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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.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Low-Cycle Fatigue, Stress Range Data, Hysteresis Loops, High Temperature, Copper-base Alloys	unclassified-unlimited

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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 $1000^{o}F$ ($538^{o}C$).
NASA CR-121260	--	High Temperature, Low-cycle Fatigue of Copper-base Alloys in Argon; Part II - Zirconium-copper at $482^{o}C$, $538^{o}C$ and $593^{o}C$.
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.

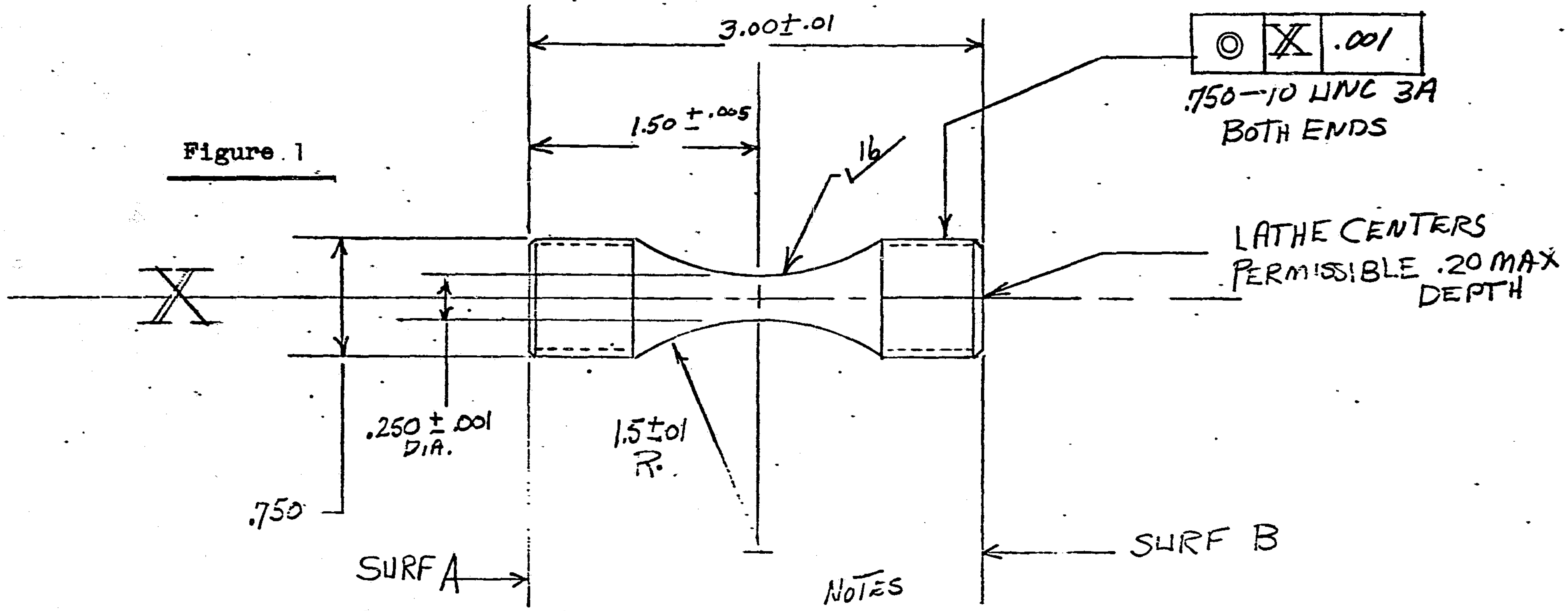
III - MATERIALS AND SPECIMENS

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 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 H28

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS ± DECIMALS ± ANGLES ± ALL SURFACES 32 ✓	DRAWN DATE APPD ISSUED	SPECIMEN LOW CYCLE FATIGUE	**Mar-Test inc.** CINCINNATI, OHIO
MATERIAL GOVT. OR COML. TO BE SPECIFIED	APPROVED / DATE ENGR ?tC 1-12-71 MFG MATL	SCALE 1/1 WT CALC ACTUAL	SIZE MTI-1002 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, ¼ 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

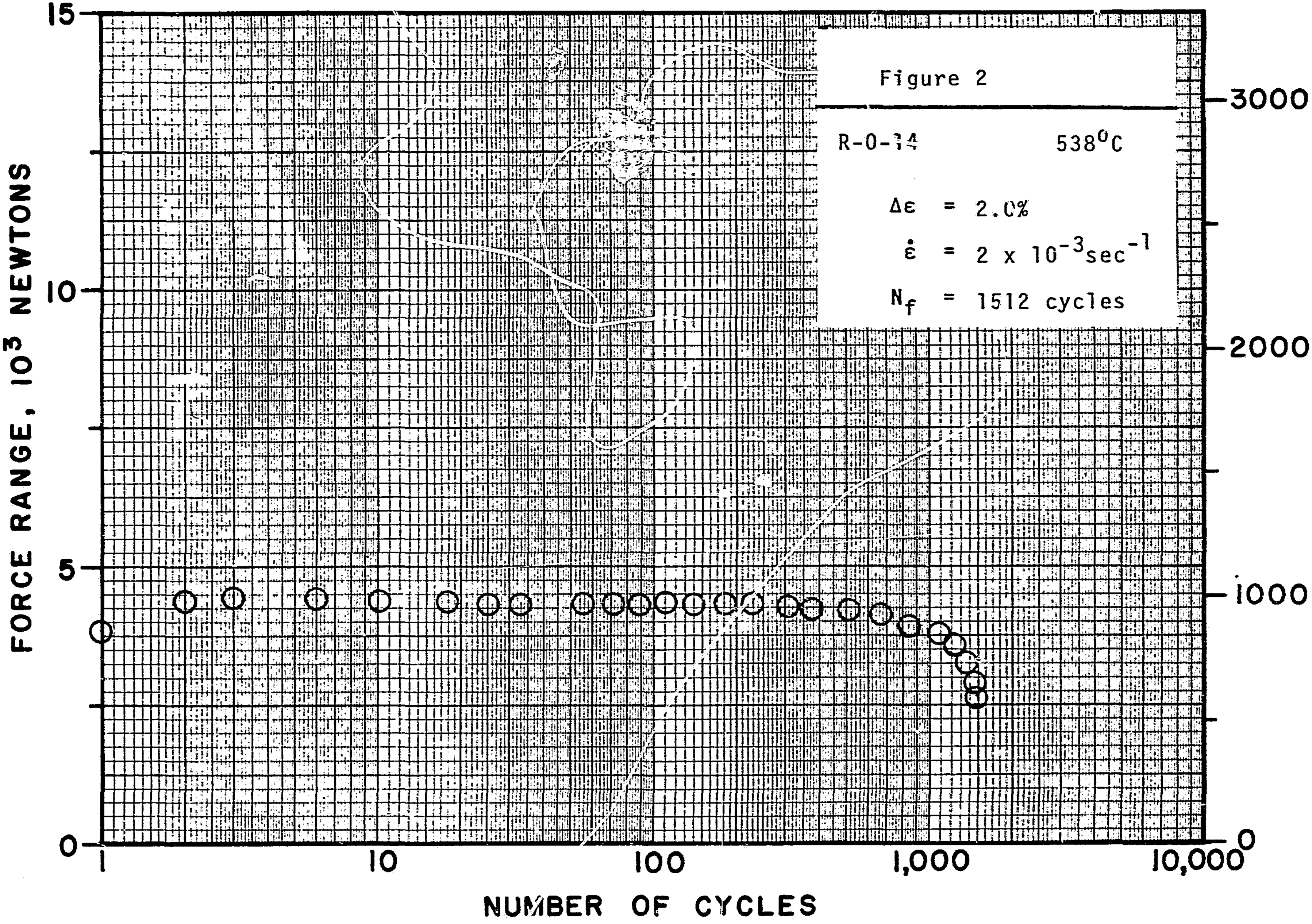


Figure 2
R-0-14
538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1512 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

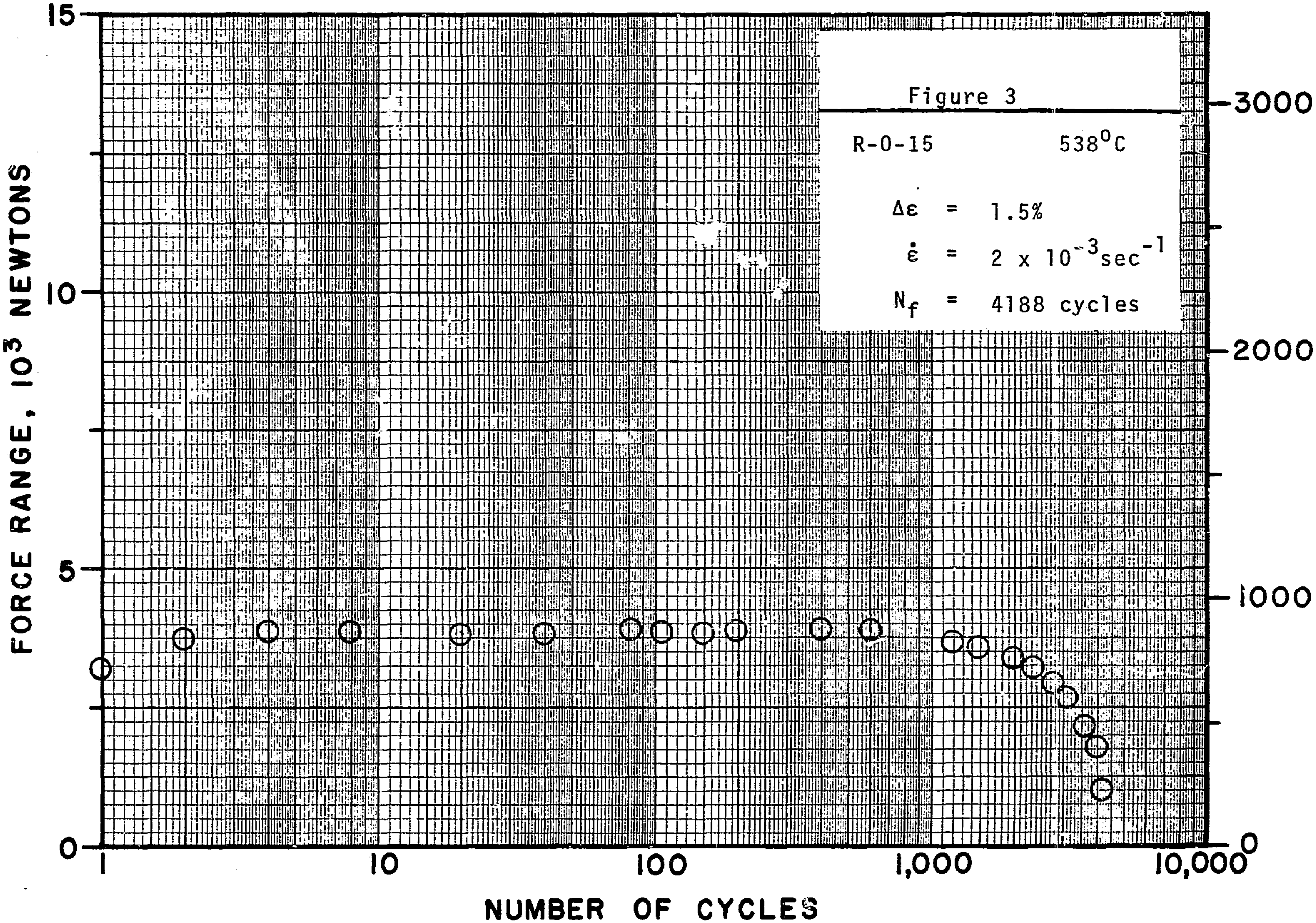


Figure 3
R-0-15
538°C
Δε = 1.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 4188 cycles
15
10
5
0
1
10
100
1,000
10,000
3000
2000
1000
0
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES

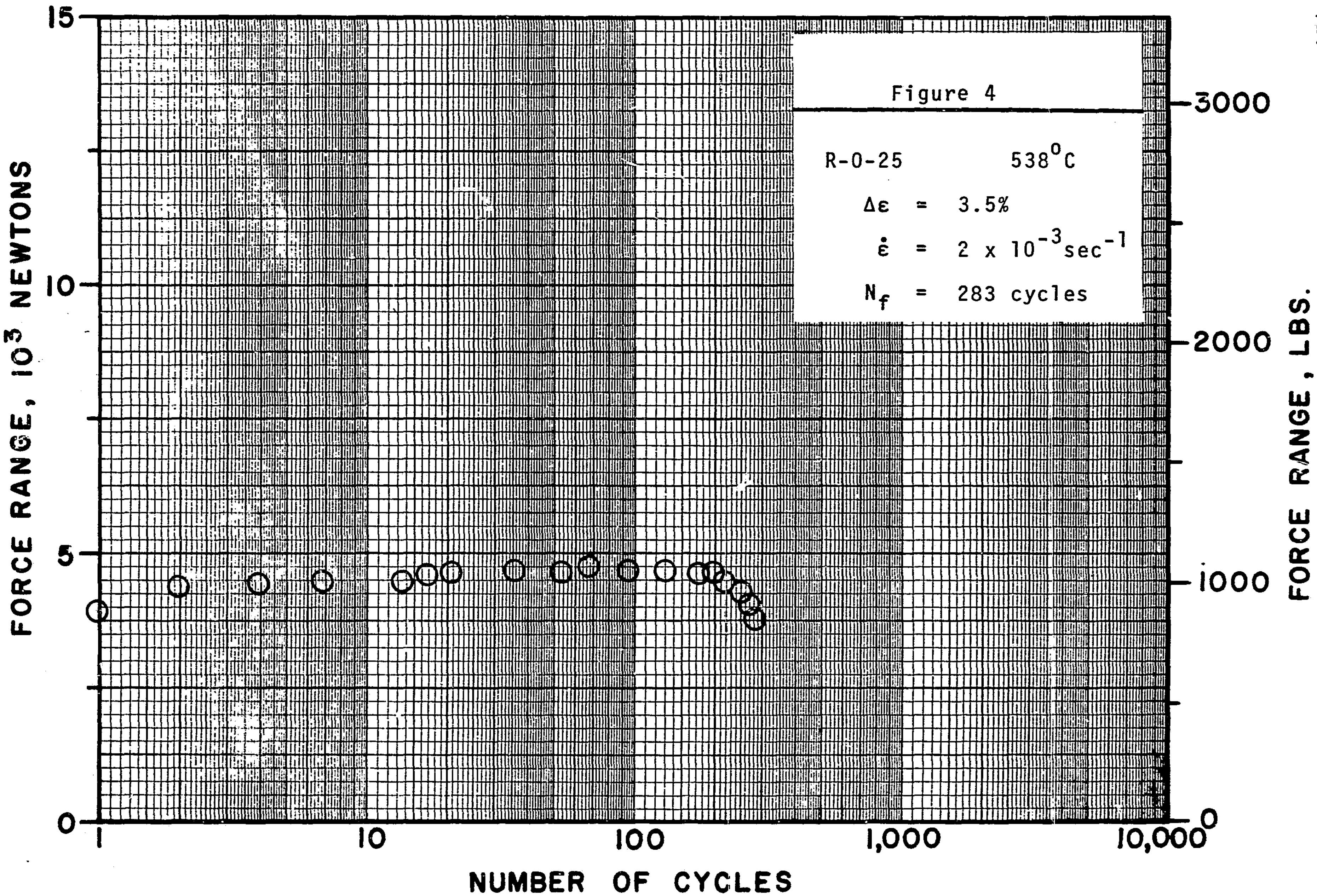


Figure 4
R-0-25 538°C
Δε = 3.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 283 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

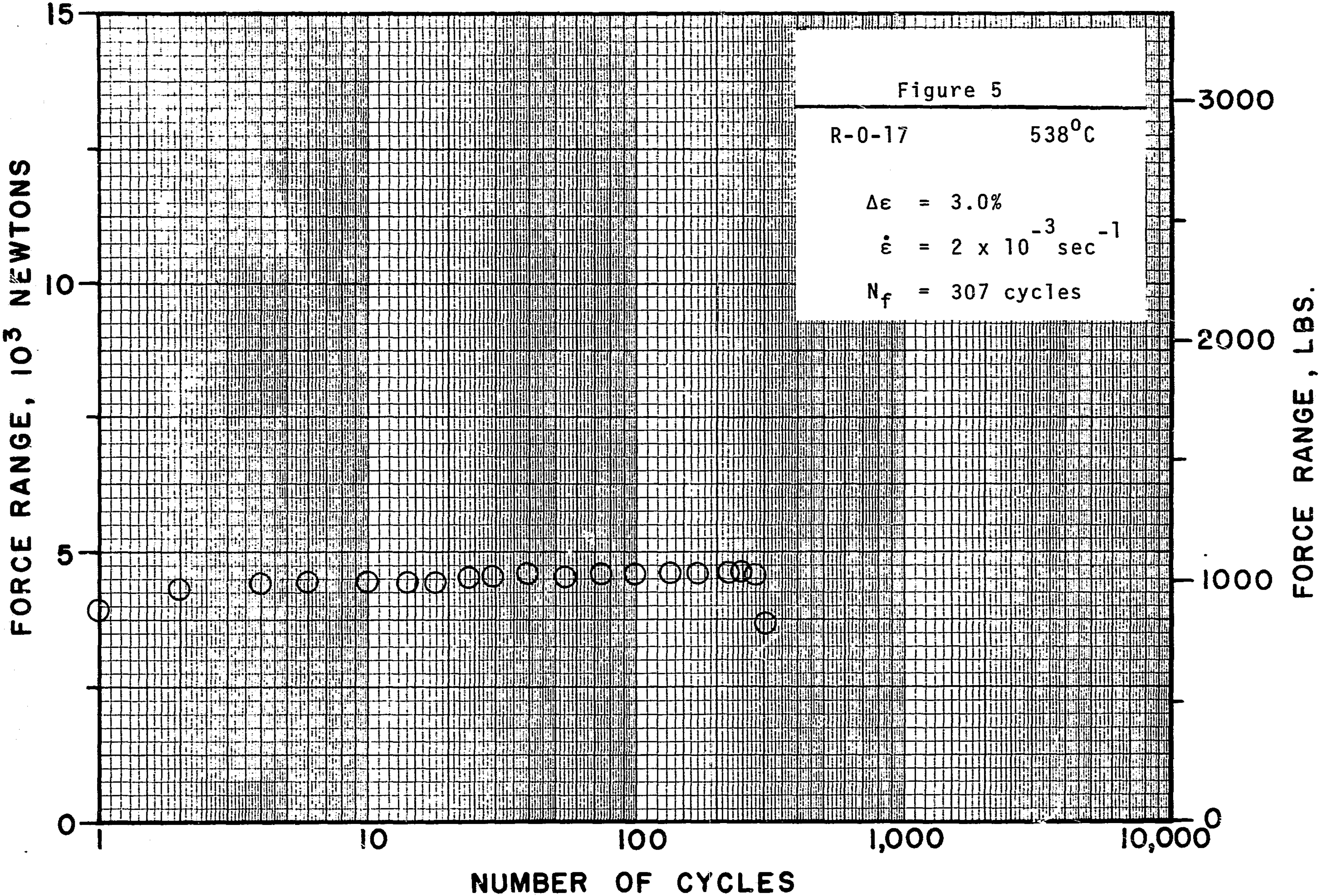


Figure 5
R-0-17
538°C
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 307 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

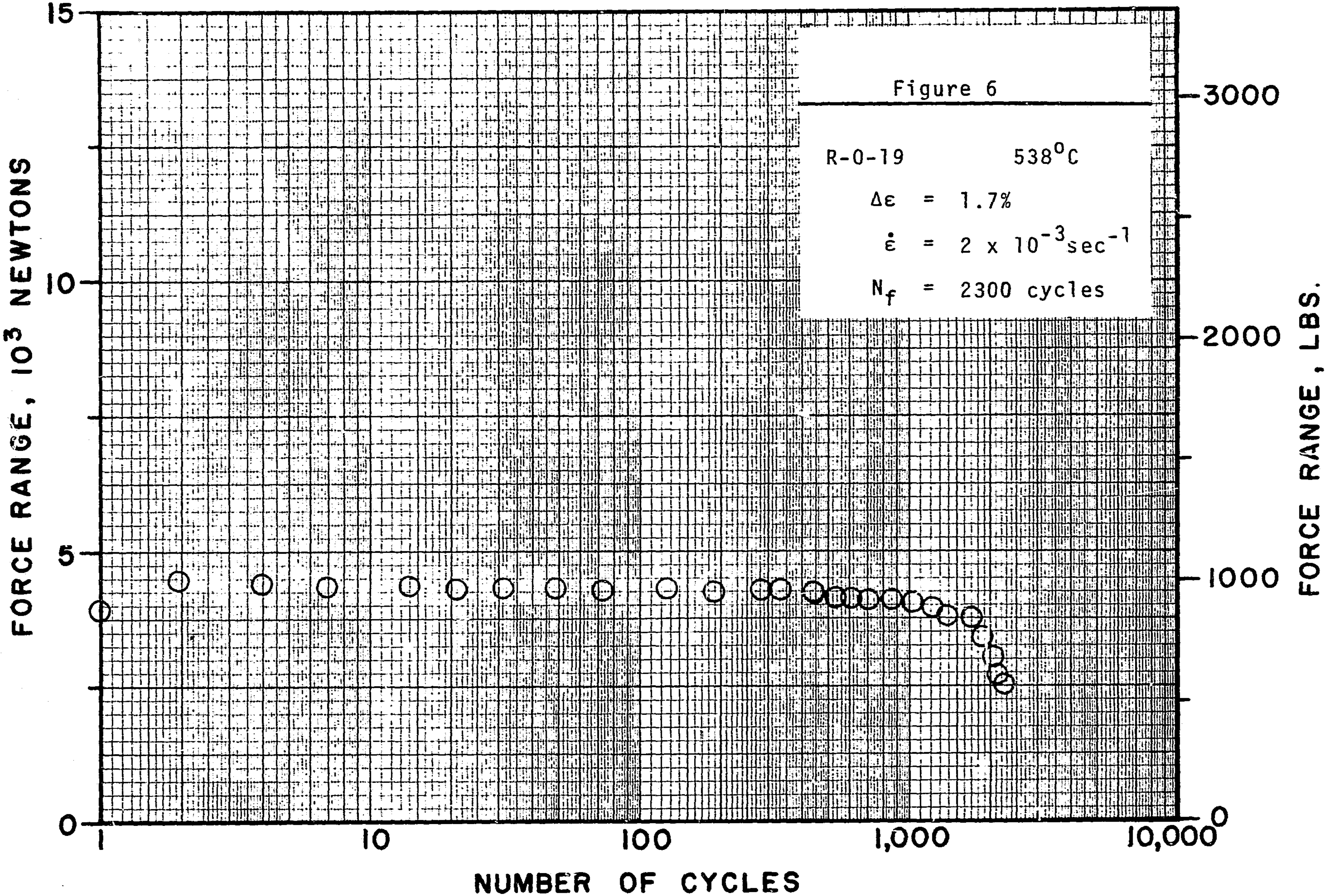

R-0-19 538°C
Δε = 1.7%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2300 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 6

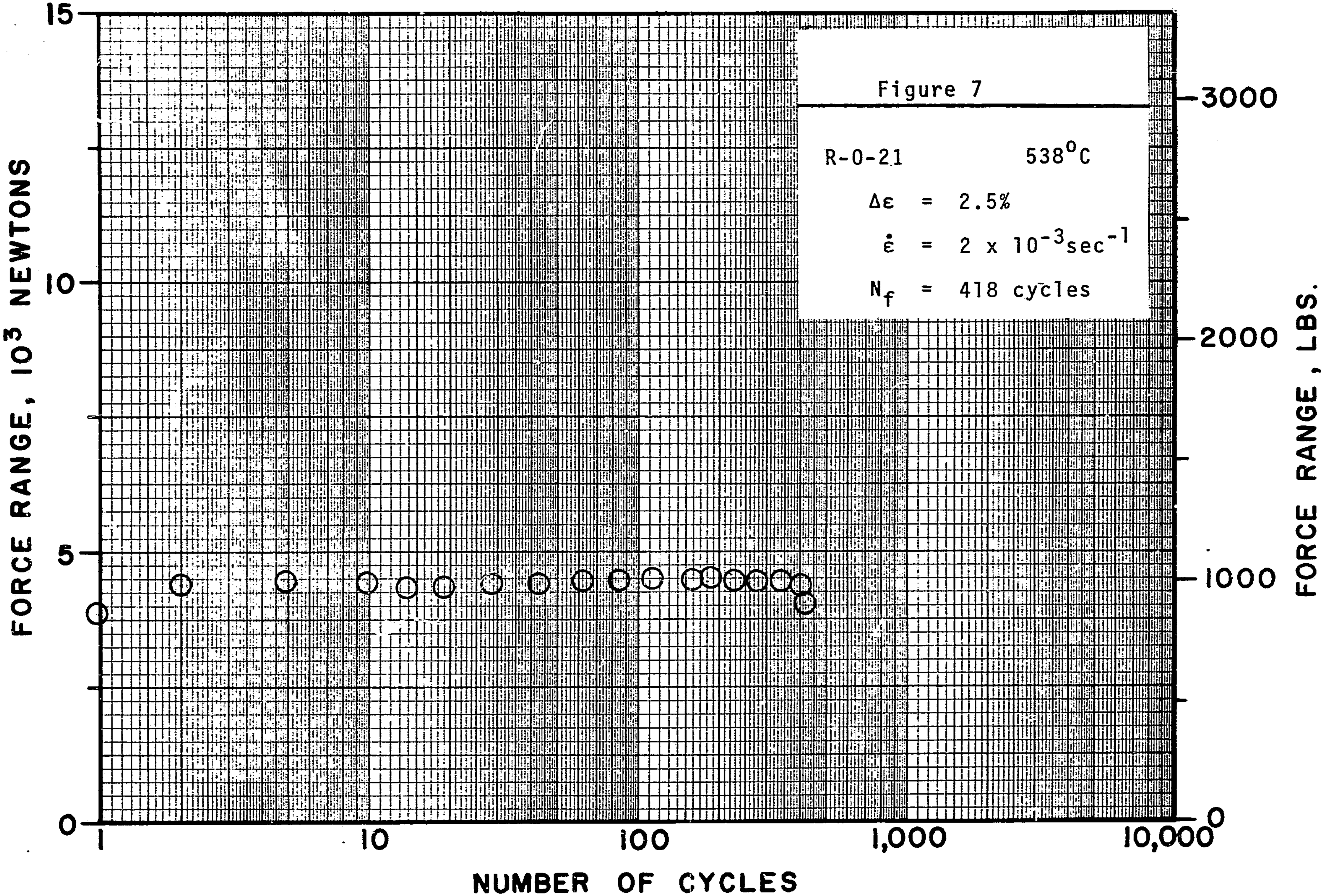


Figure 7
R-0-21 538°C
Δε = 2.5%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 418 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

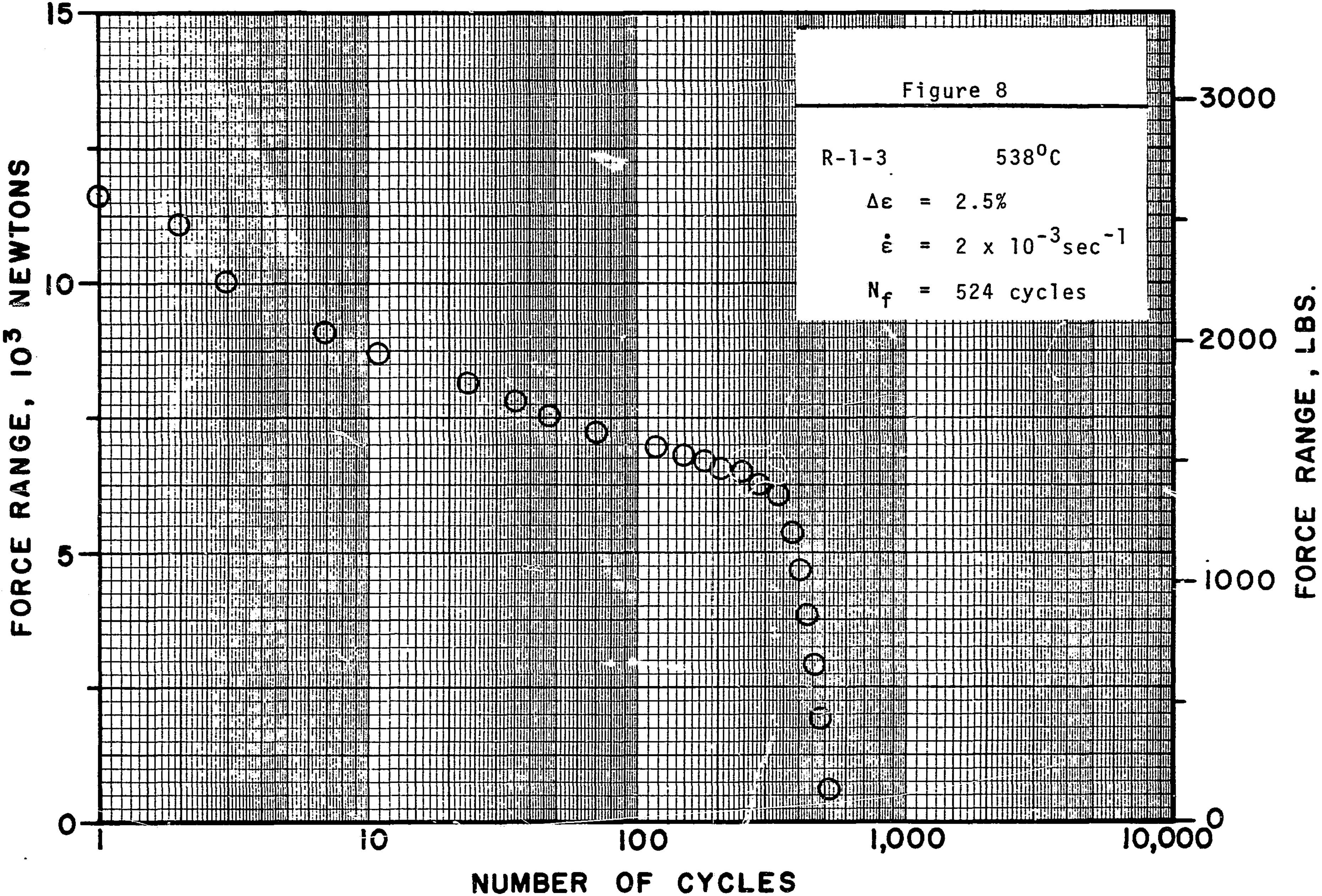


Figure 8
R-1-3 538°C
Δε = 2.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 524 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

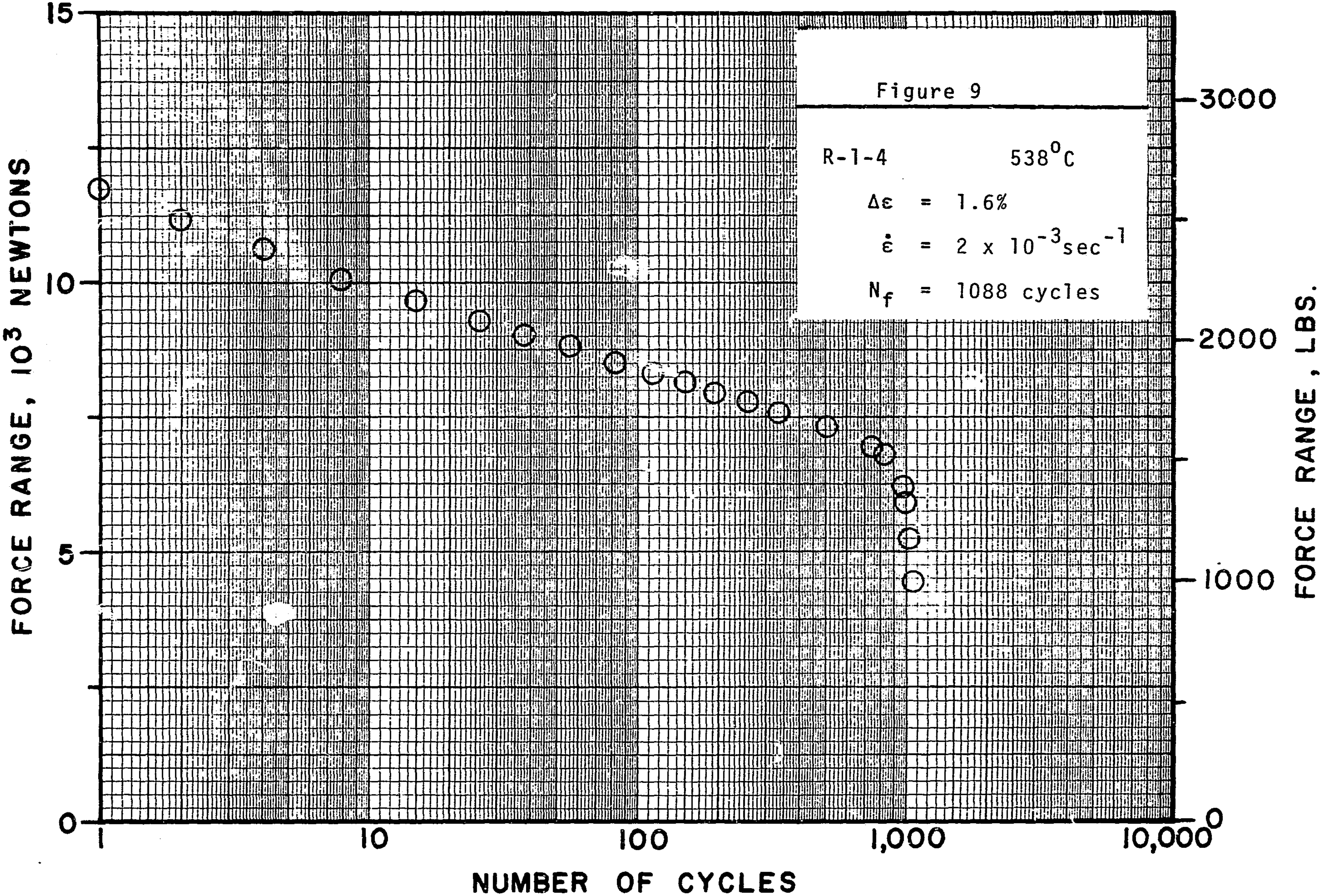


Figure 9
R-1-4 538°C
Δε = 1.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1088 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

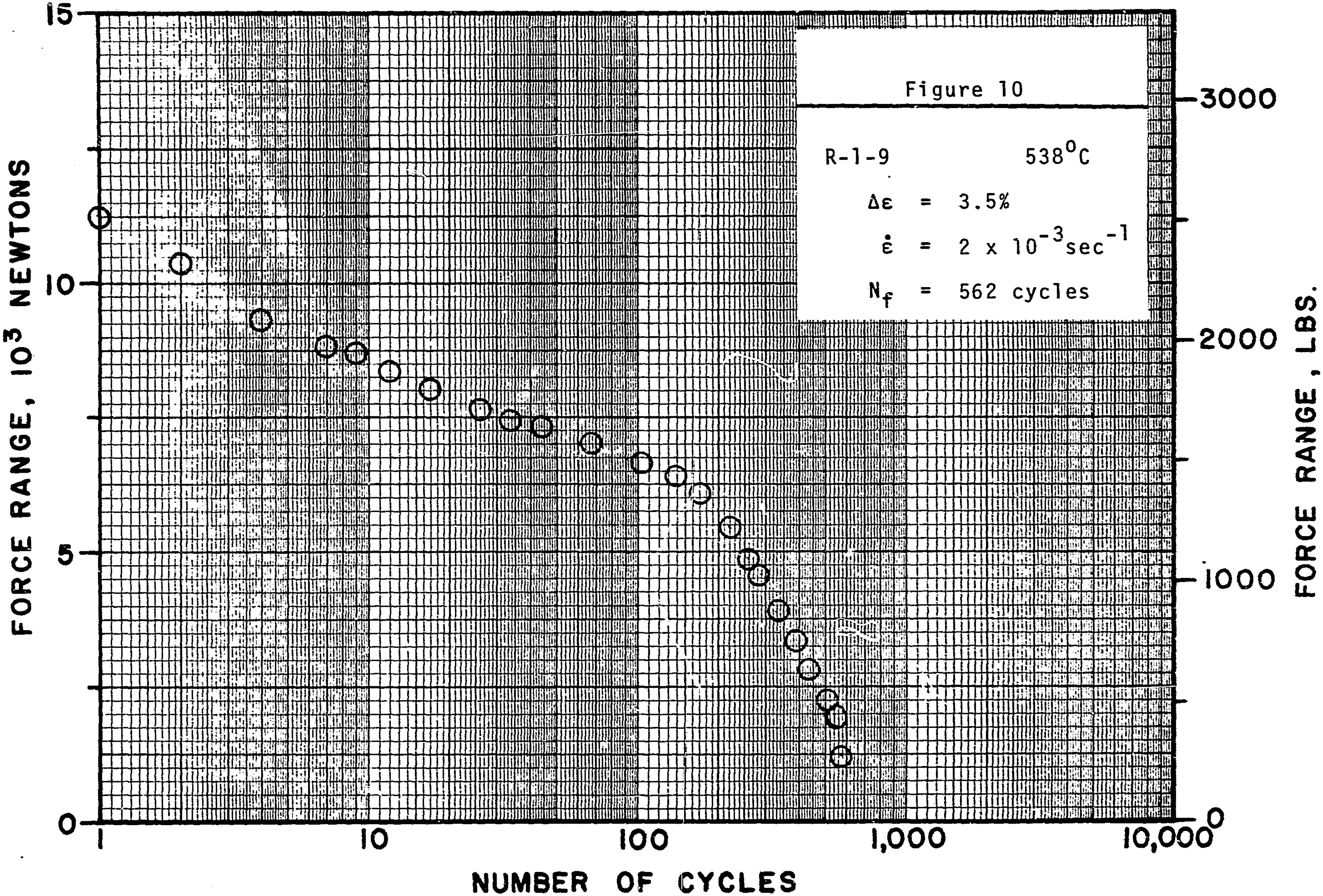


Figure 10
R-1-9
538°C
Δε = 3.5%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 562 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1000
2000
3000
1
10
100
1,000
10,000

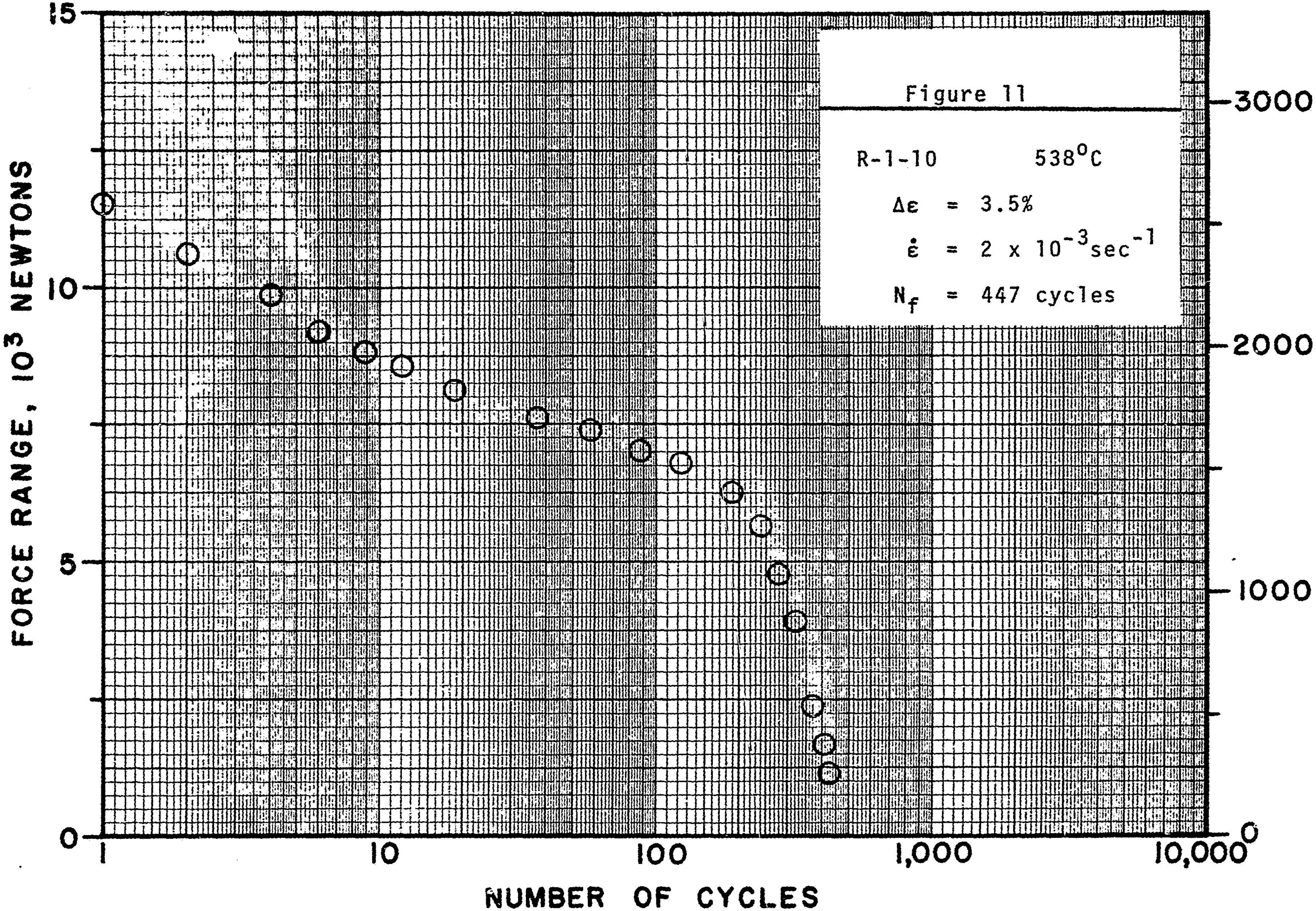


Figure 11
R-1-10 538°C
Δε = 3.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 447 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

