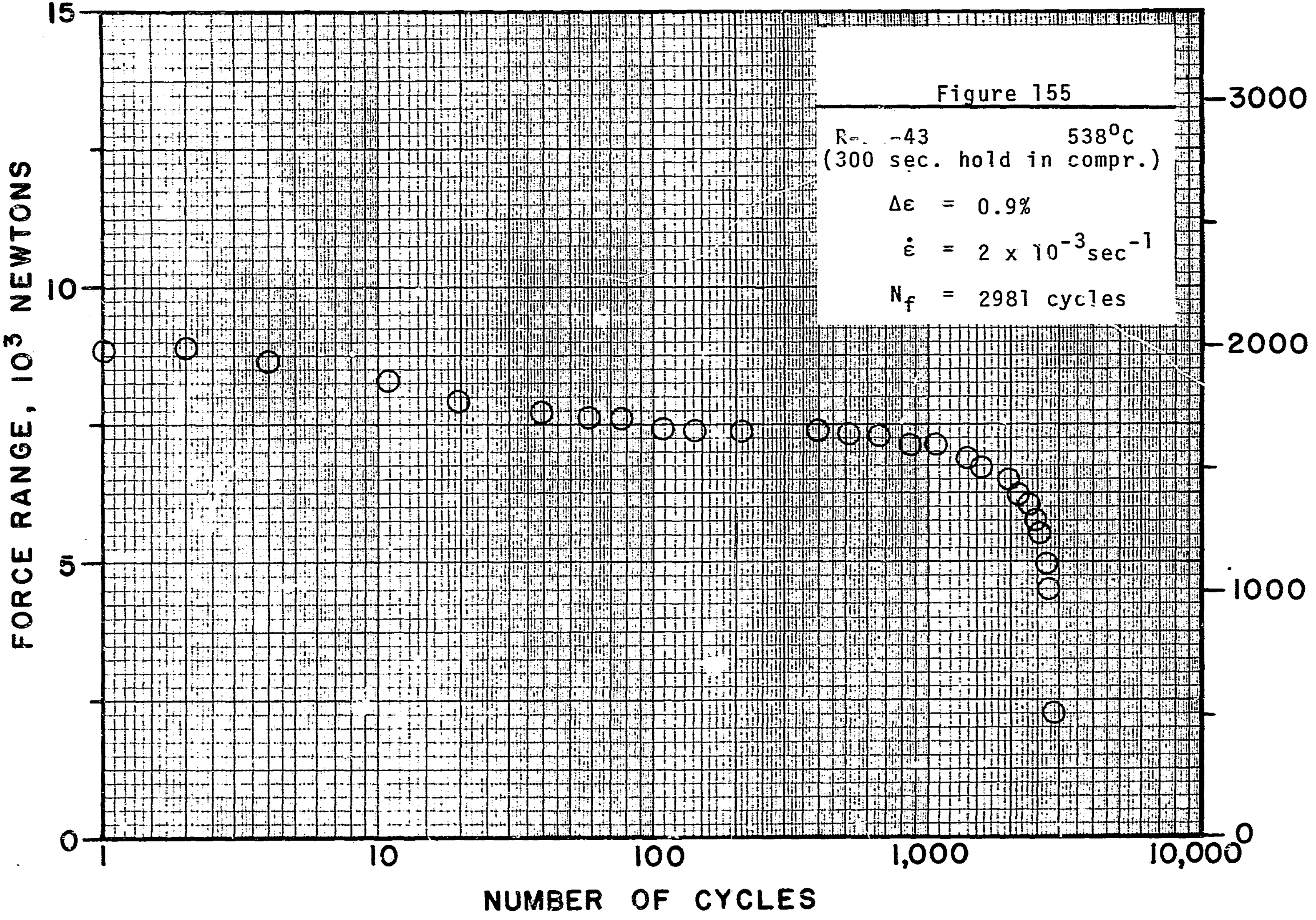


Figure 155

R- -43 538°C
(300 sec. hold in compr.)

$\Delta\varepsilon = 0.9\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 2981$ cycles

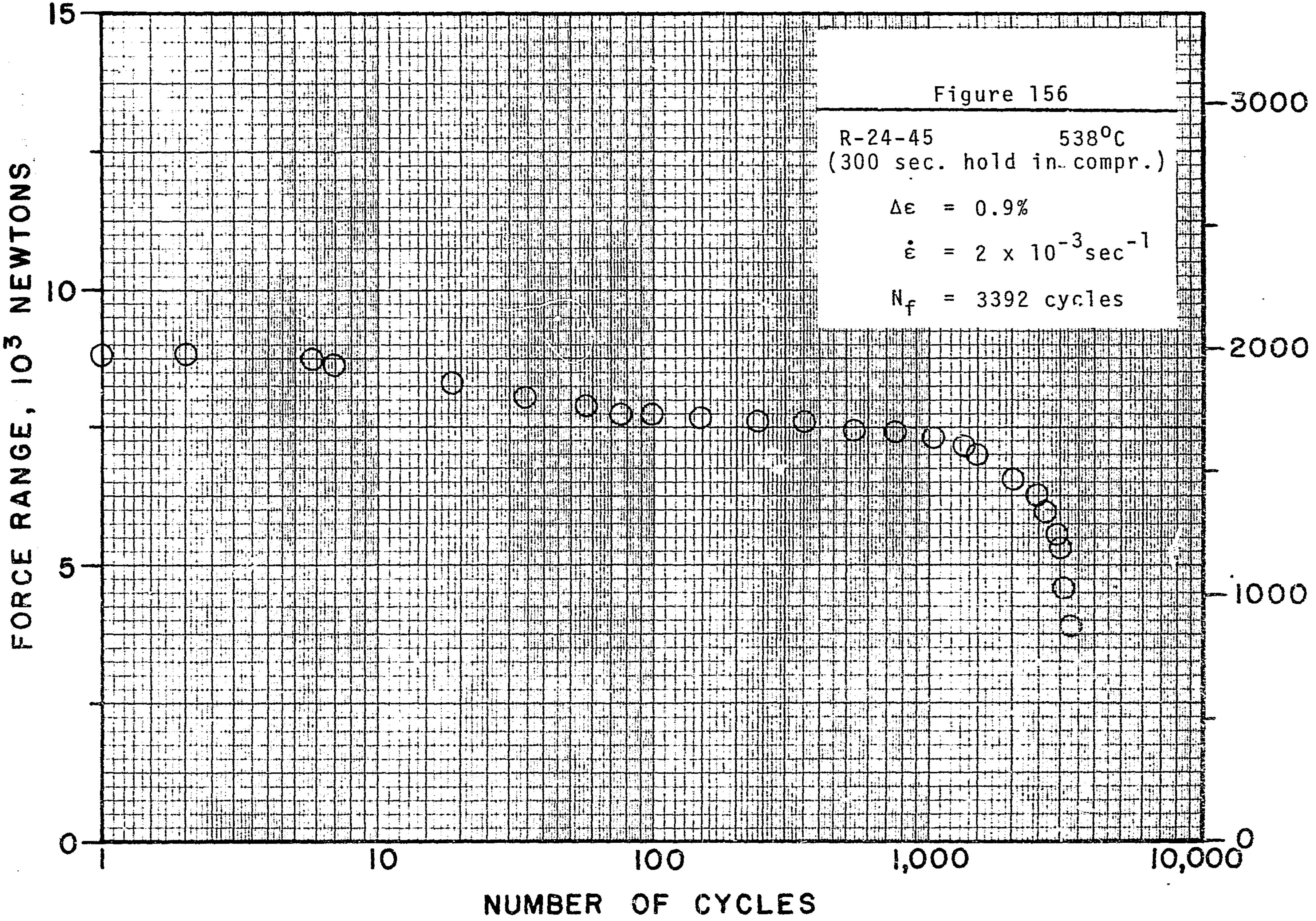


Figure 156

R-24-45 538°C
(300 sec. hold in compr.)

$\Delta\varepsilon = 0.9\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 3392$ cycles

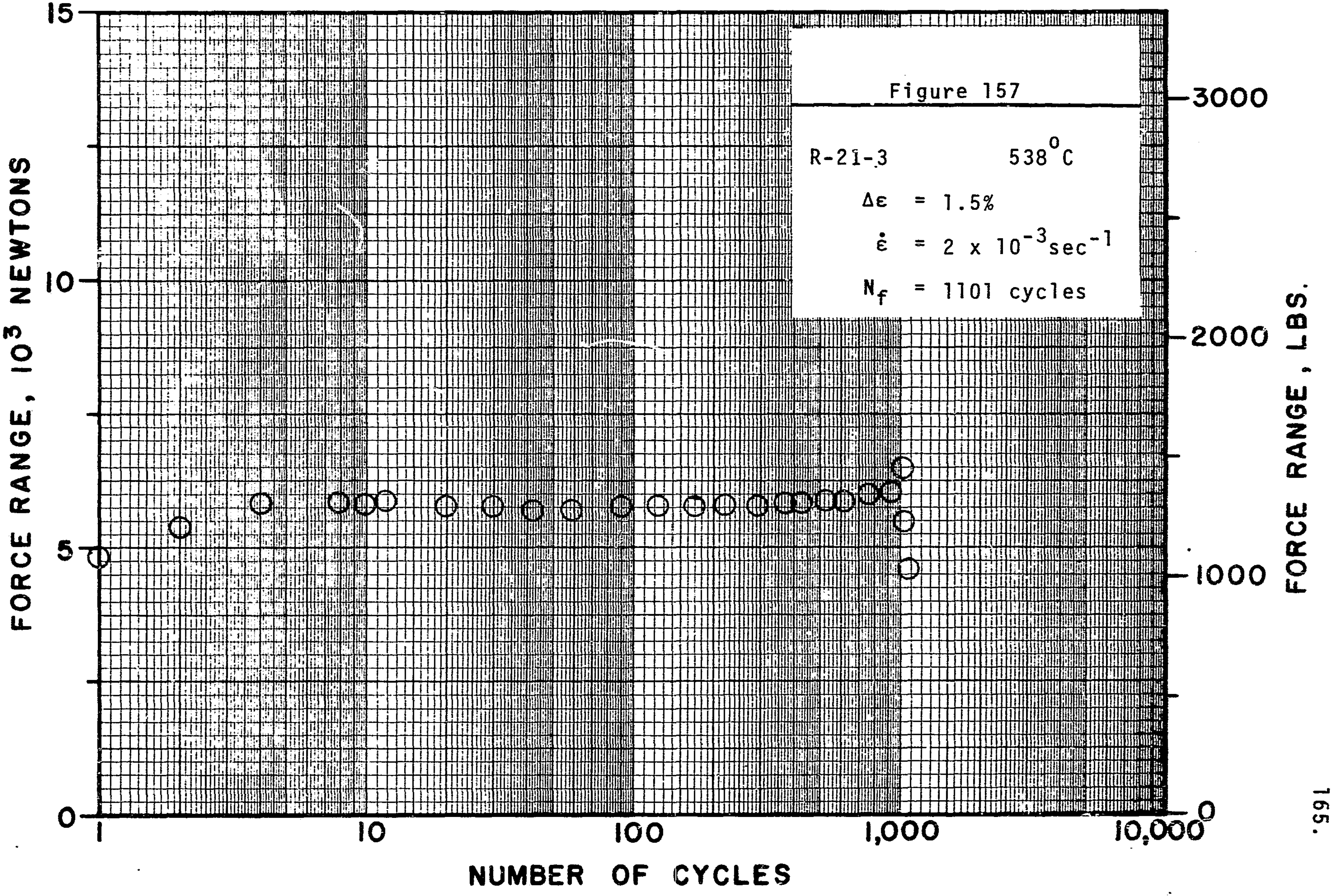


Figure 157

R-21-3 538°C
Δε = 1.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 1101 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

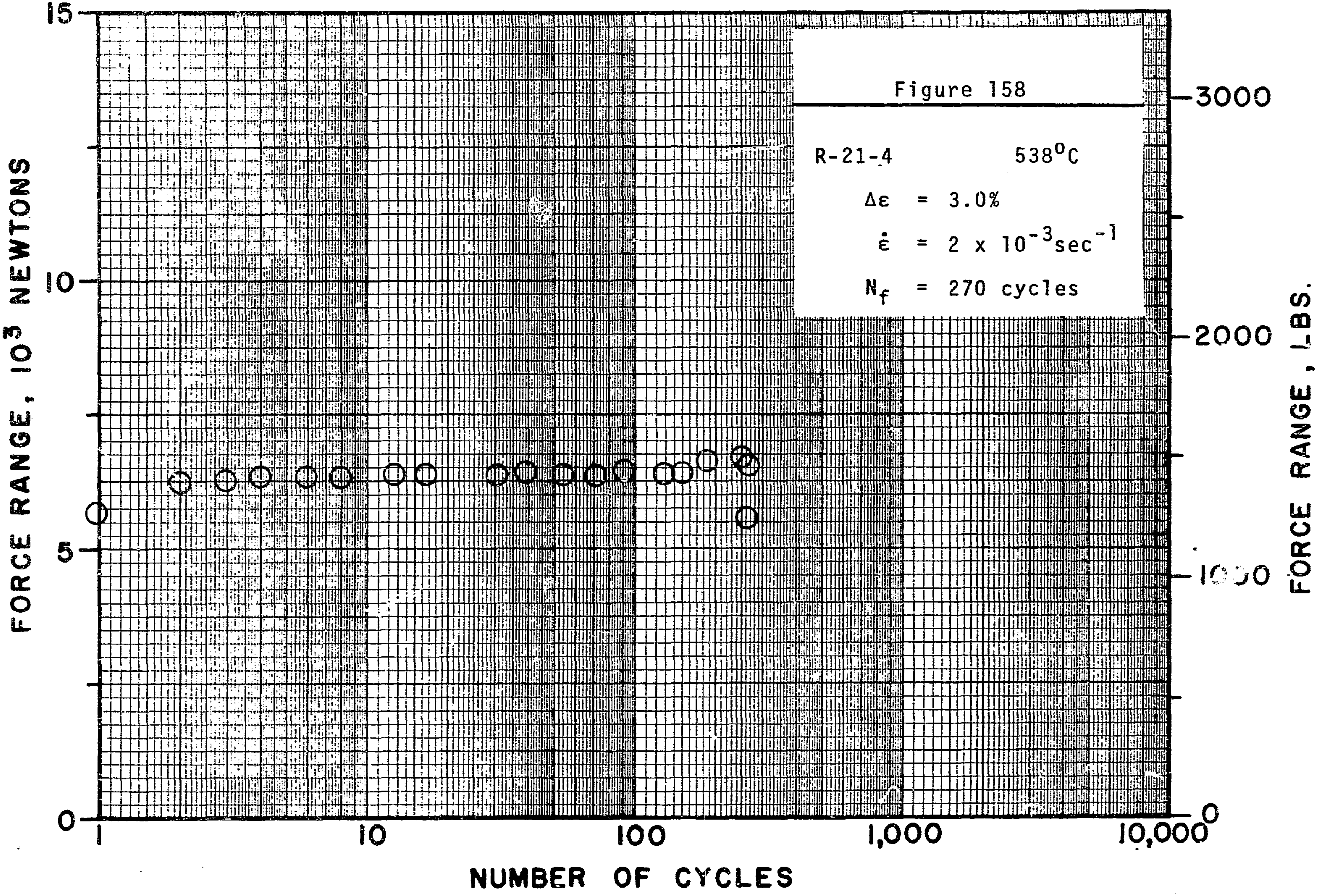


Figure 158

R-21-4 538^{0}C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}

N_f = 270 cycles

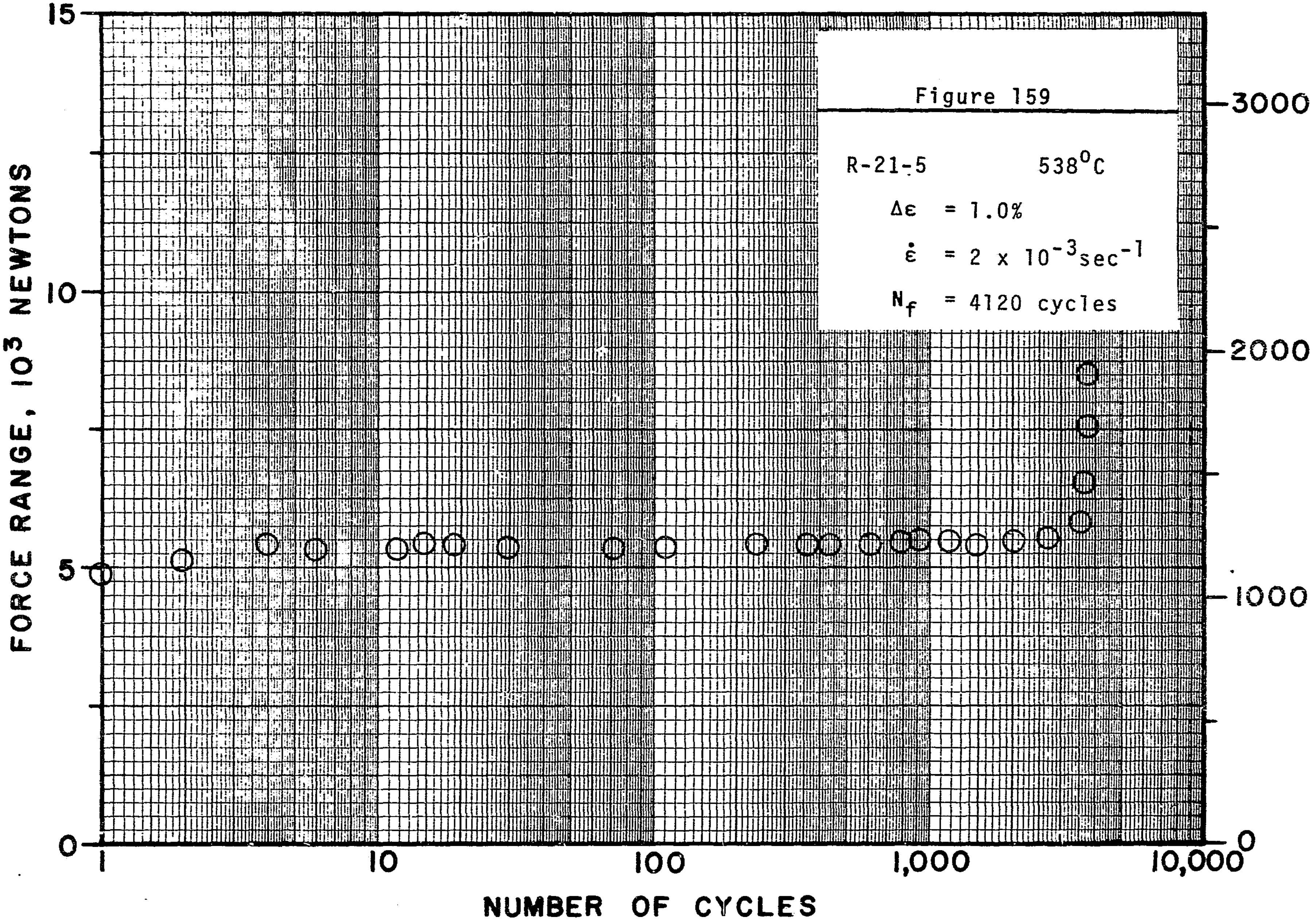


Figure 159

R-21-5 538^{0}C
$\Delta\varepsilon$ = 1.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 4120 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

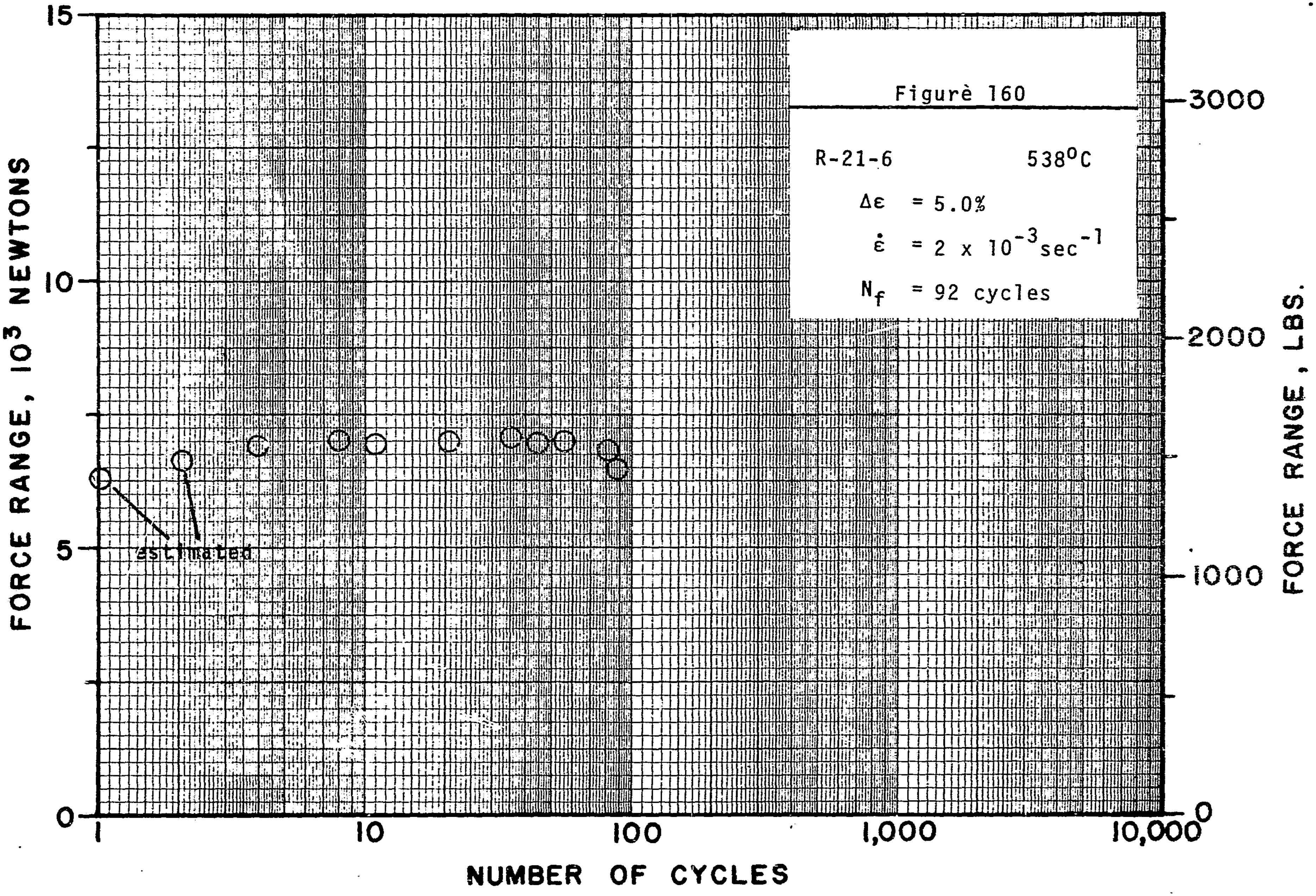


Figure 160

R-21-6
538°C
Δε = 5.0%
ε̇ = 2 x 10-3 sec-1
Nf = 92 cycles
estimated
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

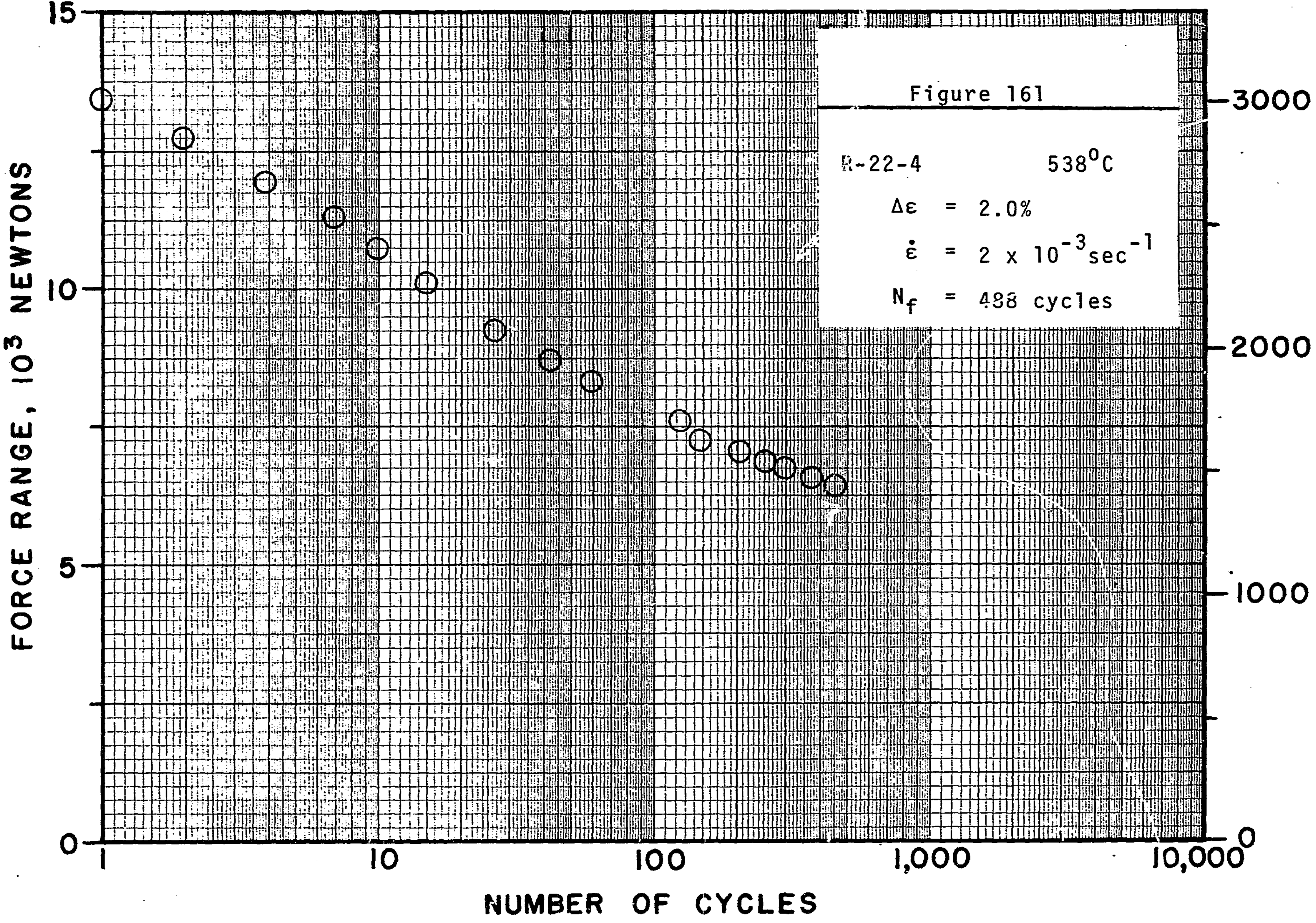


Figure 161

R-22-4
538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 488 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

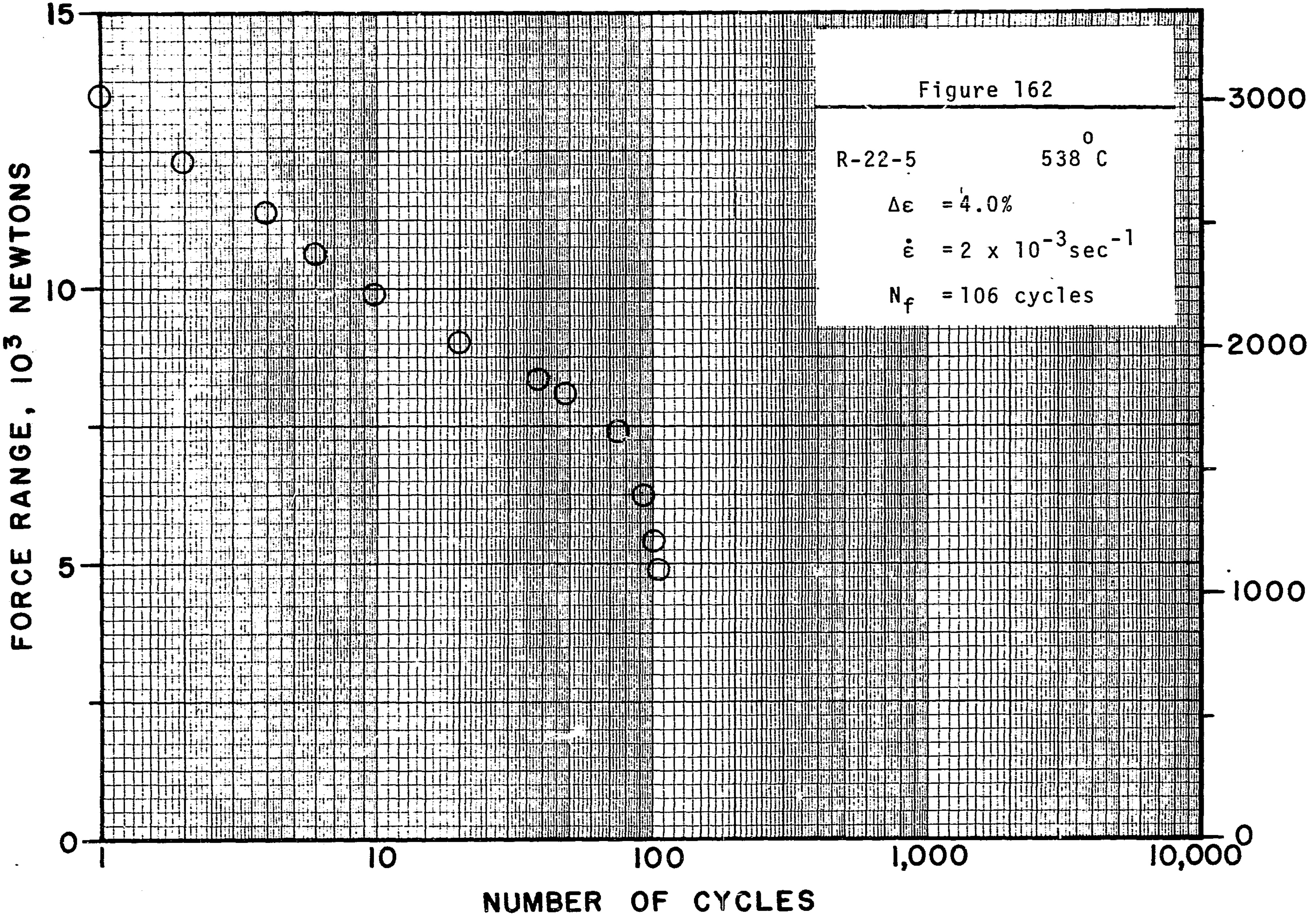


Figure 162

R-22-5 538 °C

$\Delta\varepsilon$ = 4.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 106 cycles

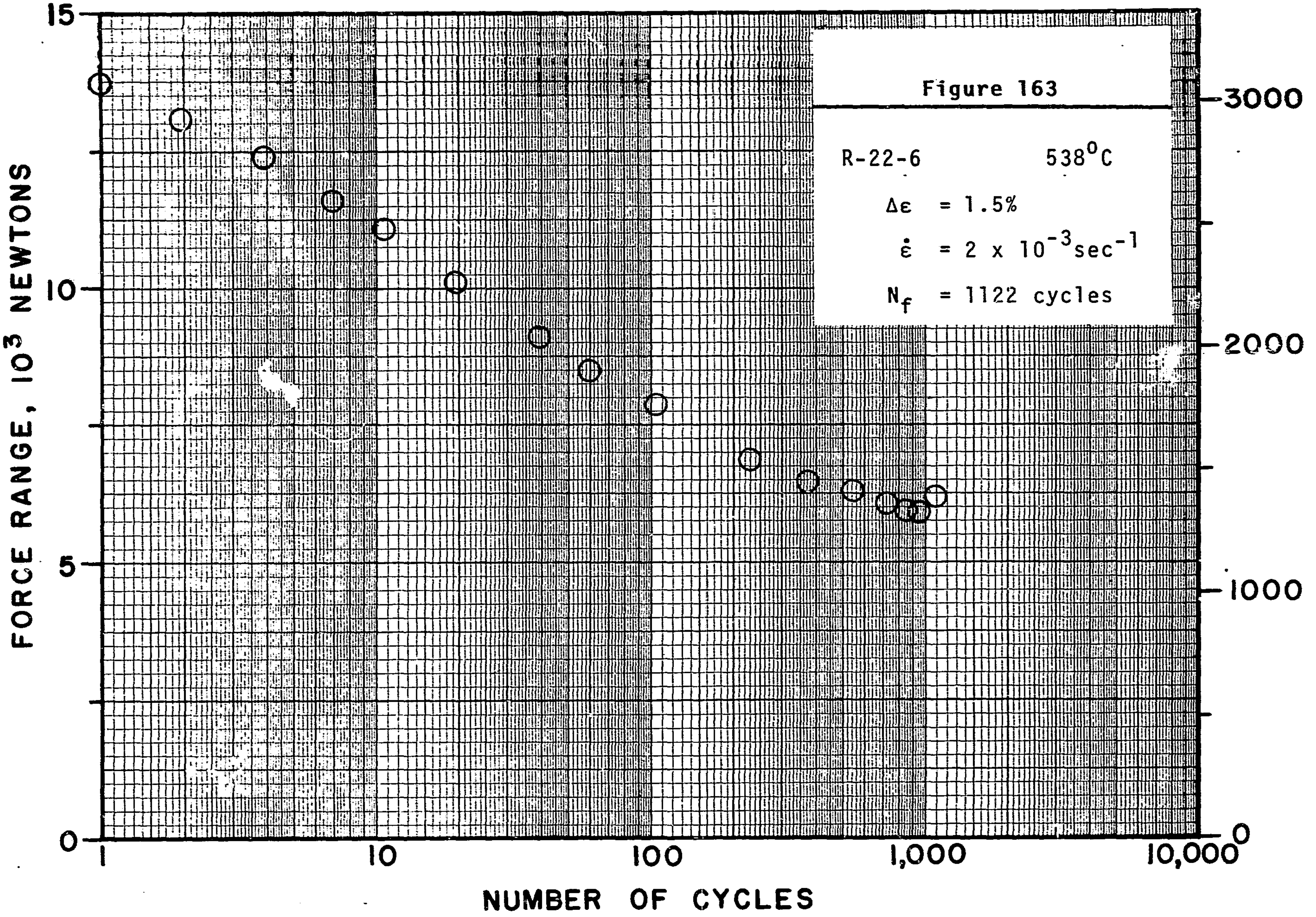

15
10
5
0
FORCE RANGE, 10^3 NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES
R-22-6
538°C
$\Delta\varepsilon$ = 1.5%
$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$
N_f = 1122 cycles

Figure 163

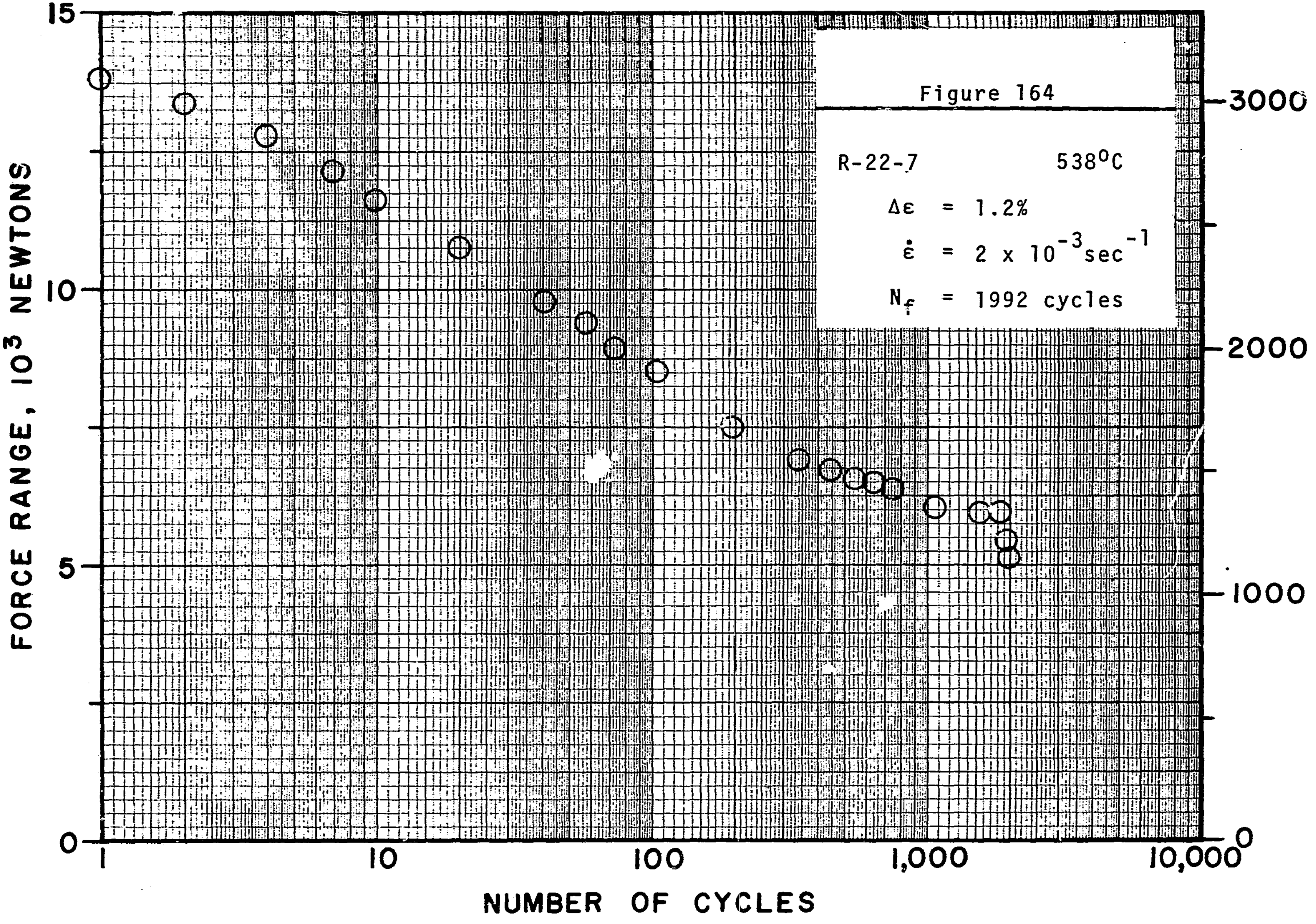


Figure 164

R-22-7
538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 1992 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

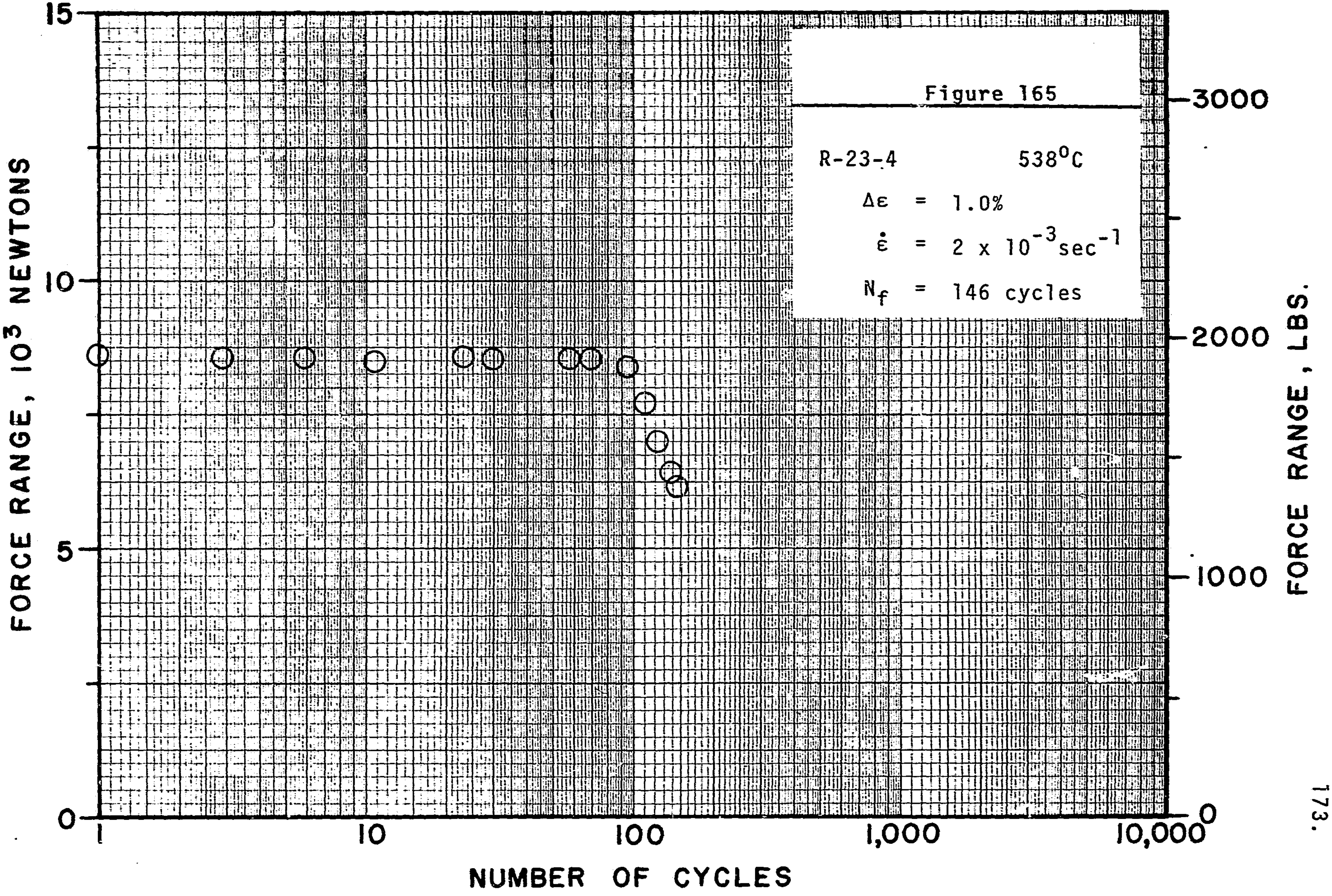


Figure 165
R-23-4 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 146 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

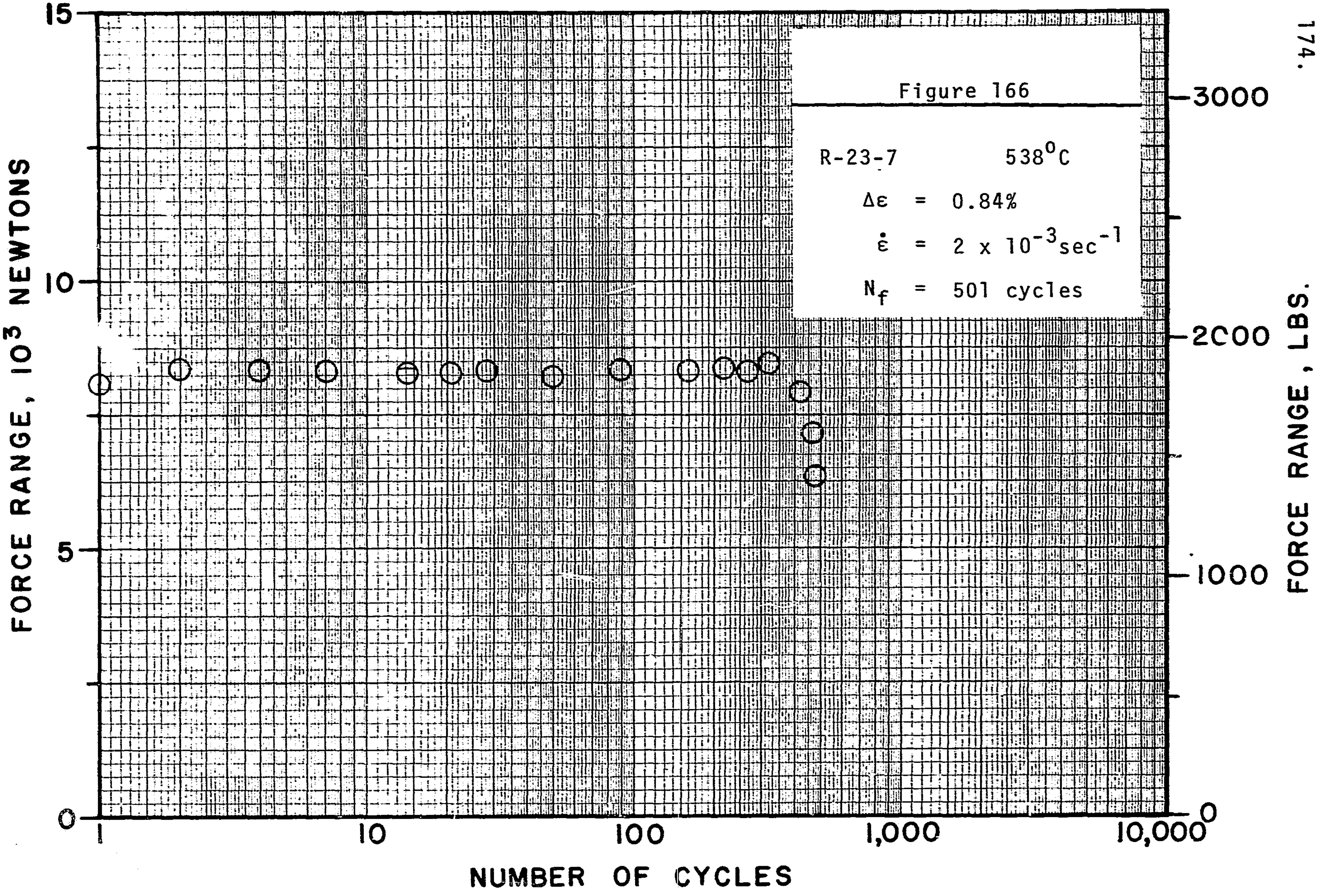


Figure 166

R-23-7 538^{0}C
$\Delta\varepsilon$ = 0.84%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 501 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

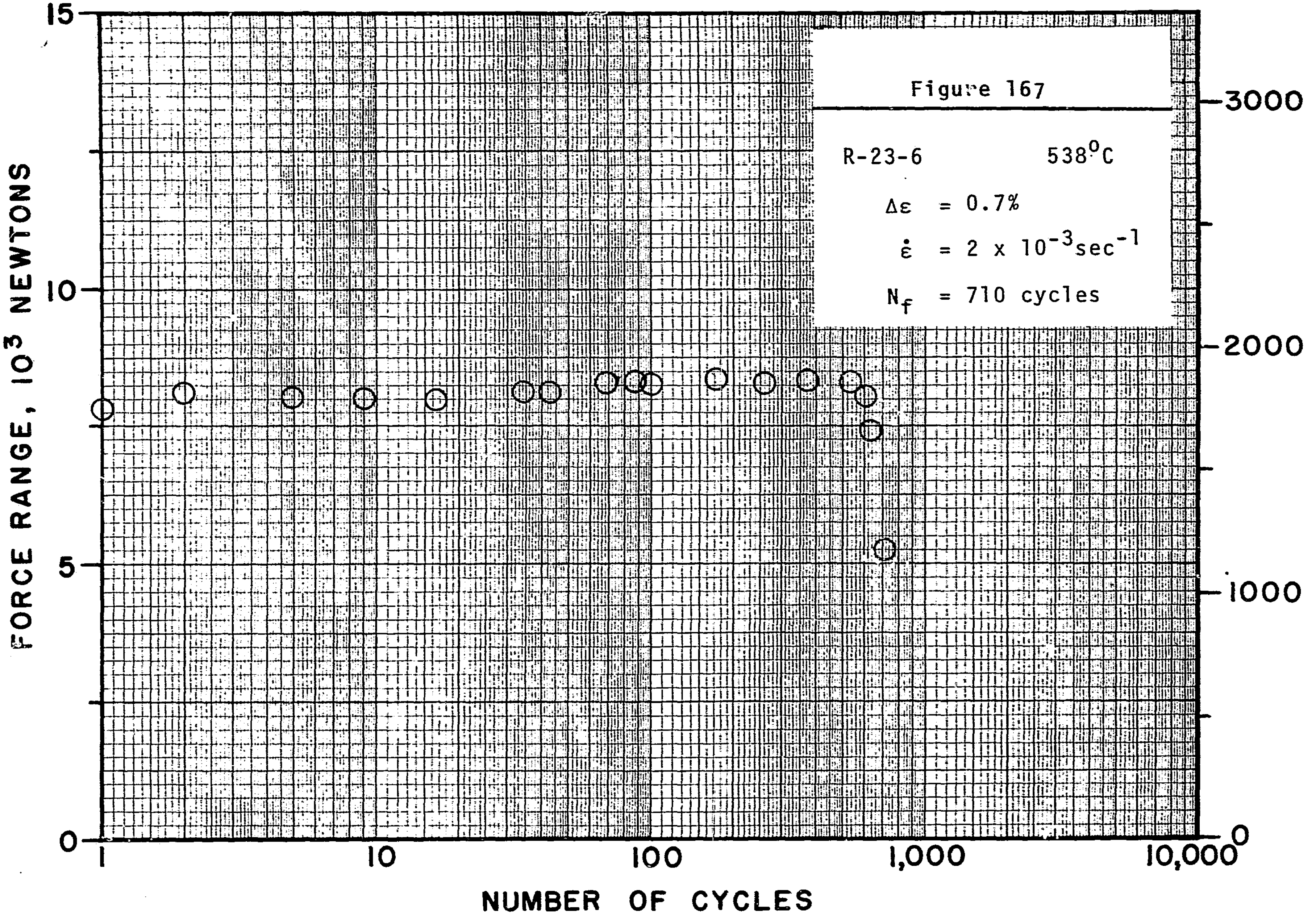


Figure 167
R-23-6
538°C
Δε = 0.7%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 710 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

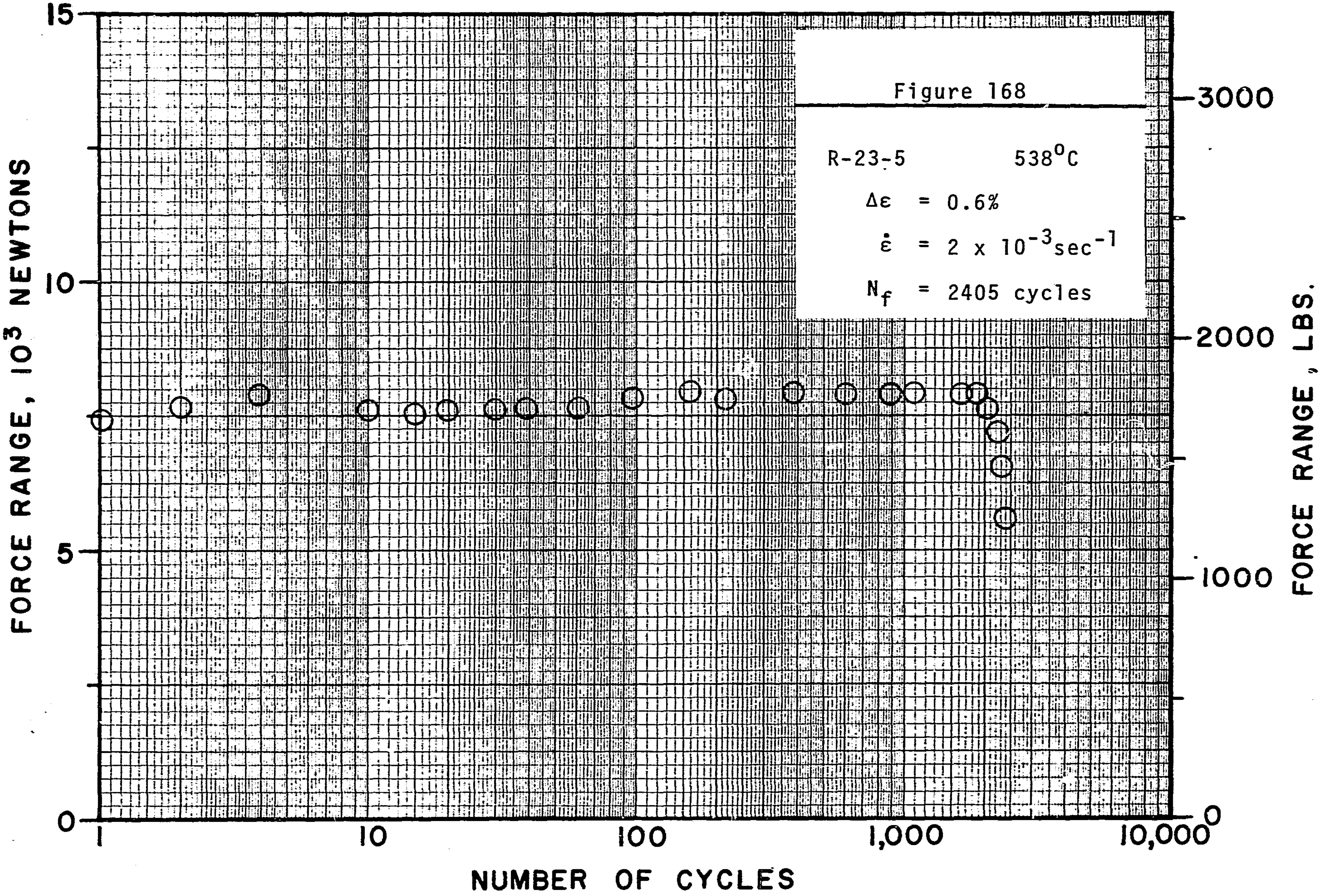


Figure 168

R-23-5 538°C

$\Delta\varepsilon = 0.6\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 2405$ cycles

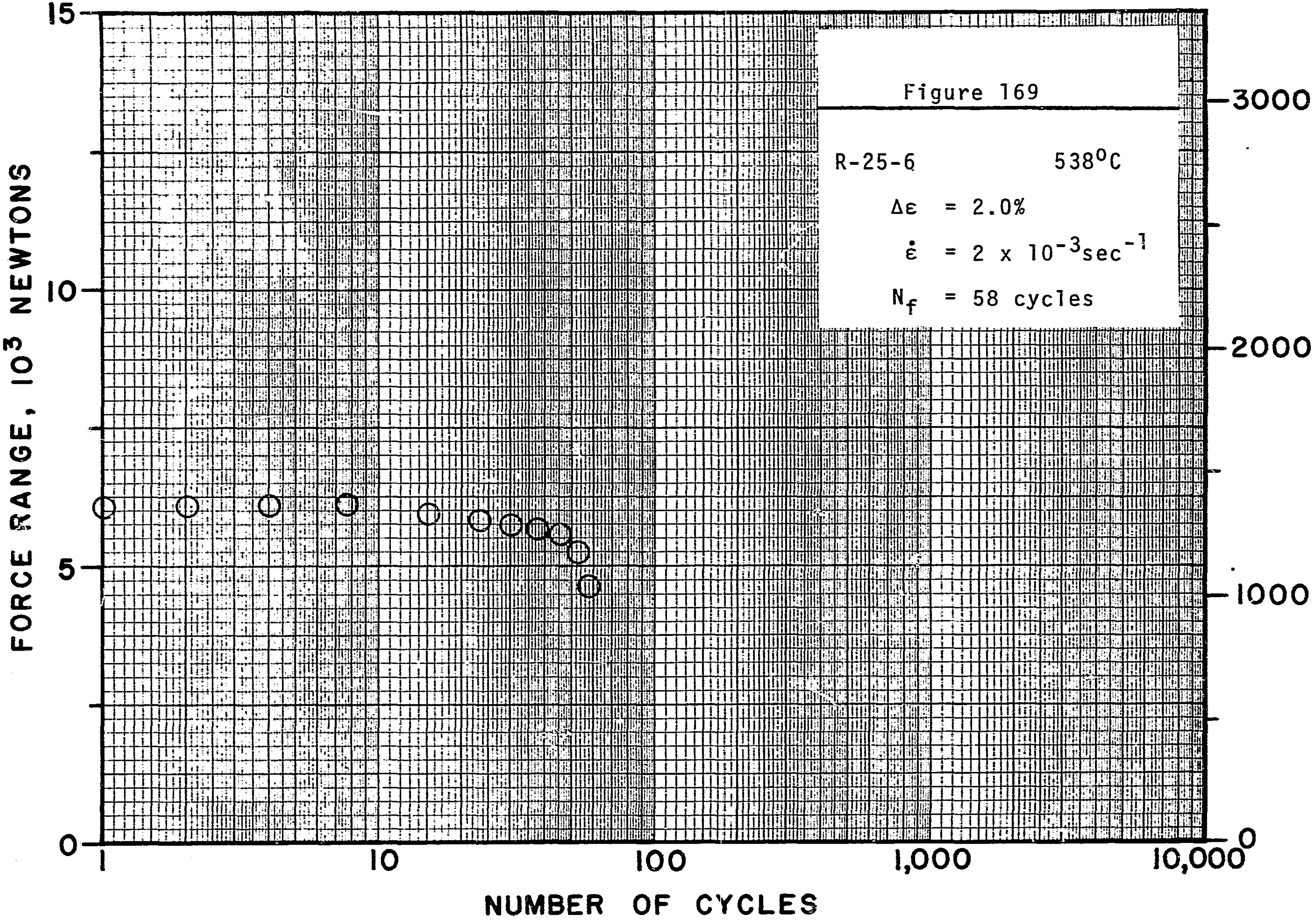


Figure 169

R-25-6 538^{o}C

$\Delta\varepsilon = 2.0\%$

$\dot{\varepsilon} = 2 \times 10^{-3} sec^{-1}$

$N_f = 58$ cycles

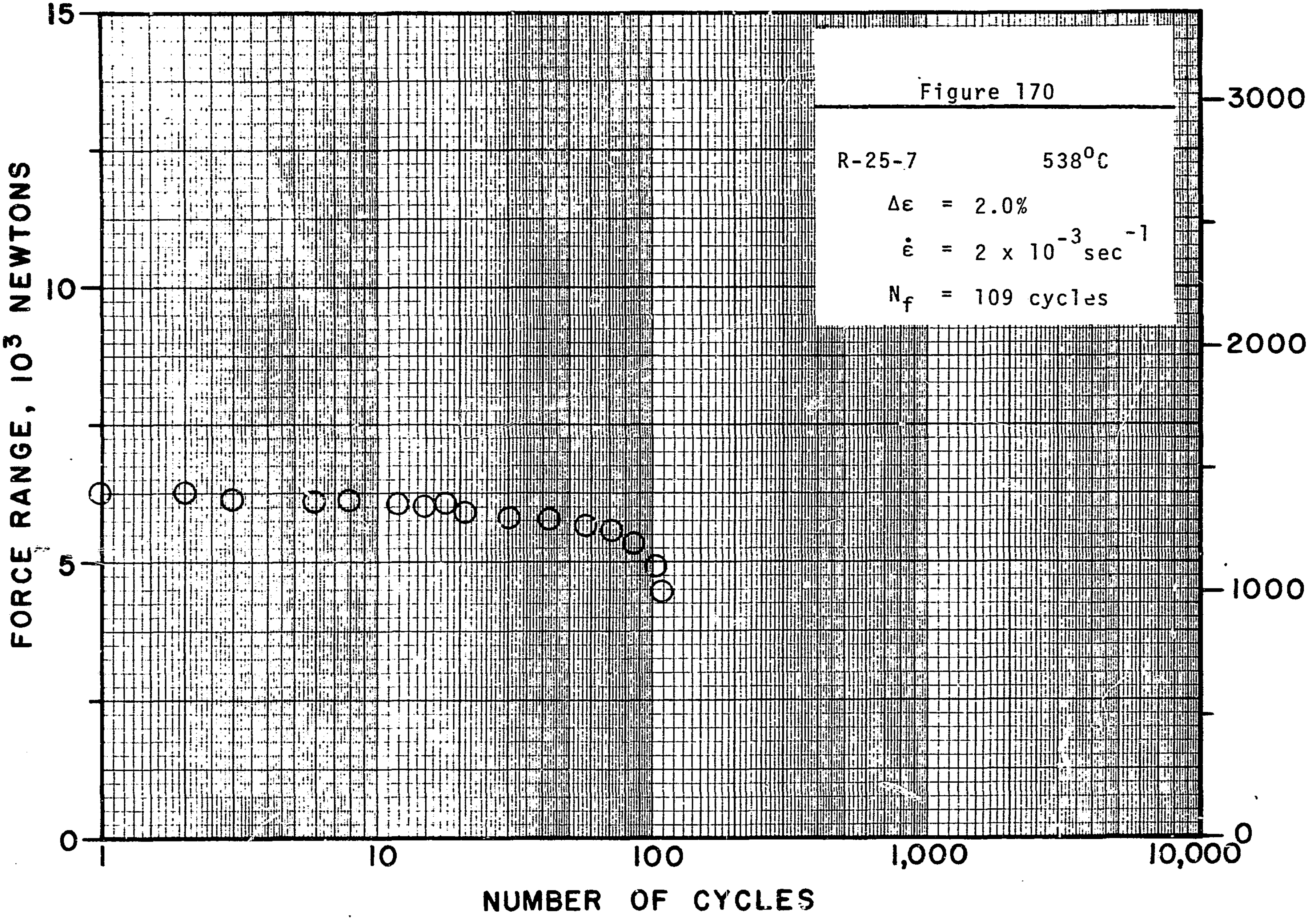


Figure 170

R-25-7 538^{0}C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 109 cycles

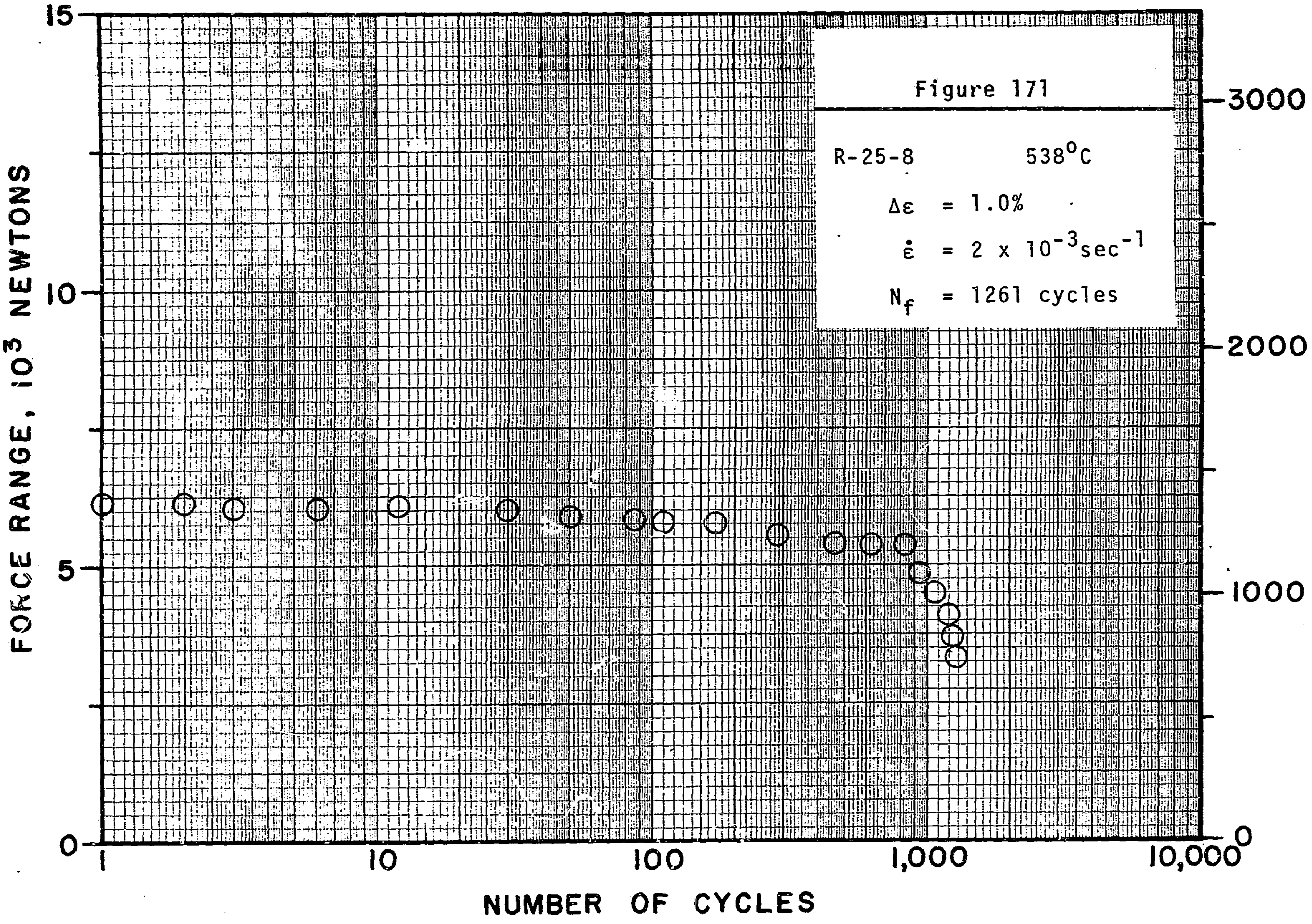


Figure 171
R-25-8 538°C
Δε = 1.0%
ε̇ = 2 x 10-3sec-1
Nf = 1261 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

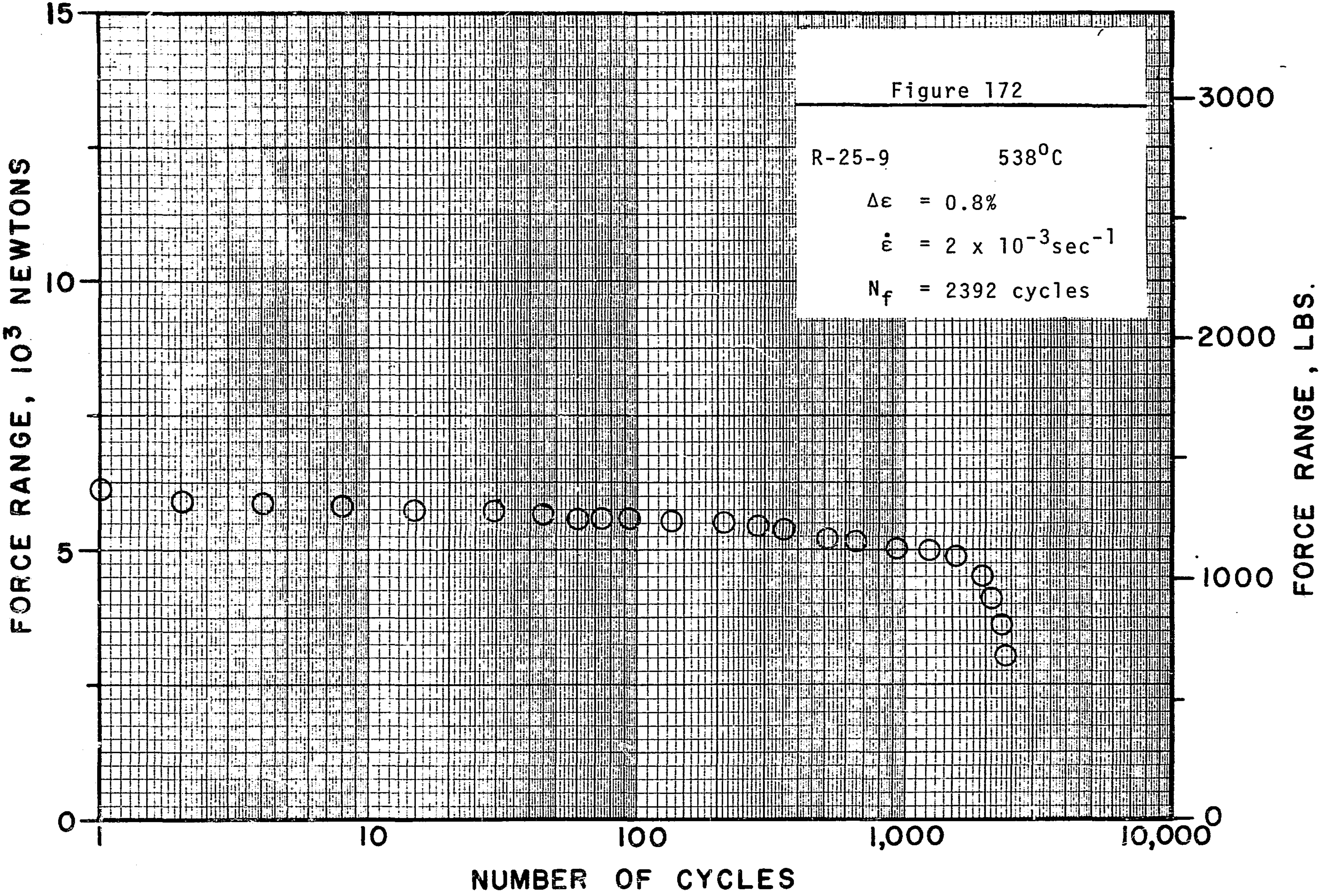


Figure 172

R-25-9 538°C
Δε = 0.8%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 2392 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

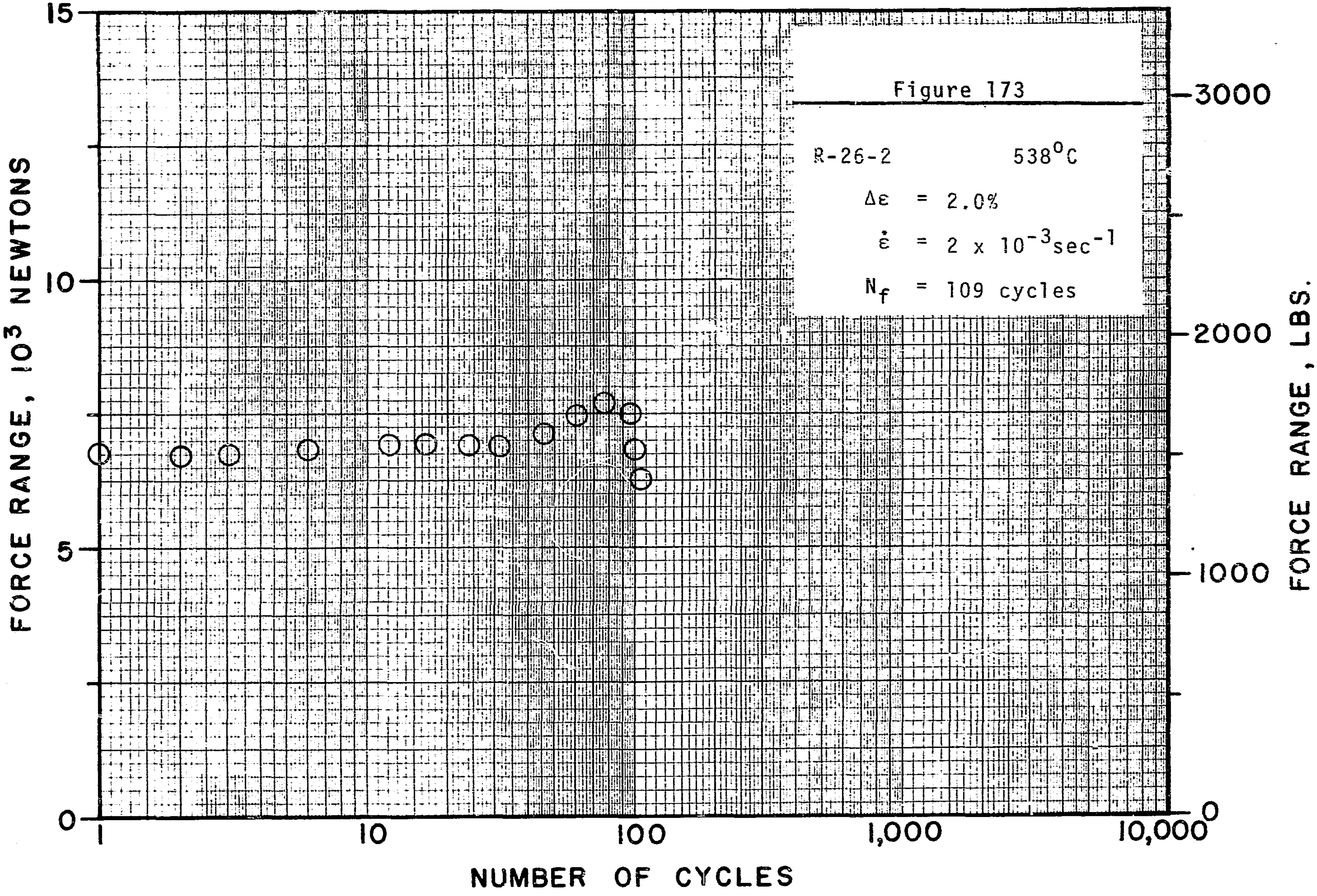


Figure 173

R-26-2 538°C

$\Delta\varepsilon$ = 2.0%

$\dot{\varepsilon}$ = 2×10^{-3} sec^{-1}

N_f = 109 cycles

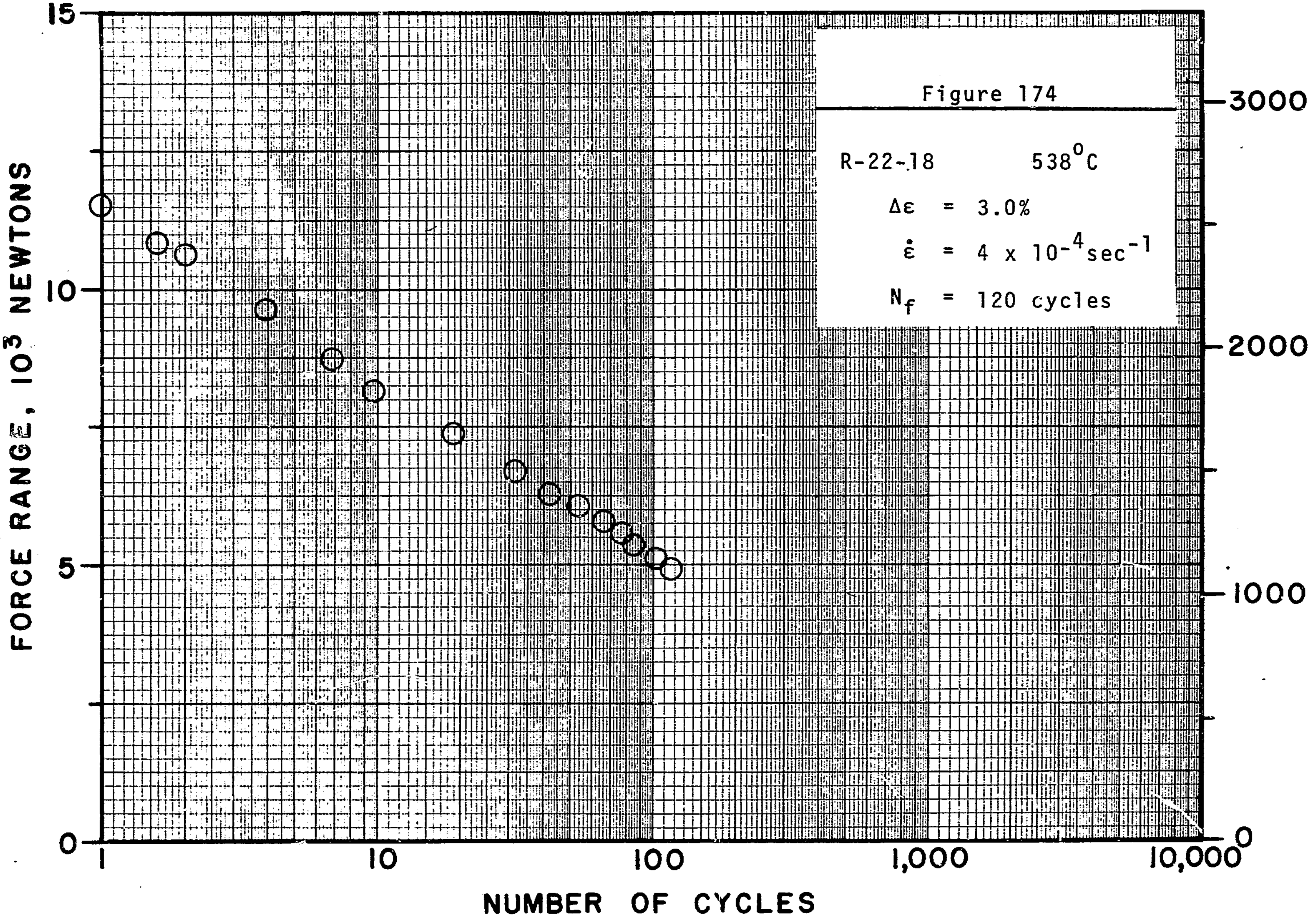


Figure 174

R-22-18 538°C
$\Delta\varepsilon$ = 3.0%
$\dot{\varepsilon}$ = 4 x 10^{-4}sec^{-1}
N_f = 120 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

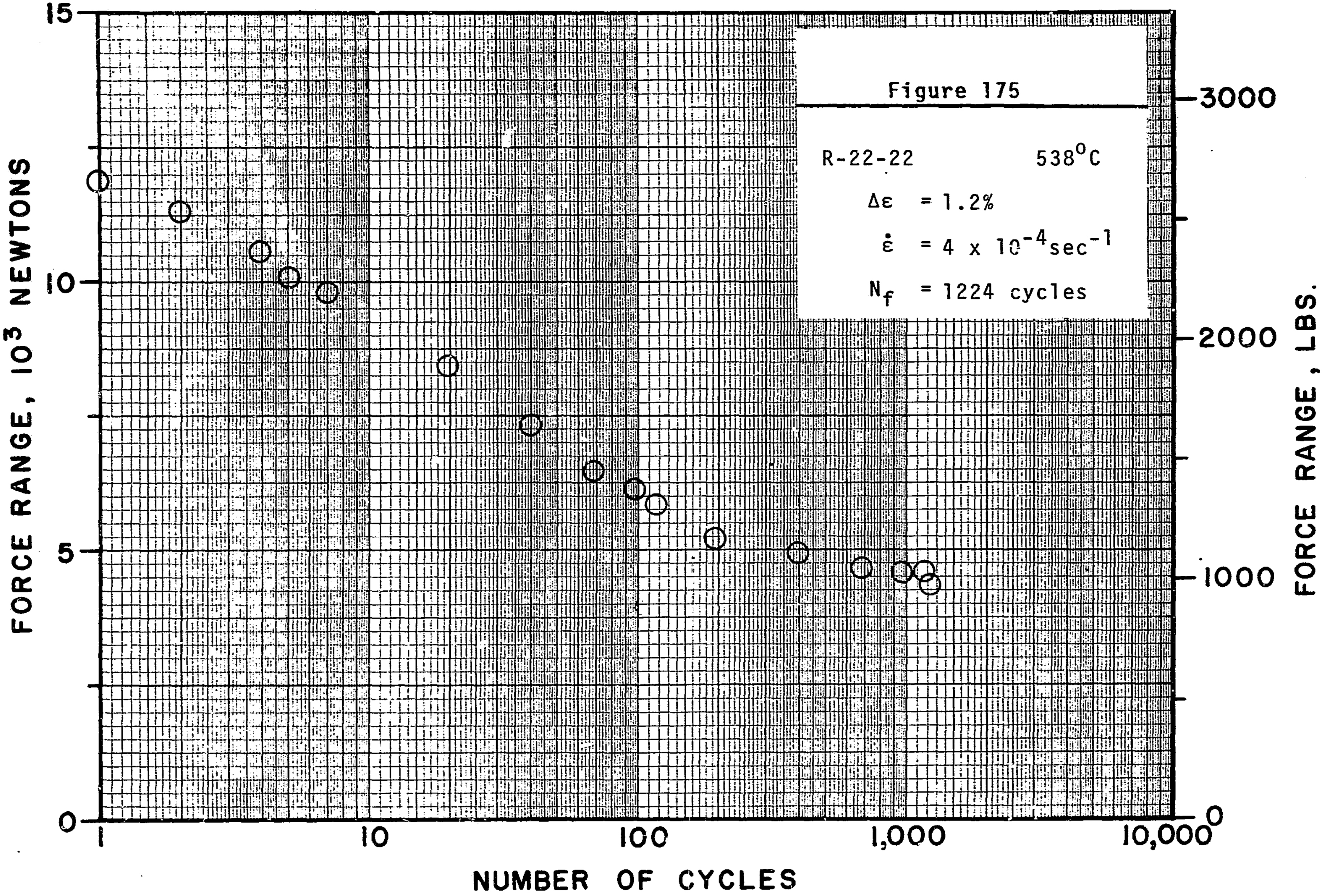


Figure 175
R-22-22
538°C
Δε = 1.2%
ε̇ = 4 x 10⁻⁴sec⁻¹
N_f = 1224 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

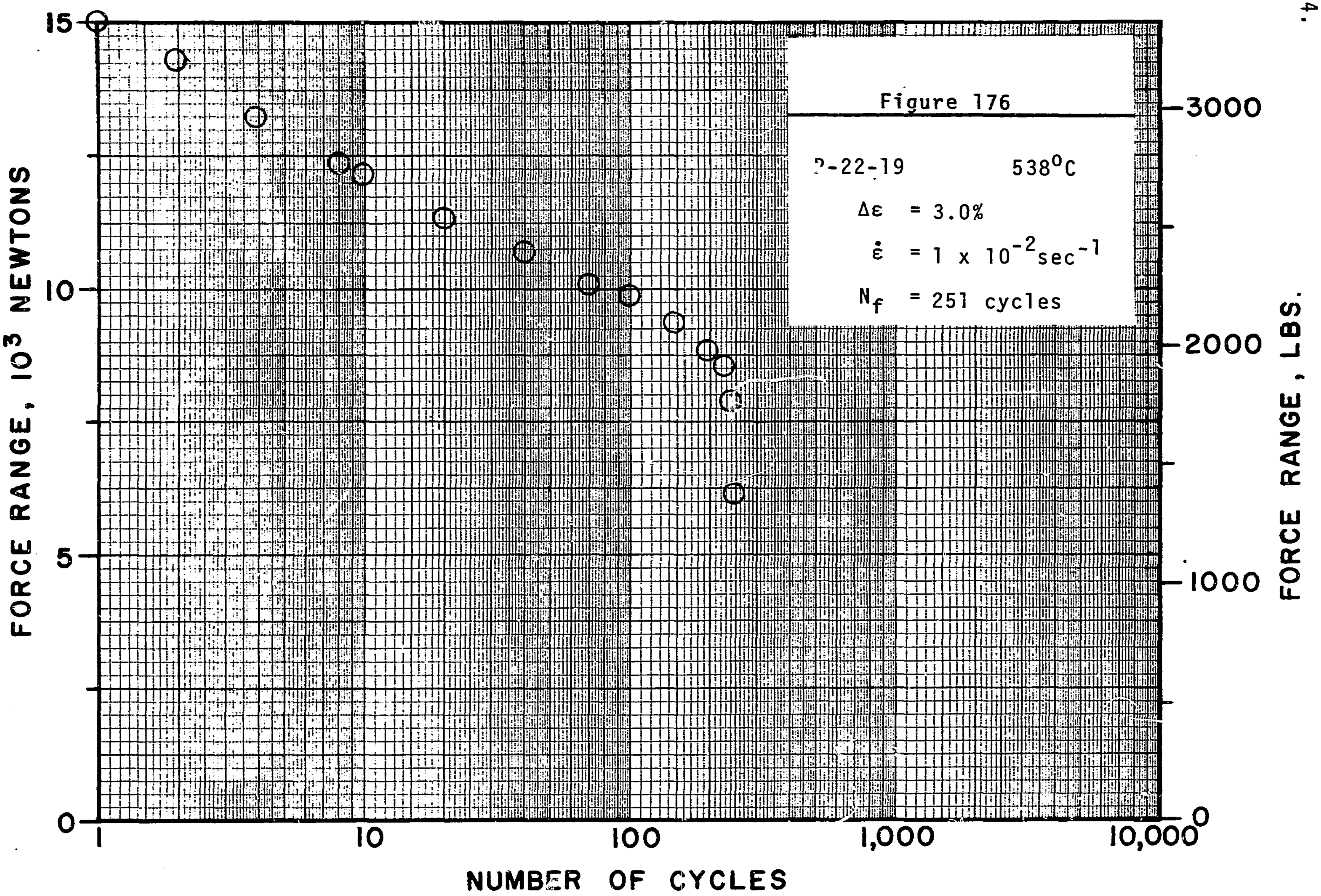


Figure 176

2-22-19
538°C
Δε = 3.0%
ε̇ = 1 x 10⁻² sec⁻¹
N_f = 251 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

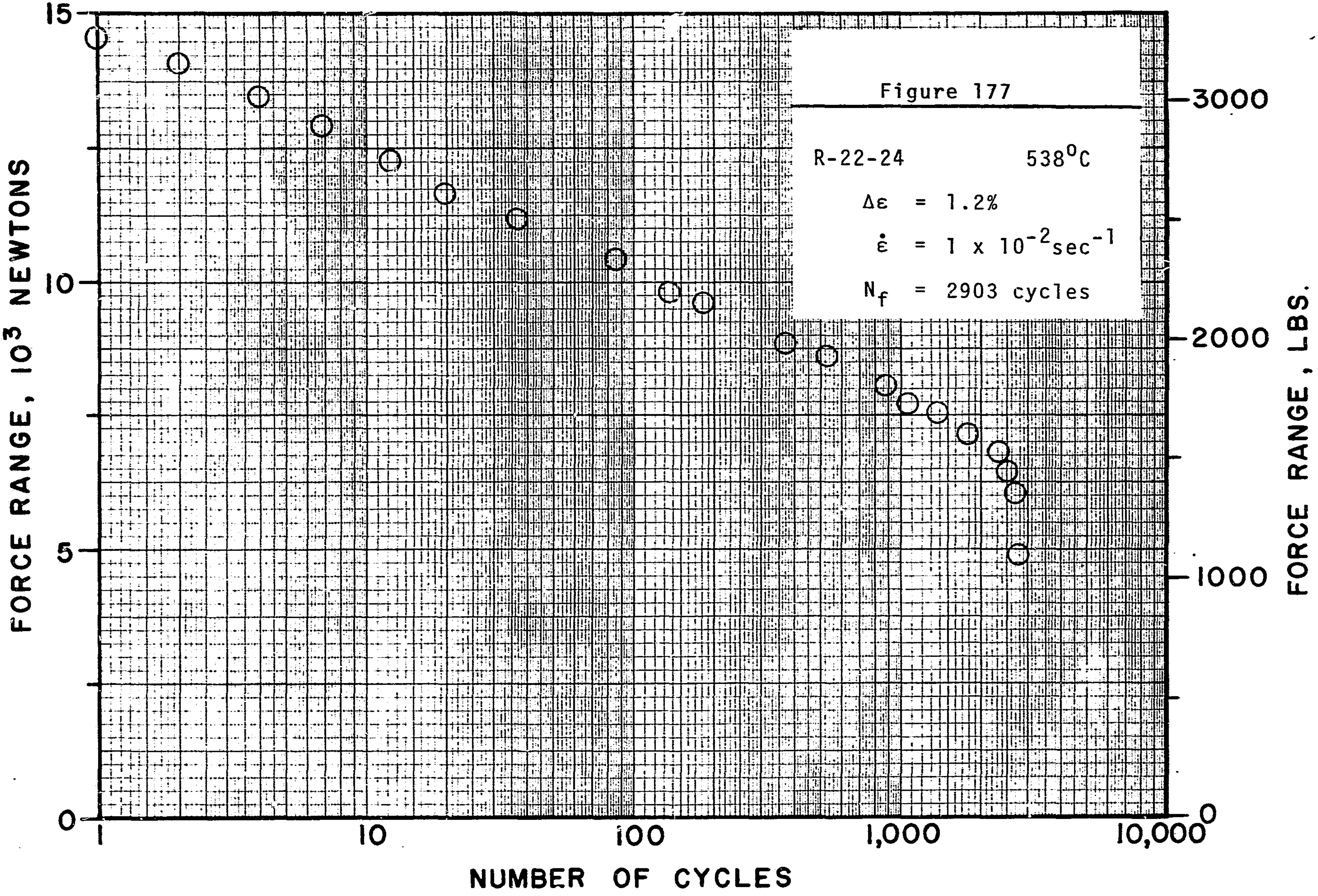


Figure 177

R-22-24
538°C
$\Delta\varepsilon$ = 1.2%
$\dot{\varepsilon}$ = $1 \times 10^{-2} sec^{-1}$
N_f = 2903 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

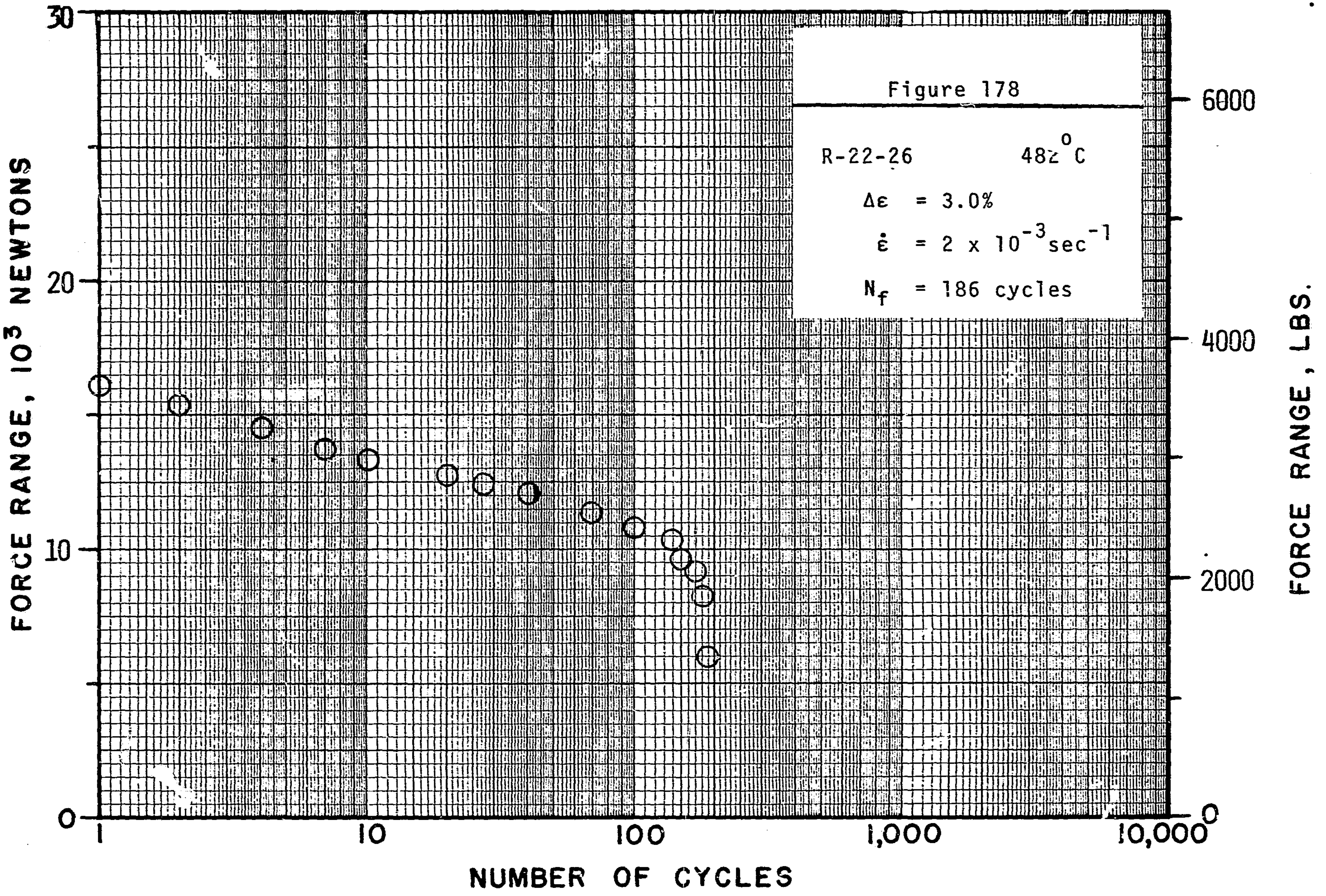


Figure 178

R-22-26
482 °C
$\Delta\varepsilon$ = 3.0%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 186 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

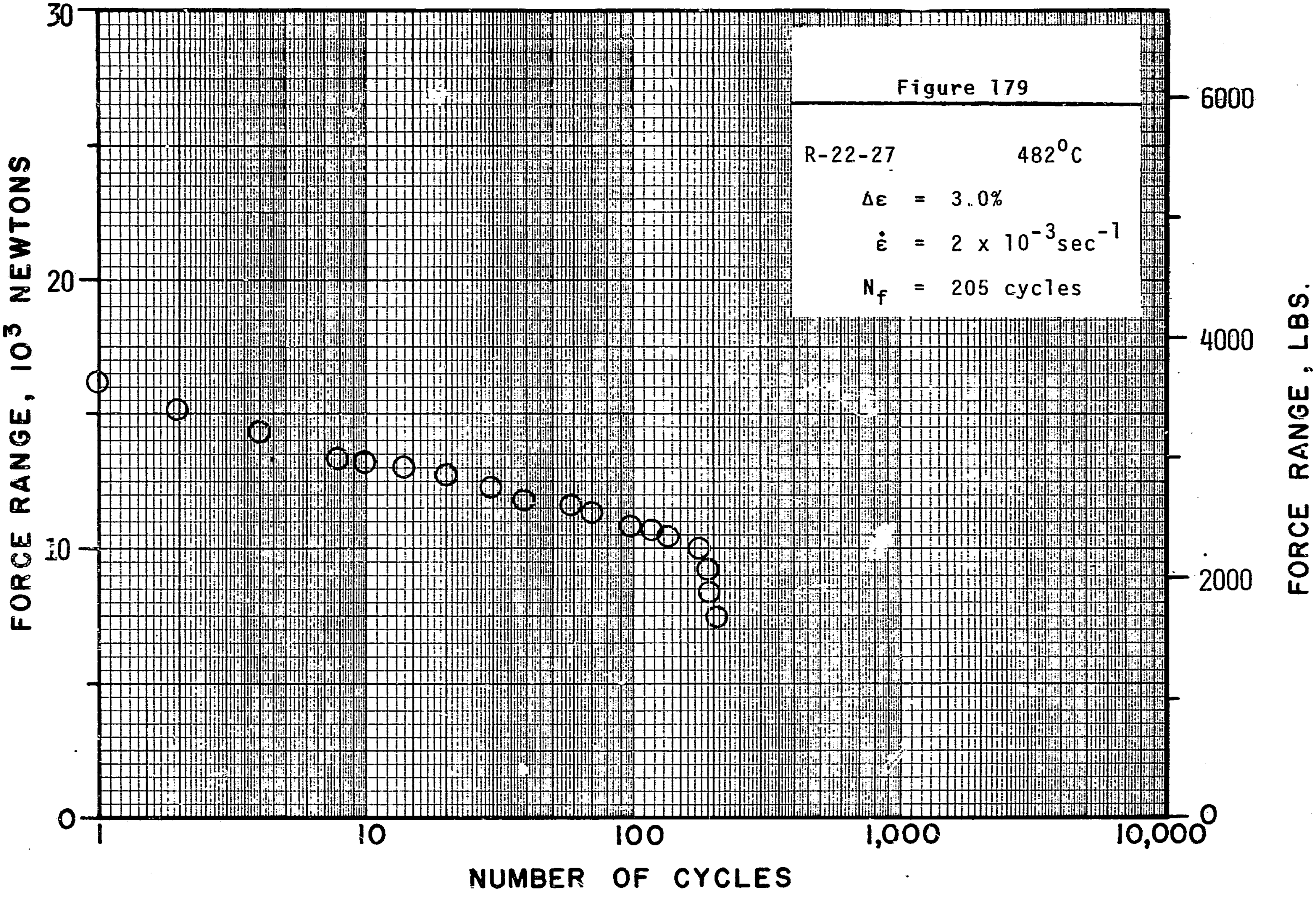


Figure 179

R-22-27 482°C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$

N_f = 205 cycles

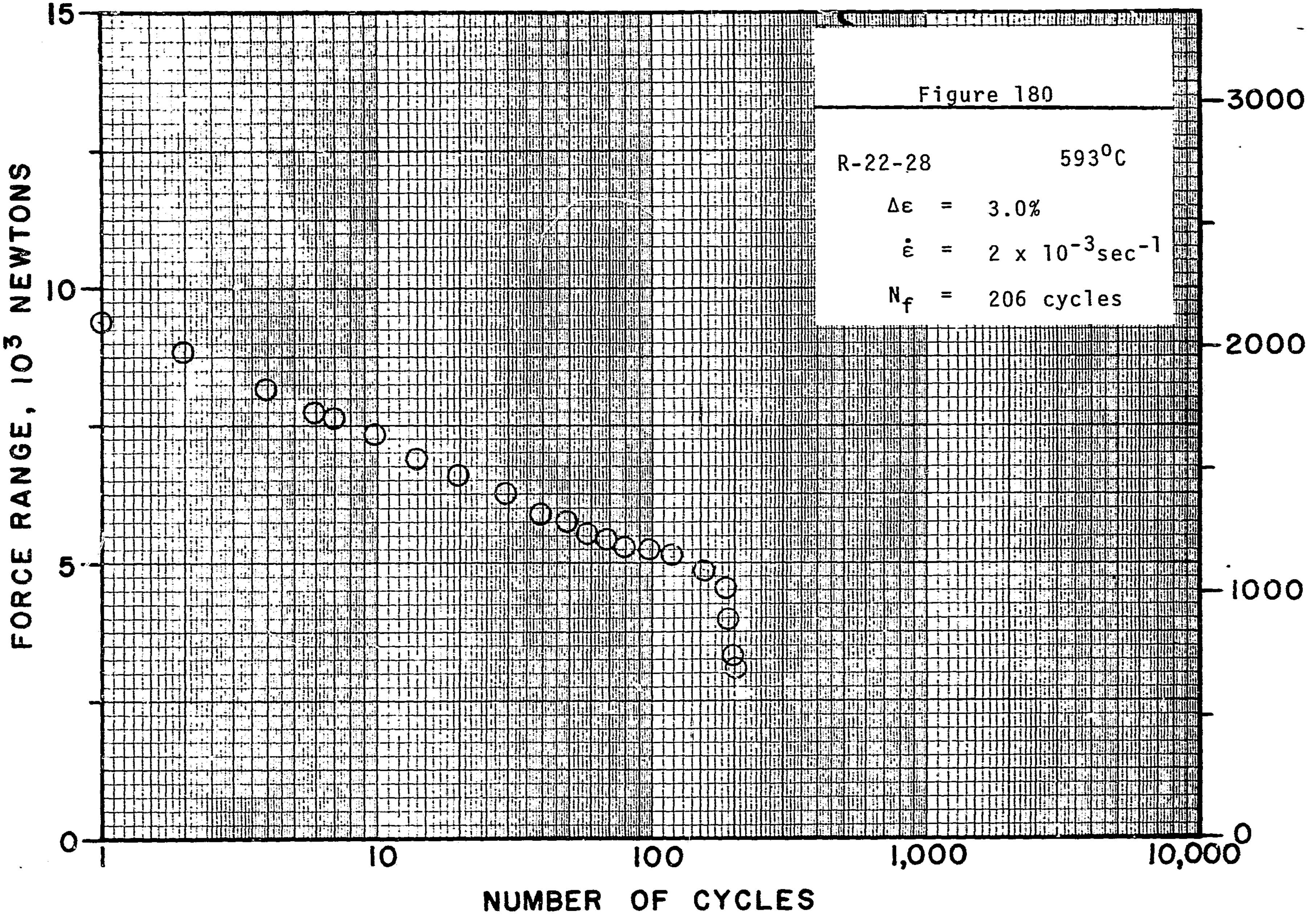


Figure 180

R-22-28
593^{0}C
$\Delta\varepsilon$ = 3.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 206 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

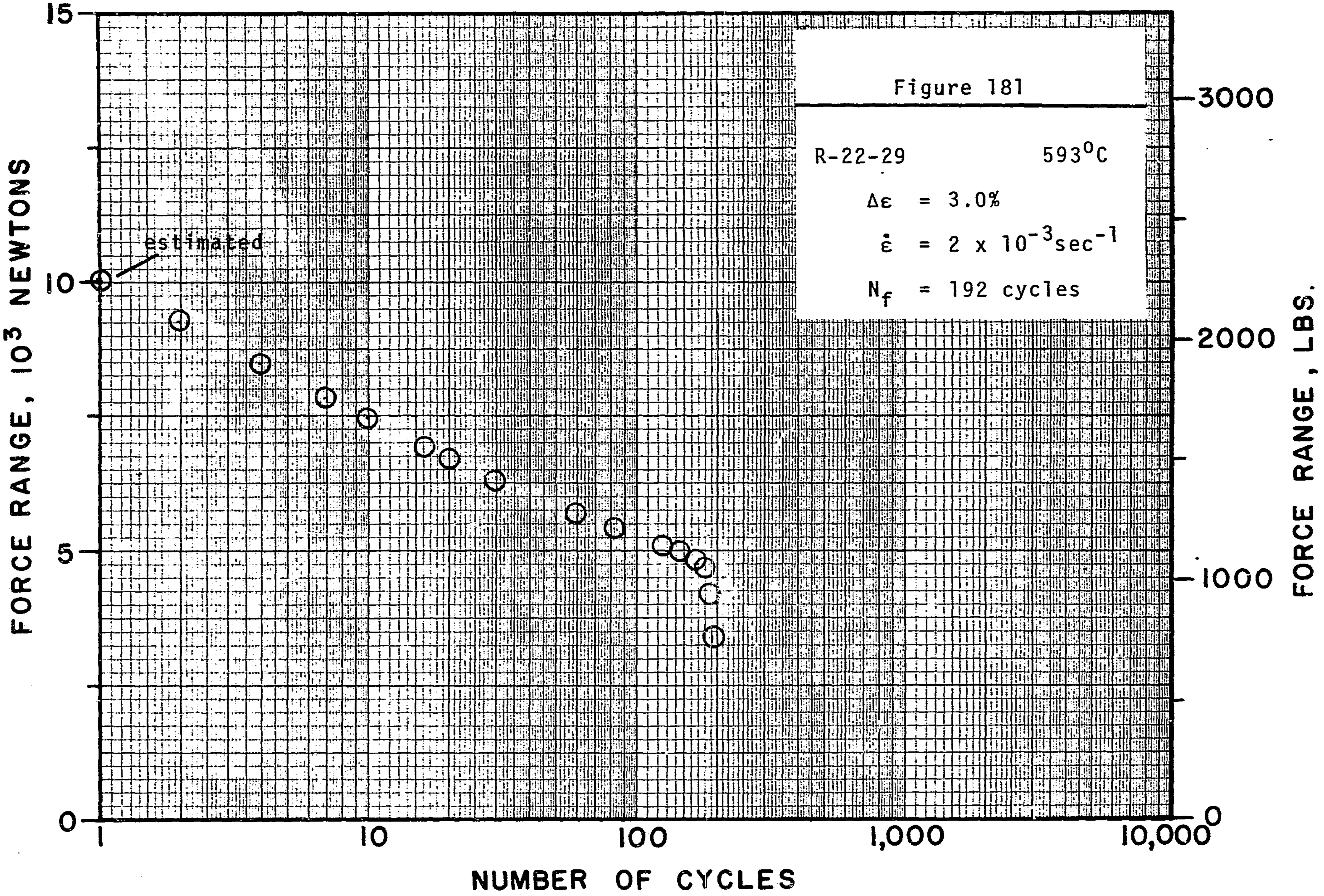


Figure 181

R-22-29 593°C

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 192 cycles

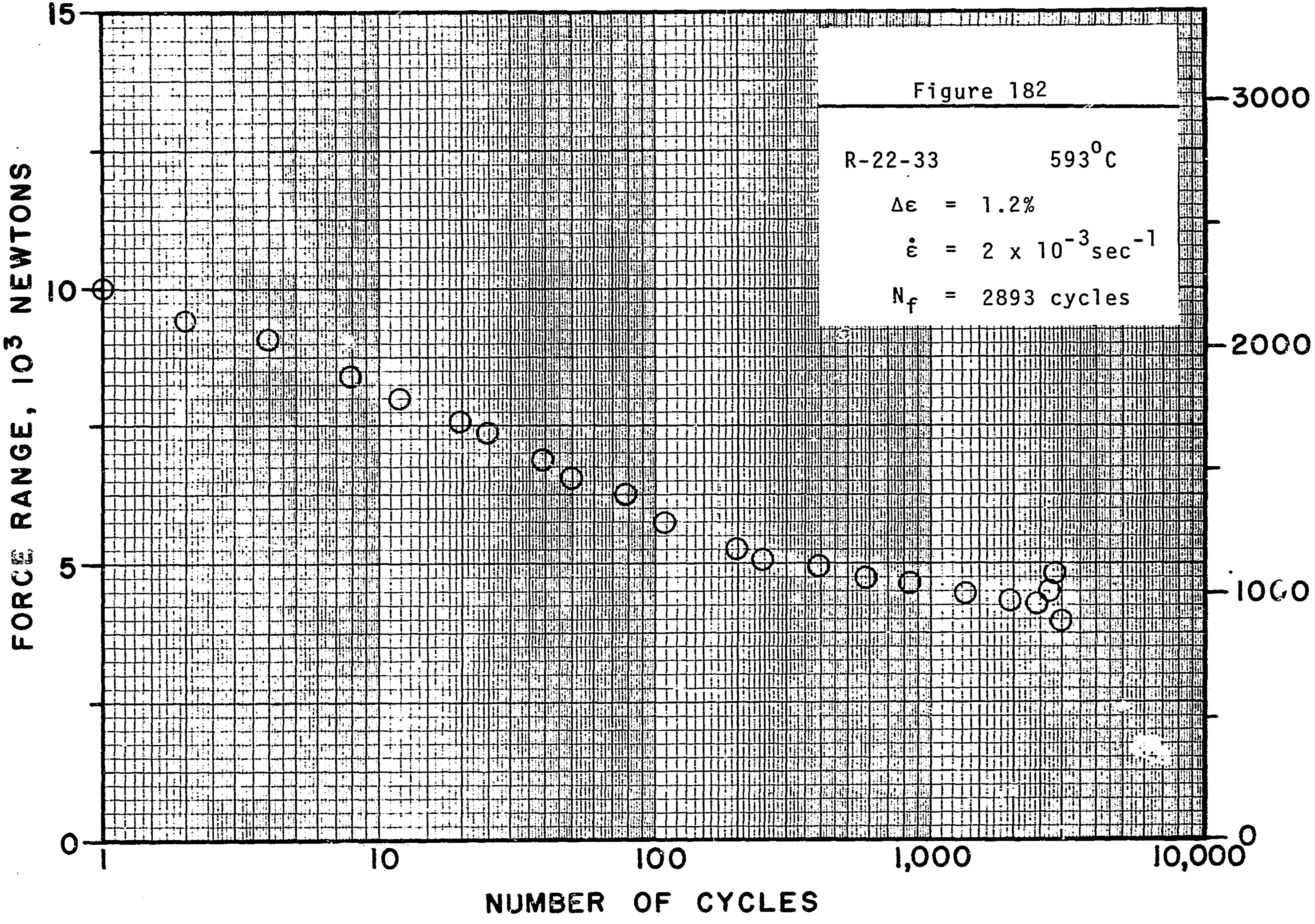


Figure 182

R-22-33
593°C
Δε = 1.2%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 2893 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

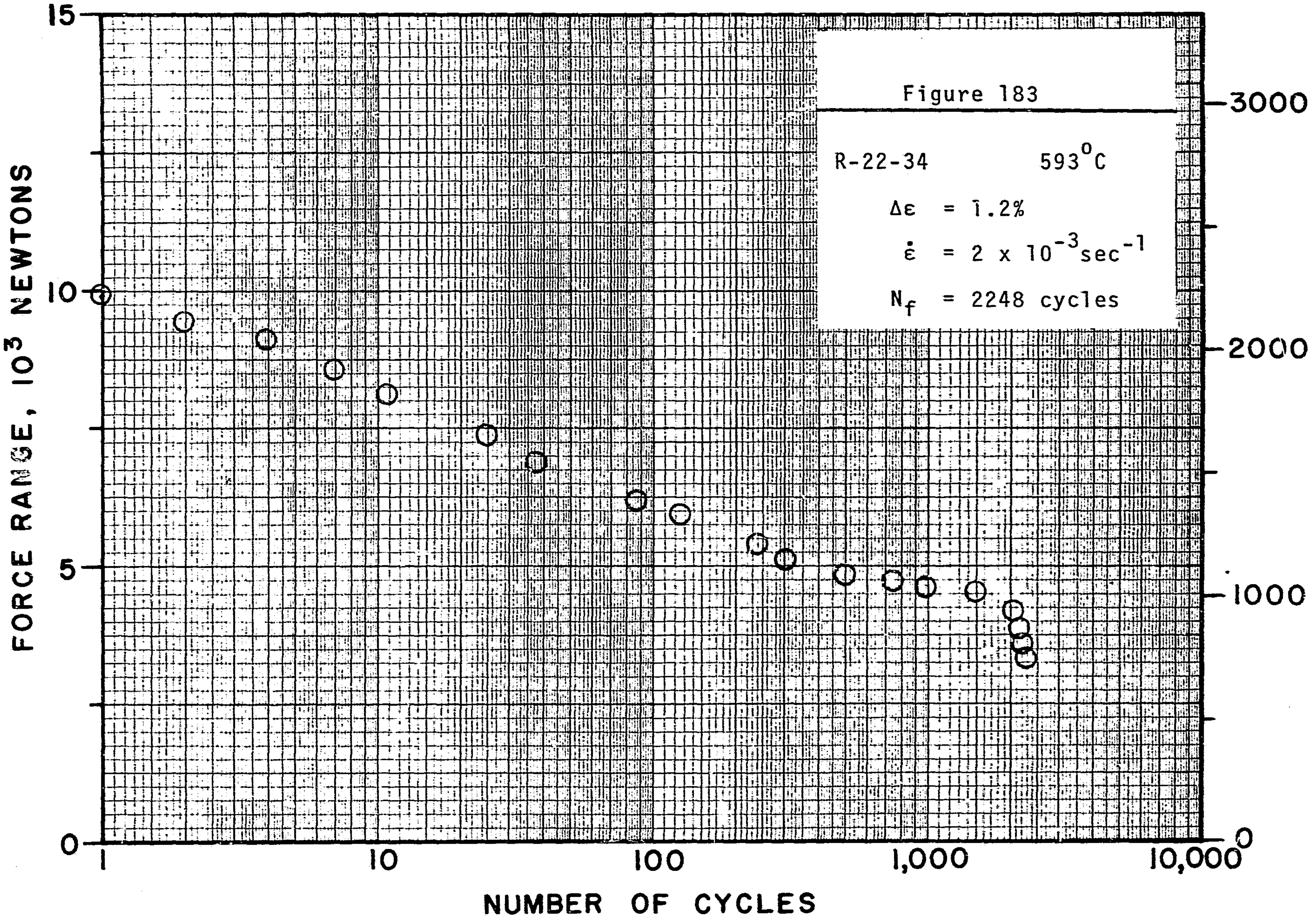


Figure 183

R-22-34 593°C

$\Delta\varepsilon = 1.2\%$

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

$N_f = 2248$ cycles

C-3

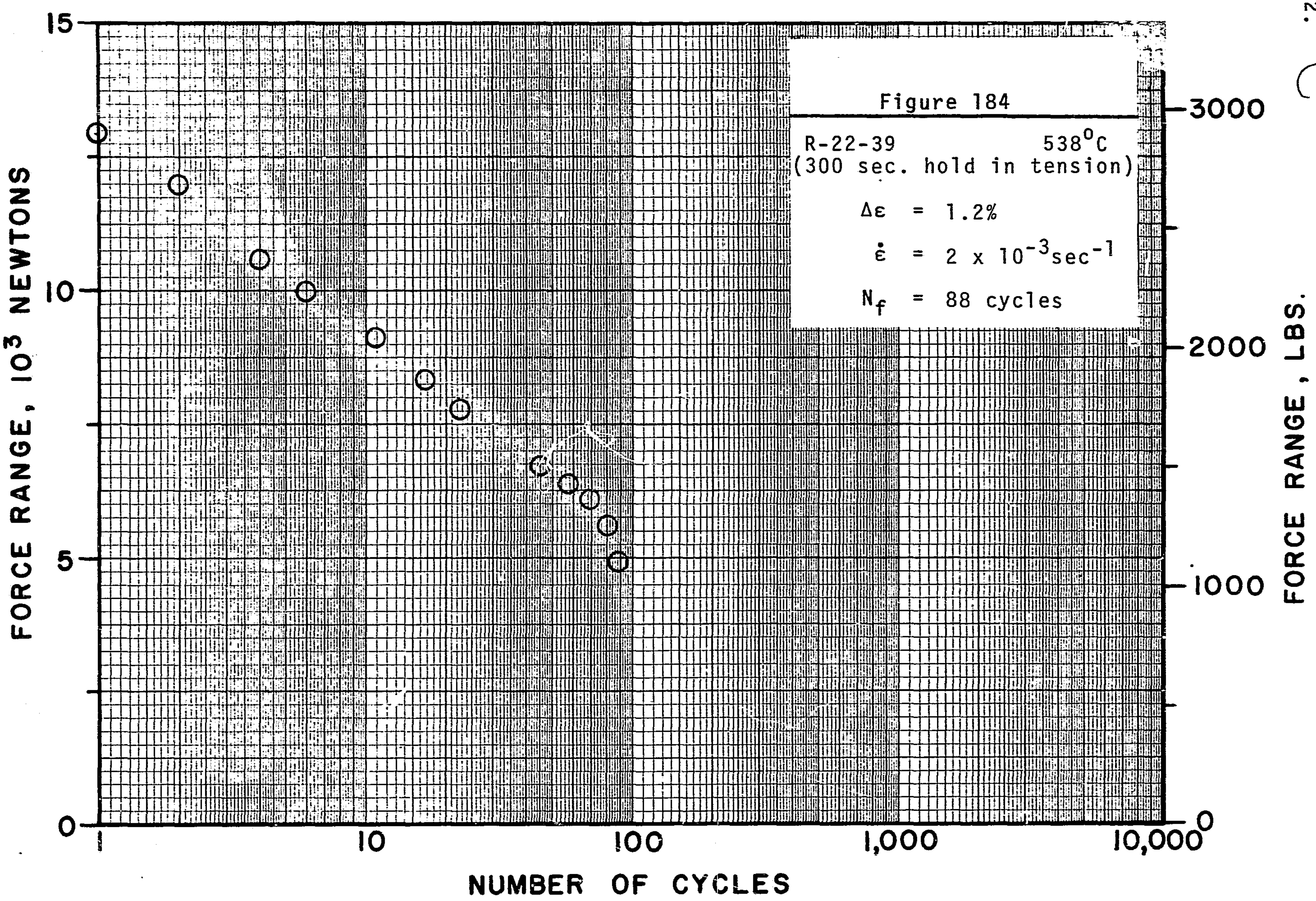


Figure 184

R-22-39 538°C

(300 sec. hold in tension)

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 88 cycles

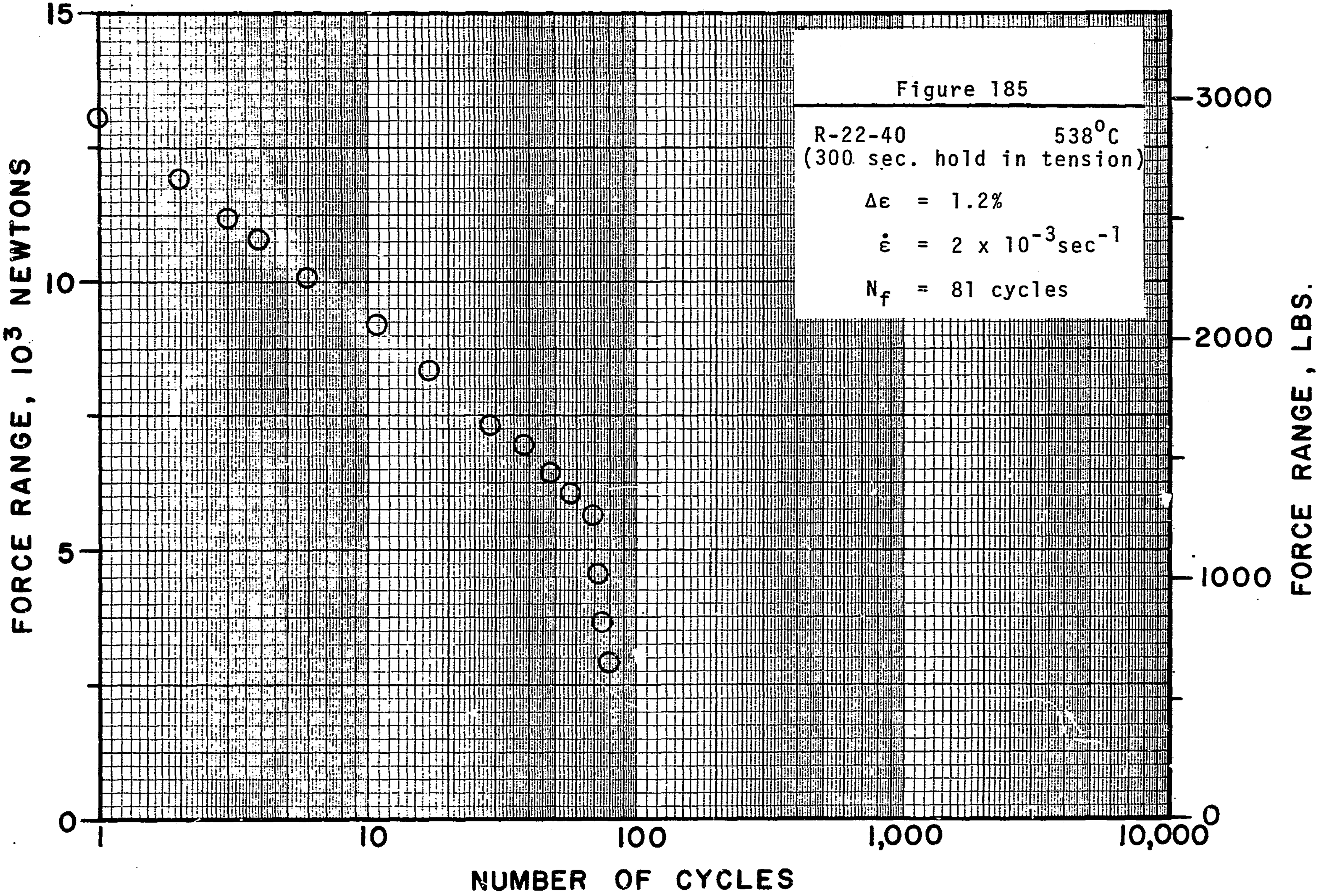


Figure 185
R-22-40
538°C
(300 sec. hold in tension)
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 81 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
NUMBER OF CYCLES
1
10
100
1,000
10,000

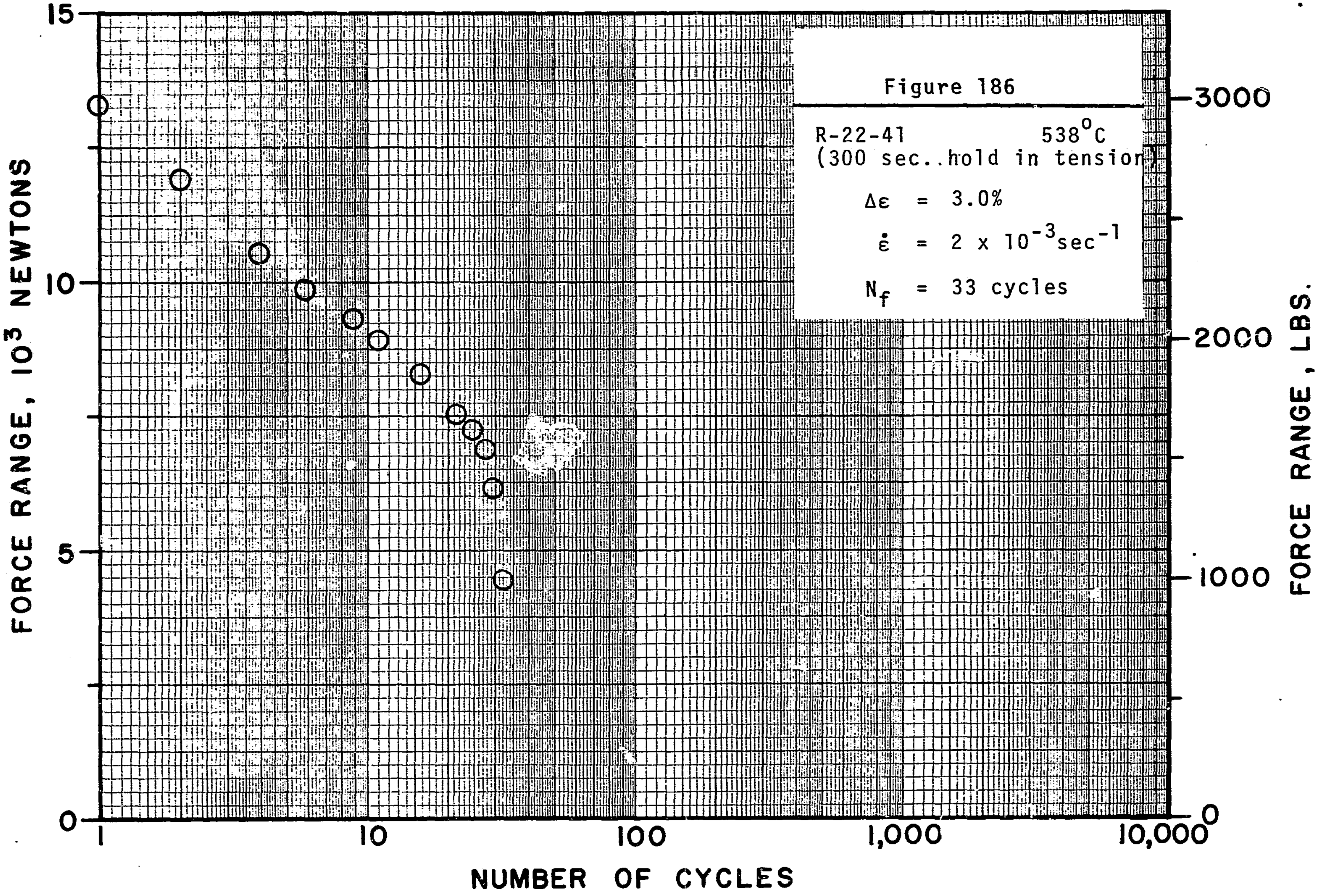


Figure 186

R-22-41 538°C
(300 sec. hold in tension)
Δε = 3.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 33 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

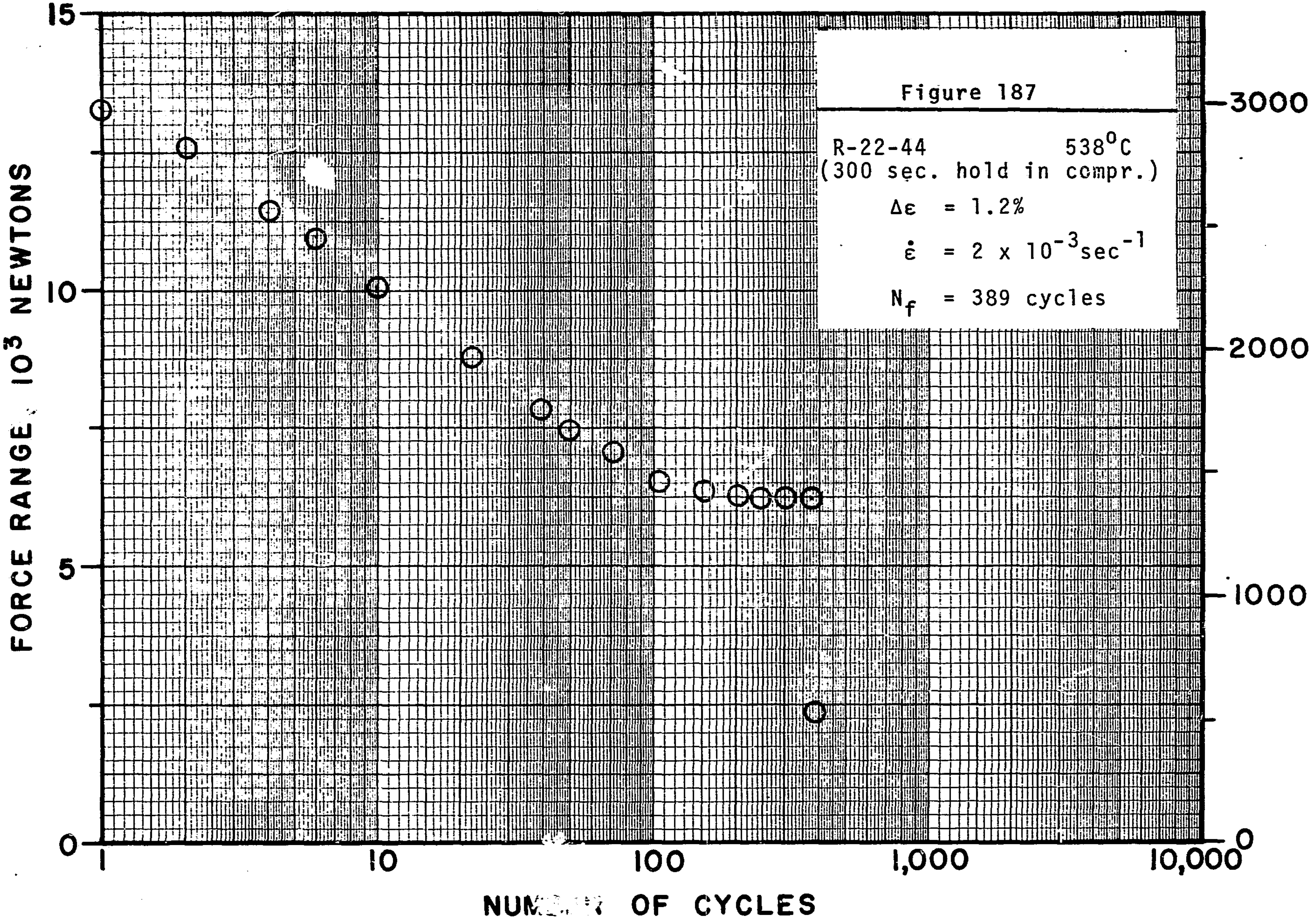


Figure 187

R-22-44 538°C
(300 sec. hold in compr.)

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon} = 2 \times 10^{-3} \text{sec}^{-1}$

N_f = 389 cycles

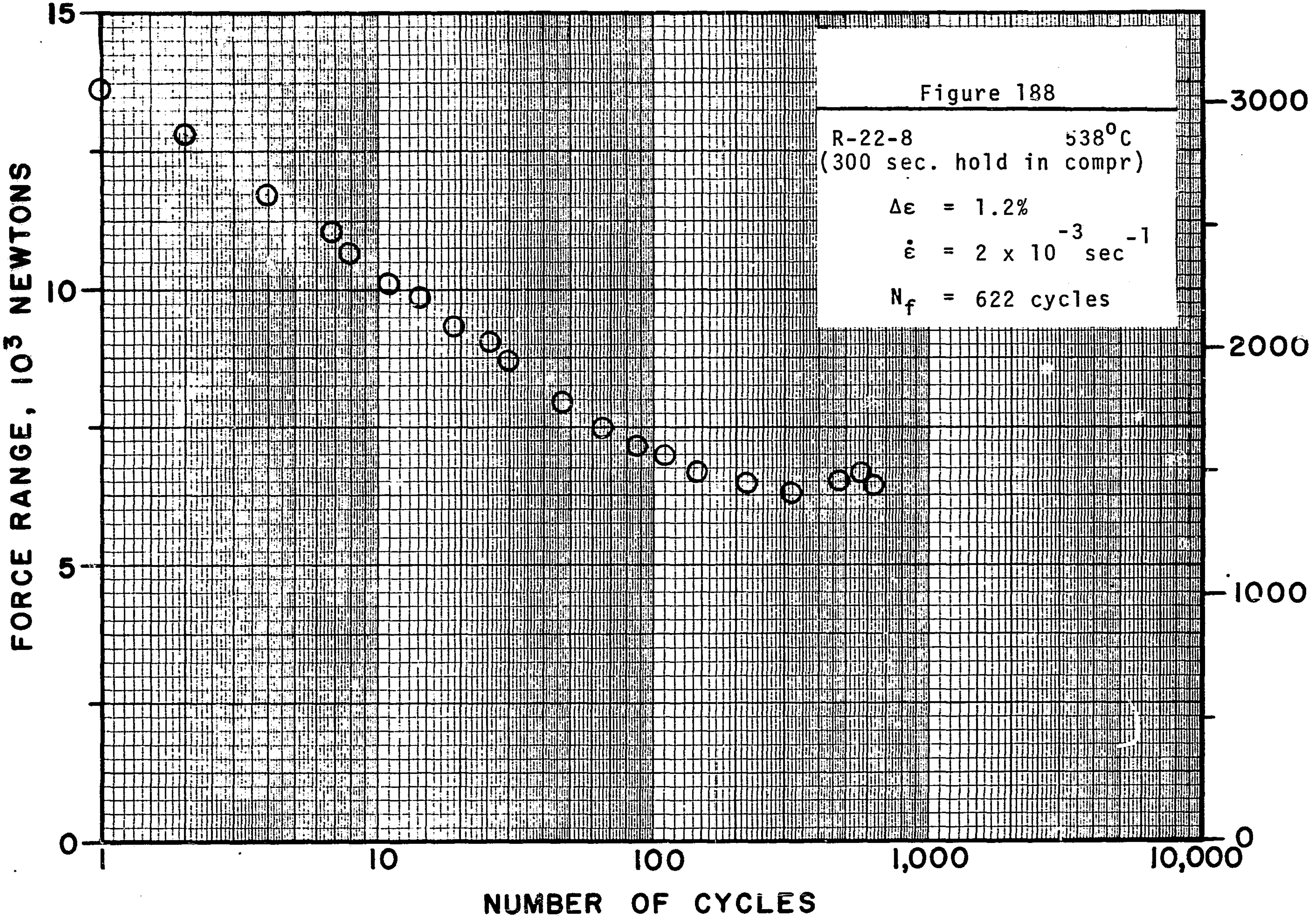


Figure 188

R-22-8 538^{0}C
(300 sec. hold in compr)

$\Delta\varepsilon$ = 1.2%

$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}

N_f = 622 cycles

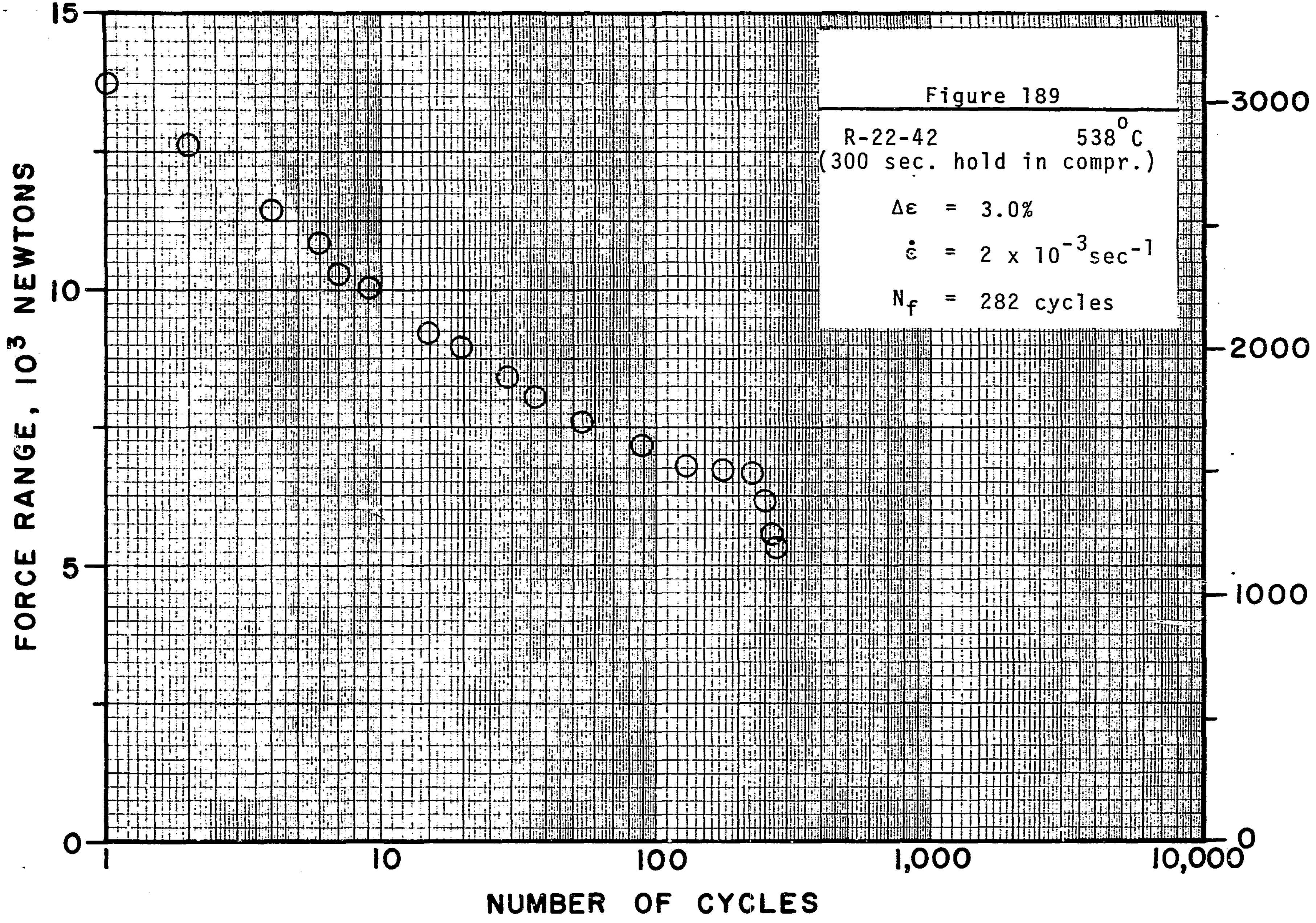


Figure 189

R-22-42 538°C
(300 sec. hold in compr.)

$\Delta\varepsilon$ = 3.0%

$\dot{\varepsilon}$ = $2 \times 10^{-3} \text{sec}^{-1}$

N_f = 282 cycles

b) HYSTERESIS LOOPS

Figures 190 through 288.