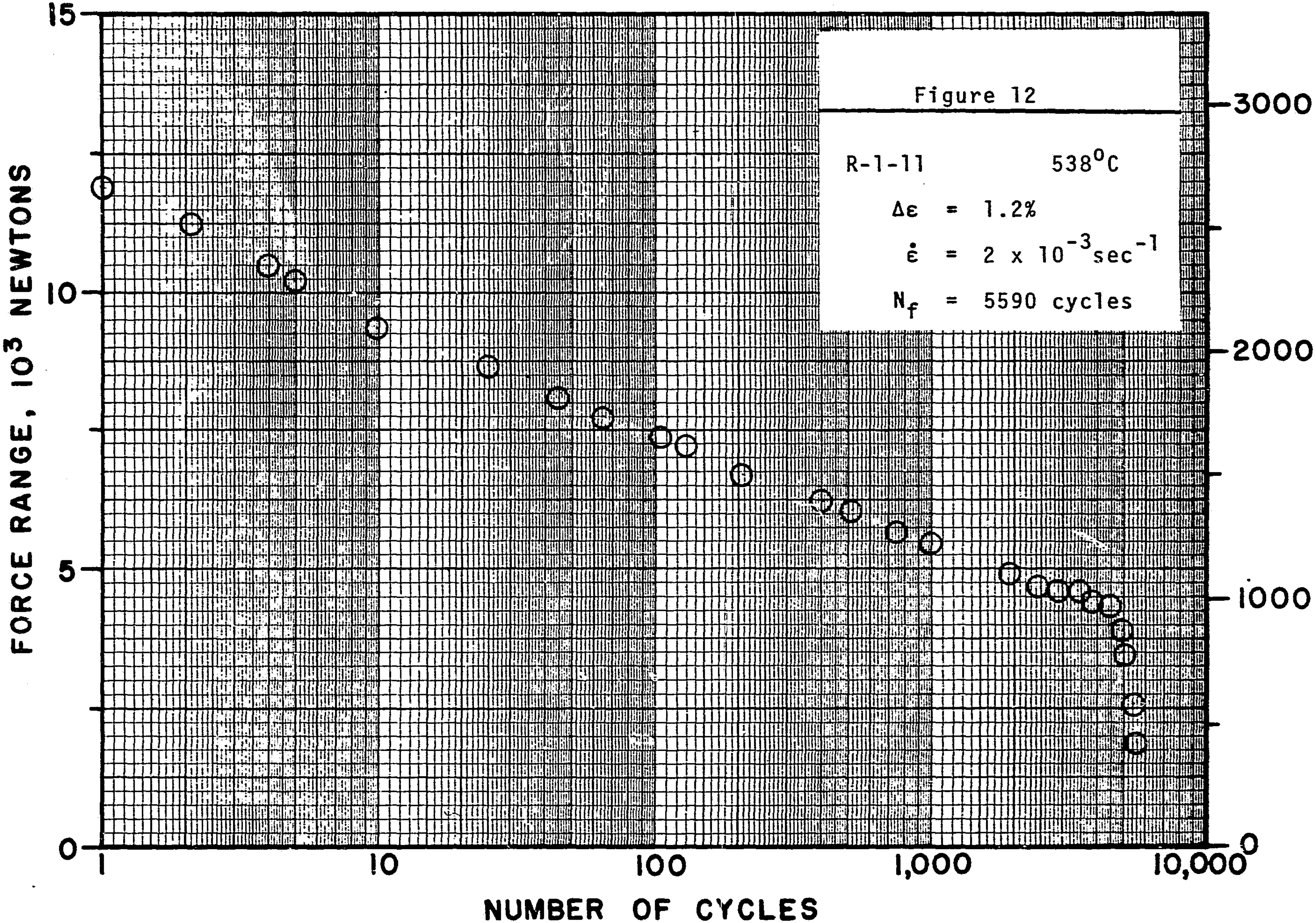


Figure 12
R-1-11 538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 5590 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

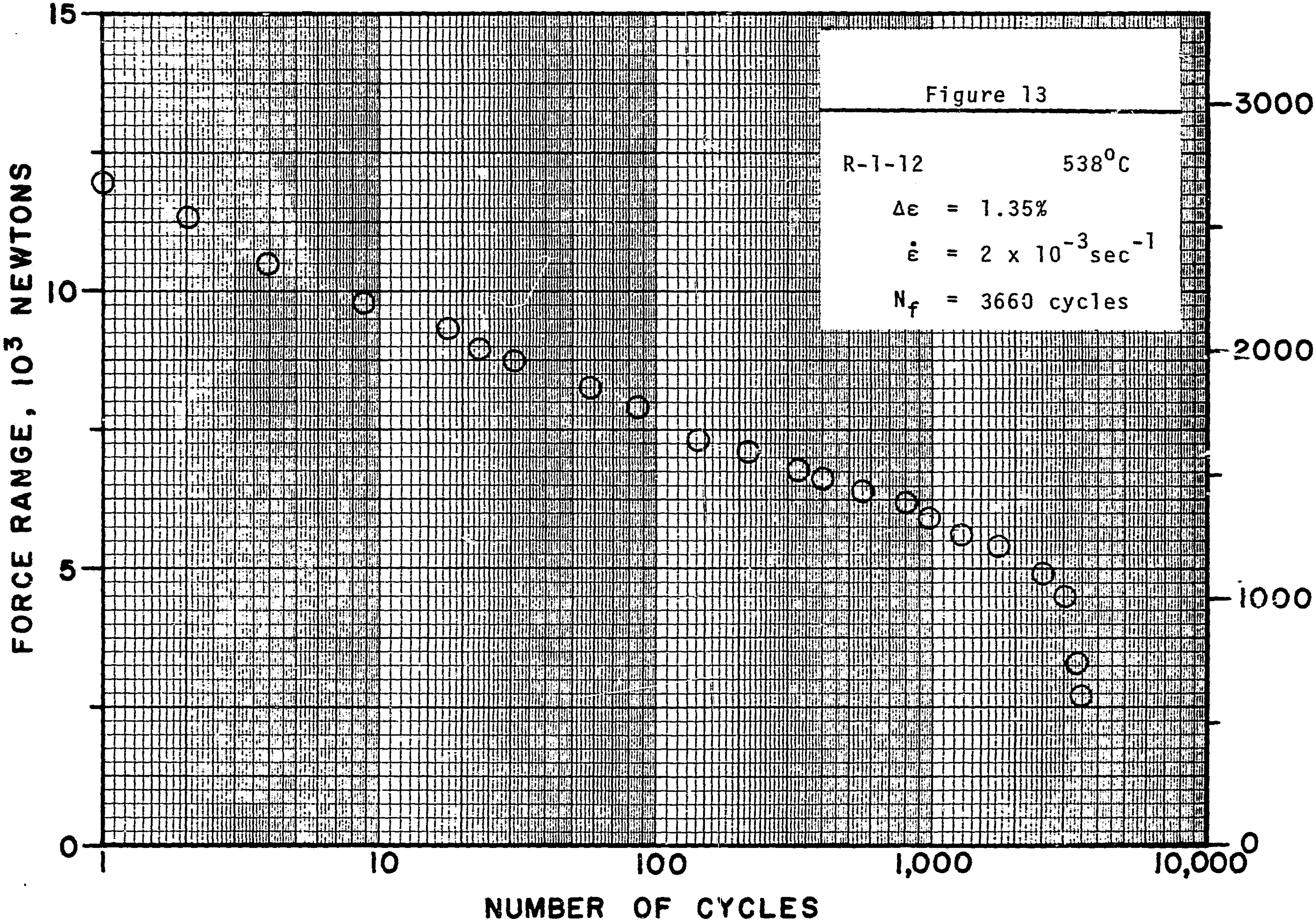


Figure 13
R-1-12 538°C
Δε = 1.35%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3660 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

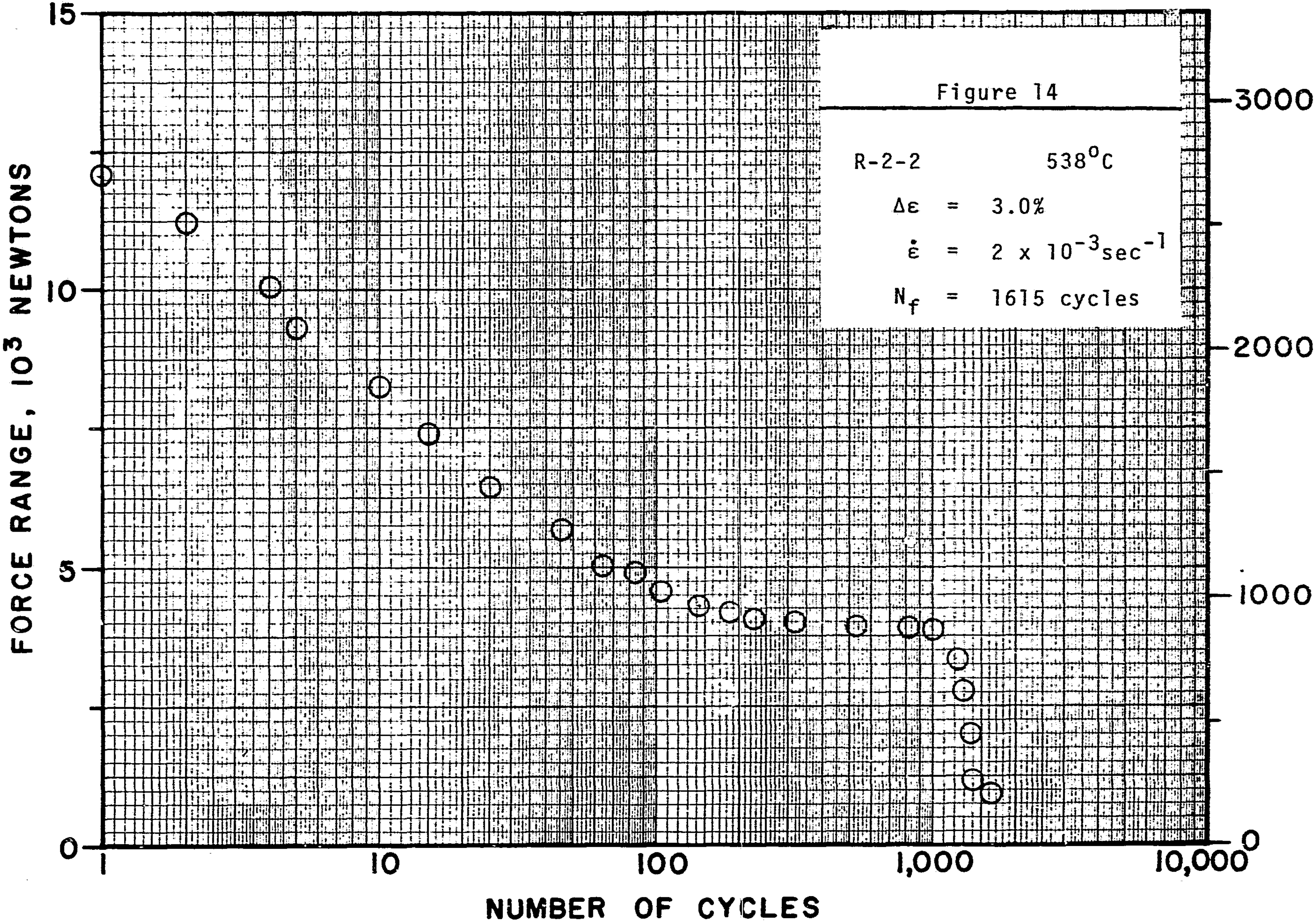


Figure 14
R-2-2 538°C
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1615 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

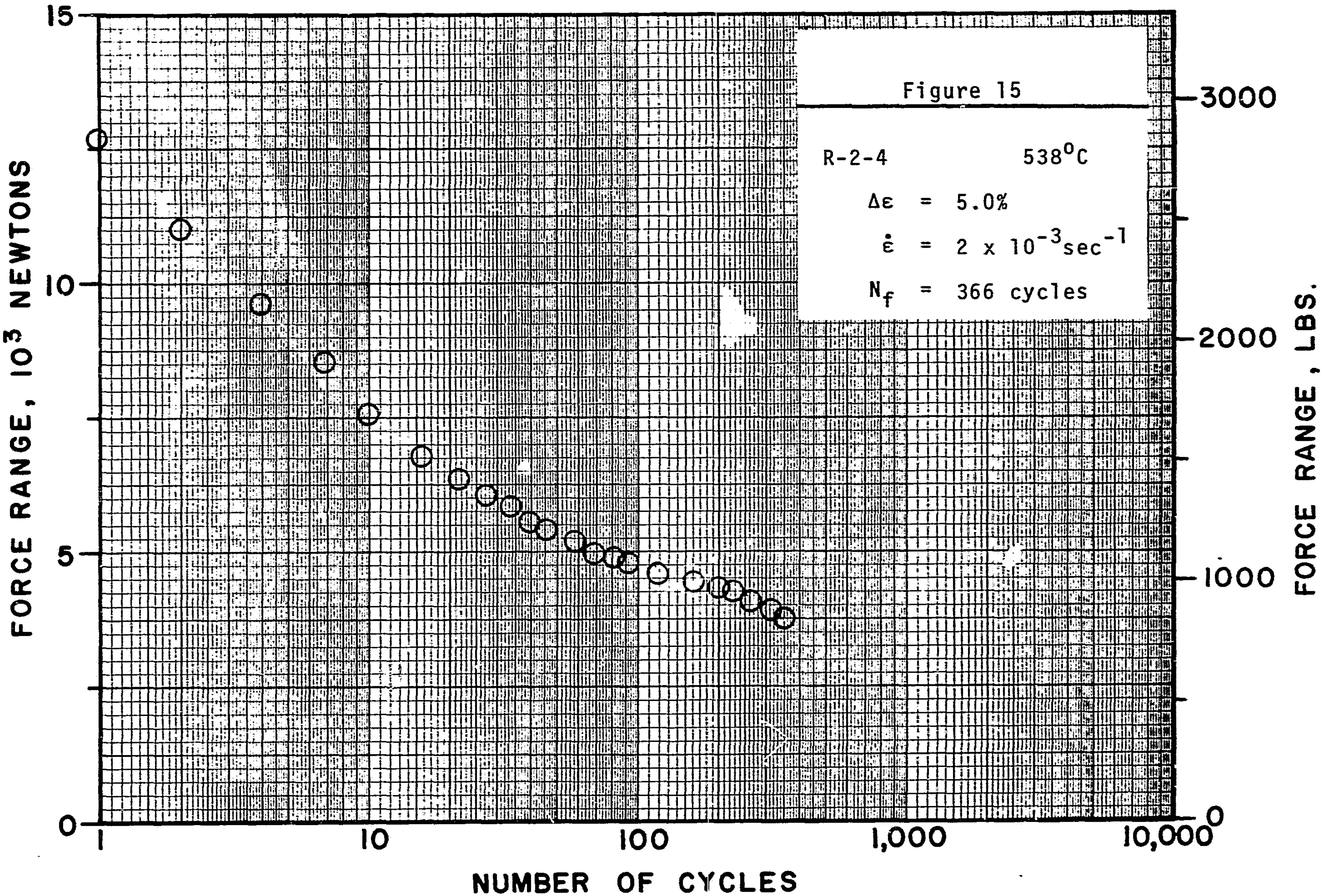


Figure 15
R-2-4
538°C
Δε = 5.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 366 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

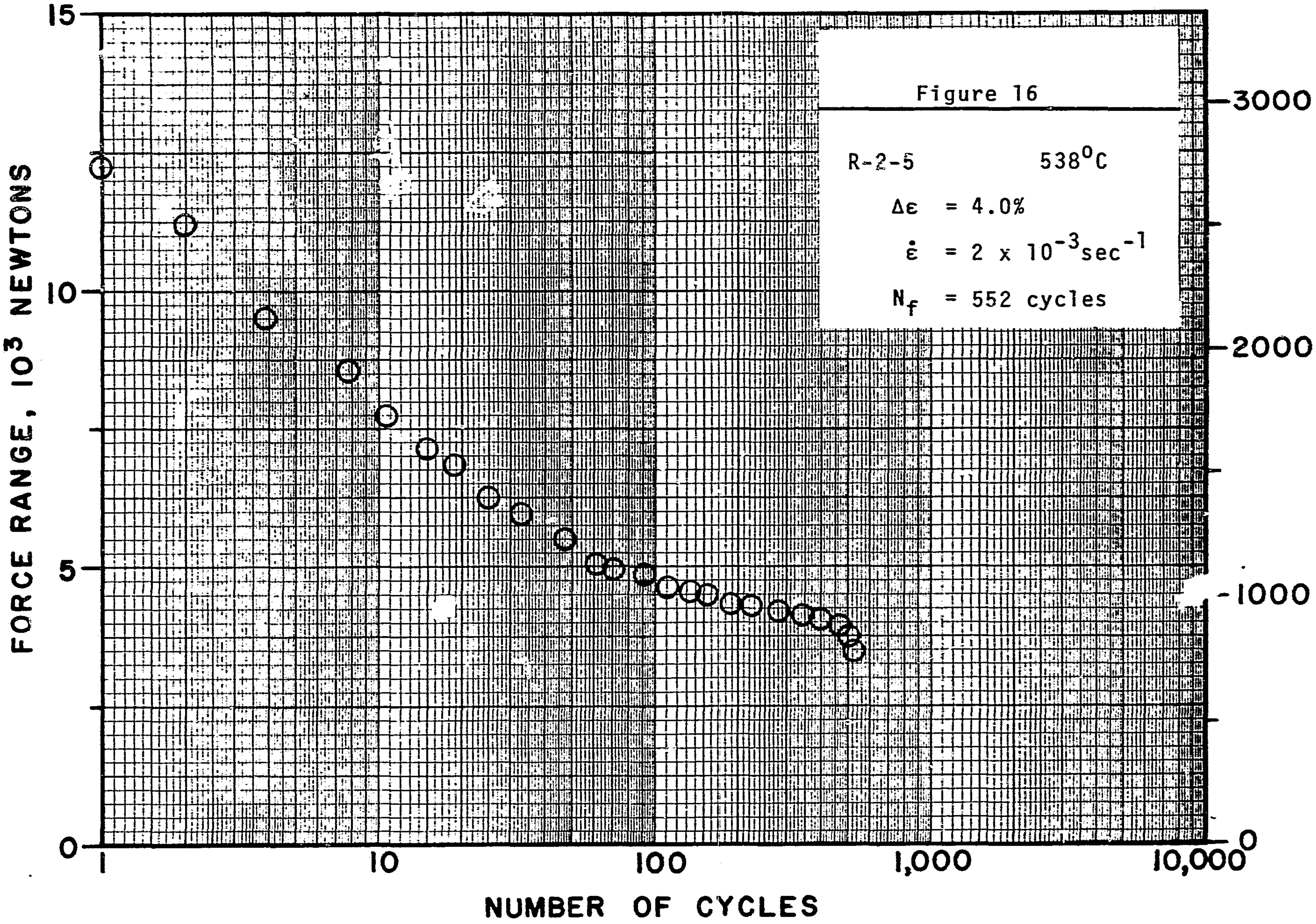


Figure 16
R-2-5
538^{0}C
$\Delta\varepsilon$ = 4.0%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 552 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
1
10
100
1,000
10,000
3000
2000
1000
0

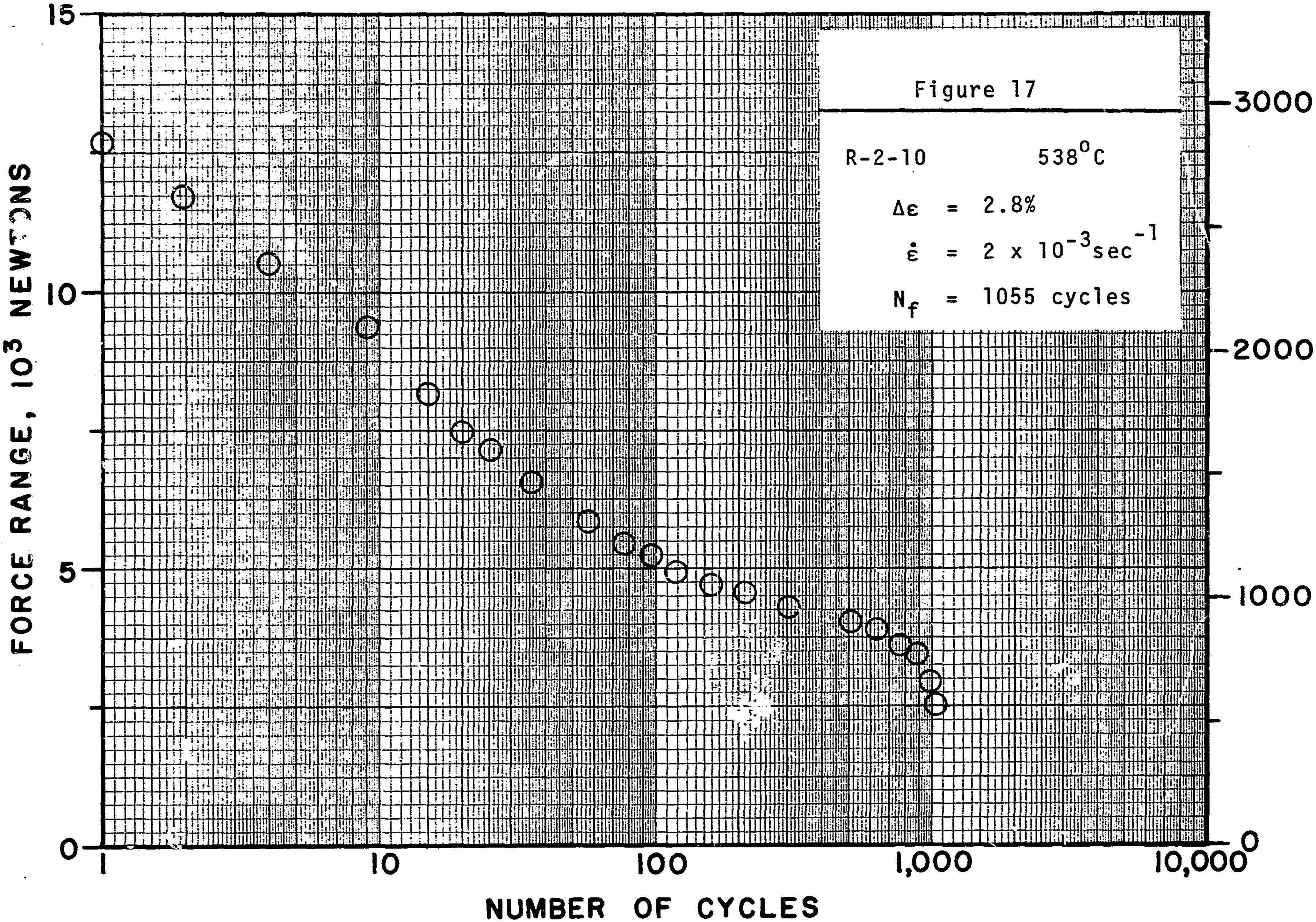


Figure 17
R-2-10 538°C
Δε = 2.8%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1055 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1000
2000
3000
1
10
100
1,000
10,000

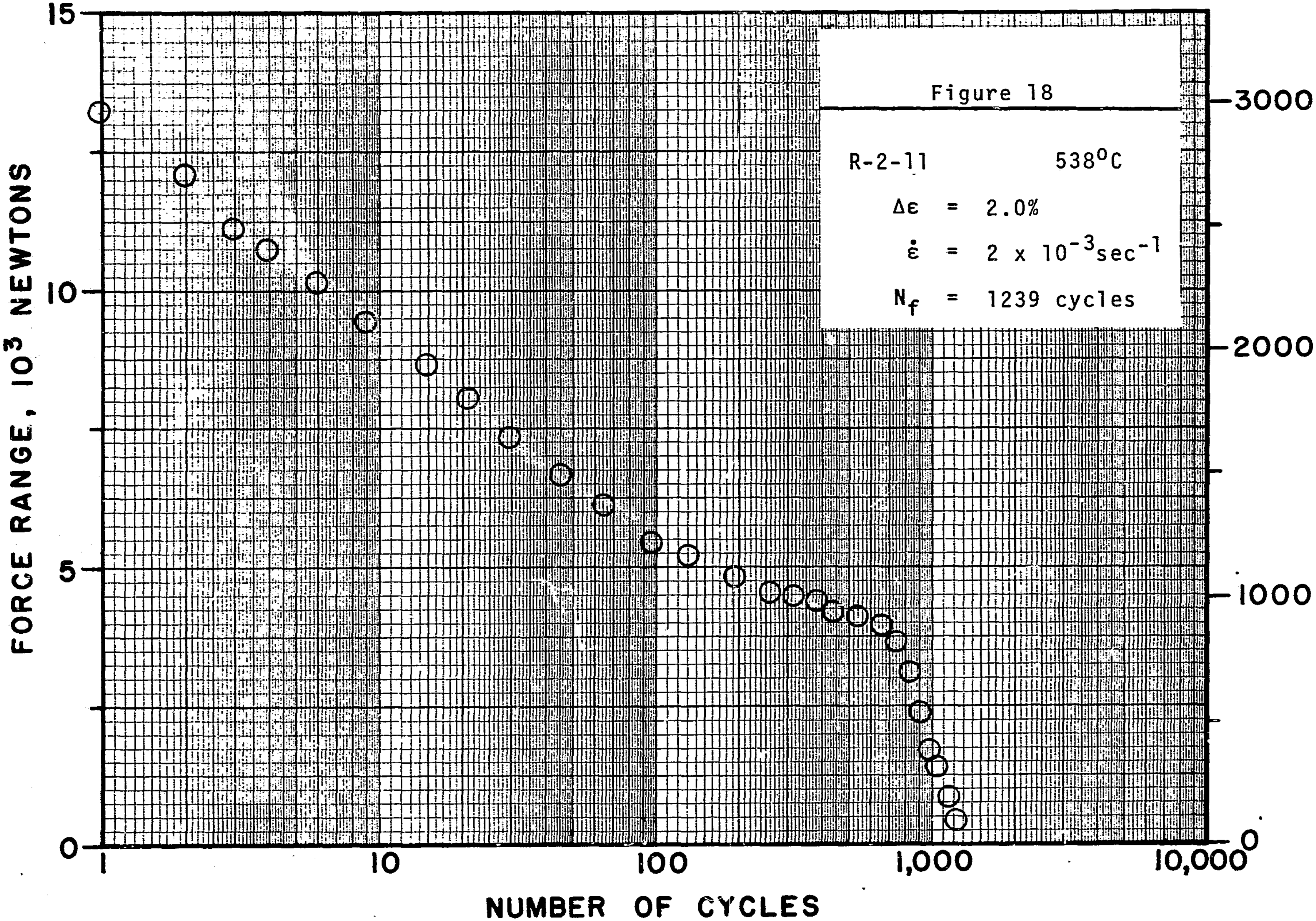


Figure 18
R-2-11 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1239 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
1
10
100
1,000
10,000
3000
2000
1000
0

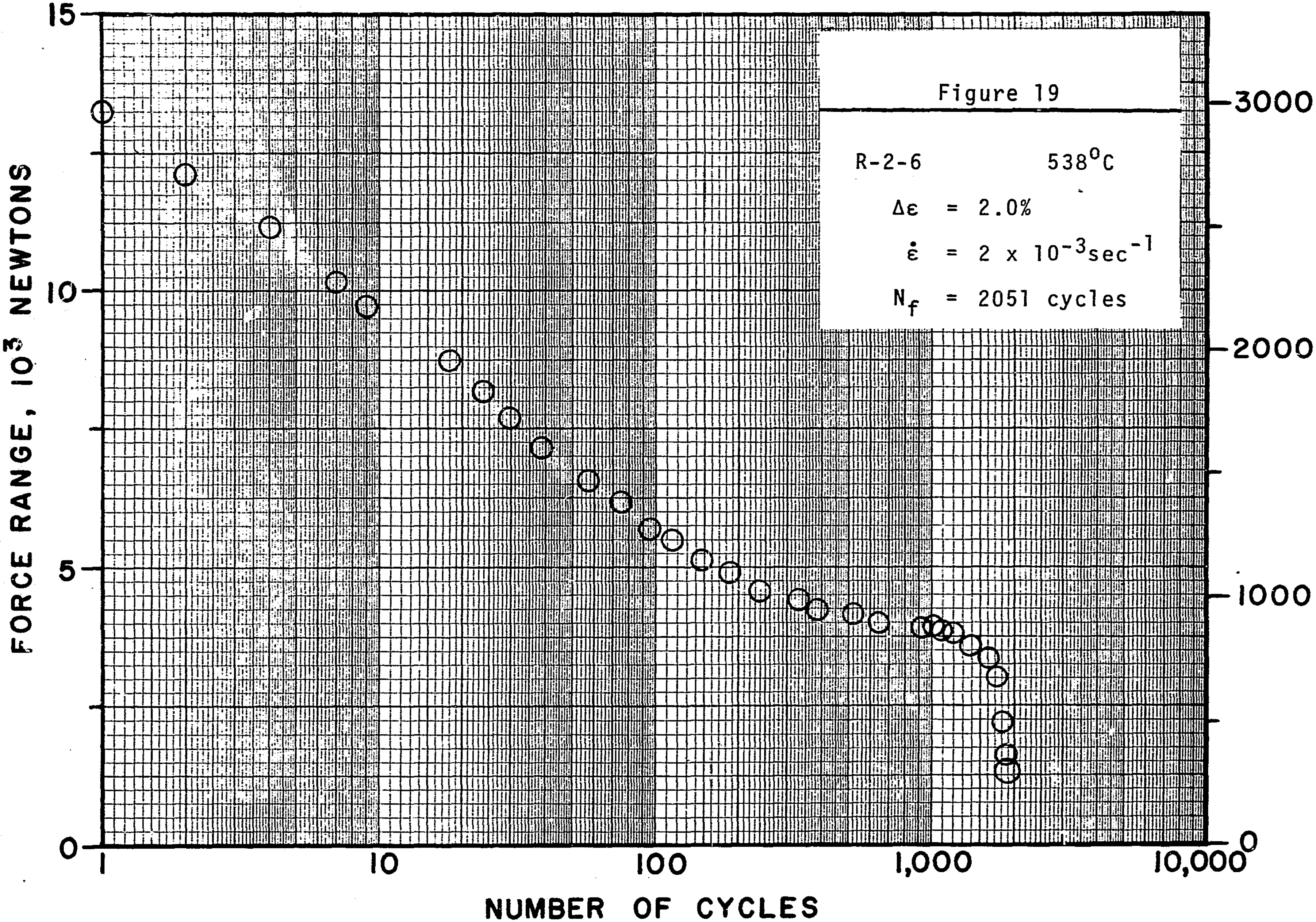


Figure 19
R-2-6
538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2051 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

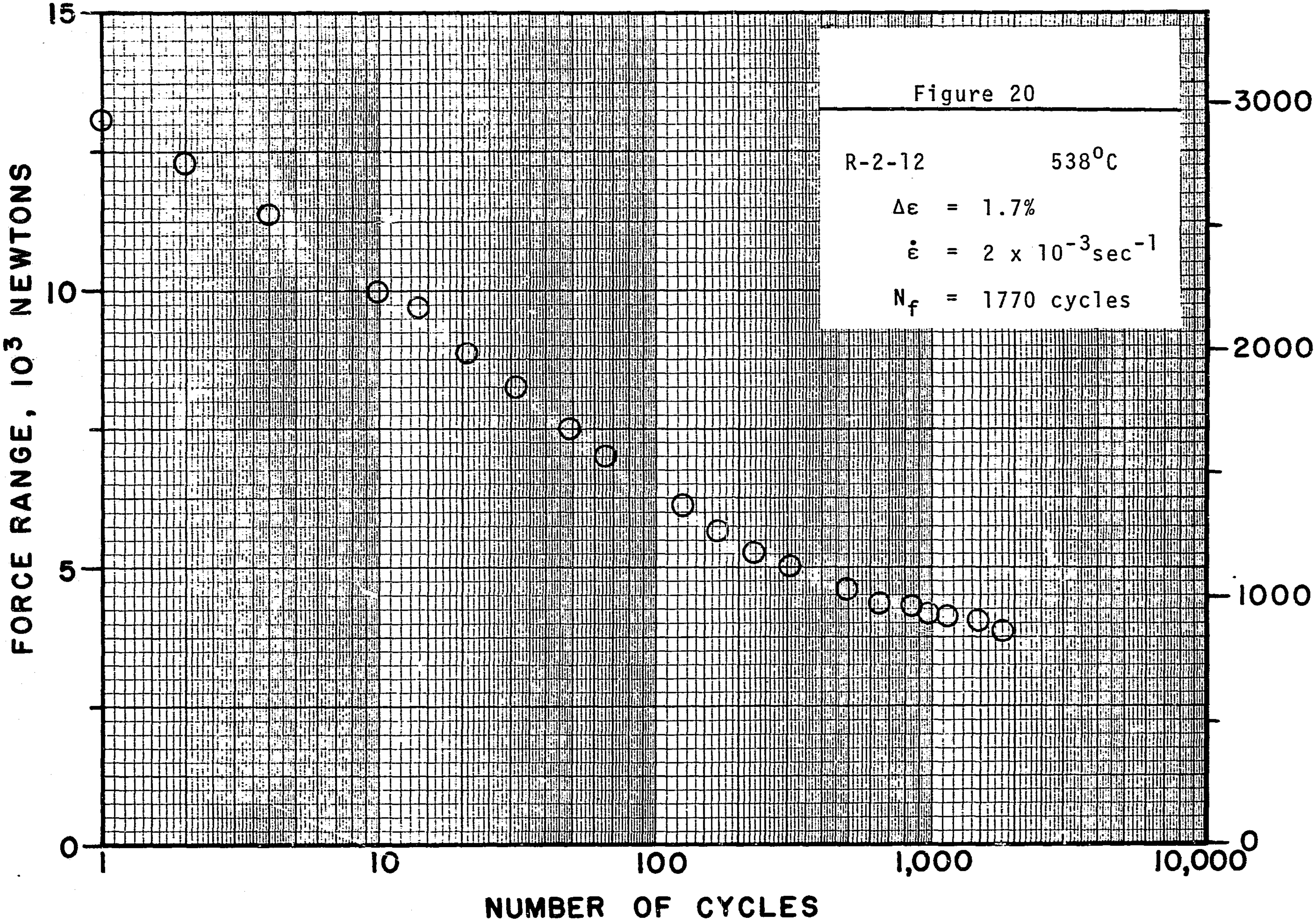


Figure 20
R-2-12 538°C
Δε = 1.7%
ε̇ = 2 x 10⁻³sec⁻¹
Nf = 1770 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

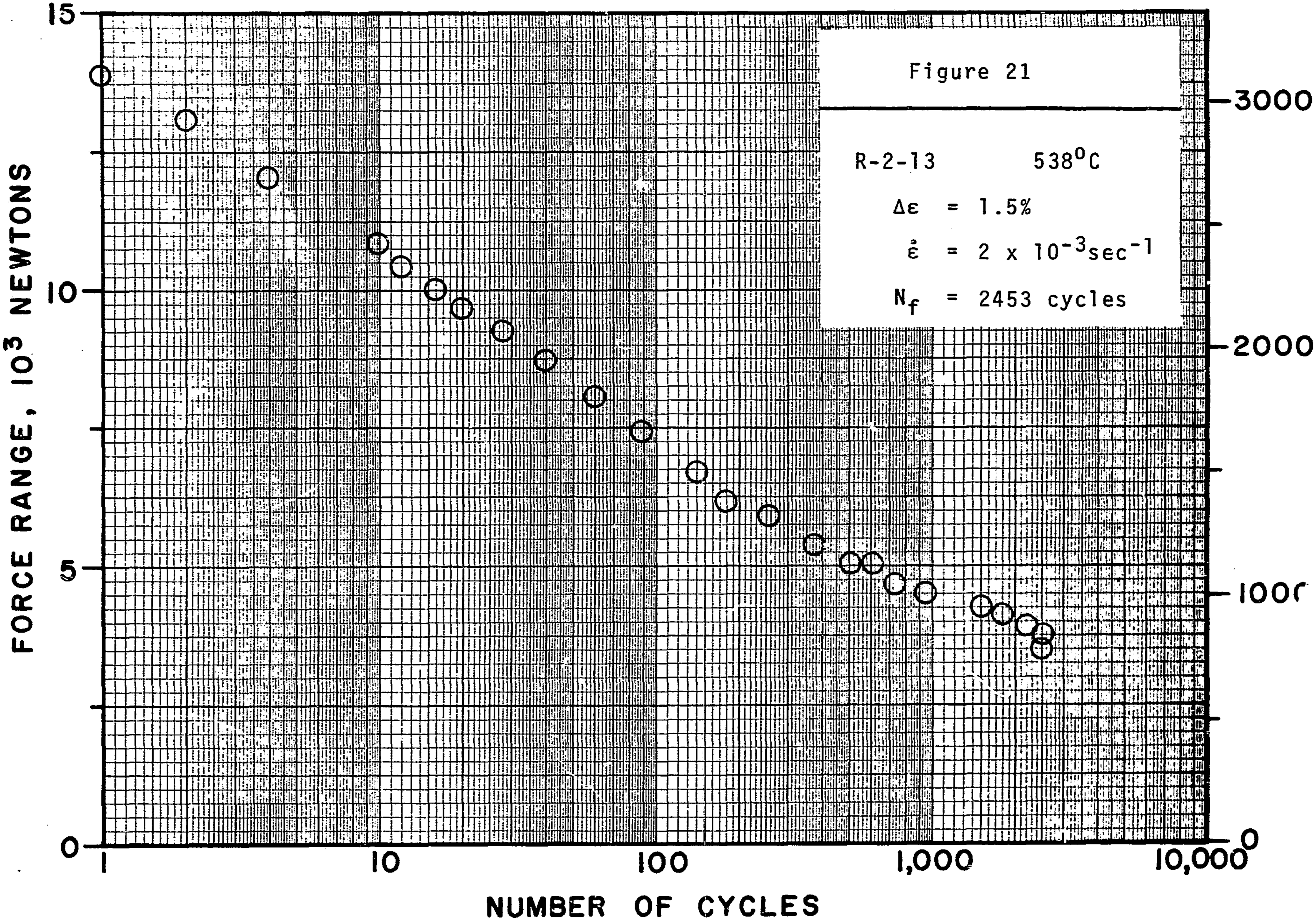


Figure 21
R-2-13 538°C
Δε = 1.5%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2453 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
1
10
100
1,000
10,000
3000
2000
1000
0

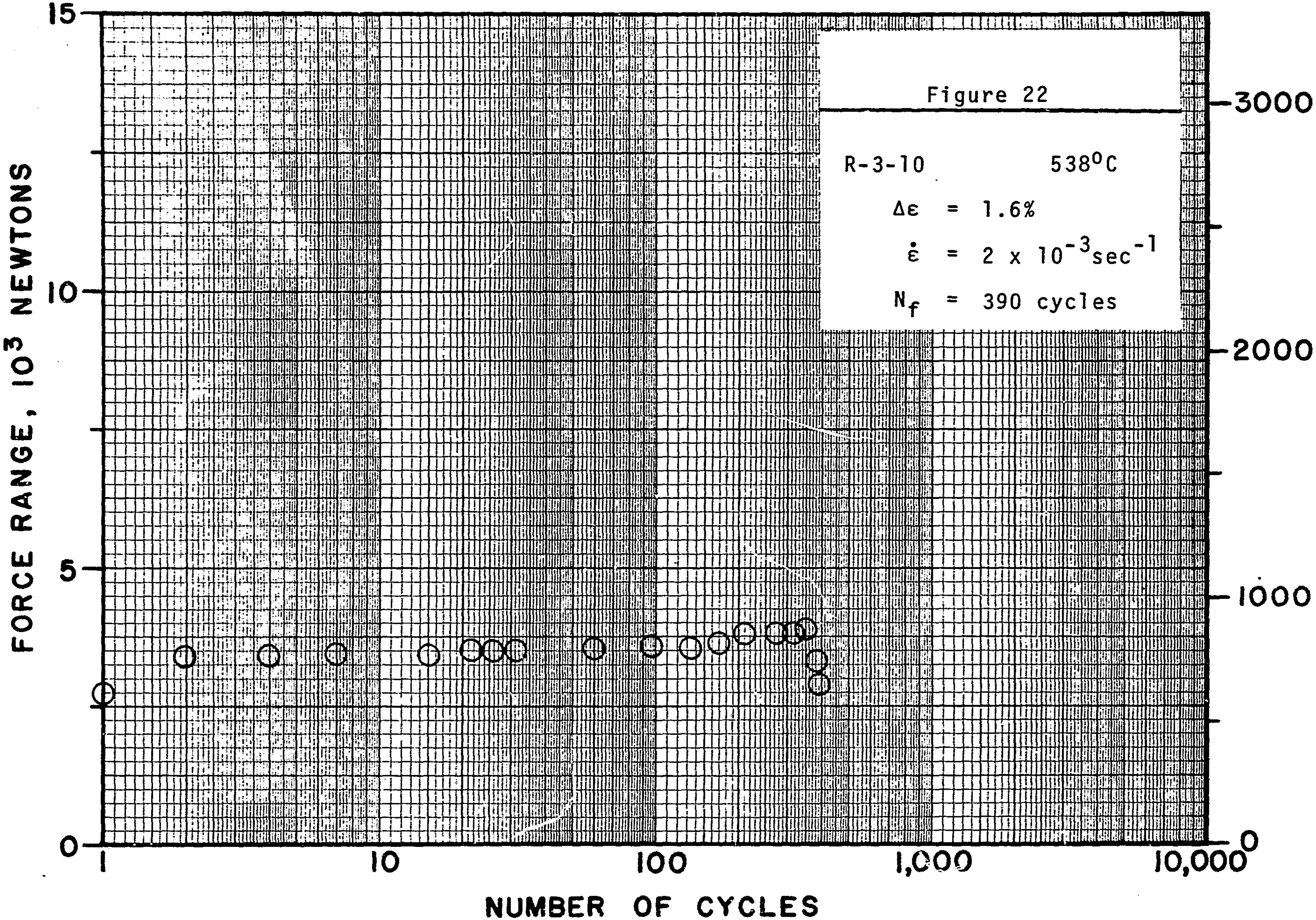


Figure 22
R-3-10 538°C
Δε = 1.6%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 390 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

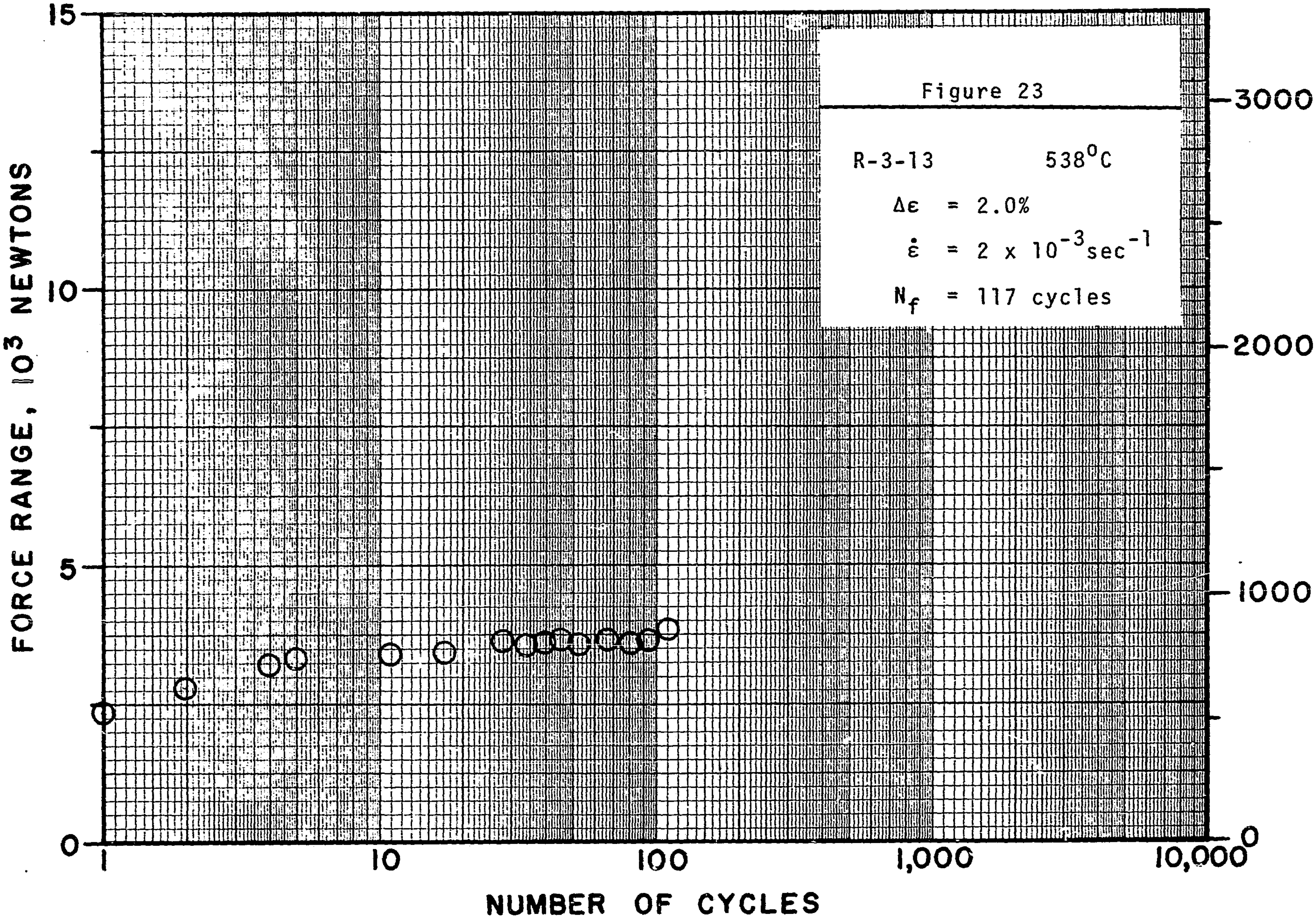


Figure 23
R-3-13 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 117 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

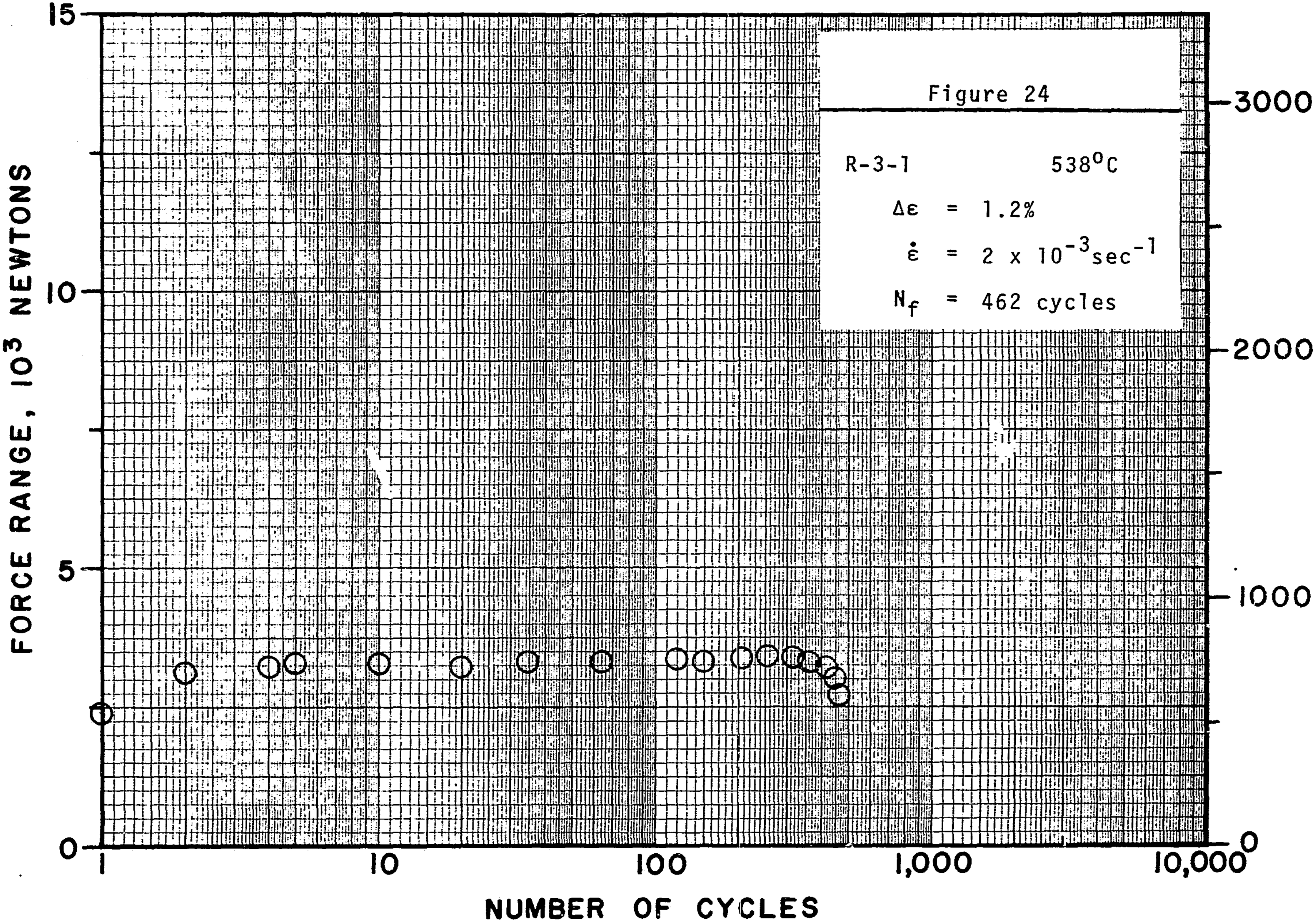


Figure 24
R-3-1 538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 462 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

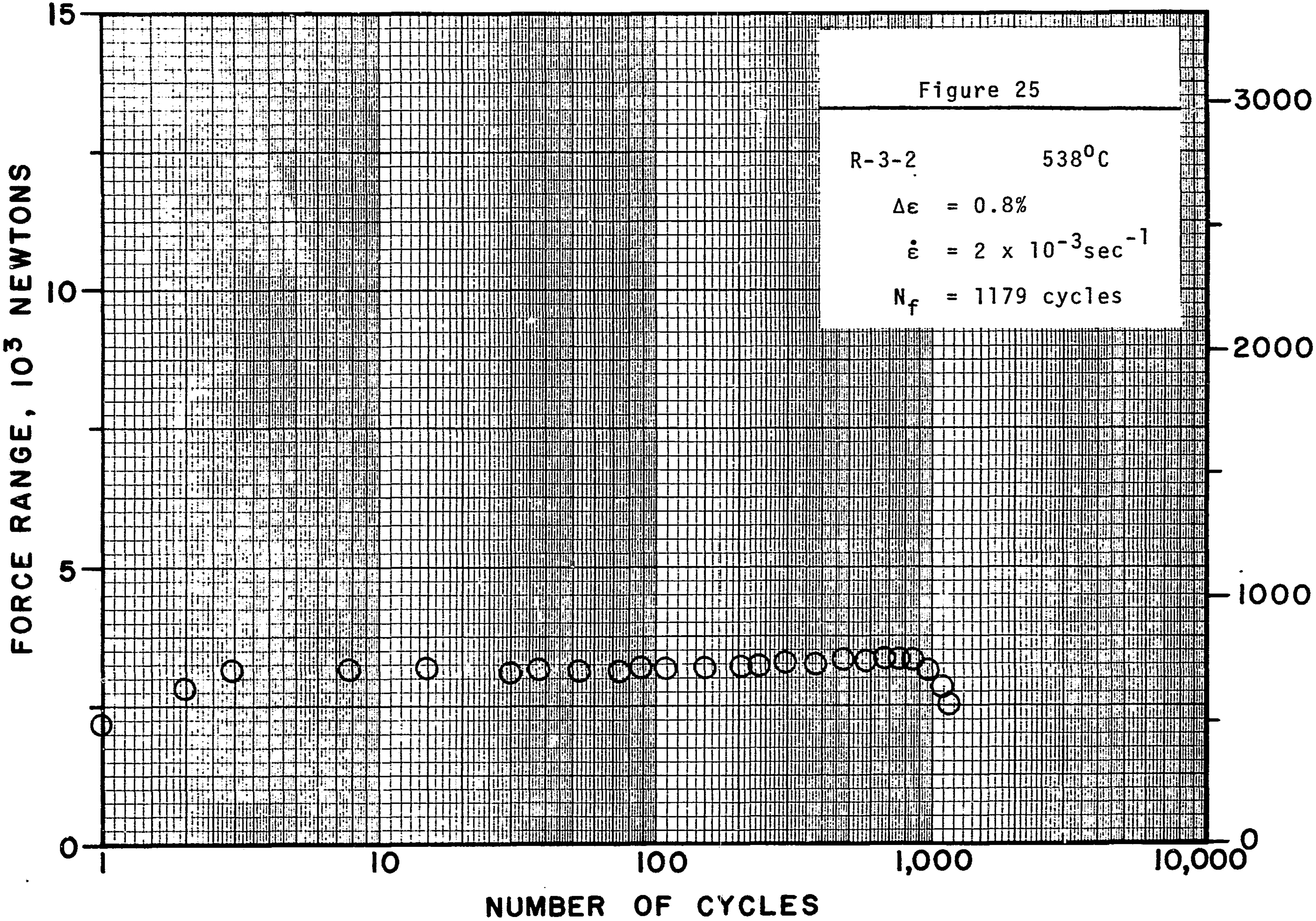


Figure 25
R-3-2 538°C
Δε = 0.8%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1179 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

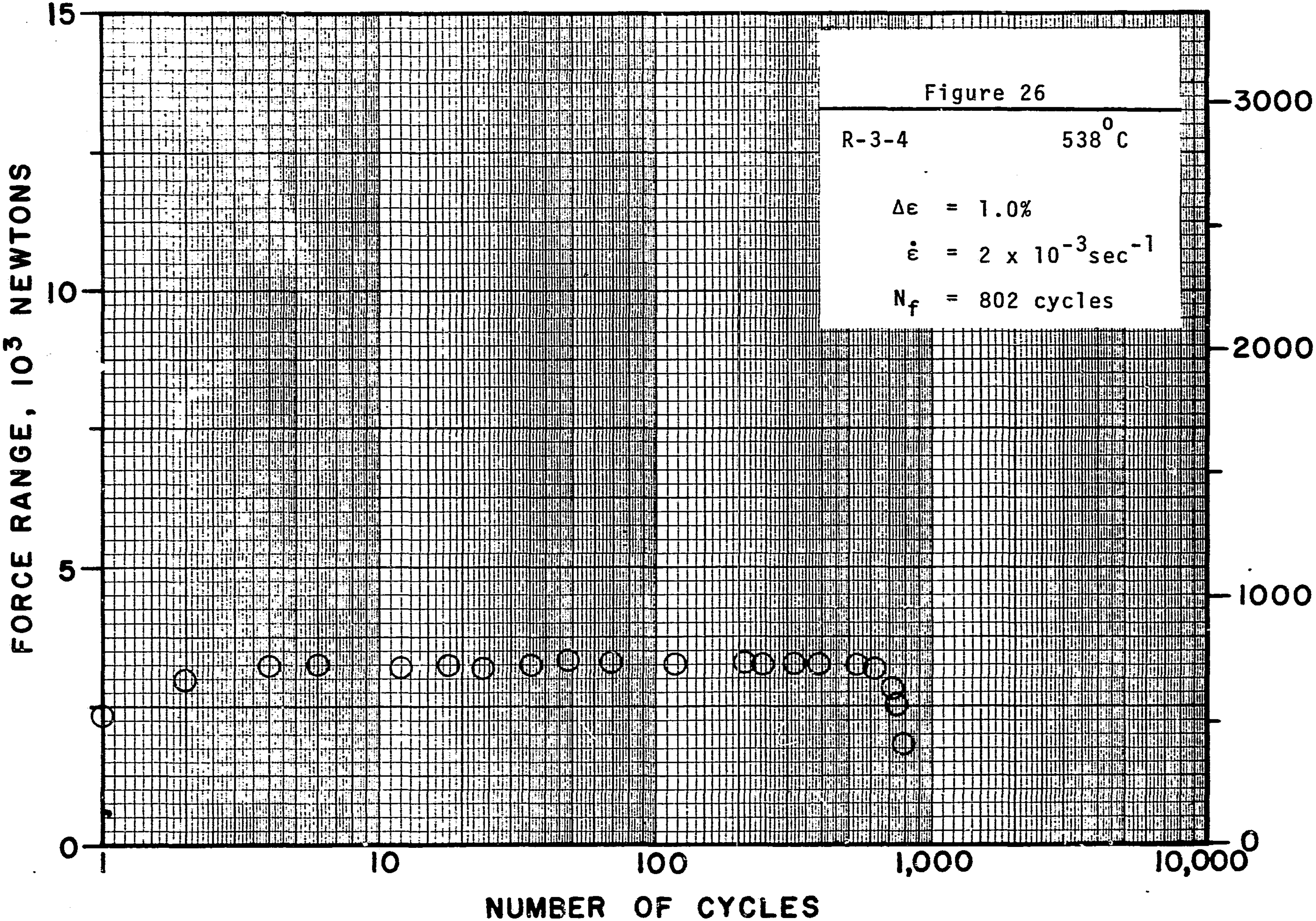


Figure 26
R-3-4
538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 802 cycles
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.

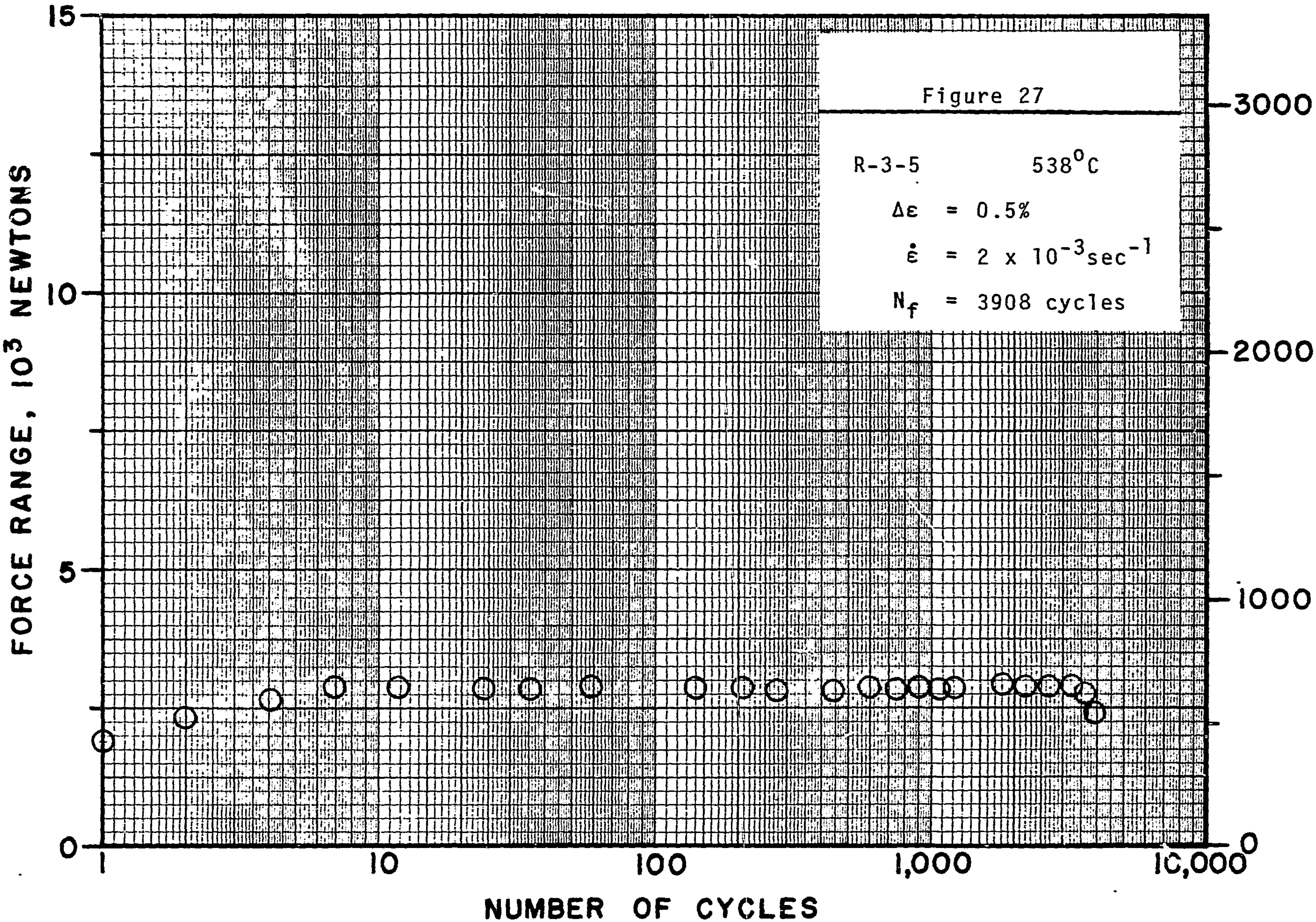


Figure 27
R-3-5 538°C
Δε = 0.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3908 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

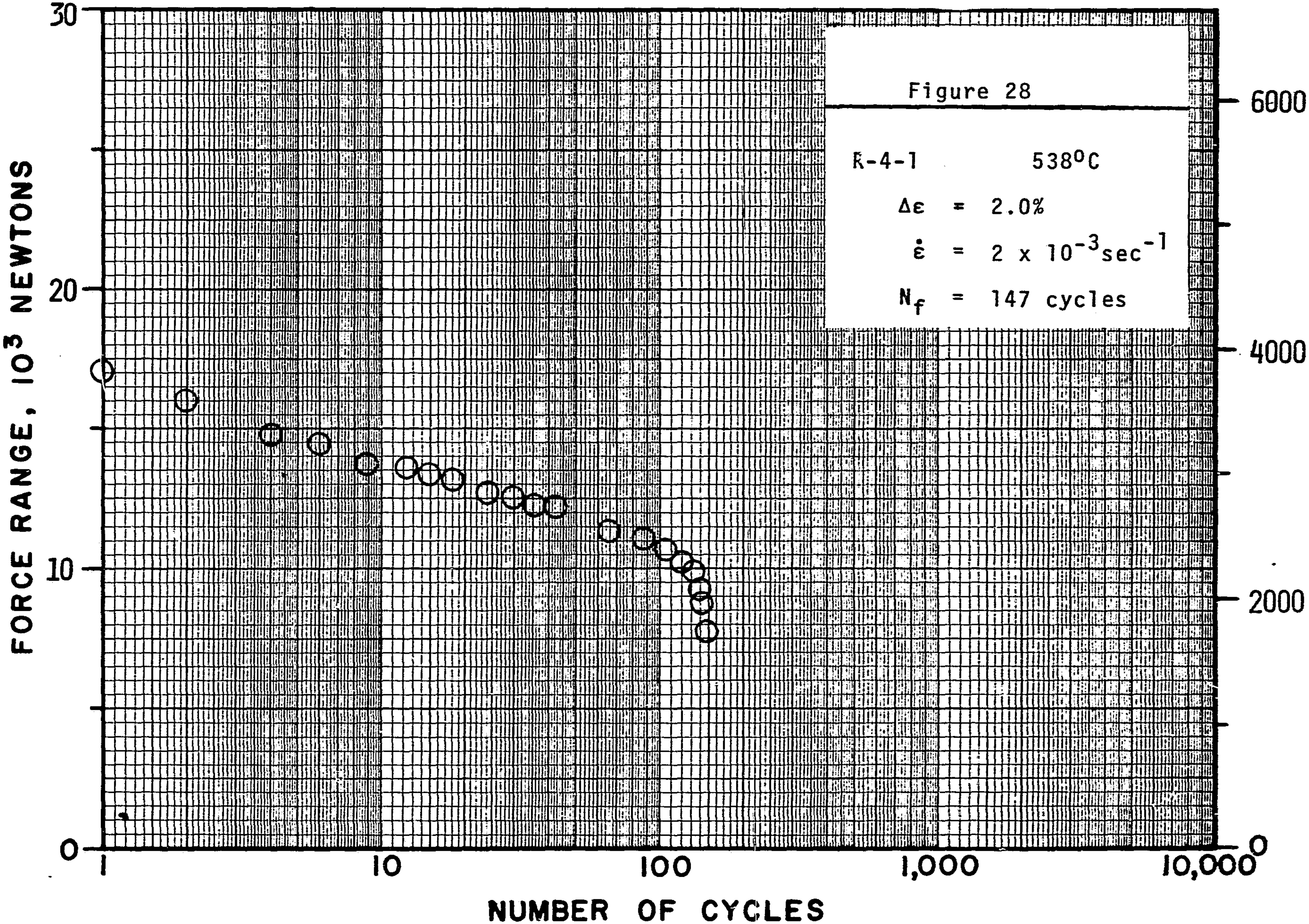


Figure 28
R-4-1 538°C
Δε = 2.0%
ε̇ = 2 x 10-3sec-1
Nf = 147 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
30
20
10
0
6000
4000
2000
0
1
10
100
1,000
10,000

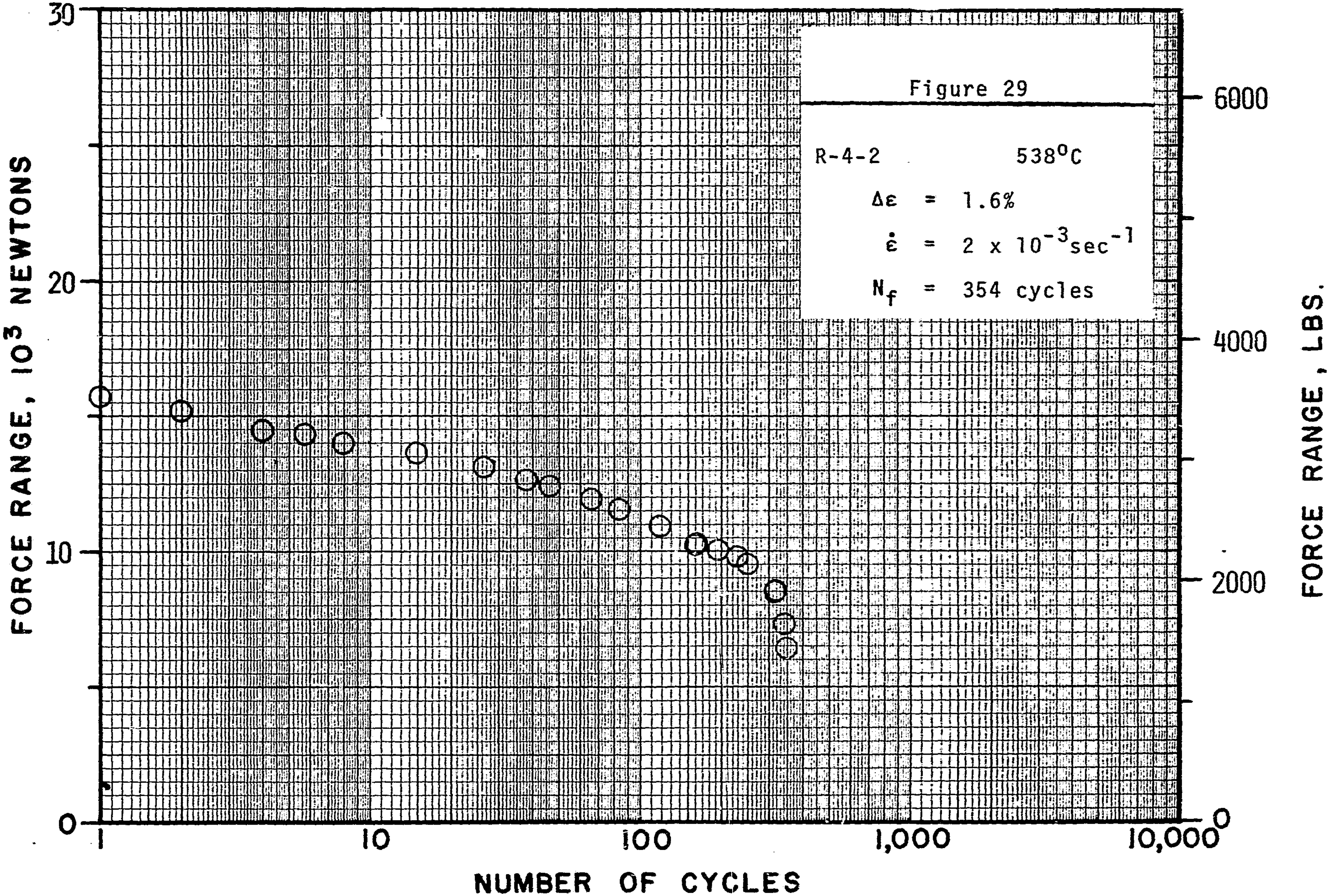


Figure 29
R-4-2 538°C
Δε = 1.6%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 354 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000

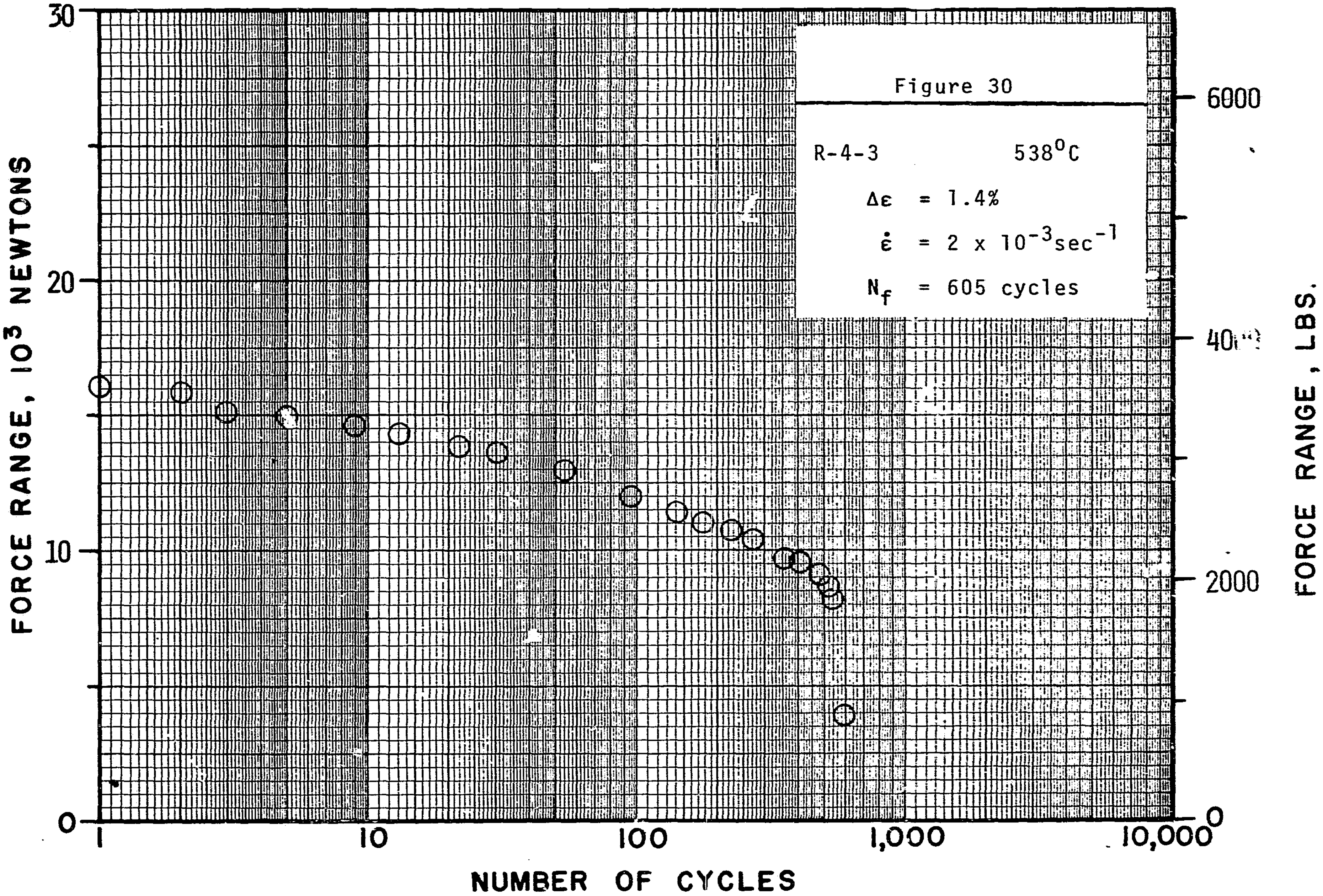


Figure 30
R-4-3
538^0C
$\Delta\varepsilon$ = 1.4%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 605 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
6000

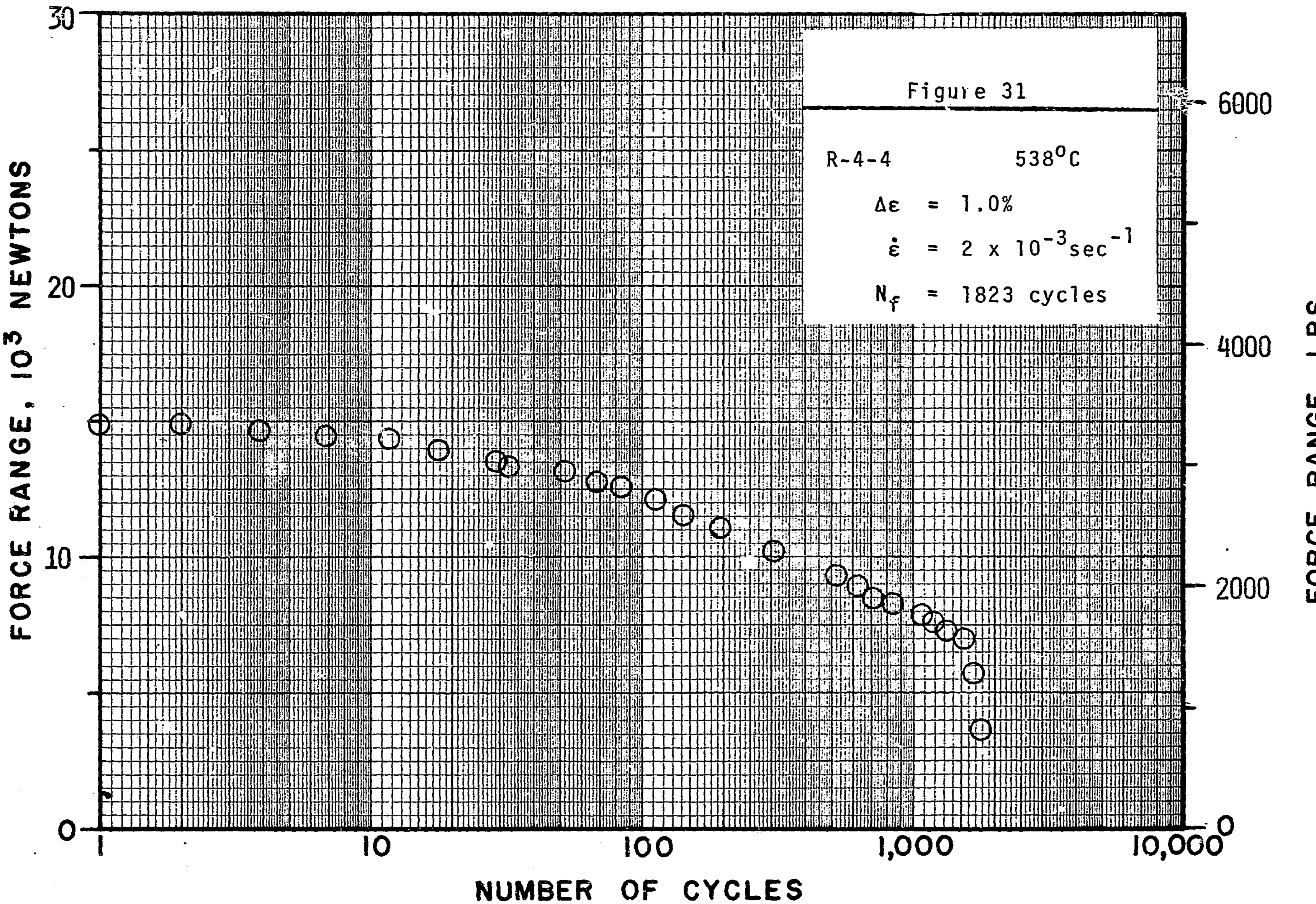


Figure 31
R-4-4 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1823 cycles
30
20
10
0
FORCE RANGE, 10³ NEWTONS
6000
4000
2000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

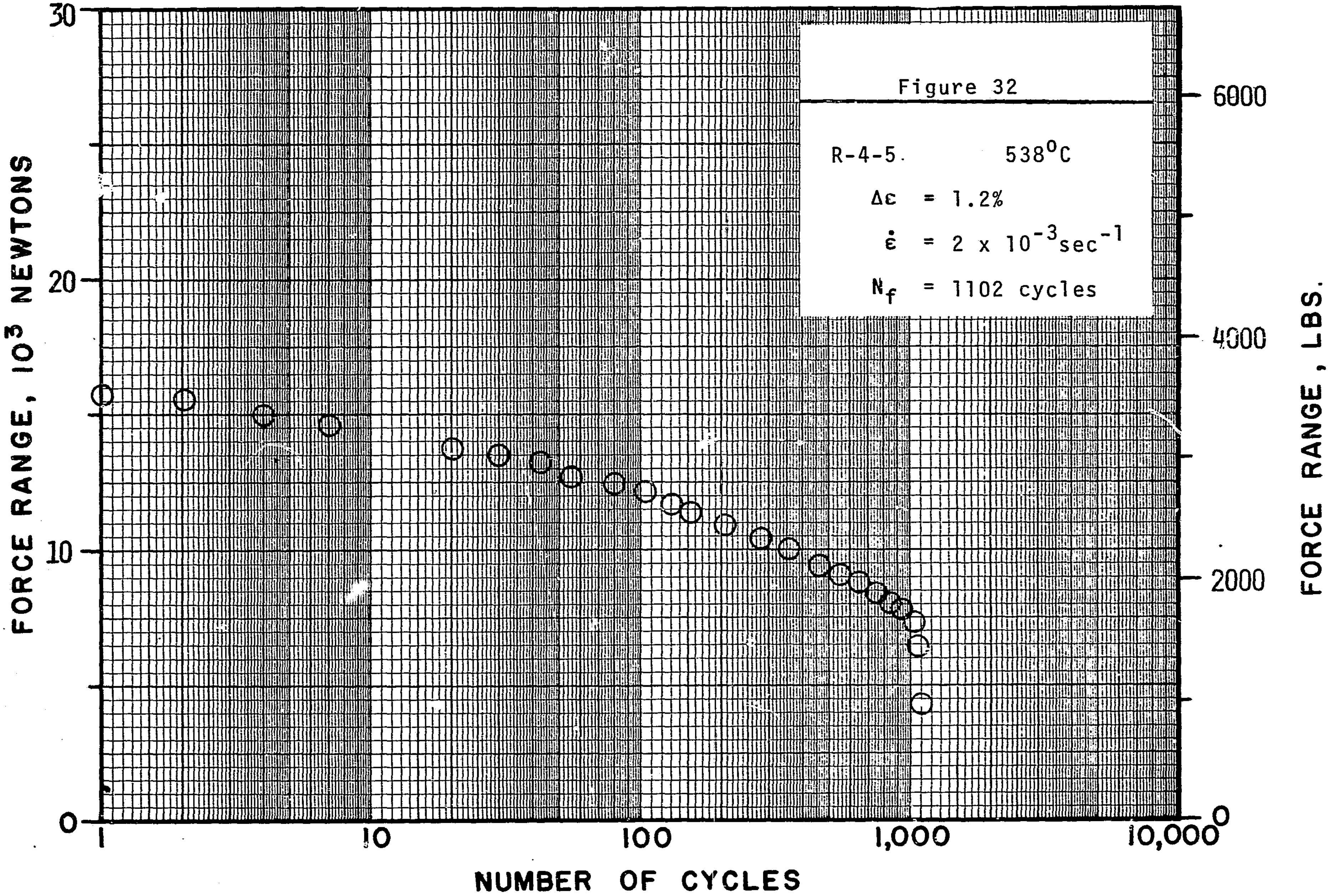


Figure 32
R-4-5 538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1102 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

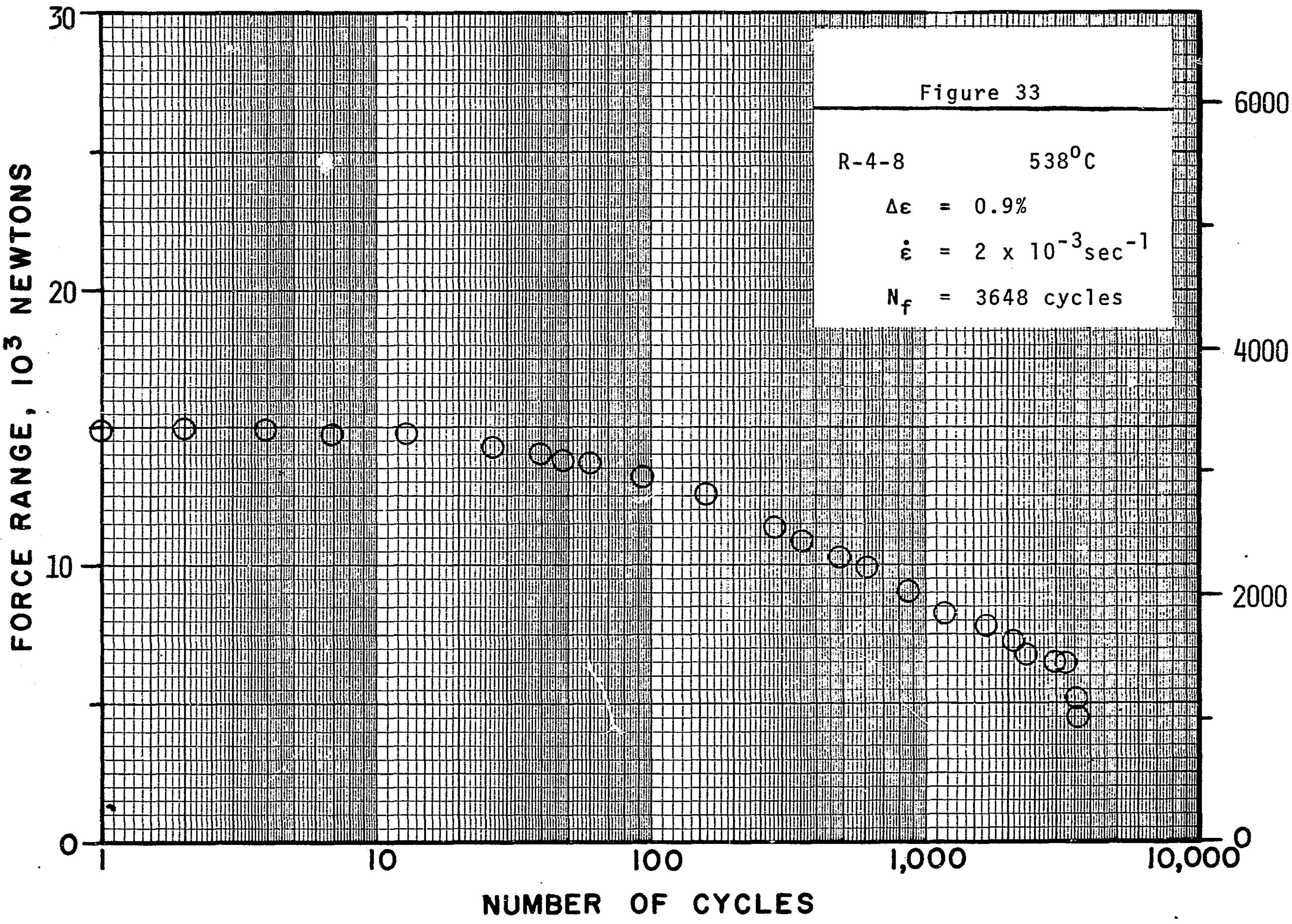


Figure 33
R-4-8 538°C
Δε = 0.9%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 3648 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