Note: A frequency of 60 cpm was employed in the testing of Specimen Numbers R-24-29, R-24-30, R-2-74 and R-2-75. Since this frequency was beyond the response characteristics of the x-y recorder, no hysteresis loops could be obtained for these tests.

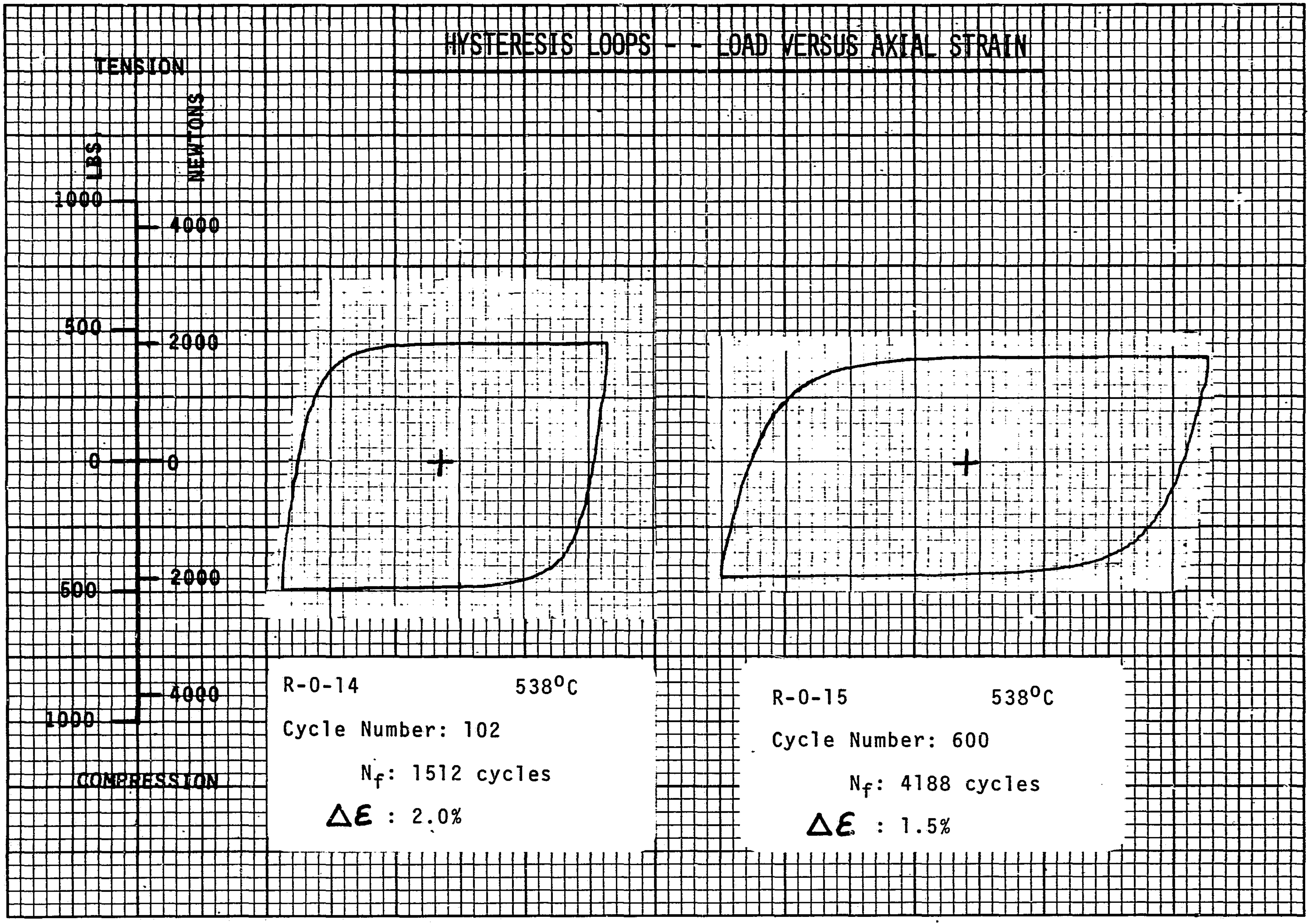

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-0-14
538°C
Cycle Number: 102
N_f: 1512 cycles
Δε : 2.0%
R-0-15
538°C
Cycle Number: 600
N_f: 4188 cycles
Δε : 1.5%

Figure 190

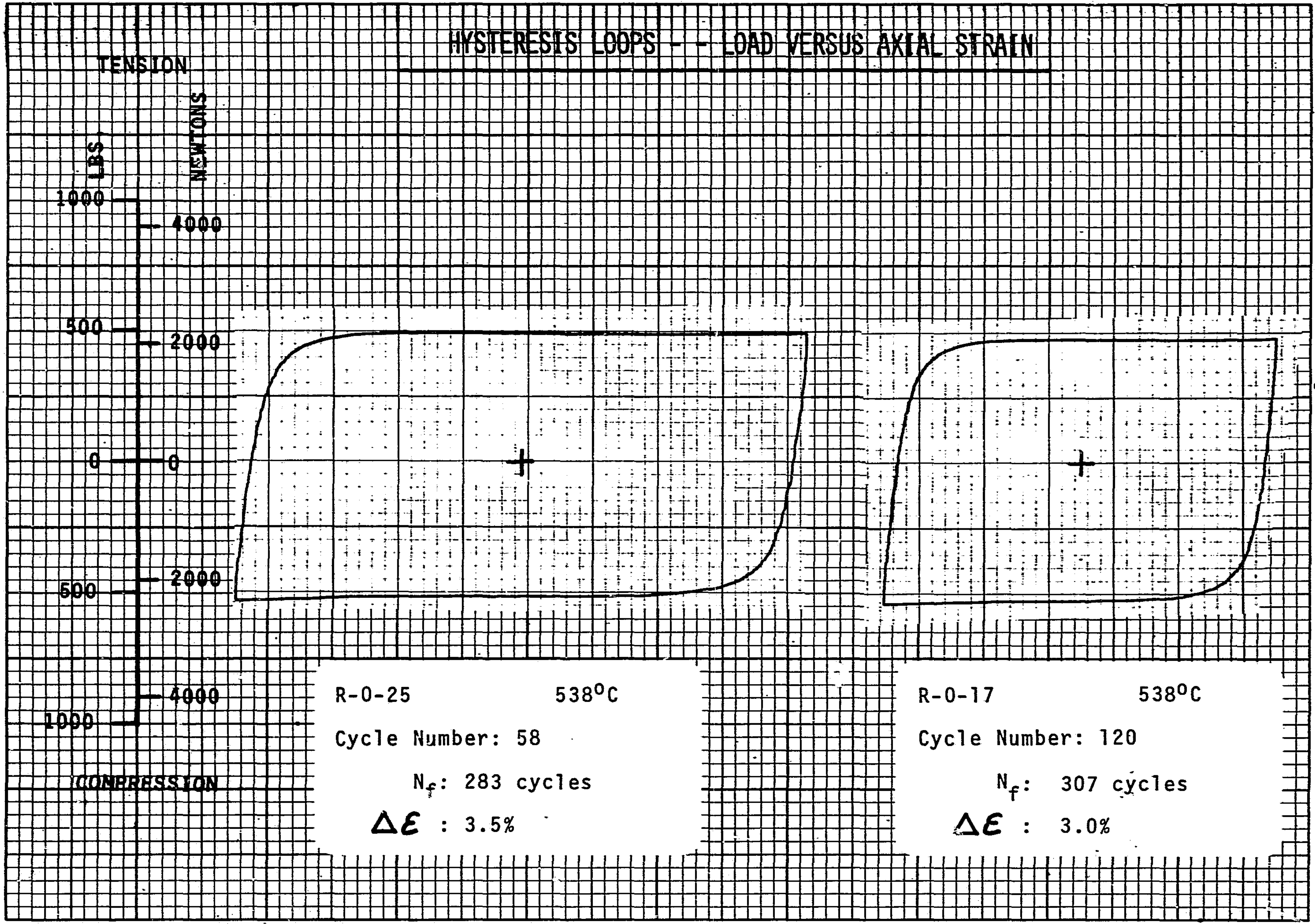
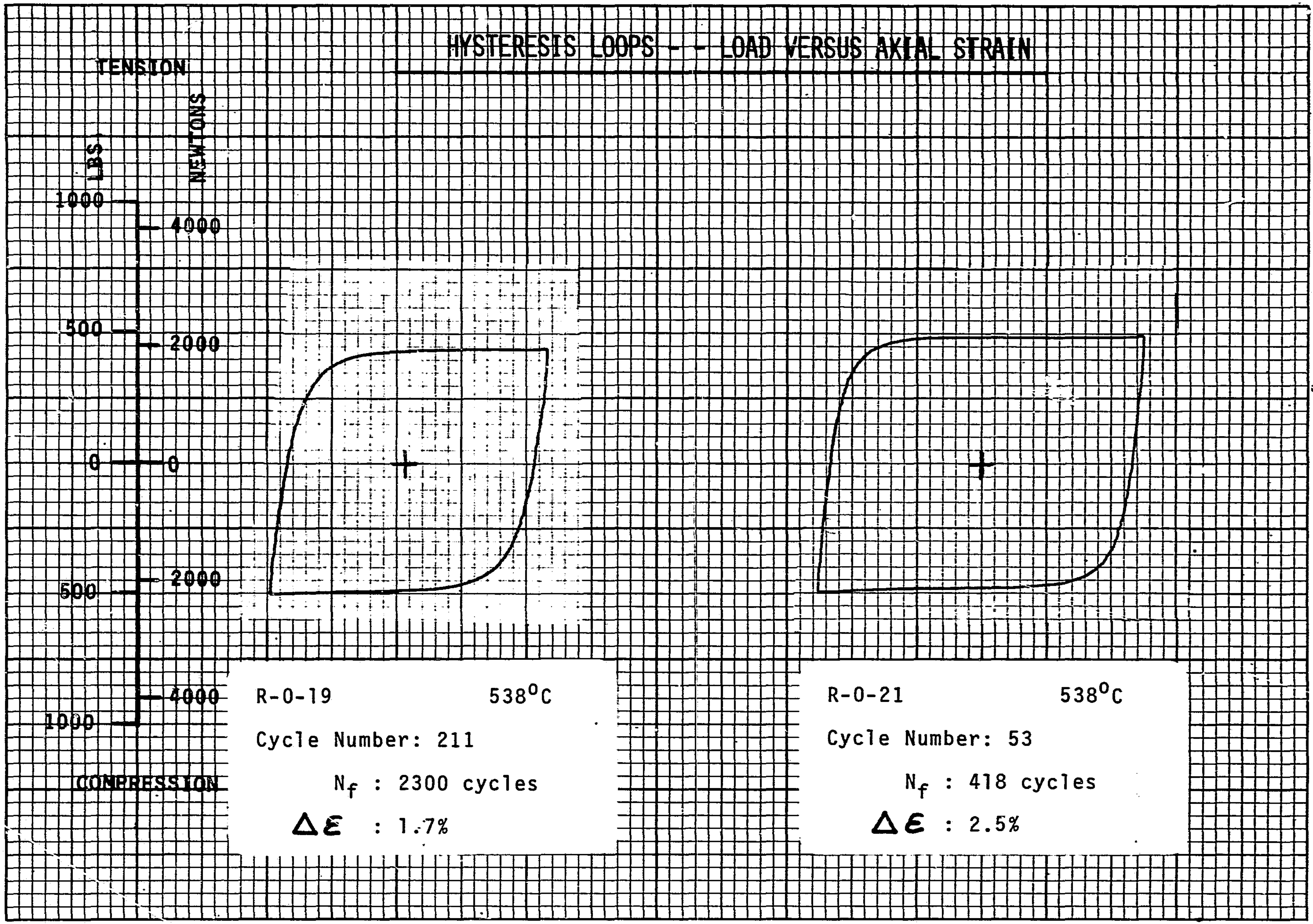

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-0-25
538°C
Cycle Number: 58
N_f: 283 cycles
ΔE : 3.5%
R-0-17
538°C
Cycle Number: 120
N_f: 307 cycles
ΔE : 3.0%

Figure 191



R-0-19 538^{o}C

Cycle Number: 211

N_f : 2300 cycles

$\Delta\varepsilon$: 1.7%

R-0-21 538^{o}C

Cycle Number: 53

N_f : 418 cycles

$\Delta\varepsilon$: 2.5%

Figure 192

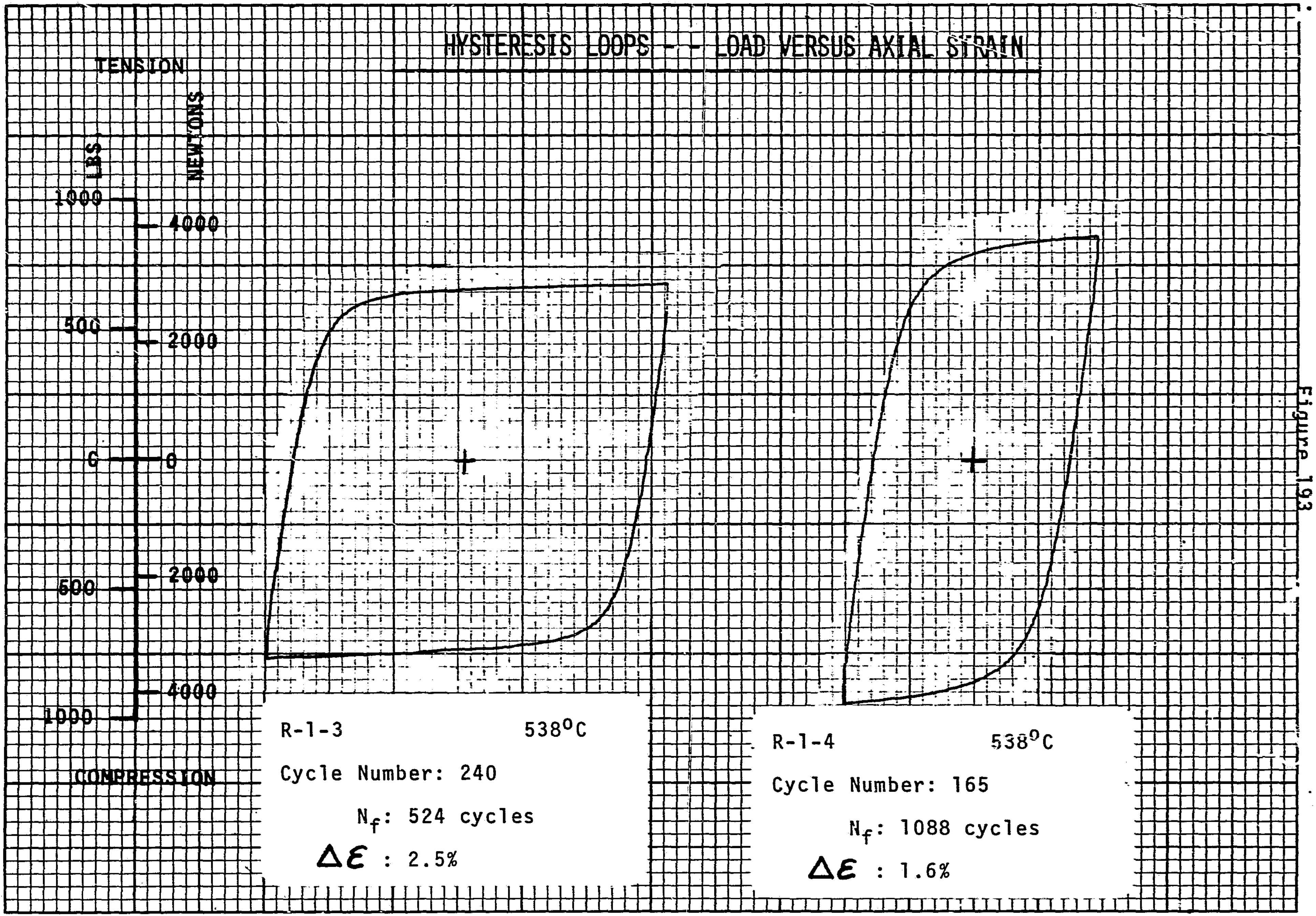

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-3
538°C
Cycle Number: 240
N_f: 524 cycles
$\Delta\varepsilon$: 2.5%
R-1-4
538°C
Cycle Number: 165
N_f: 1088 cycles
$\Delta\varepsilon$: 1.6%

Figure 193

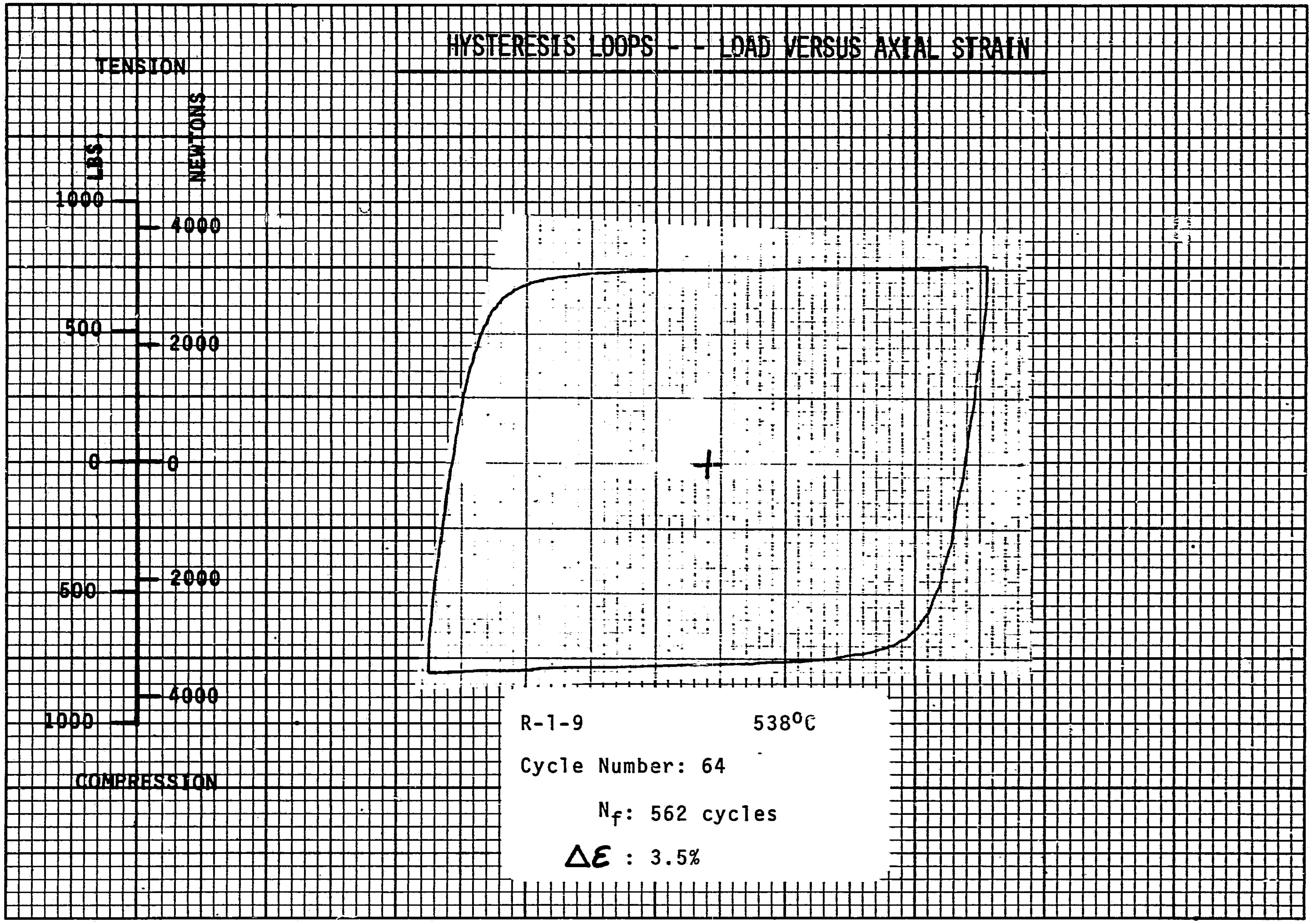

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-9
538^{o}C
Cycle Number: 64
N_f: 562 cycles
$\Delta\varepsilon$: 3.5%

Figure 194

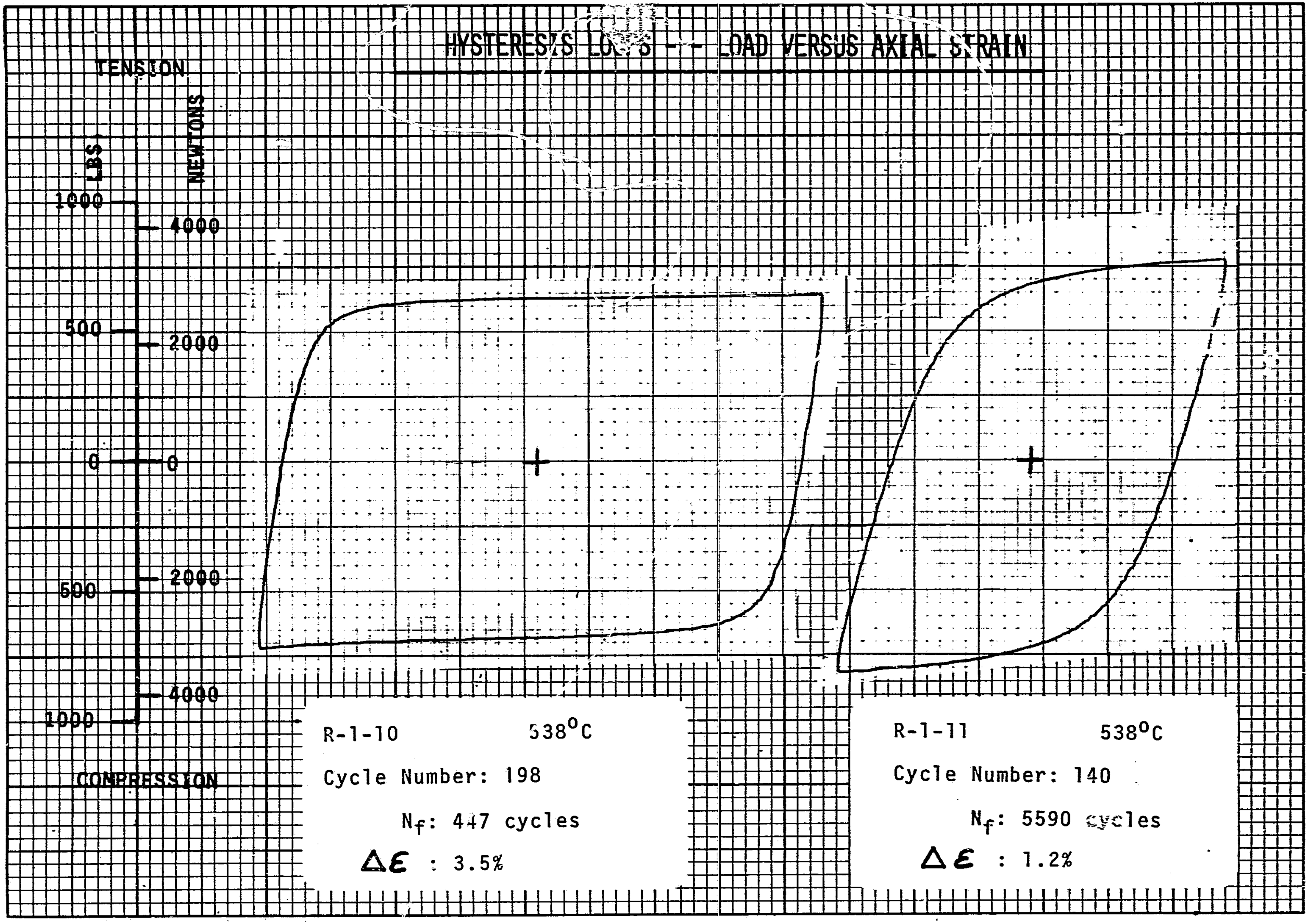

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-1-10
538°C
Cycle Number: 198
N_f: 447 cycles
Δε : 3.5%
R-1-11
538°C
Cycle Number: 140
N_f: 5590 cycles
Δε : 1.2%

Figure 195

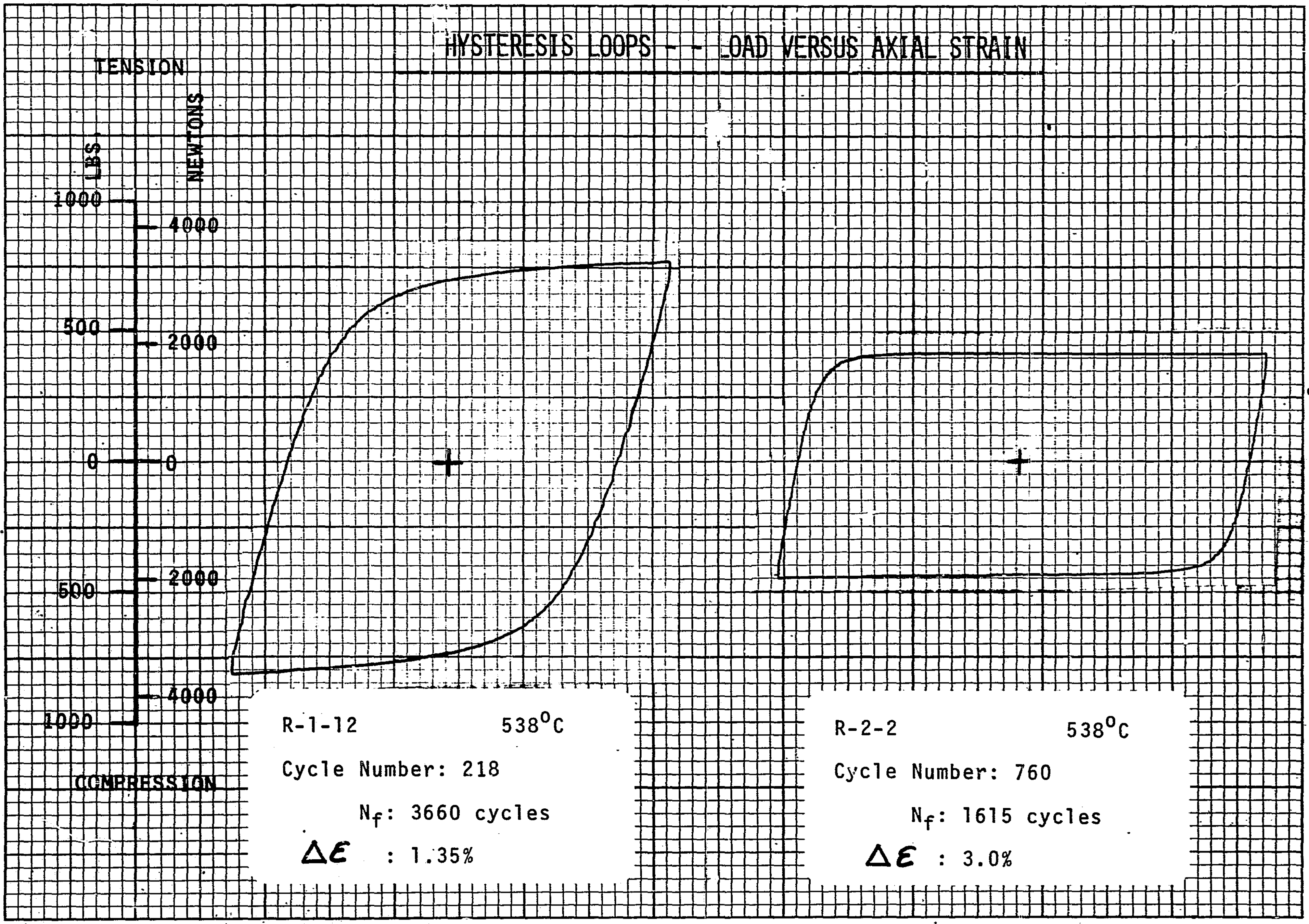

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-12
538°C
Cycle Number: 218
N_f: 3660 cycles
Δε : 1.35%
R-2-2
538°C
Cycle Number: 760
N_f: 1615 cycles
Δε : 3.0%

Figure 196

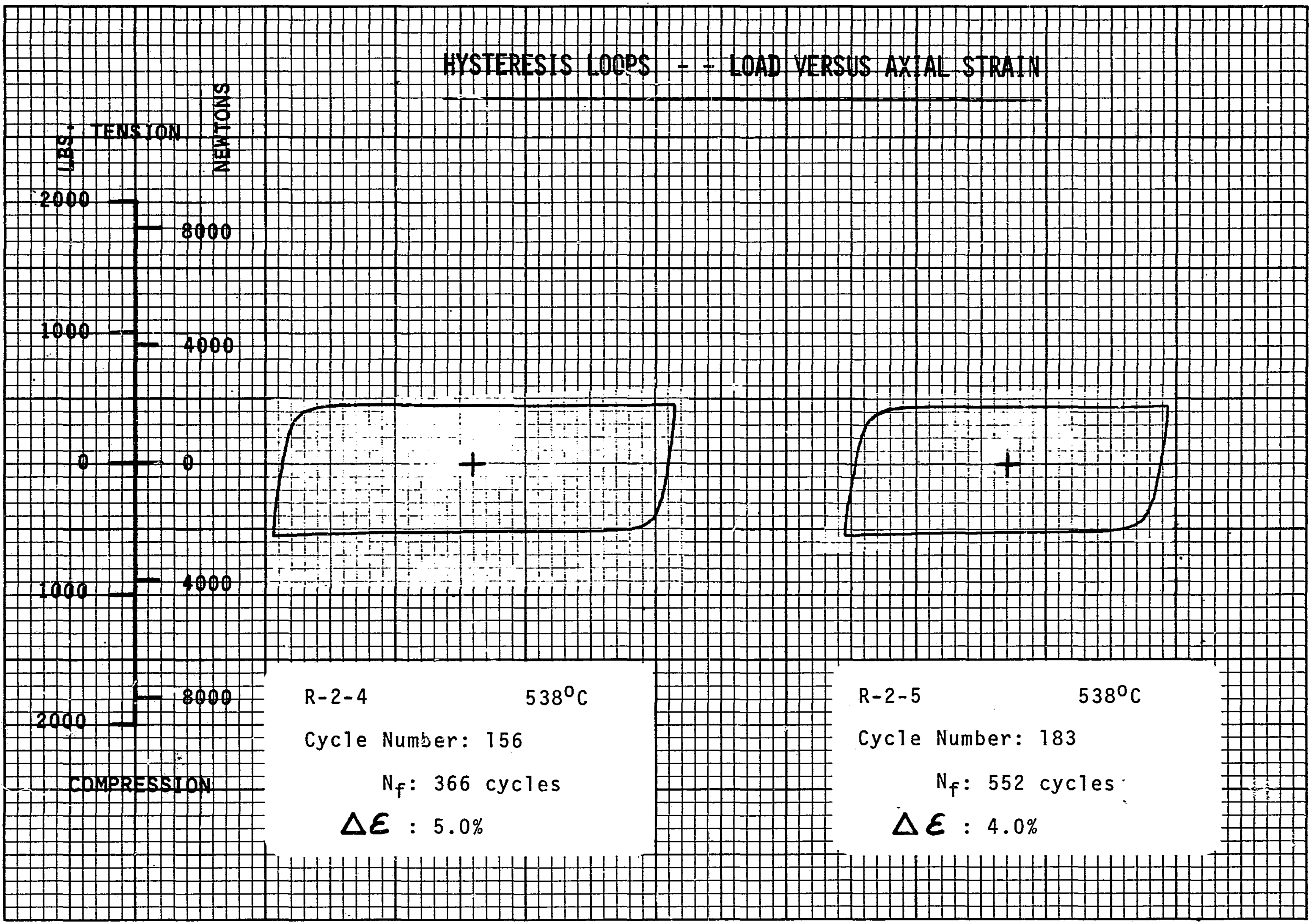

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-2-4 538°C
Cycle Number: 156
N_f: 366 cycles
Δε : 5.0%
R-2-5 538°C
Cycle Number: 183
N_f: 552 cycles
Δε : 4.0%

Figure 197

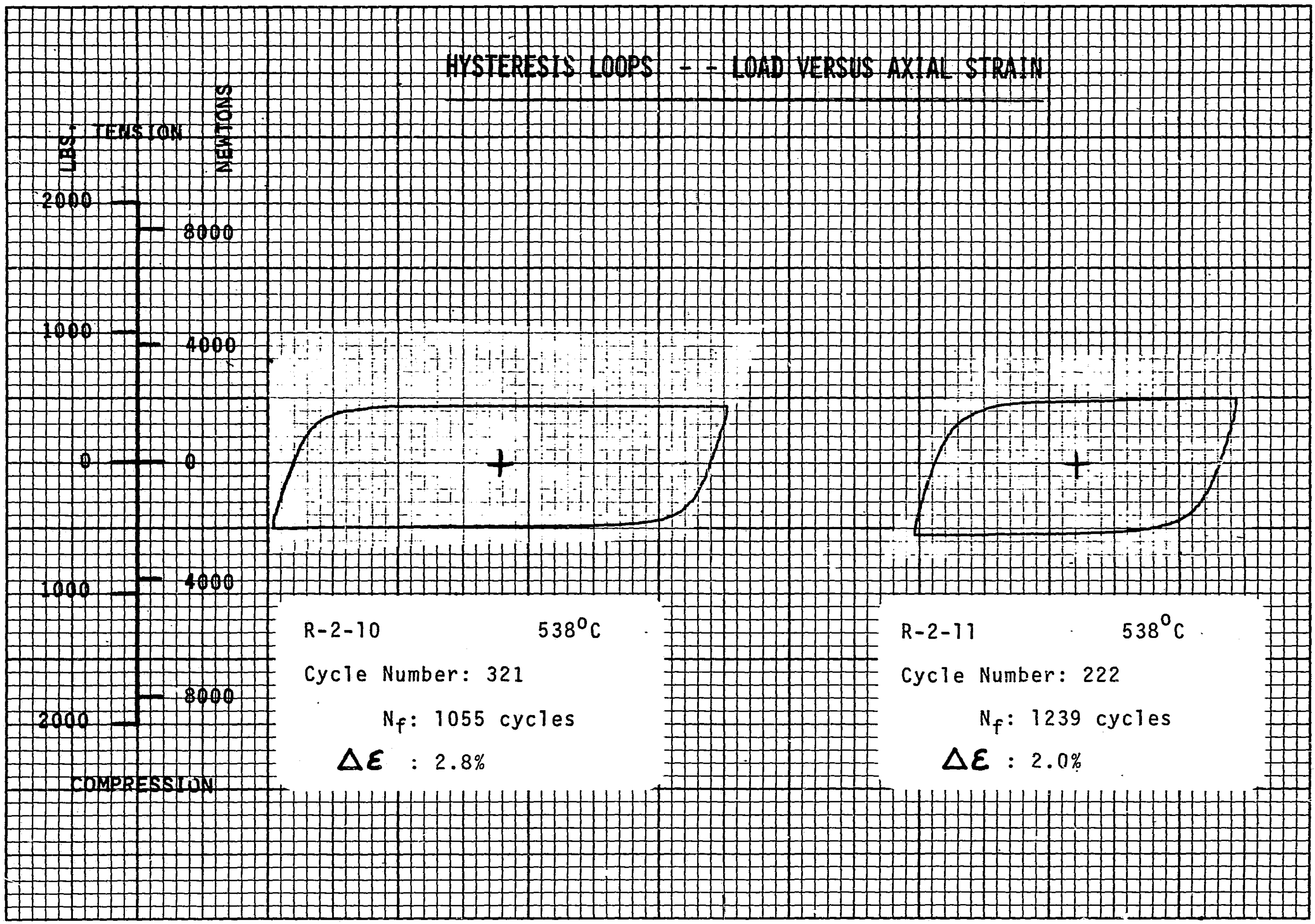

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-10 538°C
Cycle Number: 321
N_f: 1055 cycles
ΔE : 2.8%
R-2-11 538°C
Cycle Number: 222
N_f: 1239 cycles
ΔE : 2.0%

Figure 198

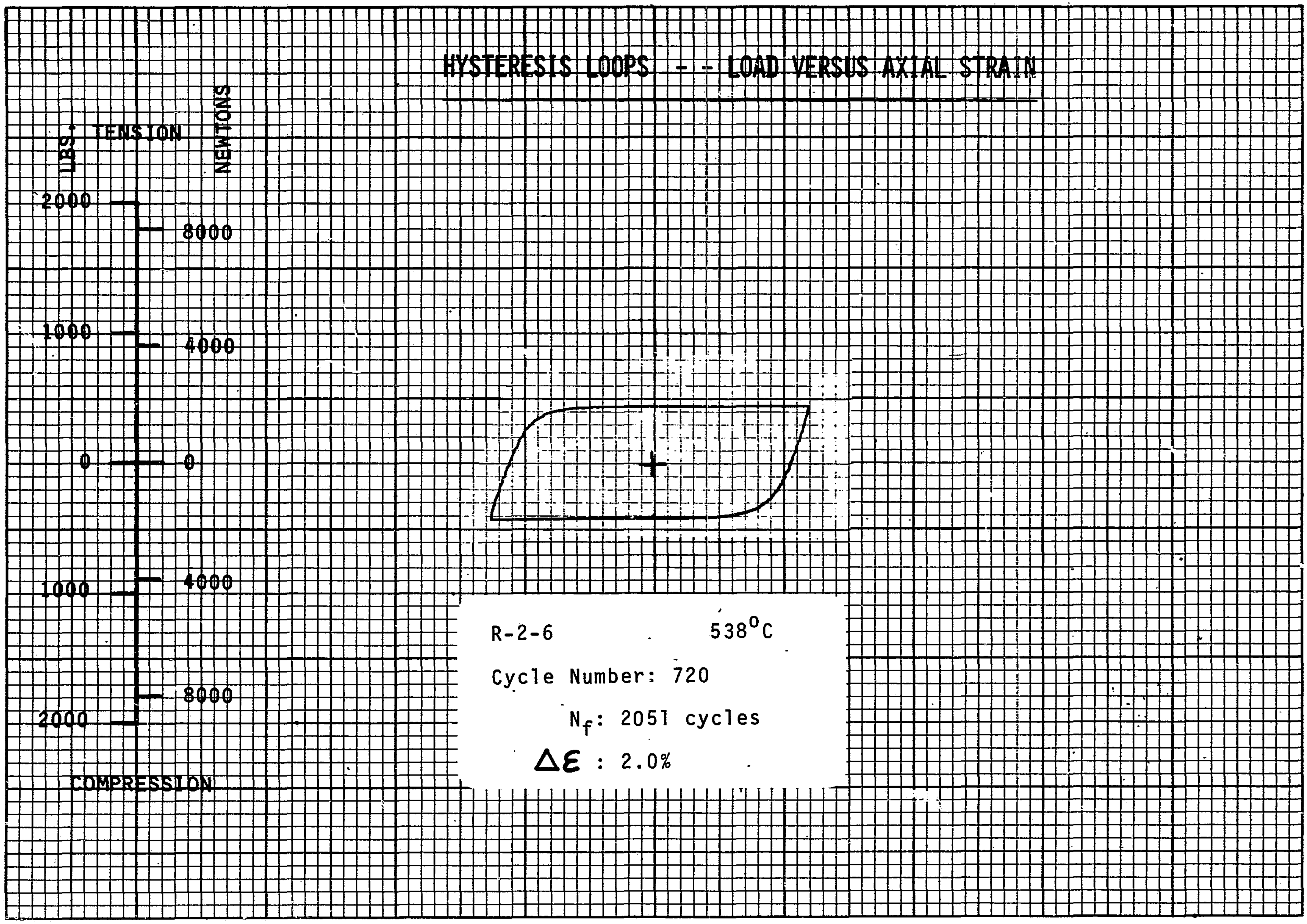

HYSTERESIS LOOPS -- LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-6
538°C
Cycle Number: 720
Nf: 2051 cycles
Δε : 2.0%

Figure 199

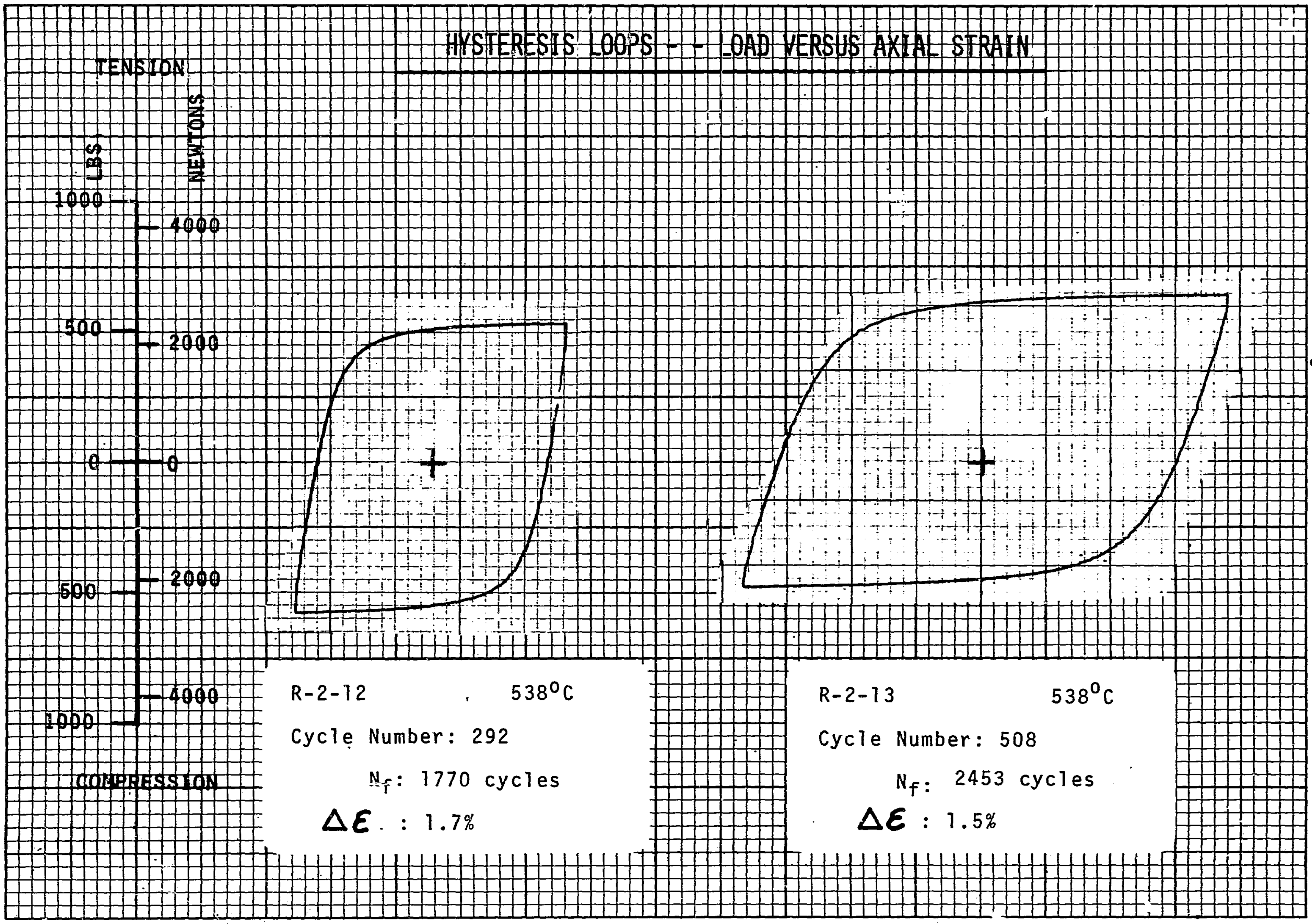
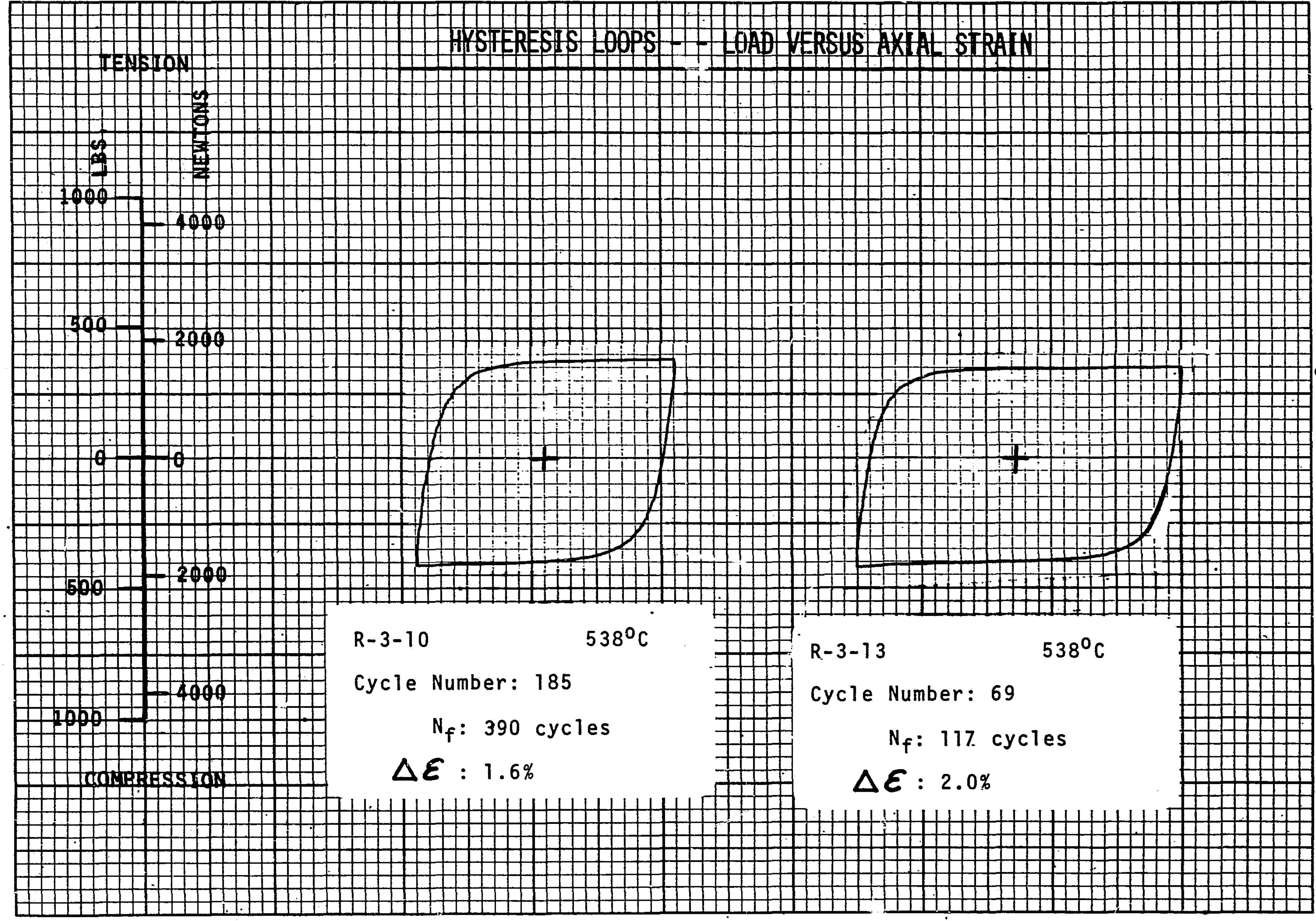


Figure 200

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-12
538°C
Cycle Number: 292
Nf: 1770 cycles
Δε : 1.7%
R-2-13
538°C
Cycle Number: 508
Nf: 2453 cycles
Δε : 1.5%



R-3-10 538°C

Cycle Number: 185

N_f: 390 cycles

$\Delta\varepsilon$: 1.6%

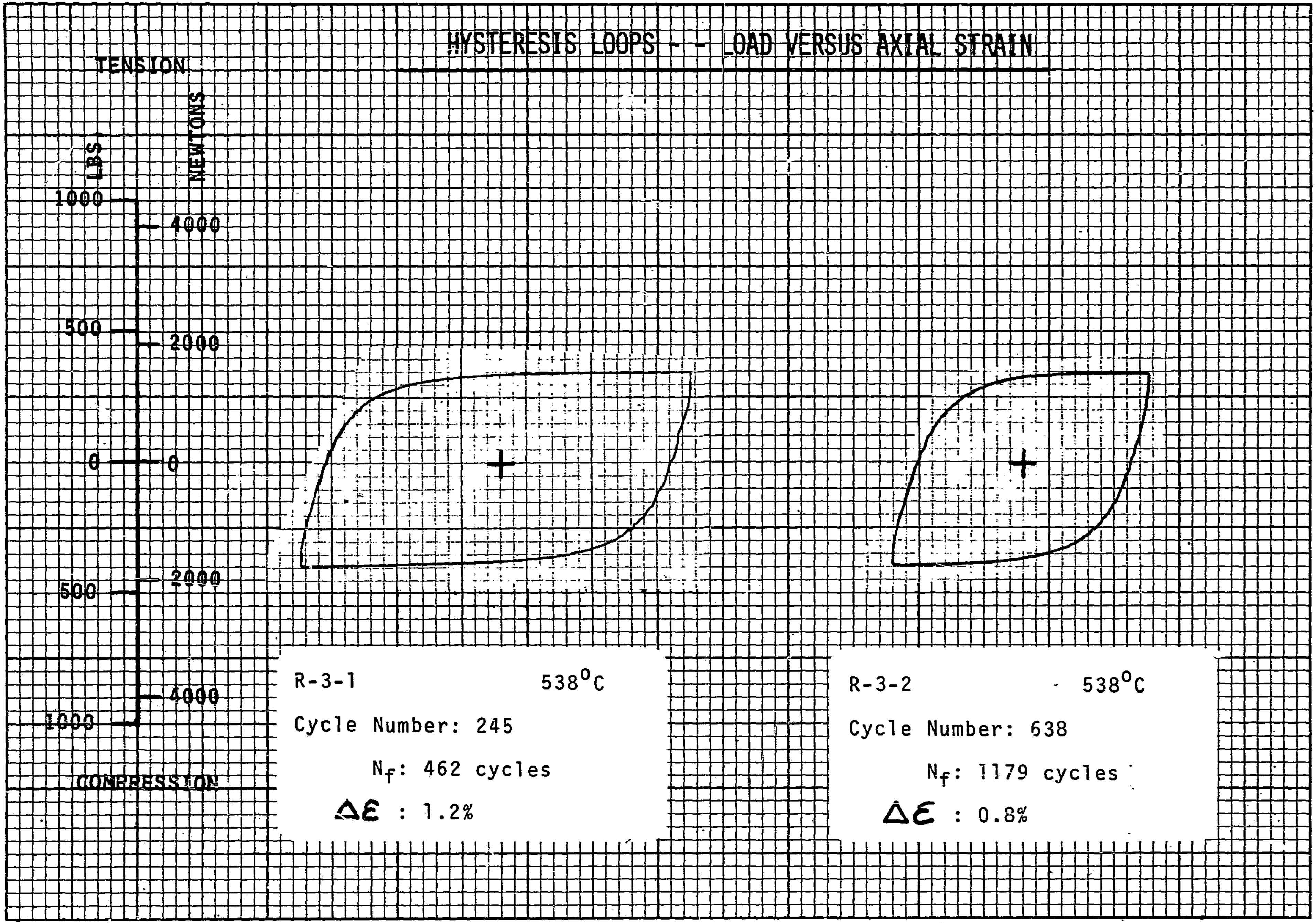
R-3-13 538°C

Cycle Number: 69

N_f: 117 cycles

$\Delta\varepsilon$: 2.0%

Figure 201



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-3-1 538°C

Cycle Number: 245

N_f: 462 cycles

$\Delta\varepsilon$: 1.2%

R-3-2 538°C

Cycle Number: 638

N_f: 1179 cycles

$\Delta\varepsilon$: 0.8%

Figure 202

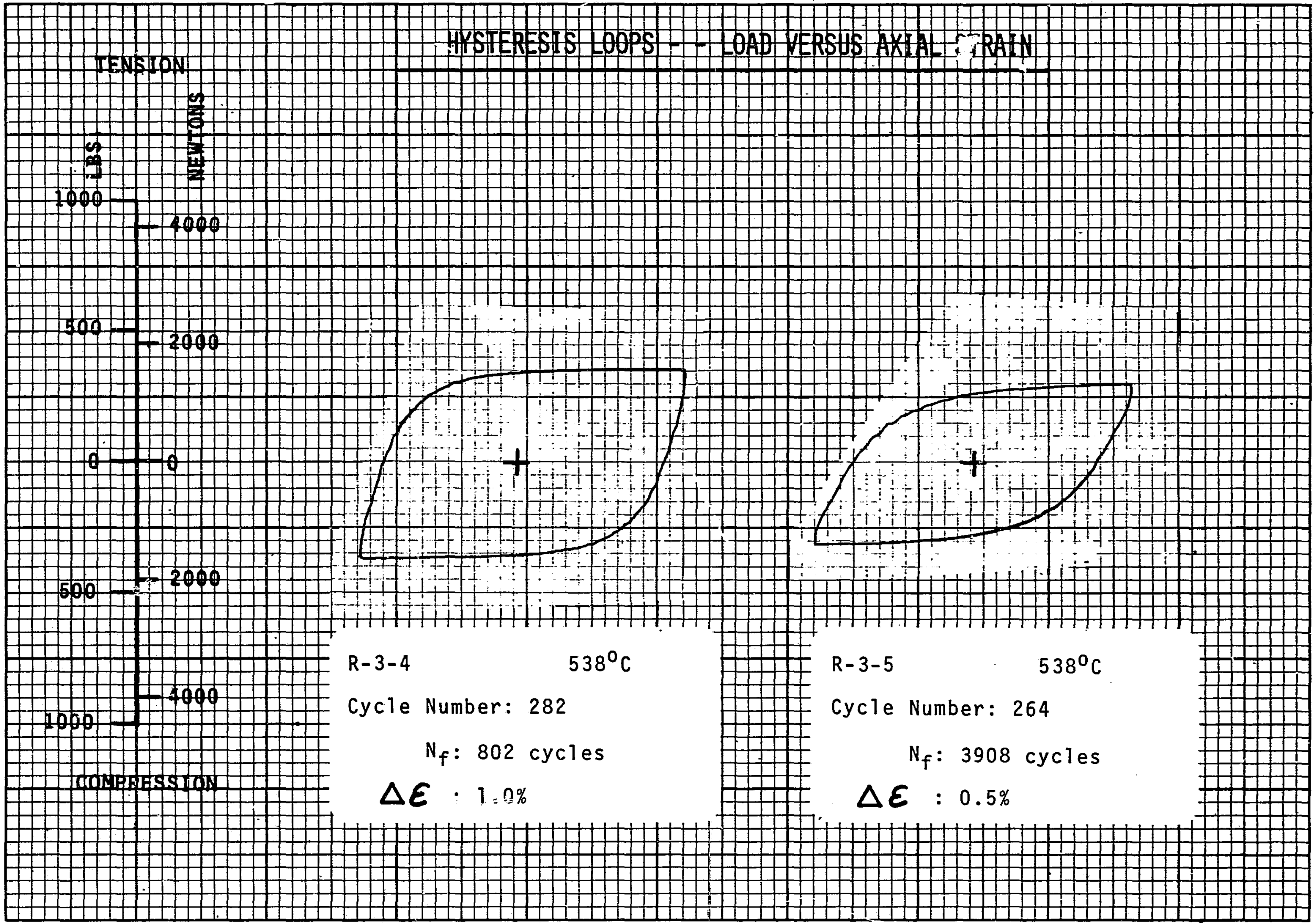

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-3-4
538°C
Cycle Number: 282
N_f: 802 cycles
$\Delta\varepsilon$: 1.0%
R-3-5
538°C
Cycle Number: 264
N_f: 3908 cycles
$\Delta\varepsilon$: 0.5%

Figure 203

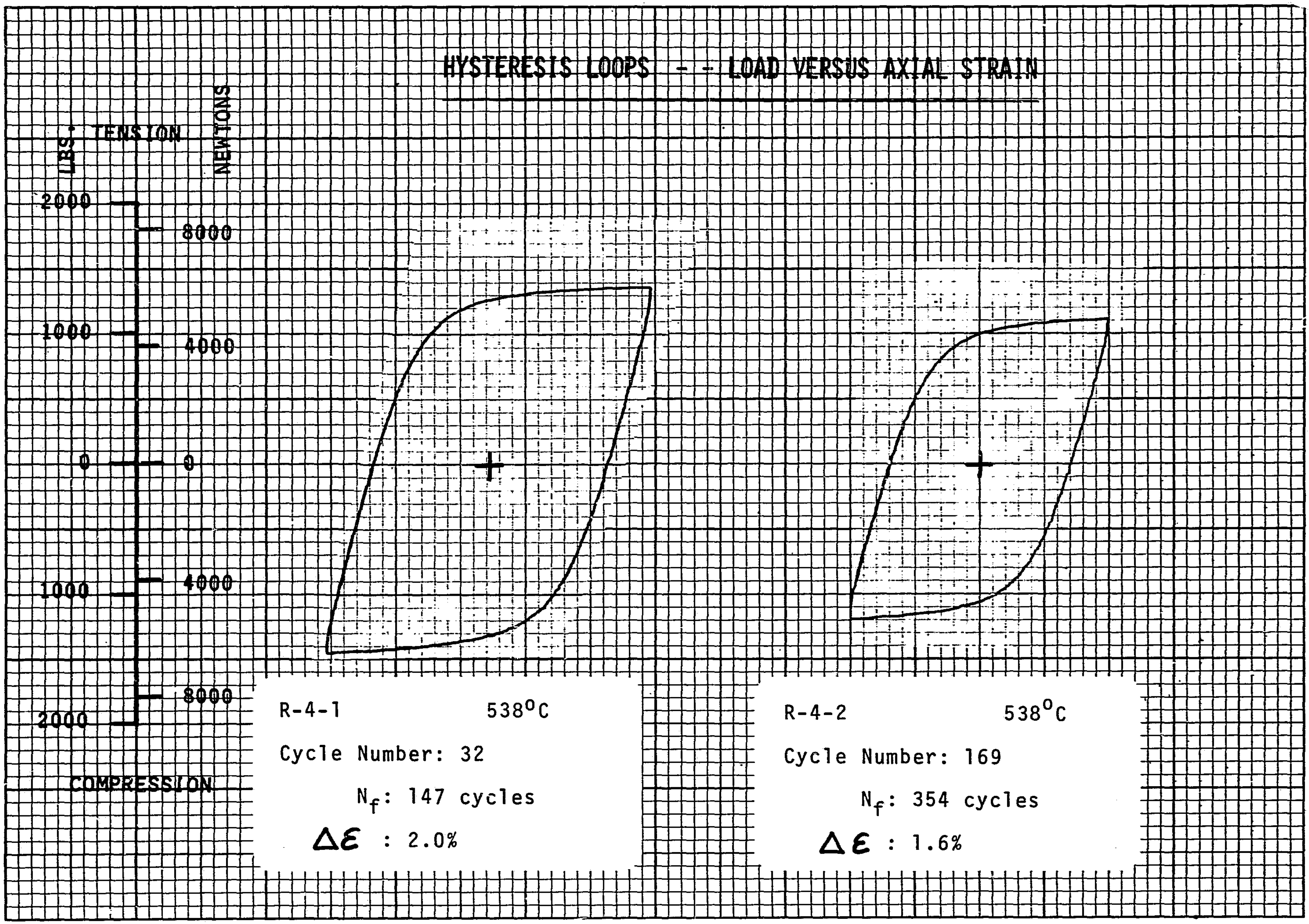
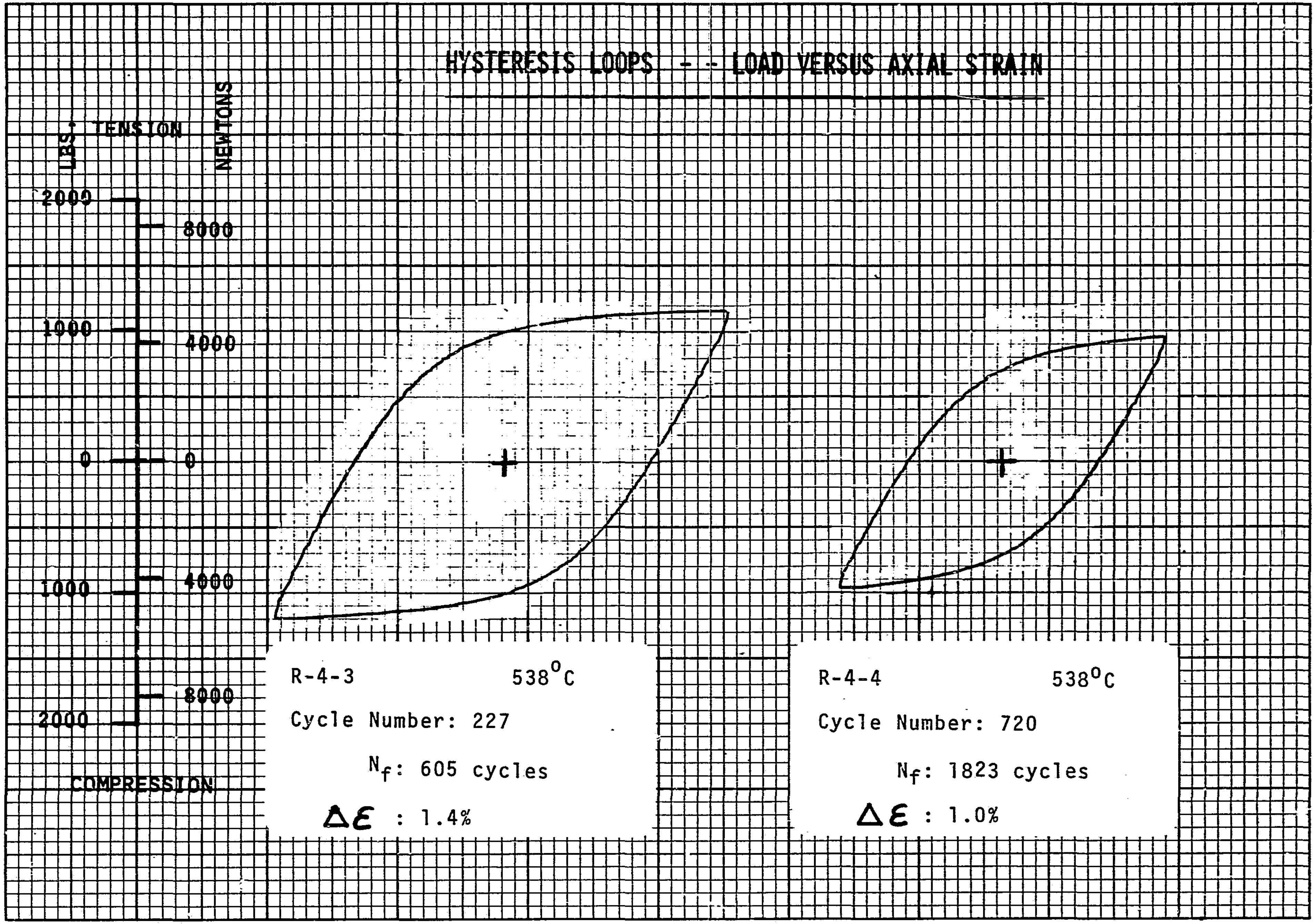

HYSTERESIS LOOPS -- LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-4-1 538°C
Cycle Number: 32
N_f: 147 cycles
Δε : 2.0%
R-4-2 538°C
Cycle Number: 169
N_f: 354 cycles
Δε : 1.6%

Figure 204

HYSTERESIS LOOPS -- LOAD VERSUS AXIAL STRAIN



R-4-3 538^{o}C

Cycle Number: 227

N_f: 605 cycles

$\Delta\varepsilon$: 1.4%

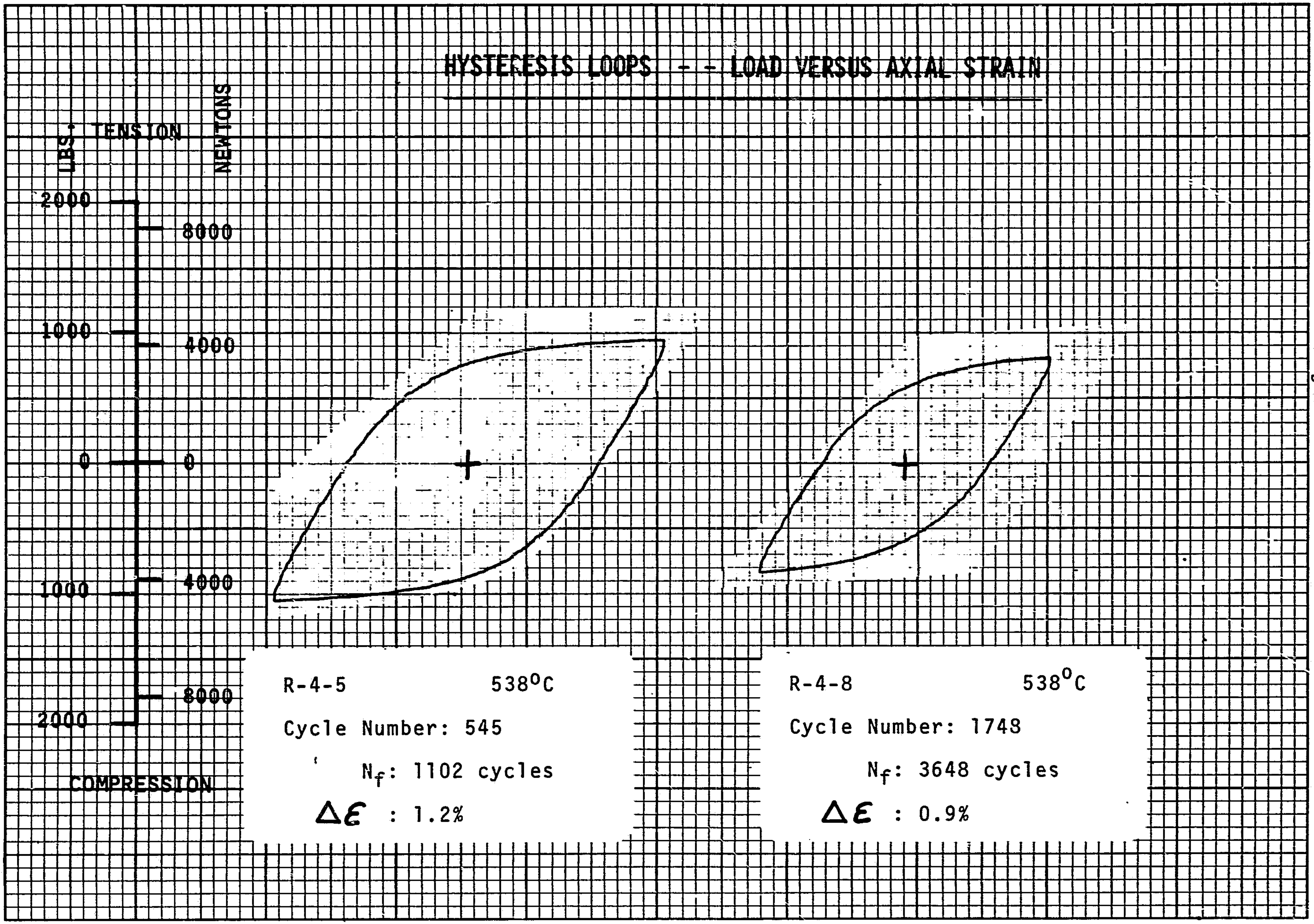
R-4-4 538^{o}C

Cycle Number: 720

N_f: 1823 cycles

$\Delta\varepsilon$: 1.0%

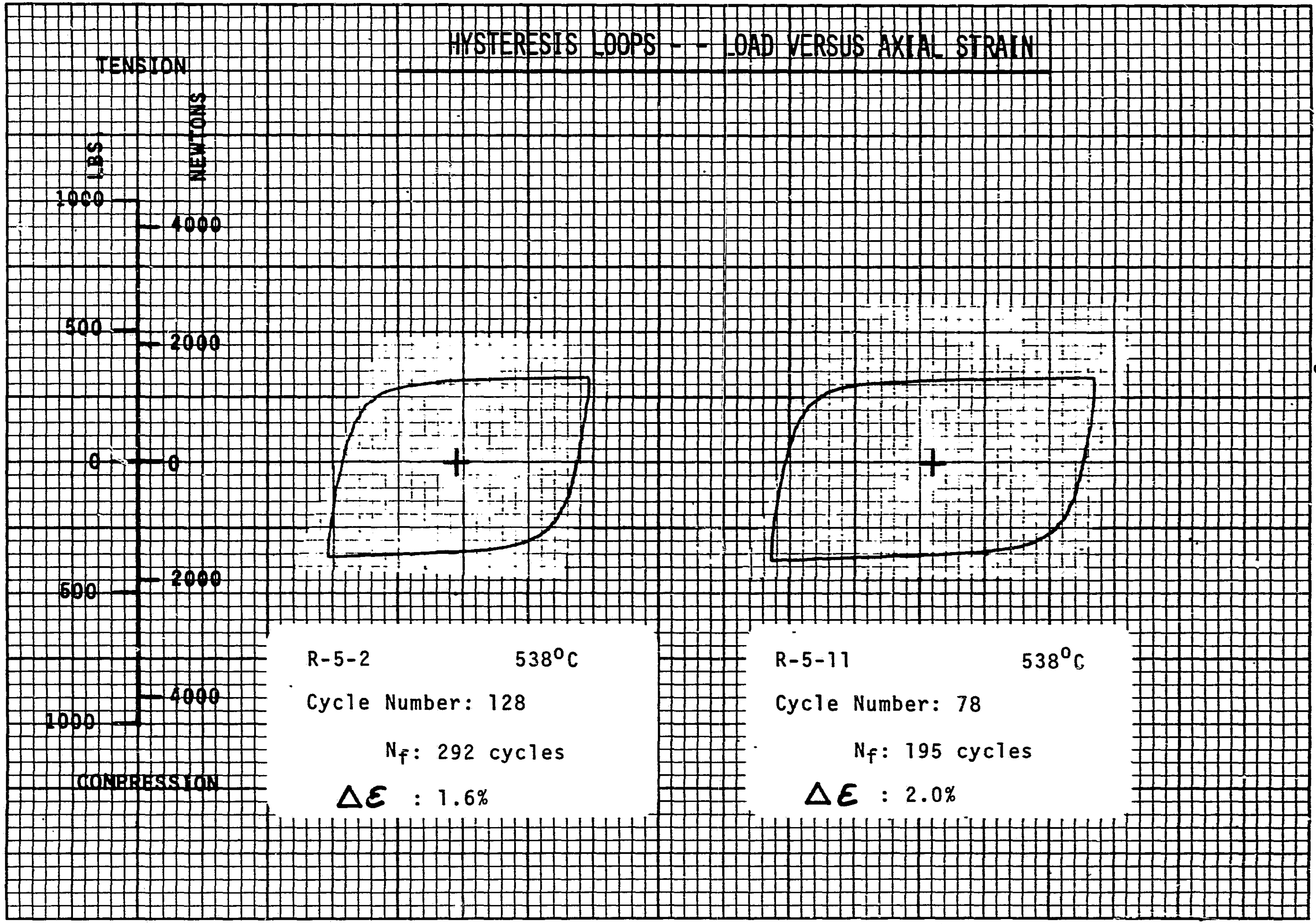
Figure 205


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-4-5 538°C
Cycle Number: 545
N_f: 1102 cycles
$\Delta\varepsilon$: 1.2%

R-4-8 538°C
Cycle Number: 1748
N_f: 3648 cycles
$\Delta\varepsilon$: 0.9%

Figure 206



R-5-2 538°C

Cycle Number: 128

N_f: 292 cycles

$\Delta\varepsilon$: 1.6%

R-5-11 538°C

Cycle Number: 78

N_f: 195 cycles

$\Delta\varepsilon$: 2.0%

Figure 207

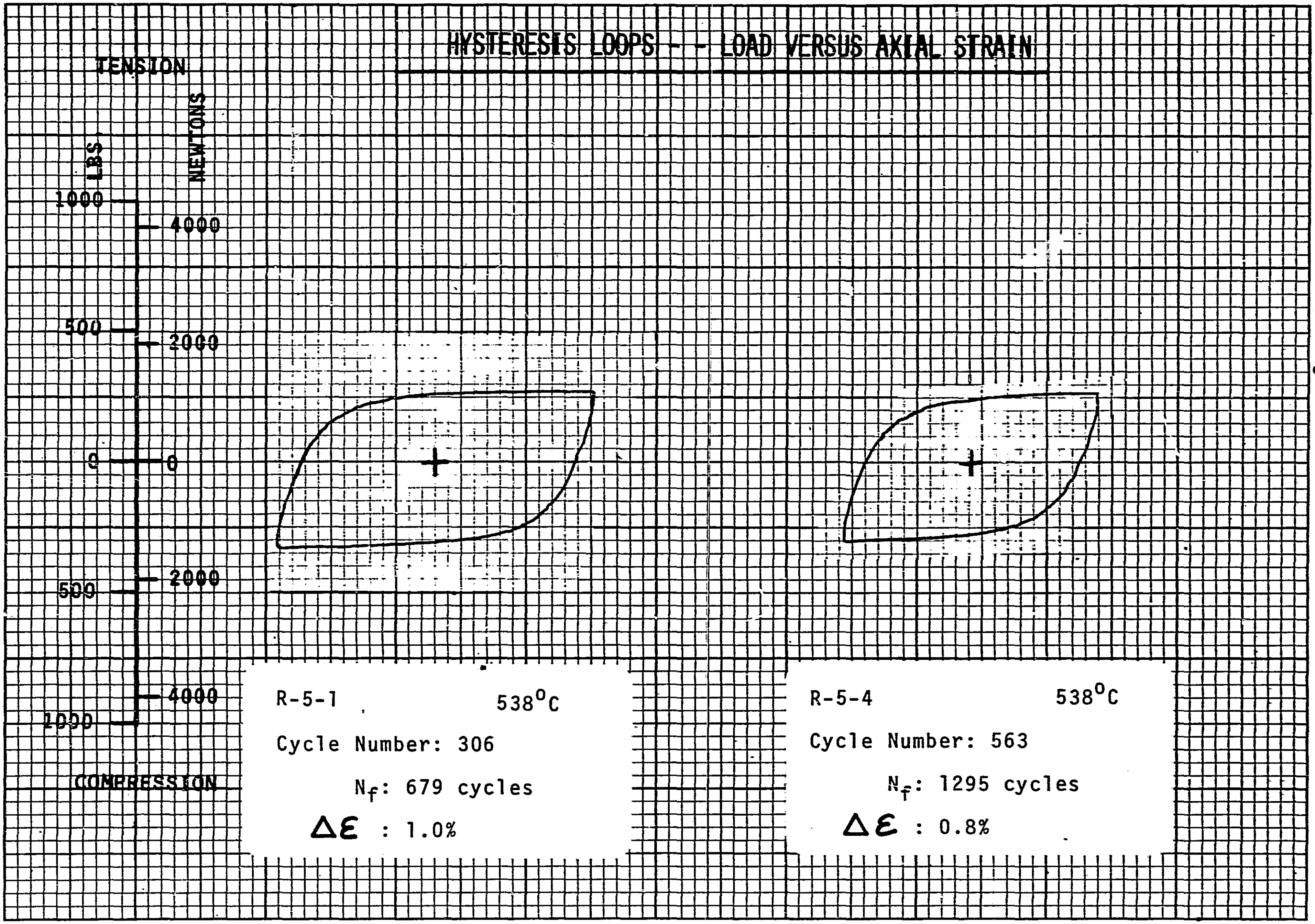

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-5-1
538°C
Cycle Number: 306
N_f: 679 cycles
$\Delta\varepsilon$: 1.0%
R-5-4
538°C
Cycle Number: 563
N_f: 1295 cycles
$\Delta\varepsilon$: 0.8%

Figure 208

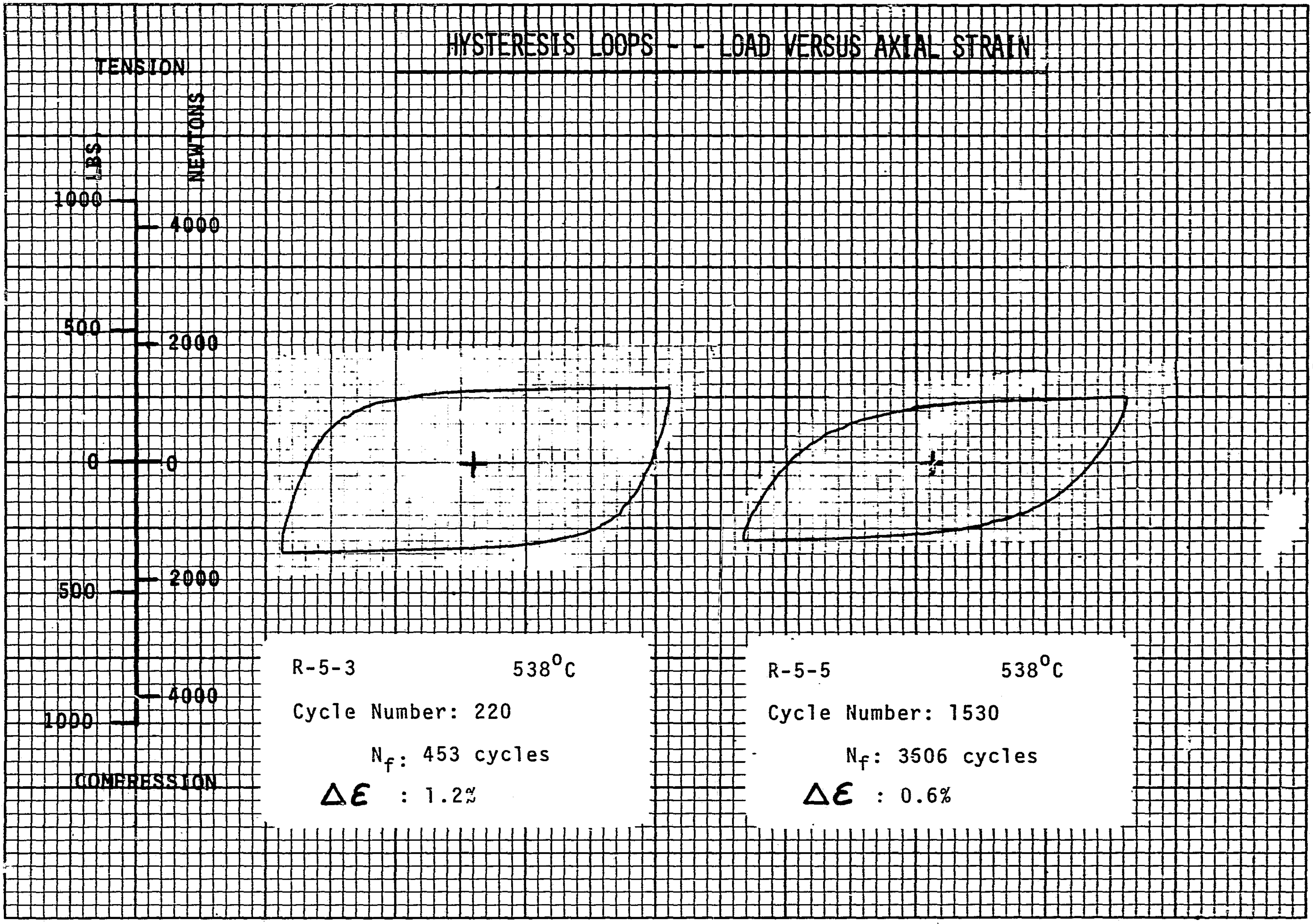

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-5-3 538°C
Cycle Number: 220
N_f: 453 cycles
$\Delta\varepsilon$: 1.2%
R-5-5 538°C
Cycle Number: 1530
N_f: 3506 cycles
$\Delta\varepsilon$: 0.6%

Figure 209

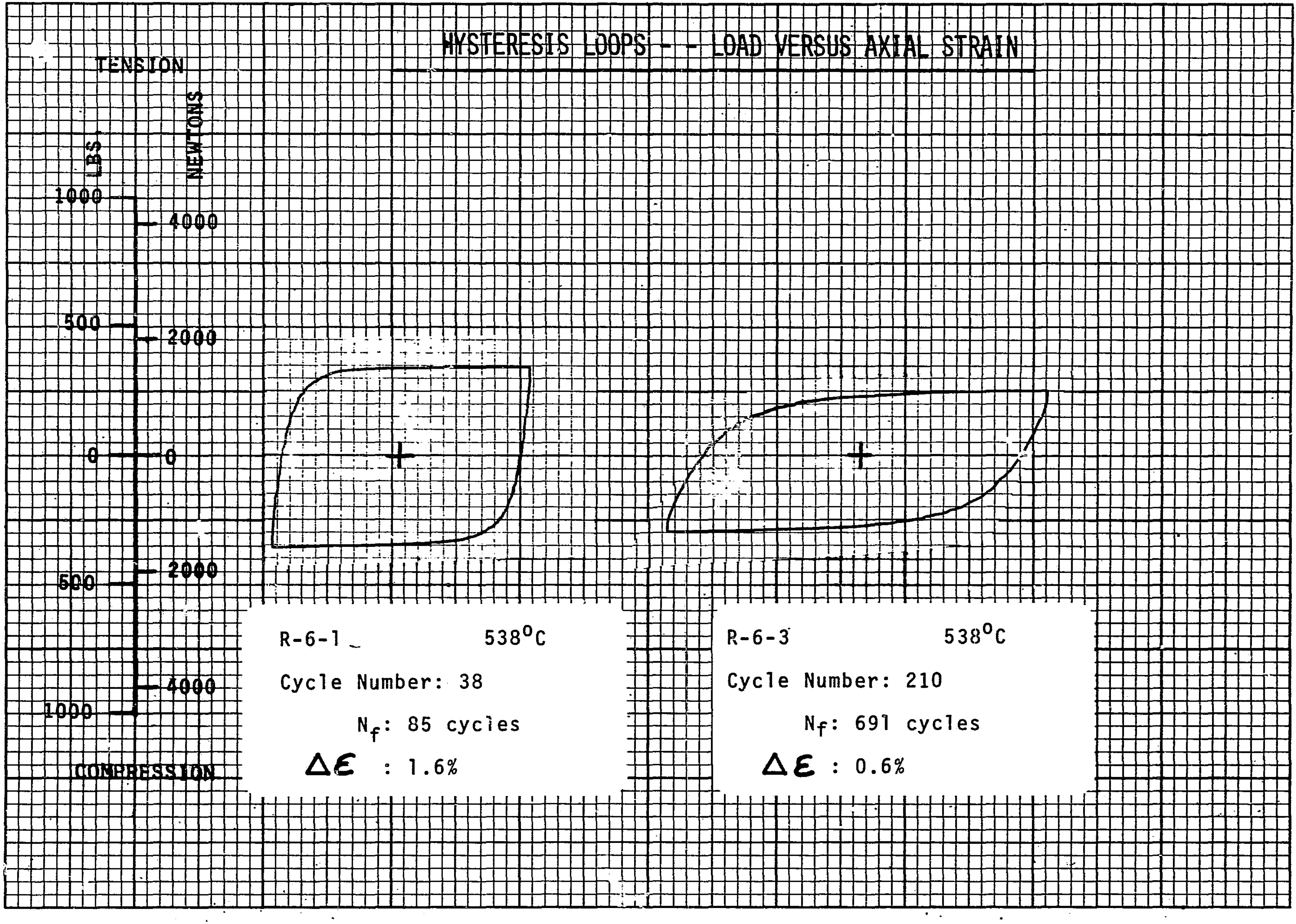

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-1
538°C
Cycle Number: 38
N_f: 85 cycles
ΔE : 1.6%
R-6-3
538°C
Cycle Number: 210
N_f: 691 cycles
ΔE : 0.6%

Figure 210

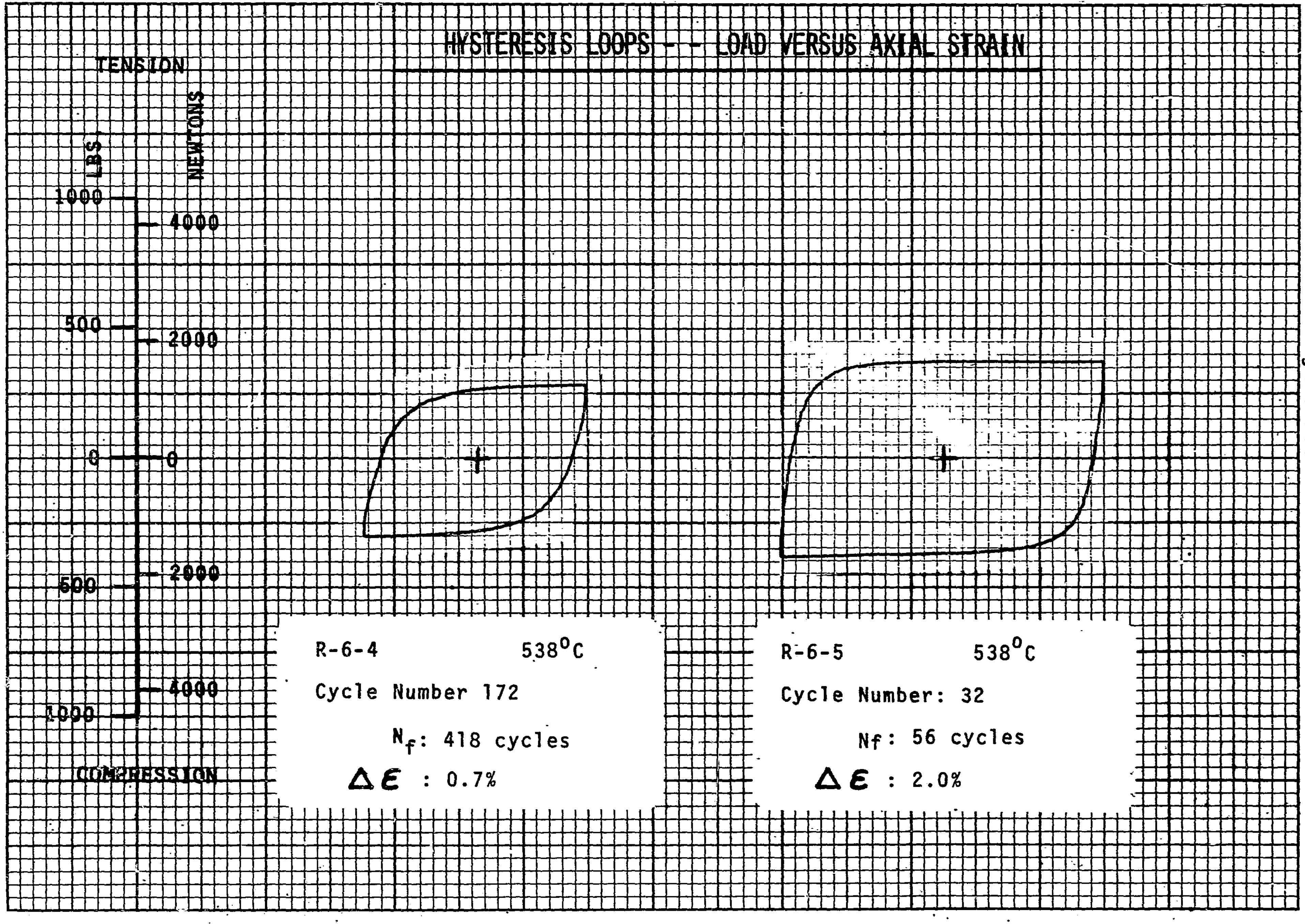

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-4 538°C
Cycle Number 172
N_f: 418 cycles
$\Delta\varepsilon$: 0.7%
R-6-5 538°C
Cycle Number: 32
Nf: 56 cycles
$\Delta\varepsilon$: 2.0%

Figure 211

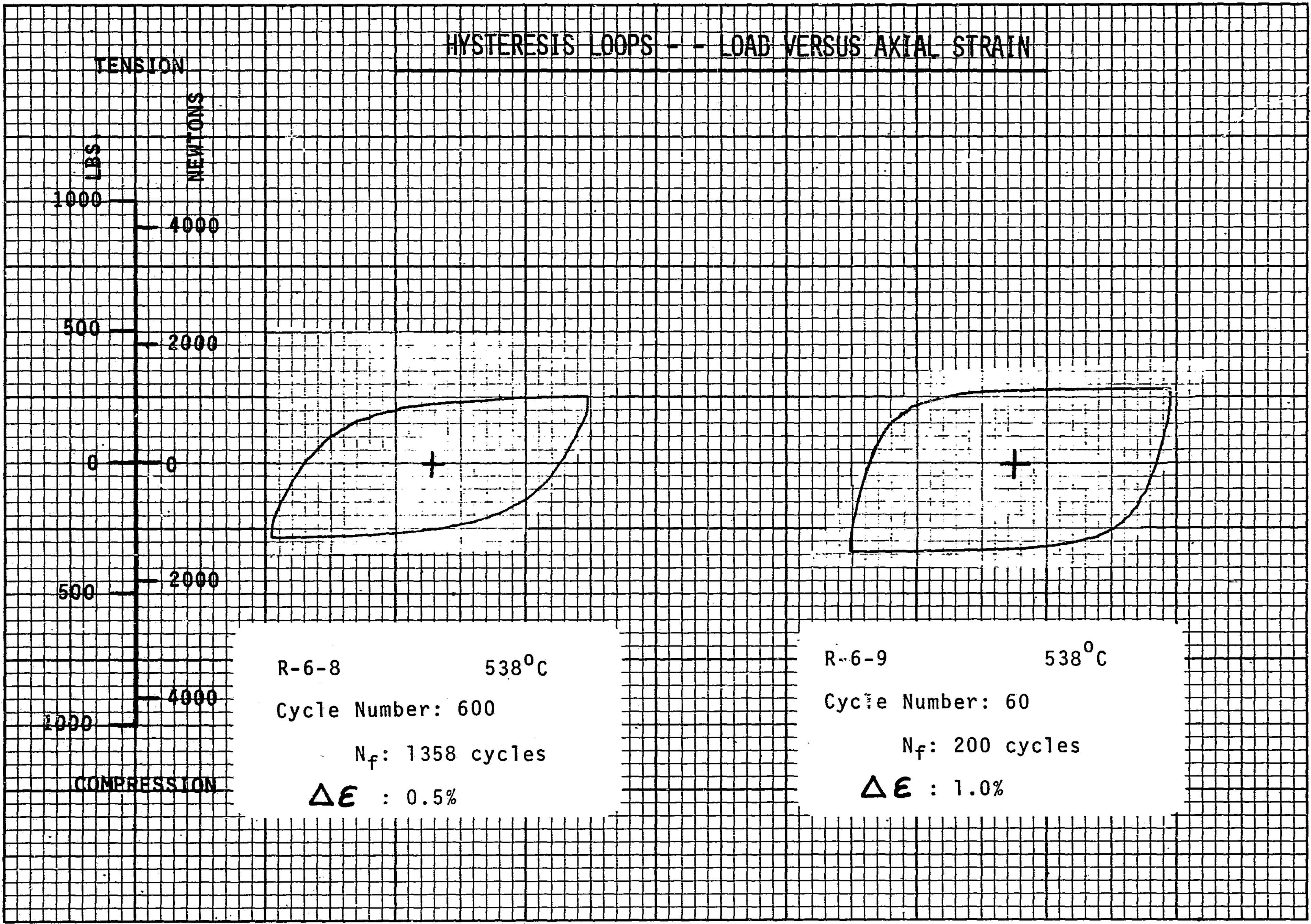

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-8
538°C
Cycle Number: 600
N$_f$: 1358 cycles
$\Delta\varepsilon$: 0.5%
R-6-9
538°C
Cycle Number: 60
N$_f$: 200 cycles
$\Delta\varepsilon$: 1.0%

Figure 212

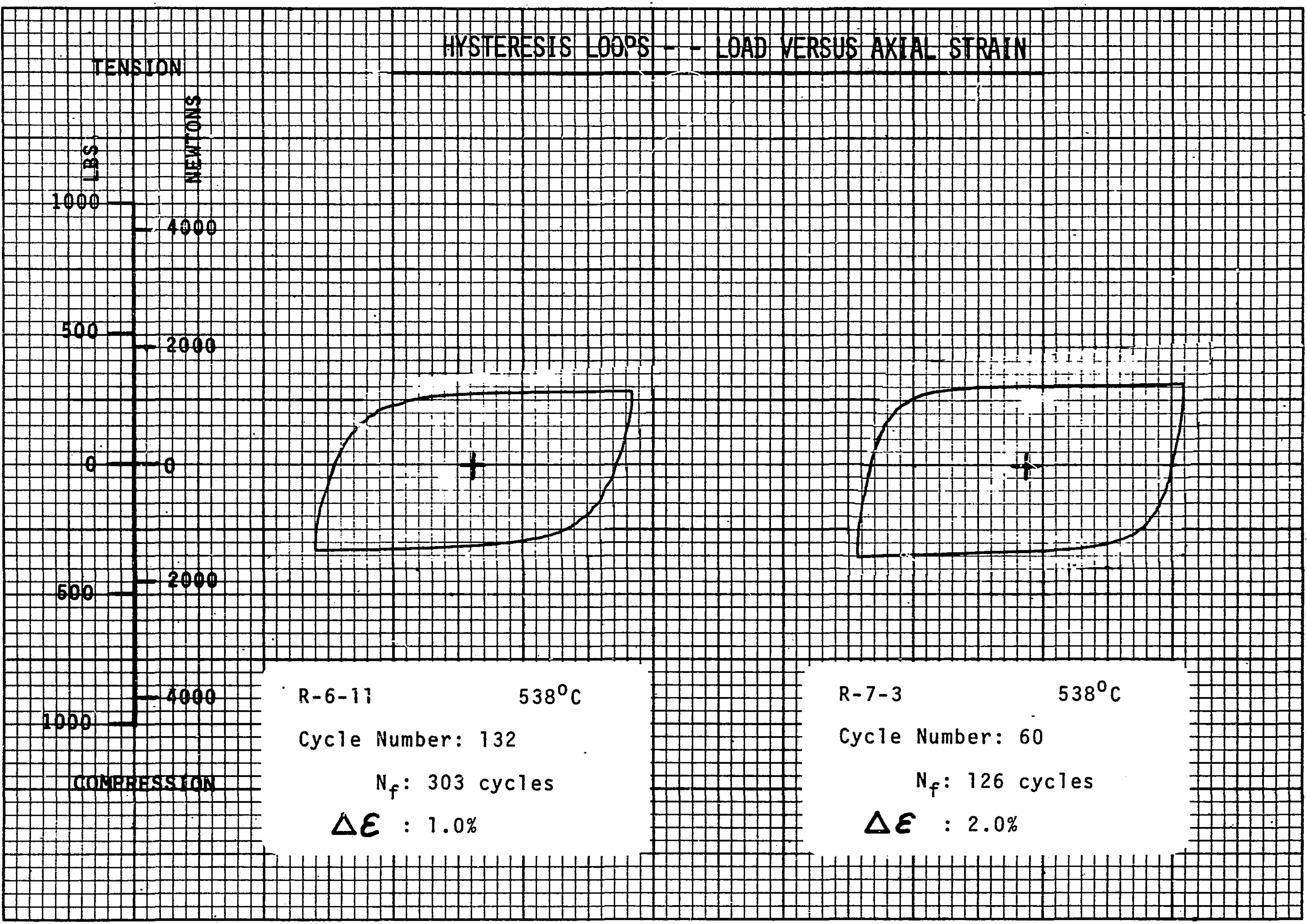

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-11
538°C
Cycle Number: 132
N_f: 303 cycles
Δε : 1.0%
R-7-3
538°C
Cycle Number: 60
N_f: 126 cycles
Δε : 2.0%

Figure 213

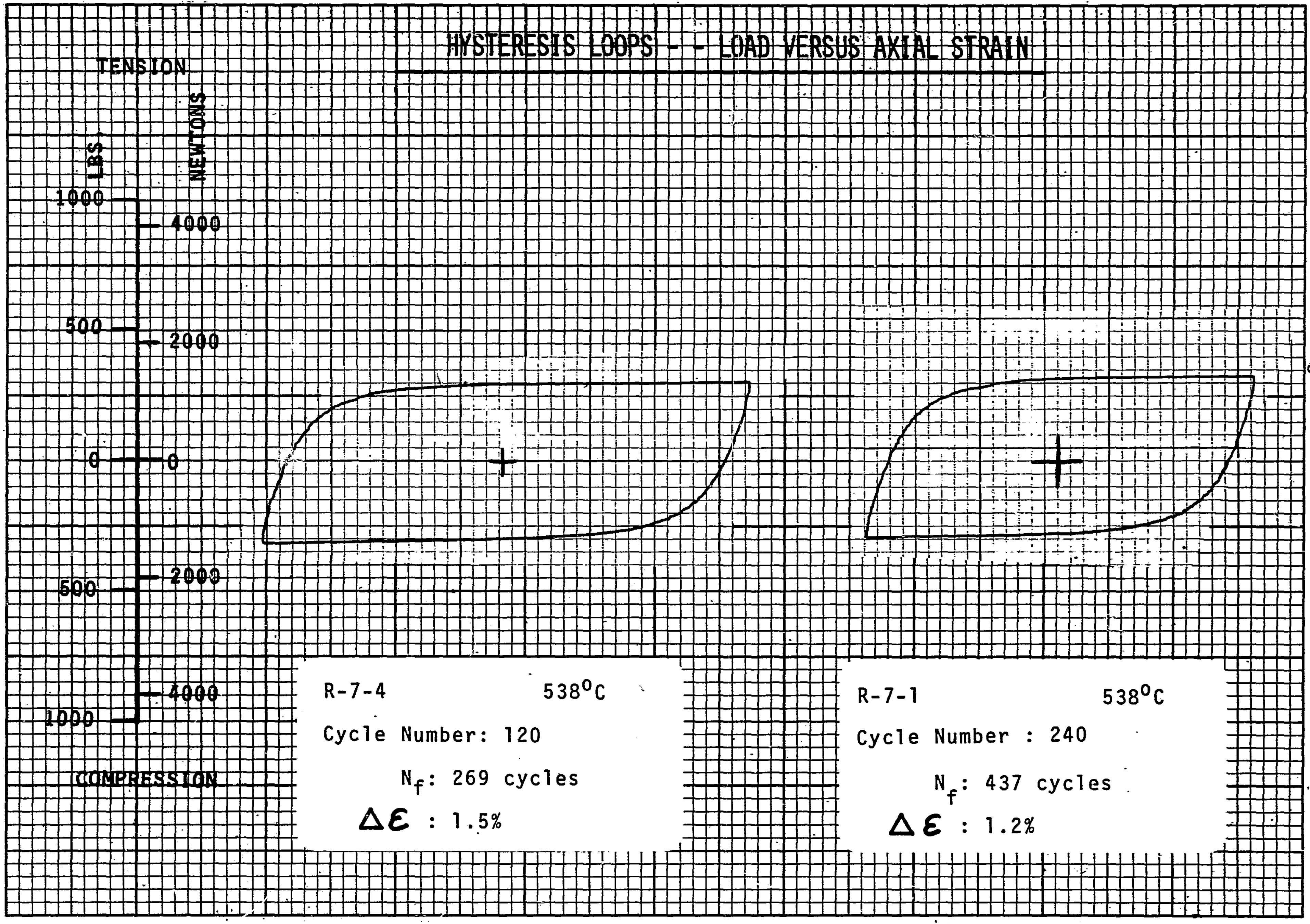
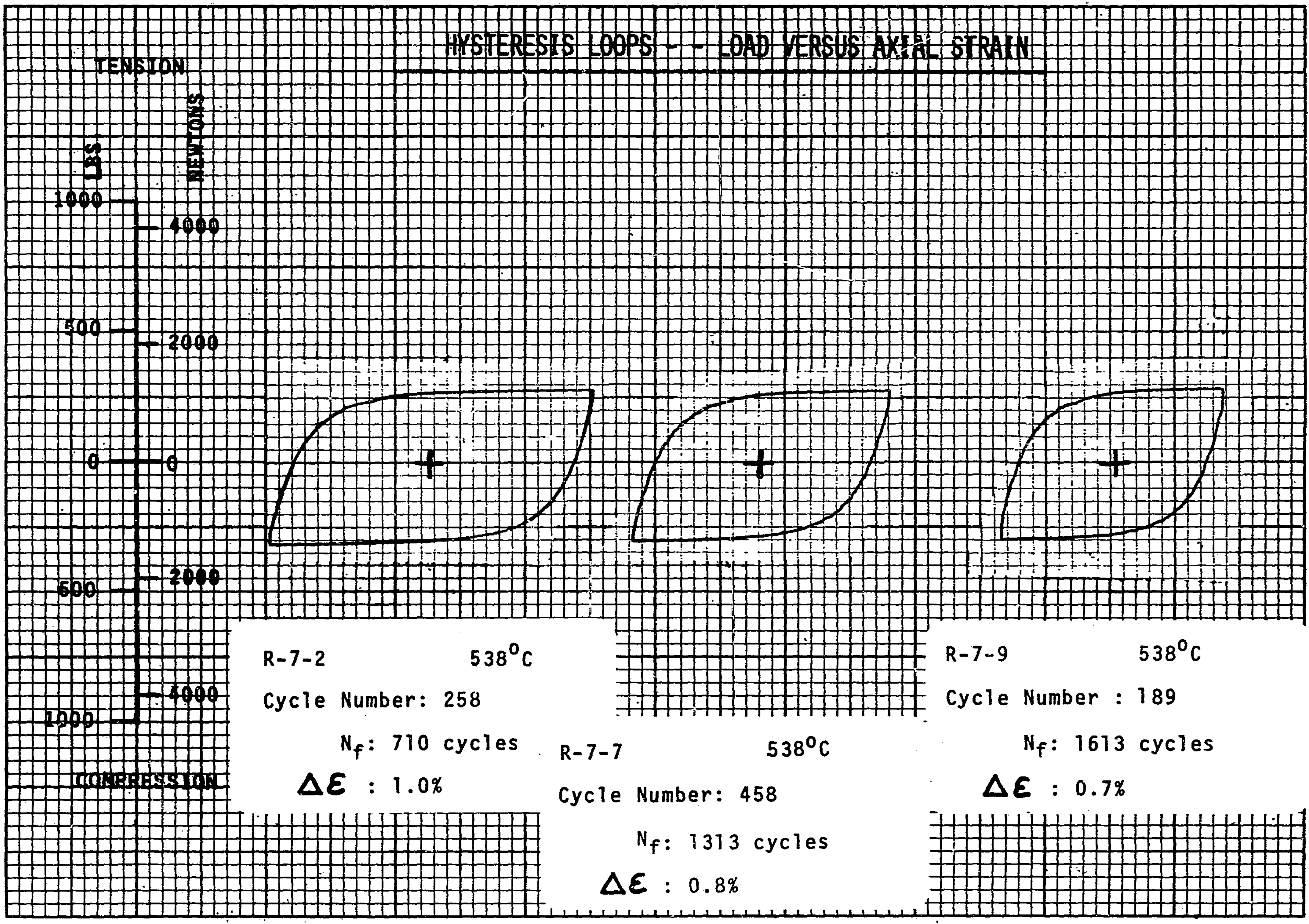

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-7-4
538°C
Cycle Number: 120
N_f: 269 cycles
ΔΕ : 1.5%
R-7-1
538°C
Cycle Number : 240
N_f: 437 cycles
ΔΕ : 1.2%

Figure 214



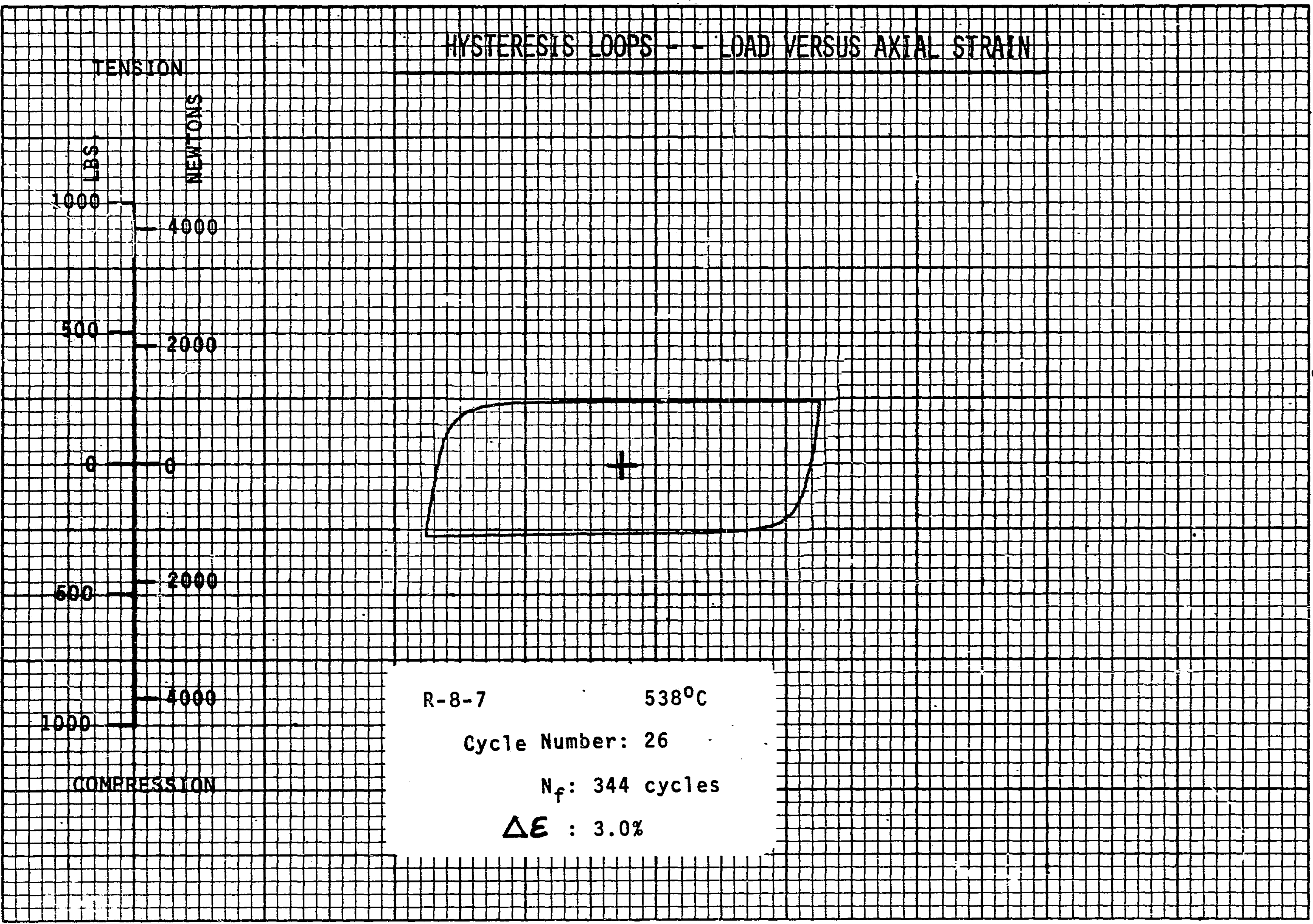
HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-7-2 538°C
Cycle Number: 258
N_f: 710 cycles
$\Delta\varepsilon$: 1.0%

R-7-7 538°C
Cycle Number: 458
N_f: 1313 cycles
$\Delta\varepsilon$: 0.8%

R-7-9 538°C
Cycle Number : 189
N_f: 1613 cycles
$\Delta\varepsilon$: 0.7%

Figure 215


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-8-7 538°C

Cycle Number: 26

N_f: 344 cycles

$\Delta\varepsilon$: 3.0%

Figure 216

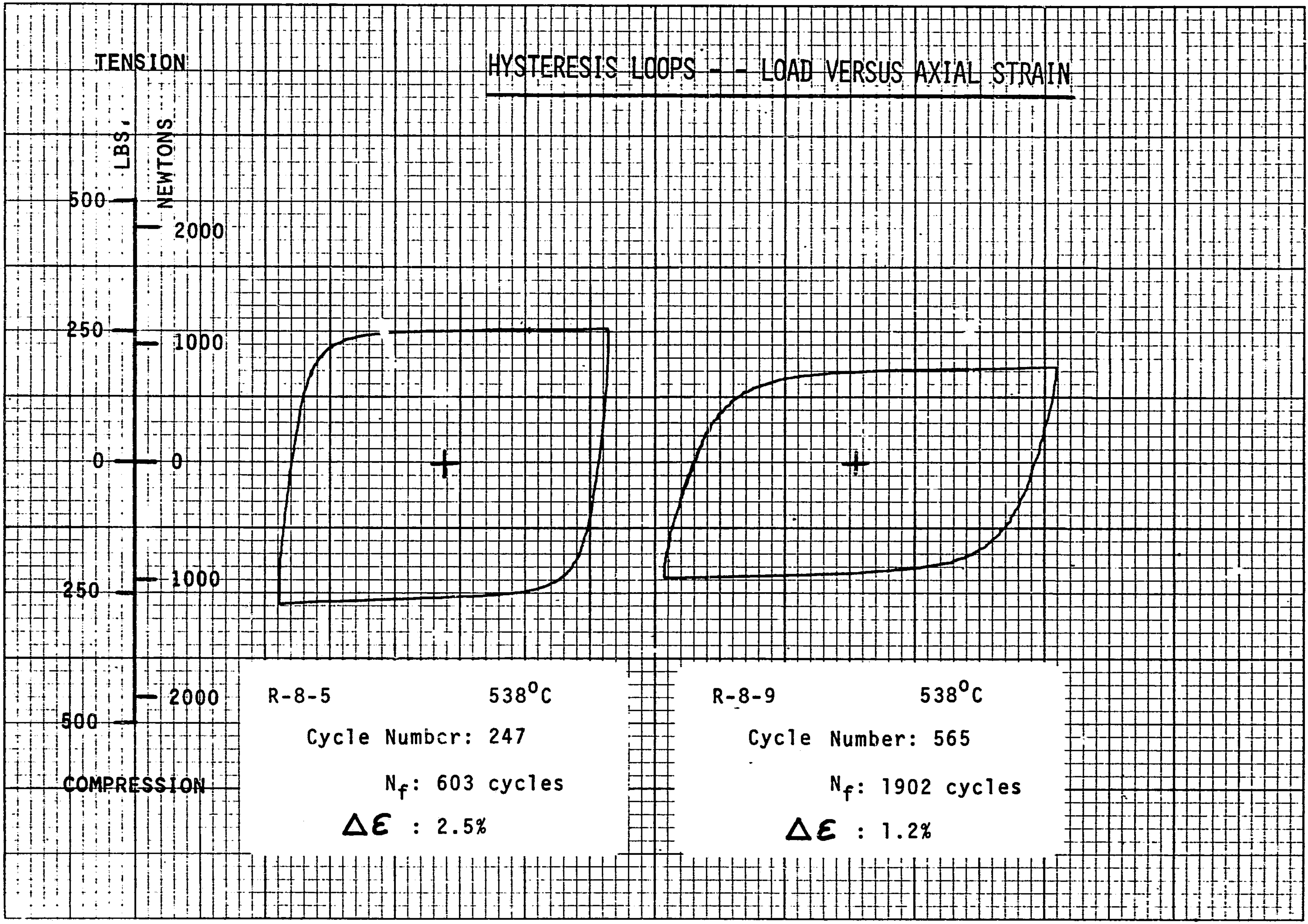
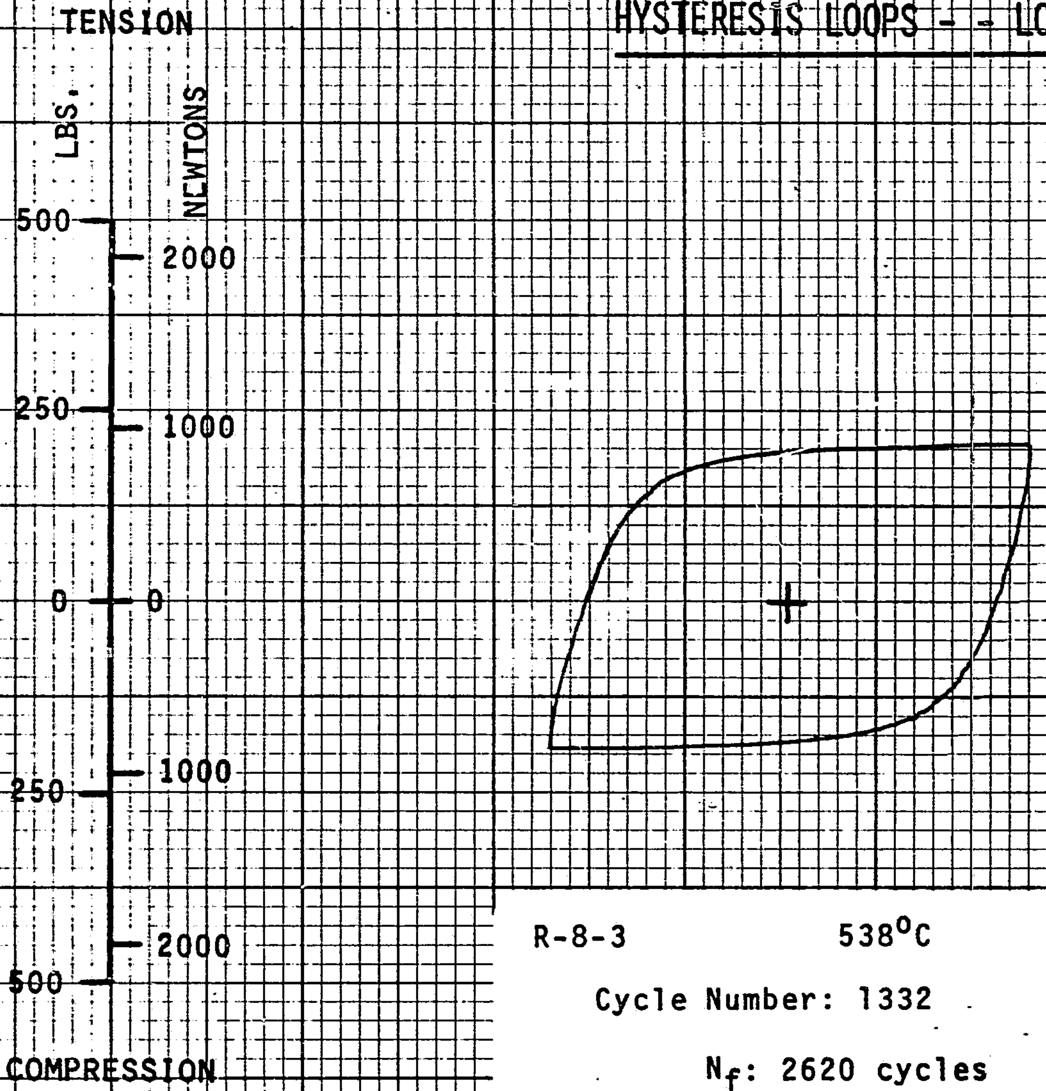

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS,
NEWTONS
500
2000
250
1000
0
0
250
1000
500
2000
COMPRESSION
R-8-5
538^{o}C
Cycle Number: 247
N_f: 603 cycles
$\Delta\varepsilon$: 2.5%
R-8-9
538^{o}C
Cycle Number: 565
N_f: 1902 cycles
$\Delta\varepsilon$: 1.2%

Figure 217

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN



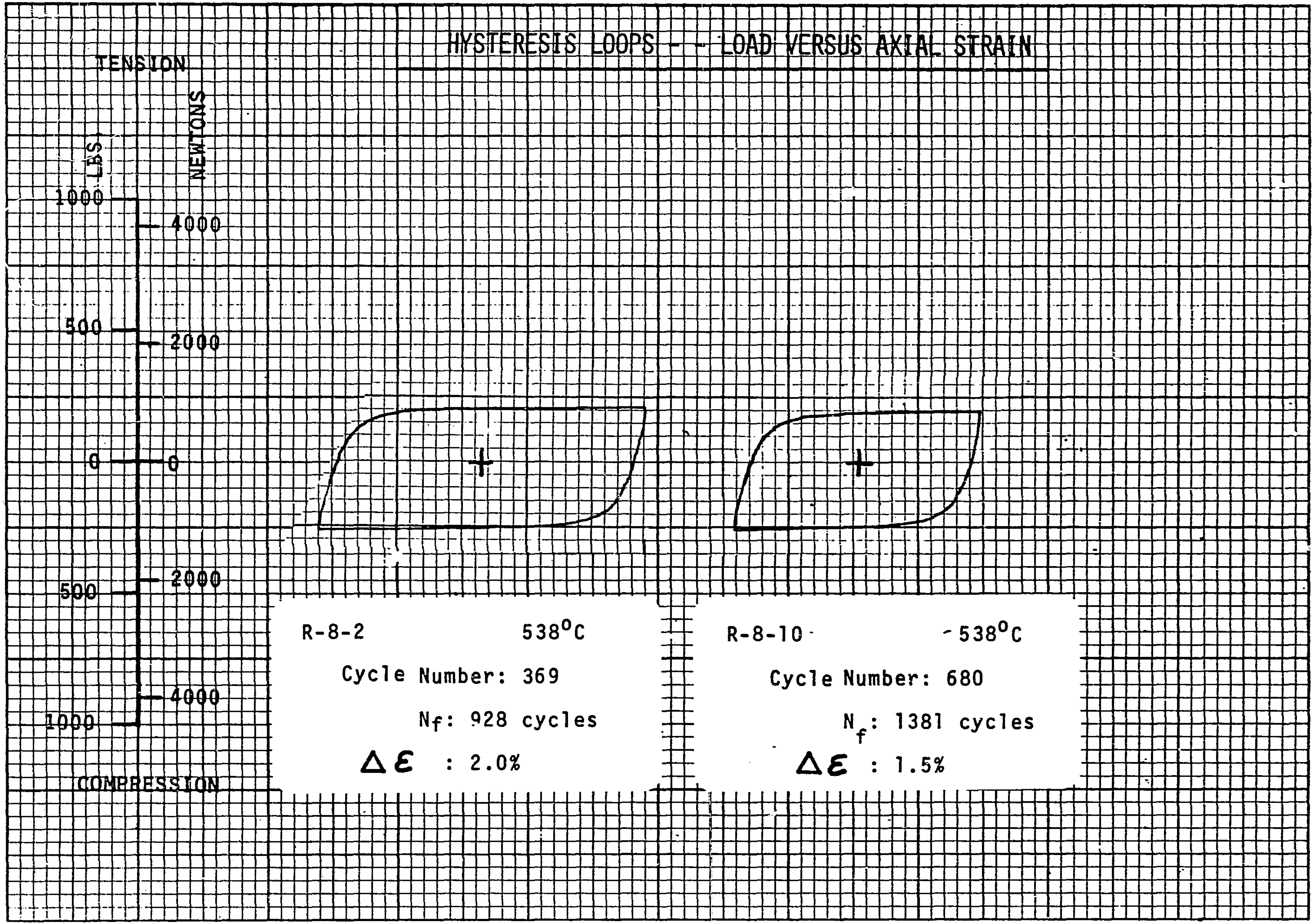
R-8-3 538°C

Cycle Number: 1332

N_f: 2620 cycles

$\Delta\varepsilon$: 1.0%

Figure 218



R-8-2 538°C

Cycle Number: 369

N_f: 928 cycles

$\Delta\varepsilon$: 2.0%

R-8-10 538°C

Cycle Number: 680

N_f: 1381 cycles

$\Delta\varepsilon$: 1.5%

Figure 219

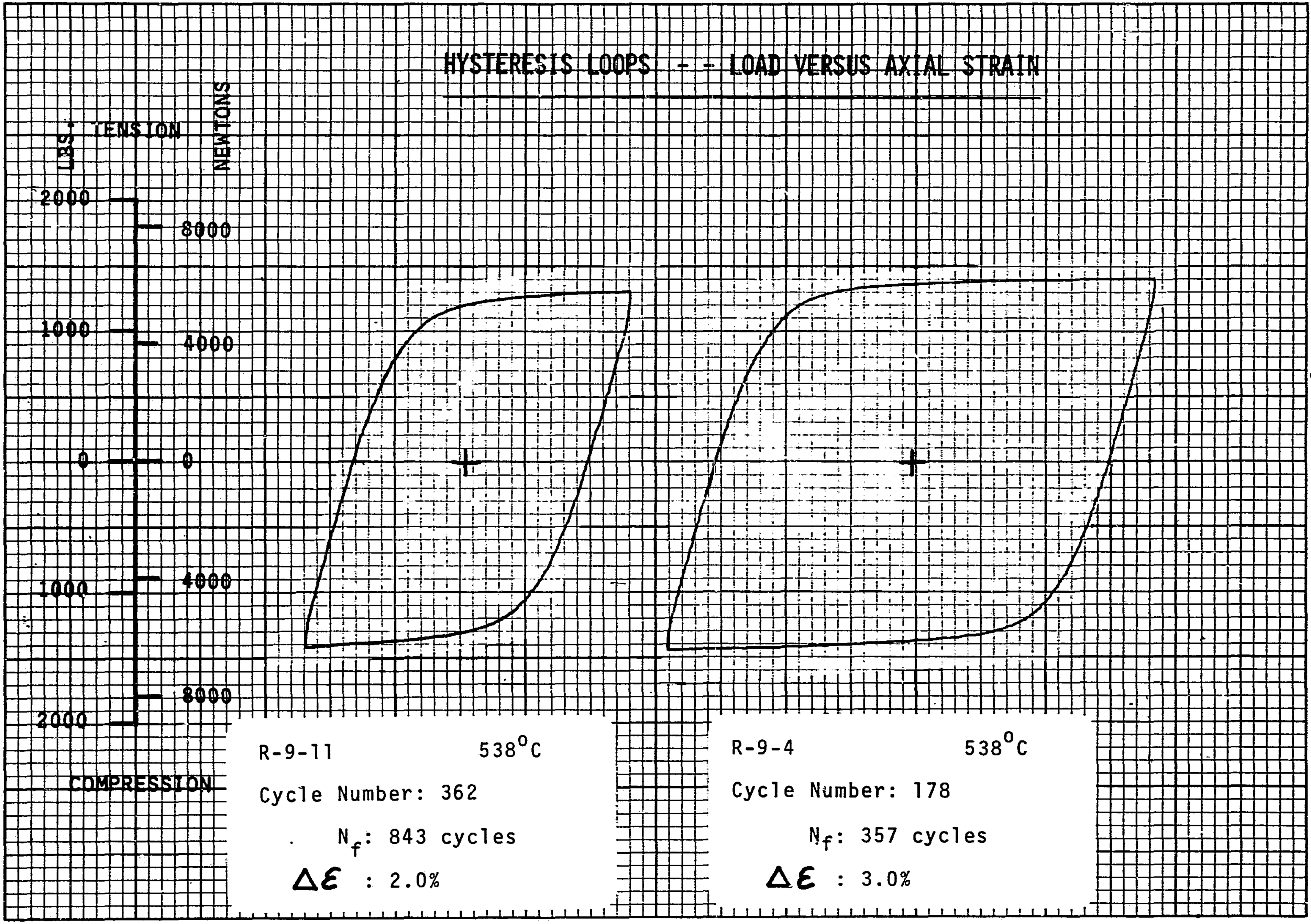
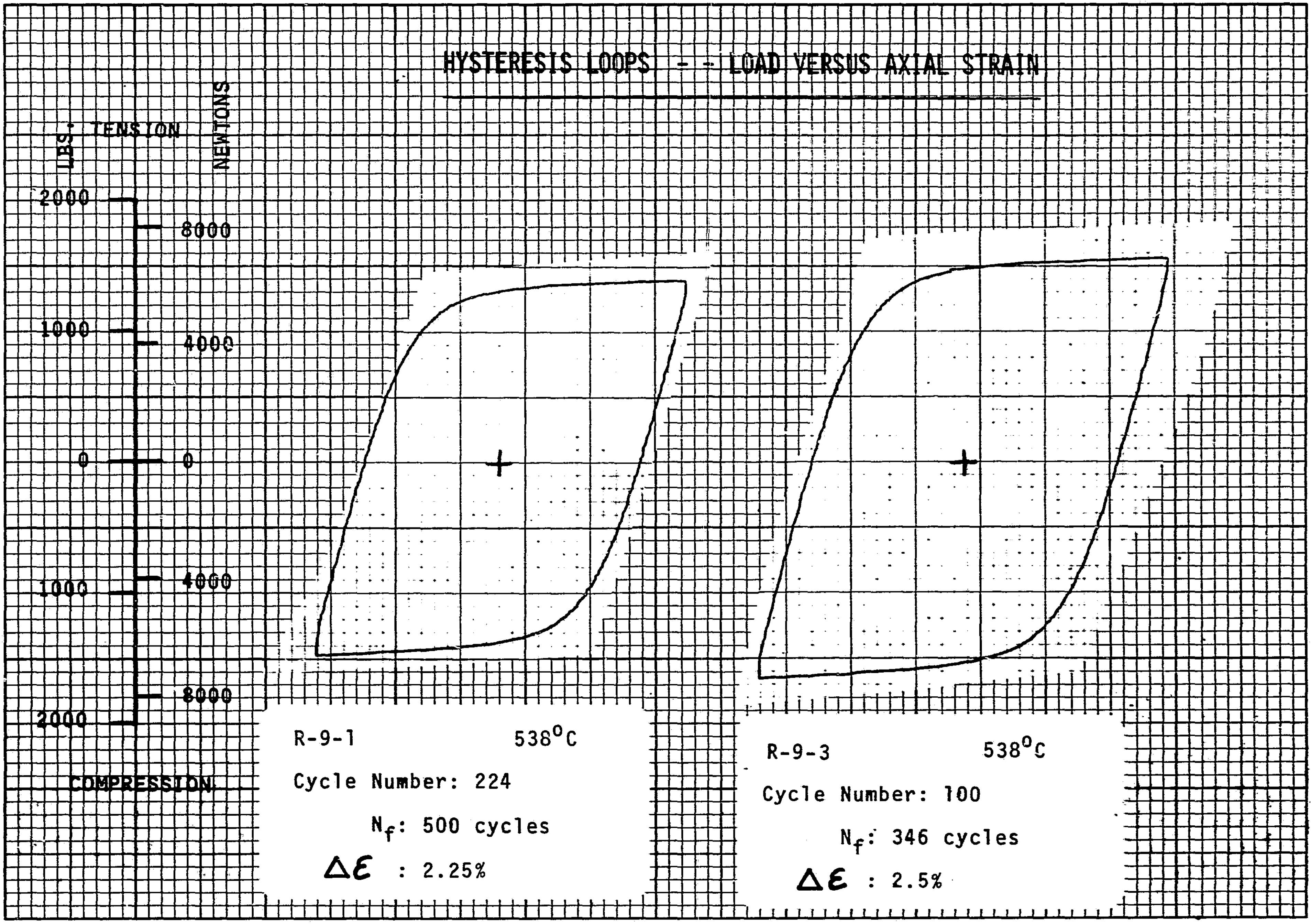

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-9-11 538°C
Cycle Number: 362
N_f: 843 cycles
Δε : 2.0%
R-9-4 538°C
Cycle Number: 178
N_f: 357 cycles
Δε : 3.0%

Figure 220



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-9-1 538°C
Cycle Number: 224
N_f: 500 cycles
$\Delta\varepsilon$: 2.25%

R-9-3 538°C
Cycle Number: 100
N_f: 346 cycles
$\Delta\varepsilon$: 2.5%

Figure 221

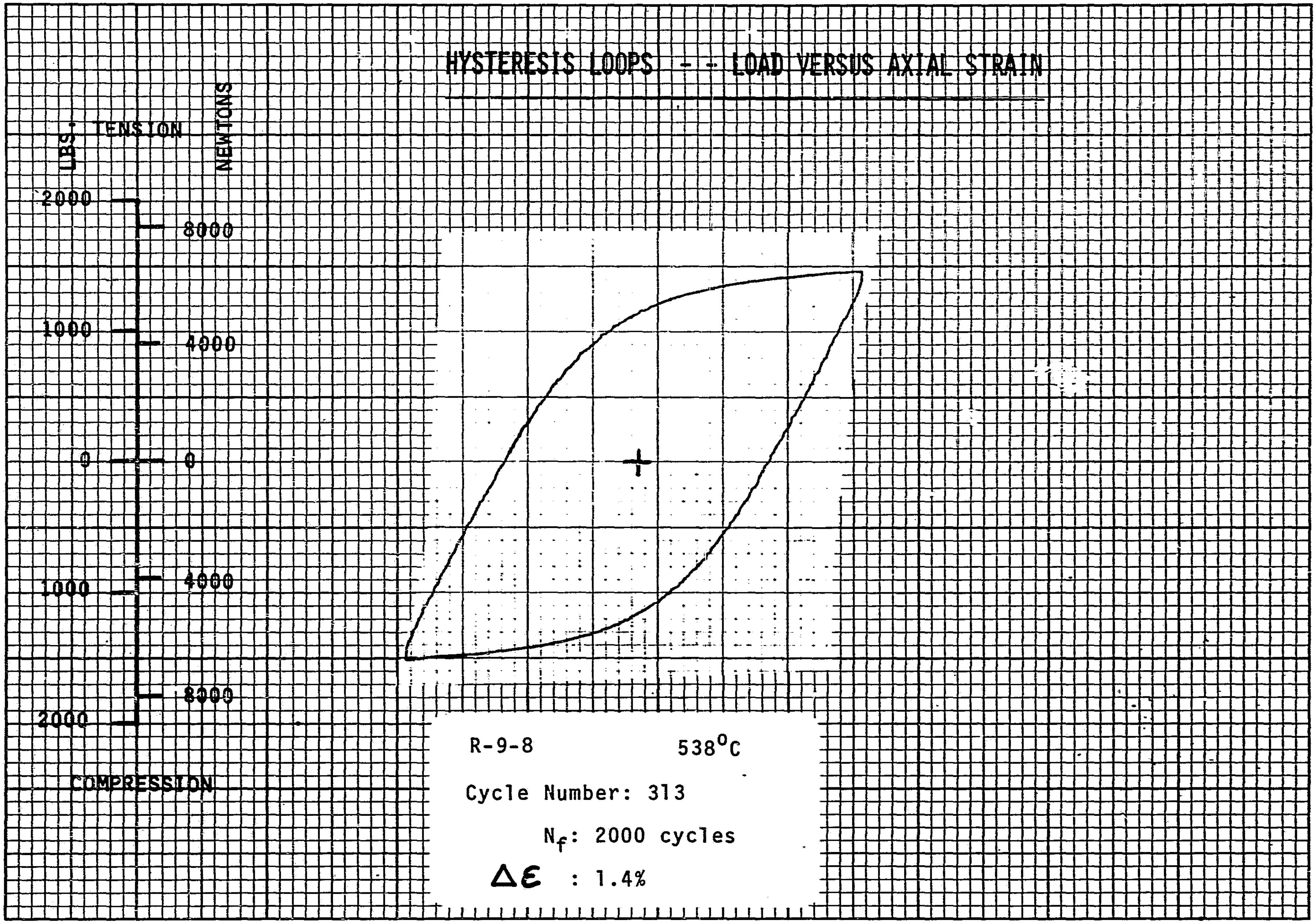


Figure 222

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-9-8 538°C

Cycle Number: 313

N_f: 2000 cycles

$\Delta\varepsilon$: 1.4%

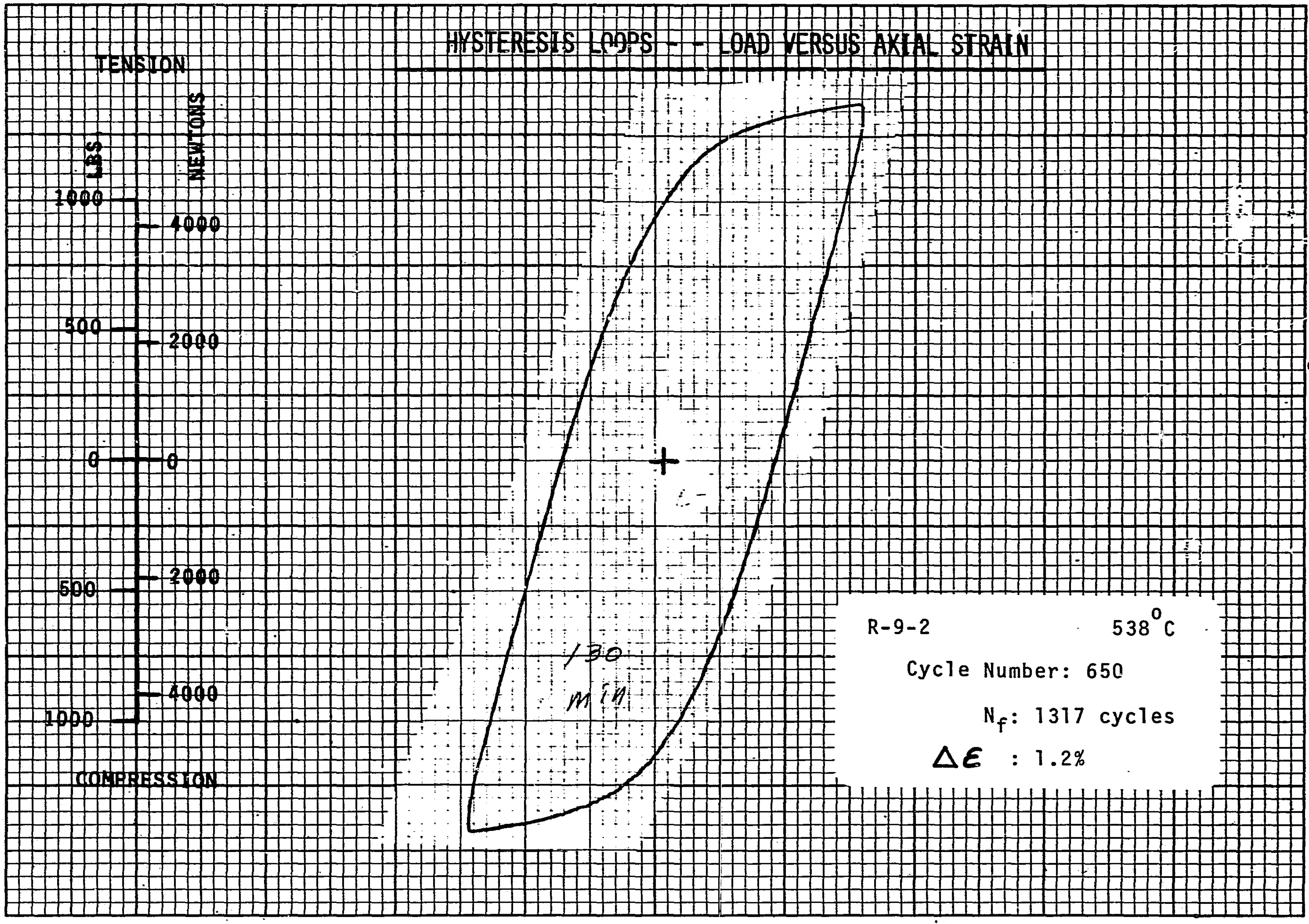
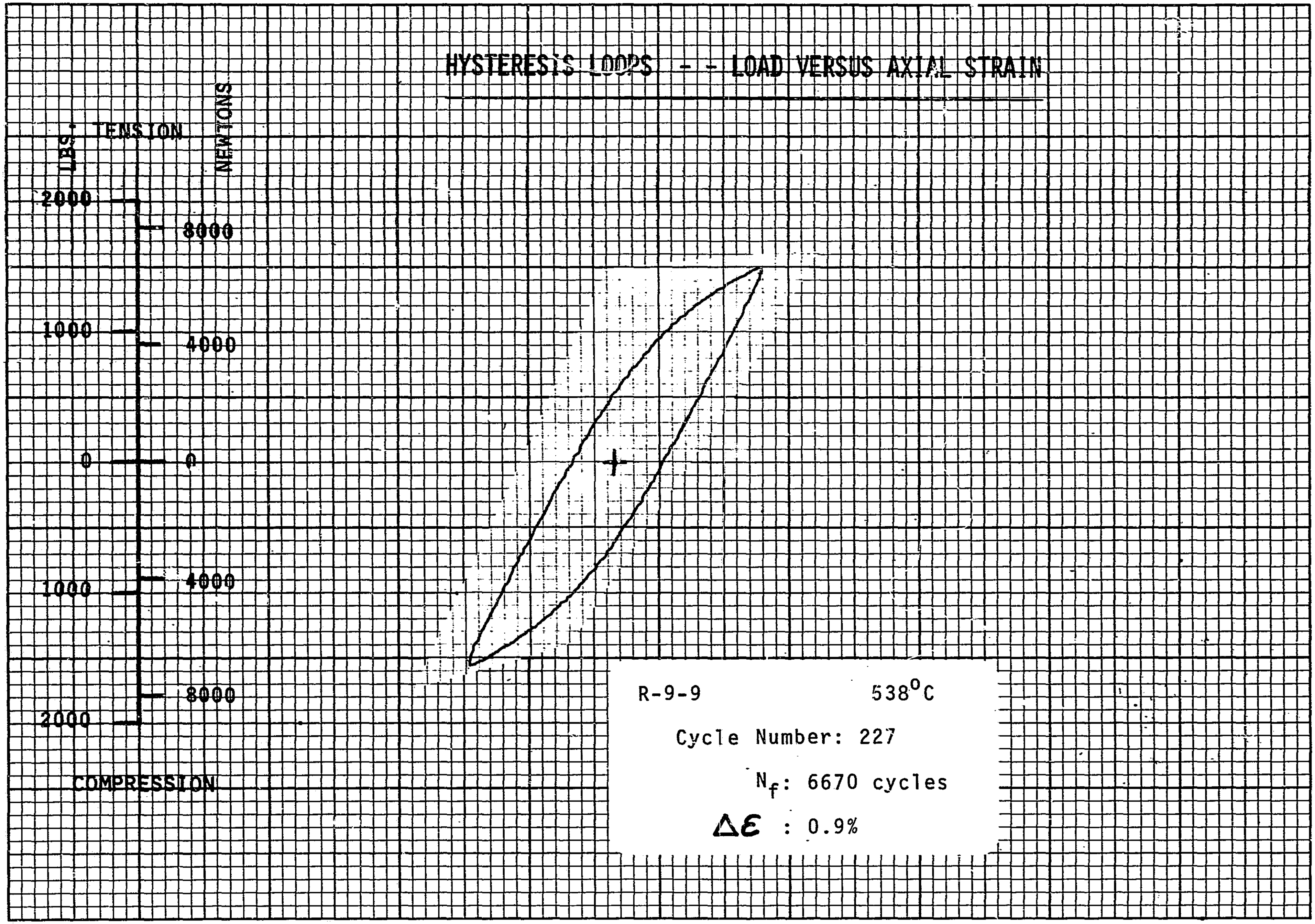