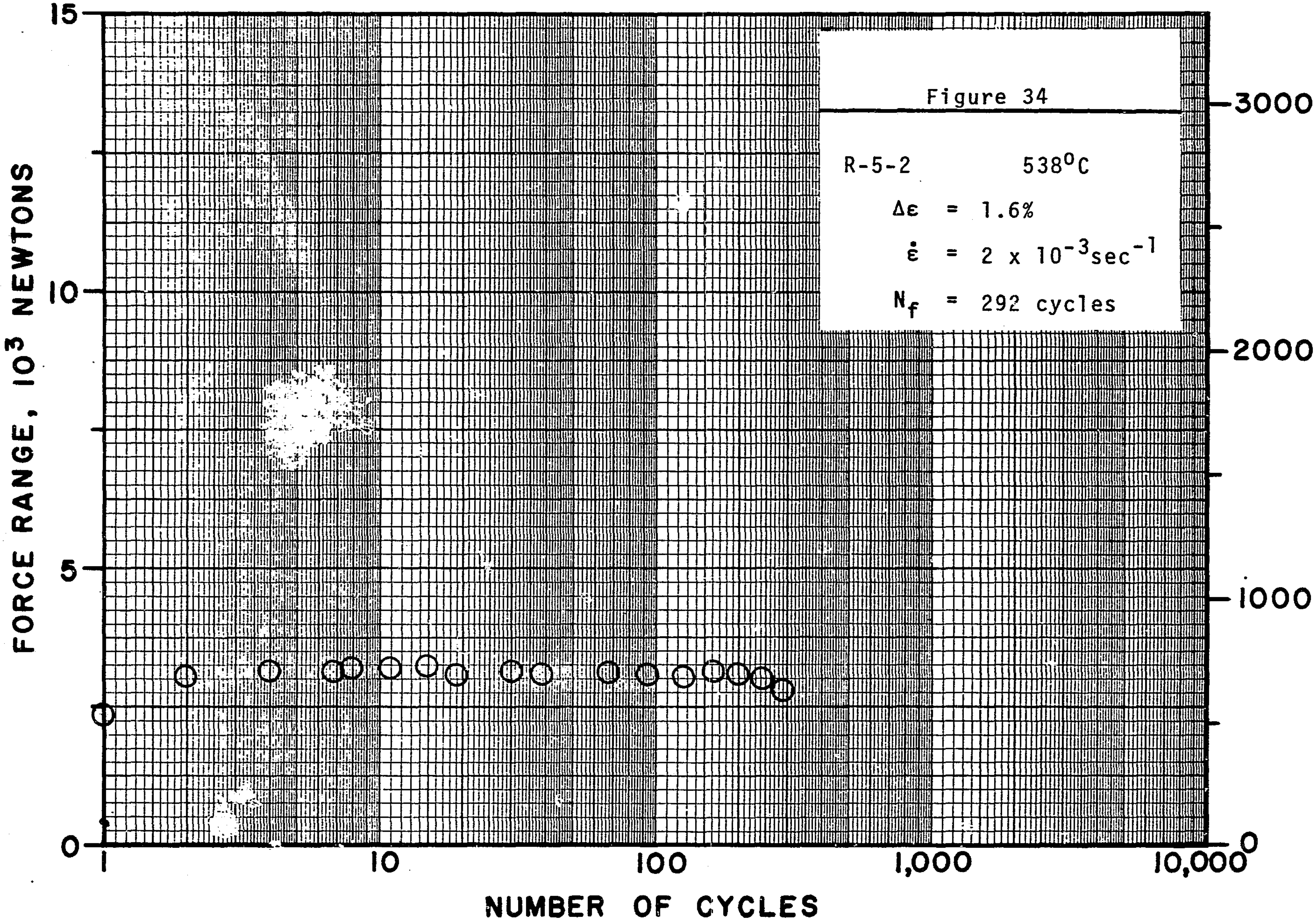


Figure 34
R-5-2 538°C
Δε = 1.6%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 292 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

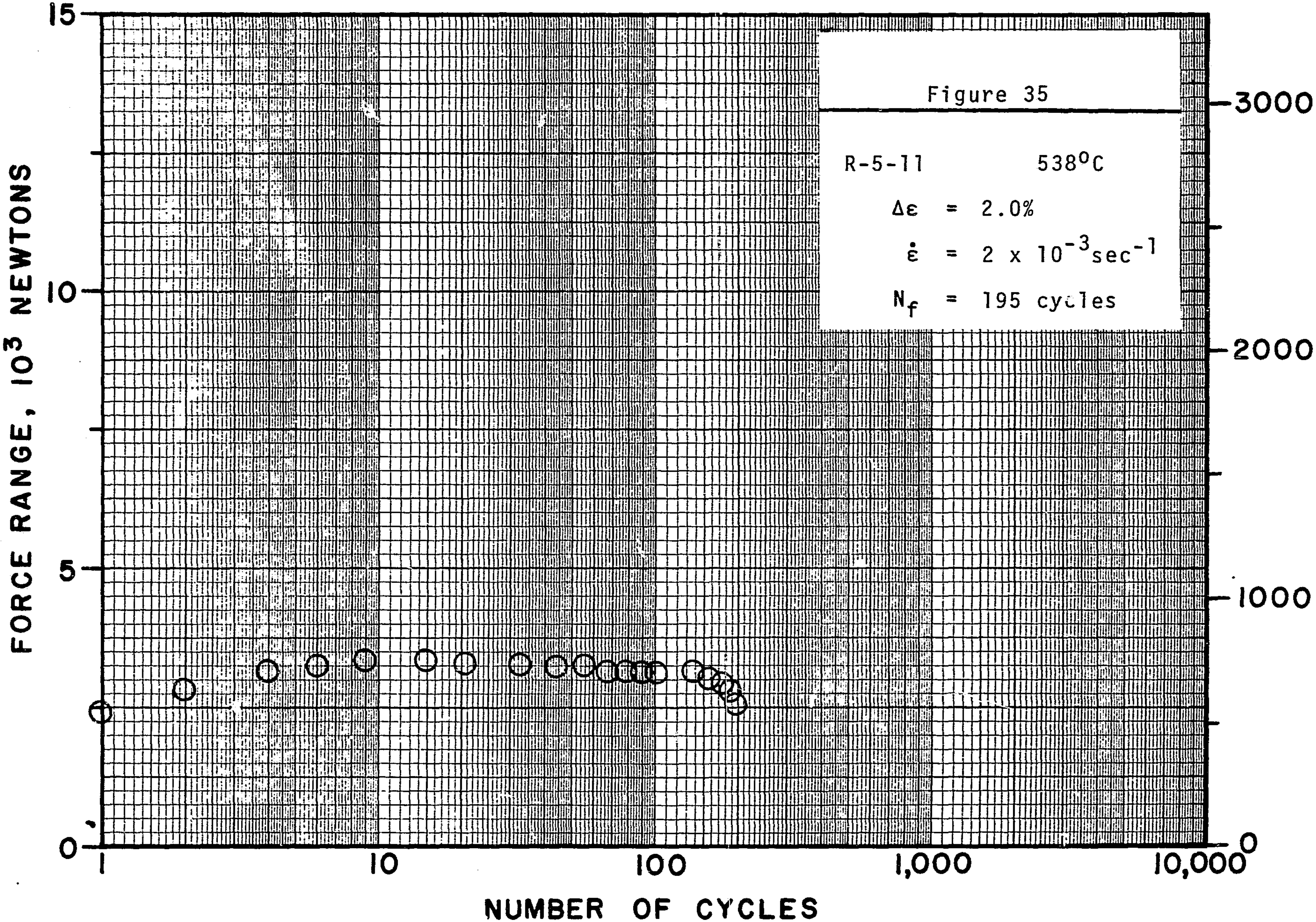


Figure 35
R-5-11 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 195 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

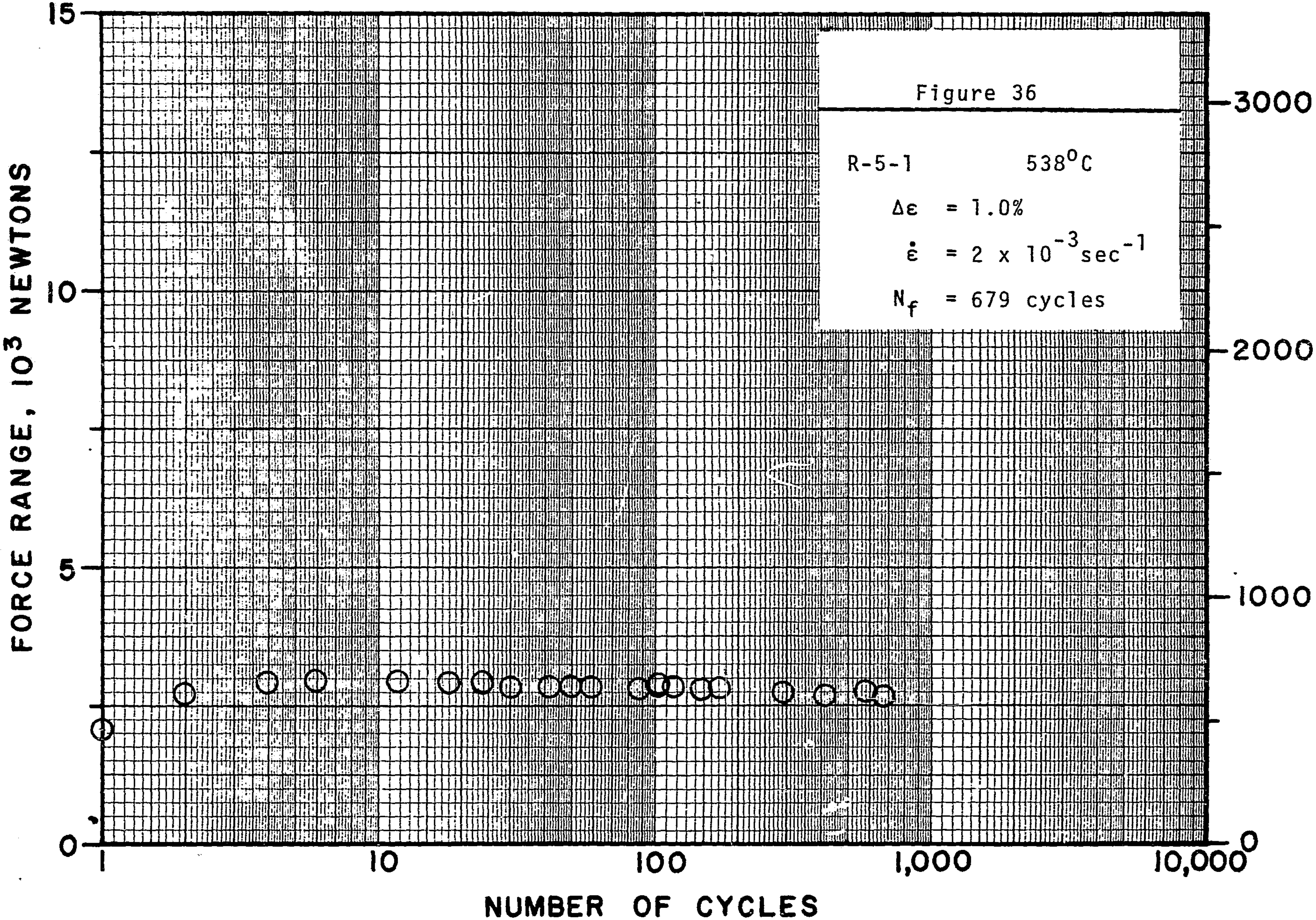


Figure 36
R-5-1 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 679 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

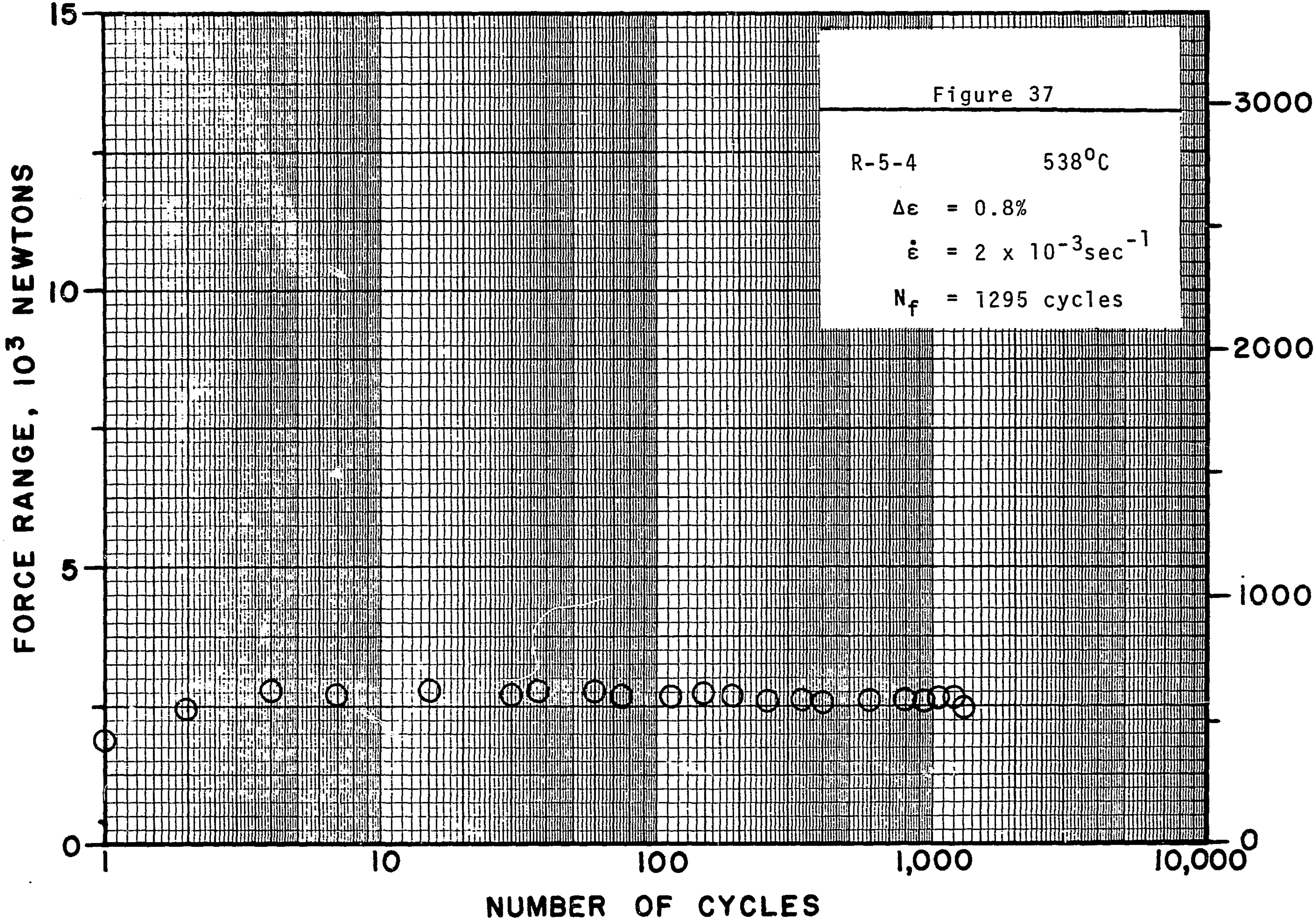


Figure 37
R-5-4 538°C
Δε = 0.8%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1295 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

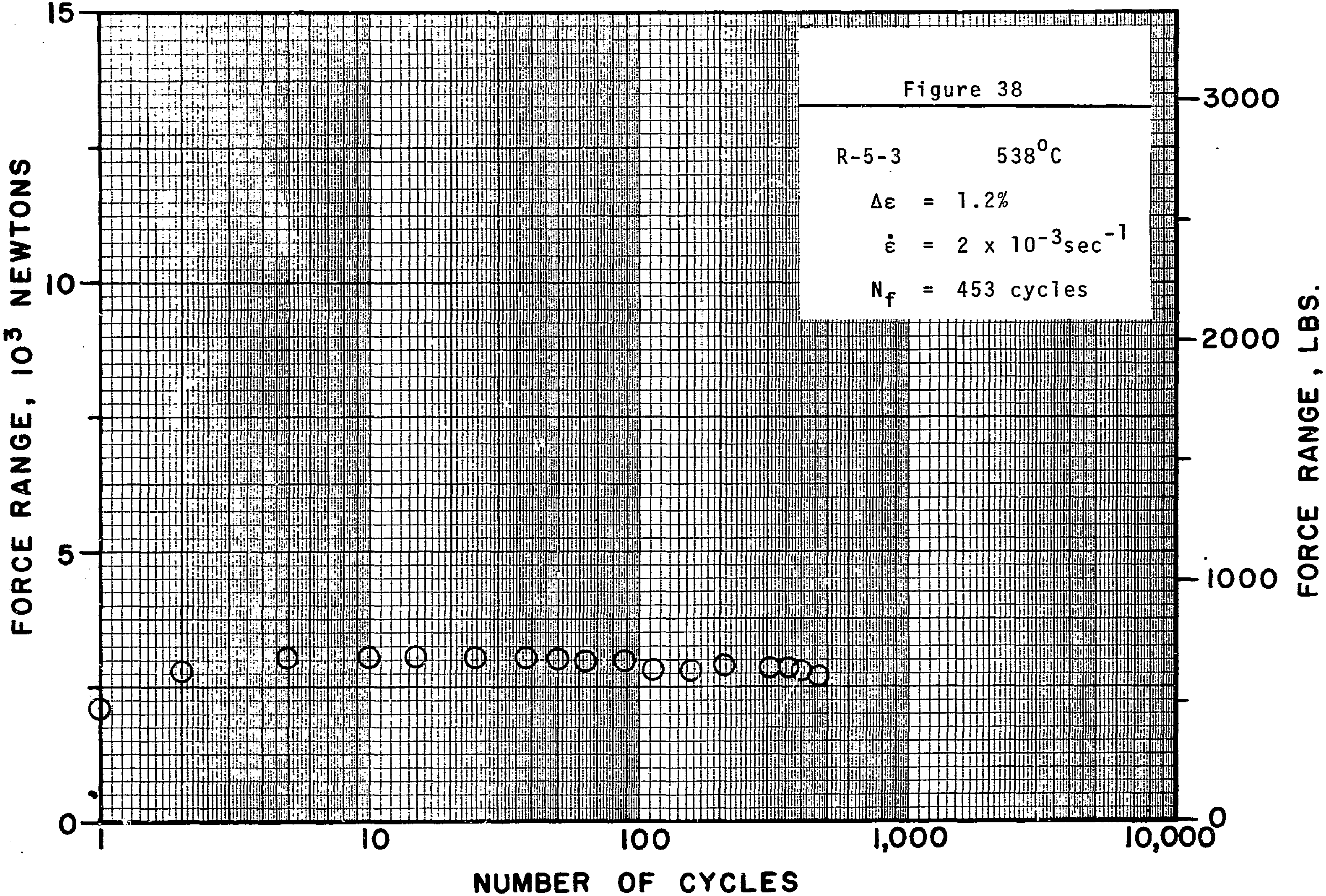


Figure 38
R-5-3 538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 453 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

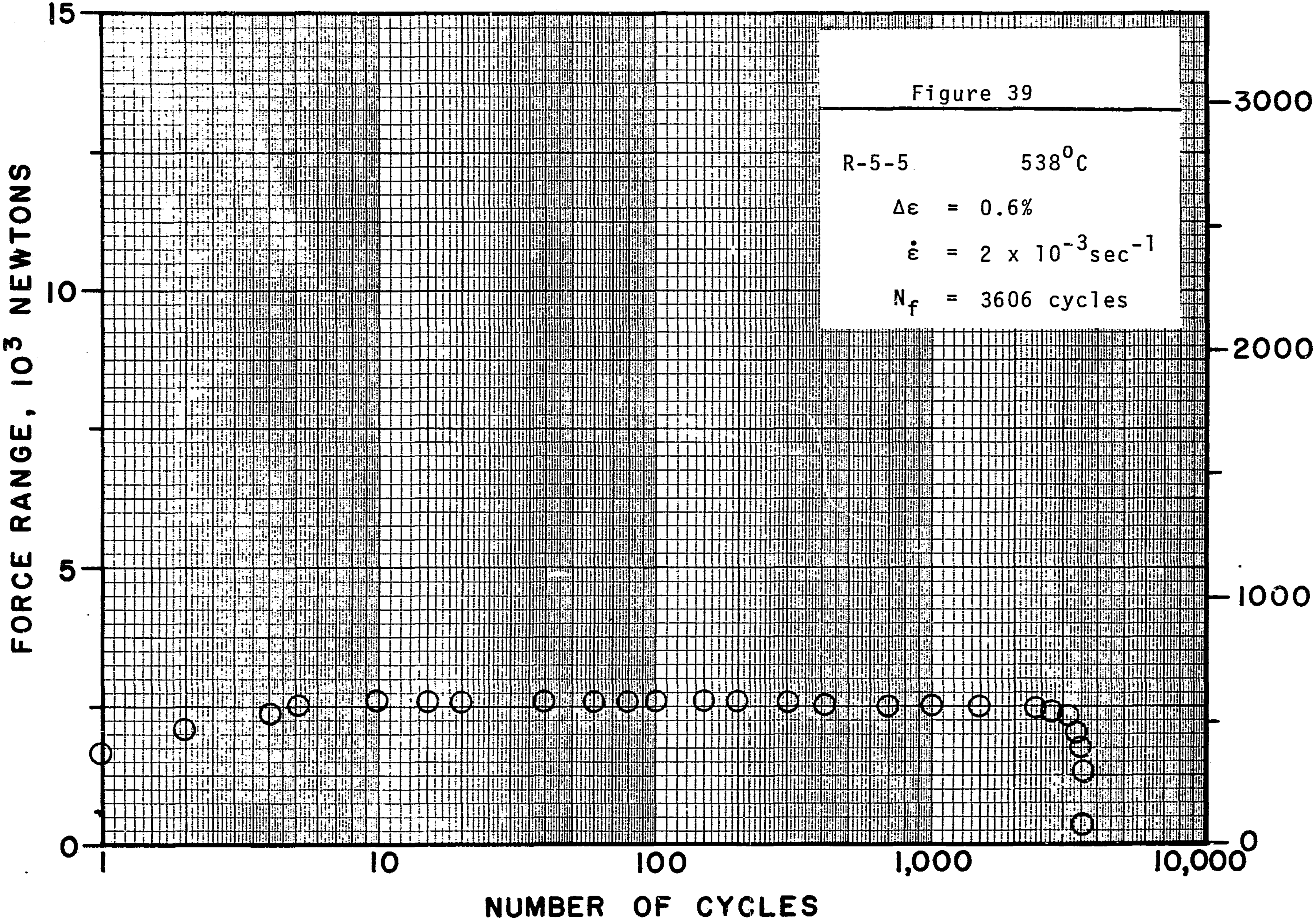


Figure 39
R-5-5 538°C
Δε = 0.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3606 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

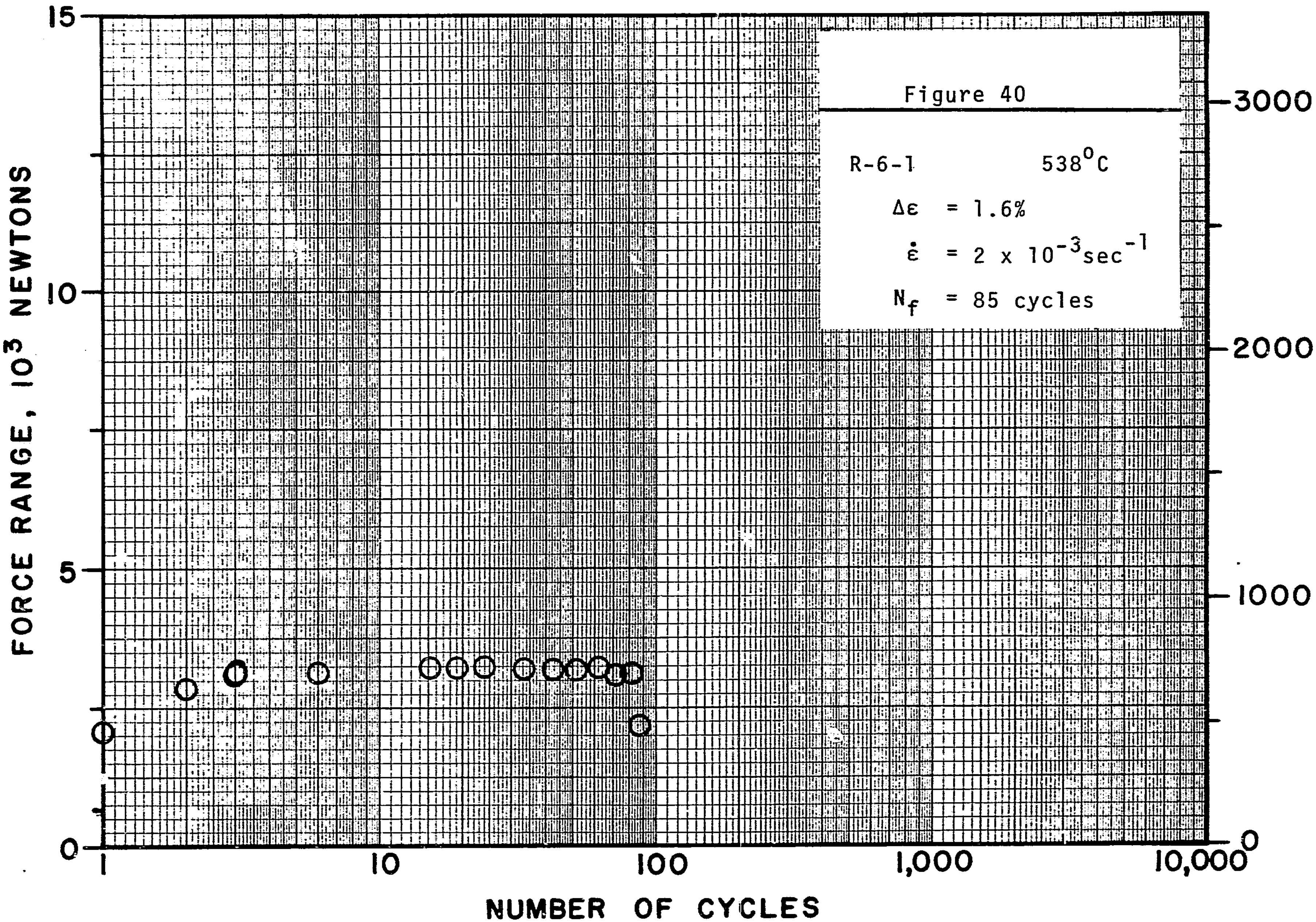


Figure 40
R-6-1 538°C
Δε = 1.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 85 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

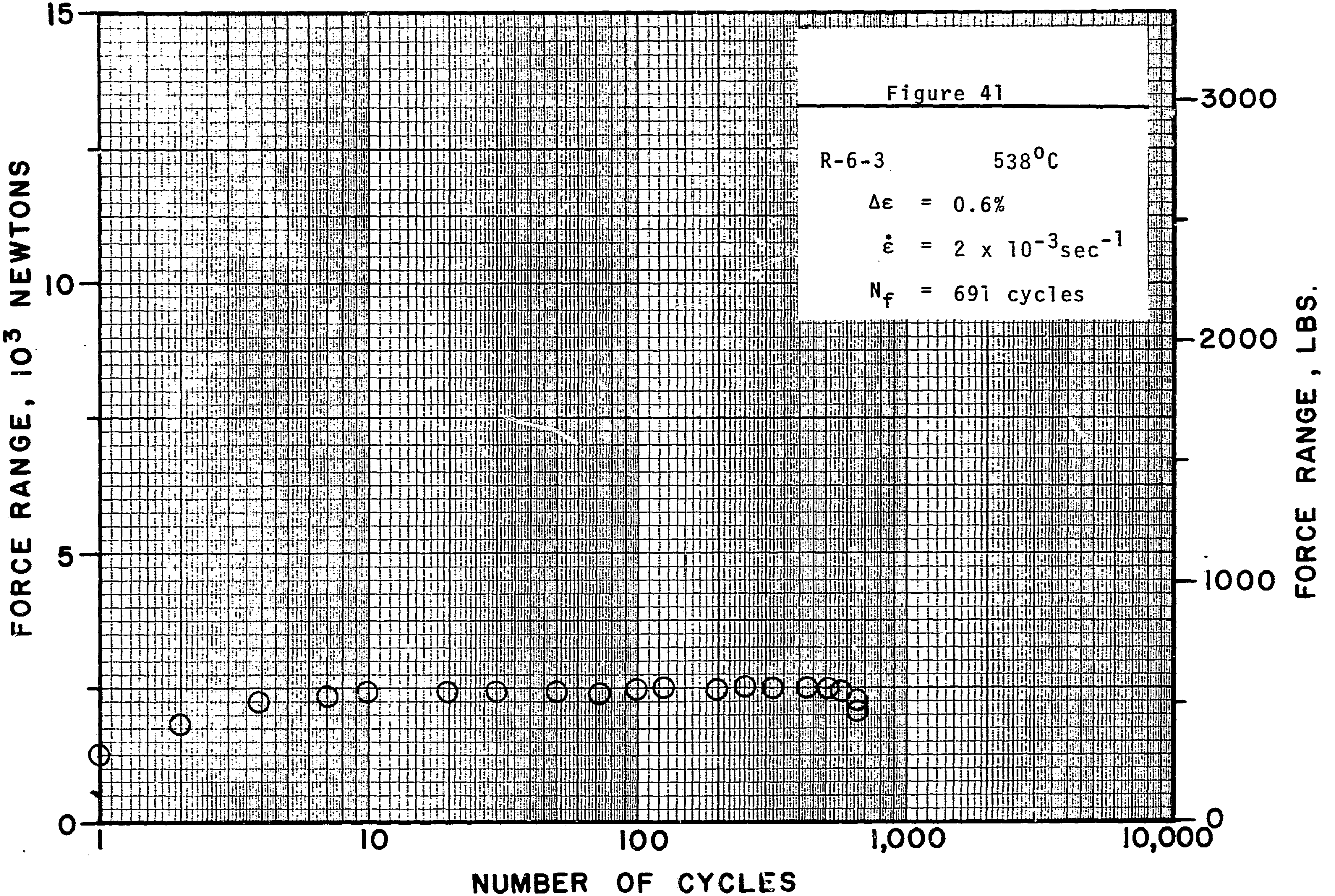

R-6-3 538°C
Δε = 0.6%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 691 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 41

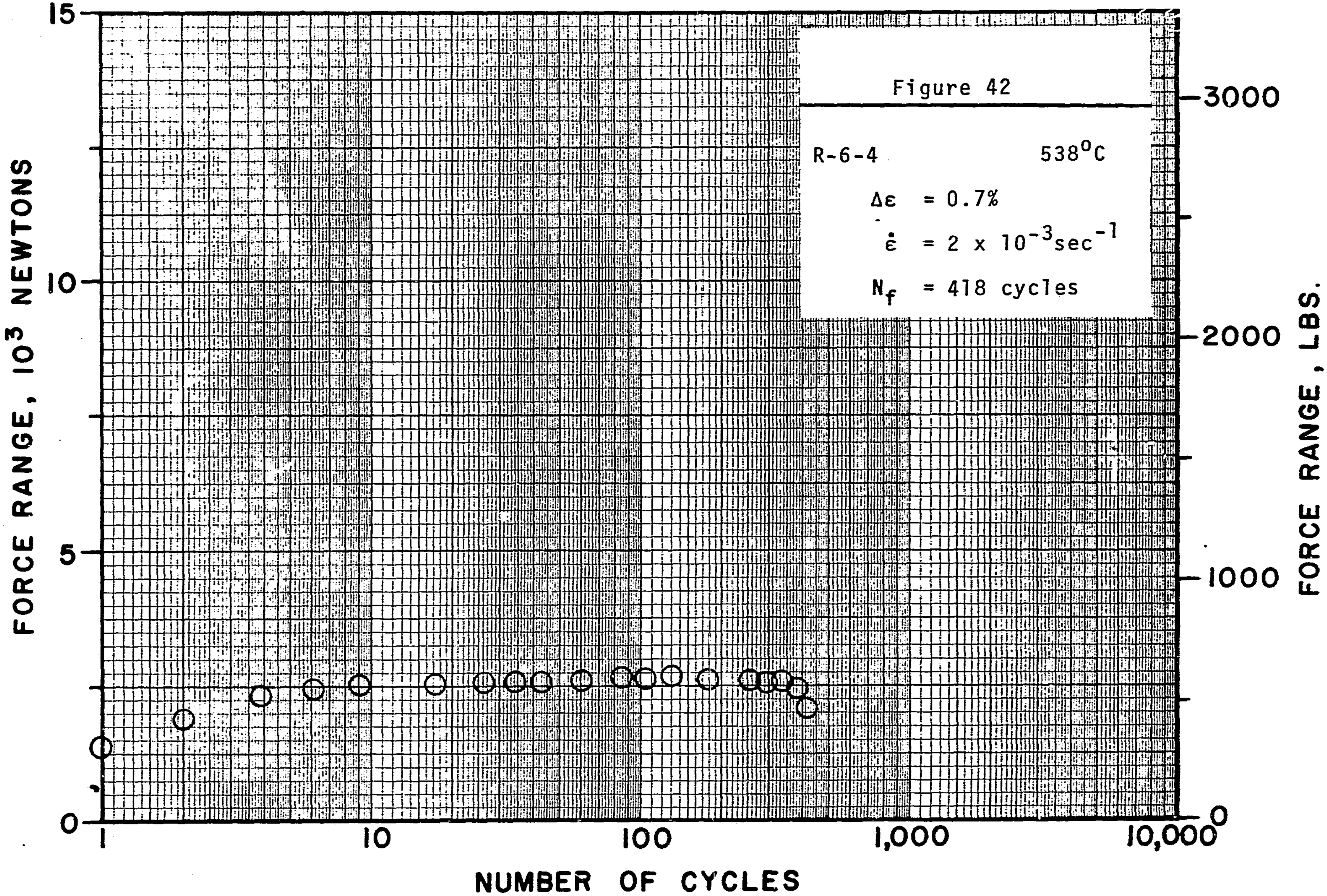


Figure 42
R-6-4
538°C
Δε = 0.7%
ε̇ = 2 x 10^-3 sec^-1
N_f = 418 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

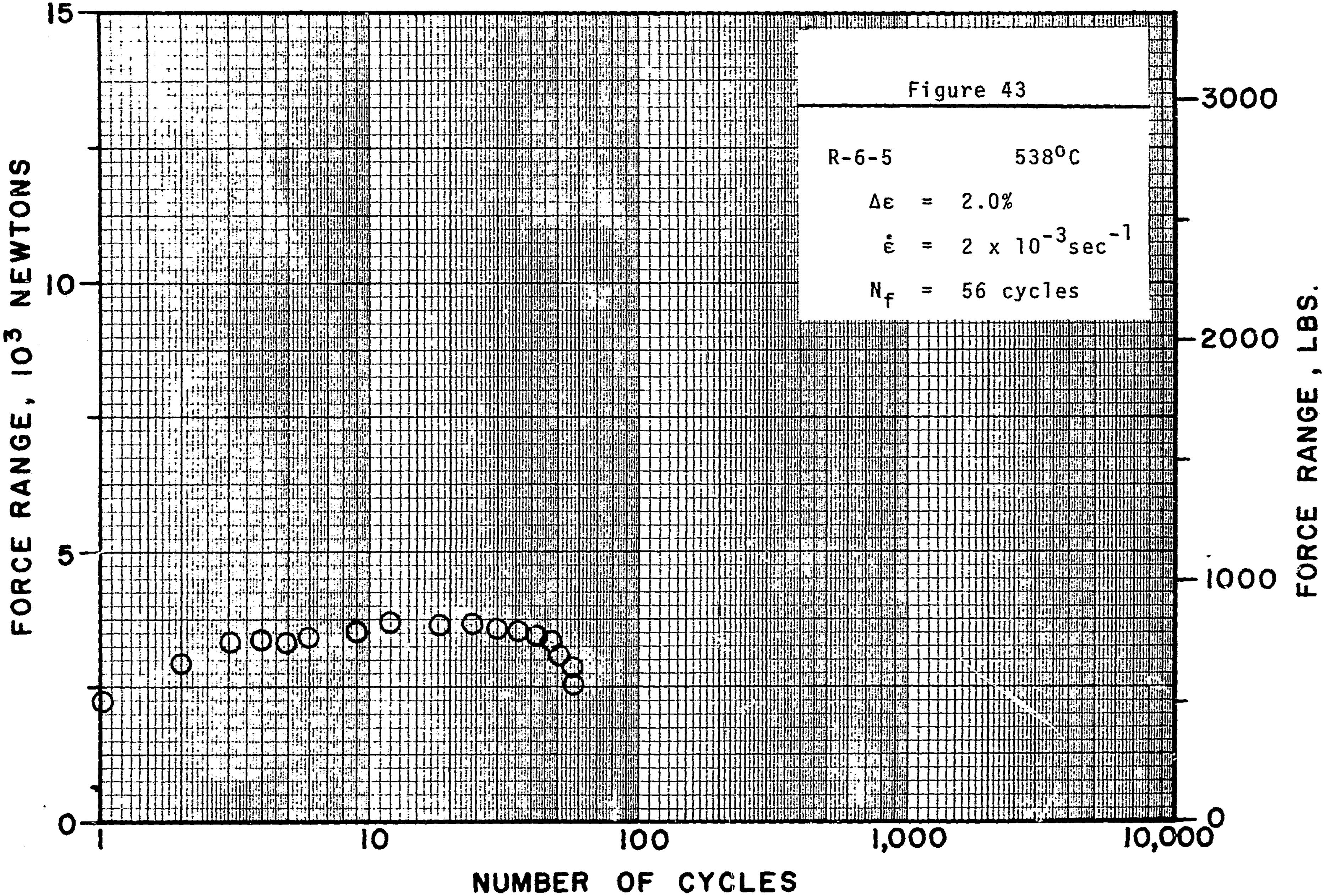

R-6-5 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 56 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 43

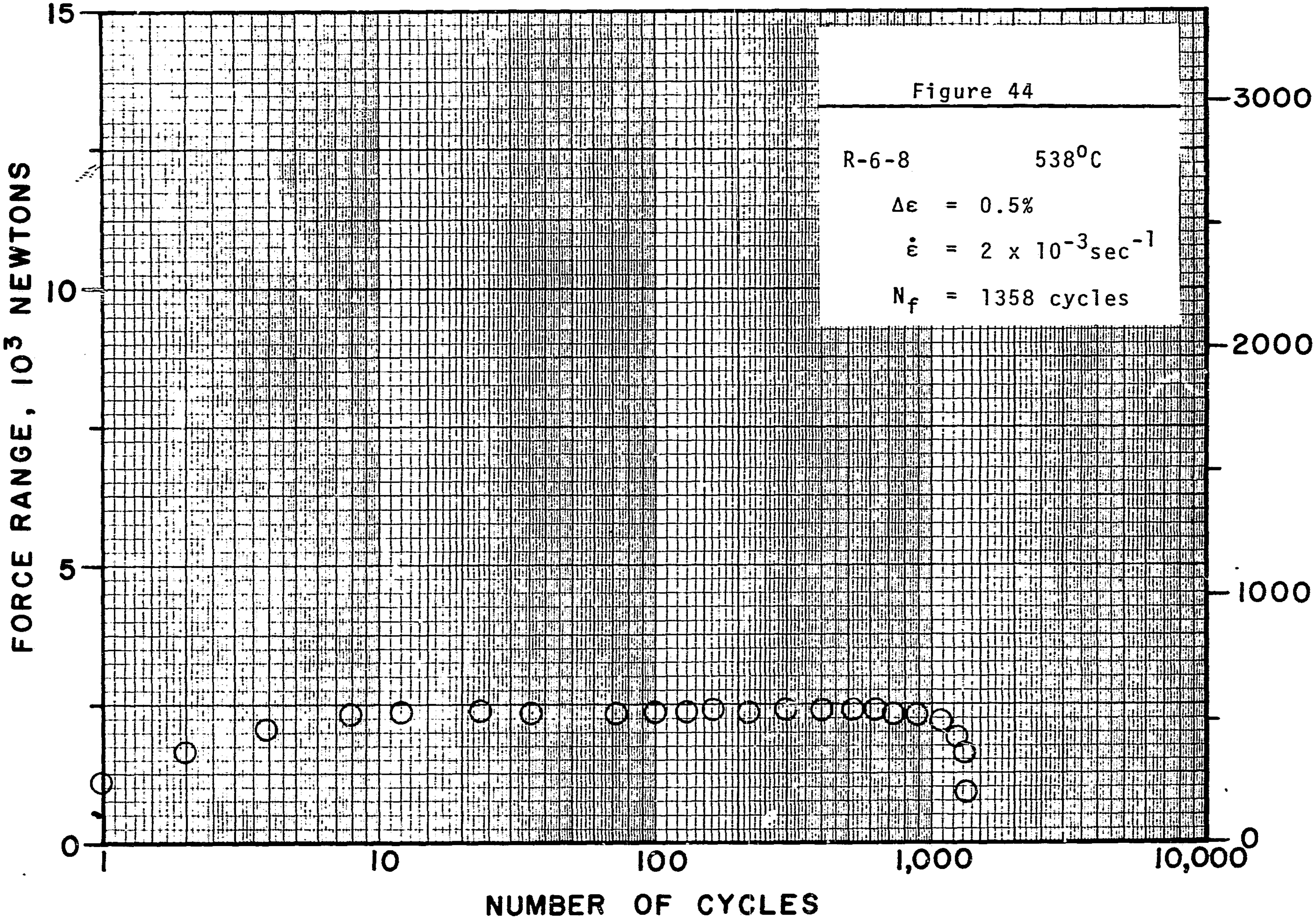

R-6-8 538°C
Δε = 0.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1358 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 44

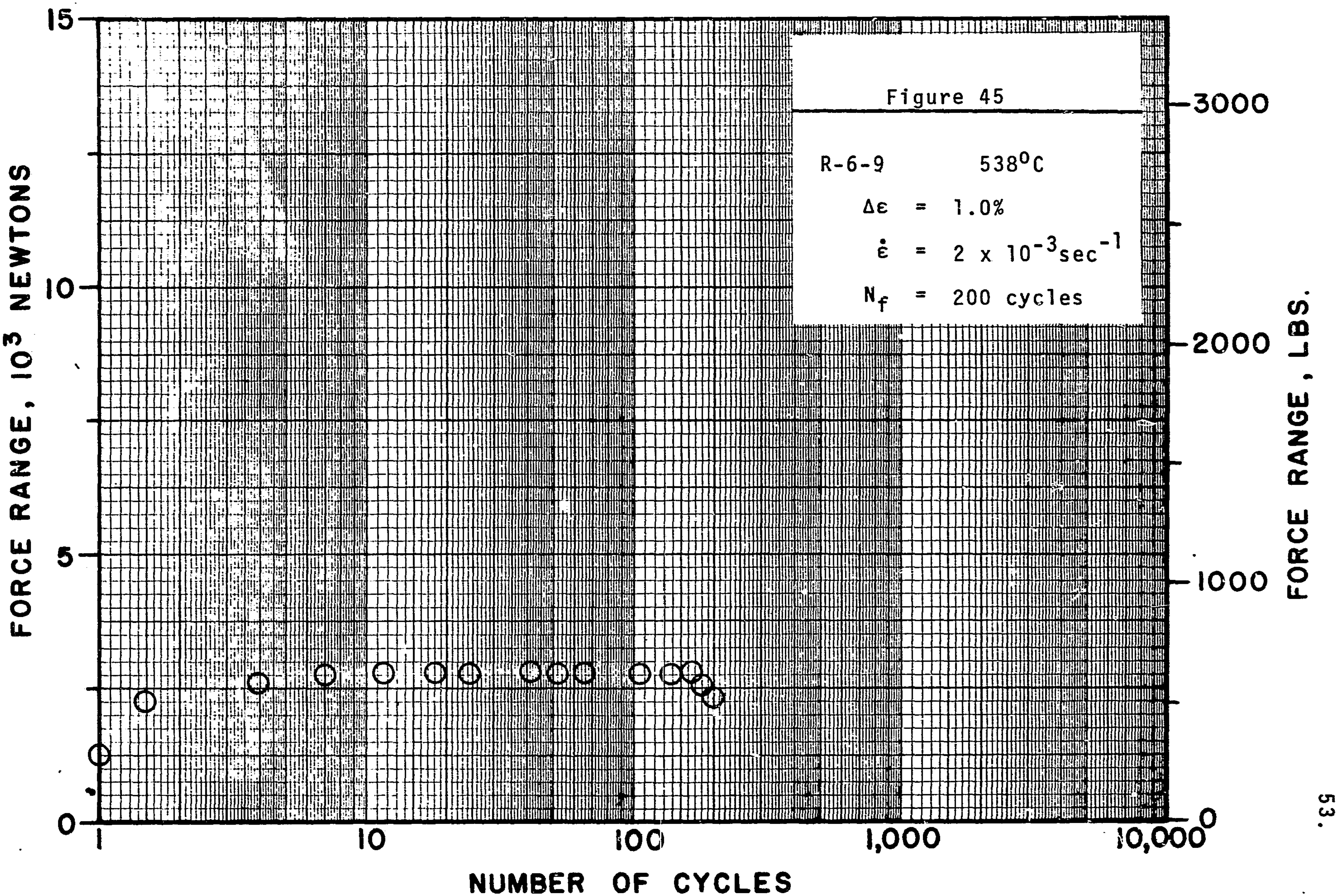


Figure 45
R-6-9 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 200 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

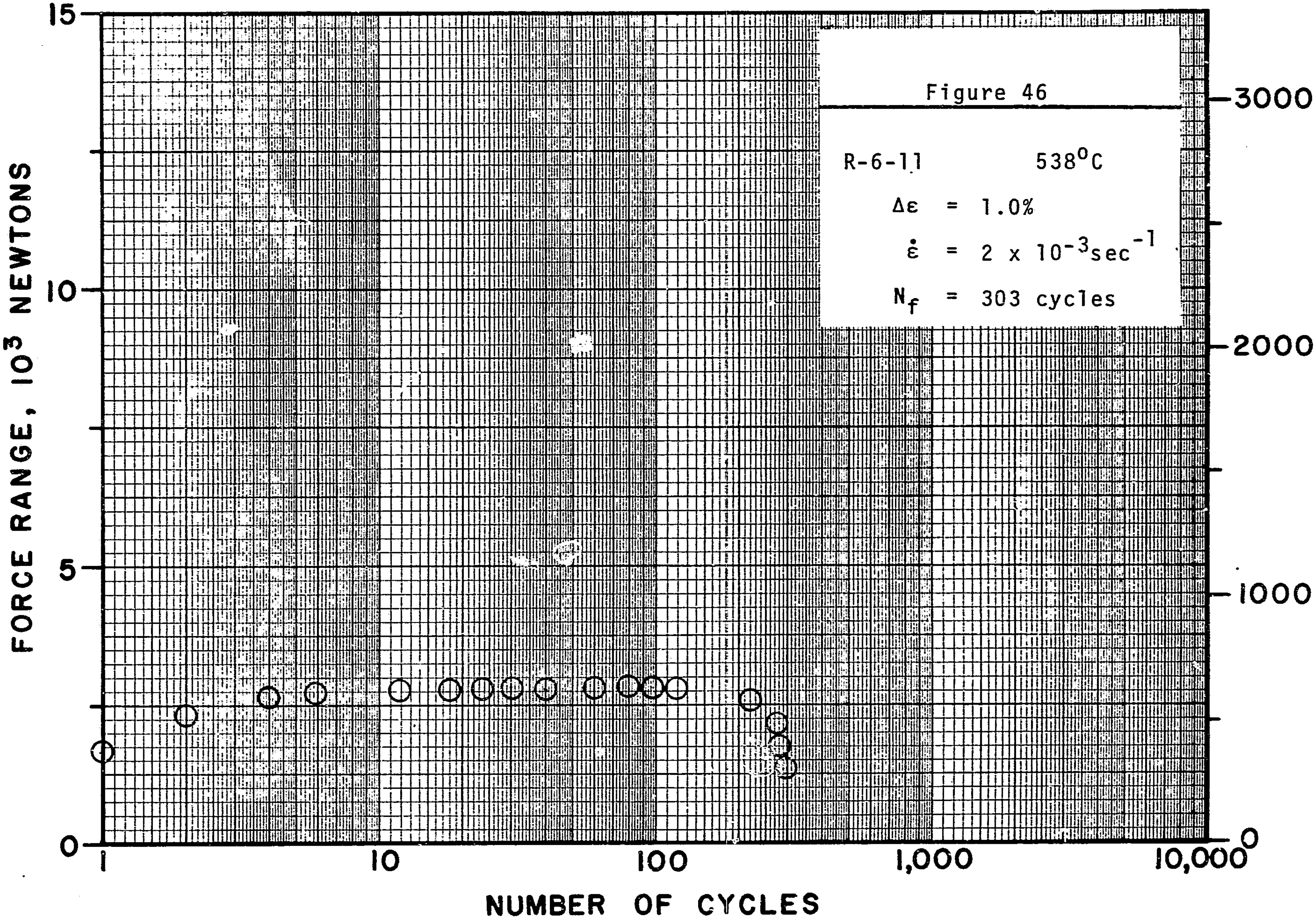


Figure 46
R-6-11 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 303 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

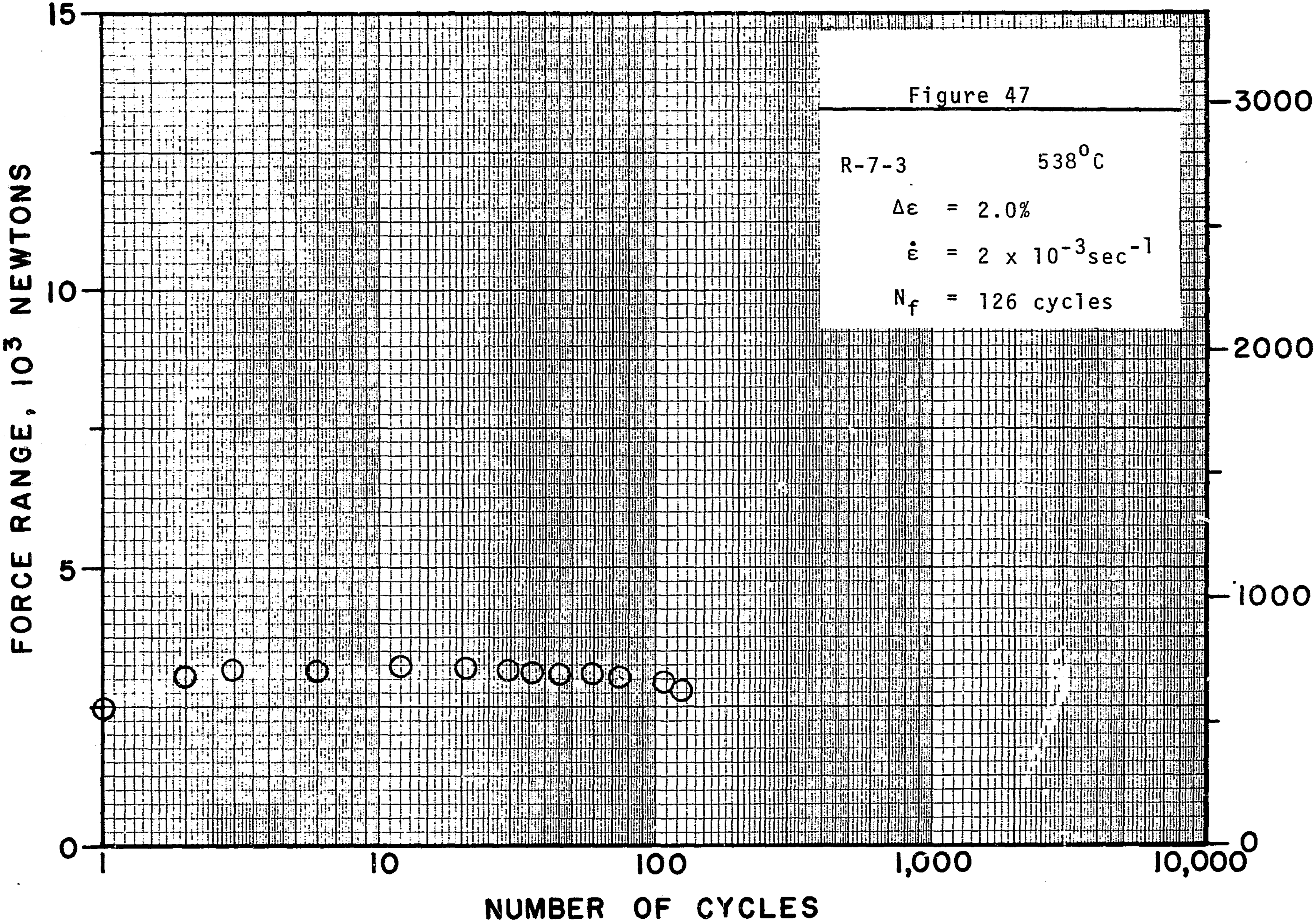


Figure 47
R-7-3
538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 126 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

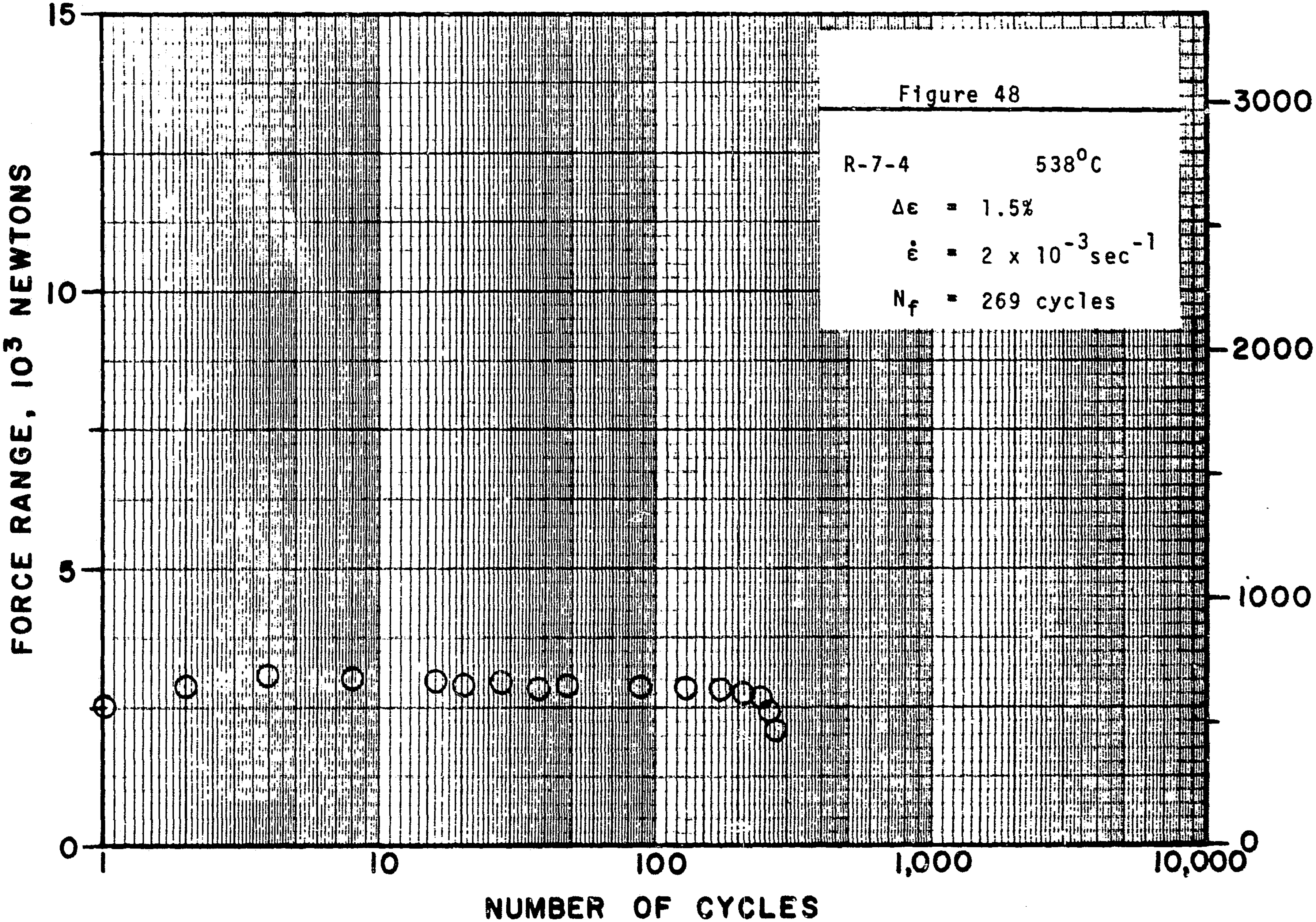


Figure 48
R-7-4 538°C
Δε = 1.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 269 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

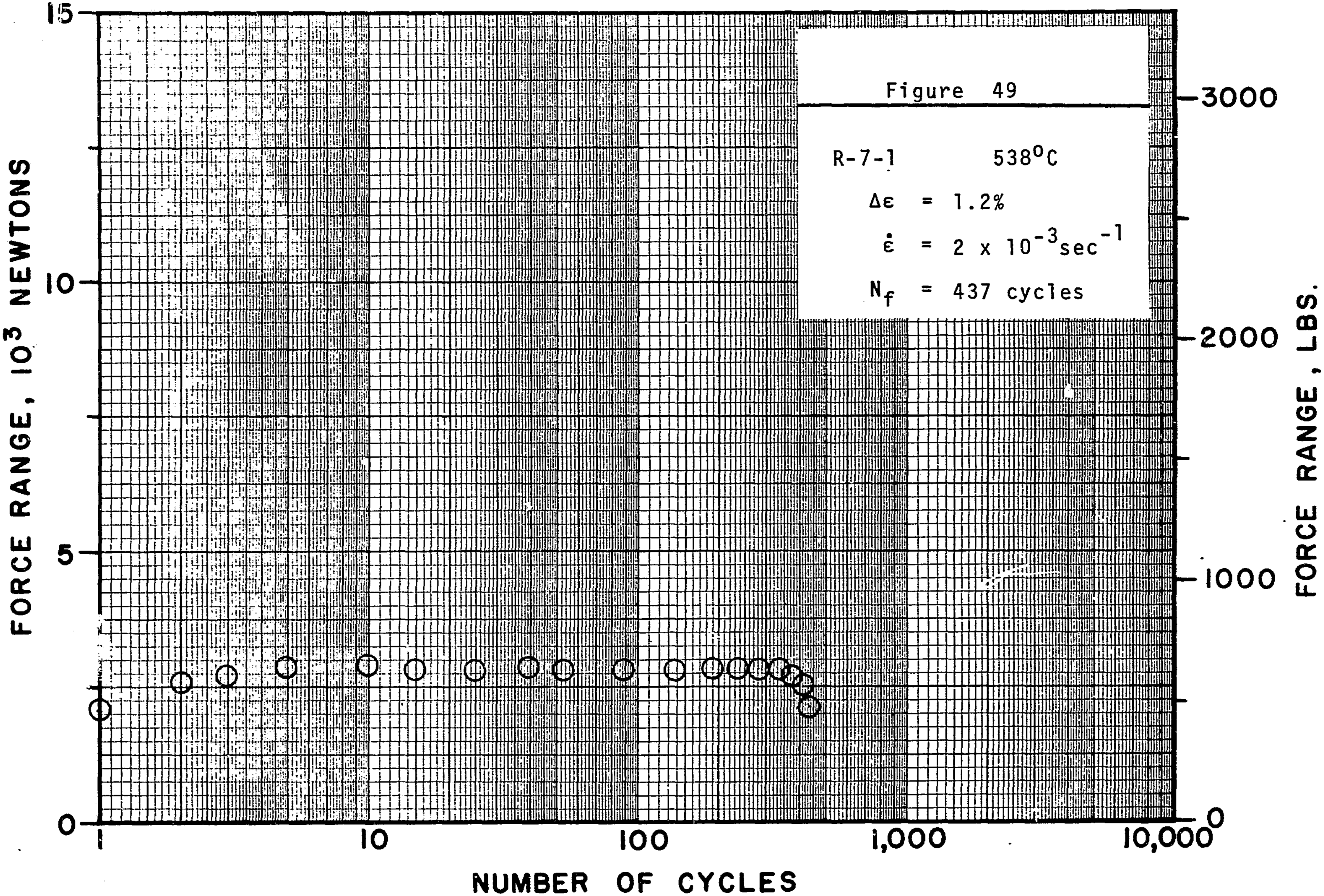


Figure 49
R-7-1 538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 437 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

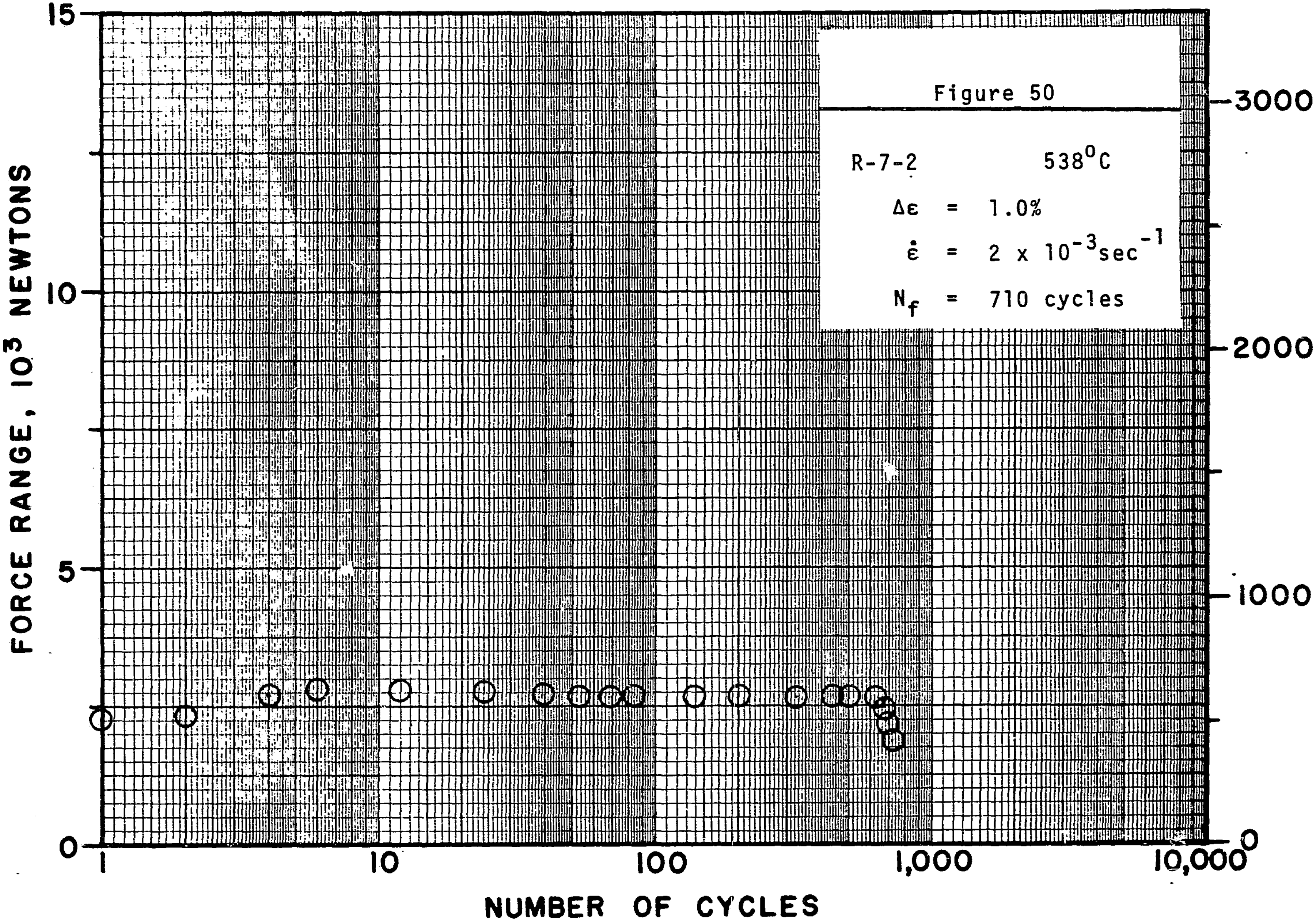


Figure 50
R-7-2 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 710 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

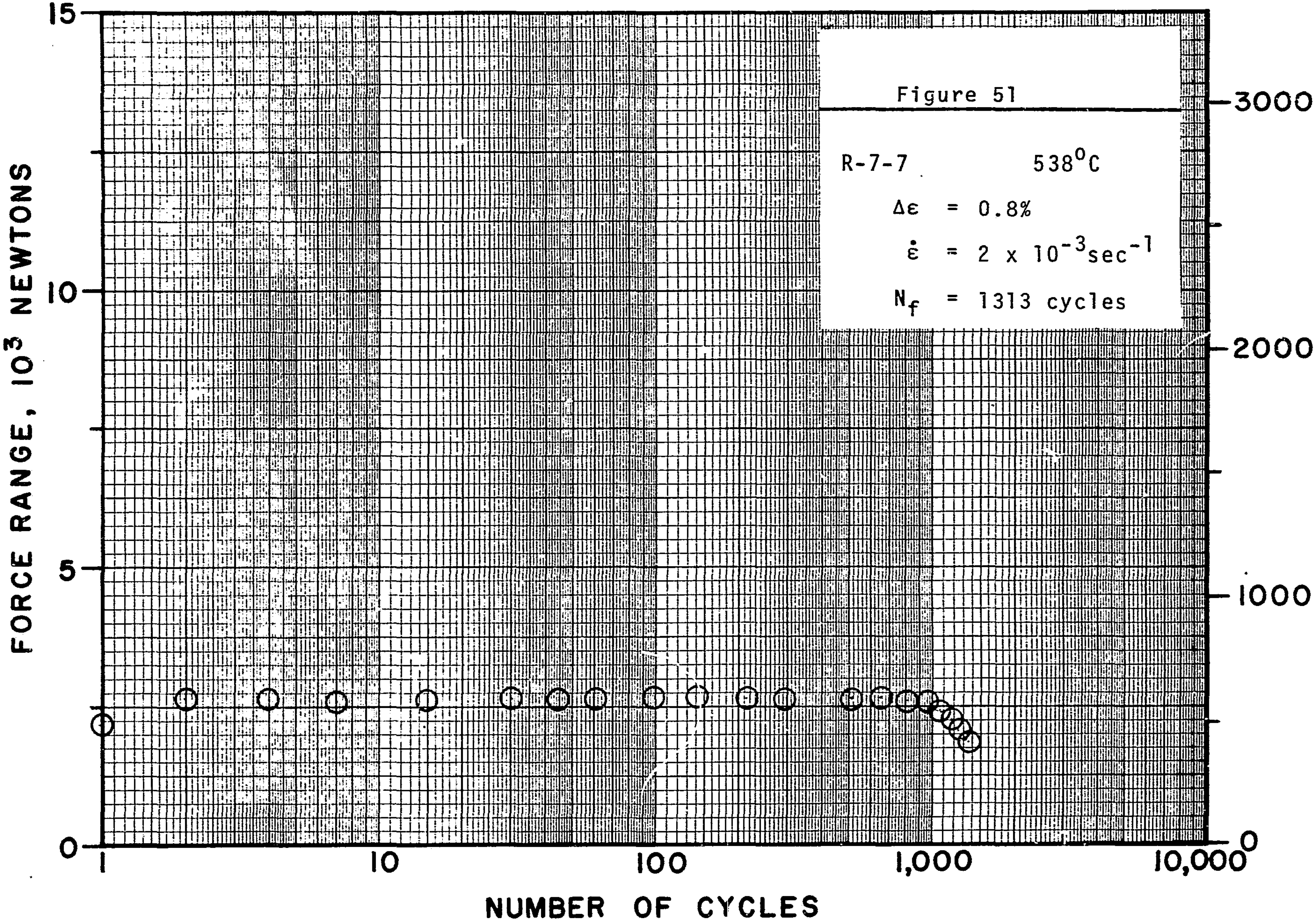

R-7-7 538°C
Δε = 0.8%
ε̇ = 2 x 10⁻³sec⁻¹
Nf = 1313 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 51

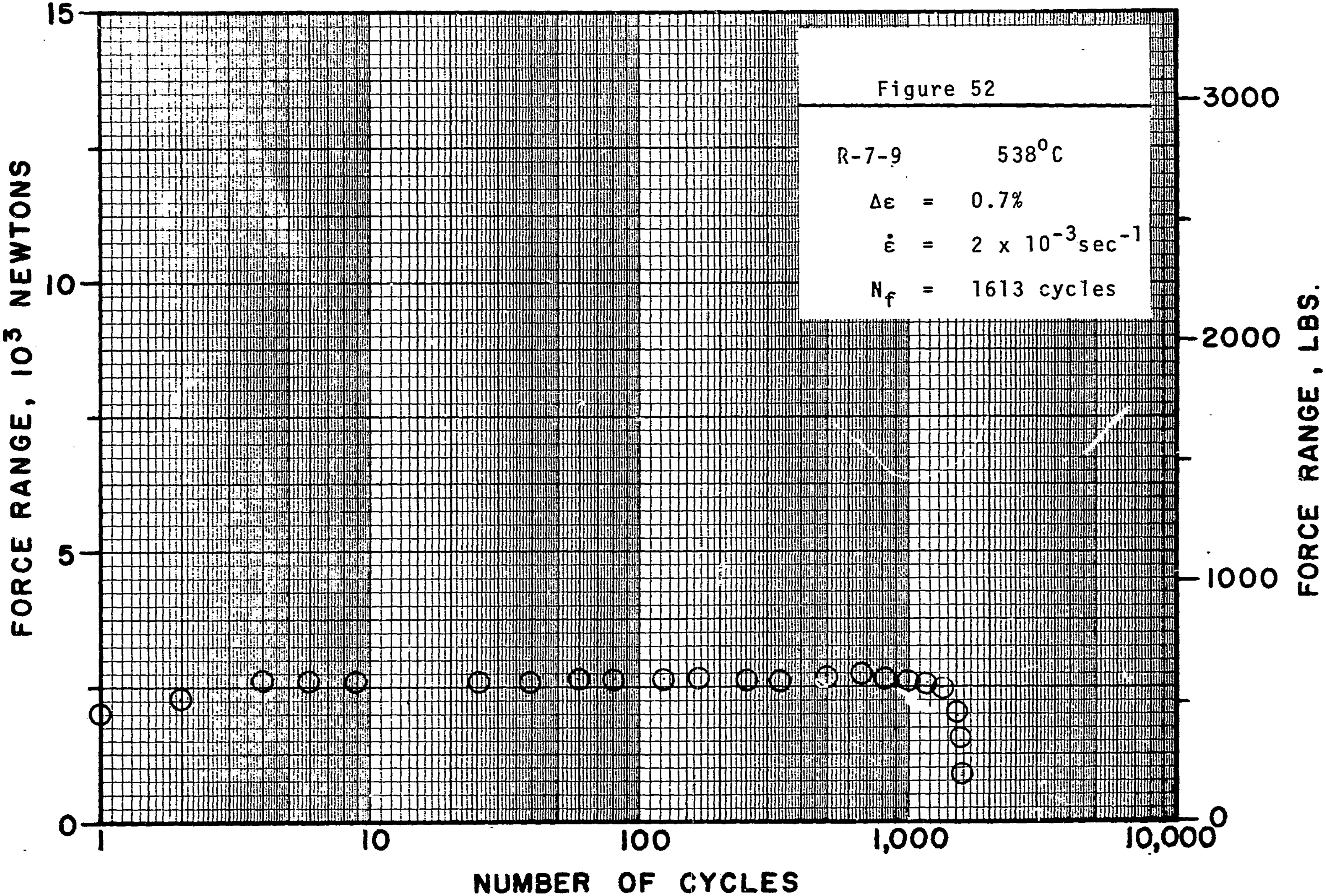


Figure 52
R-7-9 538°C
Δε = 0.7%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1613 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1000
2000
3000
1
10
100
1,000
10,000

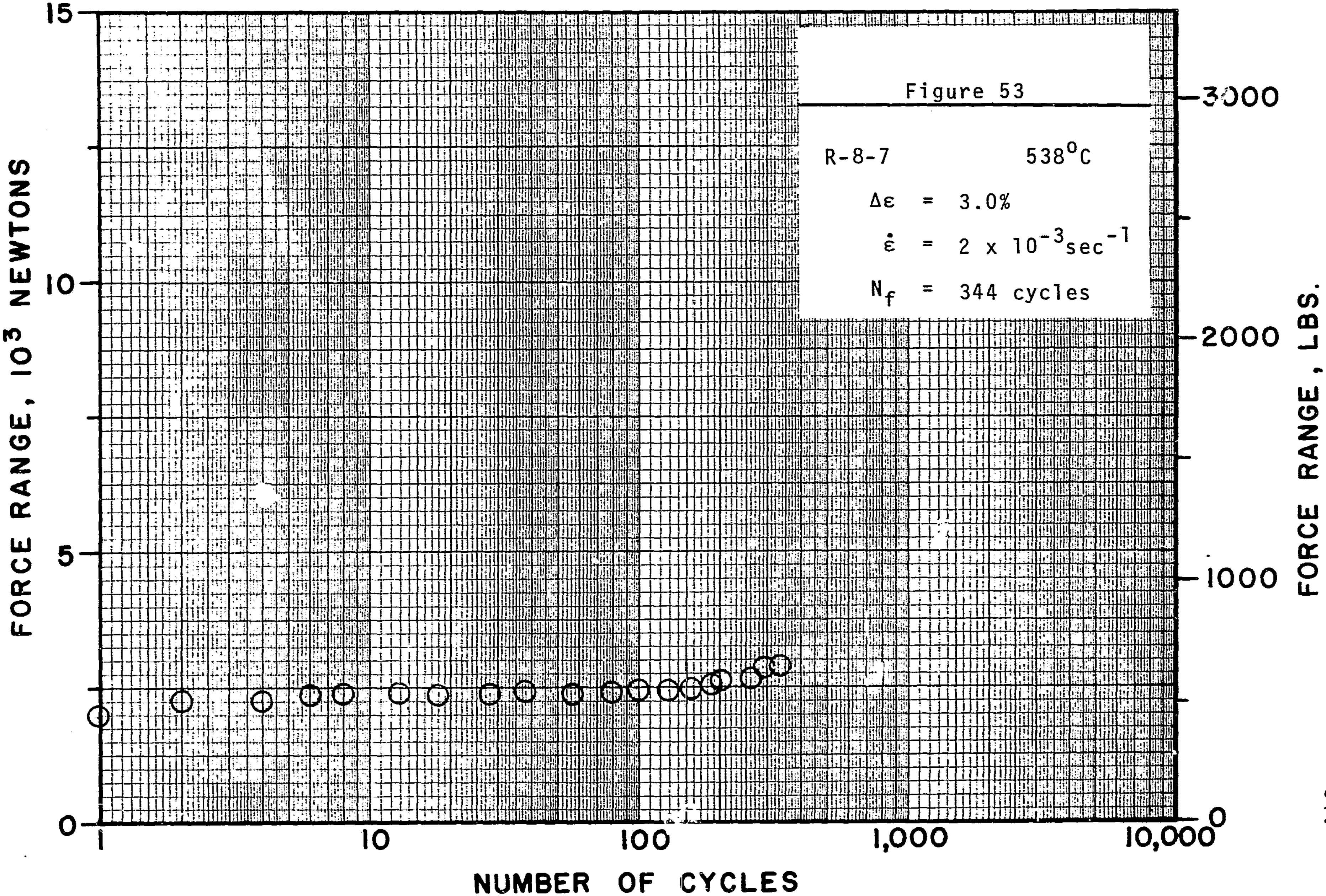

R-8-7 538°C
Δε = 3.0%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 344 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 53

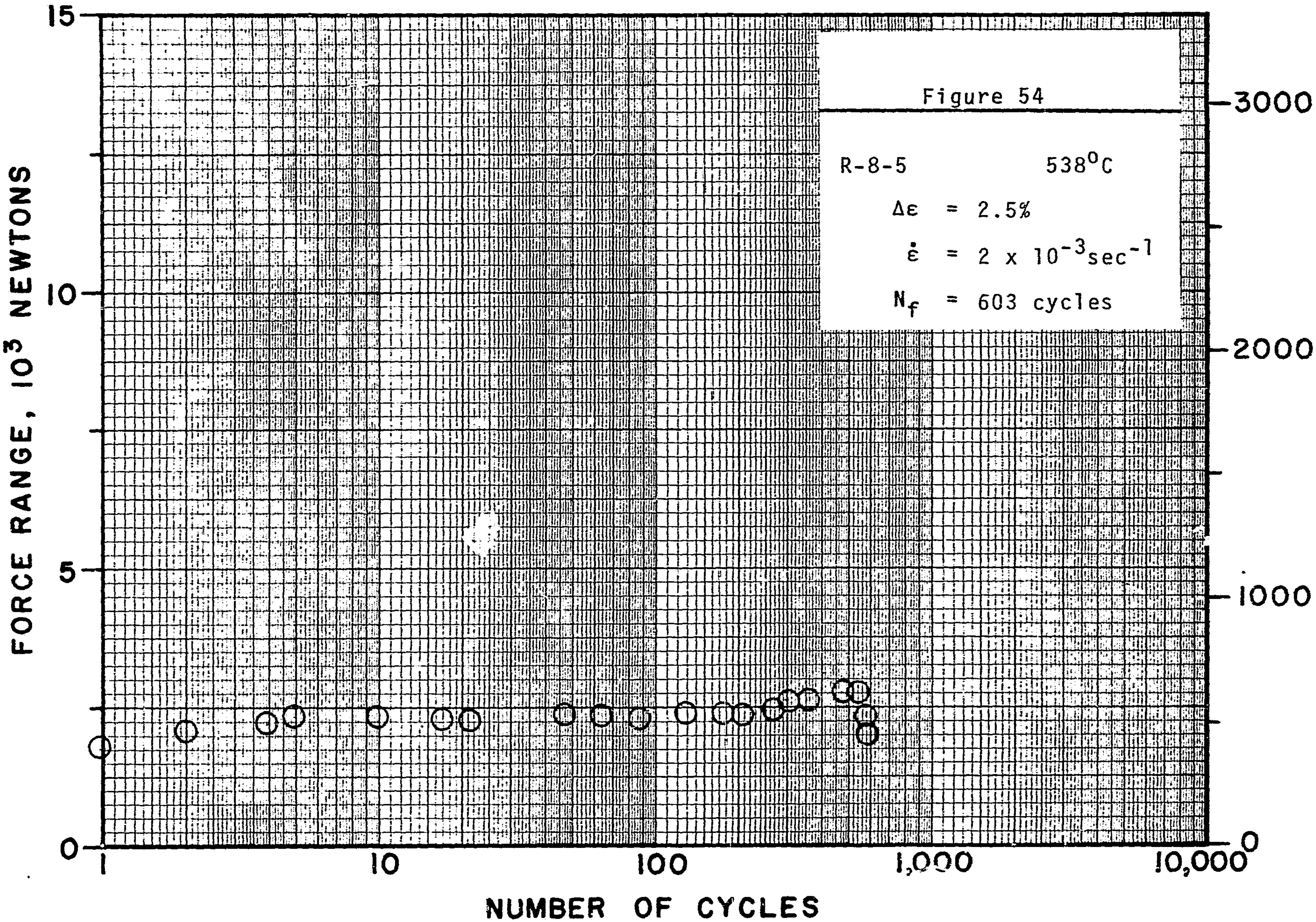


Figure 54
R-8-5 538°C
Δε = 2.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 603 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