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
130
min
R-9-2
538°C
Cycle Number: 650
N_f: 1317 cycles
Δε : 1.2%

Figure 223


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

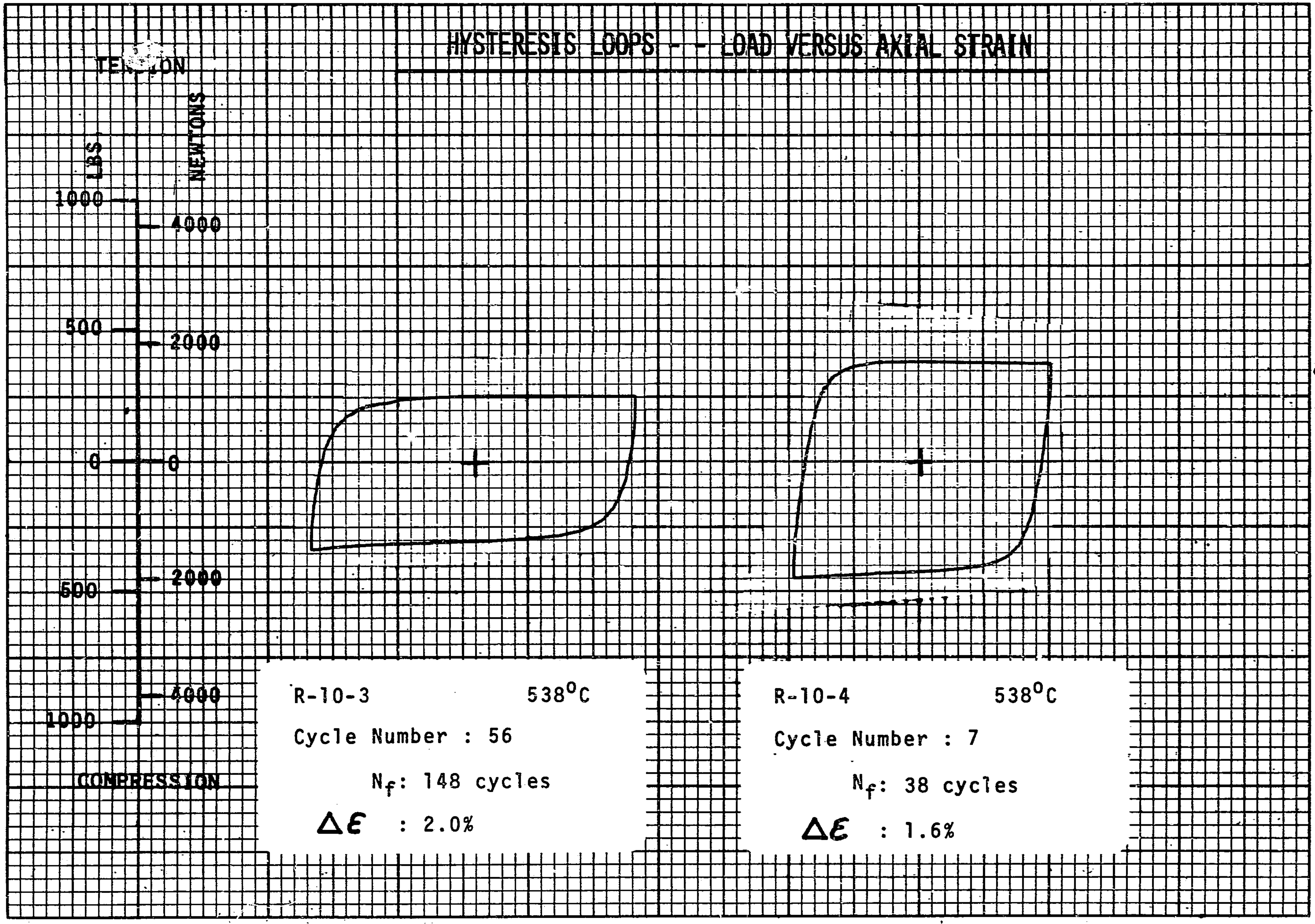
R-9-9 538°C

Cycle Number: 227

N_f: 6670 cycles

$\Delta\varepsilon$: 0.9%

Figure 224



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-10-3 538^{o}C
Cycle Number : 56
N_f: 148 cycles
$\Delta\varepsilon$: 2.0%

R-10-4 538^{o}C
Cycle Number : 7
N_f: 38 cycles
$\Delta\varepsilon$: 1.6%

Figure 225

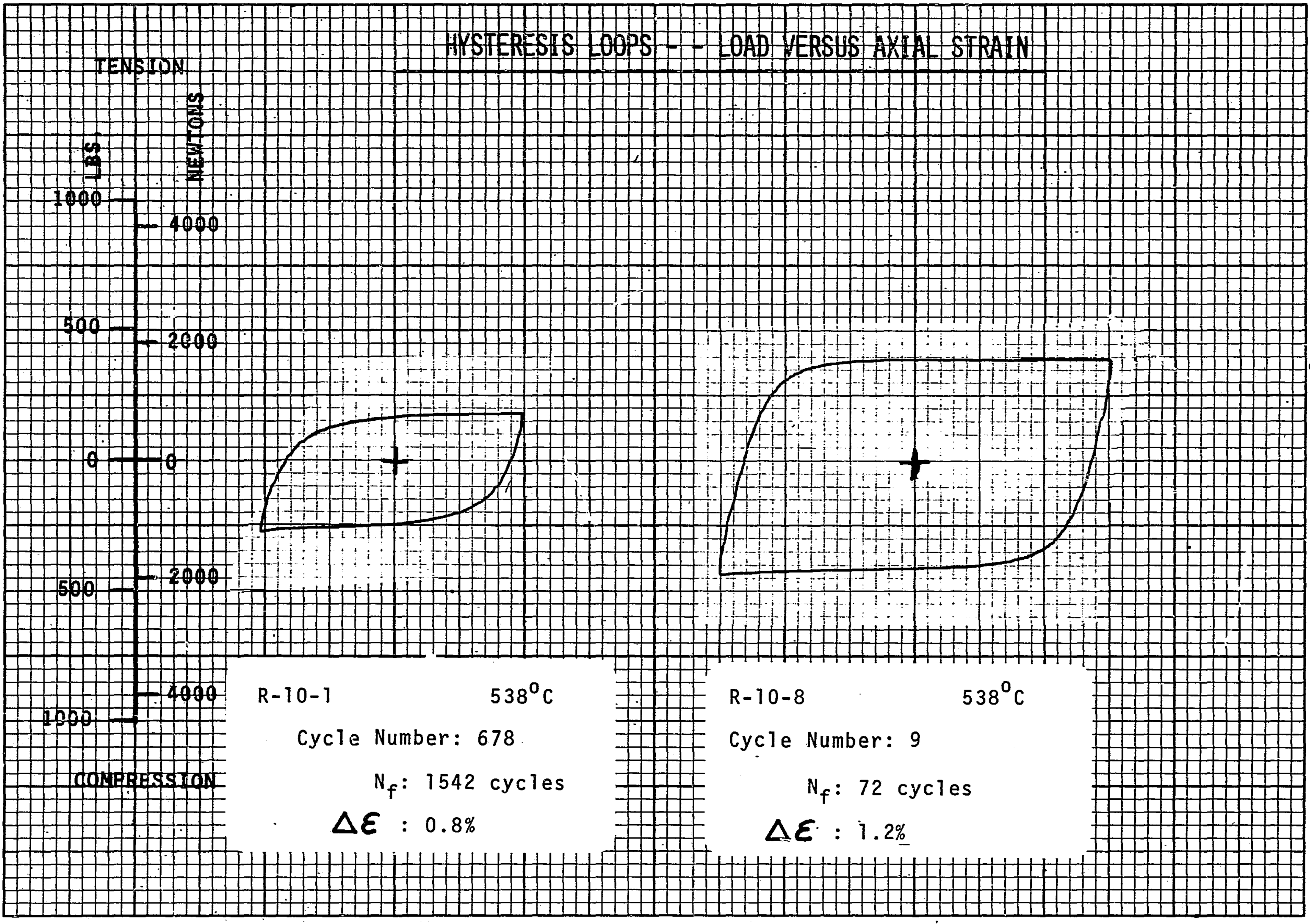

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-10-1
538°C
Cycle Number: 678
N_f: 1542 cycles
$\Delta\varepsilon$: 0.8%
R-10-8
538°C
Cycle Number: 9
N_f: 72 cycles
$\Delta\varepsilon$: 1.2%

Figure 226

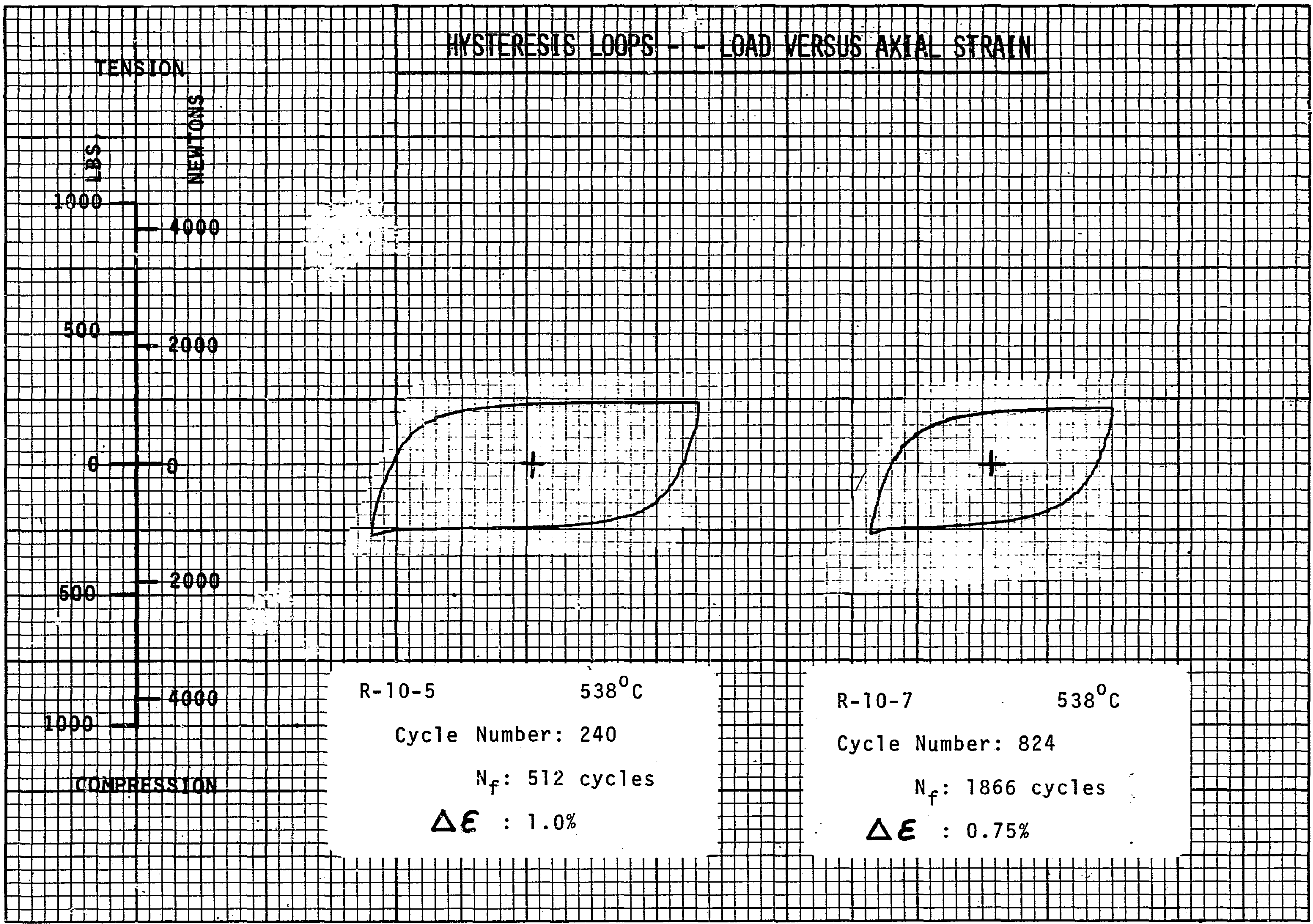

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-10-5
538°C
Cycle Number: 240
N_f: 512 cycles
Δε : 1.0%
R-10-7
538°C
Cycle Number: 824
N_f: 1866 cycles
Δε : 0.75%

Figure 227

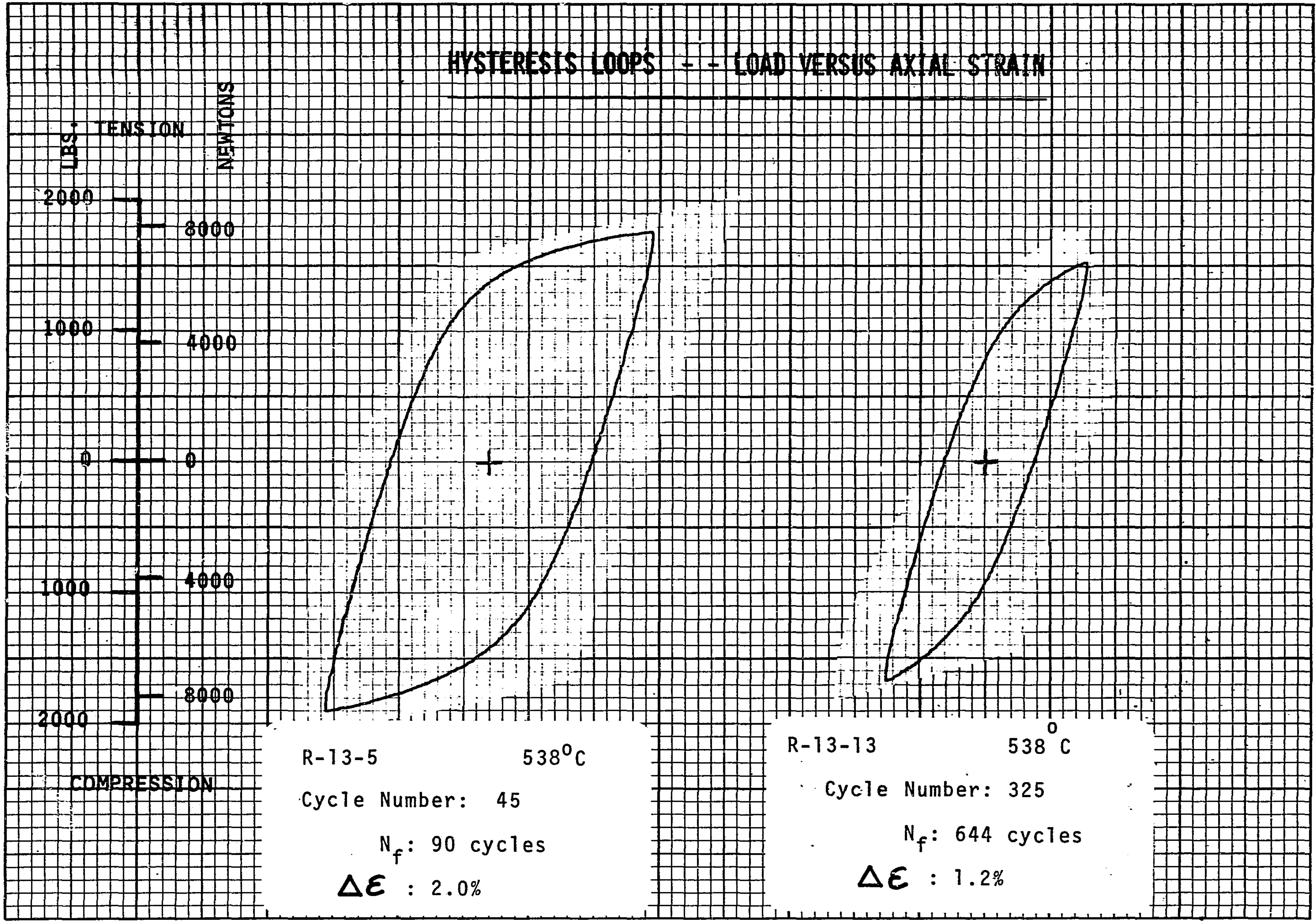

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-13-5
538°C
Cycle Number: 45
N_f: 90 cycles
Δε : 2.0%
R-13-13
538 °C
Cycle Number: 325
N_f: 644 cycles
Δε : 1.2%

Figure 228

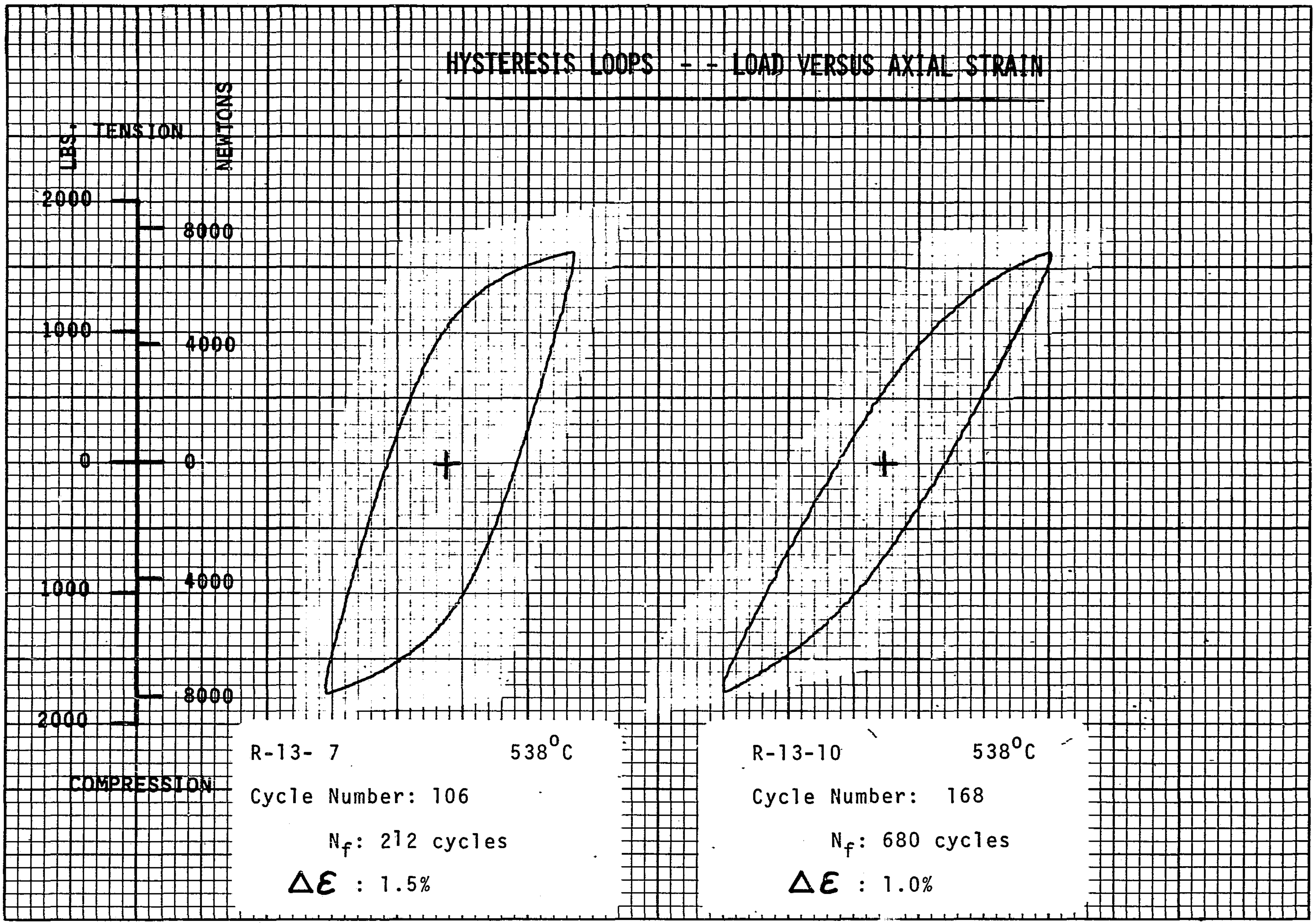
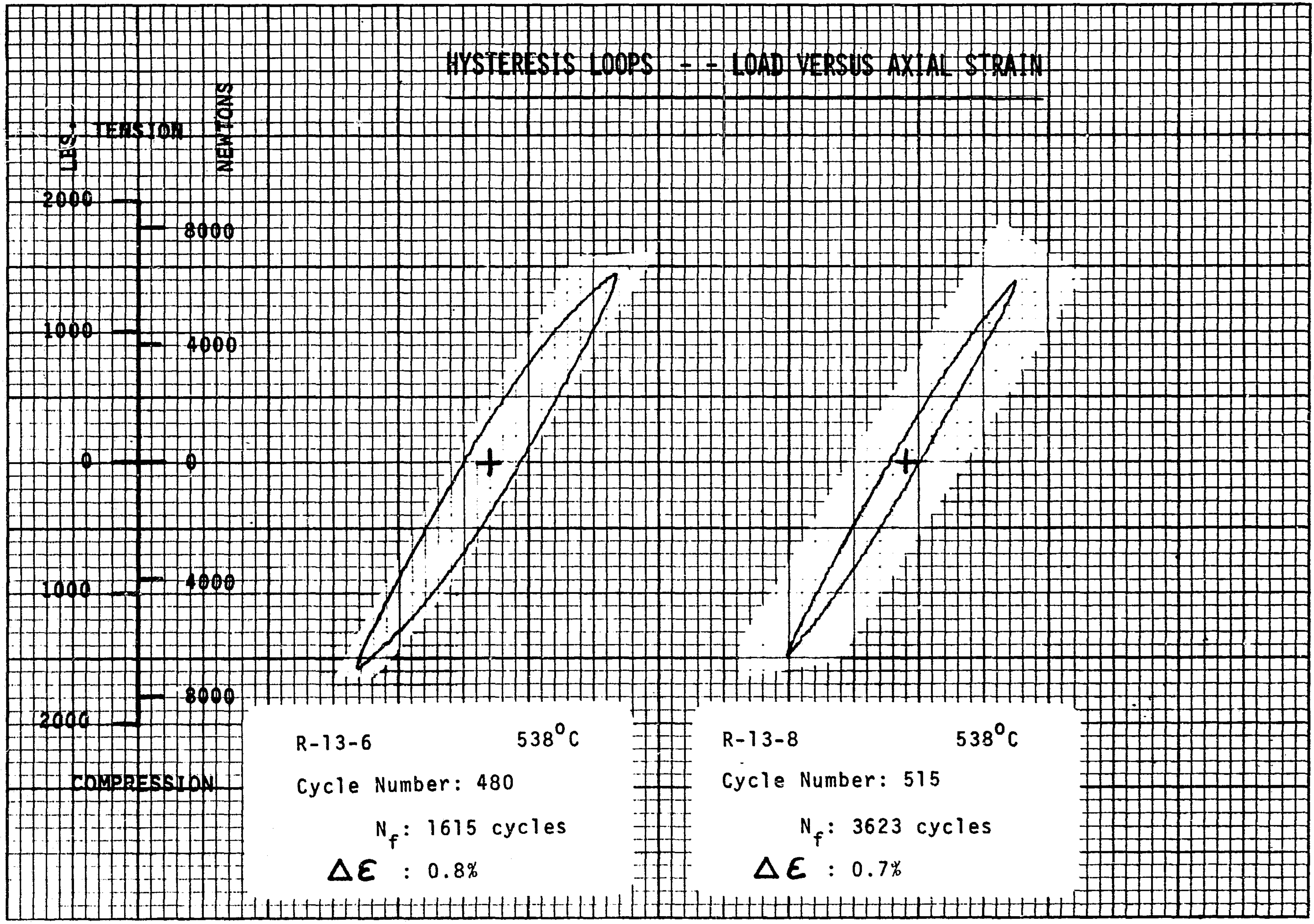

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-13- 7 538°C
Cycle Number: 106
N_f: 212 cycles
$\Delta\varepsilon$: 1.5%
R-13-10 538°C
Cycle Number: 168
N_f: 680 cycles
$\Delta\varepsilon$: 1.0%

Figure 229


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-13-6 538°C

Cycle Number: 480

N_f: 1615 cycles

$\Delta\varepsilon$: 0.8%

R-13-8 538°C

Cycle Number: 515

N_f: 3623 cycles

$\Delta\varepsilon$: 0.7%

Figure 230

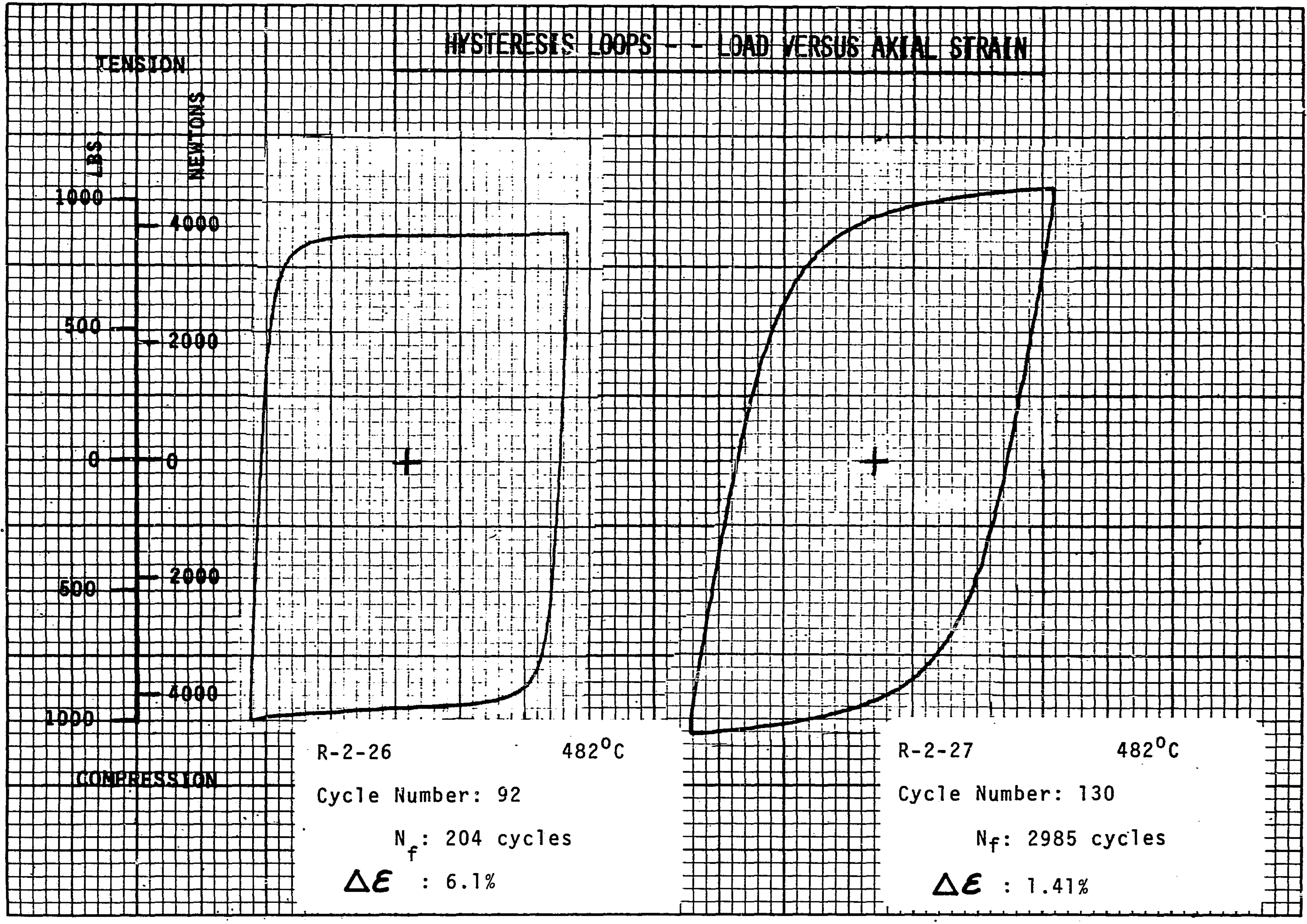

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-26
482°C
Cycle Number: 92
N_f: 204 cycles
Δε : 6.1%
R-2-27
482°C
Cycle Number: 130
N_f: 2985 cycles
Δε : 1.41%

Figure 231

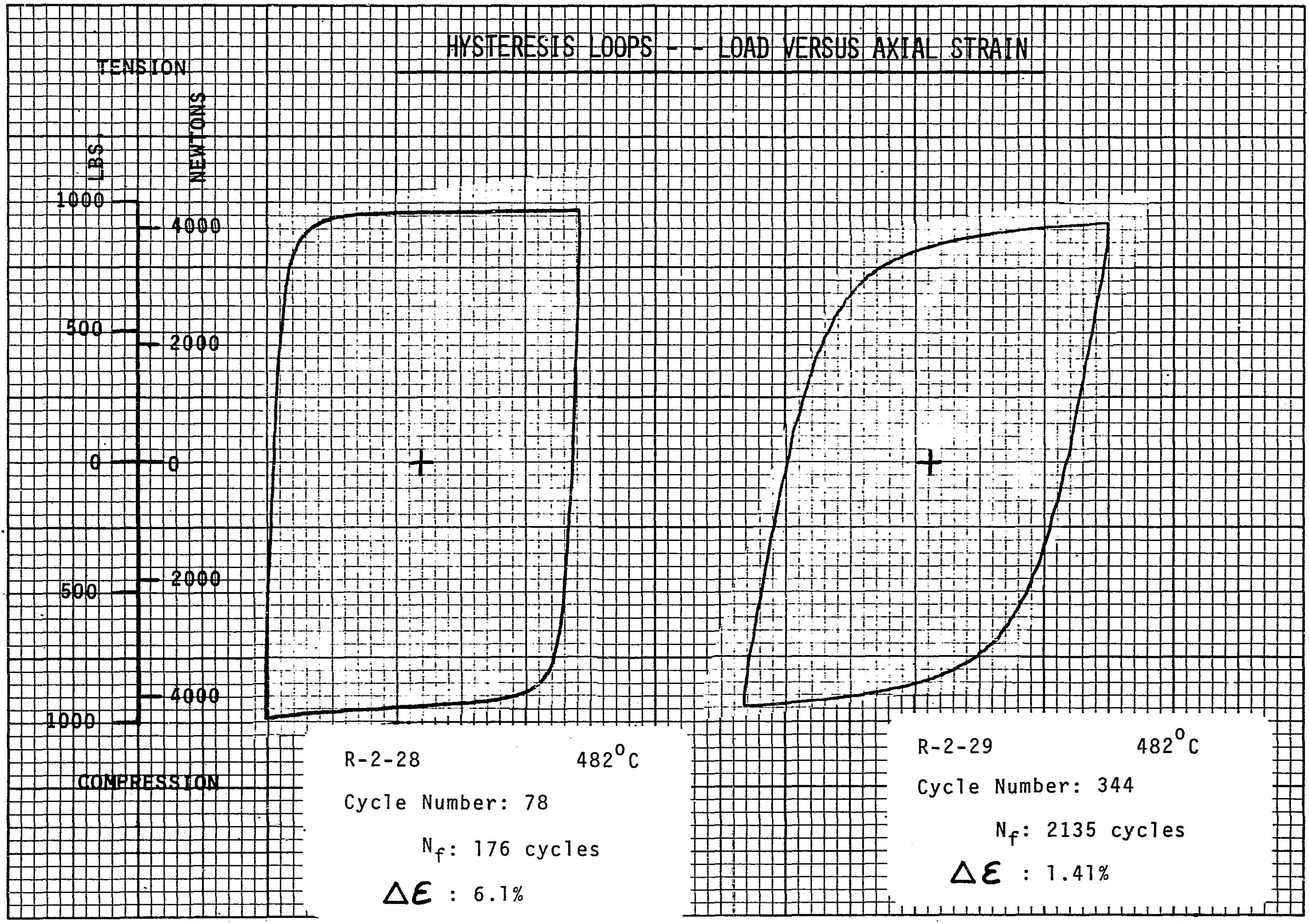
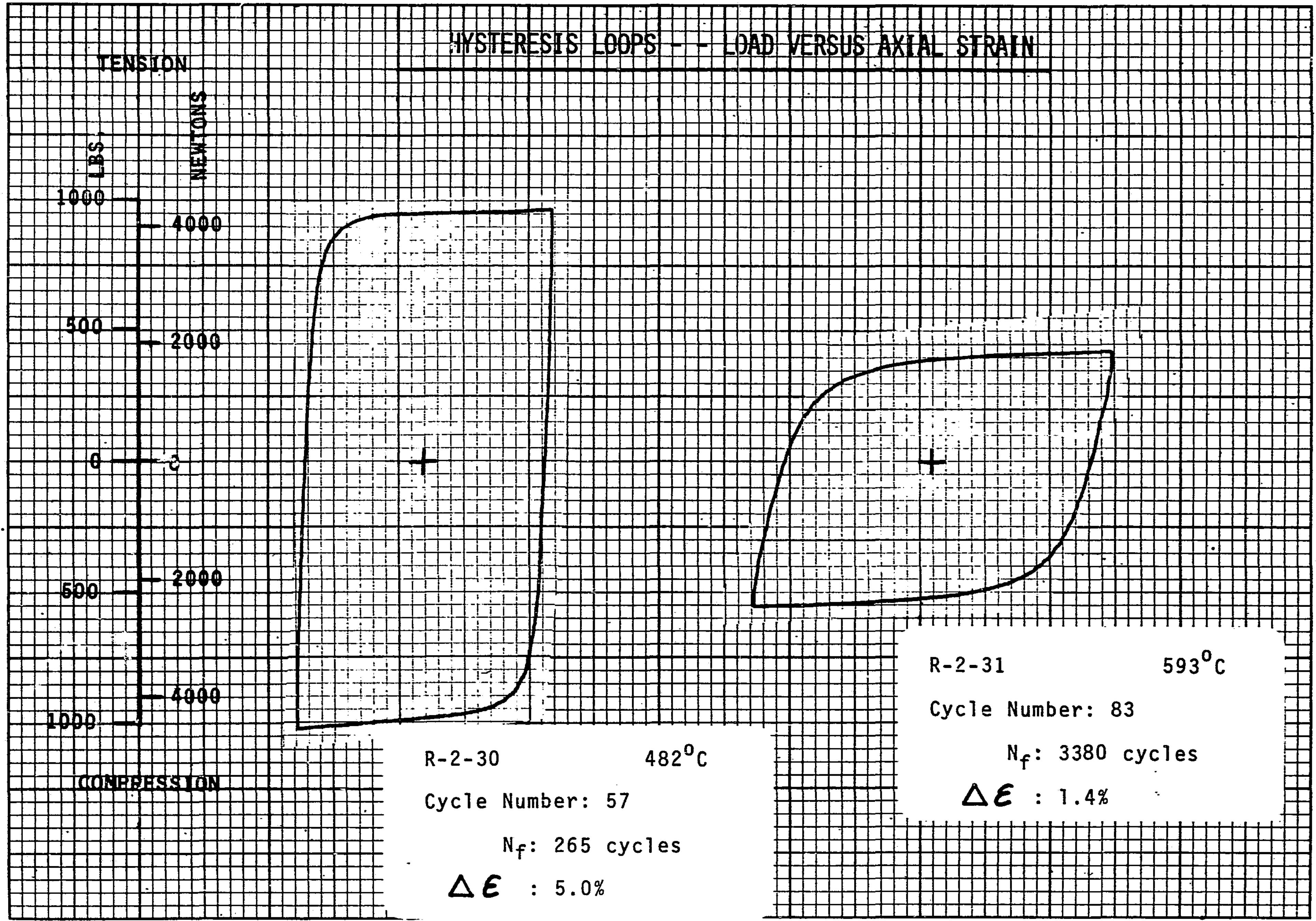


Figure 232

R-2-28 482^{o}C
Cycle Number: 78
N_f: 176 cycles
$\Delta\varepsilon$: 6.1%

R-2-29 482^{o}C
Cycle Number: 344
N_f: 2135 cycles
$\Delta\varepsilon$: 1.41%



R-2-30 482^{o}C

Cycle Number: 57

N_f: 265 cycles

$\Delta\varepsilon$: 5.0%

R-2-31 593^{o}C

Cycle Number: 83

N_f: 3380 cycles

$\Delta\varepsilon$: 1.4%

Figure 233

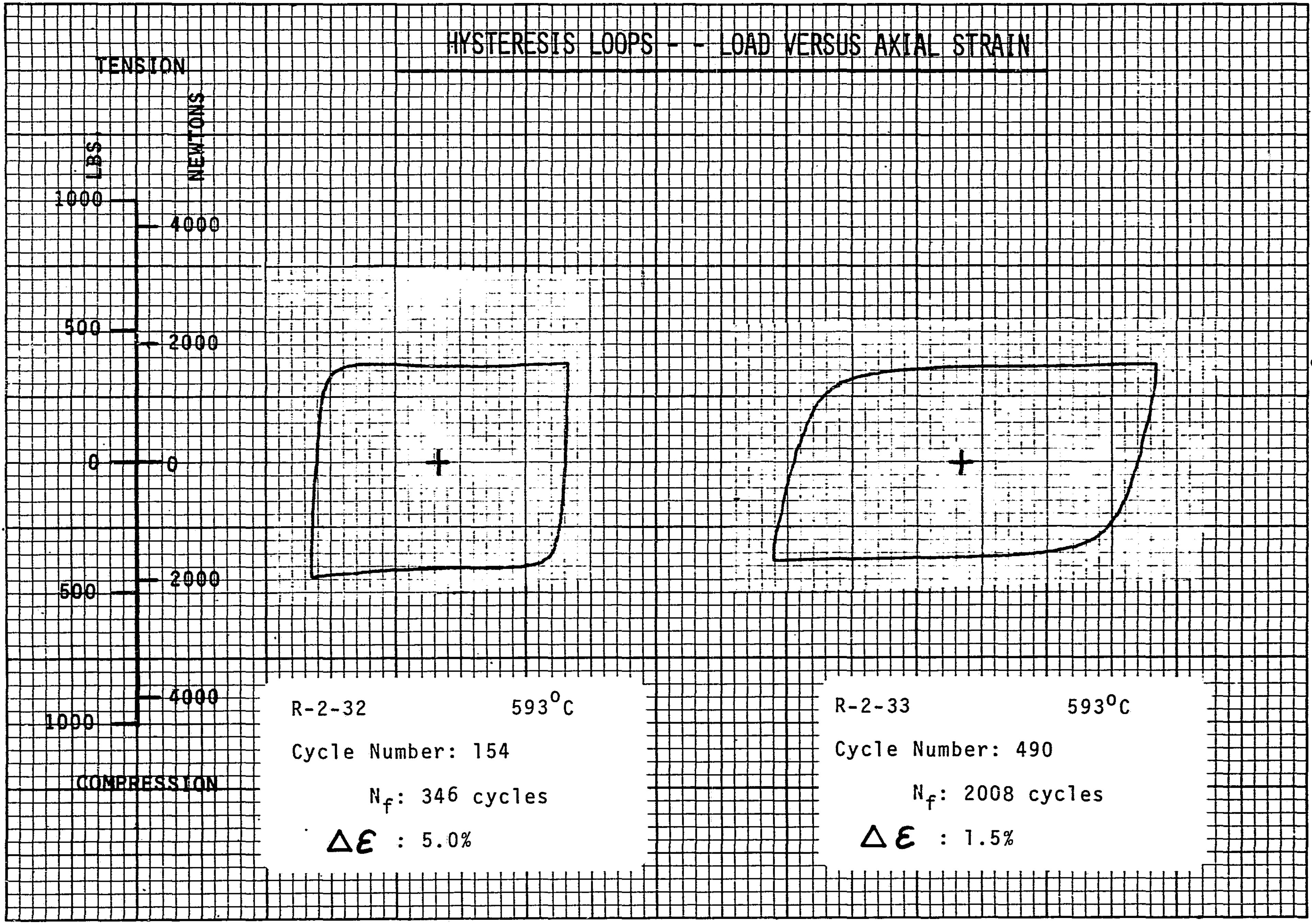

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-32
593°C
Cycle Number: 154
N_f: 346 cycles
Δε : 5.0%
R-2-33
593°C
Cycle Number: 490
N_f: 2008 cycles
Δε : 1.5%

Figure 234

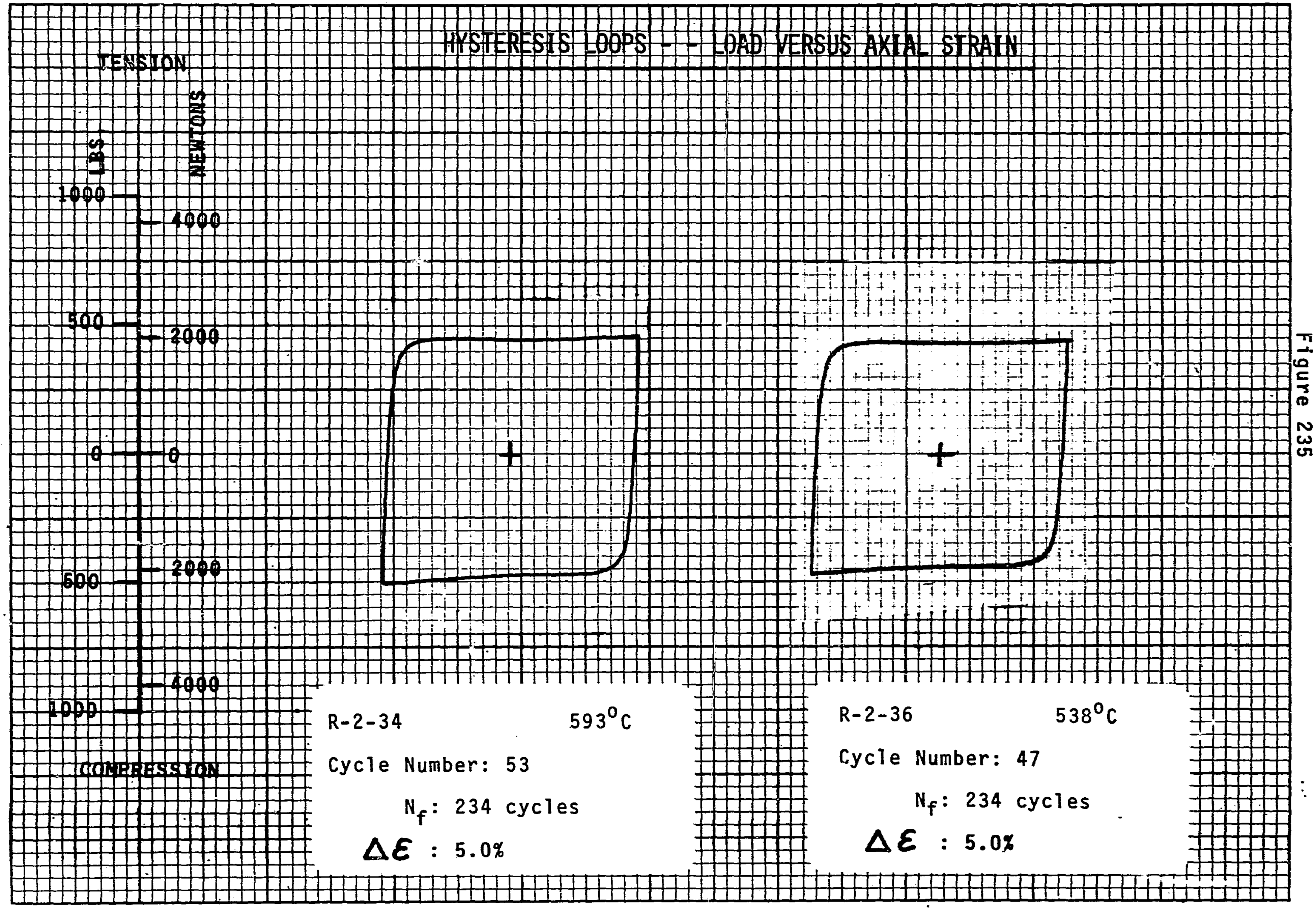

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-34
593^{o}C
Cycle Number: 53
N_f: 234 cycles
$\Delta\varepsilon$: 5.0%
R-2-36
538^{o}C
Cycle Number: 47
N_f: 234 cycles
$\Delta\varepsilon$: 5.0%

Figure 235

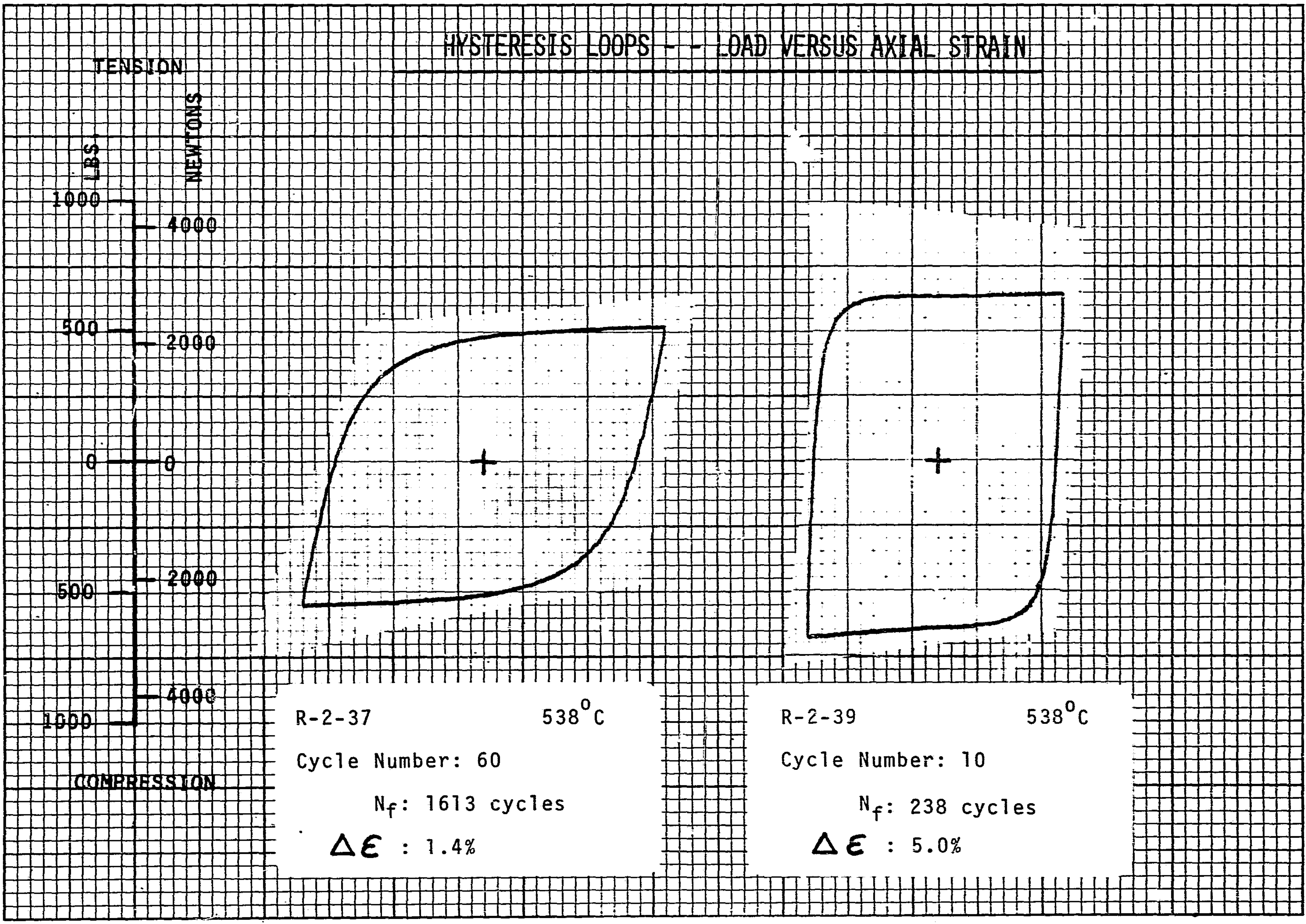
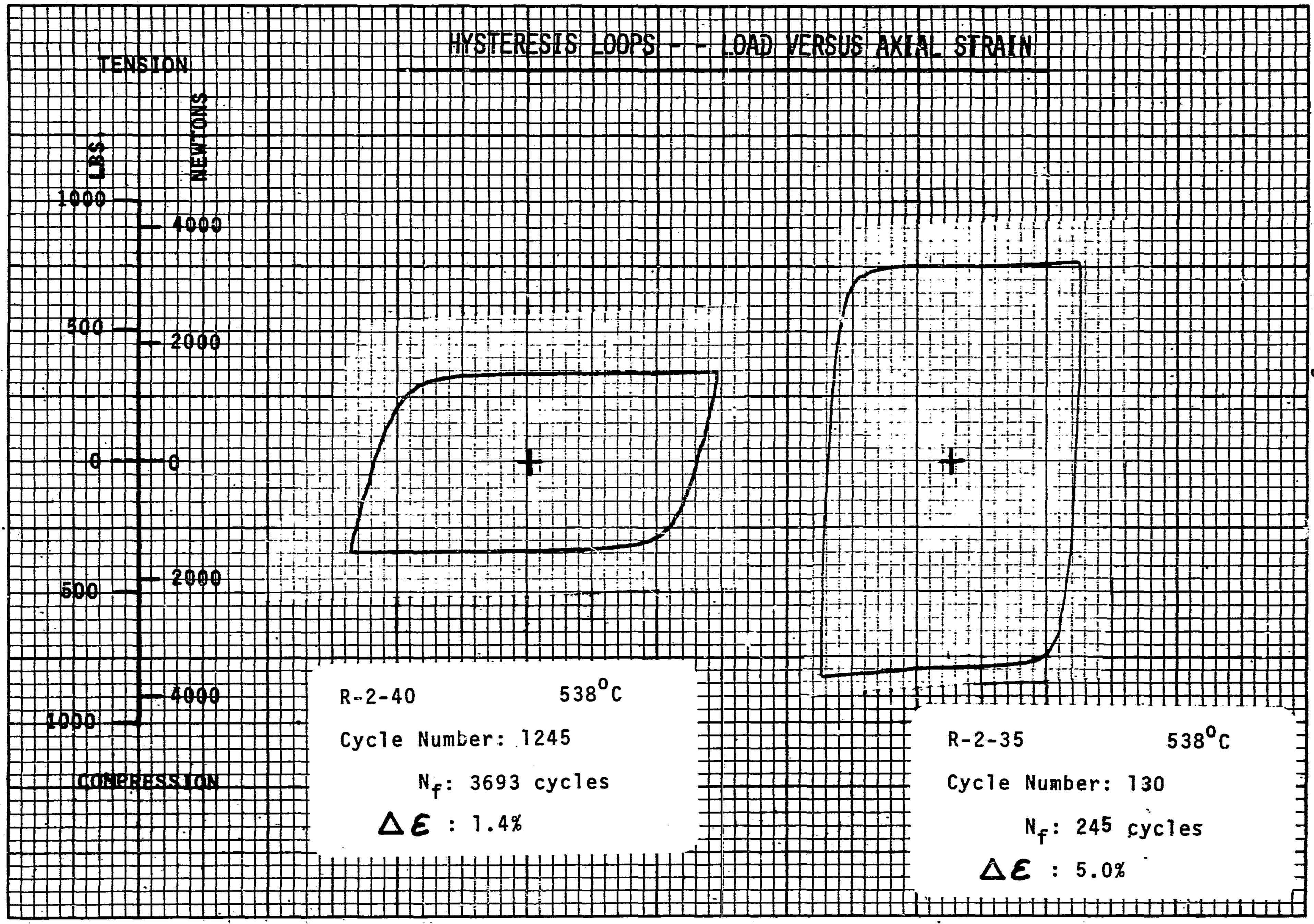

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

Figure 236



R-2-40 538^{o}C

Cycle Number: 1245

N_f: 3693 cycles

$\Delta\varepsilon$: 1.4%

R-2-35 538^{o}C

Cycle Number: 130

N_f: 245 cycles

$\Delta\varepsilon$: 5.0%

Figure 237

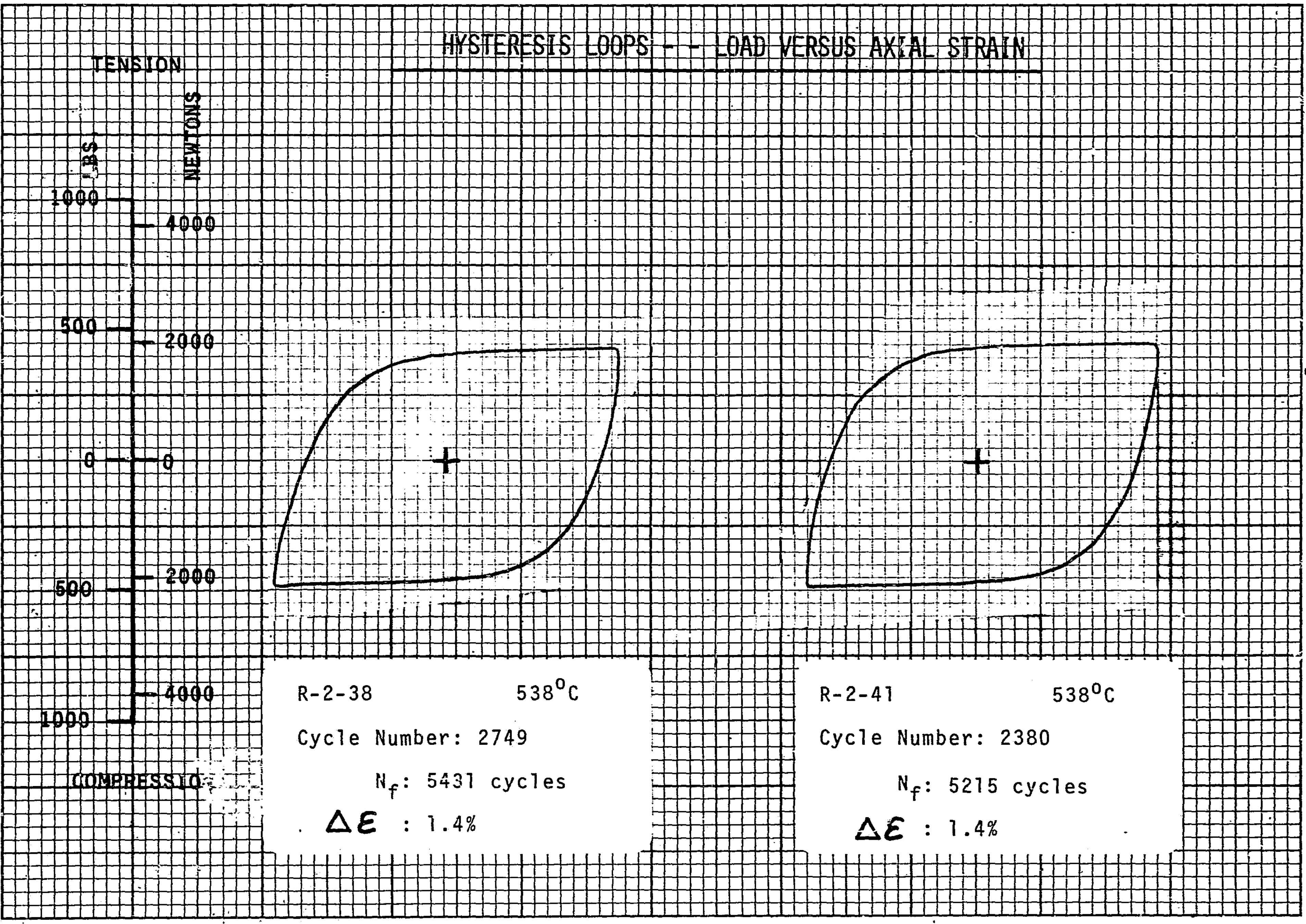

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSIO
R-2-38
538°C
Cycle Number: 2749
N_f: 5431 cycles
$\Delta\varepsilon$: 1.4%
R-2-41
538°C
Cycle Number: 2380
N_f: 5215 cycles
$\Delta\varepsilon$: 1.4%

Figure 238

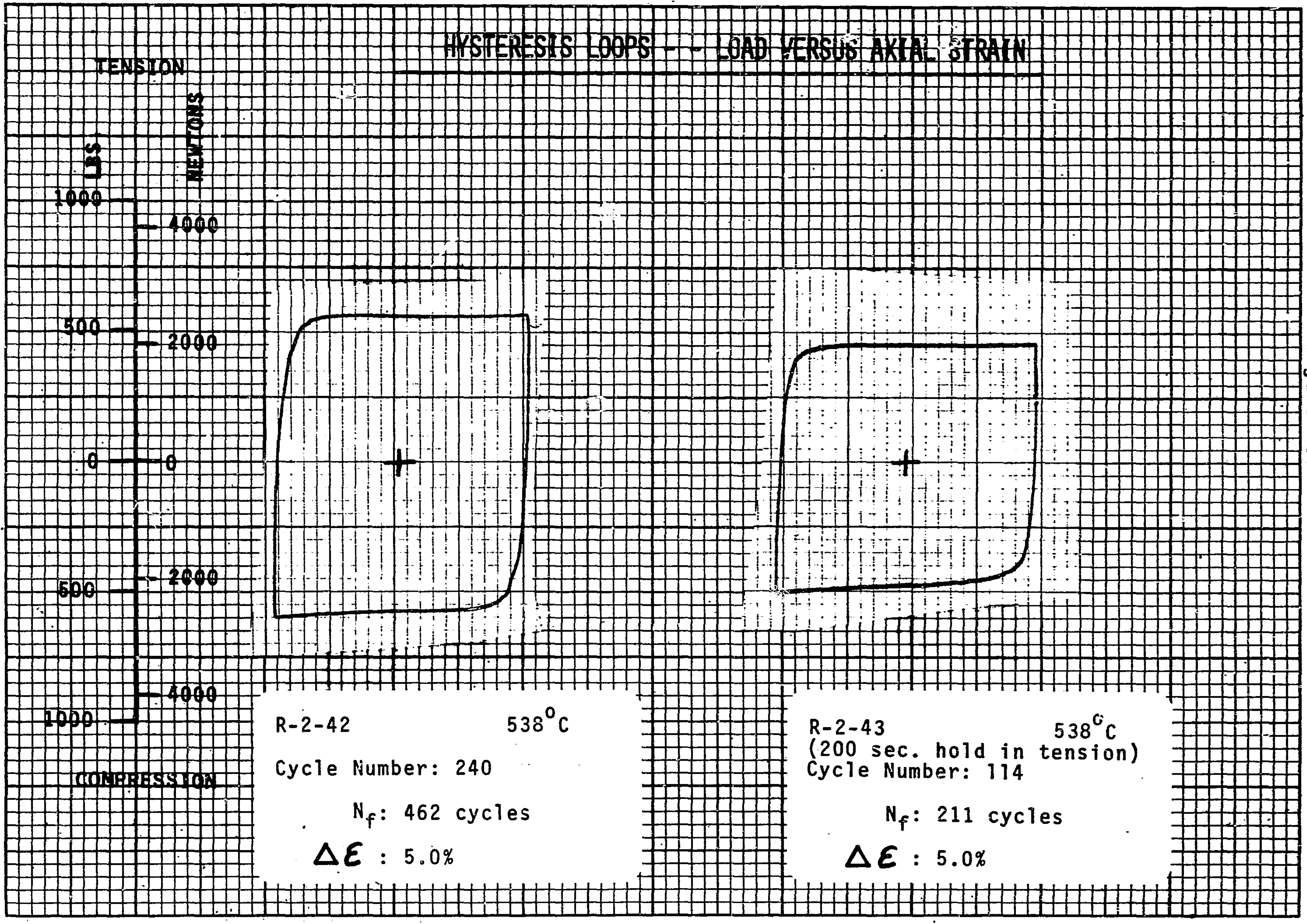
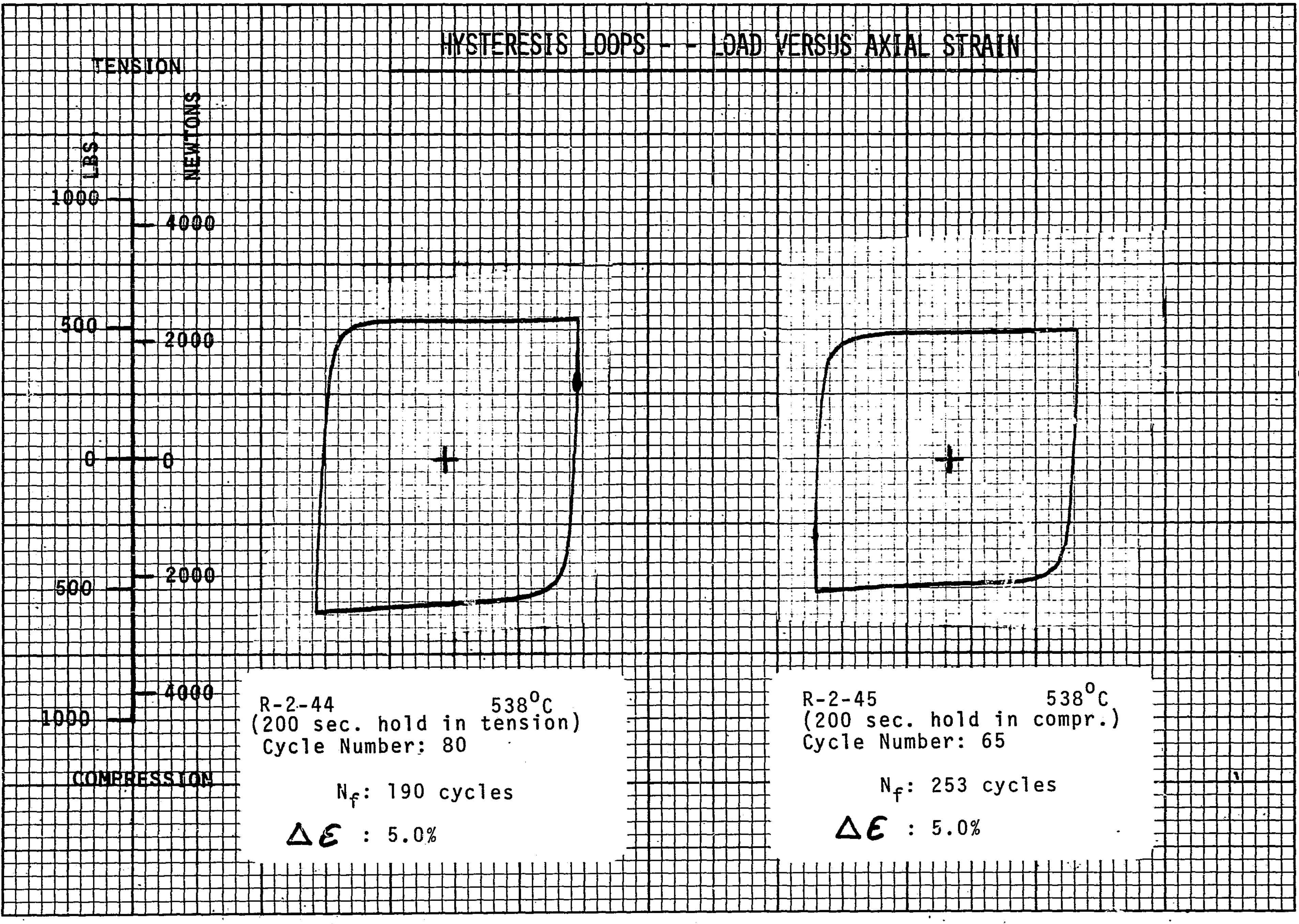