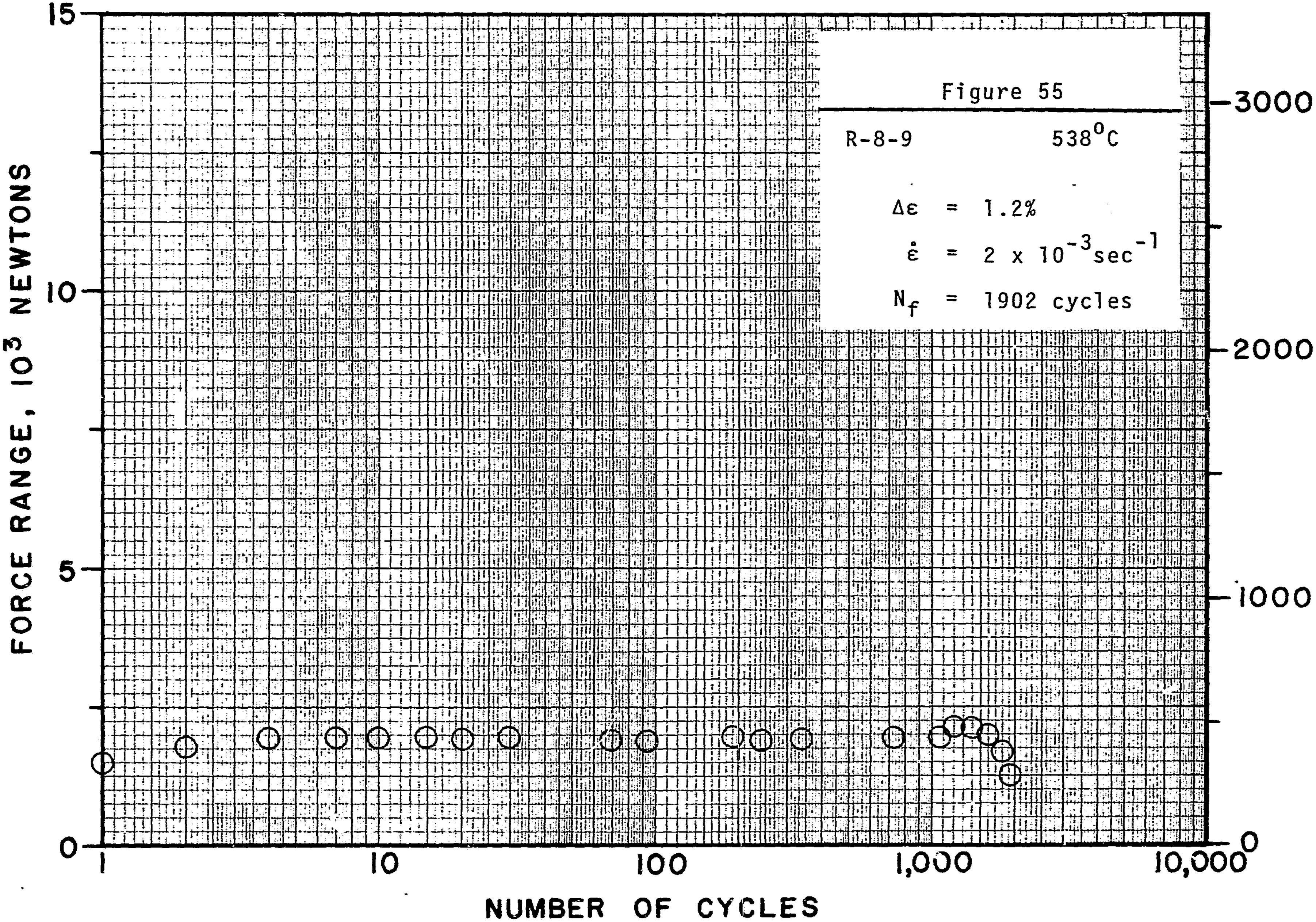


Figure 55
R-8-9
538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1902 cycles
15
10
5
0
FORCE RANGE, 10^3 NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

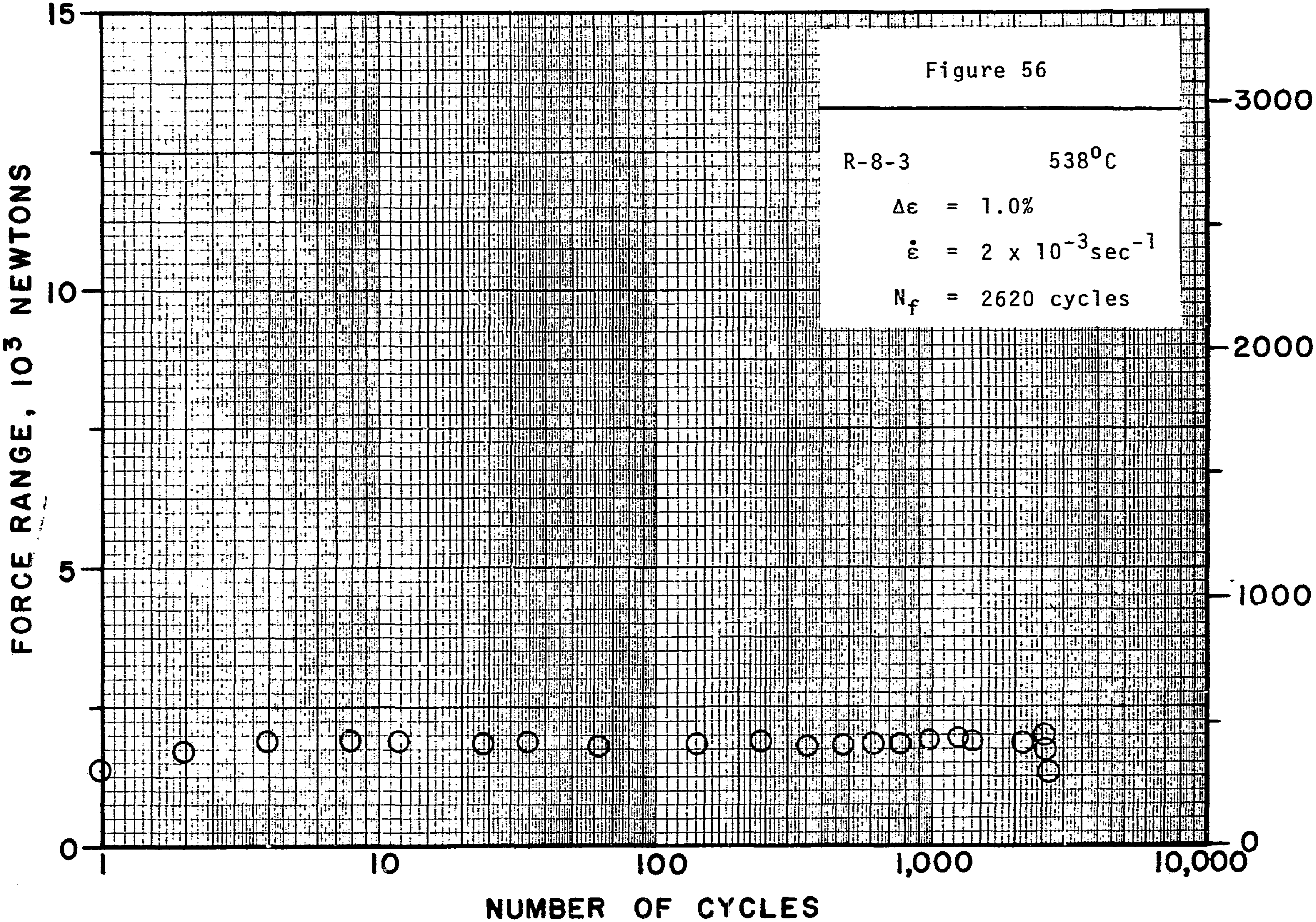

R-8-3 538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2620 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 56

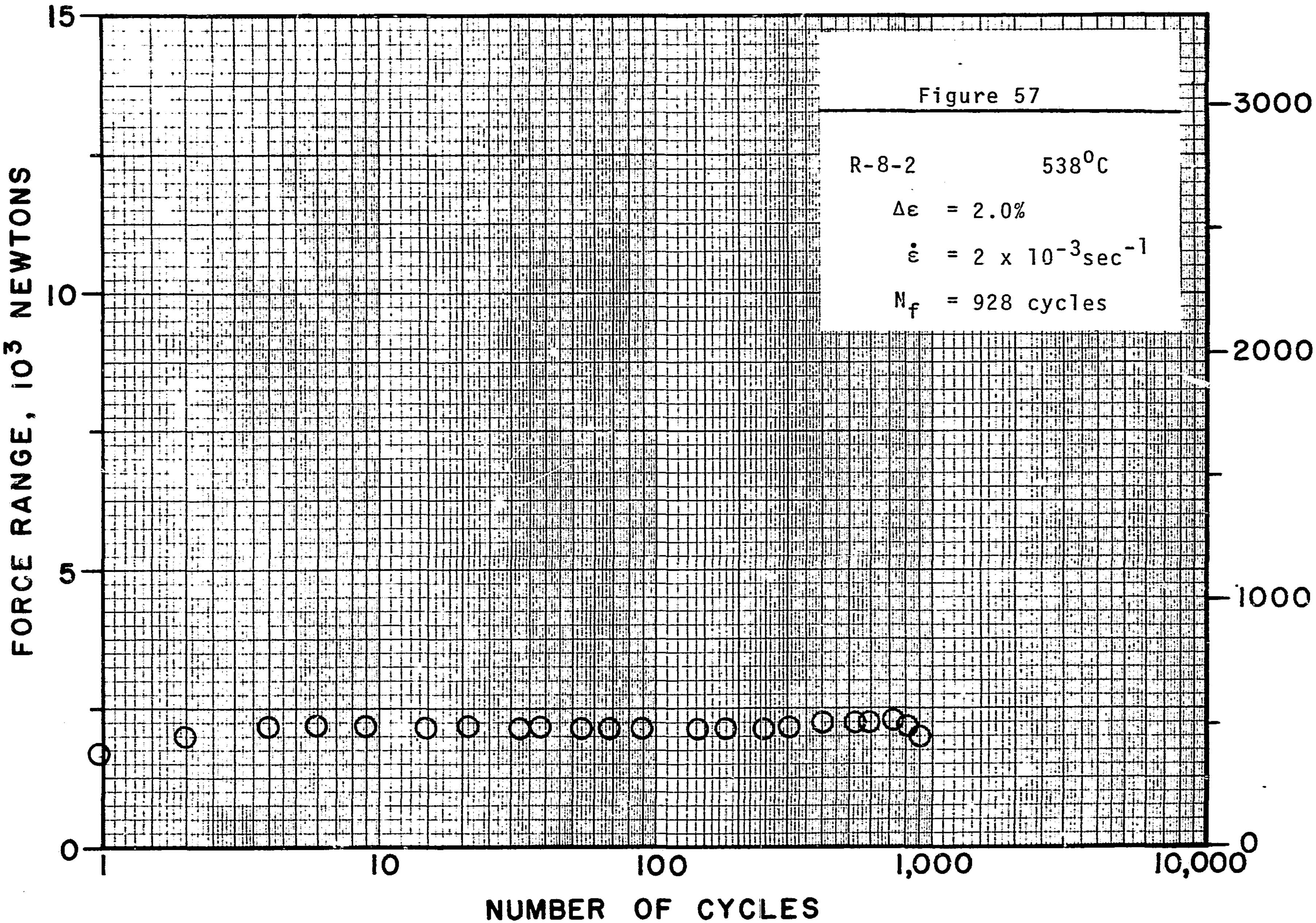

R-8-2 538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 928 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

Figure 57

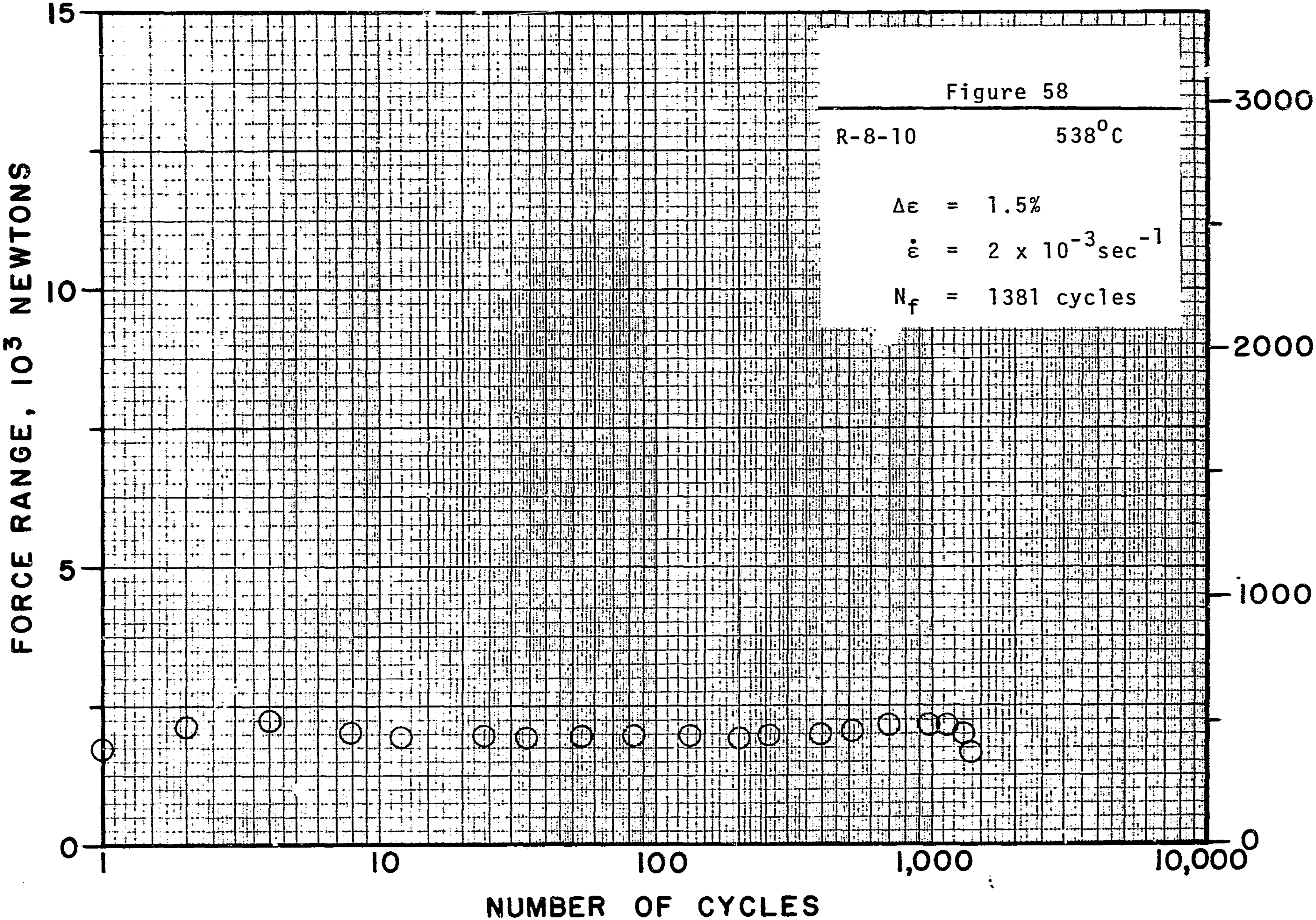


Figure 58
R-8-10
538°C
Δε = 1.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1381 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

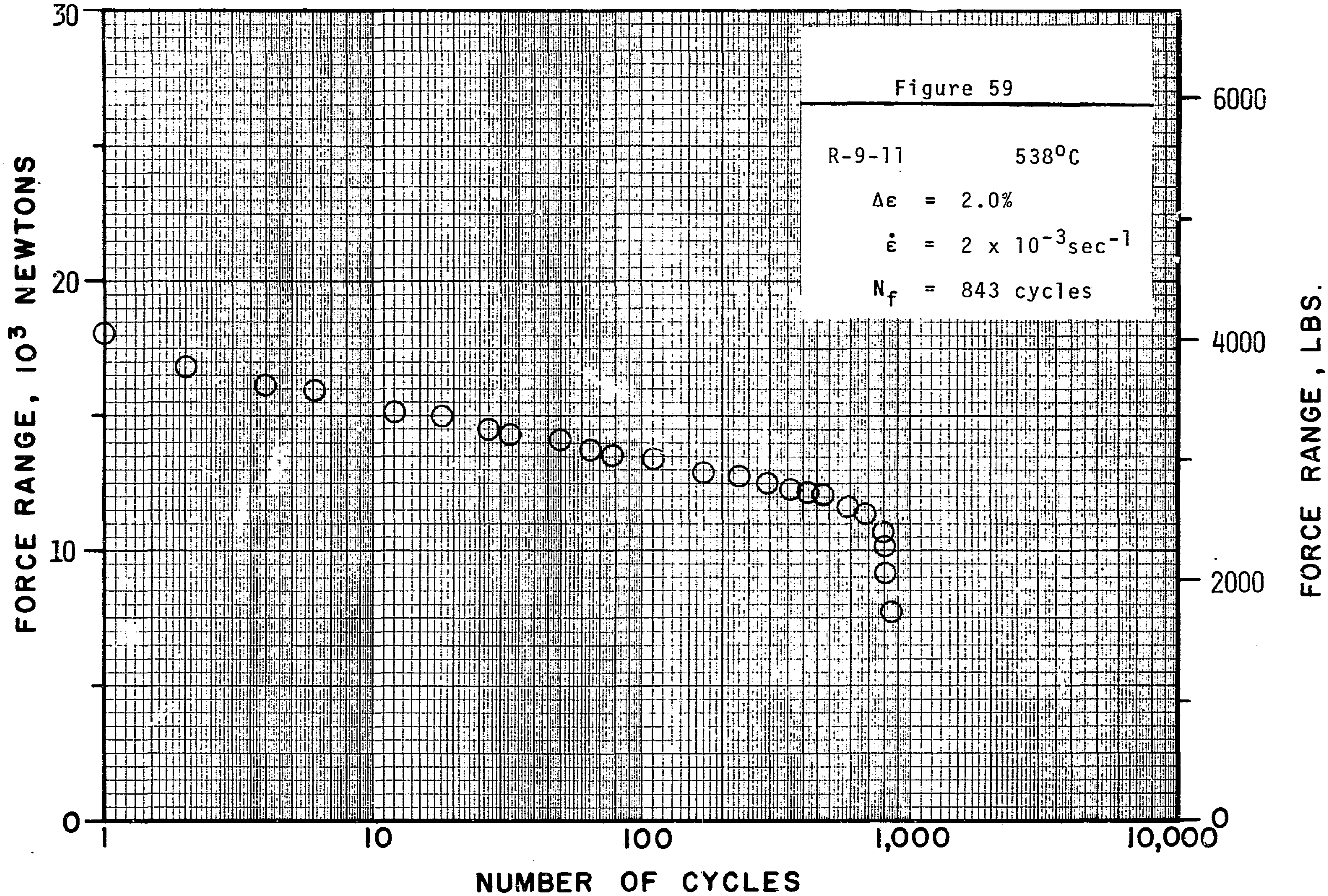


Figure 59
R-9-11 538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 843 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

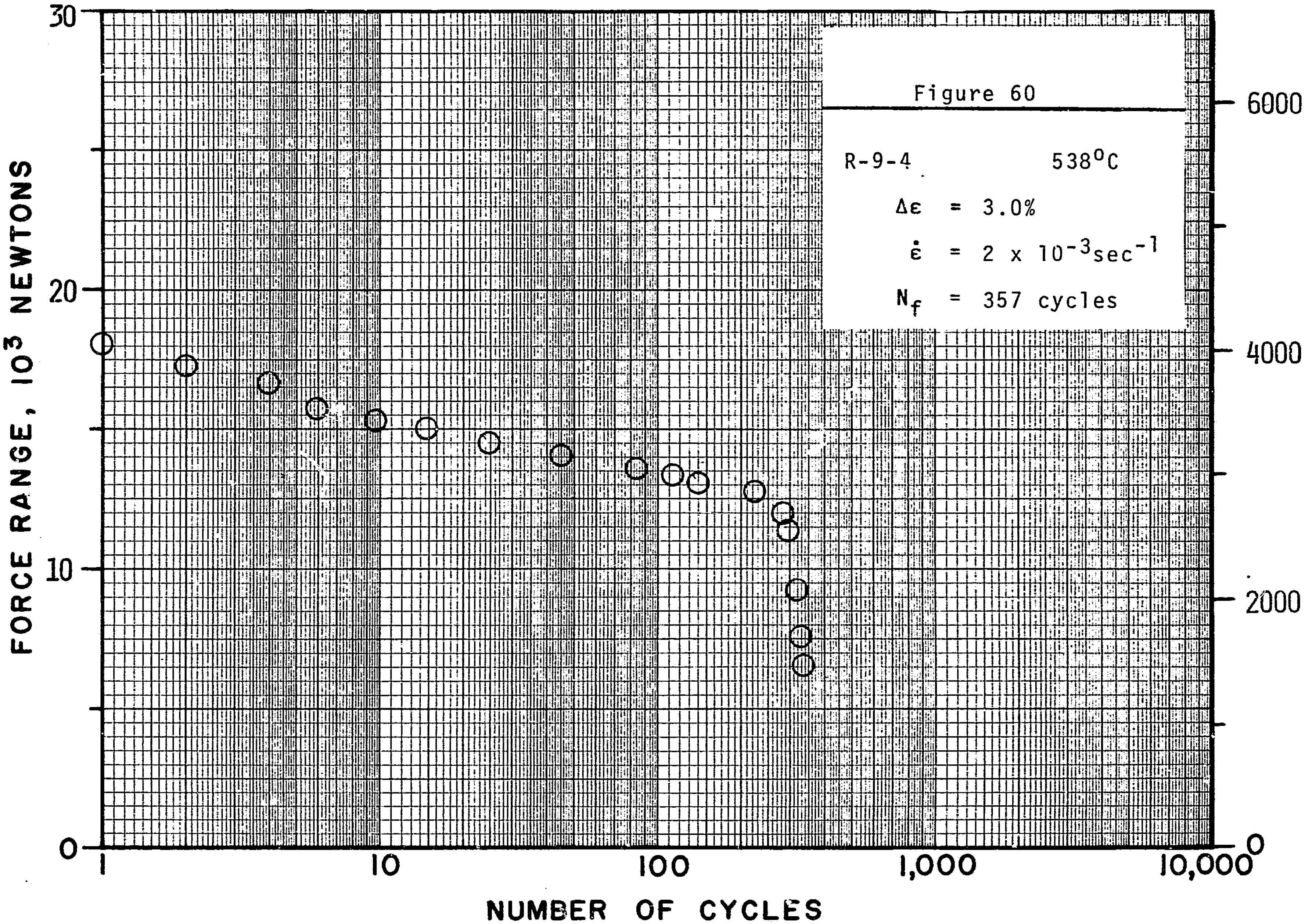


Figure 60
R-9-4 538°C
Δε = 3.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 357 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
30
20
10
0
6000
4000
2000
0
1
10
100
1,000
10,000

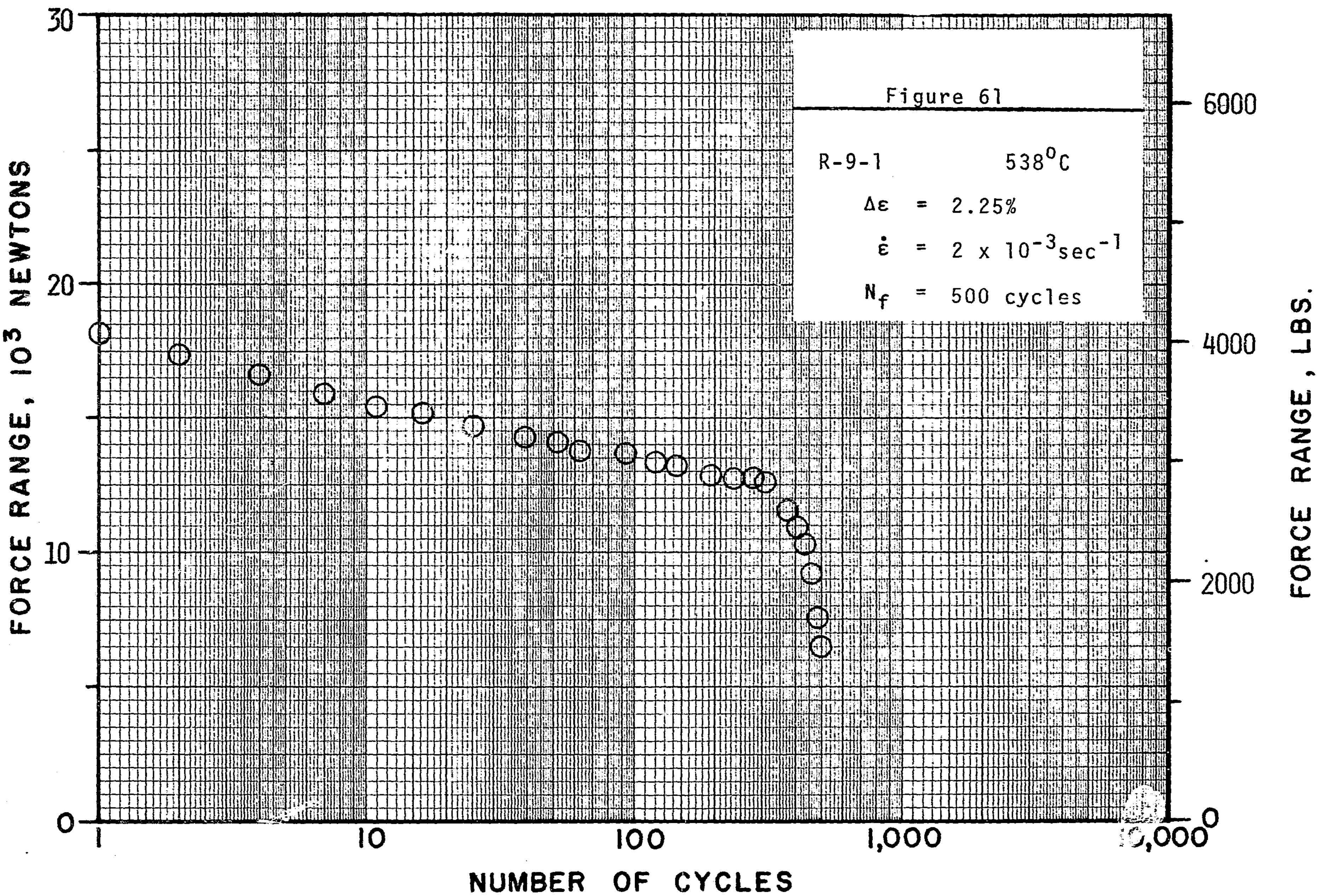

R-9-1 538°C
Δε = 2.25%
ε̇ = 2 x 10^-3 sec^-1
N_f = 500 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

Figure 61

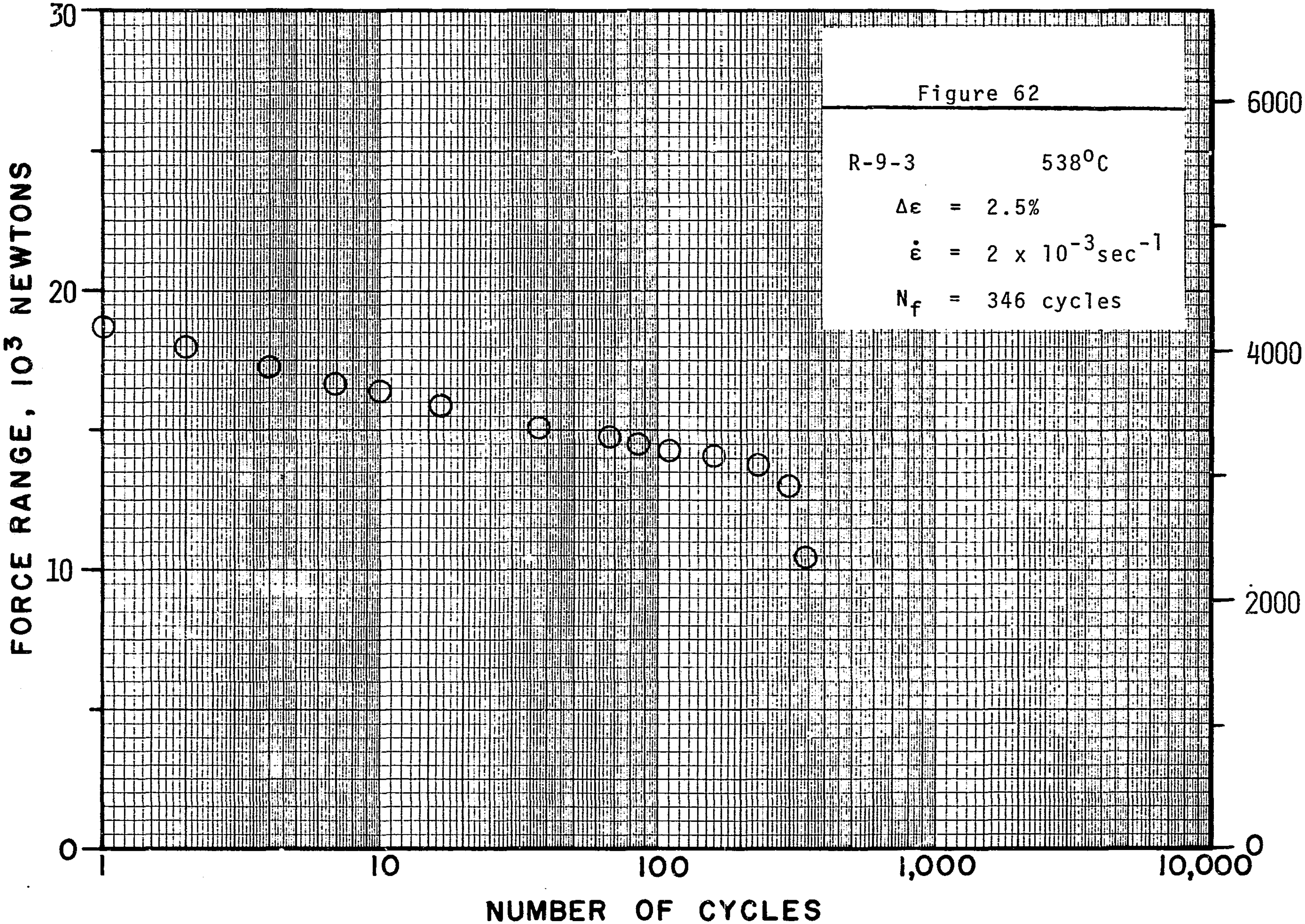

R-9-3 538°C
Δε = 2.5%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 346 cycles
FORCE RANGE, 10^3 NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
NUMBER OF CYCLES
1
10
100
1,000
10,000

Figure 62

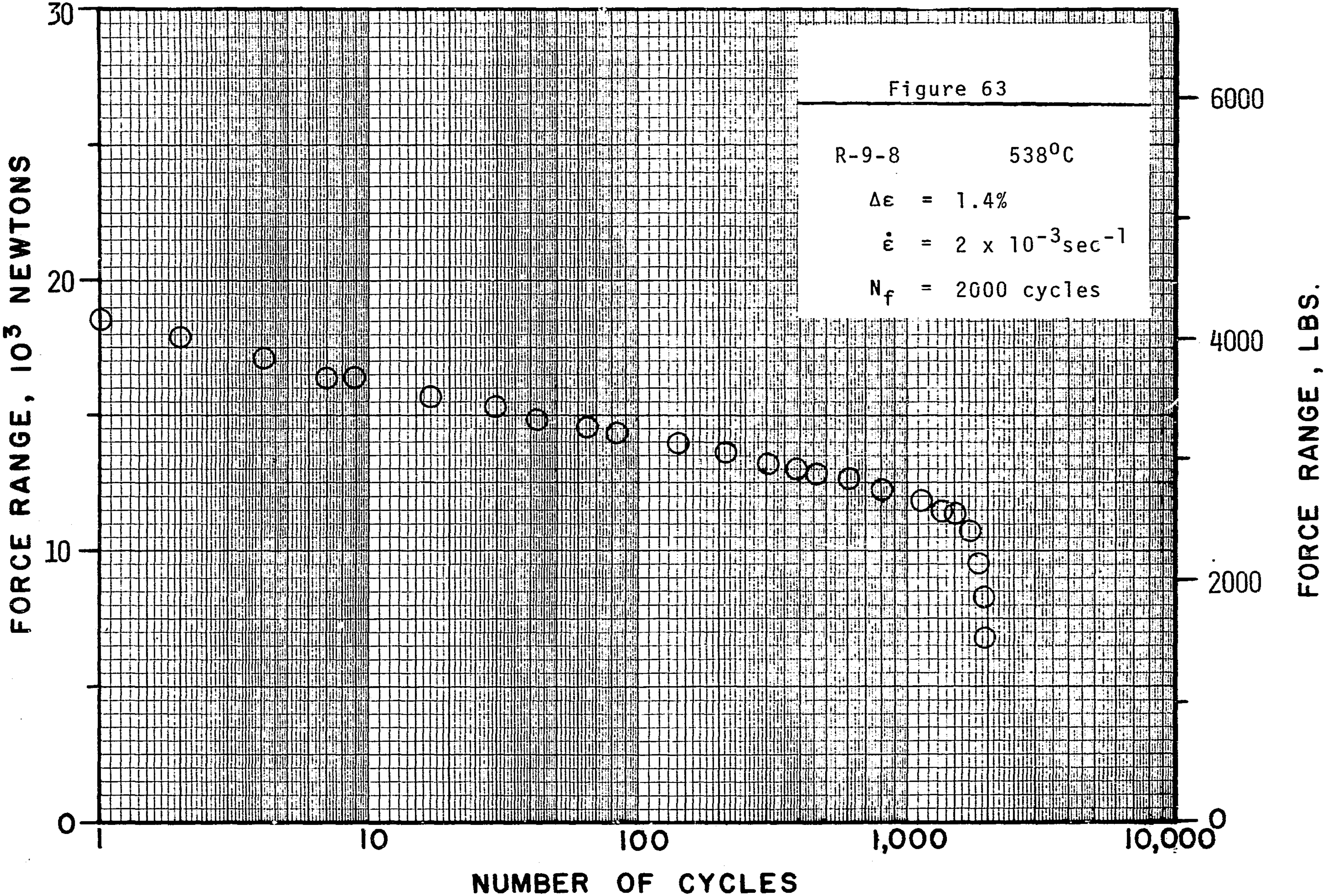


Figure 63
R-9-8 538°C
Δε = 1.4%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2000 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

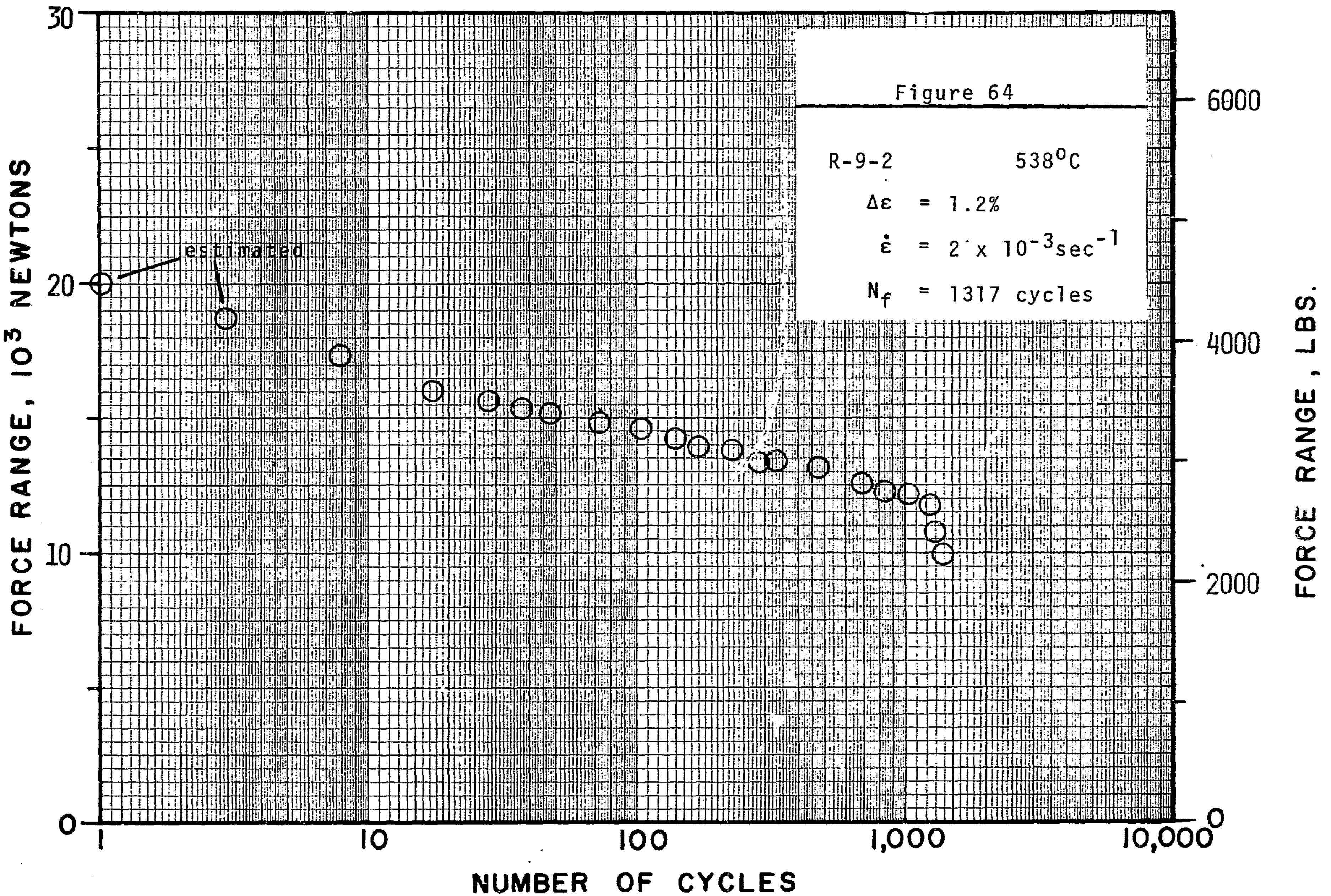

R-9-2 538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1317 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
2000
4000
6000
1
10
100
1,000
10,000

Figure 64

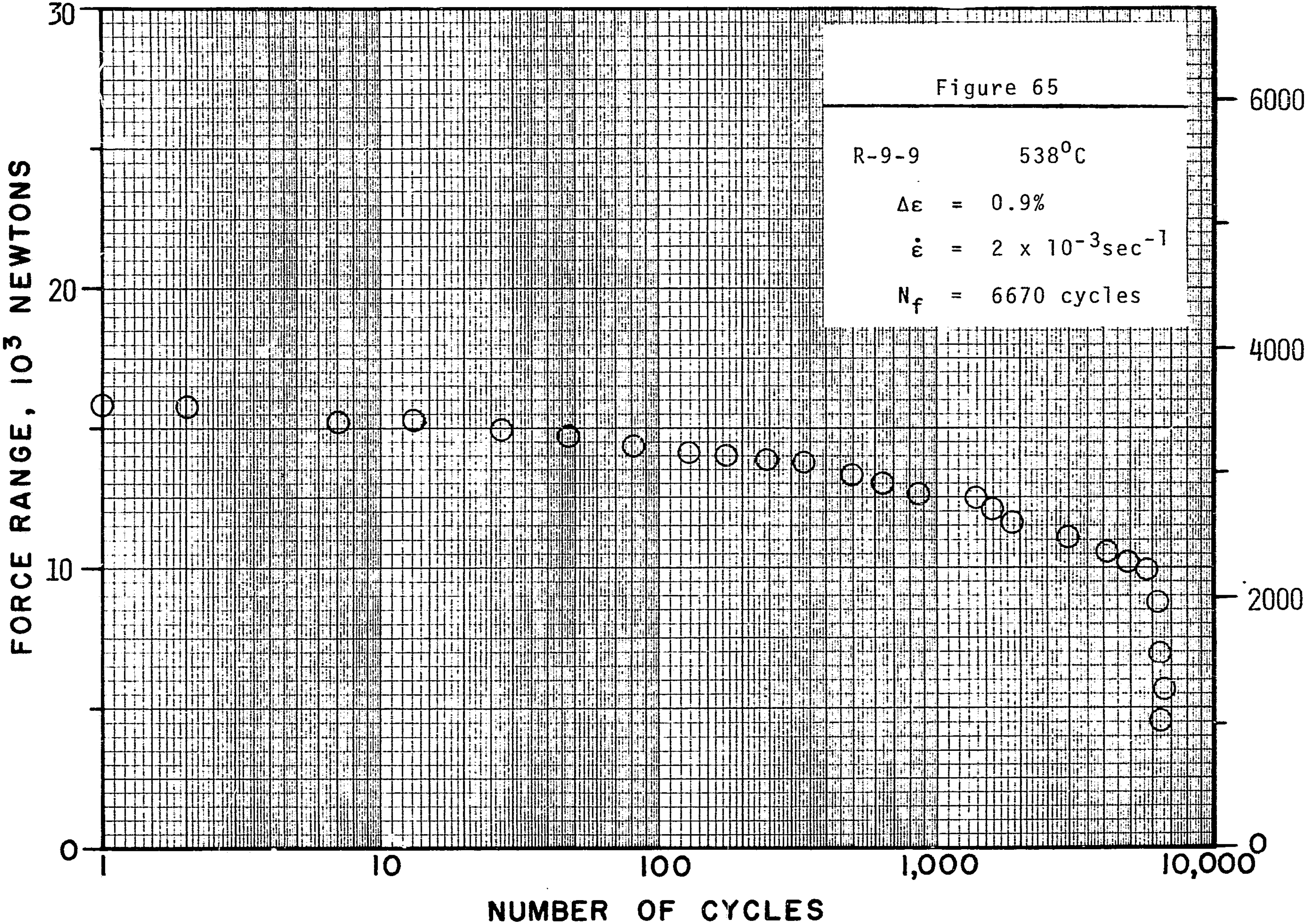


Figure 65
R-9-9 538°C
Δε = 0.9%
ε̇ = 2 x 10^-3 sec^-1
N_f = 6670 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