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-42
538°C
Cycle Number: 240
N_f: 462 cycles
$\Delta\varepsilon$: 5.0%
R-2-43
538°C
(200 sec. hold in tension)
Cycle Number: 114
N_f: 211 cycles
$\Delta\varepsilon$: 5.0%

Figure 239



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-2-44 538°C
(200 sec. hold in tension)
Cycle Number: 80

N_f: 190 cycles

$\Delta\varepsilon$: 5.0%

R-2-45 538°C
(200 sec. hold in compr.)
Cycle Number: 65

N_f: 253 cycles

$\Delta\varepsilon$: 5.0%

Figure 240

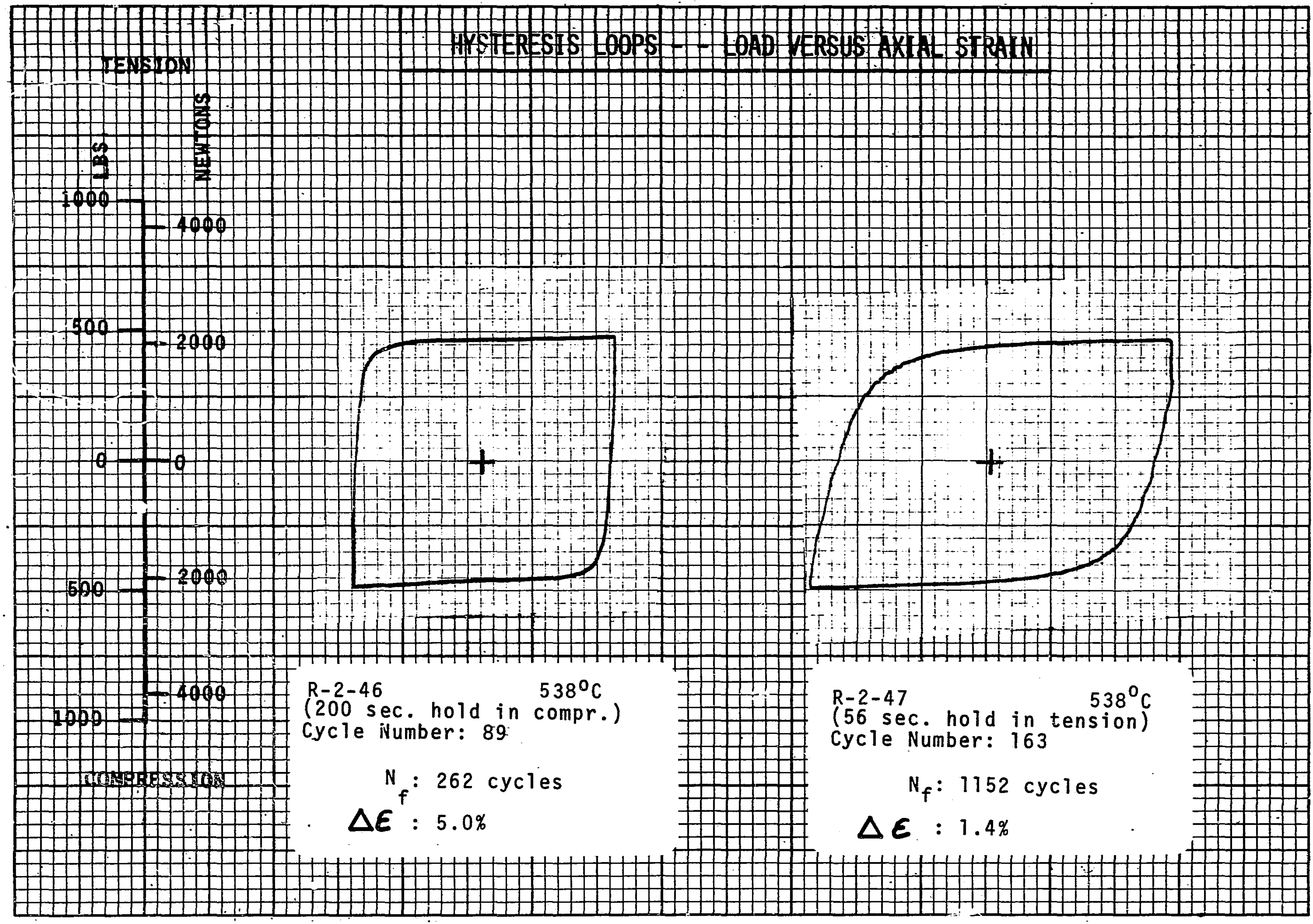
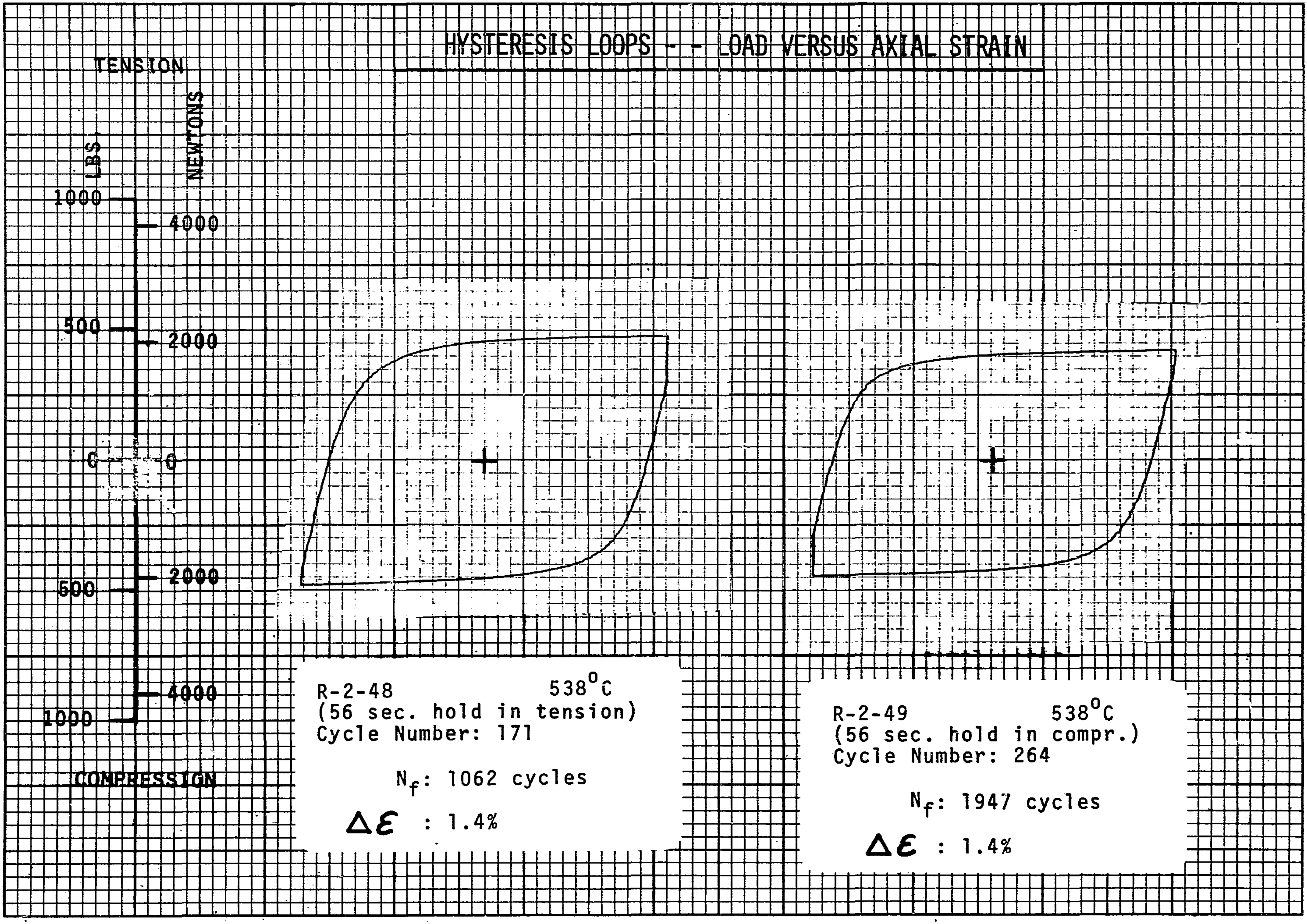
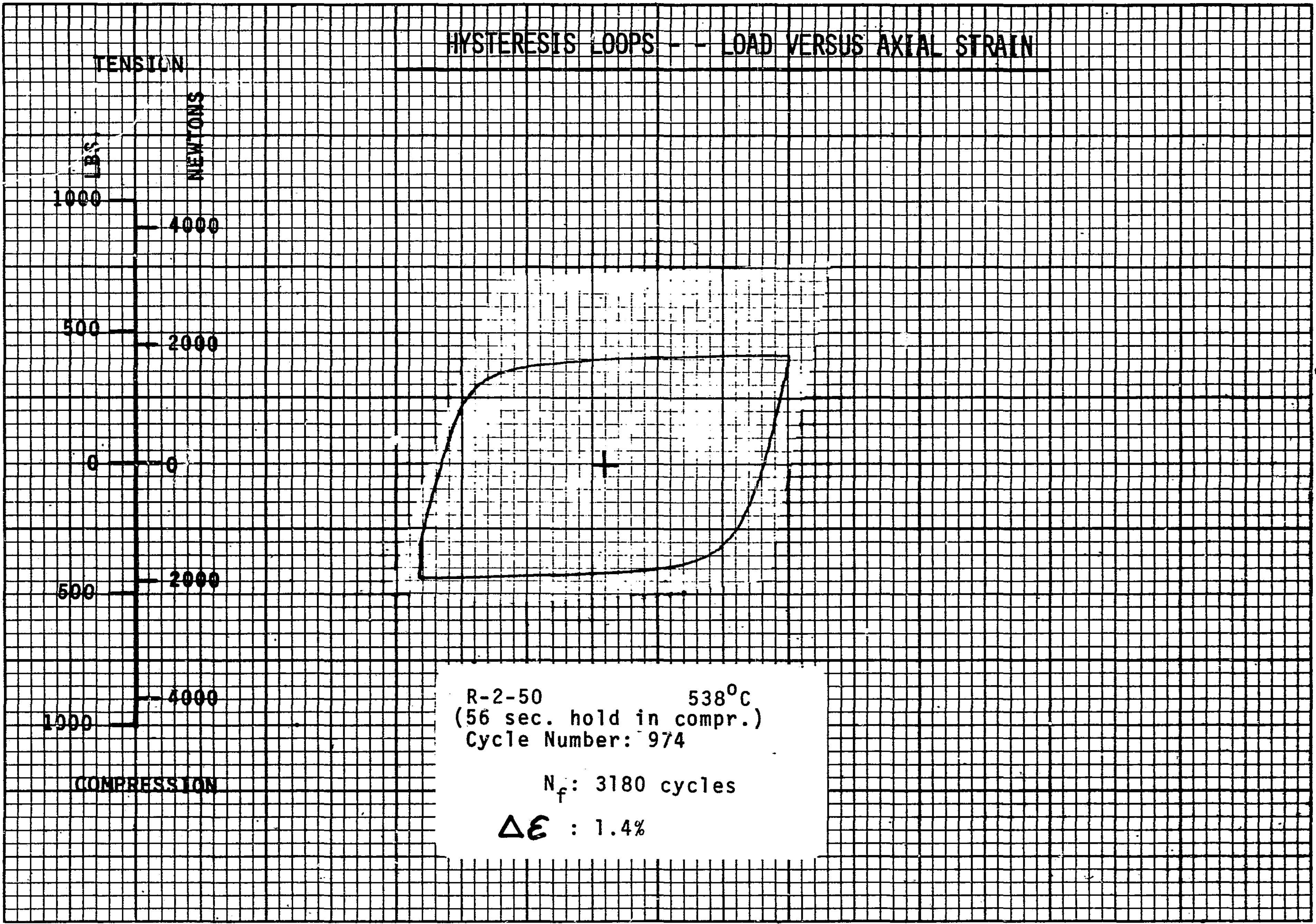

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-2-46 538°C
(200 sec. hold in compr.)
Cycle Number: 89
N_f: 262 cycles
Δε : 5.0%
R-2-47 538°C
(56 sec. hold in tension)
Cycle Number: 163
N_f: 1152 cycles
Δε : 1.4%

Figure 241



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

Figure 242



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-2-50 538^{o}C
(56 sec. hold in compr.)
Cycle Number: 974

N_f: 3180 cycles

$\Delta\varepsilon$: 1.4%

Figure 243

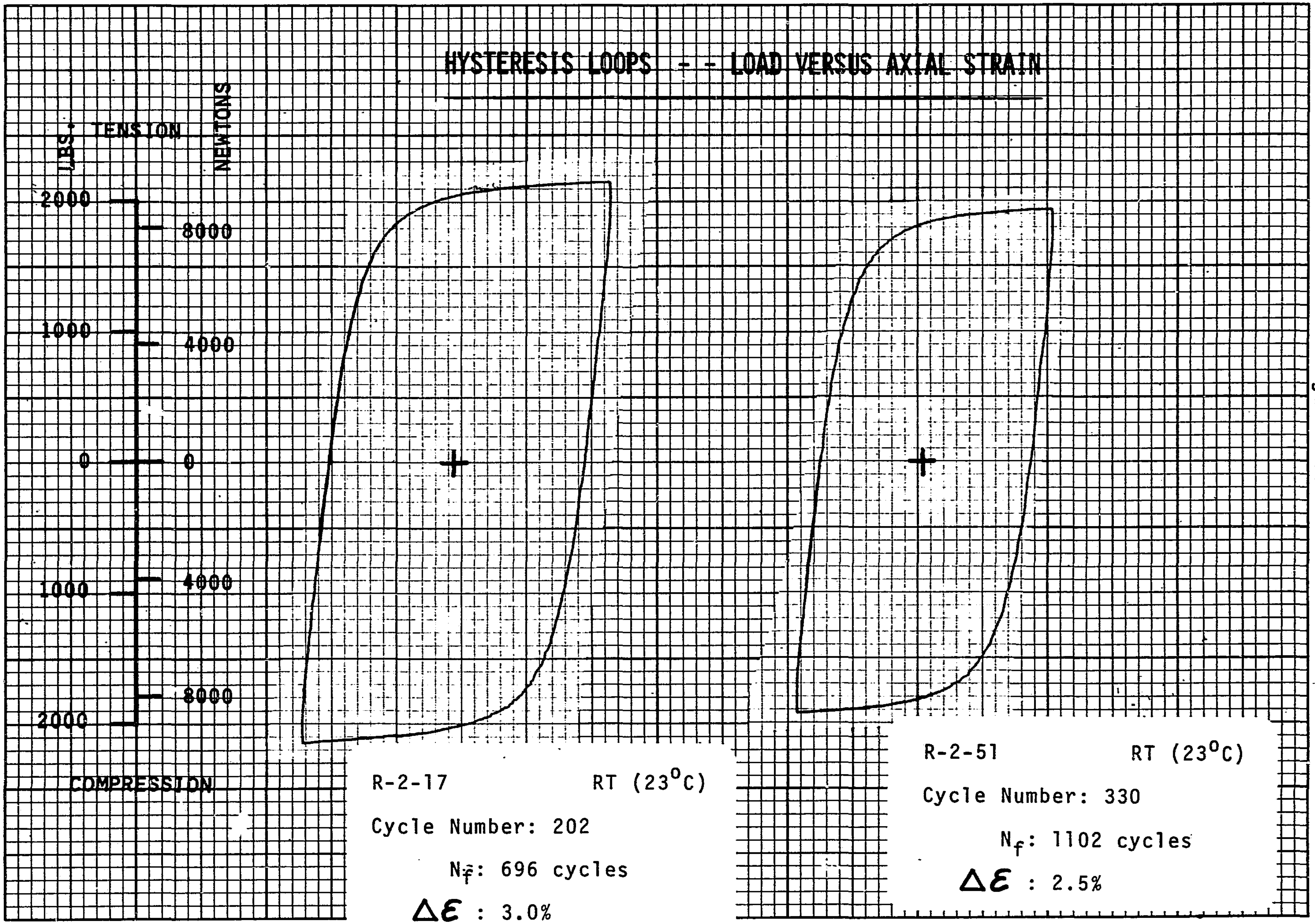
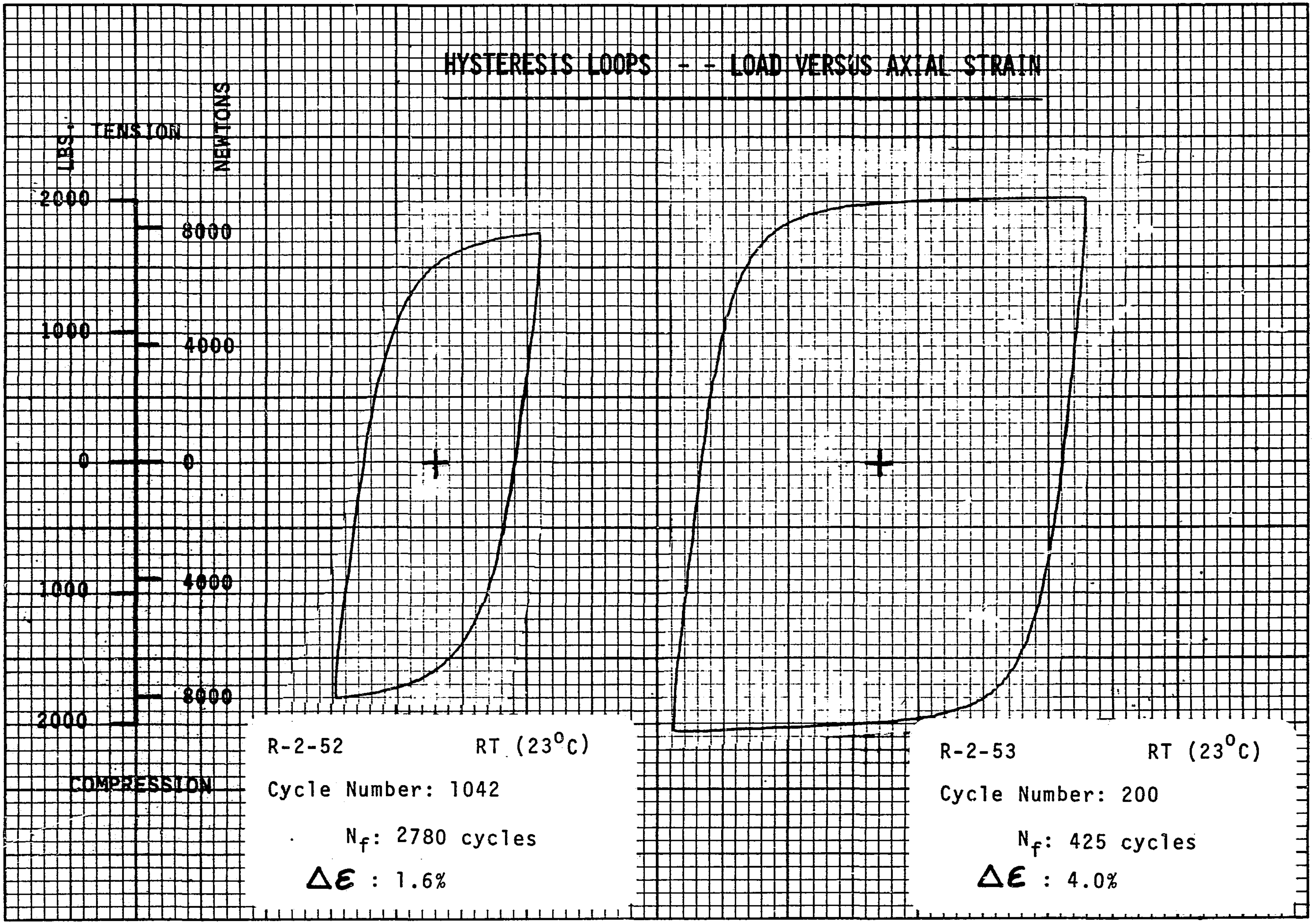

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-17
RT (23°C)
Cycle Number: 202
N$_f$: 696 cycles
$\Delta\varepsilon$: 3.0%
R-2-51
RT (23°C)
Cycle Number: 330
N$_f$: 1102 cycles
$\Delta\varepsilon$: 2.5%

Figure 244



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

Figure 245

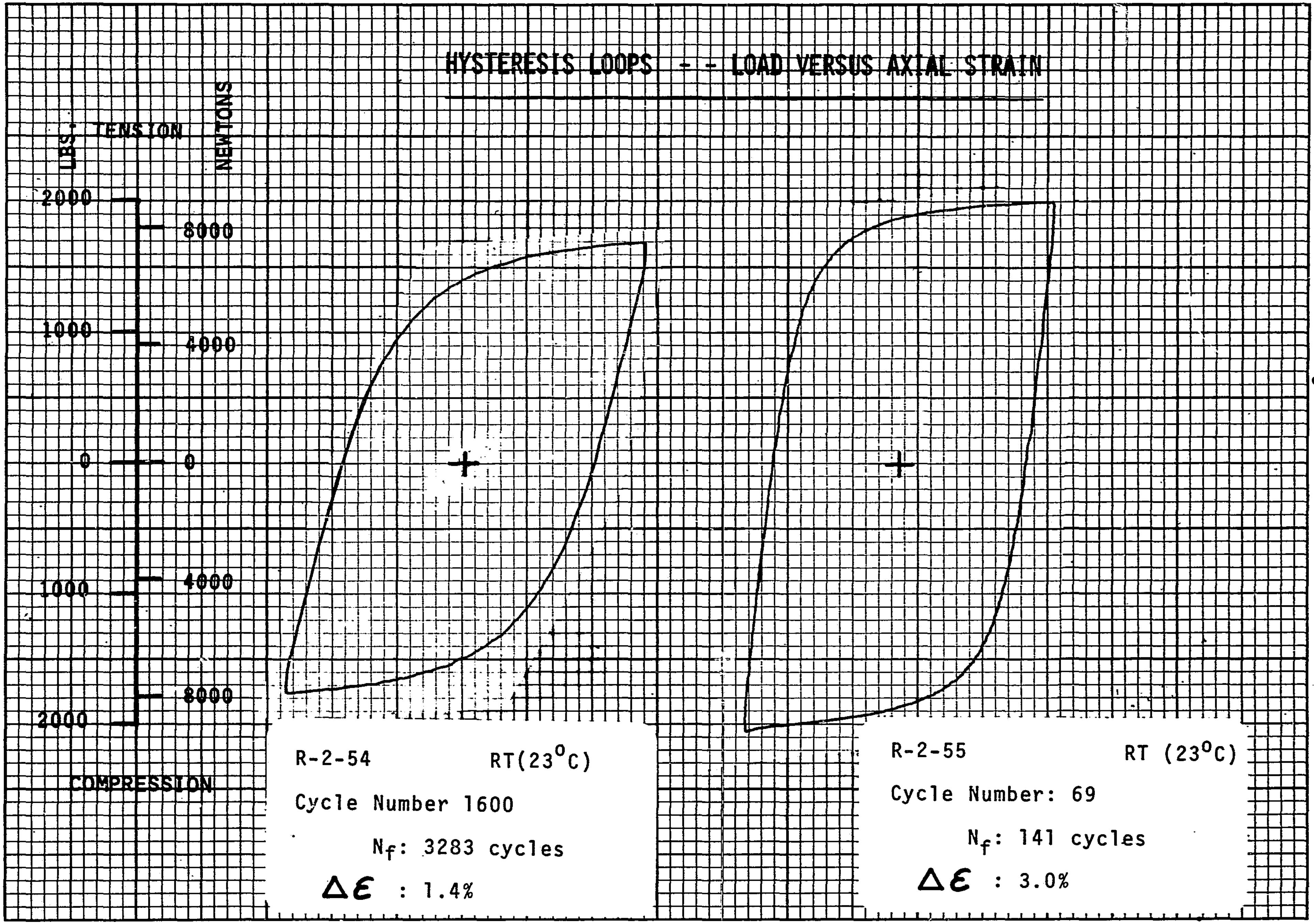

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-2-54
RT(23°C)
Cycle Number 1600
N_f: 3283 cycles
$\Delta\varepsilon$: 1.4%
R-2-55
RT (23°C)
Cycle Number: 69
N_f: 141 cycles
$\Delta\varepsilon$: 3.0%

Figure 246

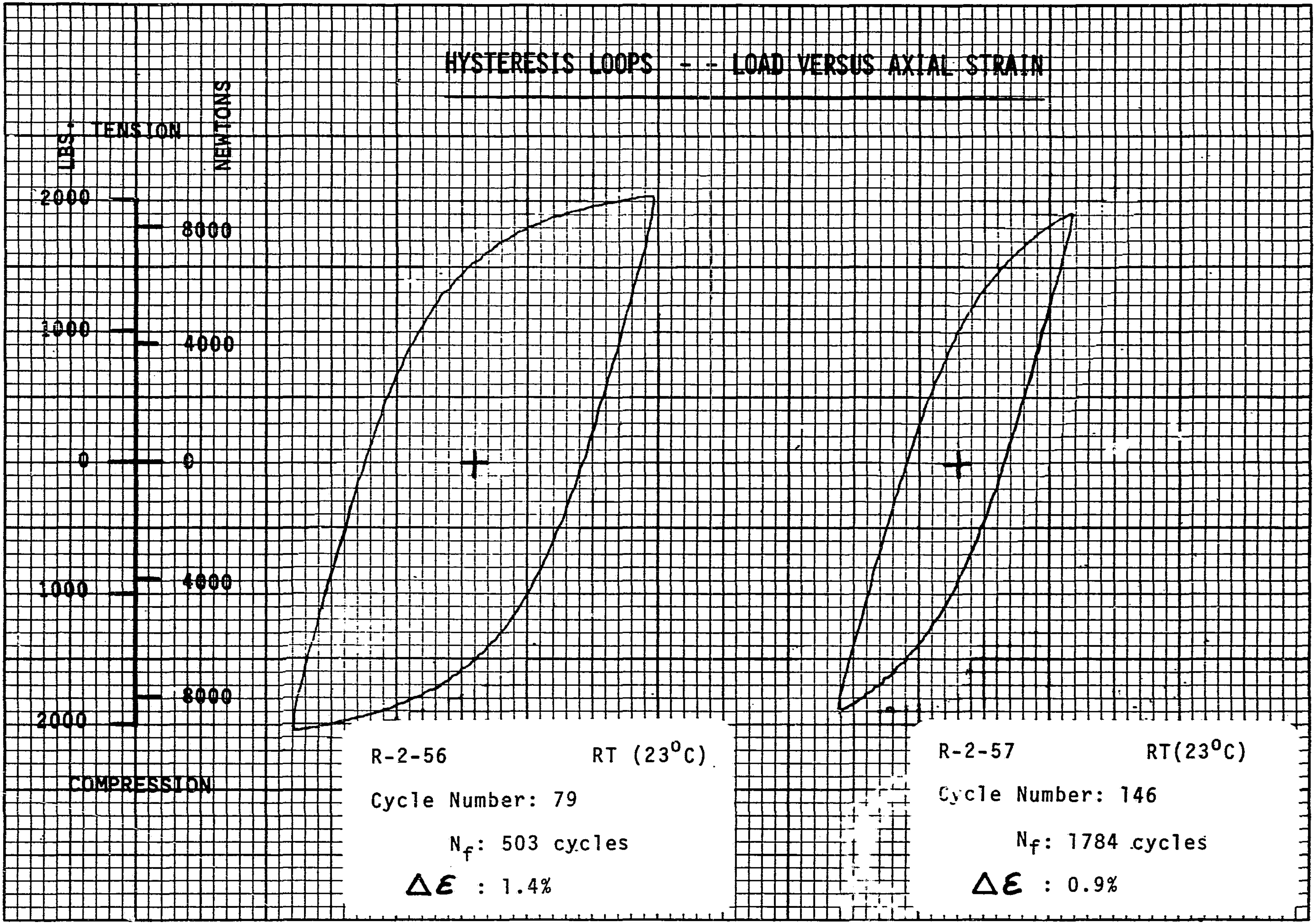

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-2-56 RT (23°C)
Cycle Number: 79
N_f: 503 cycles
Δε : 1.4%
R-2-57 RT(23°C)
Cycle Number: 146
N_f: 1784 cycles
Δε : 0.9%

Figure 247

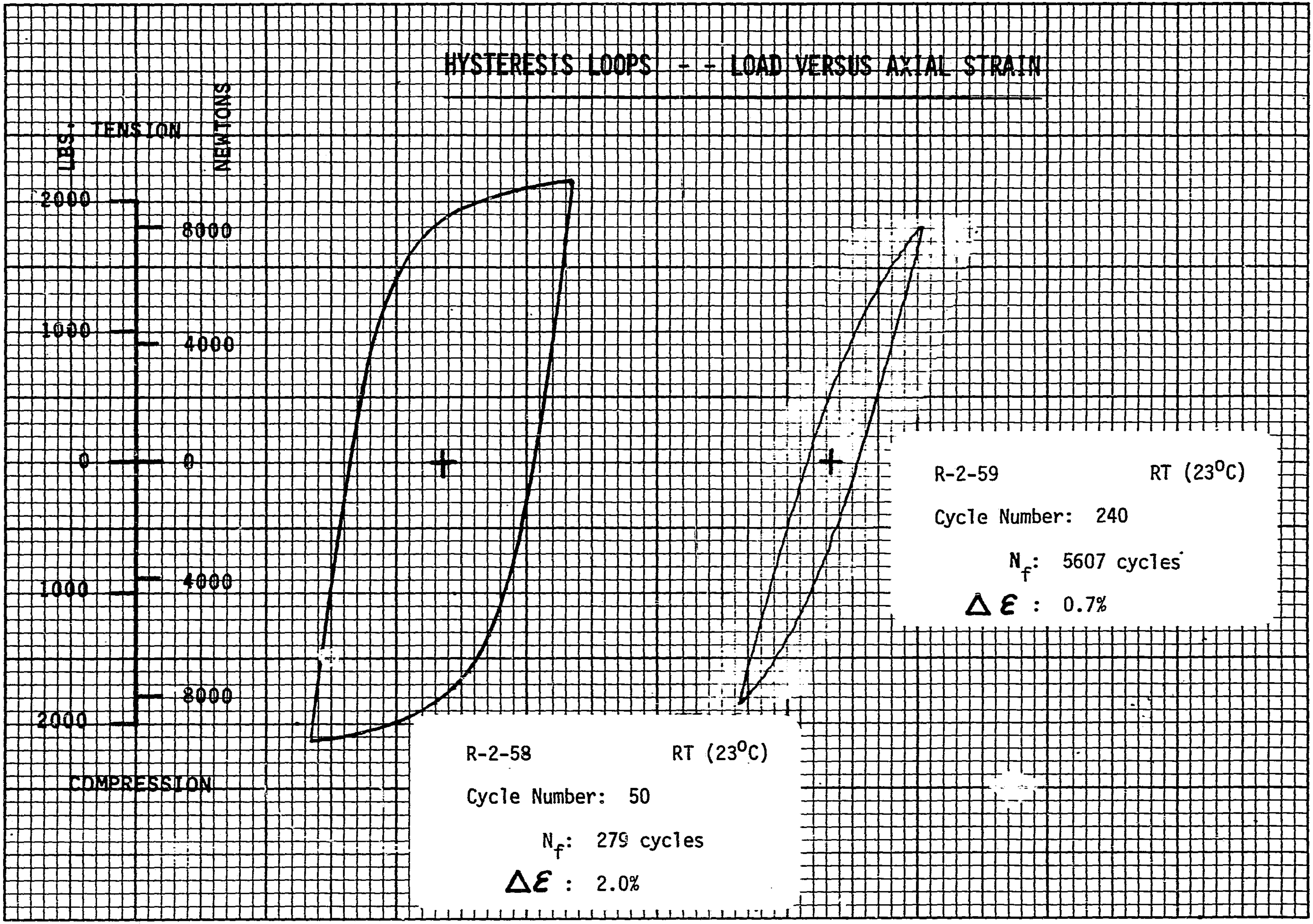
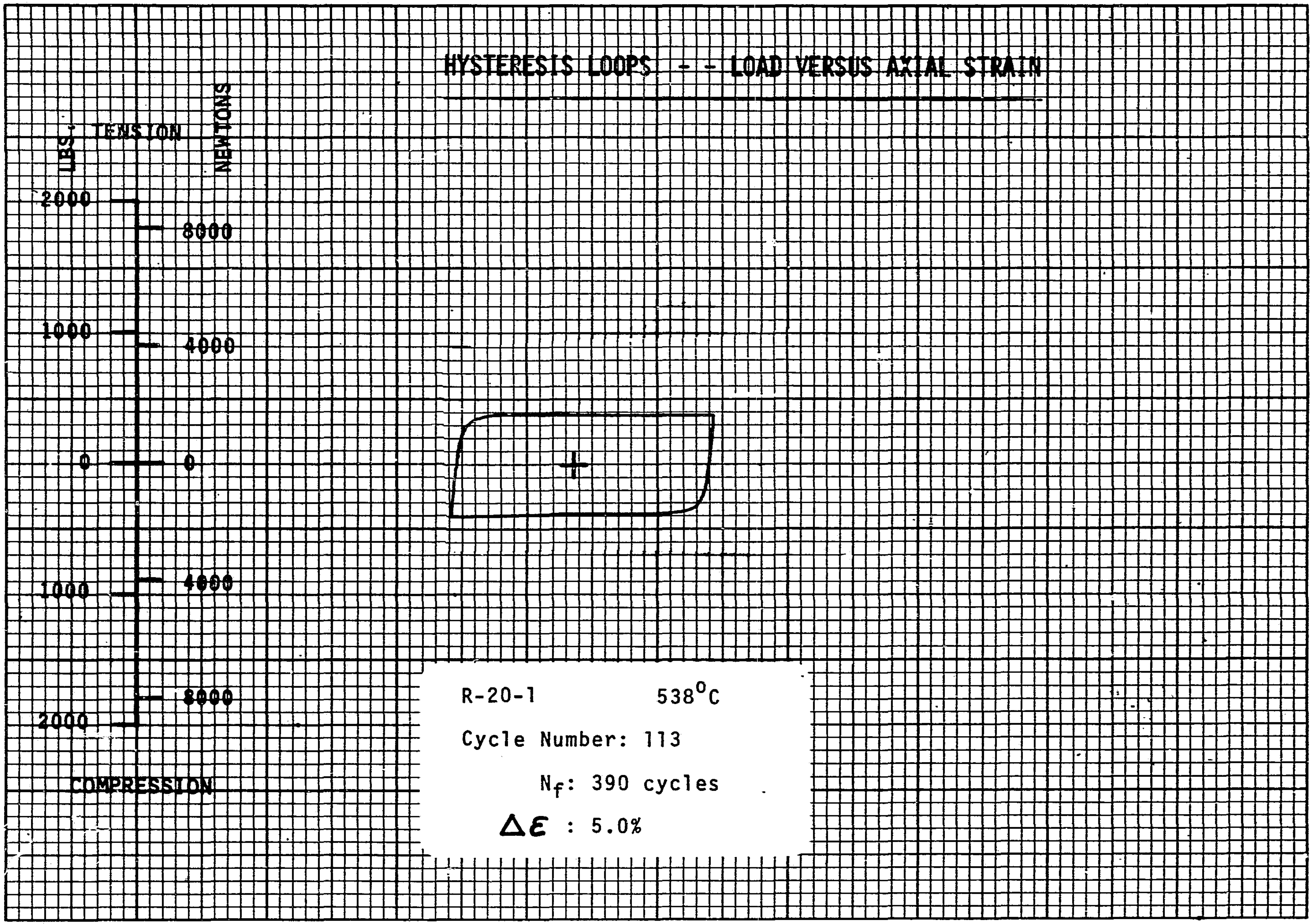

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-59
RT (23°C)
Cycle Number: 240
N_f: 5607 cycles
Δε : 0.7%
R-2-58
RT (23°C)
Cycle Number: 50
N_f: 279 cycles
Δε : 2.0%

Figure 248



R-20-1 538^{o}C

Cycle Number: 113

N_f: 390 cycles

$\Delta\varepsilon$: 5.0%

Figure 249

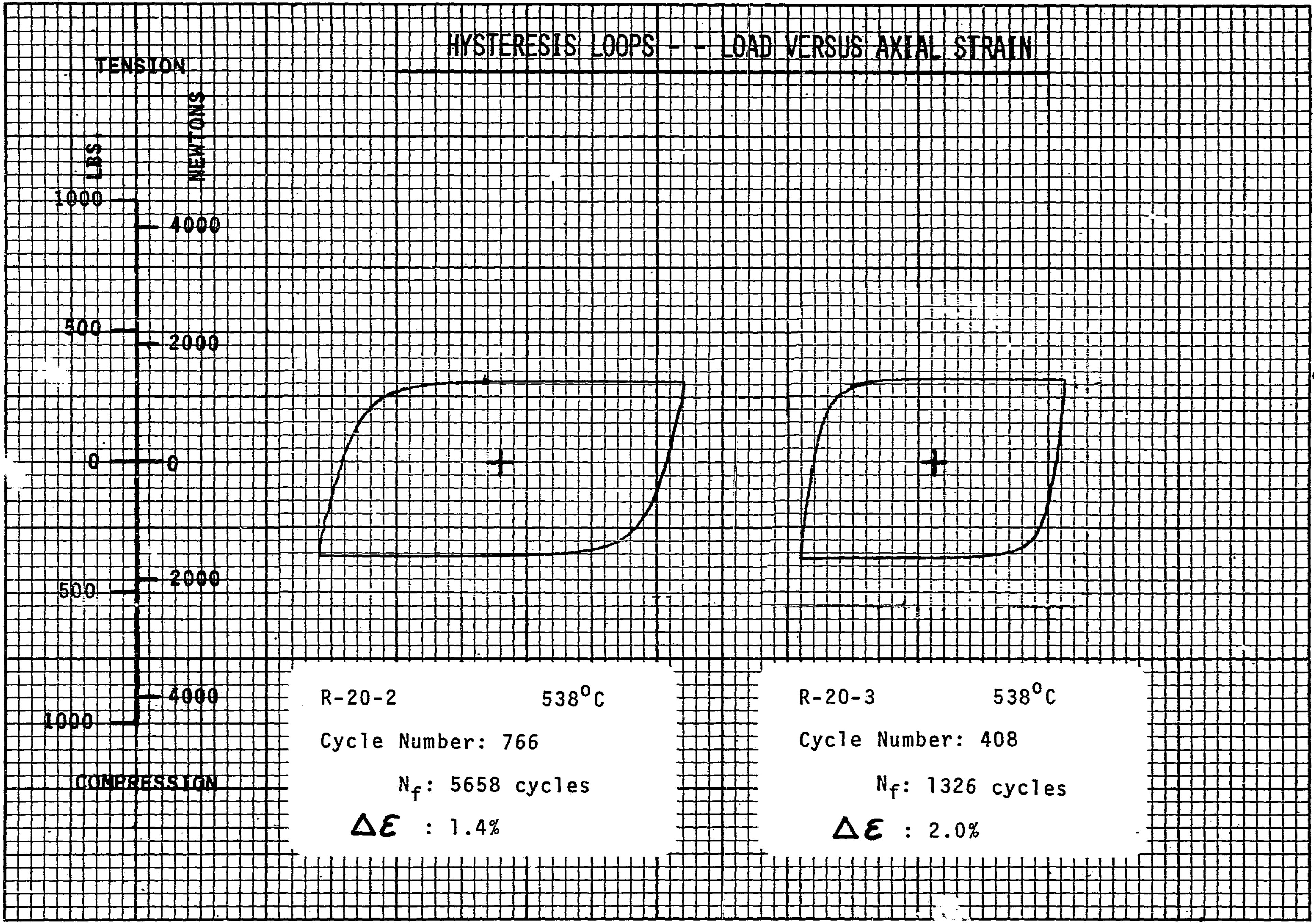

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-20-2
538^{o}C
Cycle Number: 766
N_f: 5658 cycles
$\Delta\varepsilon$: 1.4%
R-20-3
538^{o}C
Cycle Number: 408
N_f: 1326 cycles
$\Delta\varepsilon$: 2.0%

Figure 250

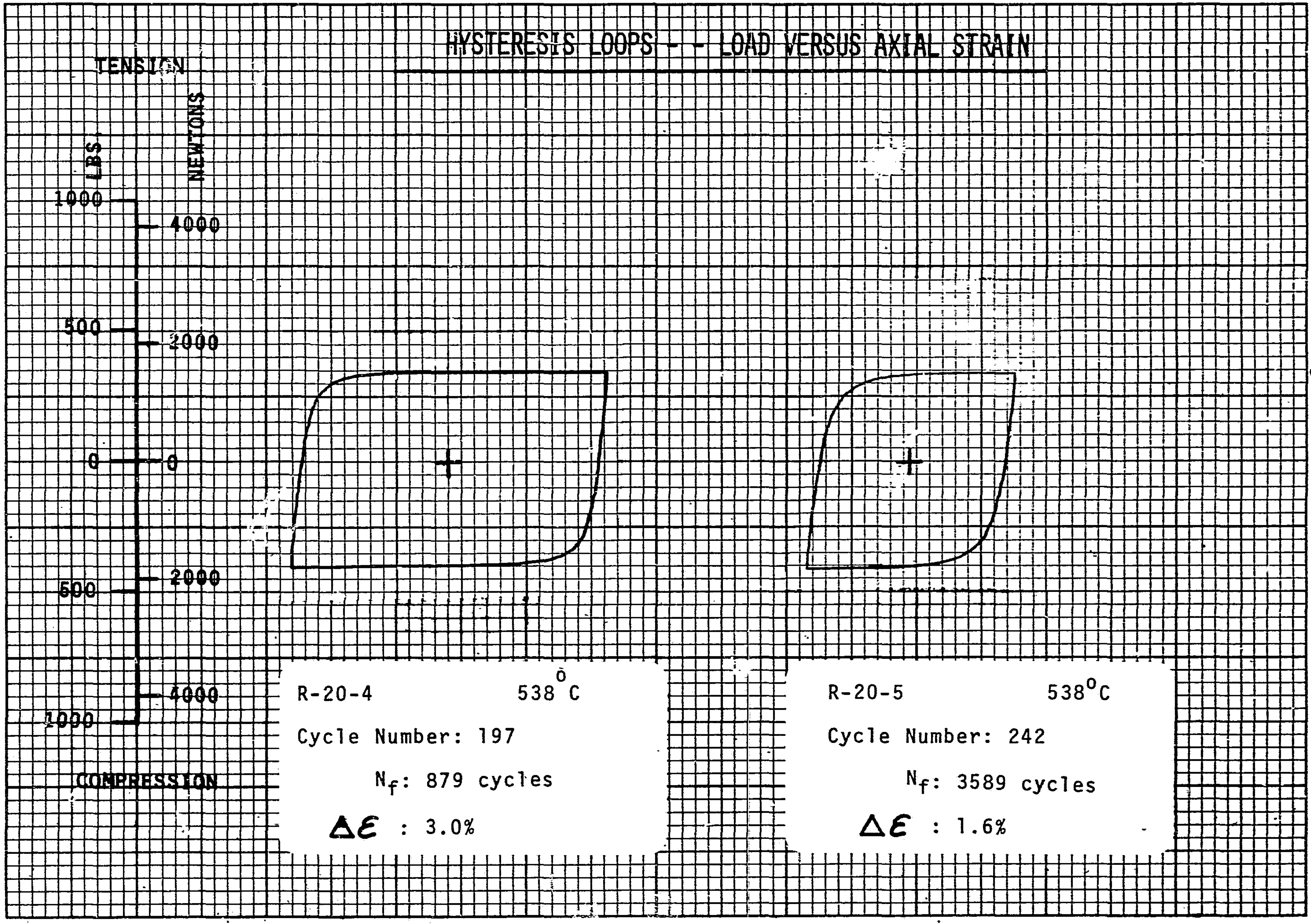
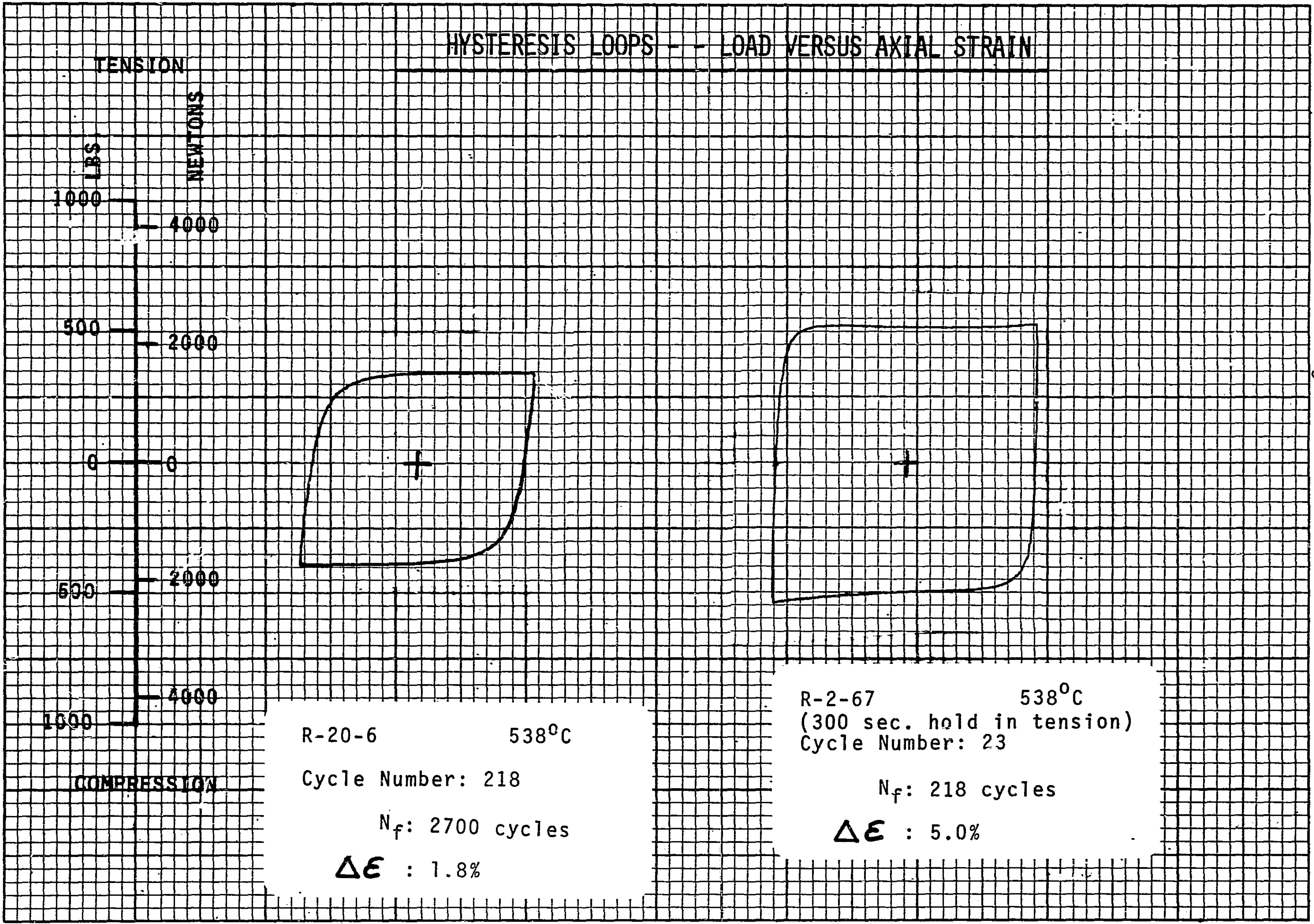

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-20-4
538°C
Cycle Number: 197
N_f: 879 cycles
$\Delta\varepsilon$: 3.0%
R-20-5
538°C
Cycle Number: 242
N_f: 3589 cycles
$\Delta\varepsilon$: 1.6%

Figure 251

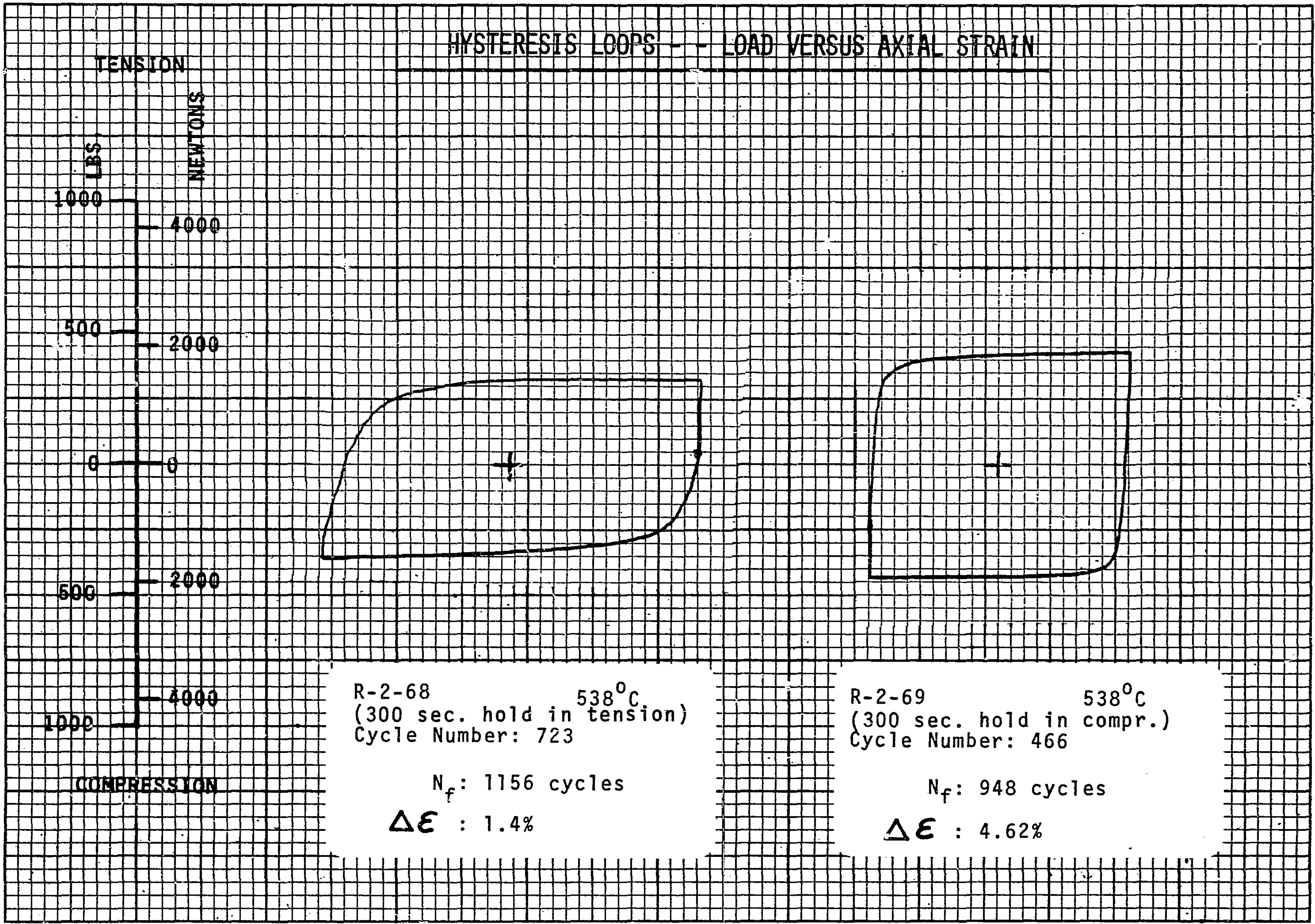


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-20-6 538°C
Cycle Number: 218
N_f: 2700 cycles
$\Delta\varepsilon$: 1.8%

R-2-67 538°C
(300 sec. hold in tension)
Cycle Number: 23
N_f: 218 cycles
$\Delta\varepsilon$: 5.0%

Figure 252



R-2-68 538°C
(300 sec. hold in tension)
Cycle Number: 723

N_f: 1156 cycles

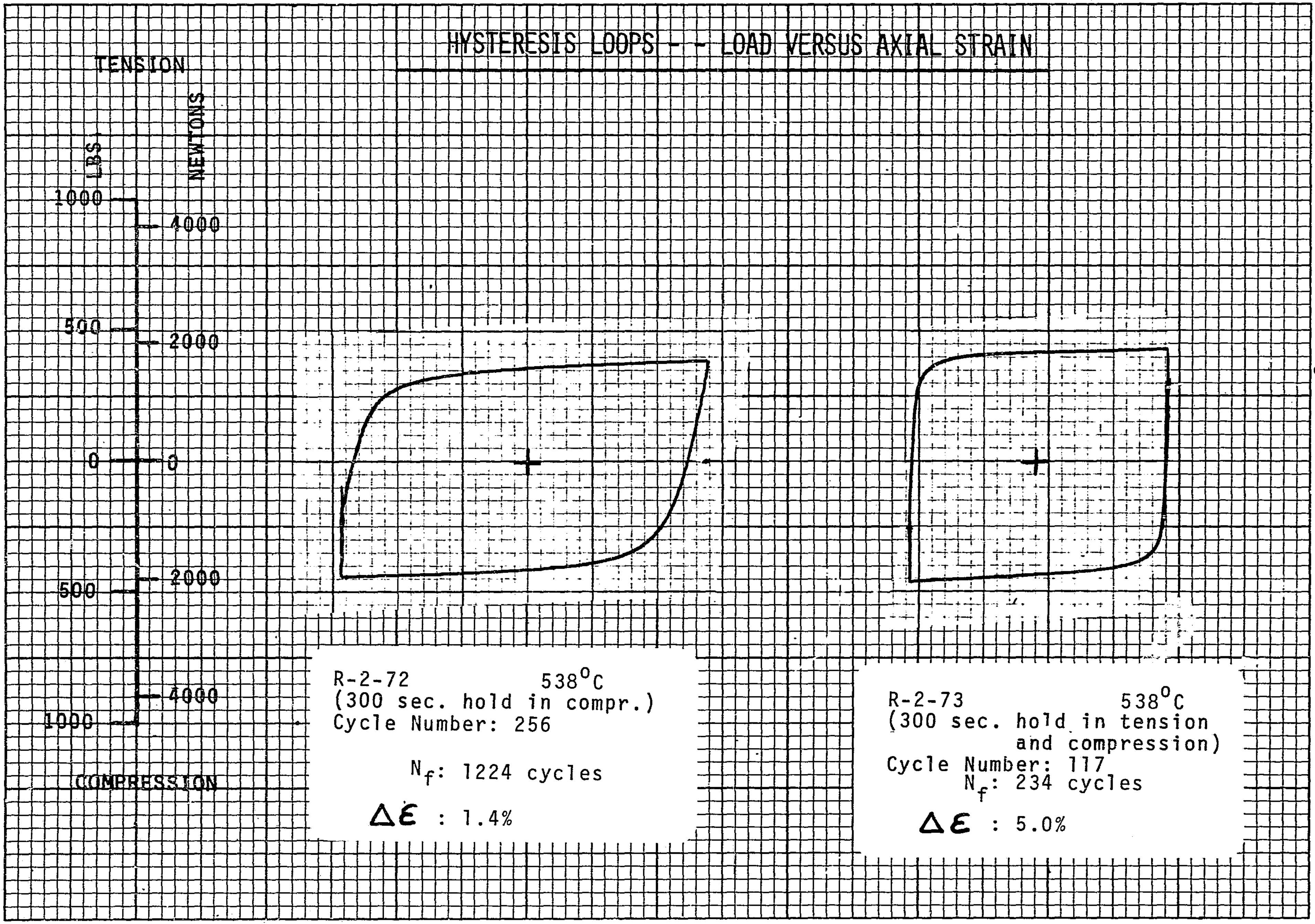
$\Delta\varepsilon$: 1.4%

R-2-69 538°C
(300 sec. hold in compr.)
Cycle Number: 466

N_f: 948 cycles

$\Delta\varepsilon$: 4.62%

Figure 253



R-2-72 538^{o}C
(300 sec. hold in compr.)
Cycle Number: 256

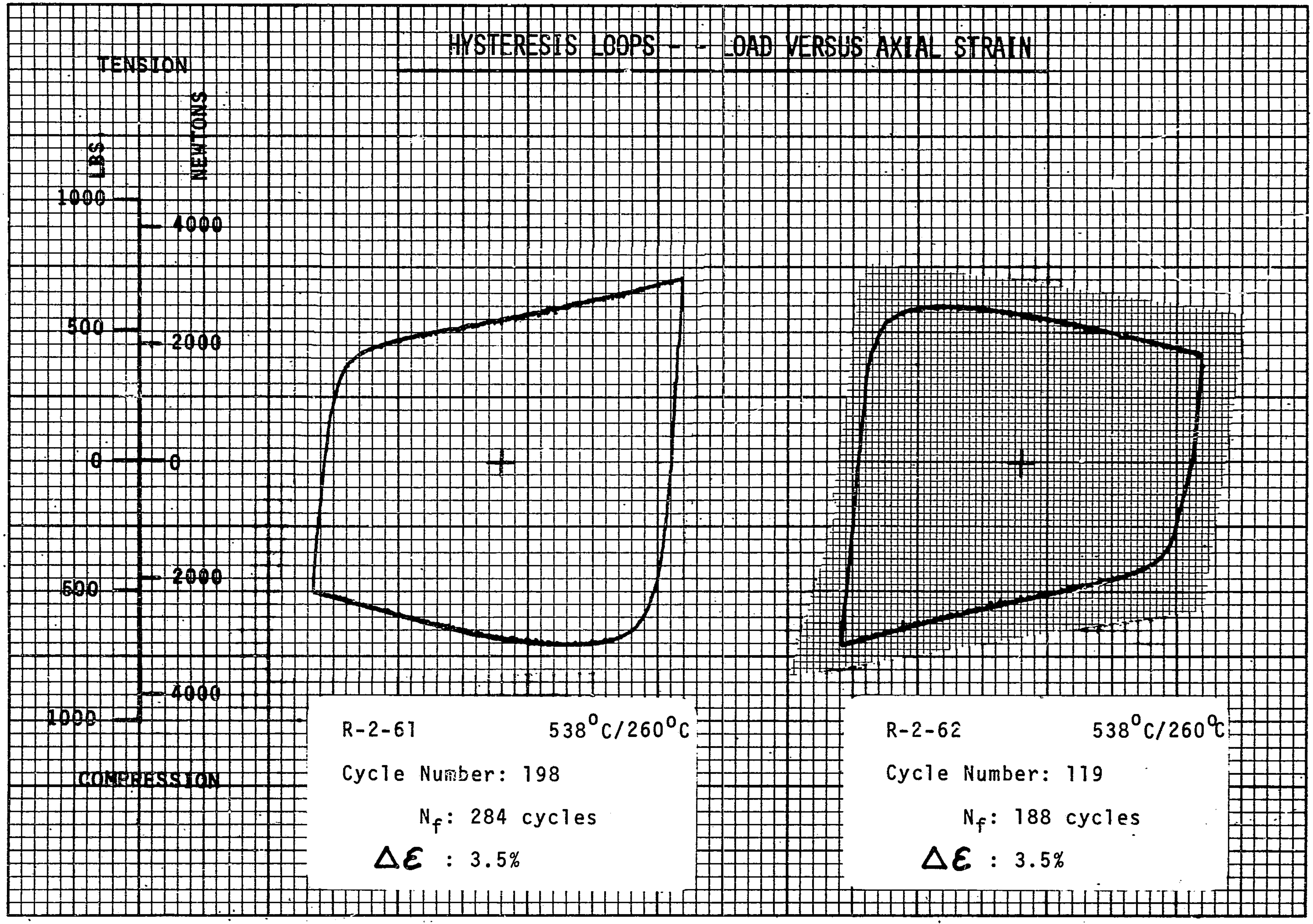
N_f: 1224 cycles

$\Delta\varepsilon$: 1.4%

R-2-73 538^{o}C
(300 sec. hold in tension
and compression)
Cycle Number: 117
N_f: 234 cycles

$\Delta\varepsilon$: 5.0%

Figure 254



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

Figure 255

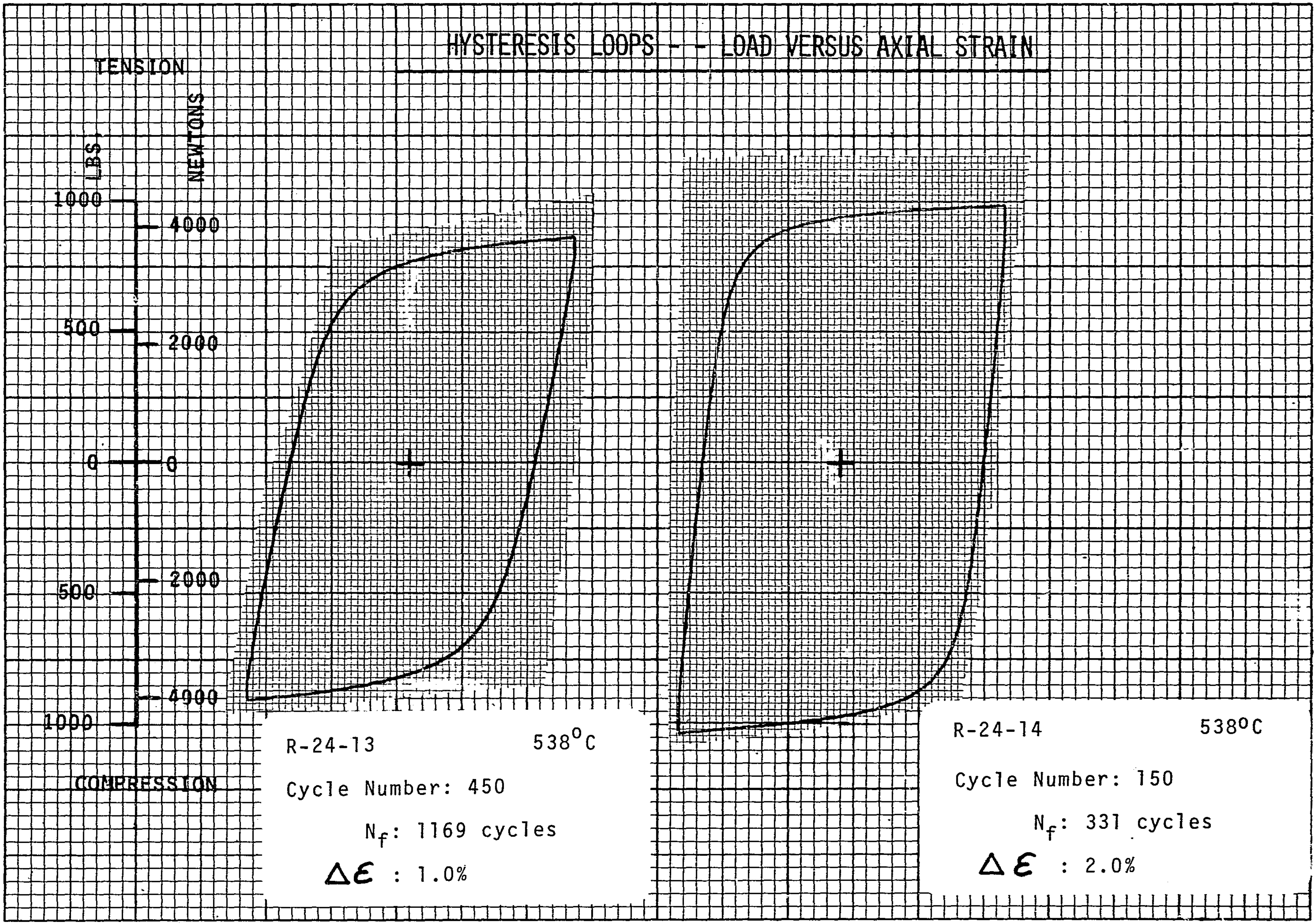
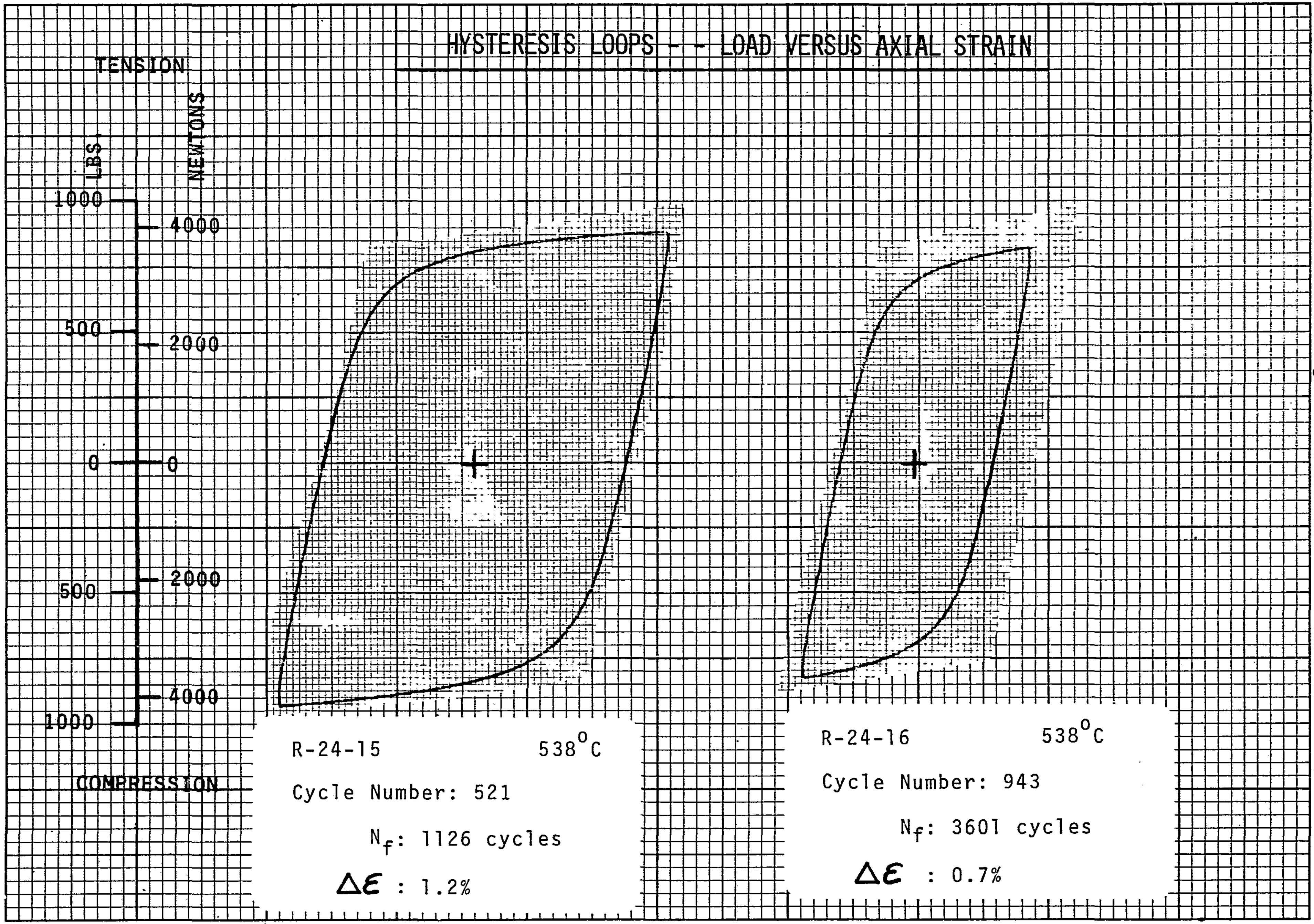