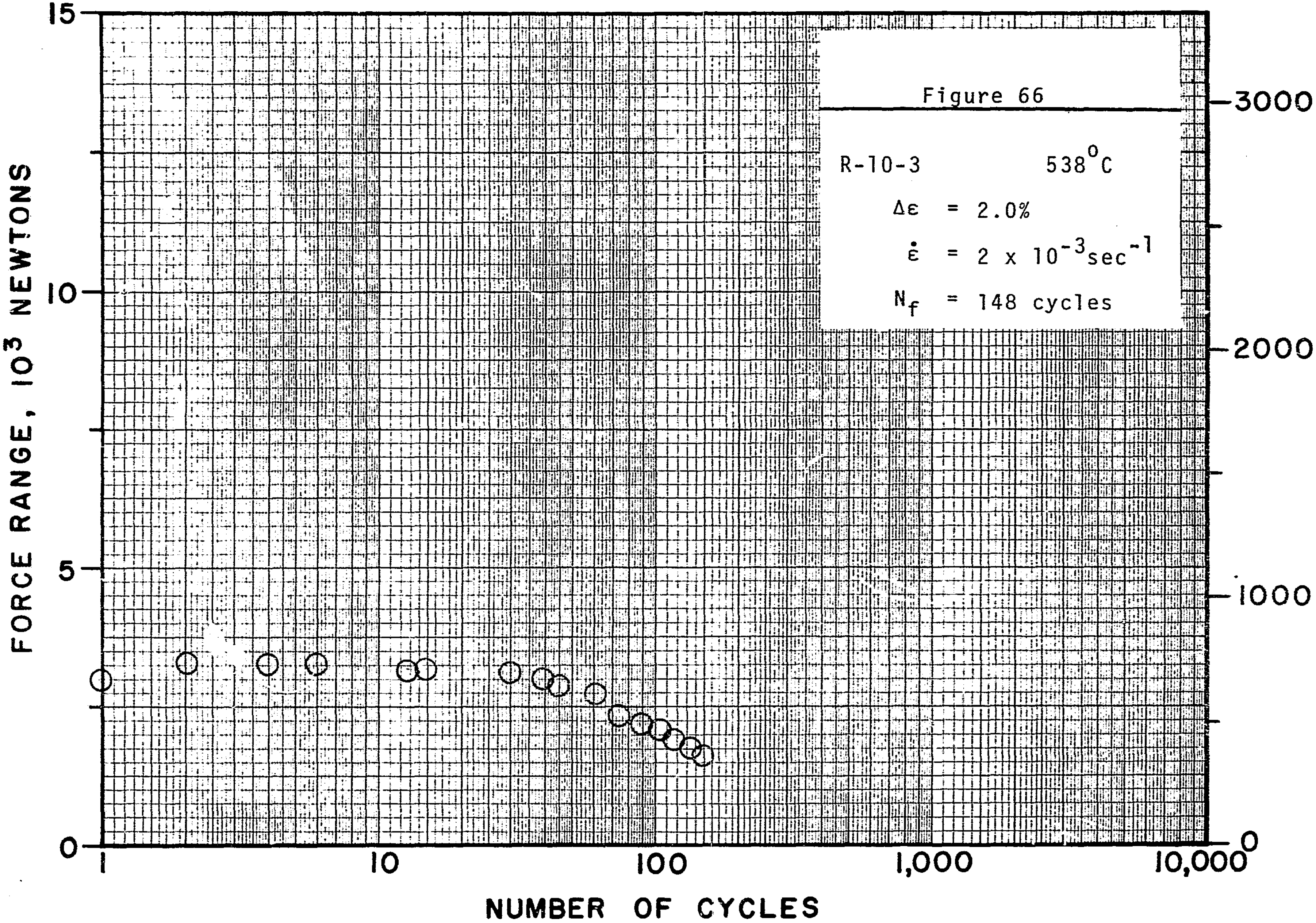


Figure 66
R-10-3 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 148 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

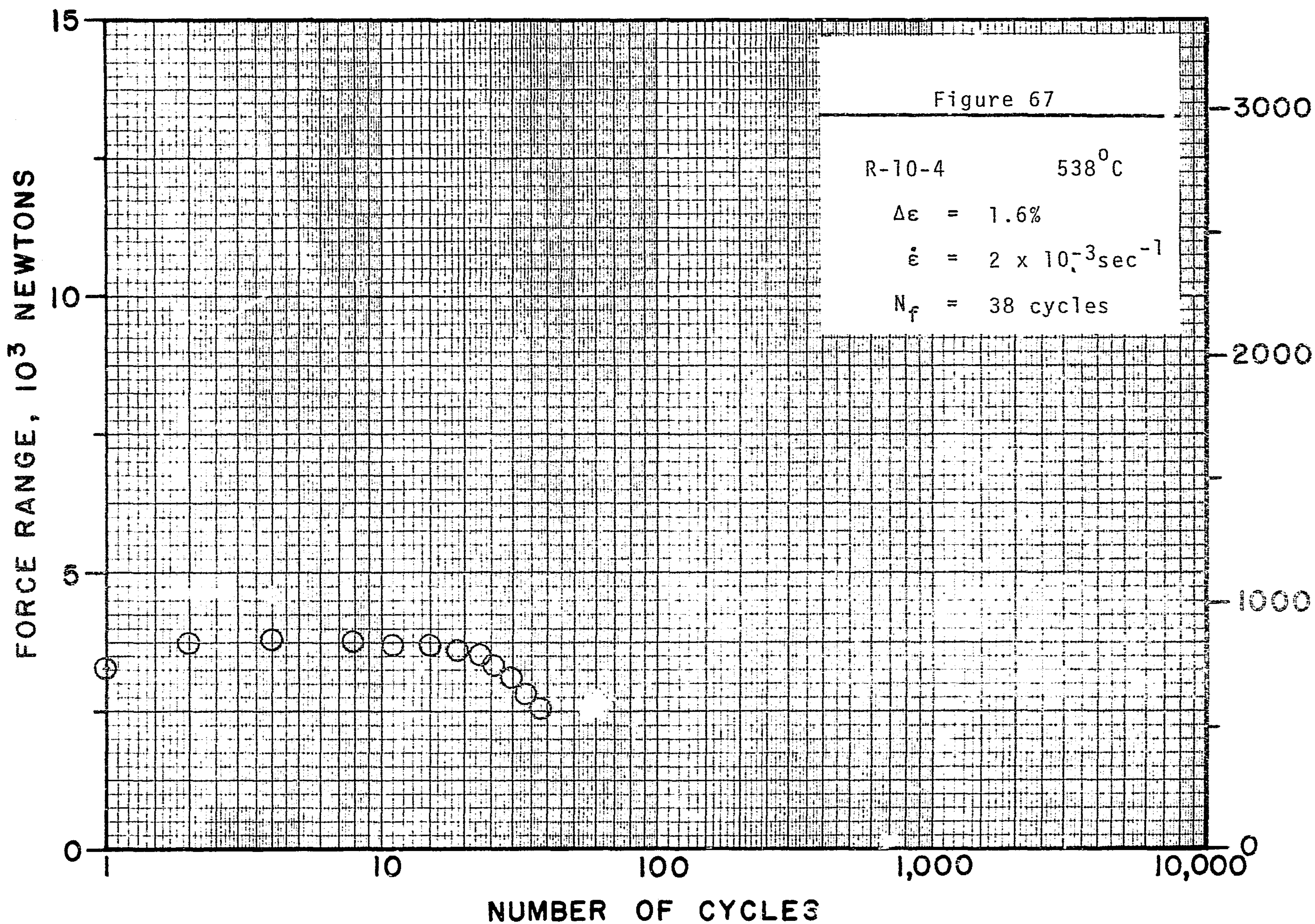


Figure 67
R-10-4
538°C
Δε = 1.6%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 38 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

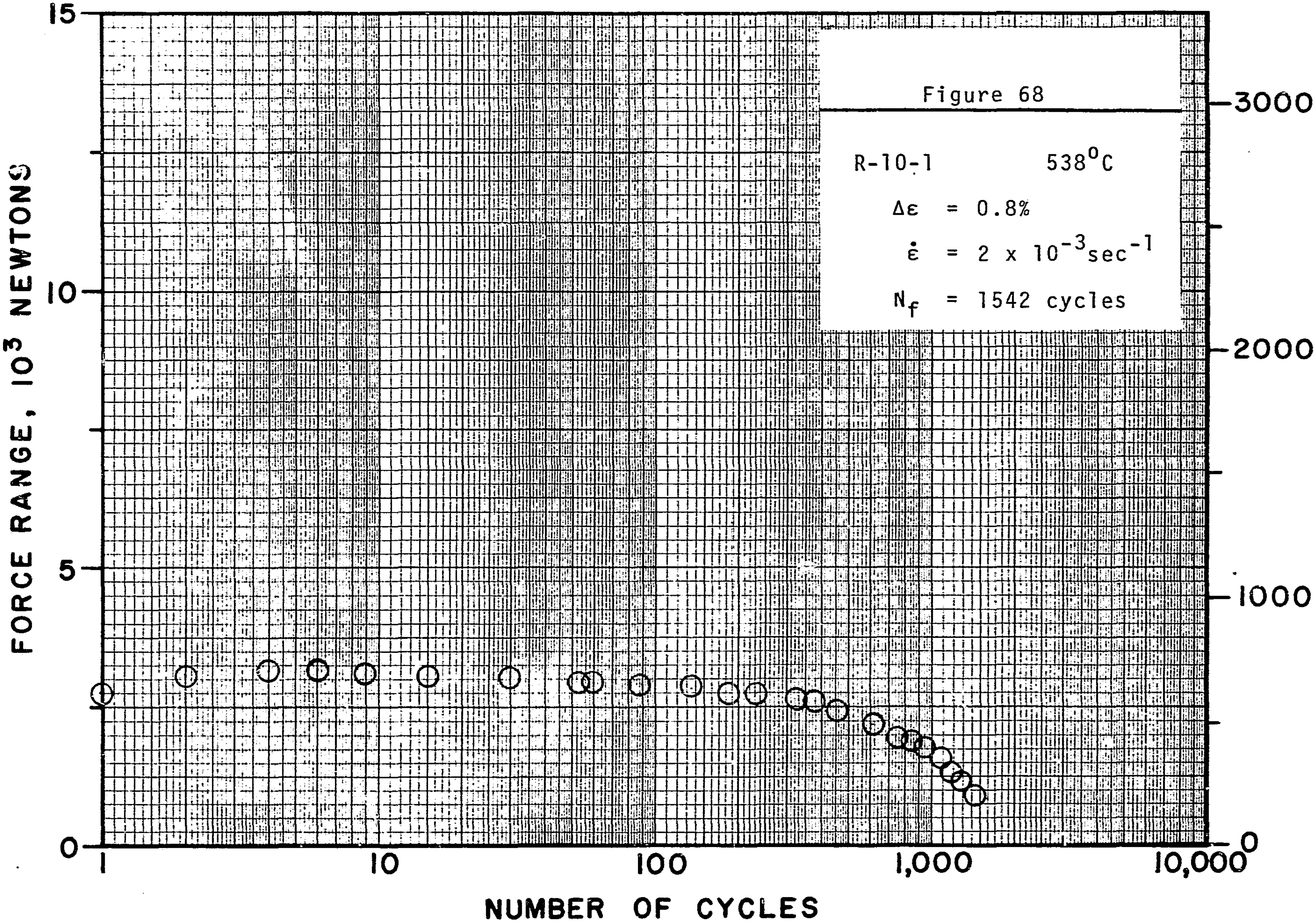

R-10-1 538°C
Δε = 0.8%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1542 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

Figure 68

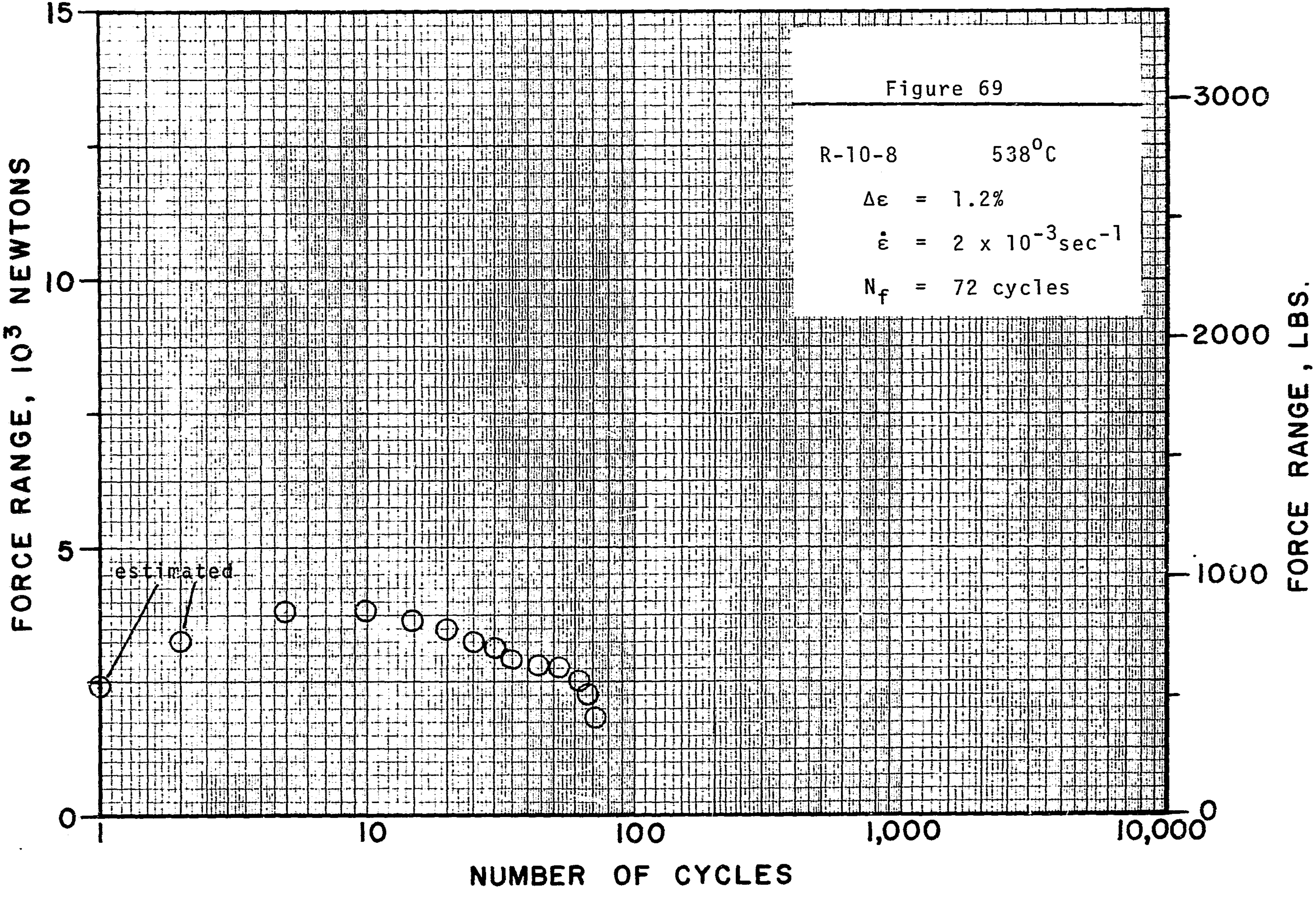


Figure 69
R-10-8
538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 72 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

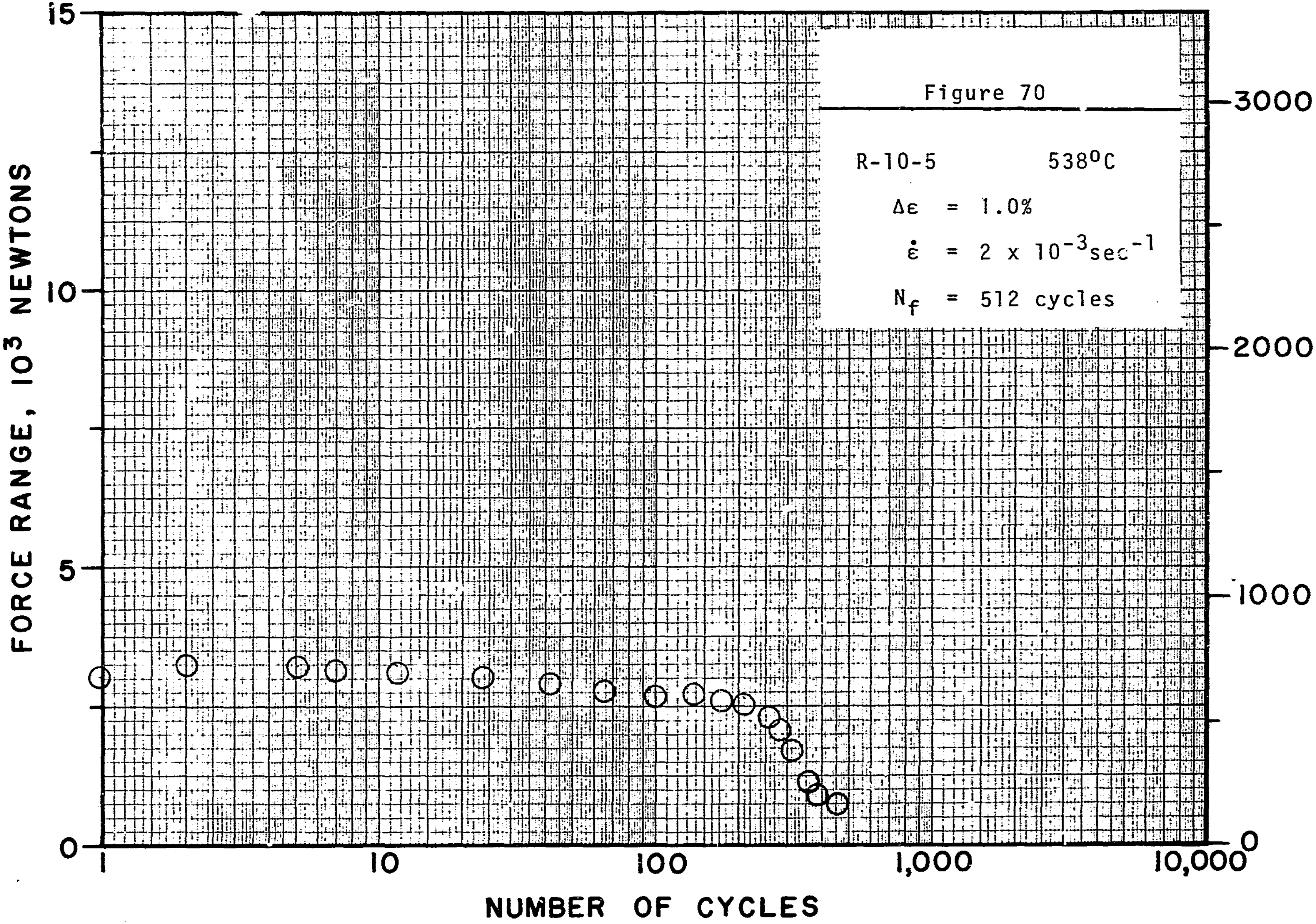


Figure 70
R-10-5 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 512 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

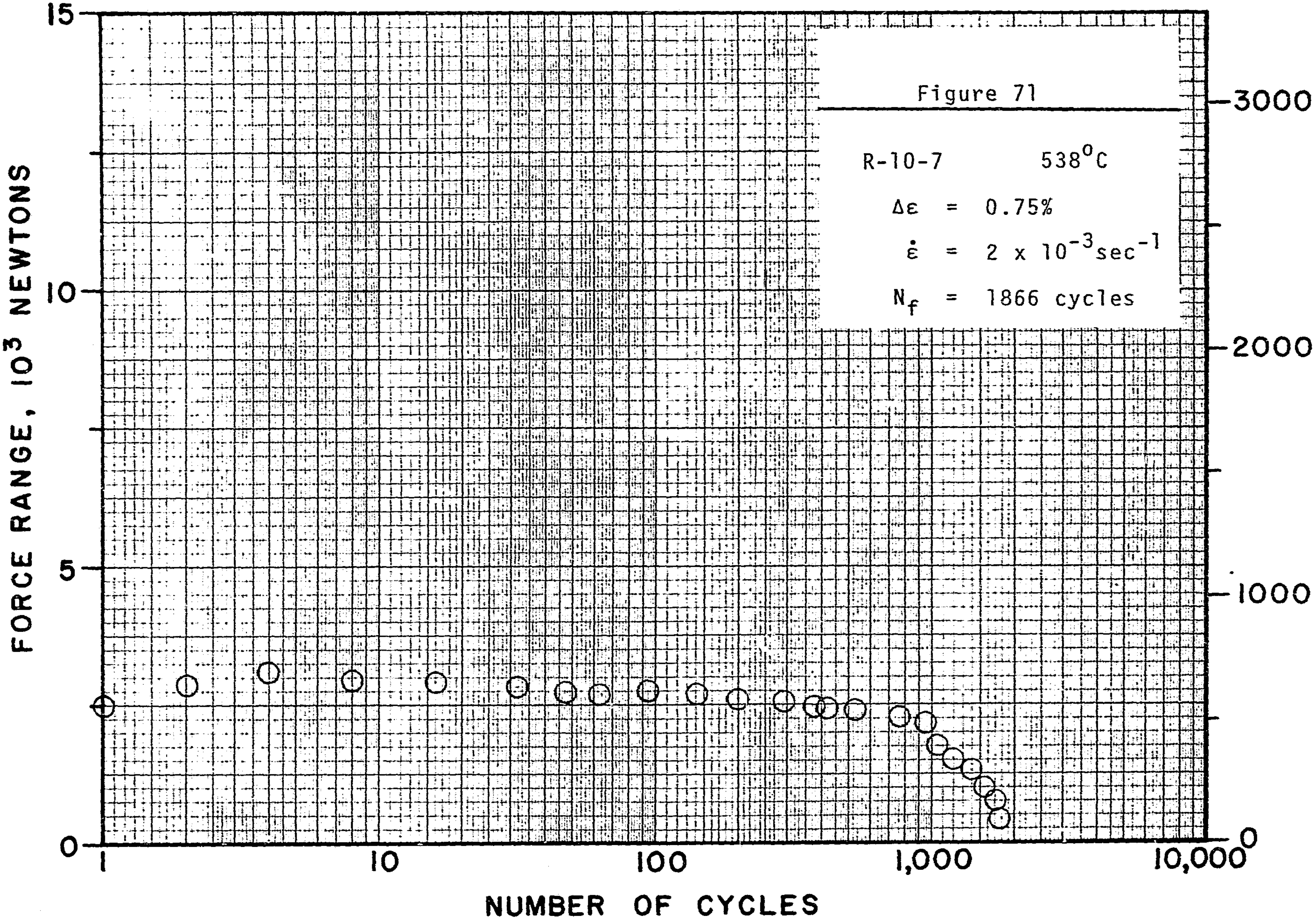


Figure 71
R-10-7 538°C
Δε = 0.75%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 1866 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

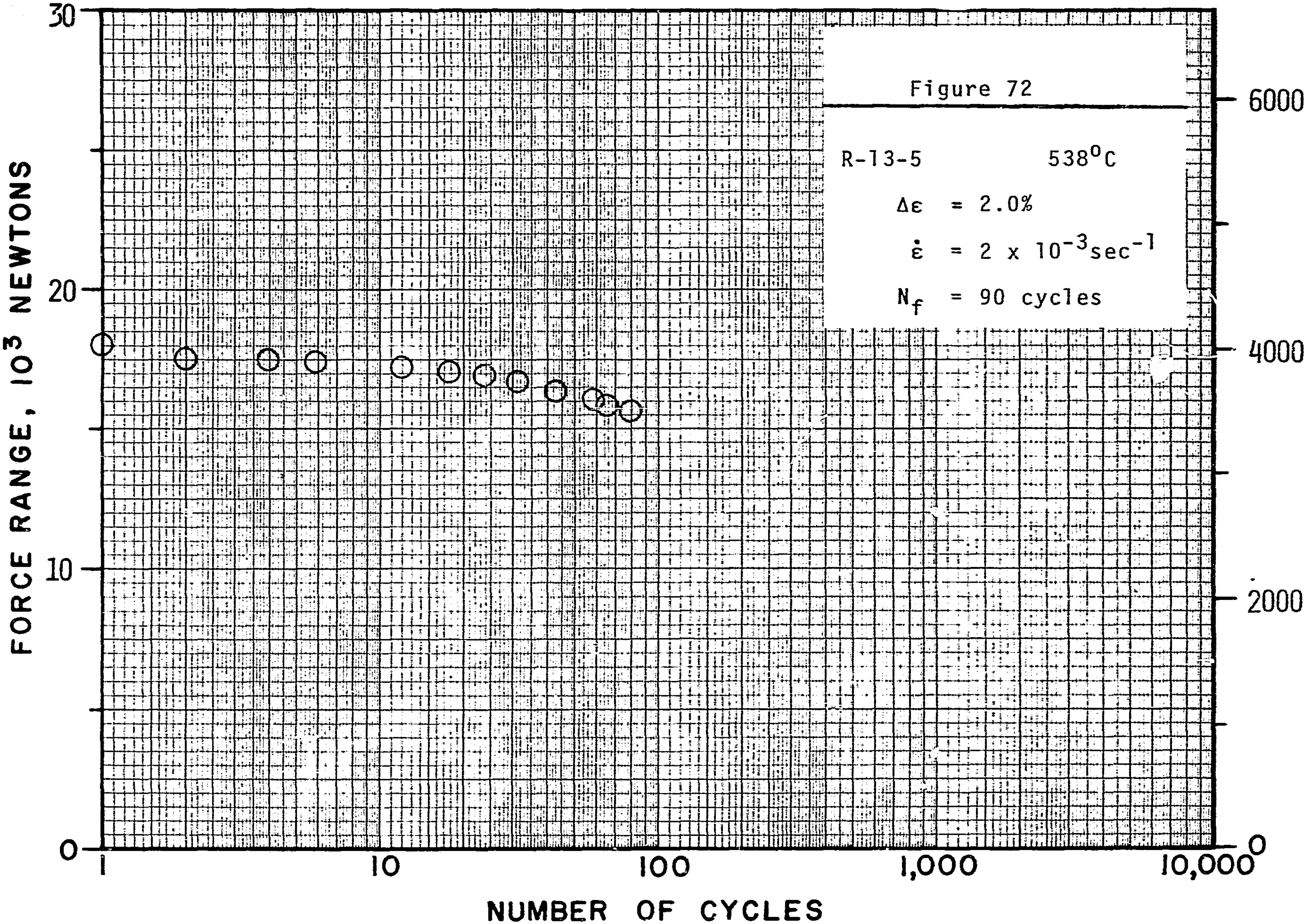


Figure 72
R-13-5 538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 90 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

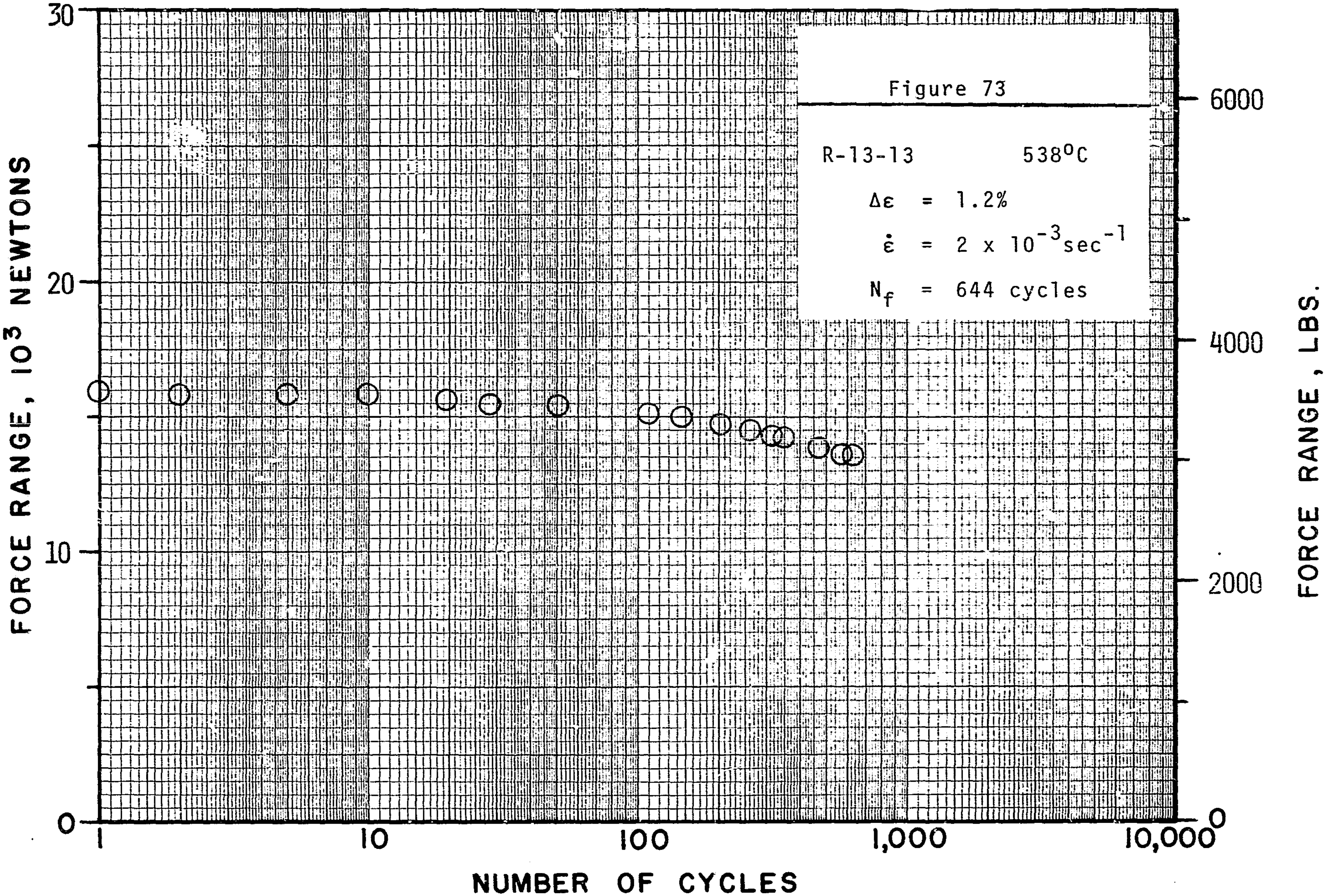

R-13-13 538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³ sec⁻¹
Nf = 644 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

Figure 73

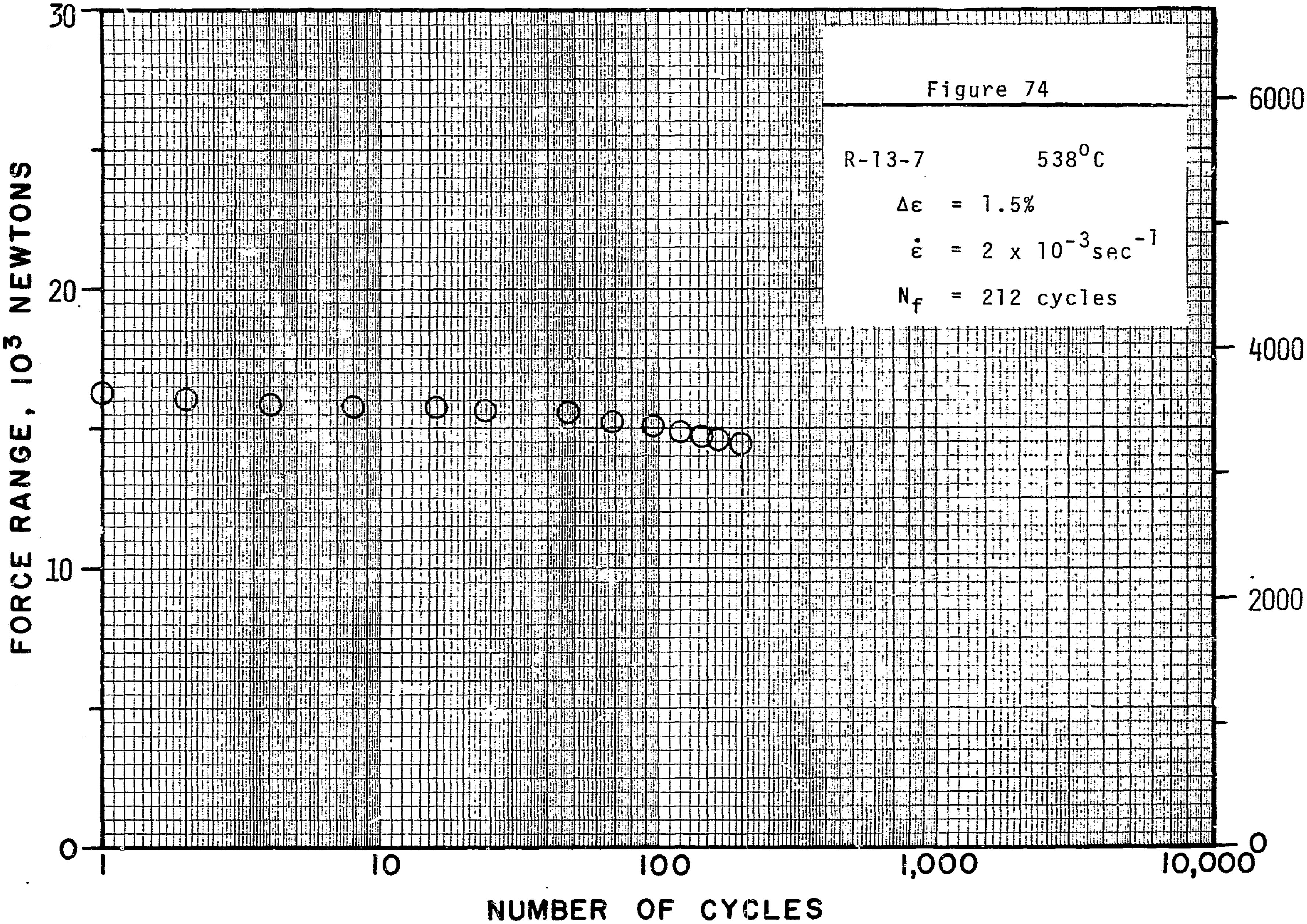


Figure 74
R-13-7 538°C
Δε = 1.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 212 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

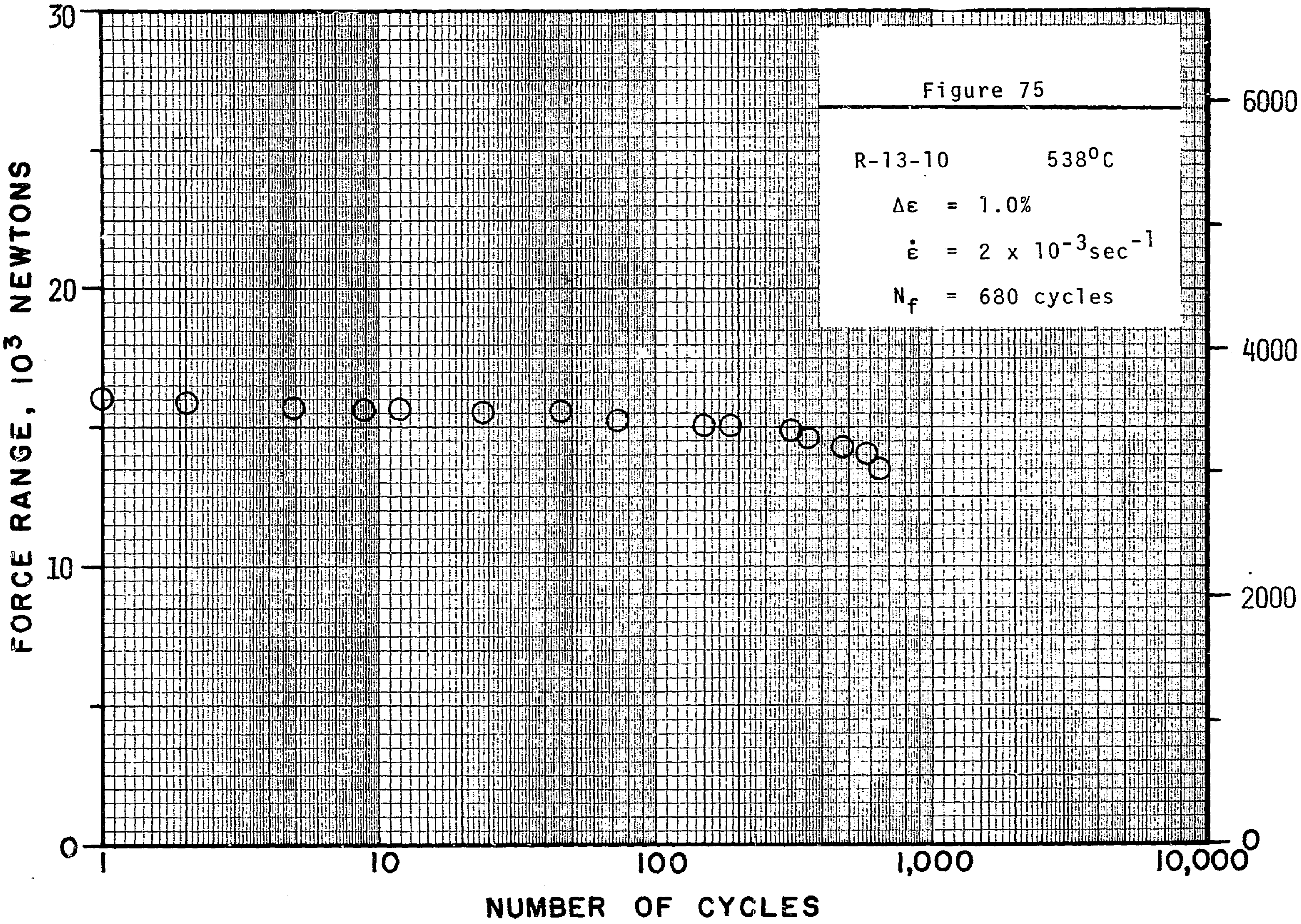


Figure 75
R-13-10 538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 680 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

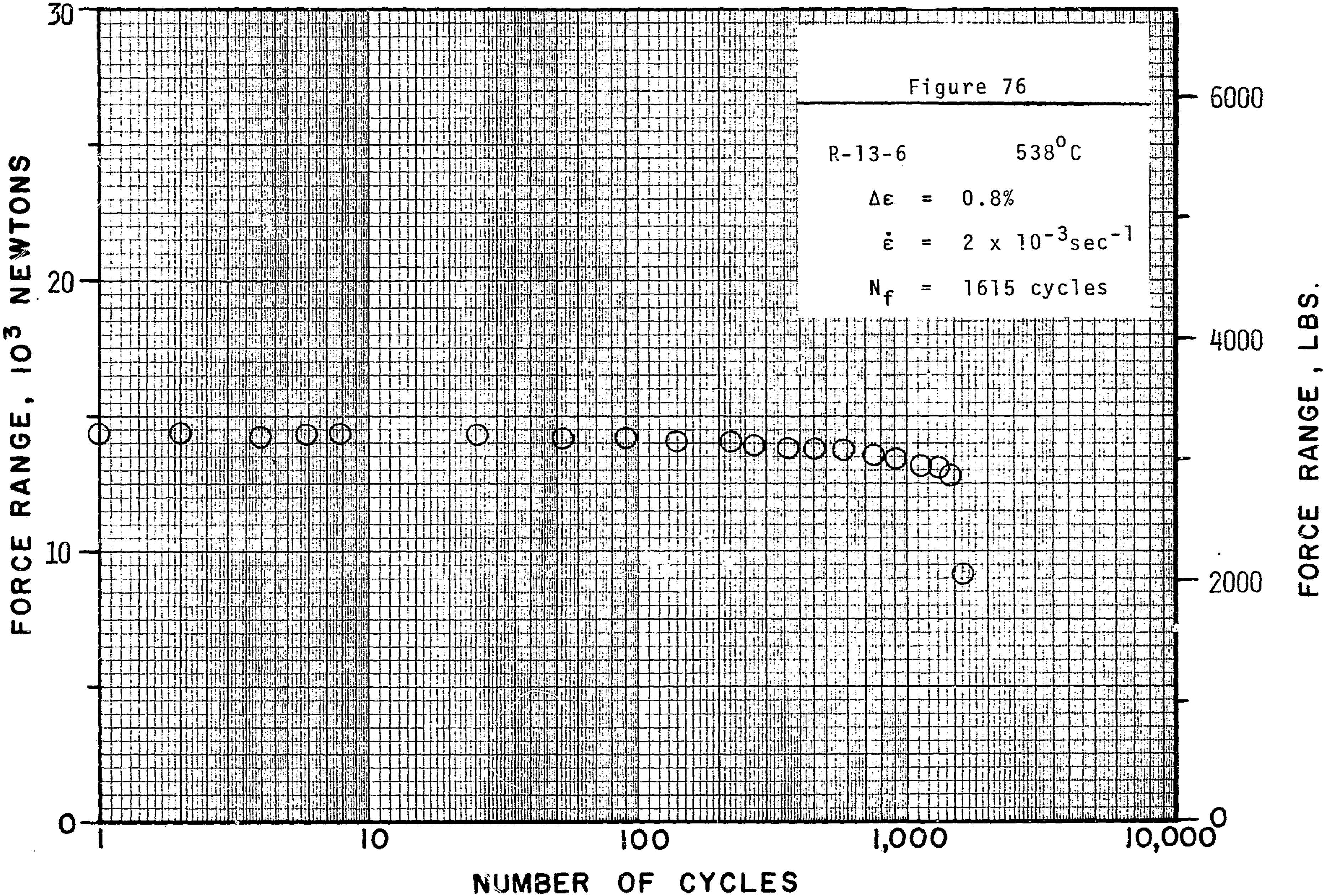

R-13-6 538°C
Δε = 0.8%
ε̇ = 2 x 10-3sec-1
Nf = 1615 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