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-13
538°C
Cycle Number: 450
N_f: 1169 cycles
$\Delta\varepsilon$: 1.0%
R-24-14
538°C
Cycle Number: 150
N_f: 331 cycles
$\Delta\varepsilon$: 2.0%

Figure 256



R-24-15 538°C

Cycle Number: 521

N_f: 1126 cycles

$\Delta\varepsilon$: 1.2%

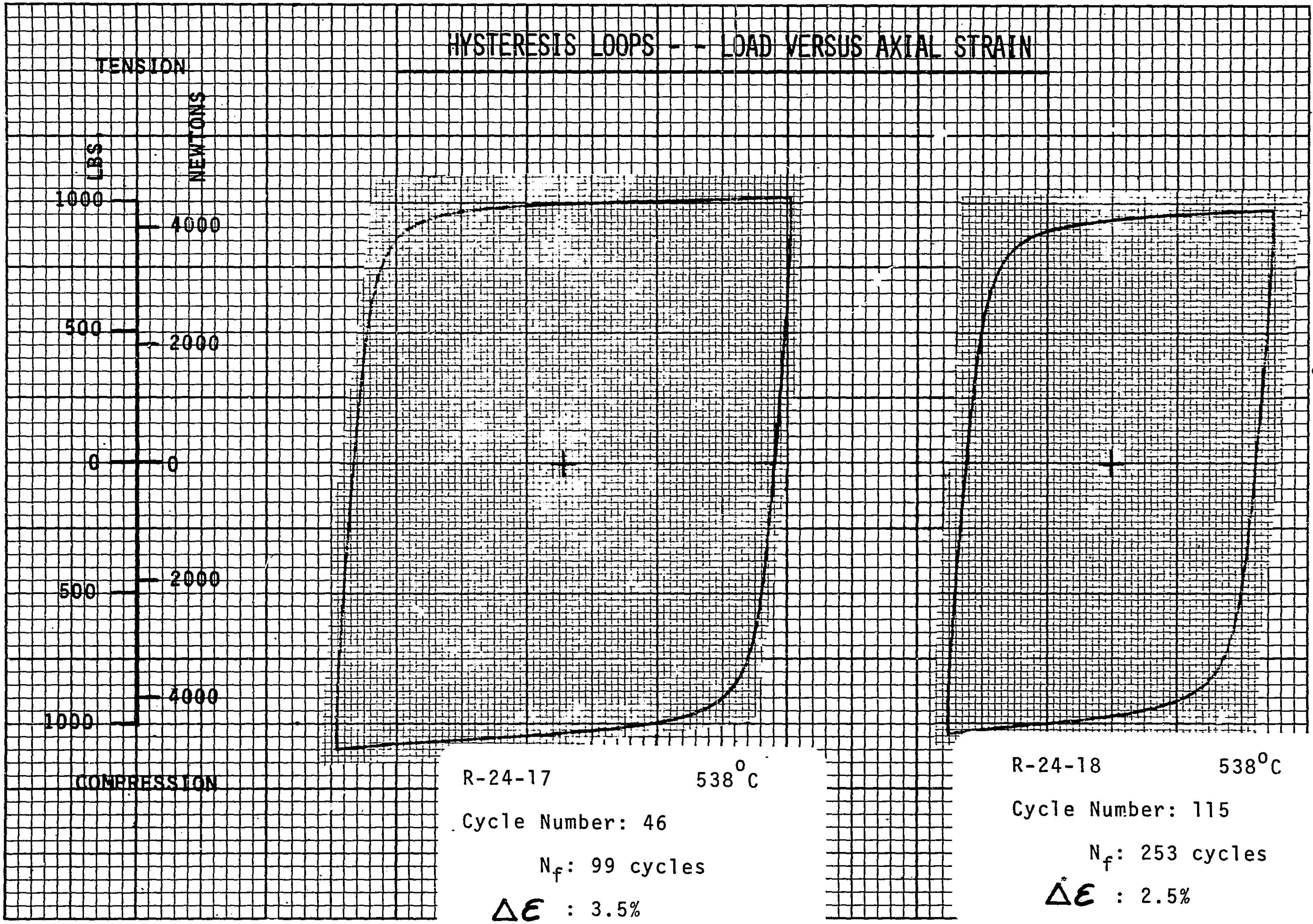
R-24-16 538°C

Cycle Number: 943

N_f: 3601 cycles

$\Delta\varepsilon$: 0.7%

Figure 257



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-24-17 538°C

Cycle Number: 46

N_f: 99 cycles

$\Delta\varepsilon$: 3.5%

R-24-18 538°C

Cycle Number: 115

N_f: 253 cycles

$\Delta\varepsilon$: 2.5%

Figure 258

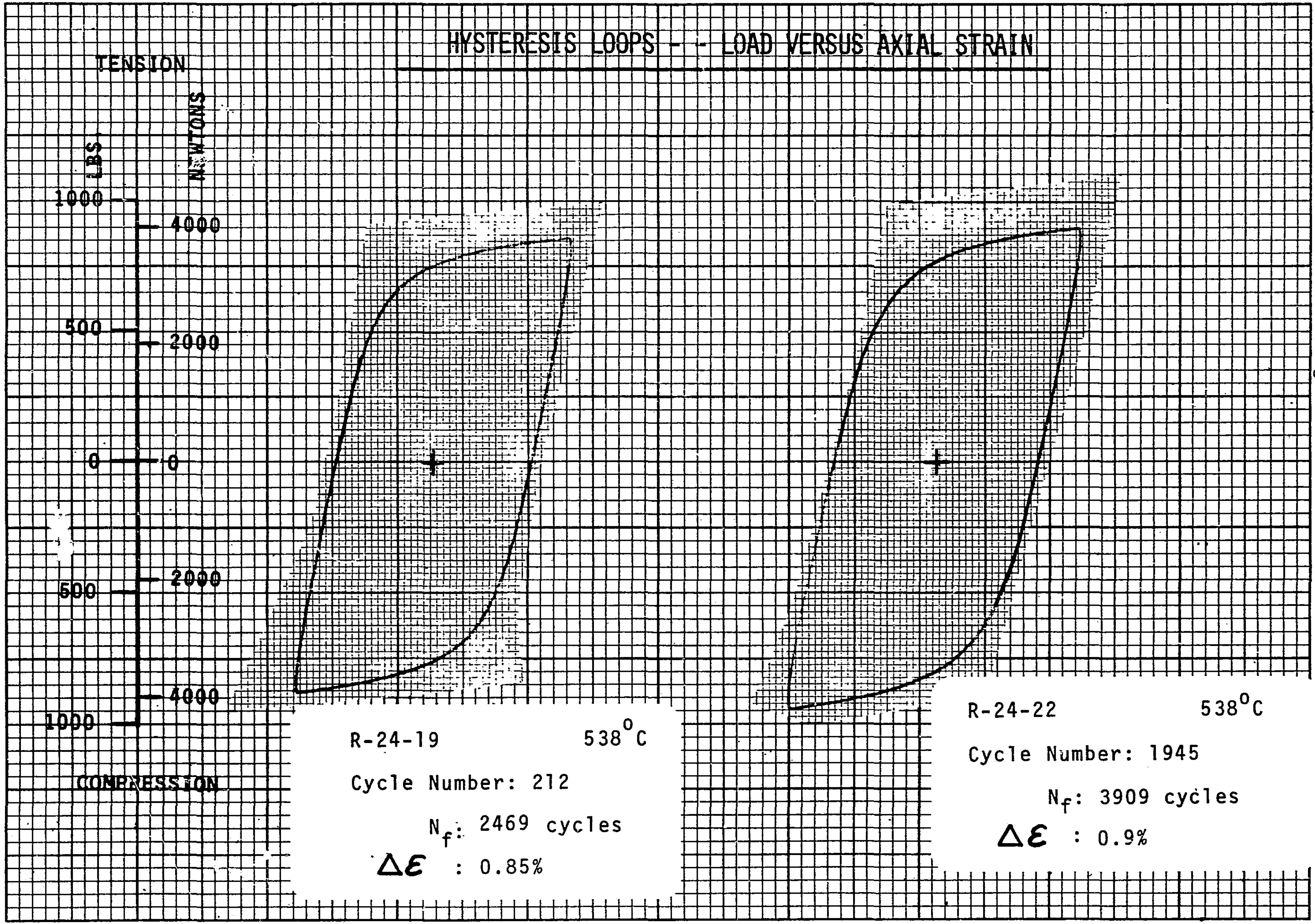
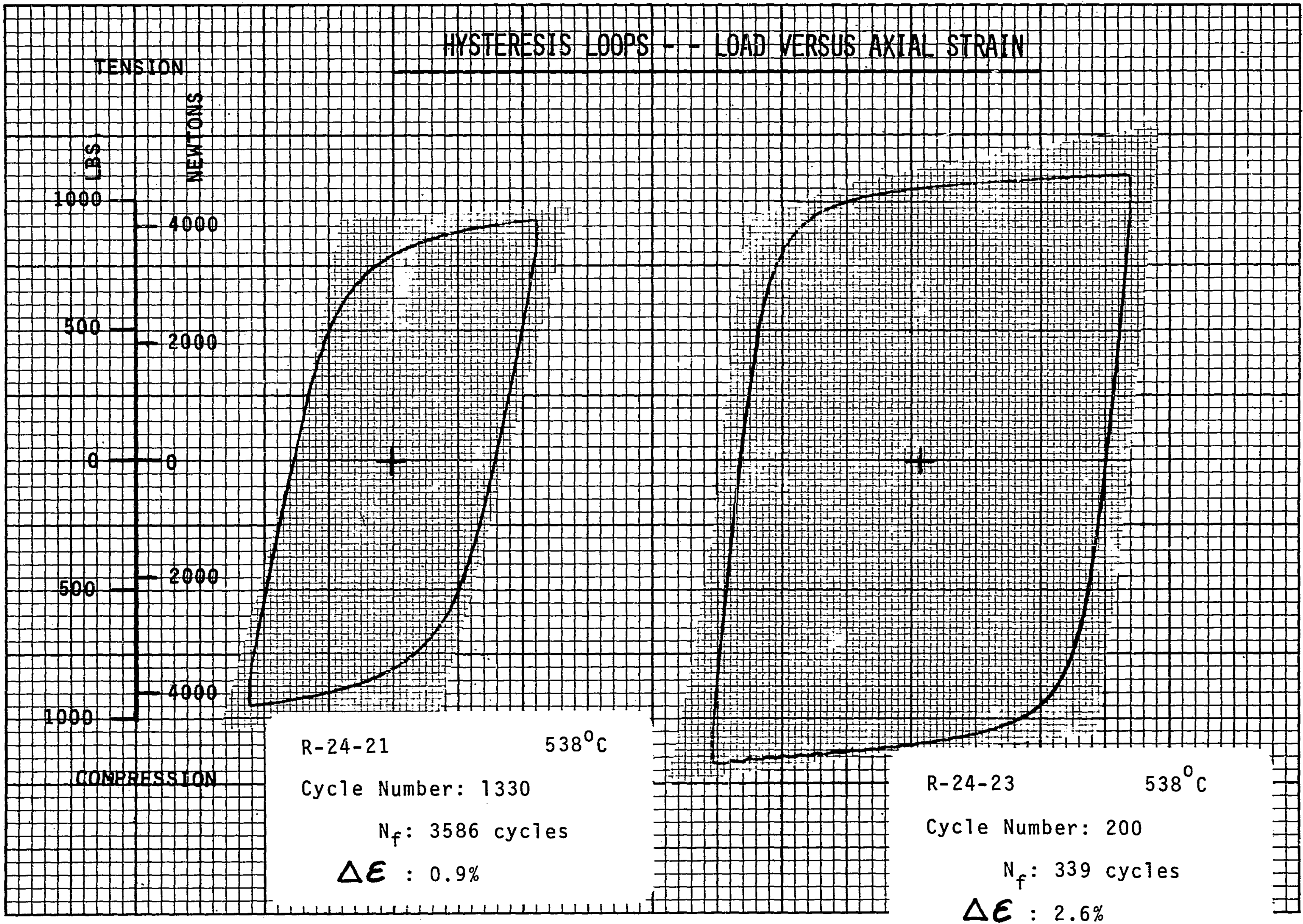

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-24-19
538°C
Cycle Number: 212
N_f: 2469 cycles
$\Delta\varepsilon$: 0.85%
R-24-22
538°C
Cycle Number: 1945
N_f: 3909 cycles
$\Delta\varepsilon$: 0.9%

Figure 259



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-24-21 538°C

Cycle Number: 1330

N_f: 3586 cycles

$\Delta\varepsilon$: 0.9%

R-24-23 538°C

Cycle Number: 200

N_f: 339 cycles

$\Delta\varepsilon$: 2.6%

Figure 260

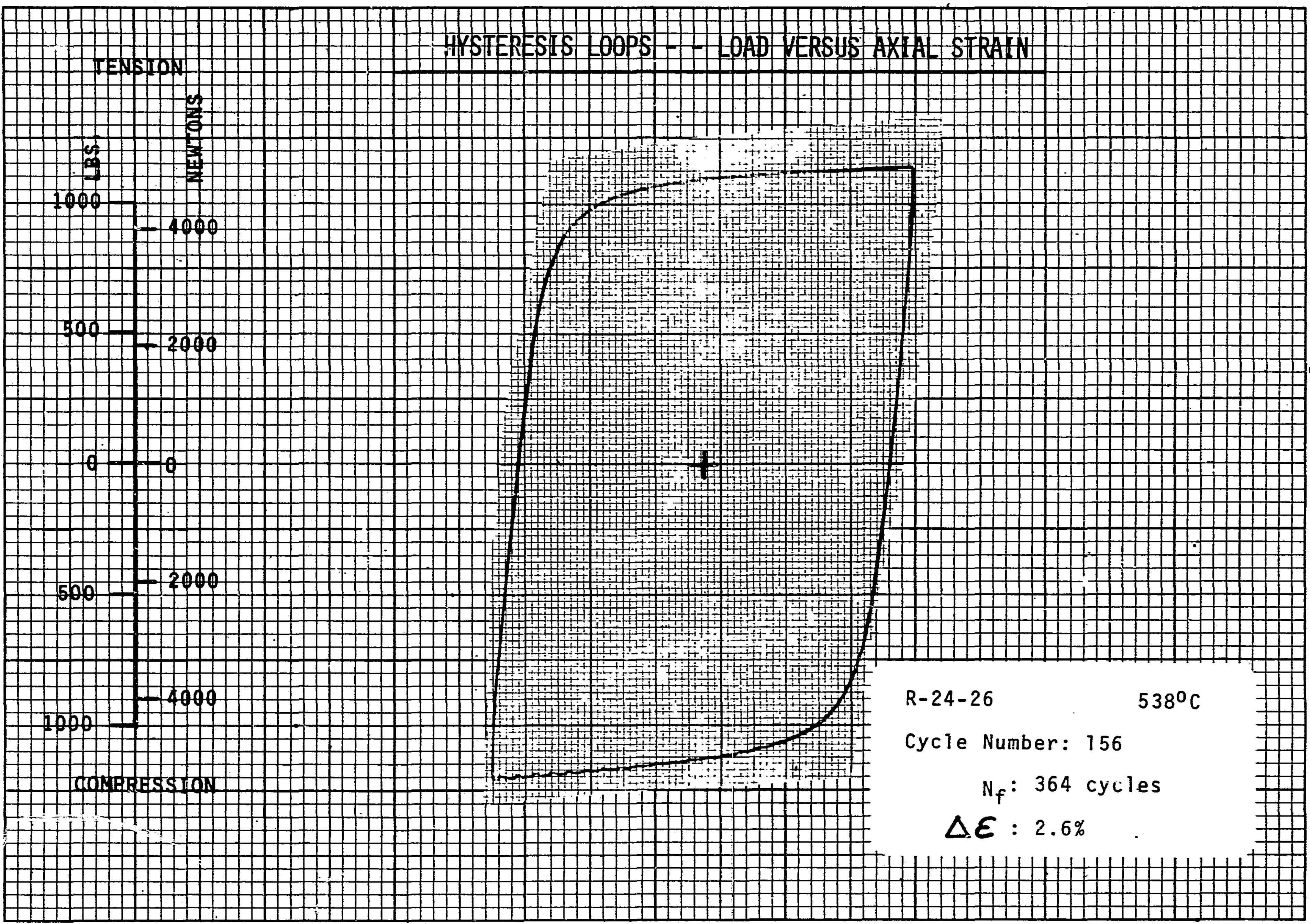
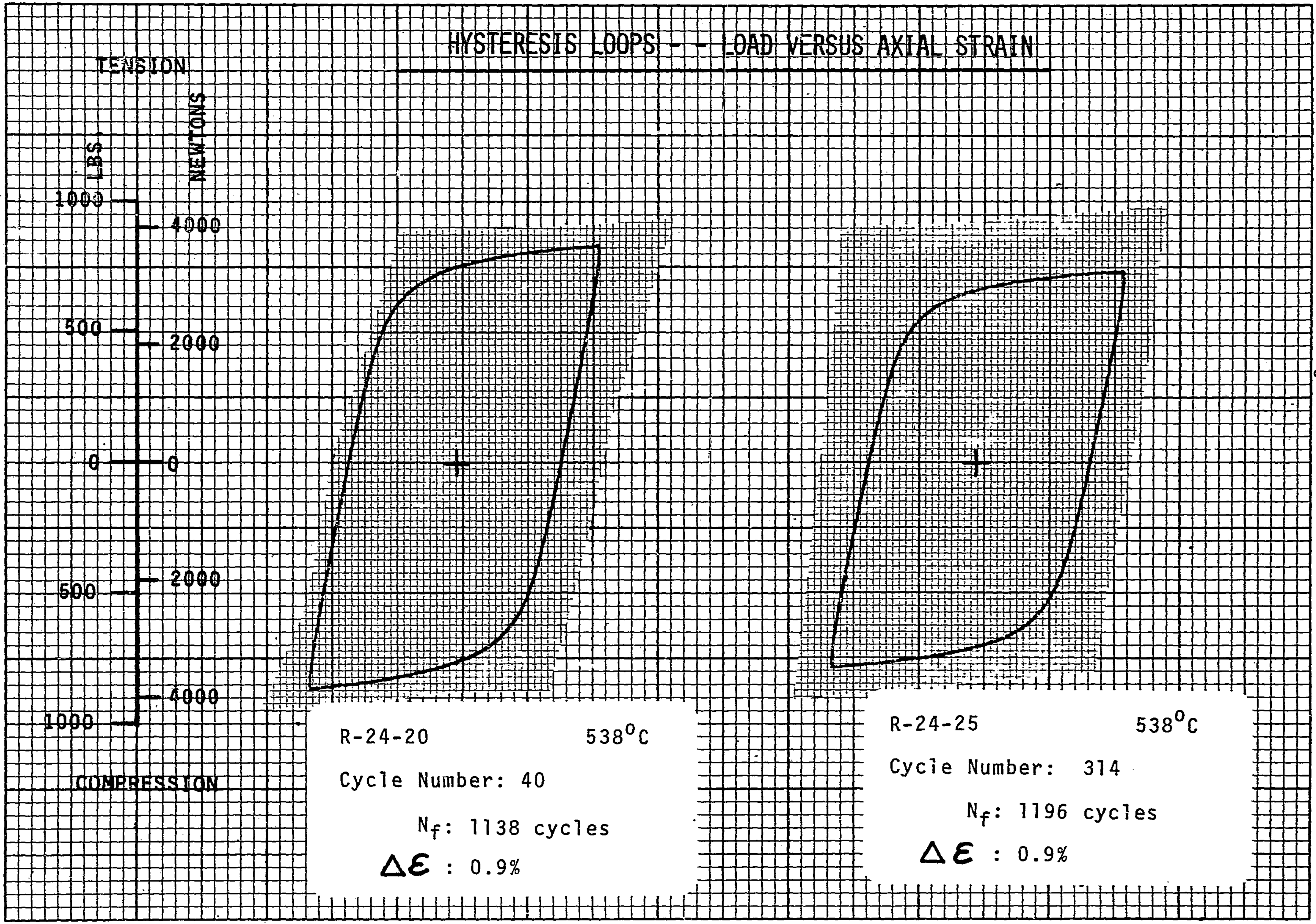

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-26
538°C
Cycle Number: 156
N_f: 364 cycles
Δε : 2.6%

Figure 261



R-24-20 538°C

Cycle Number: 40

N_f: 1138 cycles

$\Delta\varepsilon$: 0.9%

R-24-25 538°C

Cycle Number: 314

N_f: 1196 cycles

$\Delta\varepsilon$: 0.9%

Figure 262

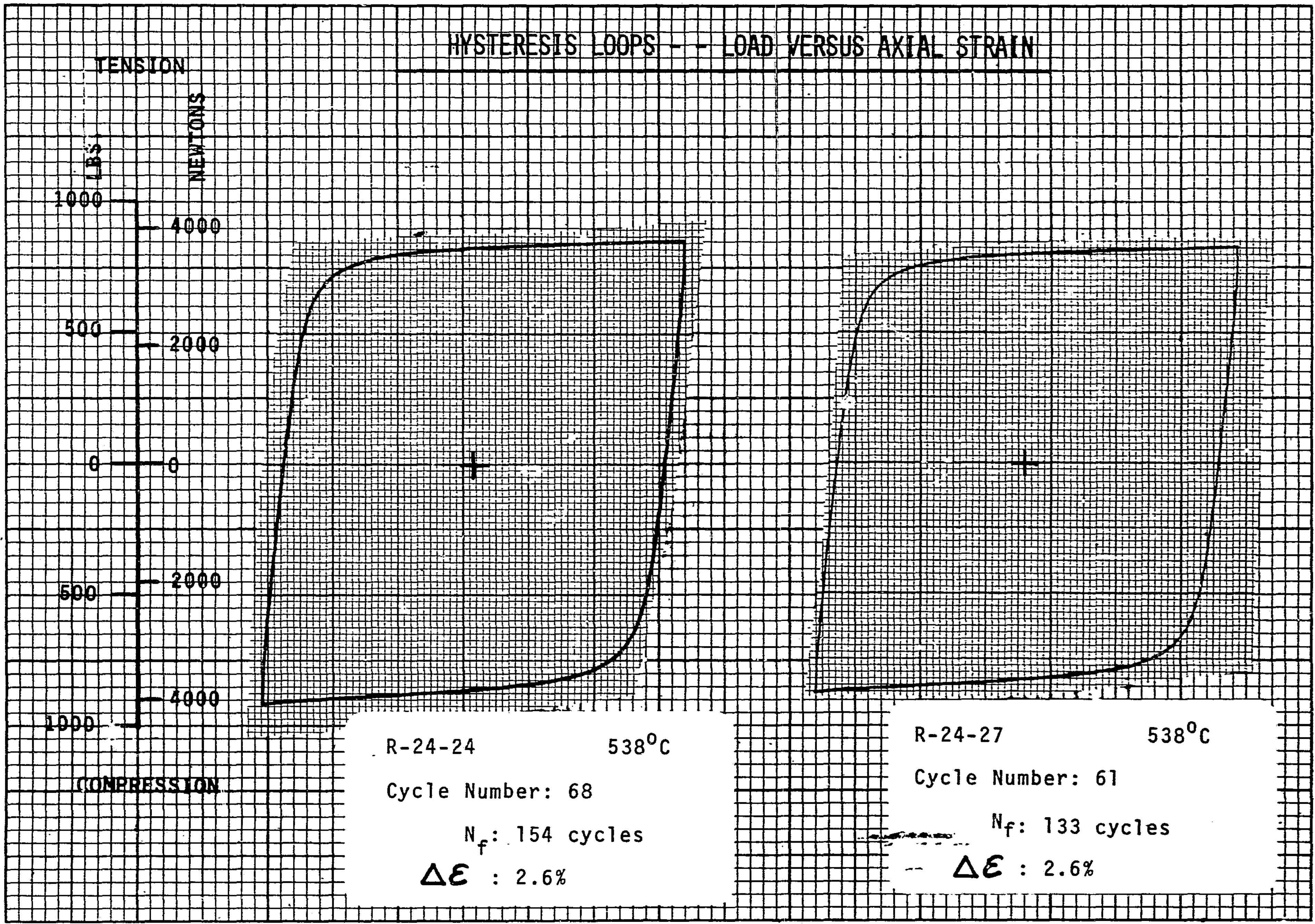

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-24
538°C
Cycle Number: 68
N_f: 154 cycles
Δε : 2.6%
R-24-27
538°C
Cycle Number: 61
N_f: 133 cycles
Δε : 2.6%

Figure 263

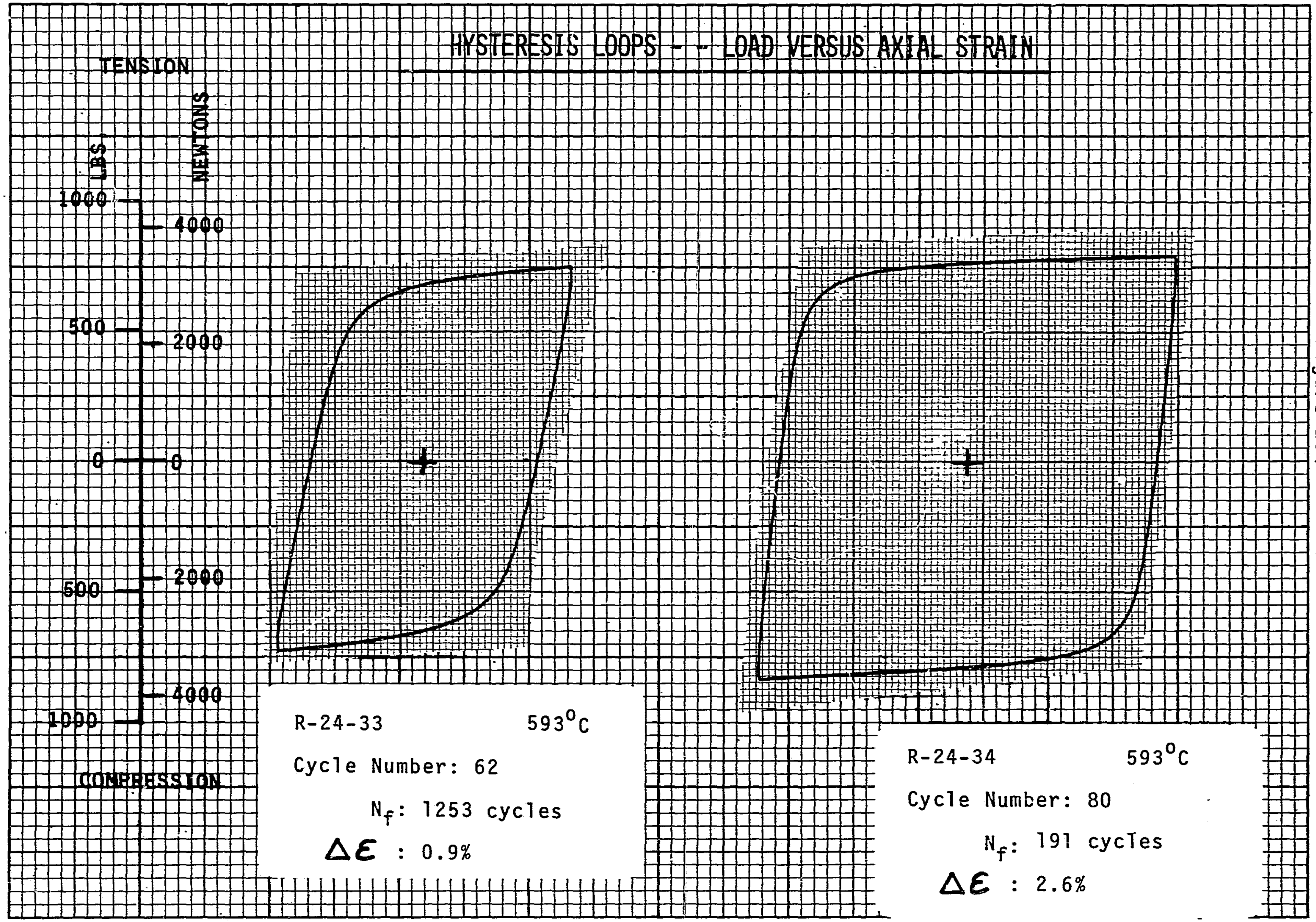

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-33
593°C
Cycle Number: 62
N_f: 1253 cycles
Δε : 0.9%
R-24-34
593°C
Cycle Number: 80
N_f: 191 cycles
Δε : 2.6%

Figure 264

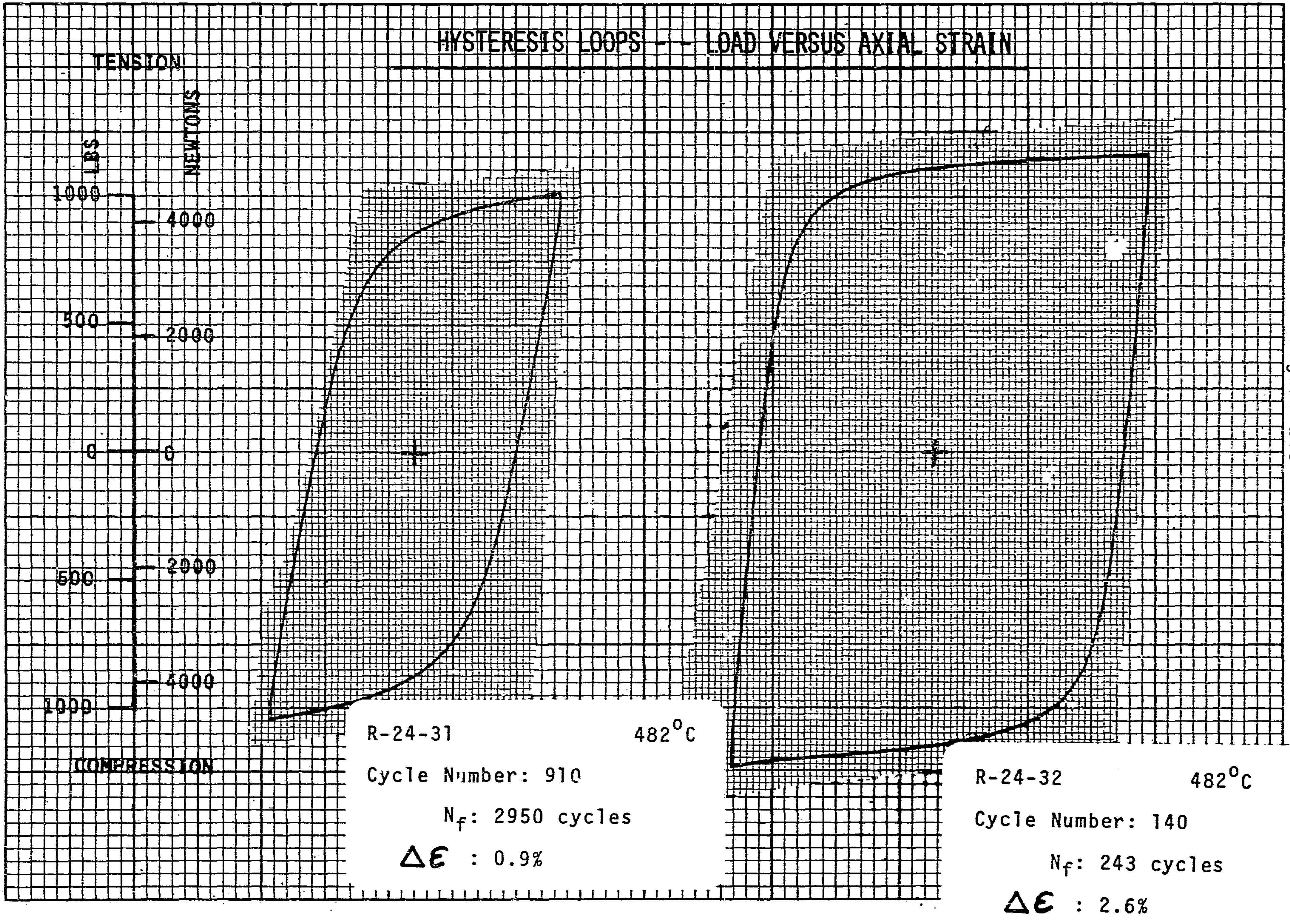
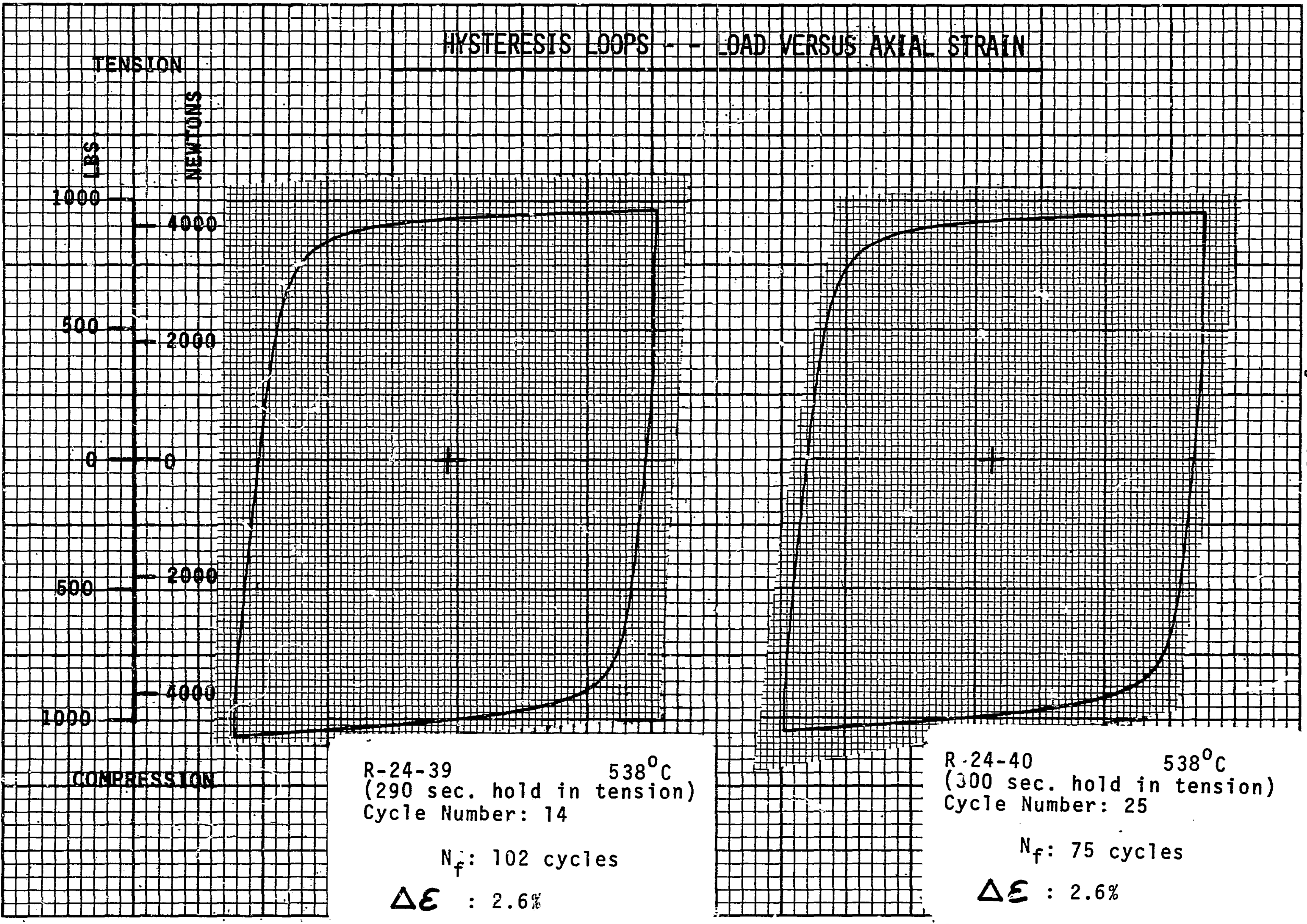

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-31
482°C
Cycle Number: 910
N_f: 2950 cycles
Δε : 0.9%
R-24-32
482°C
Cycle Number: 140
N_f: 243 cycles
Δε : 2.6%

Figure 265



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-24-39 538^{0}C
(290 sec. hold in tension)
Cycle Number: 14

N_f: 102 cycles

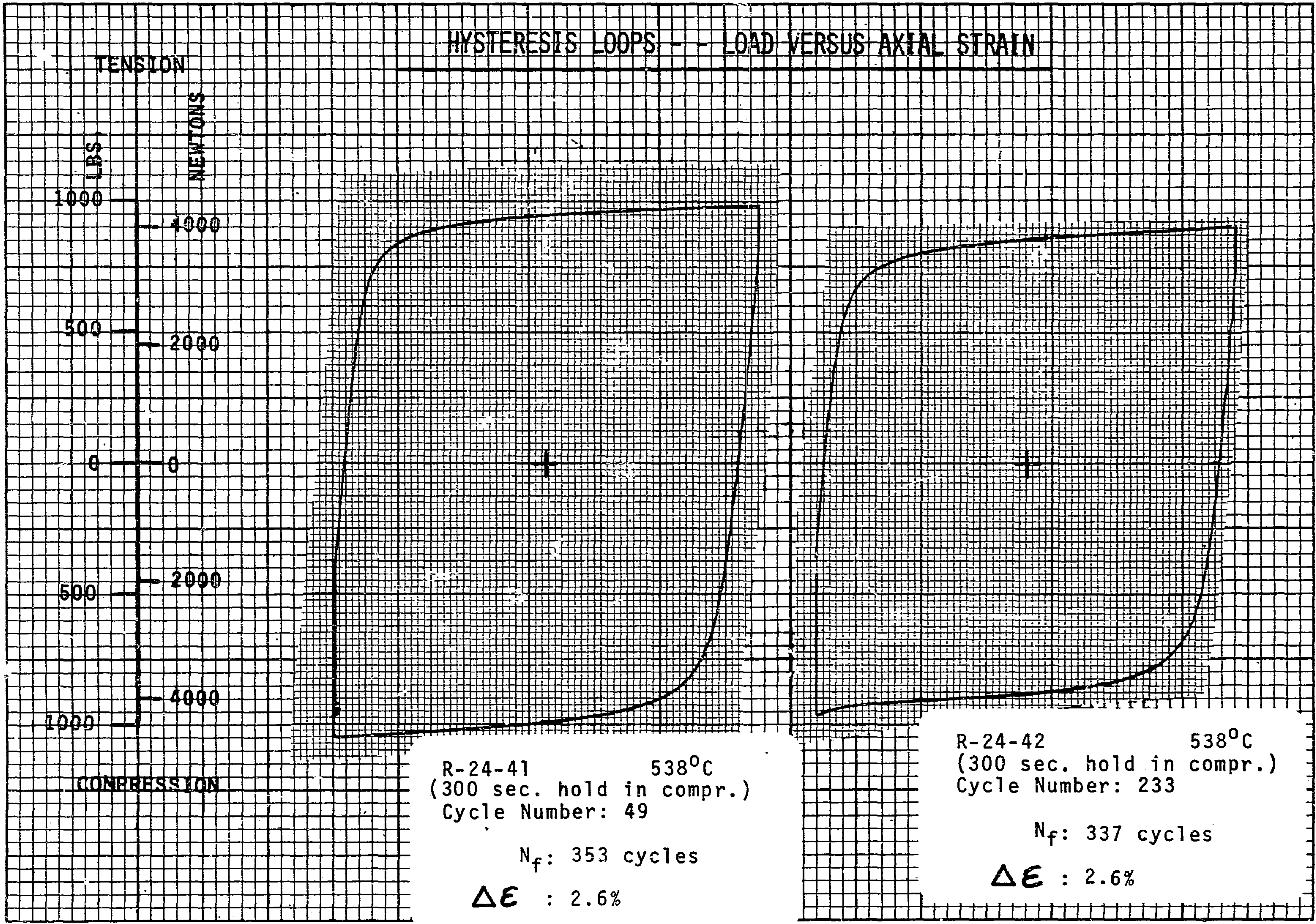
$\Delta\varepsilon$: 2.6%

R-24-40 538^{0}C
(300 sec. hold in tension)
Cycle Number: 25

N_f: 75 cycles

$\Delta\varepsilon$: 2.6%

Figure 266



R-24-41 538^{o}C
(300 sec. hold in compr.)
Cycle Number: 49

N_f: 353 cycles

$\Delta\varepsilon$: 2.6%

R-24-42 538^{o}C
(300 sec. hold in compr.)
Cycle Number: 233

N_f: 337 cycles

$\Delta\varepsilon$: 2.6%

Figure 267

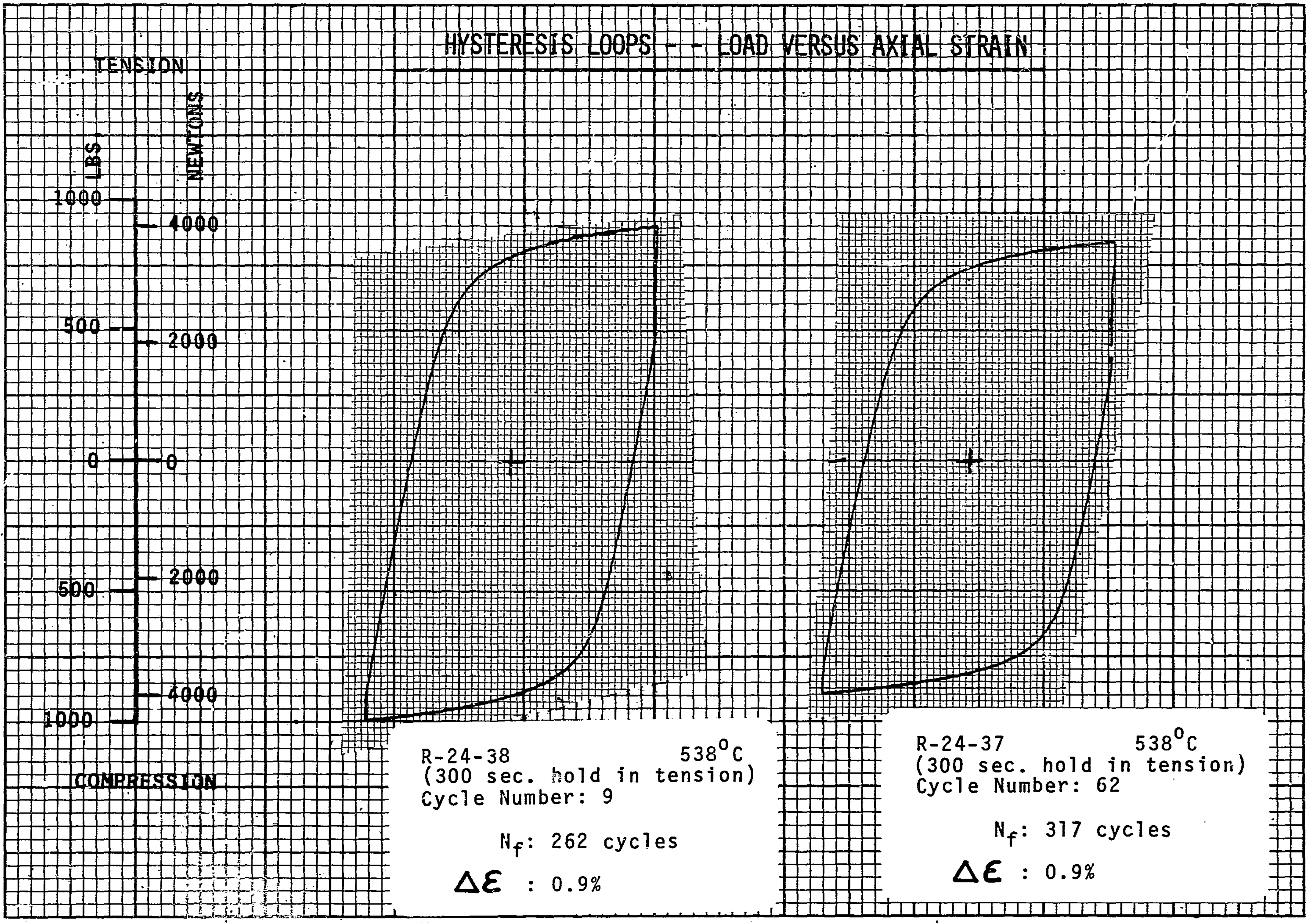
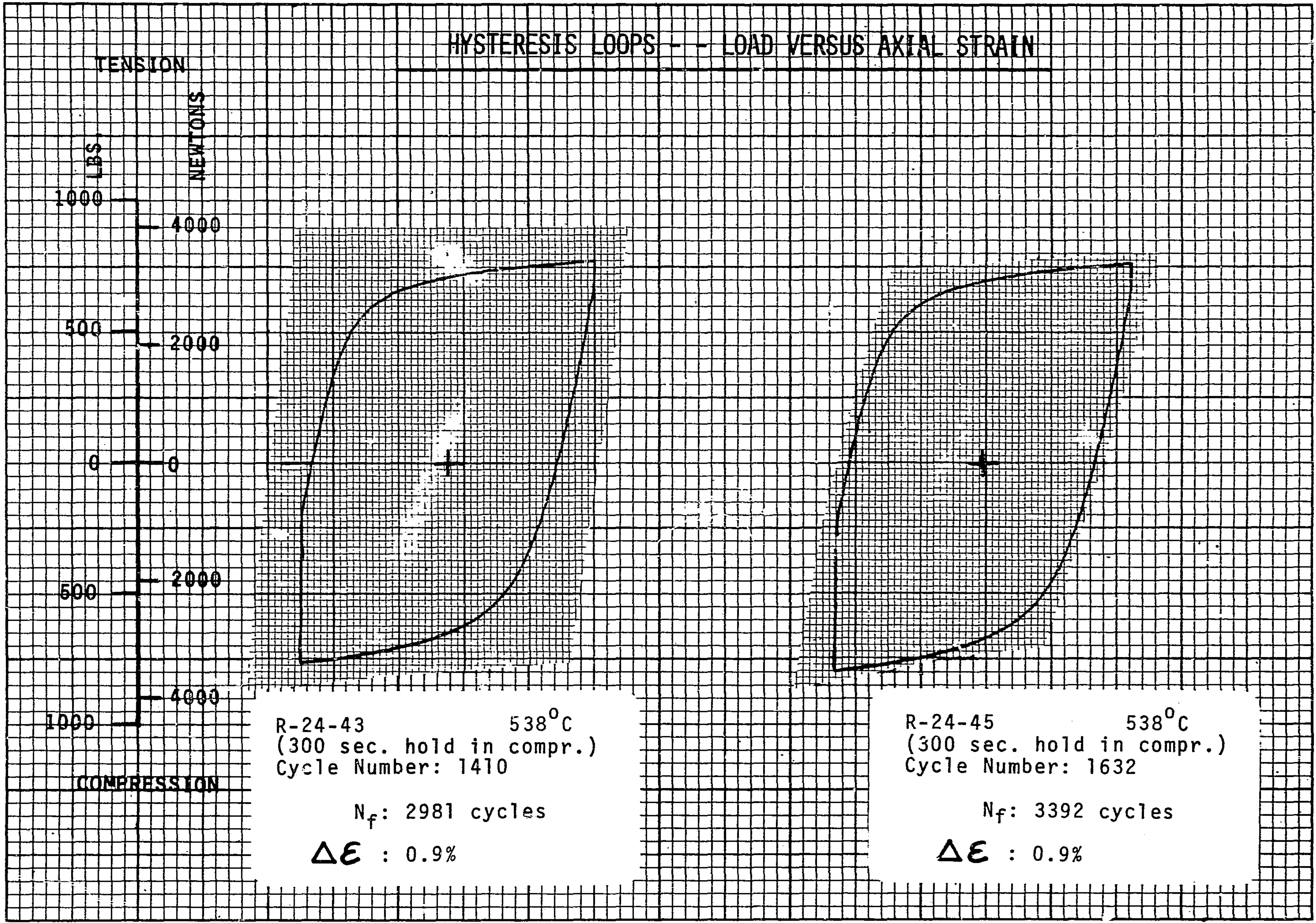

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-38 538^{o}C
(300 sec. hold in tension)
Cycle Number: 9
N_f: 262 cycles
$\Delta\varepsilon$: 0.9%
R-24-37 538^{o}C
(300 sec. hold in tension)
Cycle Number: 62
N_f: 317 cycles
$\Delta\varepsilon$: 0.9%

Figure 268



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-24-43 538°C
(300 sec. hold in compr.)
Cycle Number: 1410

N_f: 2981 cycles

$\Delta\varepsilon$: 0.9%

R-24-45 538°C
(300 sec. hold in compr.)
Cycle Number: 1632

N_f: 3392 cycles

$\Delta\varepsilon$: 0.9%

Figure 269

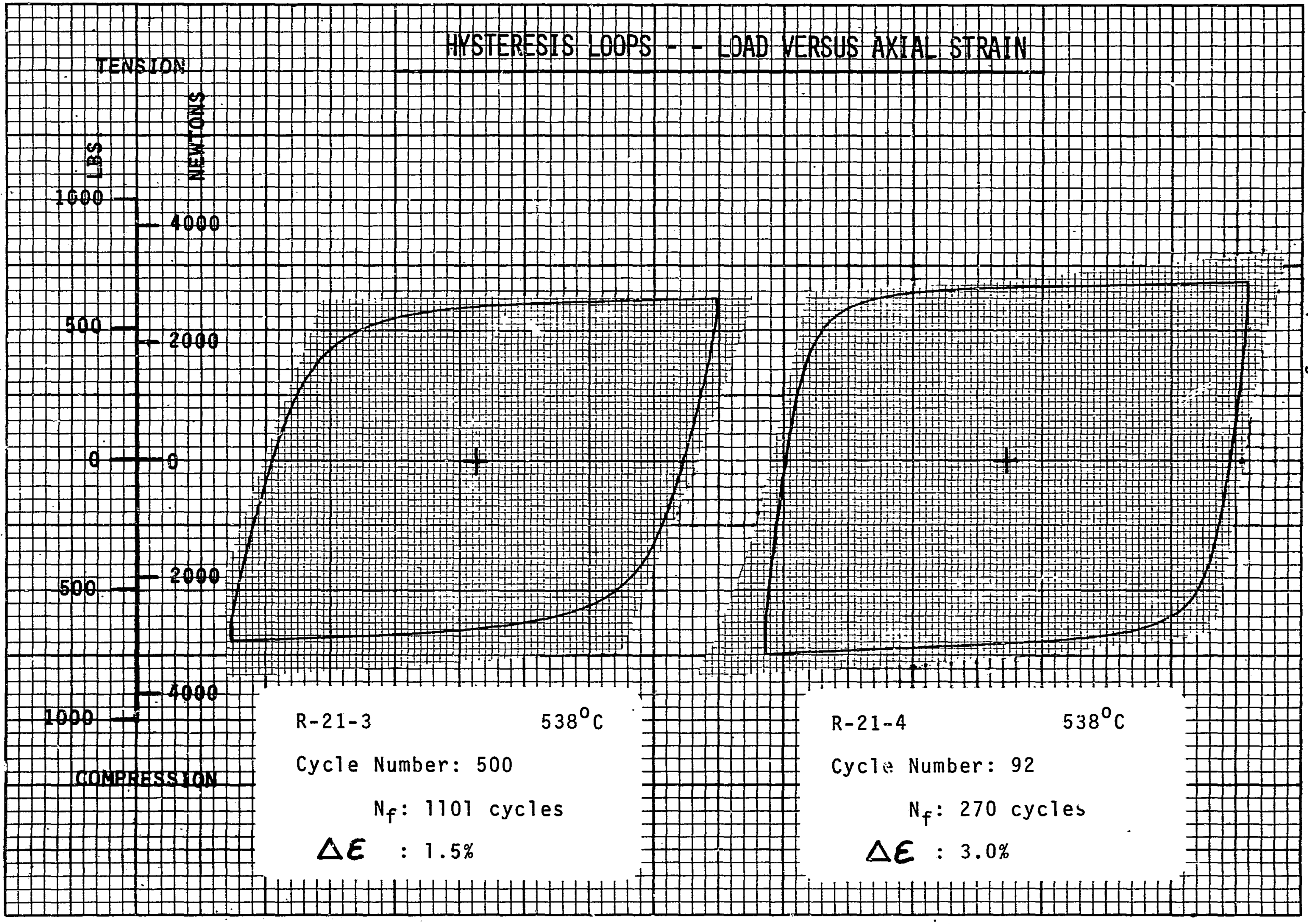

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-21-3
538°C
Cycle Number: 500
N_f: 1101 cycles
ΔE : 1.5%
R-21-4
538°C
Cycle Number: 92
N_f: 270 cycles
ΔE : 3.0%

Figure 270

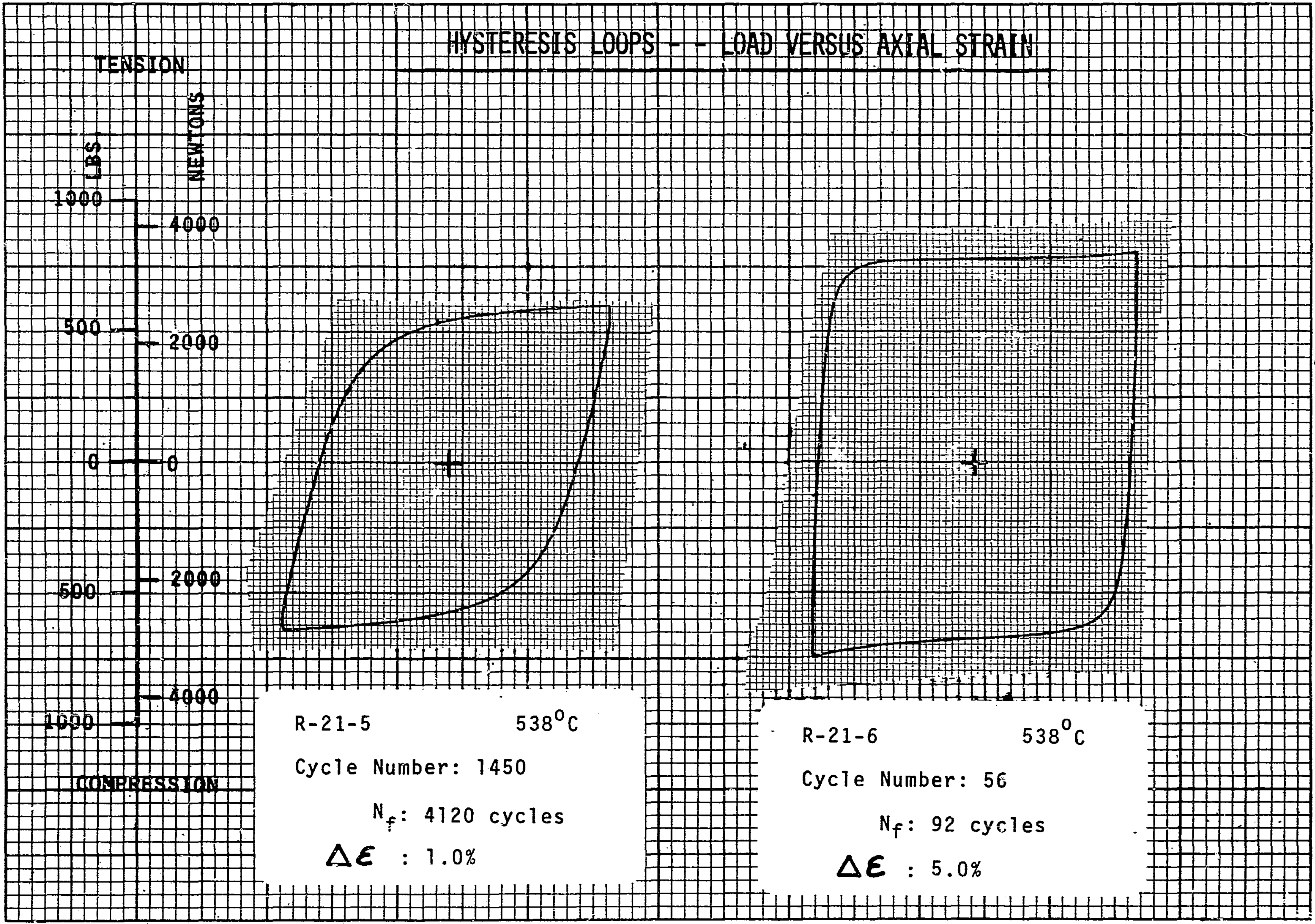

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-21-5 538°C
Cycle Number: 1450
N_f: 4120 cycles
Δε : 1.0%
R-21-6 538°C
Cycle Number: 56
N_f: 92 cycles
Δε : 5.0%

Figure 271

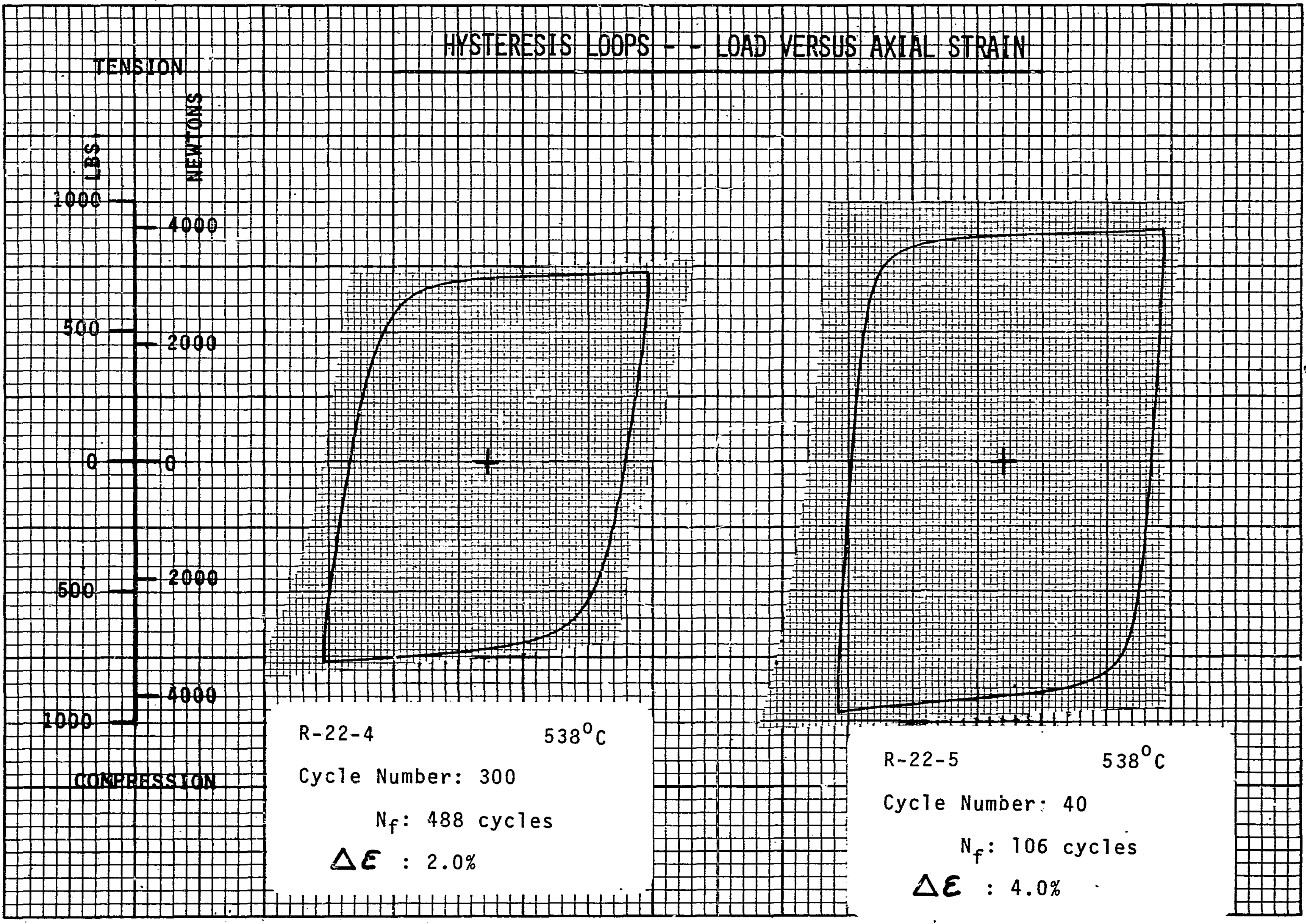

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-4
538°C
Cycle Number: 300
N_f: 488 cycles
ΔE : 2.0%
R-22-5
538°C
Cycle Number: 40
N_f: 106 cycles
ΔE : 4.0%

Figure 272

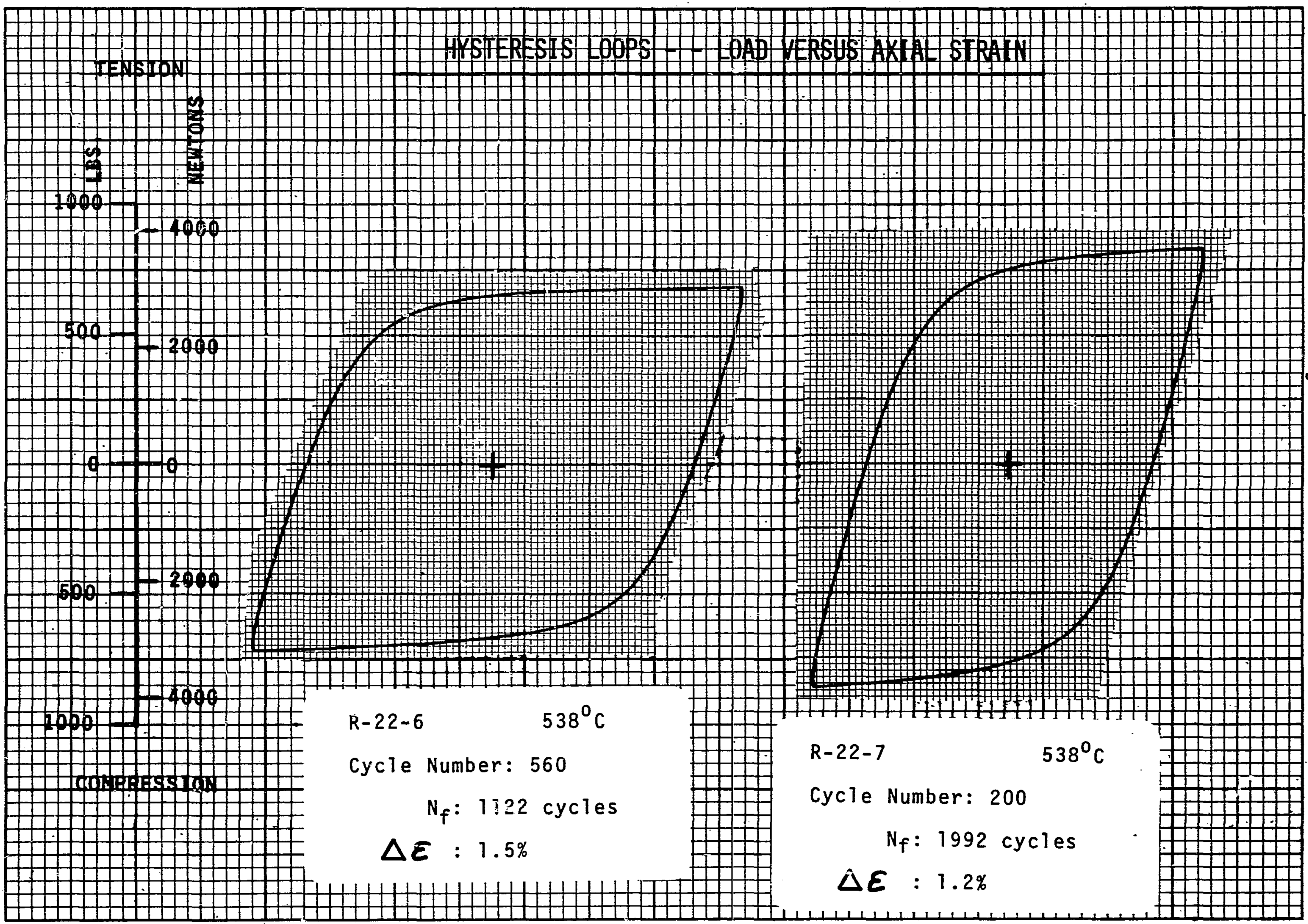

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-6
538°C
Cycle Number: 560
Nf: 1122 cycles
ΔE : 1.5%
R-22-7
538°C
Cycle Number: 200
Nf: 1992 cycles
ΔE : 1.2%

Figure 273

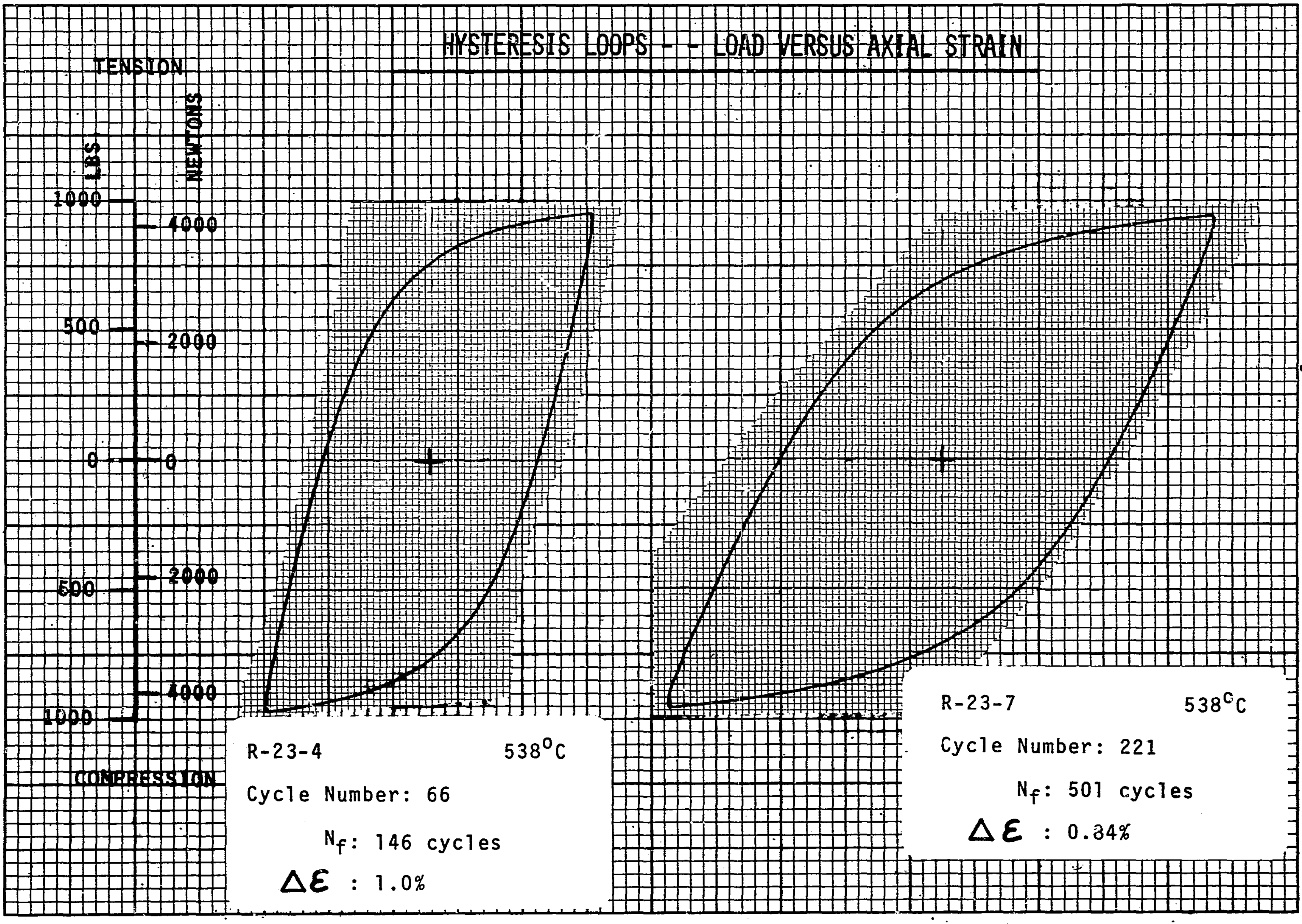
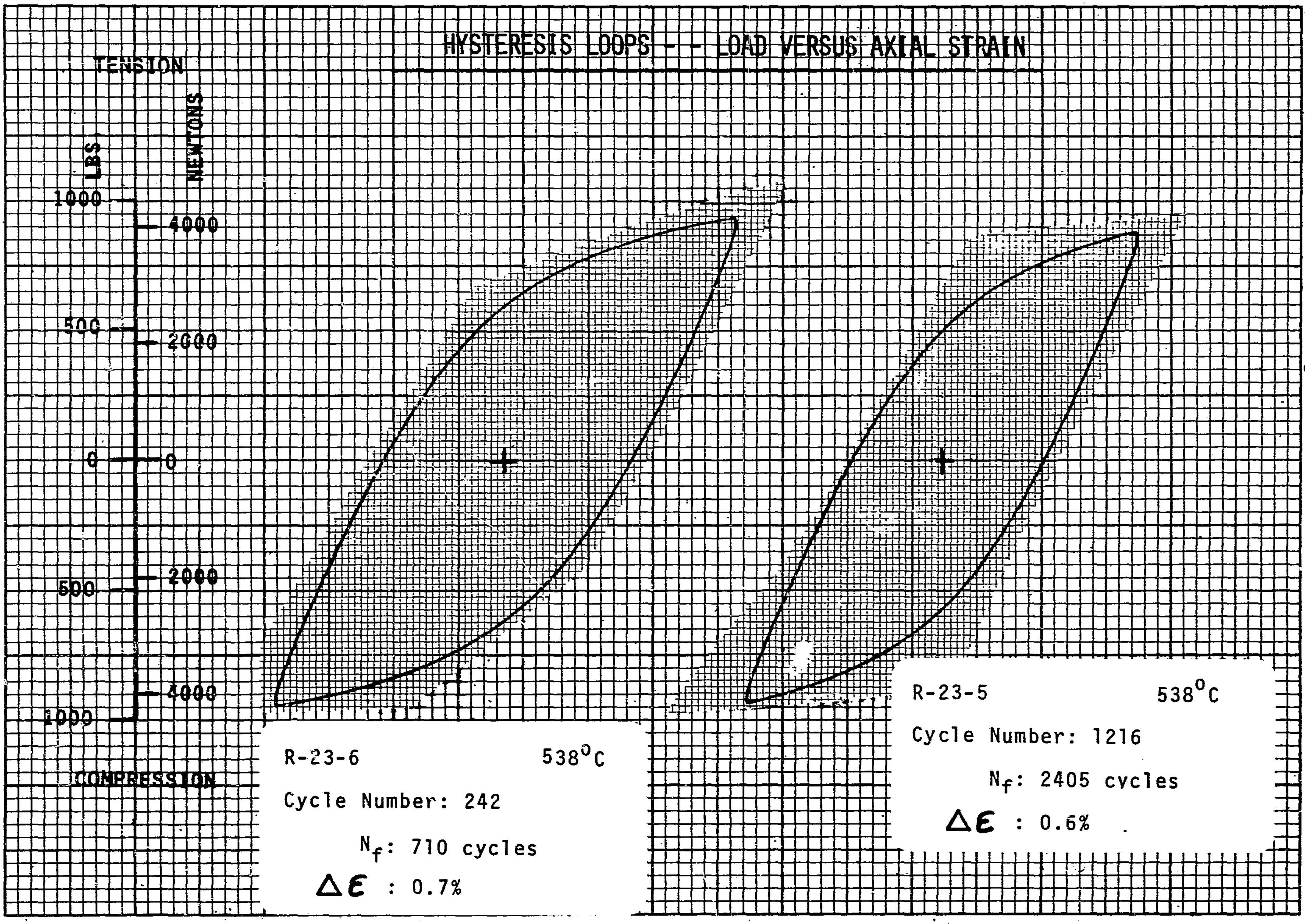

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-23-4
538°C
Cycle Number: 66
N_f: 146 cycles
ΔE : 1.0%
R-23-7
538°C
Cycle Number: 221
N_f: 501 cycles
ΔE : 0.34%

Figure 274



R-23-6 538^{o}C

Cycle Number: 242

N_f: 710 cycles

$\Delta\varepsilon$: 0.7%

R-23-5 538^{o}C

Cycle Number: 1216

N_f: 2405 cycles

$\Delta\varepsilon$: 0.6%

Figure 275

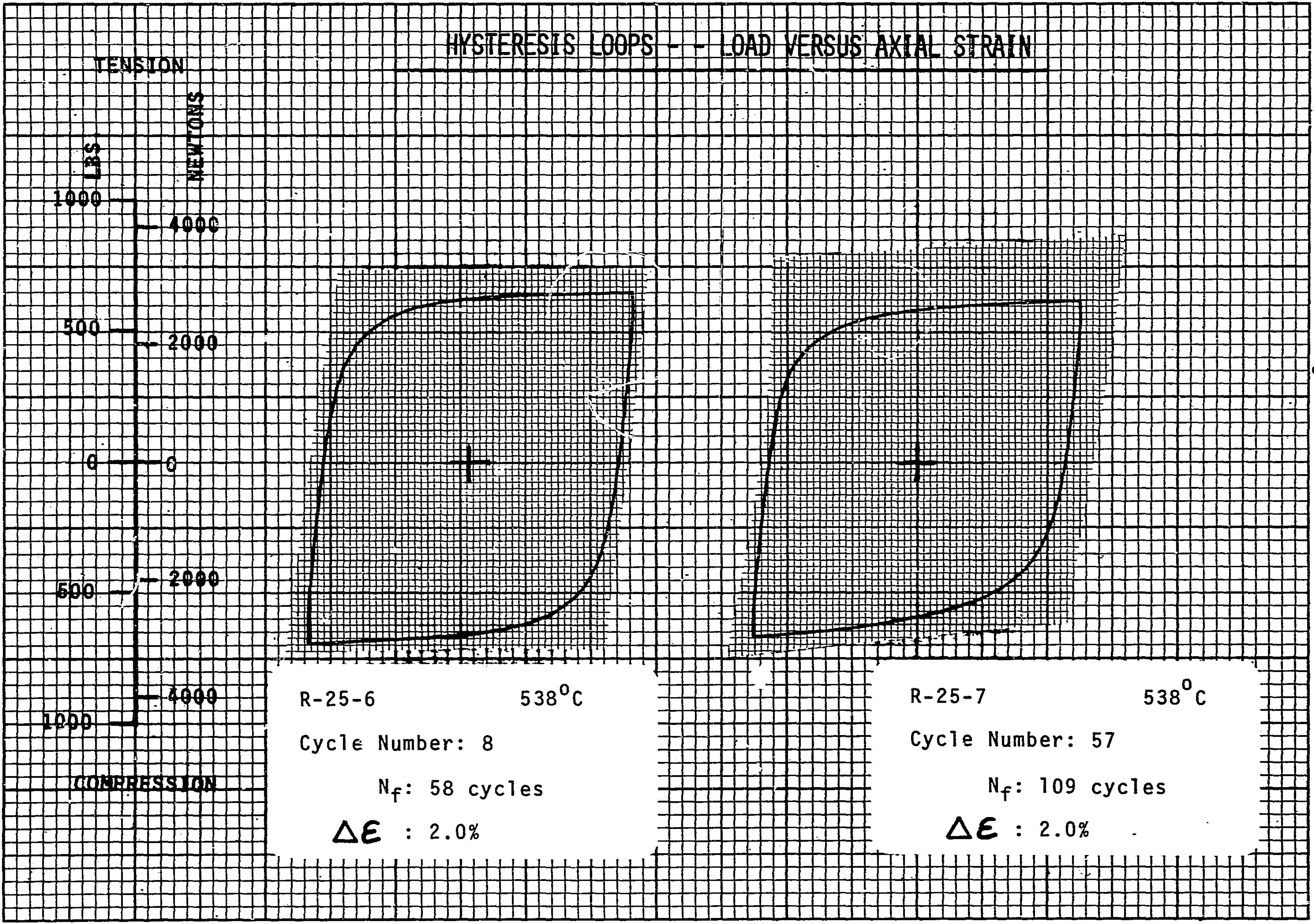

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-25-6 538°C
Cycle Number: 8
N_f: 58 cycles
ΔE : 2.0%
R-25-7 538°C
Cycle Number: 57
N_f: 109 cycles
ΔE : 2.0%

Figure 276

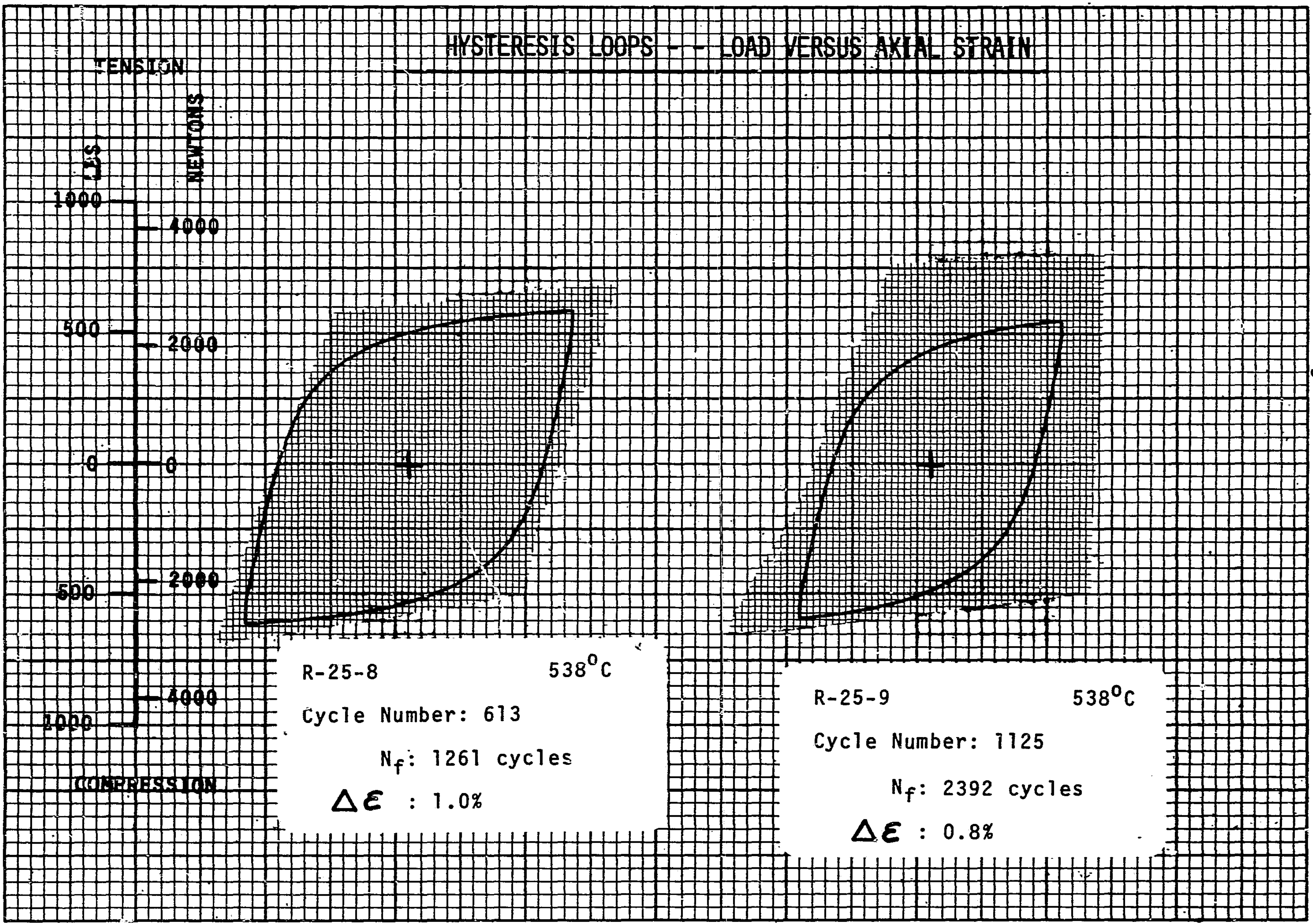

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-25-8
538°C
Cycle Number: 613
N$_f$: 1261 cycles
$\Delta\varepsilon$: 1.0%
R-25-9
538°C
Cycle Number: 1125
N$_f$: 2392 cycles
$\Delta\varepsilon$: 0.8%

Figure 277

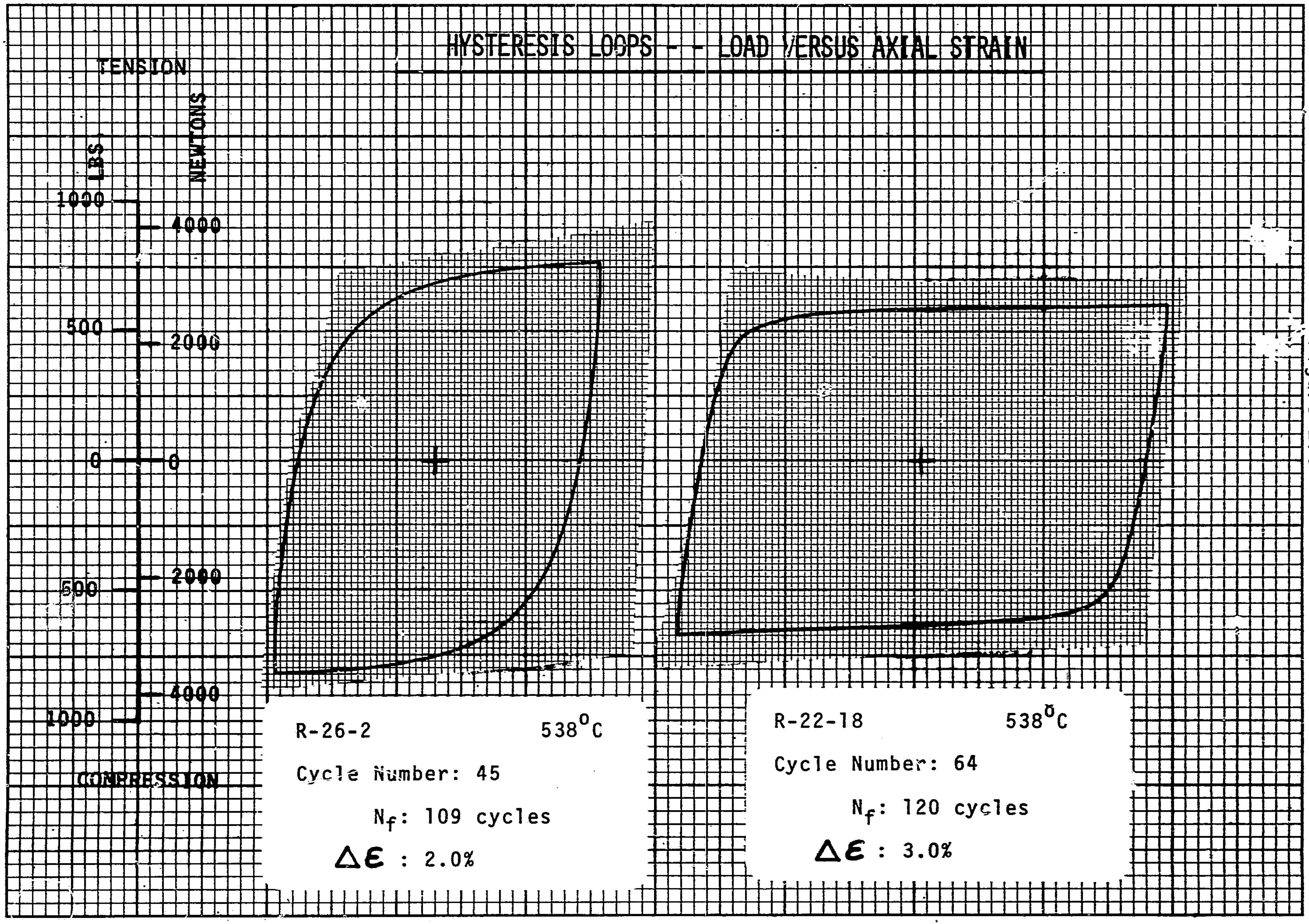
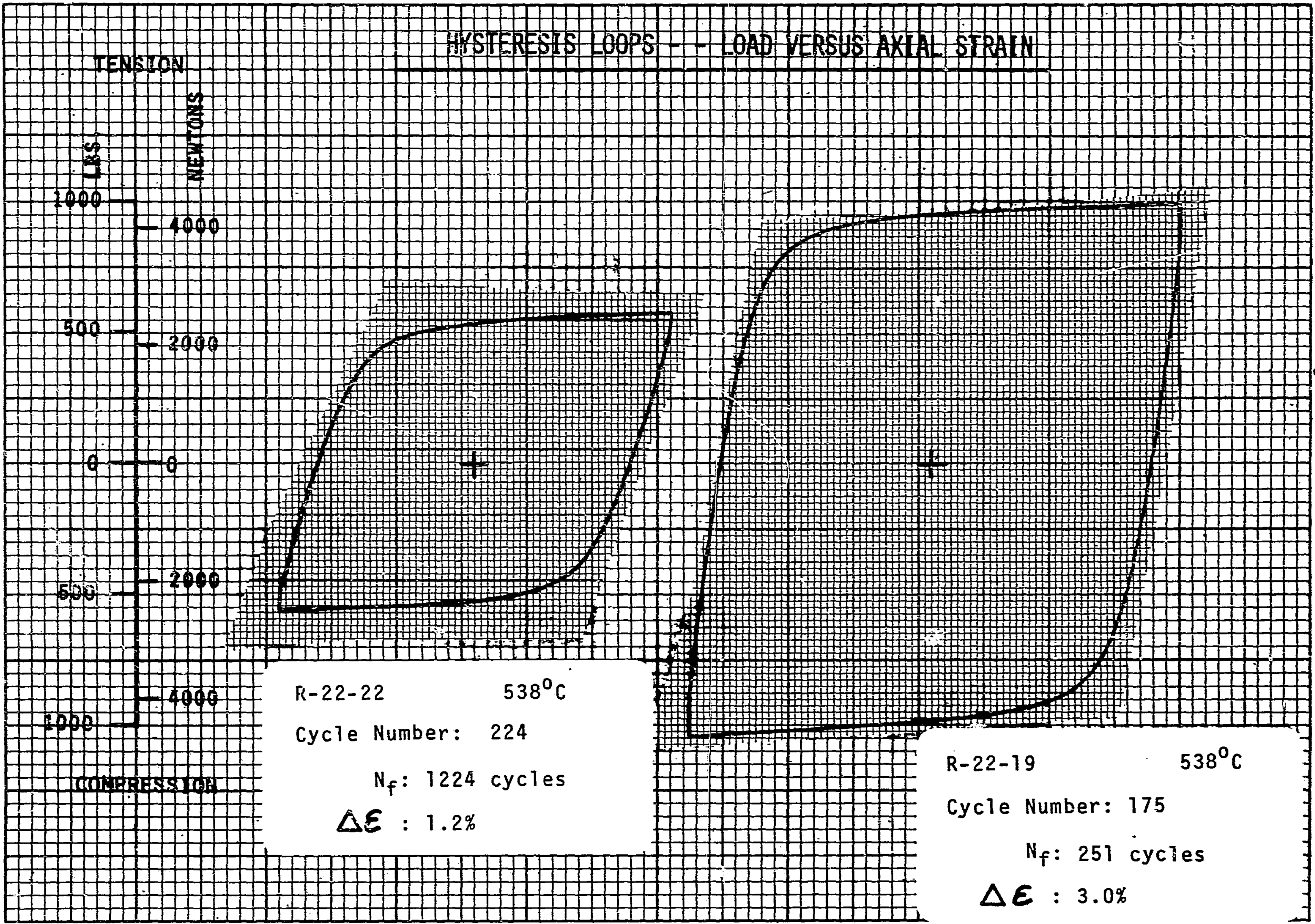

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-26-2
538°C
Cycle Number: 45
N_f: 109 cycles
$\Delta\varepsilon$: 2.0%
R-22-18
538°C
Cycle Number: 64
N_f: 120 cycles
$\Delta\varepsilon$: 3.0%

Figure 278



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-22-22 538°C

Cycle Number: 224

N_f: 1224 cycles

$\Delta\varepsilon$: 1.2%

R-22-19 538°C

Cycle Number: 175

N_f: 251 cycles

$\Delta\varepsilon$: 3.0%

Figure 279

C-4

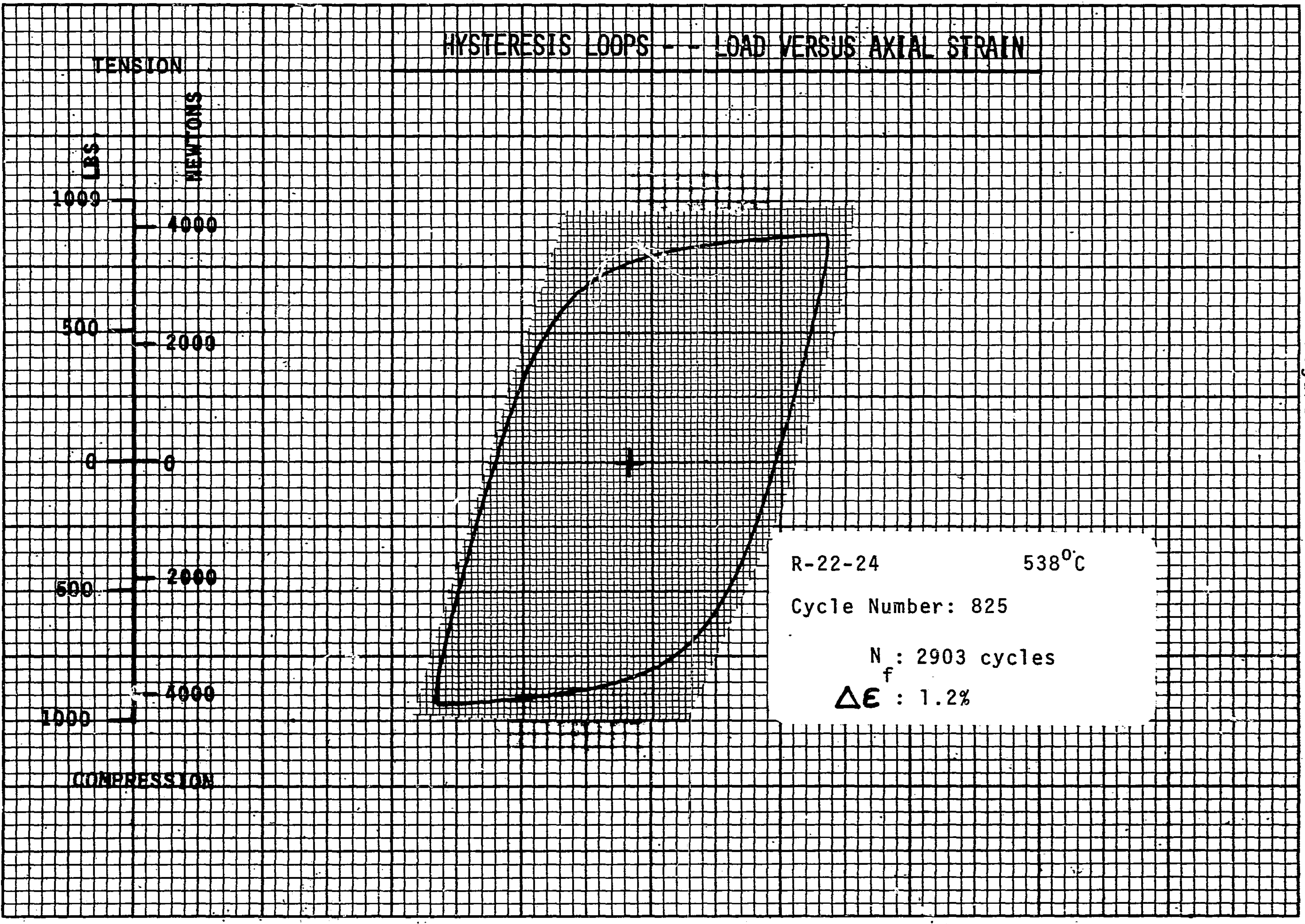


Figure 280

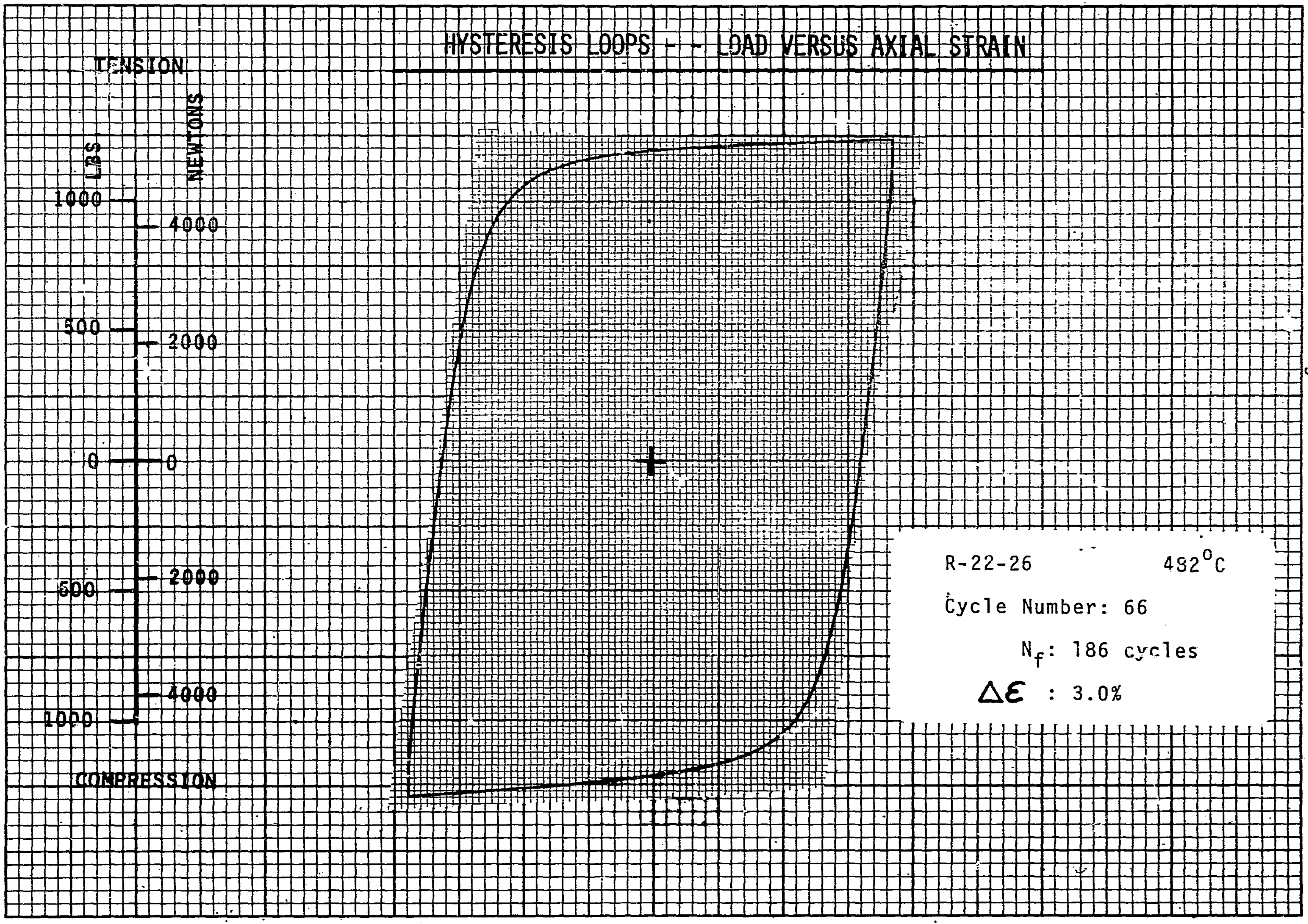

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-22-26
482°C
Cycle Number: 66
N_f: 186 cycles
$\Delta\varepsilon$: 3.0%

Figure 281

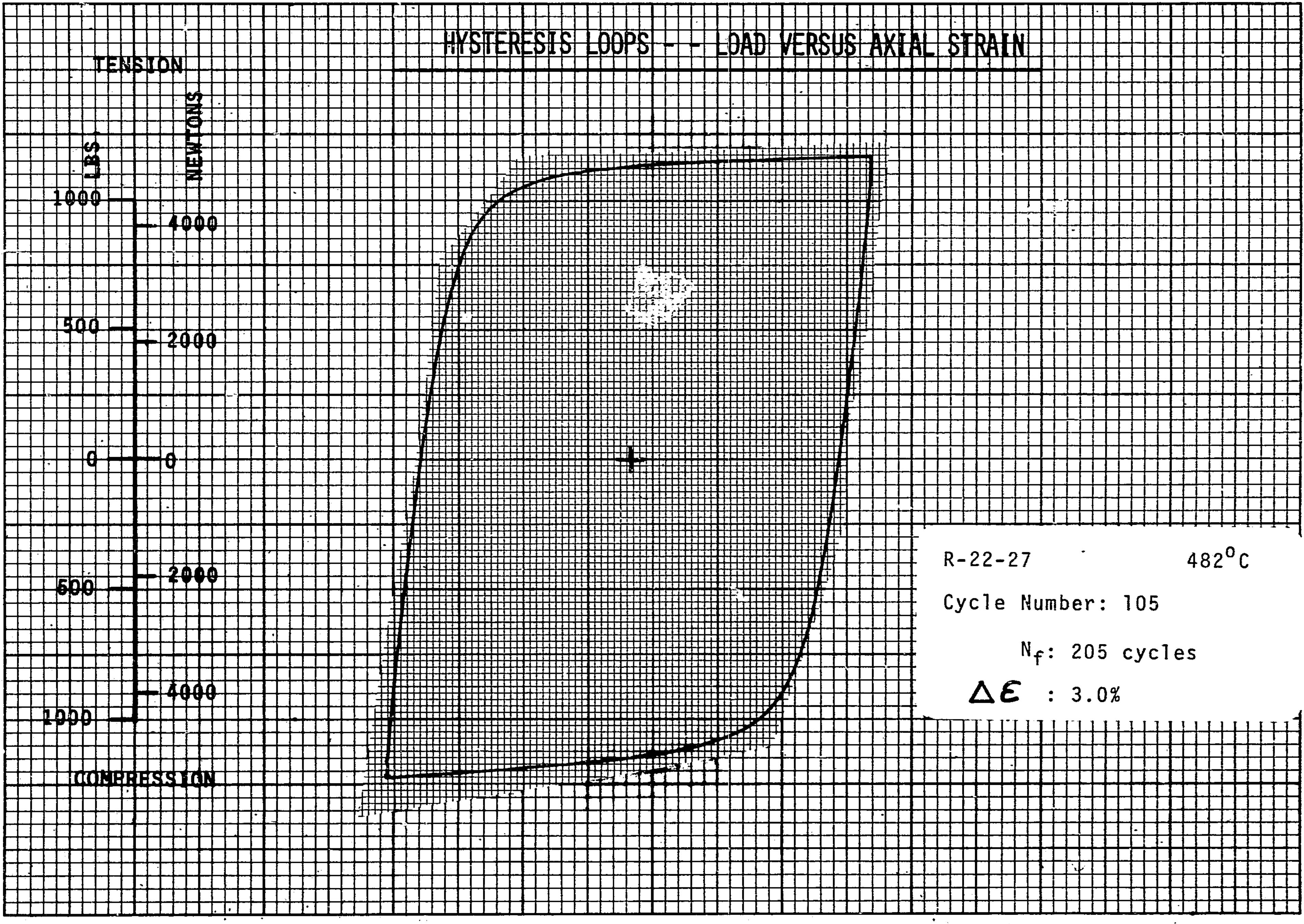
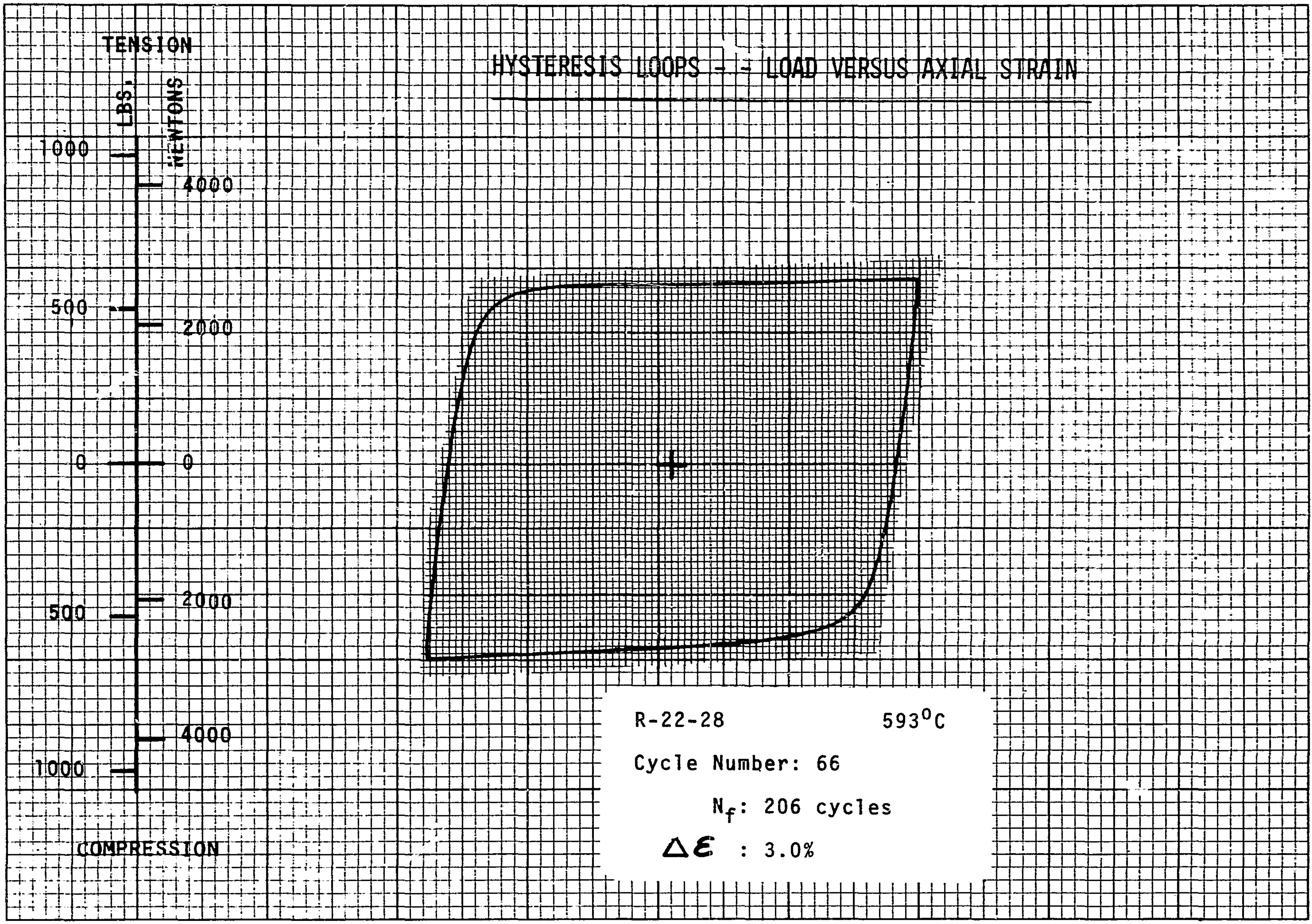

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-22-27
482°C
Cycle Number: 105
Nf: 205 cycles
ΔƐ : 3.0%

Figure 282



HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

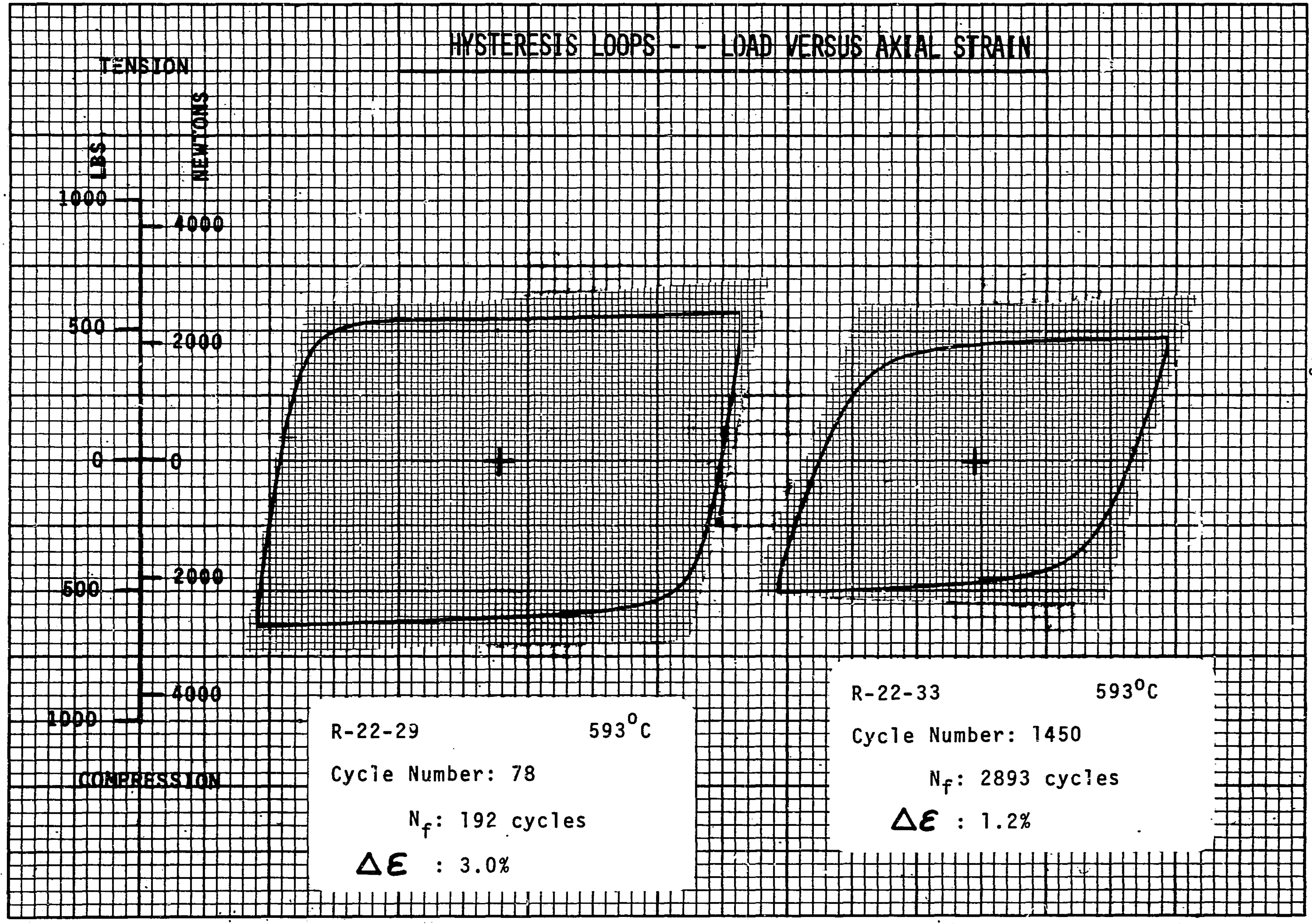
R-22-28 593^{0}C

Cycle Number: 66

N_f: 206 cycles

$\Delta\varepsilon$: 3.0%

Figure 283



R-22-29 593°C

Cycle Number: 78

N_f: 192 cycles

$\Delta\varepsilon$: 3.0%

R-22-33 593°C

Cycle Number: 1450

N_f: 2893 cycles

$\Delta\varepsilon$: 1.2%

Figure 284

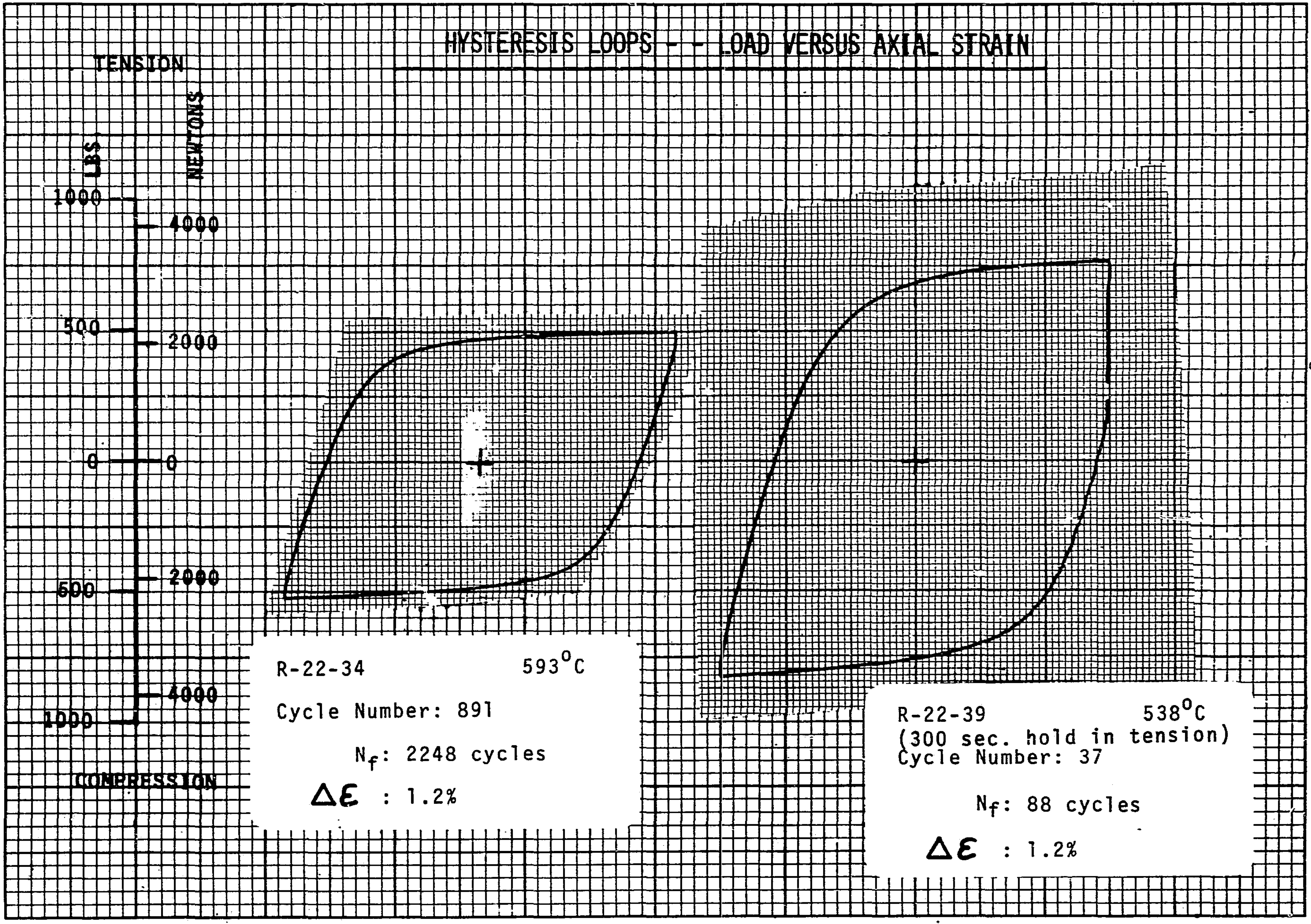
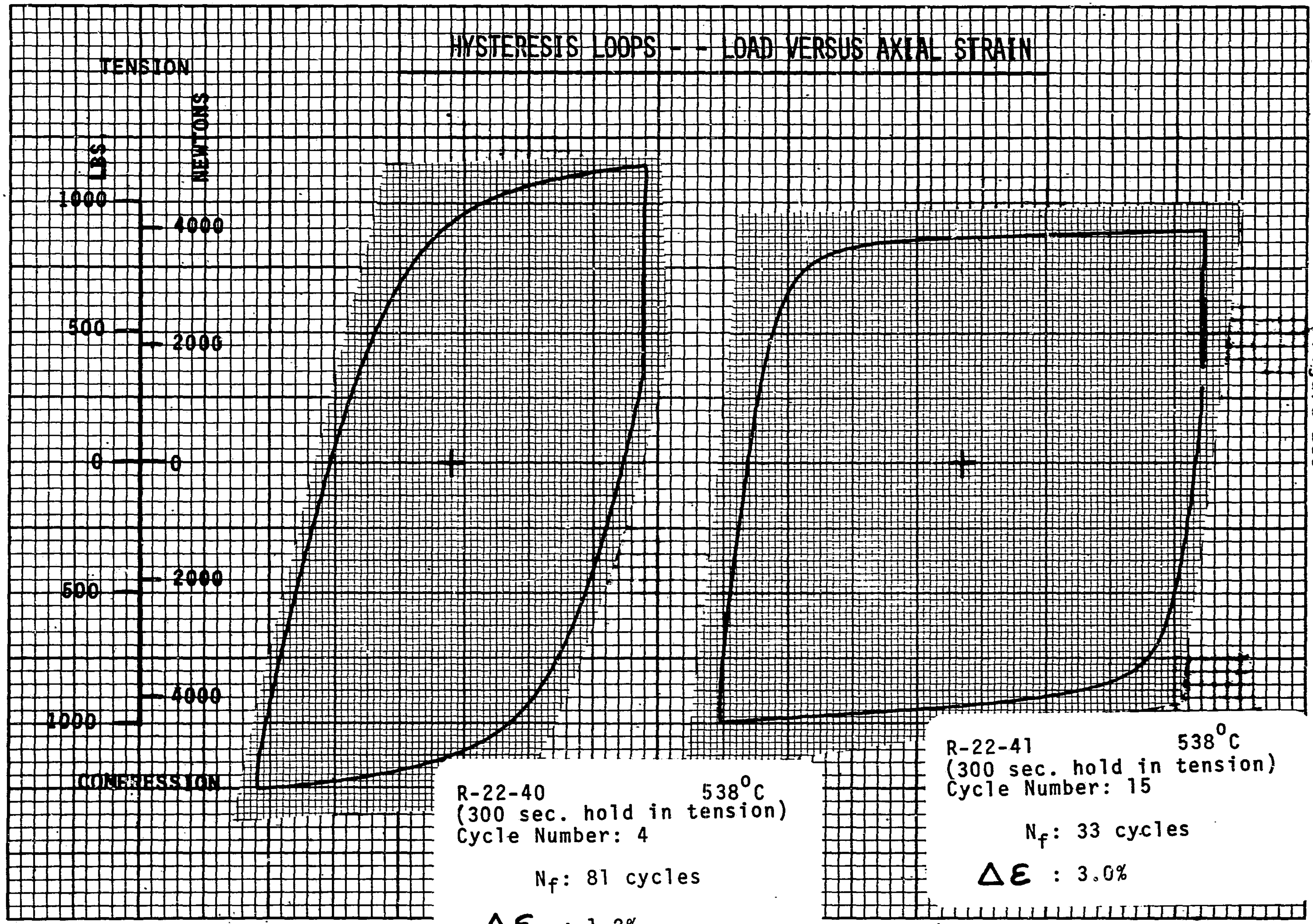

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-34
593°C
Cycle Number: 891
N_f: 2248 cycles
$\Delta\varepsilon$: 1.2%
R-22-39
538°C
(300 sec. hold in tension)
Cycle Number: 37
N_f: 88 cycles
$\Delta\varepsilon$: 1.2%

Figure 285



R-22-40 538°C
(300 sec. hold in tension)
Cycle Number: 4

N_f: 81 cycles

$\Delta\varepsilon$: 1.2%

R-22-41 538°C
(300 sec. hold in tension)
Cycle Number: 15

N_f: 33 cycles

$\Delta\varepsilon$: 3.0%

Figure 286

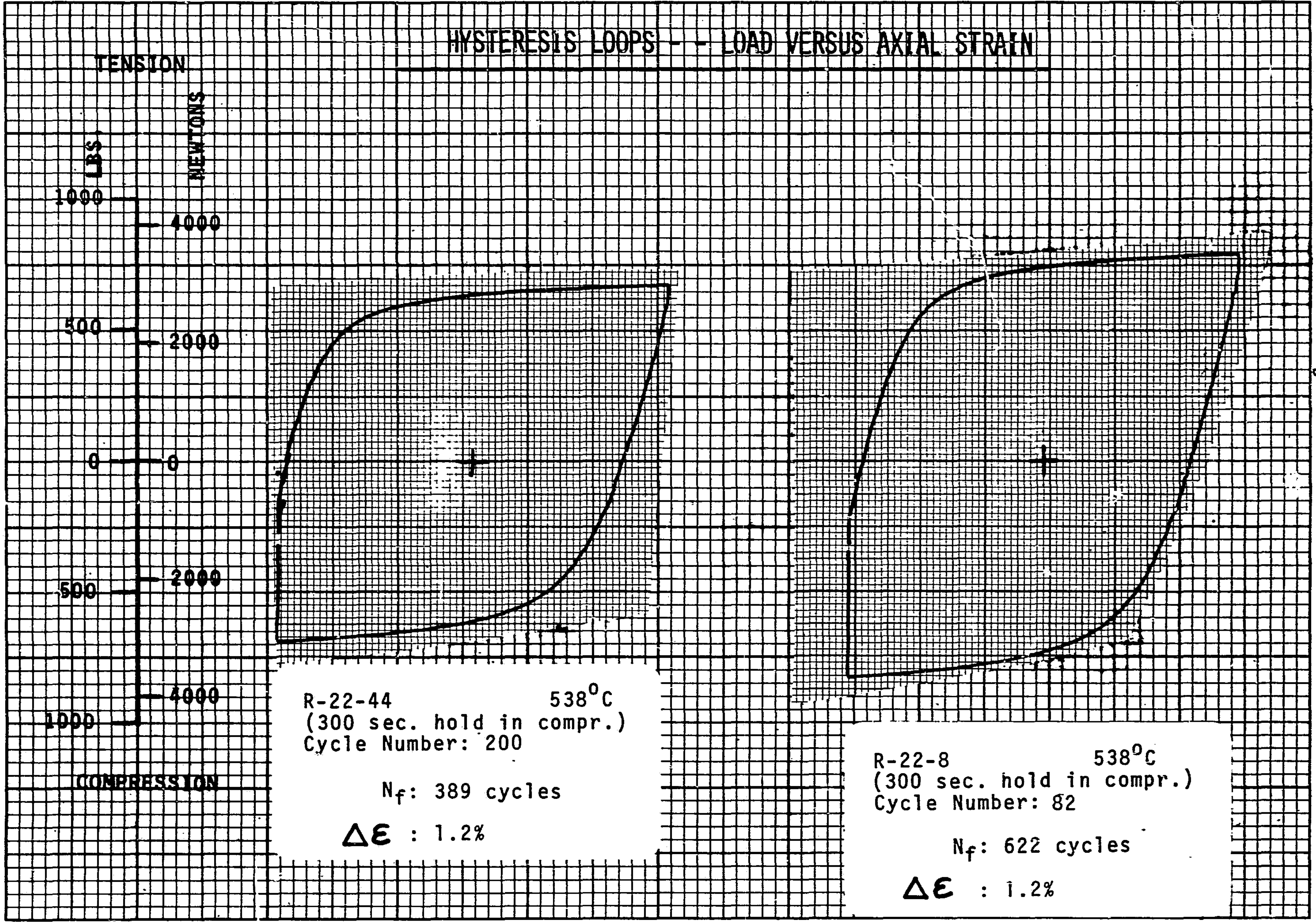
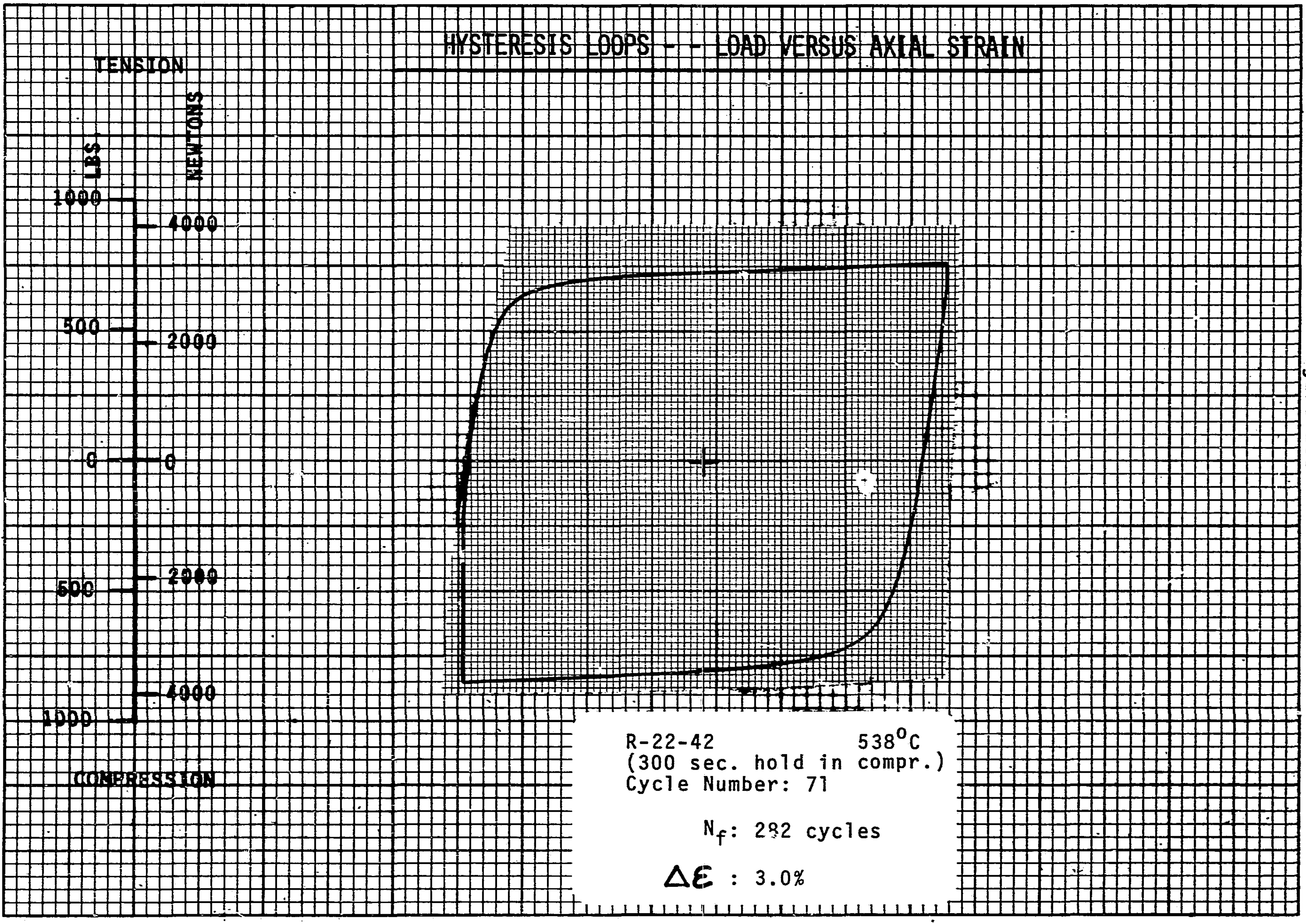

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-44
538°C
(300 sec. hold in compr.)
Cycle Number: 200
N_f: 389 cycles
$\Delta\varepsilon$: 1.2%
R-22-8
538°C
(300 sec. hold in compr.)
Cycle Number: 82
N_f: 622 cycles
$\Delta\varepsilon$: 1.2%

Figure 287


HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN

R-22-42 538^{o}C
(300 sec. hold in compr.)
Cycle Number: 71

N_f: 282 cycles

$\Delta\varepsilon$: 3.0%

Figure 288

Table 2 - Values of N_5 and N_f for all Tests

(N_5 is the number of cycles to a five percent load range drop and N_f is the number of cycles to complete separation of the specimen)

Specimen Number	Temp., °C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
		Zirconium-copper, annealed			
R-0-14	538	2.0	2×10^{-3}	680	1512
R-0-15	↓	1.5	↓	1200	4188
R-0-25		3.5		220	283
R-0-17		3.0		190	307
R-0-19		1.7		1000	2300
R-0-21		2.5		410	418
		Zirconium-copper, ¼ Hard			
R-1-3	538	2.5	2×10^{-3}	320	524
R-1-4	↓	1.6	↓	800	1088
R-1-9		3.5		170	562
R-1-10		3.5		180	447
R-1-11		1.2		4900	5590
R-1-12		1.35		2100	3660
		Zirconium-copper, ½ Hard			
R-2-2	538	3.0	2×10^{-3}	1120	1615
R-2-4	↓	5.0	↓	280	366
R-2-5		4.0		480	552
R-2-10		2.8		780	1055
R-2-11		2.0		720	1239
R-2-6		2.0		1400	2051
R-2-12		1.7		1770	1770
R-2-13		1.5		2400	2453
		Tellurium-copper, ½ Hard			
R-3-10	538	1.6	2×10^{-3}	385	390
R-3-13	↓	2.0	↓	116	117
R-3-1		1.2		390	462
R-3-2		0.8		970	1179
R-3-4		1.0		660	802
R-3-5		0.5		3900	3908
		Chromium-copper, SA and aged			
R-4-1	538	2.0	2×10^{-3}	110	147
R-4-2	↓	1.6	↓	290	354
R-4-3		1.4		530	605

Table 2 continued

Specimen Number	Temp., °C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
		Chromium-copper, SA and aged			
R-4-4	538	1.0	2×10^{-3}	1600	1823
R-4-5	↓	1.2	↓	970	1102
R-4-8		0.9		3500	3648
		OFHC Copper, Hard			
R-5-2	538	1.6	2×10^{-3}	280	292
R-5-11	↓	2.0	↓	160	195
R-5-1		1.0		-	679
R-5-4		0.8		-	1295
R-5-3		1.2		450	453
R-5-5		0.6		2800	3606
		OFHC Copper, ¼ Hard			
R-6-1	538	1.6	2×10^{-3}	82	85
R-6-3	↓	0.6	↓	630	691
R-6-4		0.7		300	418
R-6-5		2.0		40	56
R-6-8		0.5		900	1358
R-6-9		1.0		180	200
R-6-11		1.0		200	303
		OFHC Copper, Annealed			
R-7-3	538	2.0	2×10^{-3}	75	126
R-7-4	↓	1.5	↓	230	269
R-7-1		1.2		400	437
R-7-2		1.0		660	710
R-7-7		0.8		1100	1313
R-7-9		0.7		1300	1613
		Silver, As-drawn			
R-8-7	538	3.0	2×10^{-3}	-	344
R-8-5	↓	2.5	↓	590	603
R-8-9		1.2		1700	1902
R-8-3		1.0		2500	2620
R-8-2		2.0		850	928
R-8-10		1.5		1350	1381
		Zr-Cr-Mg Copper, SA, CW and Aged			
R-9-11	538	2.0	2×10^{-3}	700	843
R-9-4	↓	3.0	↓	270	357
R-9-1		2.25		360	500
R-9-3		2.5		300	346

Table 2 continued

Specimen Number	Temp., °C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
		Zr-Cr-Mg Copper, SA, CW and aged			
R-9-8	538	1.4	2×10^{-3}	1500	2000
R-9-2		1.2		1250	1317
R-9-9		0.9		4500	6670
		Electroformed Copper, 30-35 ksi			
R-10-3	538	2.0	2×10^{-3}	30	148
R-10-4		1.6		25	38
R-10-1		0.8		450	1542
R-10-8		1.2		60	72
R-10-5		1.0		250	512
R-10-7		0.75		1000	1866
		Co-Be-Zr Copper, SA and aged			
R-13-5	538	2.0	2×10^{-3}	70	90
R-13-13		1.2		350	644
R-13-7		1.5		130	212
R-13-10		1.0		450	680
R-13-6		0.8		700	1615
R-13-8		0.7		1800	3623
		Zirconium-Copper, ½ Hard			
R-2-26	482	6.1	2×10^{-3}	100	204
R-2-27		1.41		2000	2985
R-2-28		6.1		98	176
R-2-29		1.41		1900	2135
R-2-30		5.0		145	265
R-2-31	593	1.4	2×10^{-3}	3100	3380
R-2-32		5.0		230	346
R-2-33		1.5		1750	2008
R-2-34		5.0		175	234
R-2-36	538	5.0	4×10^{-4}	170	234
R-2-37		1.4		-	1613
R-2-39		5.0		200	238
R-2-40		1.4		3000	3693
R-2-35		5.0	1×10^{-2}	-	245
R-2-38		1.4		2500	5431
R-2-41		1.4		2600	5215
R-2-42		5.0		230	462
R-2-43		5.0	200 sec,T	170	211
R-2-44		5.0	200 sec,T	165	190
R-2-45		5.0	200 sec,C	253	253
R-2-46		5.0	200 sec,C	210	262

Table 2 continued

Specimen Number	Temp., °C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
			Zirconium-Copper, ½ Hard		
R-2-47	538	1.4	56 sec,T	1100	1152
R-2-48	↓	1.4	56 sec,T	-	1062
R-2-49	↓	1.4	56 sec,C	-	1947
R-2-50	↓	1.4	56 sec,C	2800	3180
R-2-17	RT	3.0	5×10^{-3}	-	696
R-2-51	↓	2.5	↓	1000	1102
R-2-52	↓	1.6	↓	-	2780
R-2-53	↓	4.0	↓	400	425
R-2-54	↓	1.4	↓	2900	3283
R-2-55	↓	3.0	↓	70	141
R-2-56	↓	1.4	↓	250	503
R-2-57	↓	0.9	3×10^{-3}	750	1784
R-2-58	↓	2.0	5×10^{-3}	130	279
R-2-59	↓	0.7	3×10^{-3}	2000	5607
R-20-1	538	5.0	2×10^{-3}	250	390
R-20-2	↓	1.4	↓	4000	5658
R-20-3	↓	2.0	↓	1200	1326
R-20-4	↓	3.0	↓	-	879
R-20-5	↓	1.6	↓	3400	3589
R-20-6	↓	1.8	↓	2600	2700
R-2-67	538	5.0	300 sec,T	-	218
R-2-68	↓	1.4	300 sec,T	-	1156
R-2-69	↓	4.62	300 sec,C	-	948
R-2-72	↓	1.4	300 sec,C	-	1224
R-2-73	↓	5.0	300 sec,T,C	-	234
R-2-61	538/260	3.5	8.75×10^{-5}	240	284
R-2-62	538/260	3.5	8.75×10^{-5}	-	188
			Narloy Z, Cent. cast, hot-rolled, solution annealed and aged		
R-24-13	538	1.0	2×10^{-3}	1150	1169
R-24-14	↓	2.0	↓	260	331
R-24-15	↓	1.2	↓	870	1126
R-24-16	↓	0.7	↓	3000	3601
R-24-17	↓	3.5	↓	92	99
R-24-18	↓	2.5	↓	200	253
R-24-19	↓	0.85	↓	1700	2469
R-24-22	↓	0.9	1×10^{-2}	2800	3909
R-24-21	↓	0.9	↓	3230	3586
R-24-23	↓	2.6	↓	290	339
R-24-26	↓	2.6	↓	340	364
R-24-20	↓	0.9	4×10^{-4}	860	1138
R-24-25	↓	0.9	4×10^{-4}	880	1196

Table 2 continued

Specimen Number	Temp., °C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
Narloy Z, Cent. cast, hot-rolled, solution annealed and aged					
R-24-24	538	2.6	4×10^{-4}	120	154
R-24-27	538	2.6	4×10^{-4}	122	133
R-24-29	538	2.6	5.2×10^{-2}	474	474
R-24-30	538	2.6	5.2×10^{-2}	570	588
Zirconium-Copper, ½ Hard					
R-2-74	538	2.6	5.2×10^{-2}	2500	3132
R-2-75	538	2.6	5.2×10^{-2}	-	3480
Narloy Z, Cent. cast, hot-rolled, solution annealed and aged					
R-24-33	593	0.9	2×10^{-3}	1180	1253
R-24-34	593	2.6	↓	160	191
R-24-31	482	0.9		2800	2950
R-24-32	482	2.6		180	243
R-24-39	538	2.6	290 sec,T	63	102
R-24-40	↓	2.6	300 sec,T	55	75
R-24-41		2.6	300 sec,C	220	353
R-24-42		2.6	300 sec,C	220	337
R-24-38		0.9	300 sec,T	190	262
R-24-37		0.9	300 sec,T	195	317
R-24-43		0.9	300 sec,C	1500	2981
R-24-45		0.9	300 sec,C	1500	3392
NASA 1-1A Copper Alloy, Aged					
R-21-3	538	1.5	2×10^{-3}	1090	1101
R-21-4	↓	3.0	↓	265	270
R-21-5		1.0		-	4120
R-21-6		5.0		85	92
NASA 1-1B Copper Alloy, As-received					
R-22-4	538	2.0	2×10^{-3}	-	488
R-22-5	↓	4.0	↓	90	106
R-22-6		1.5		-	1122
R-22-7		1.2		1950	1992
Glidcop AL-10					
R-23-4	538	1.0	2×10^{-3}	110	146
R-23-7	↓	0.84	↓	420	501
R-23-6		0.7		620	710
R-23-5		0.6		2000	2405

Specimen Number	Temp., ^{o}C	Total Strain Range, %	Strain Rate, sec^{-1}	N_5, cycles	N_f, cycles
Sputtered Zirconium-Copper, Annealed					
R-25-6	538	2.0	2×10^{-3}	50	58
R-25-7	↓	2.0	↓	80	109
R-25-8		1.0		900	1261
R-25-9		0.8		1700	2392
Sputtered Zirconium-Copper, As-sputtered					
R-26-2	538	2.0	2×10^{-3}	100	109
NASA 1-1B Copper Alloy, As-received					
R-22-18	538	3.0	4×10^{-4}	-	120
R-22-22	↓	1.2	4×10^{-4}	-	1224
R-22-19		3.0	1×10^{-2}	190	251
R-22-24		1.2	1×10^{-2}	2450	2903
R-22-26	482	3.0	2×10^{-3}	150	186
R-22-27	482	3.0	↓	155	205
R-22-28	593	3.0		180	206
R-22-29	↓	3.0		182	192
R-22-33		1.2		2880	2893
R-22-34		1.2		1900	2248
R-22-39	538	1.2	300 sec,T	77	88
R-22-40	↓	1.2	300 sec,T	67	81
R-22-41		3.0	300 sec,T	29	33
R-22-44		1.2	300 sec,C	389	389
R-22-8		1.2	300 sec,C	-	622
R-22-42		3.0	300 sec,C	240	282