Figure 76

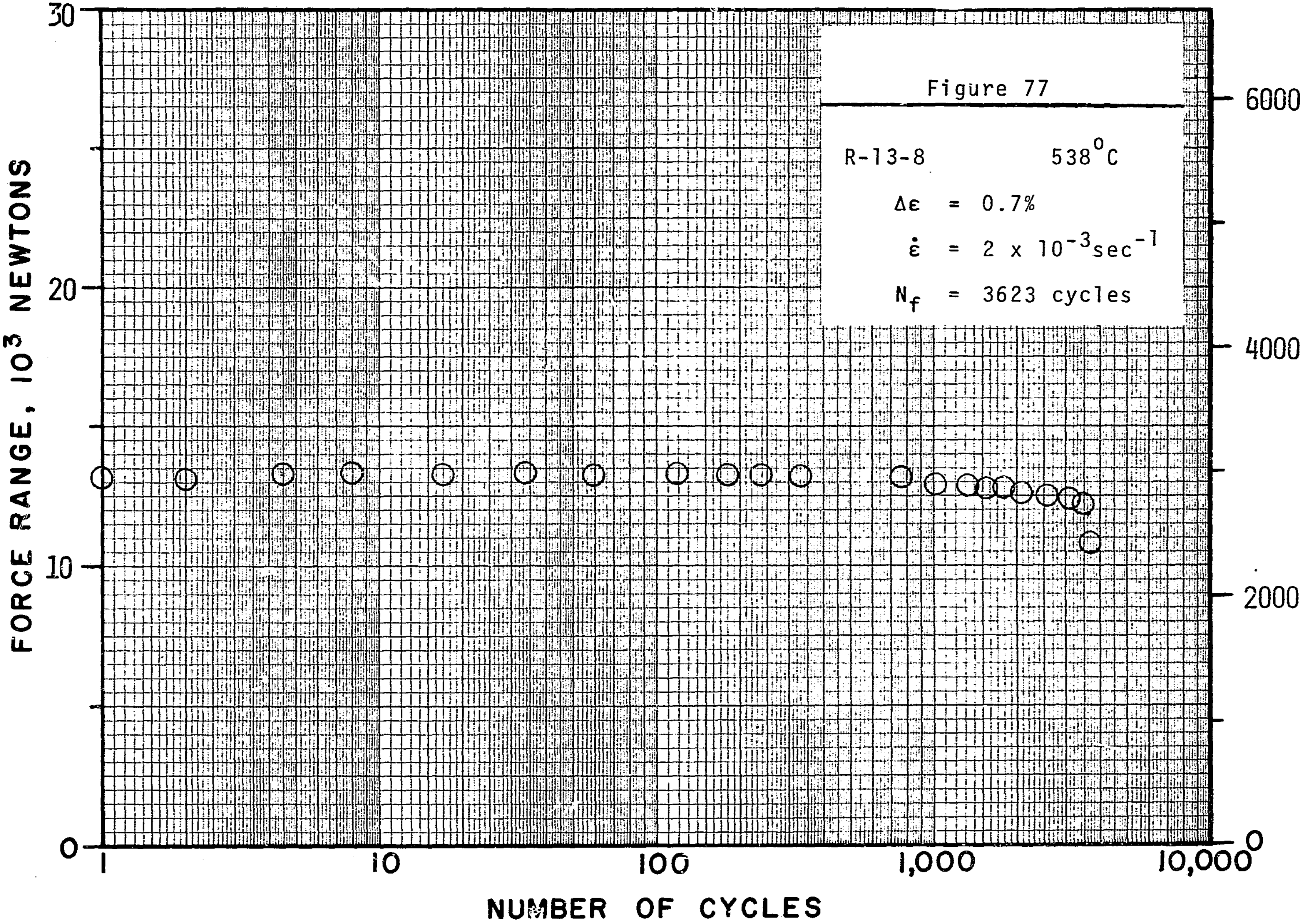


Figure 77
R-13-8 538°C
Δε = 0.7%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 3623 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

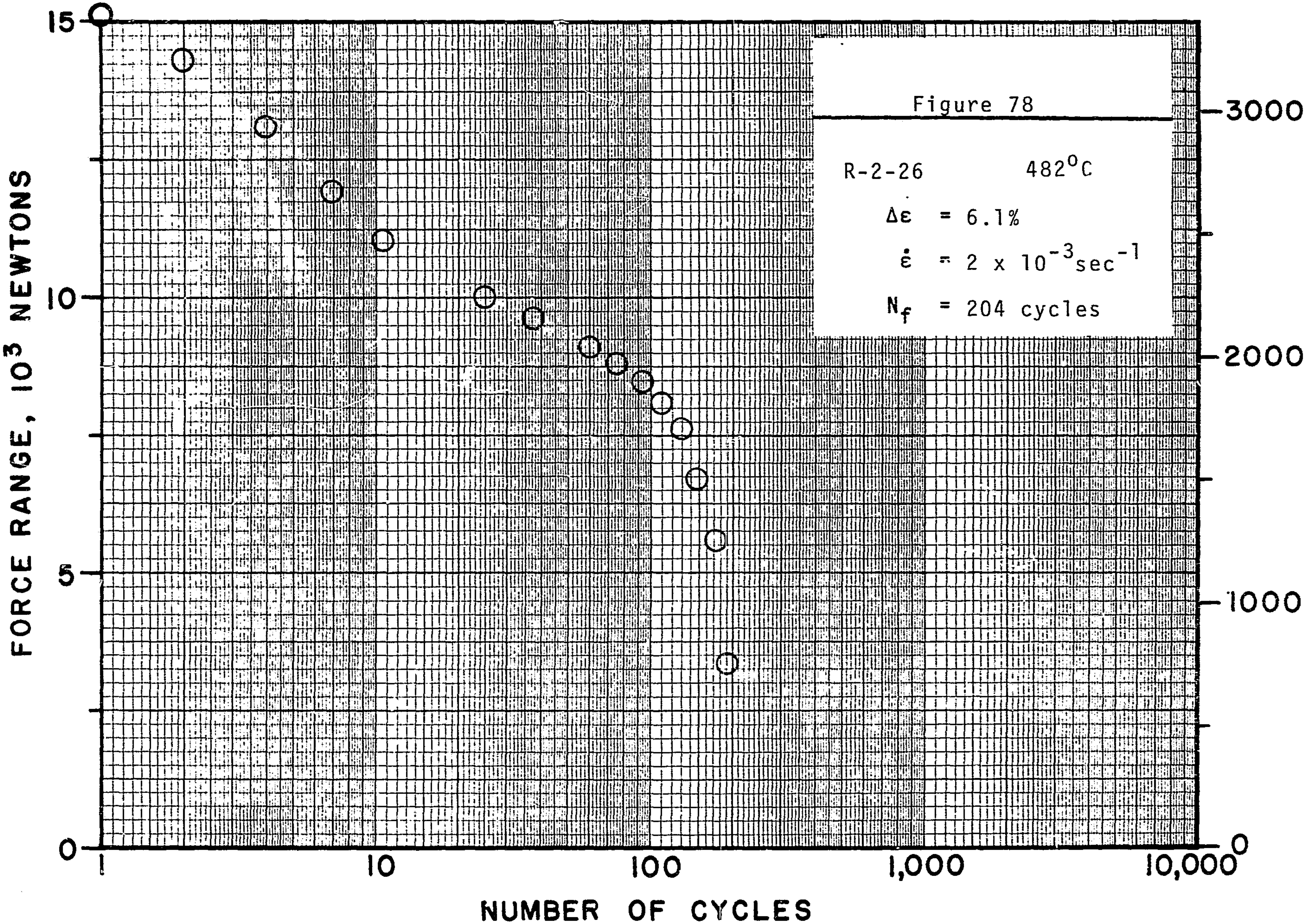

R-2-26 482°C
Δε = 6.1%
ε̇ = 2 x 10^-3 sec^-1
N_f = 204 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 78

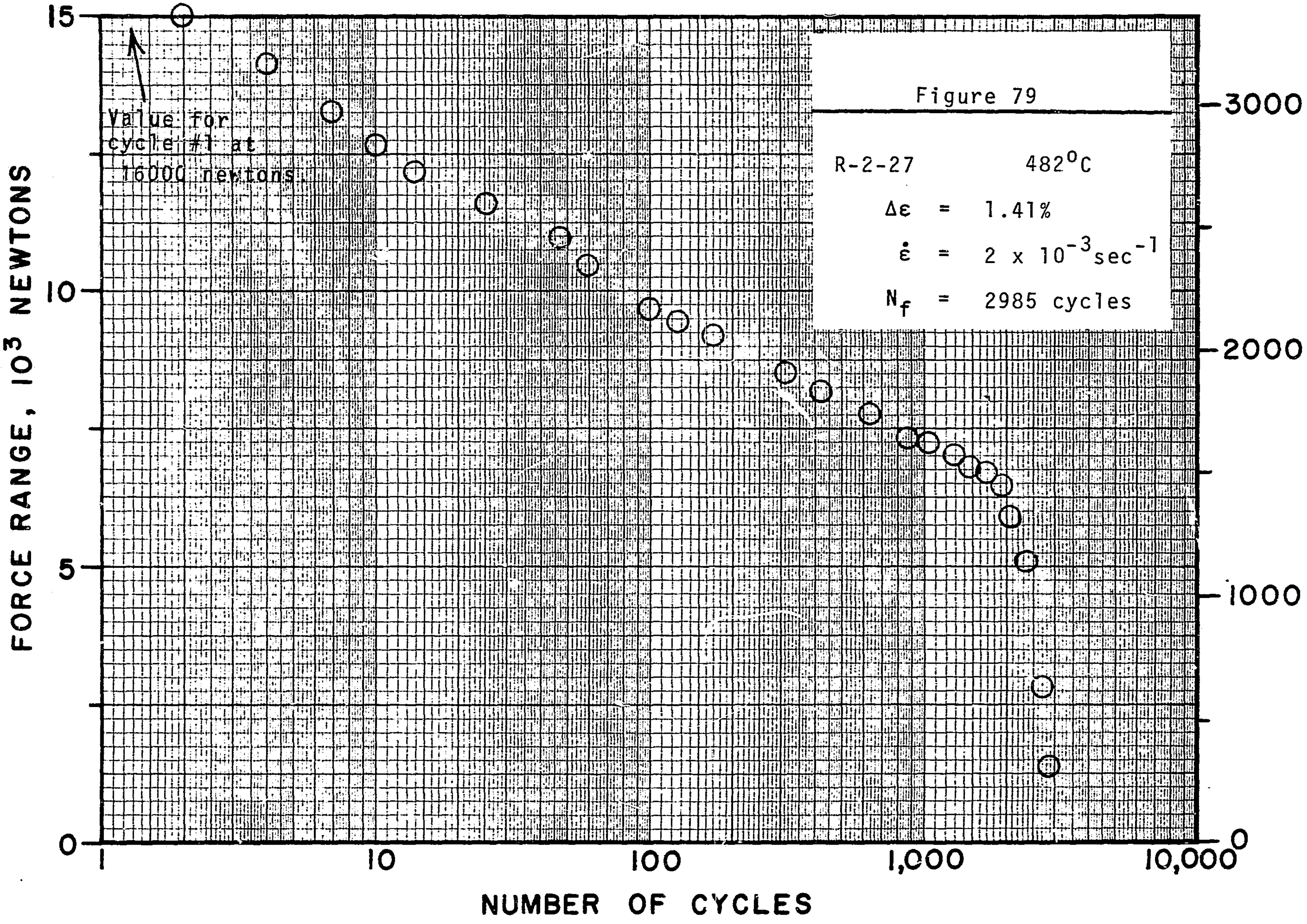

R-2-27 482°C
Δε = 1.41%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2985 cycles
Value for cycle #1 at 16000 newtons
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 79

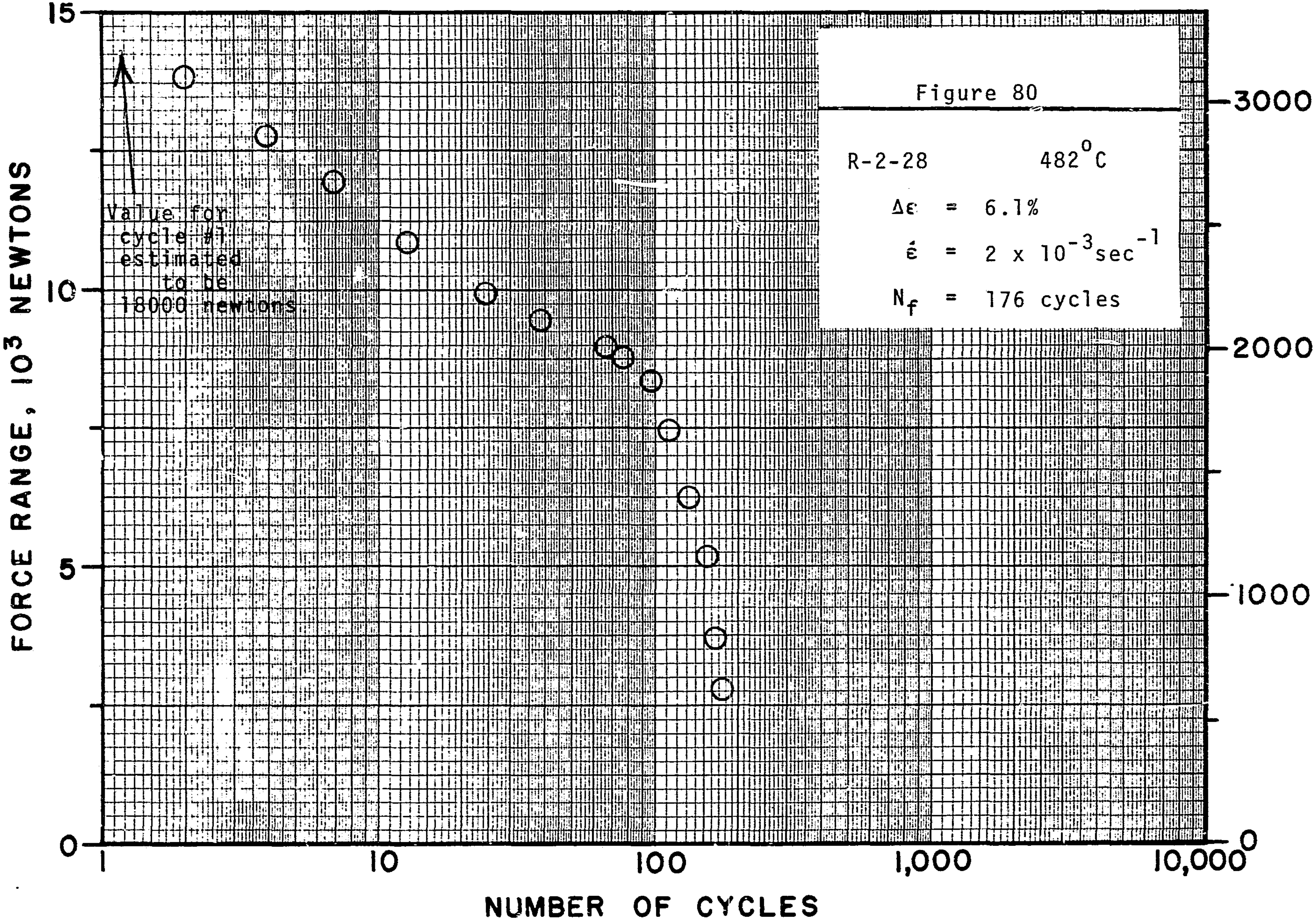


Figure 80
R-2-28 482°C
Δε = 6.1%
ε̇ = 2 x 10^-3 sec^-1
N_f = 176 cycles
Value for cycle #1 estimated to be 18000 newtons
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

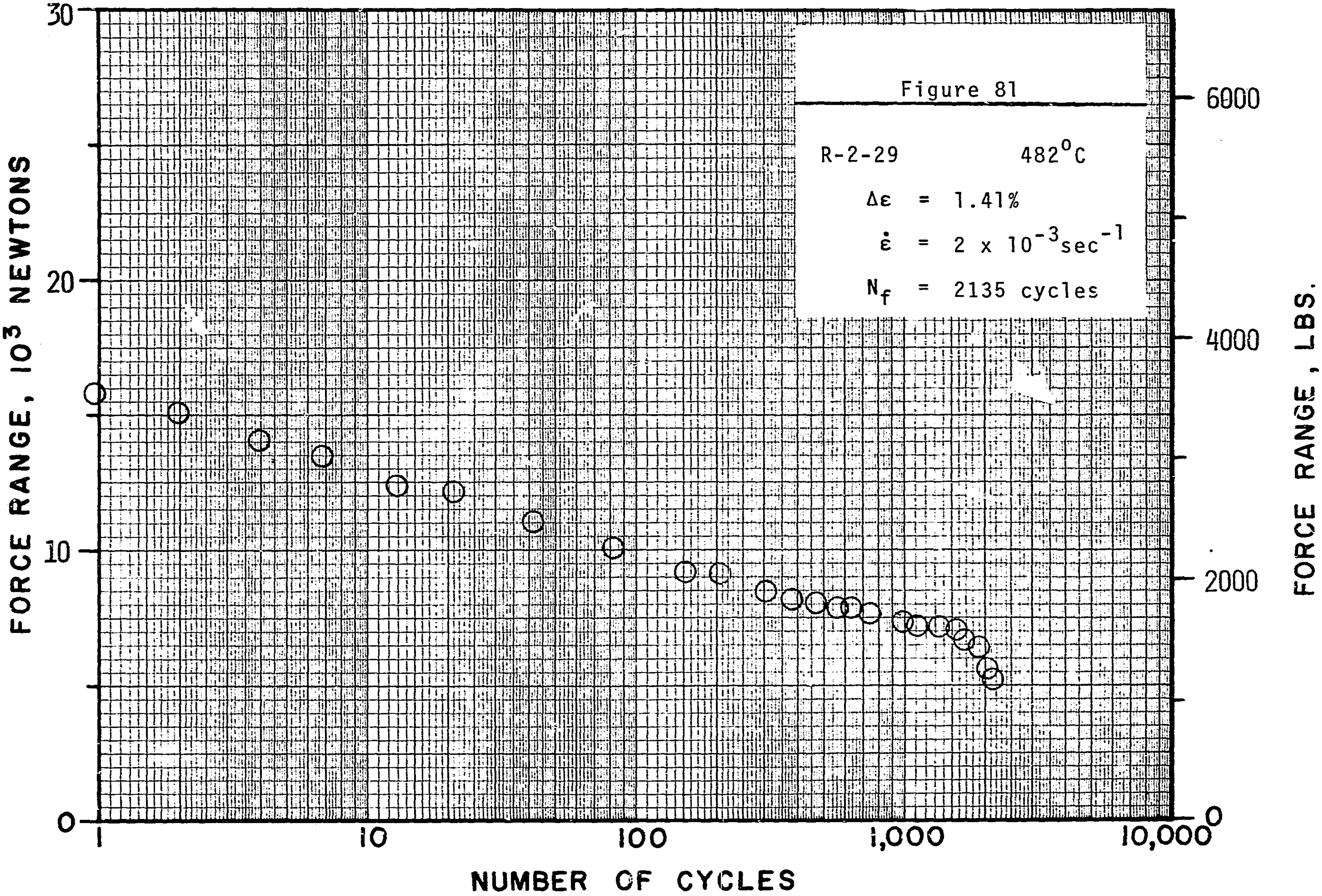

R-2-29 482°C
Δε = 1.41%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2135 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000

Figure 81

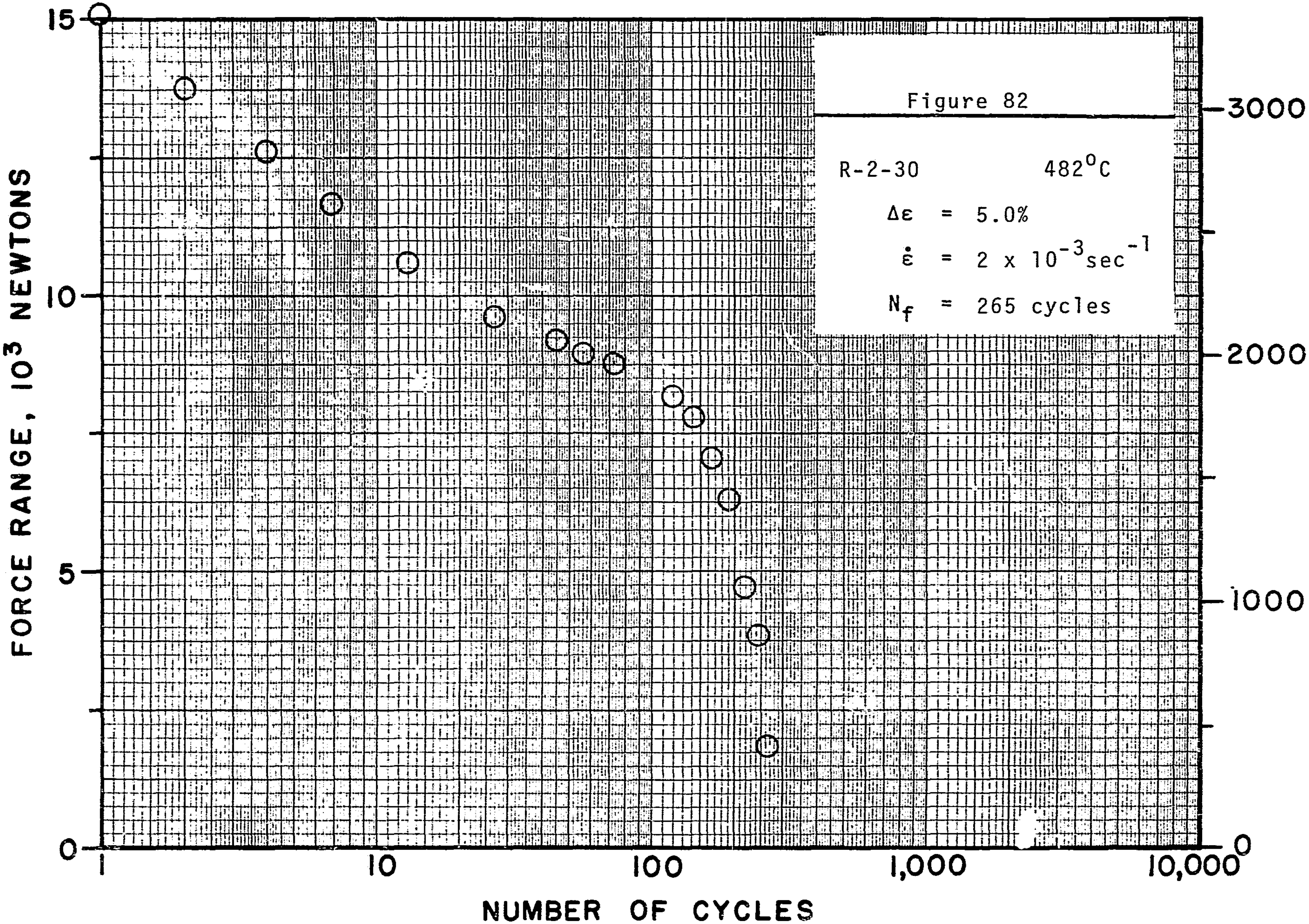


Figure 82
R-2-30 482°C
Δε = 5.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 265 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

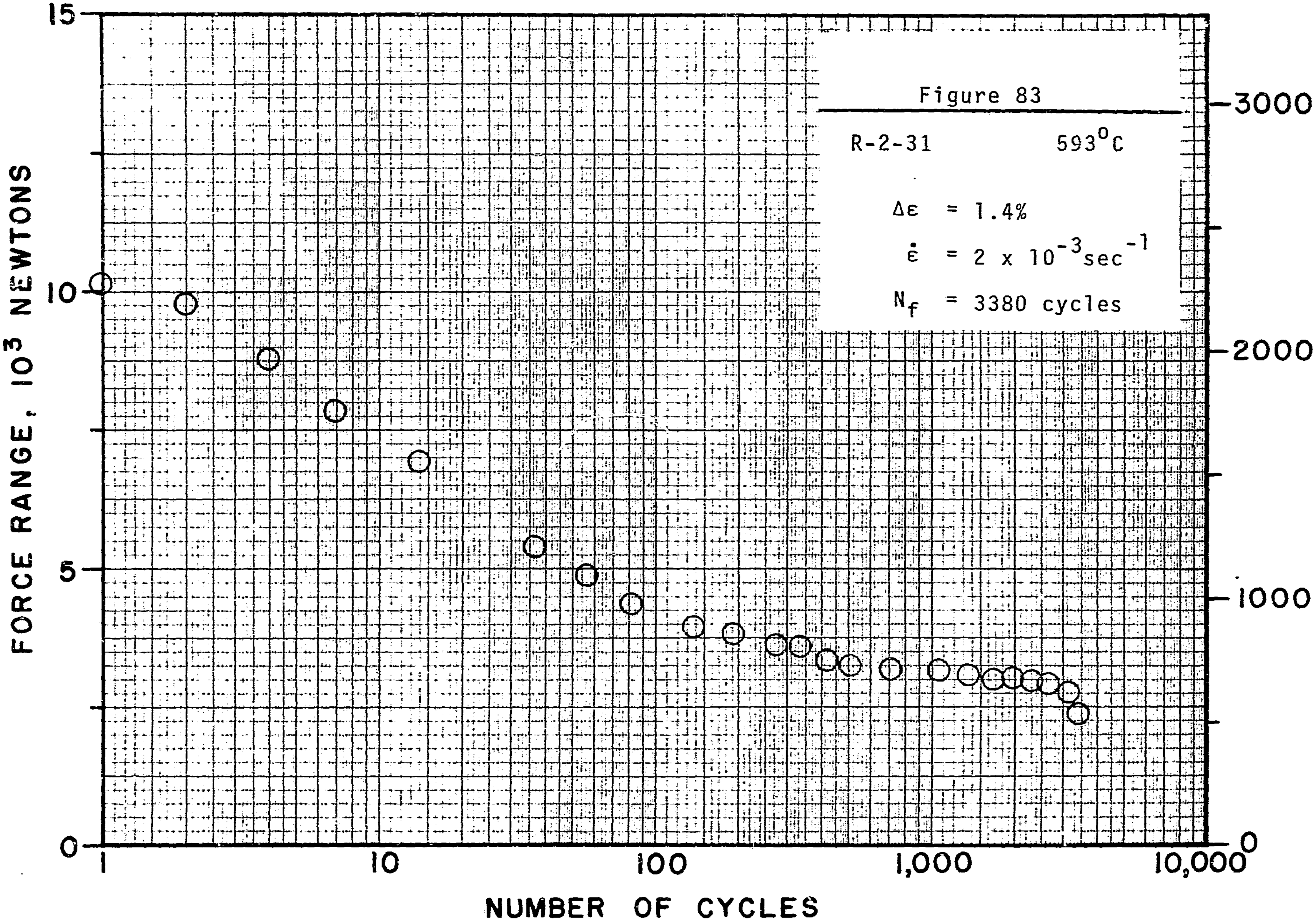


Figure 83
R-2-31
593°C
Δε = 1.4%
ε̇ = 2 x 10-3sec-1
Nf = 3380 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

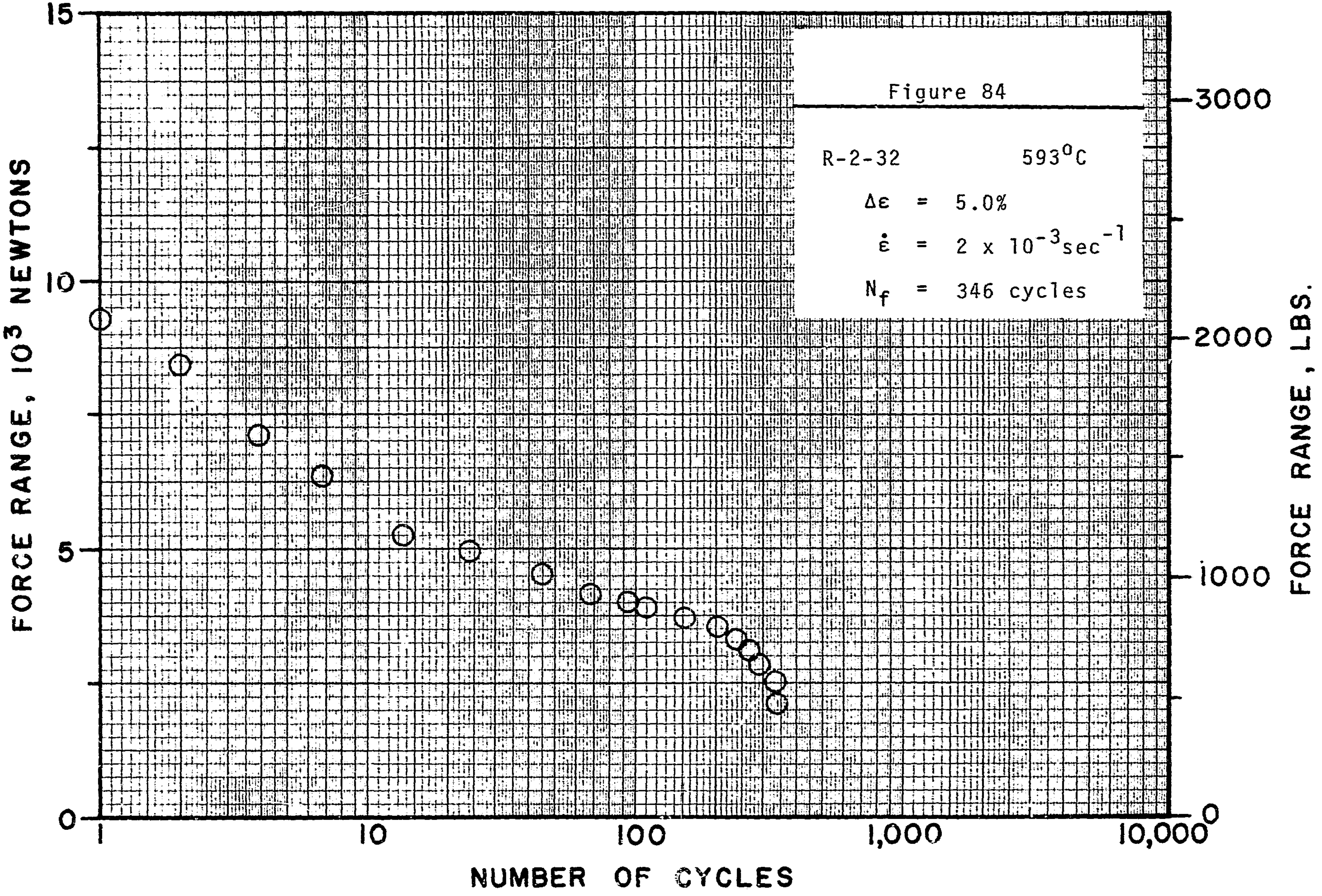

R-2-32
593°C
Δε = 5.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 346 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 84

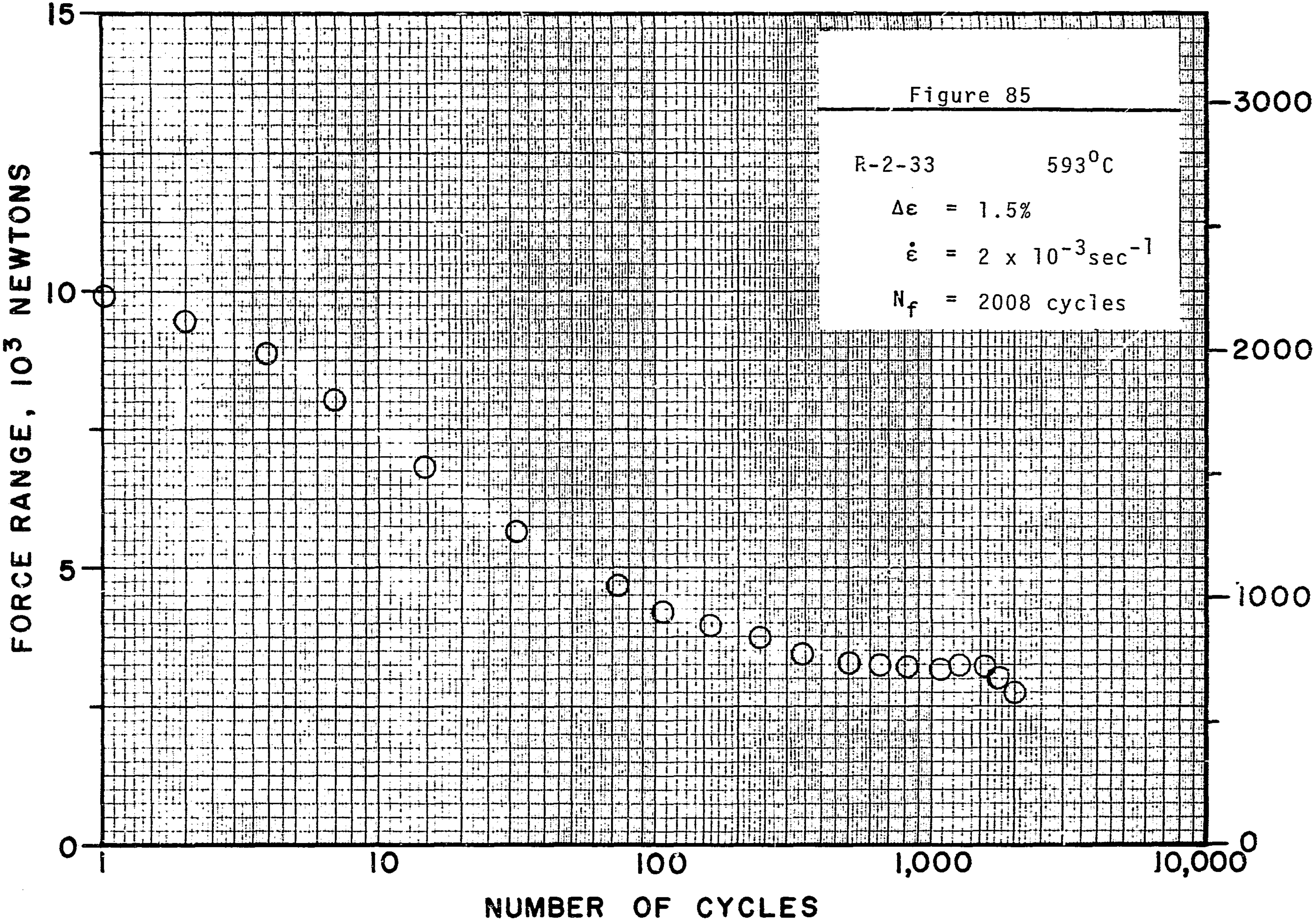


Figure 85
R-2-33 593°C
Δε = 1.5%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2008 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

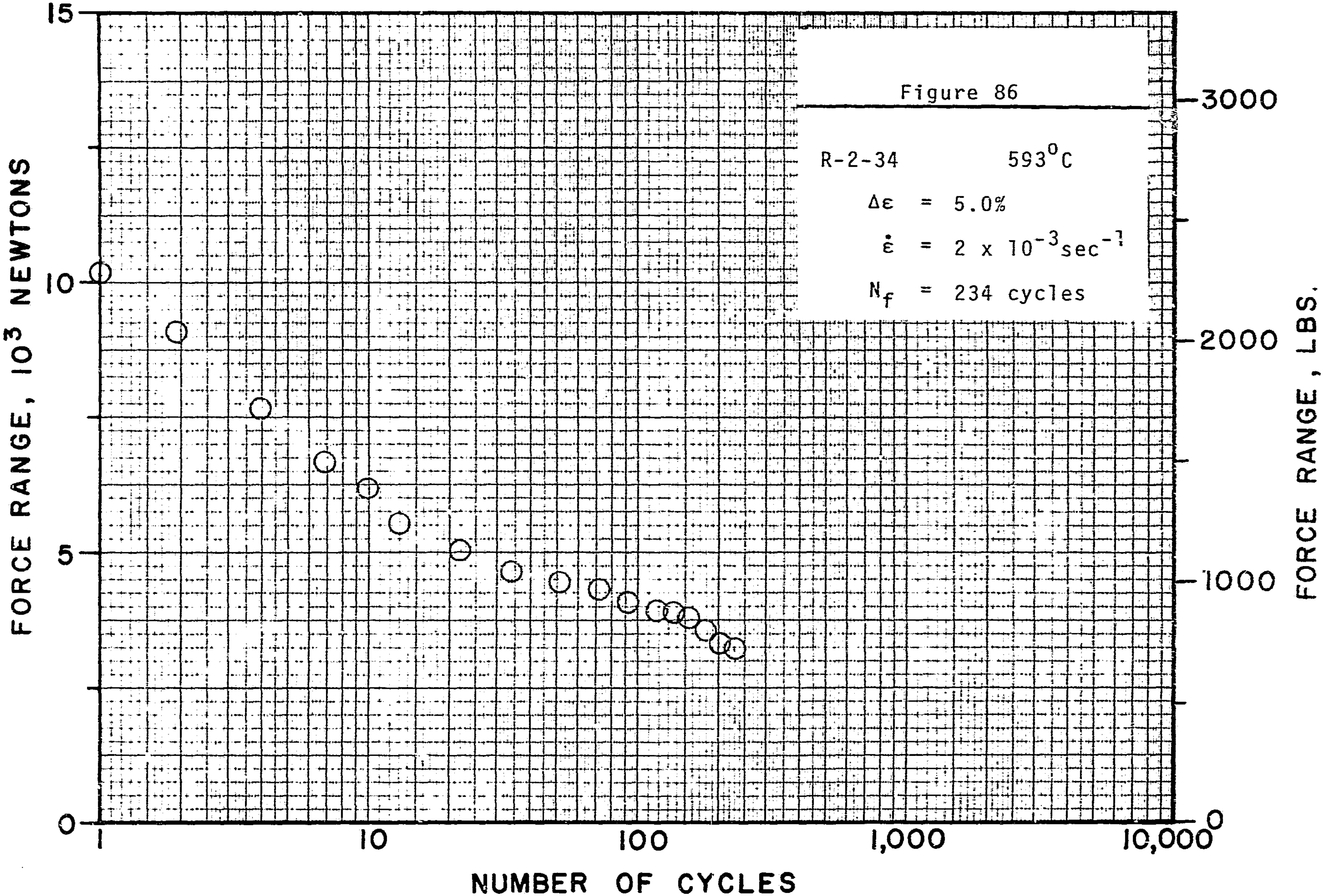


Figure 86
R-2-34 593°C
Δε = 5.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 234 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

C-2

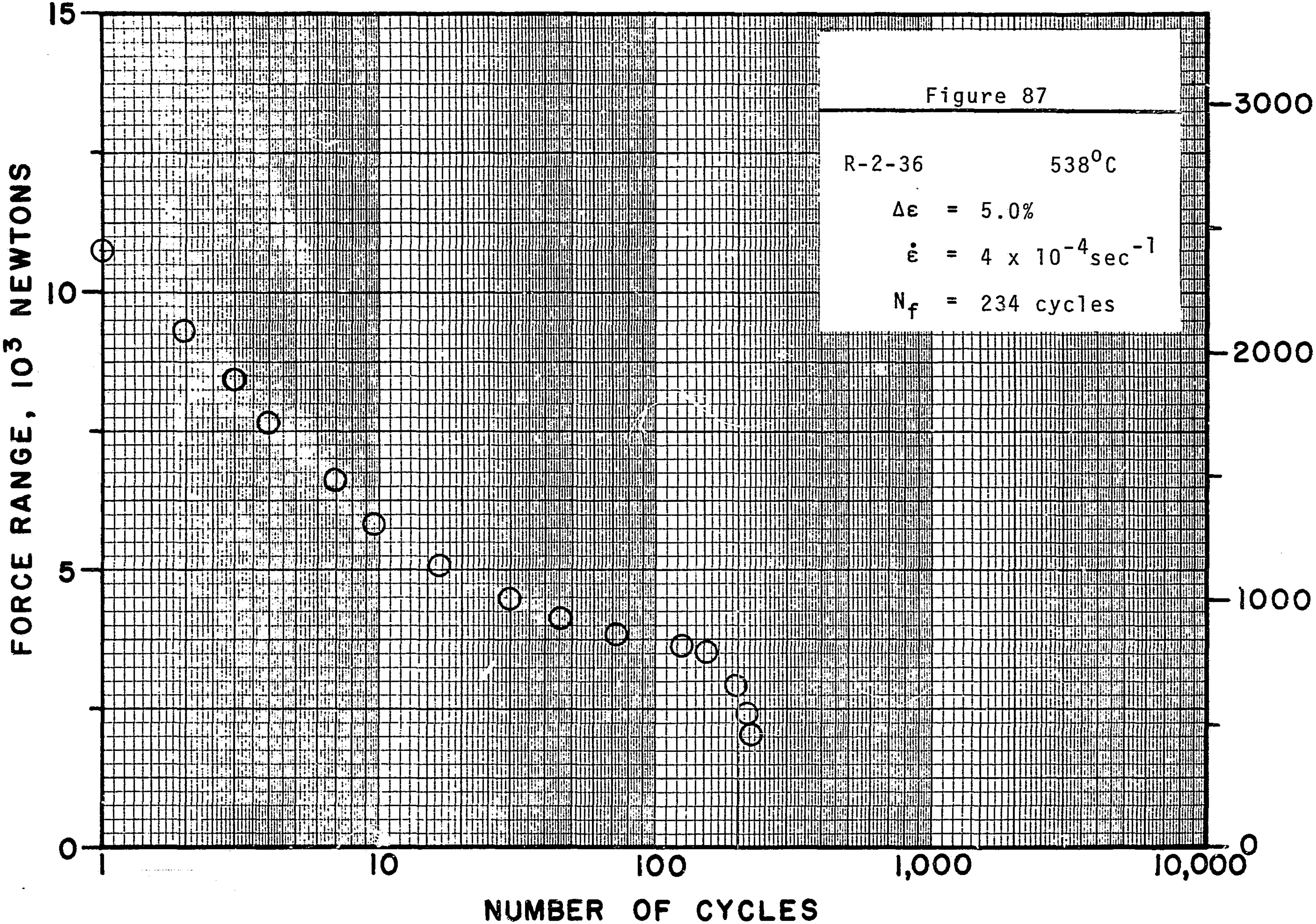

R-2-36 538°C
Δε = 5.0%
ε̇ = 4 x 10^-4 sec^-1
N_f = 234 cycles
15
10
5
0
FORCE RANGE, 10³ NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 87

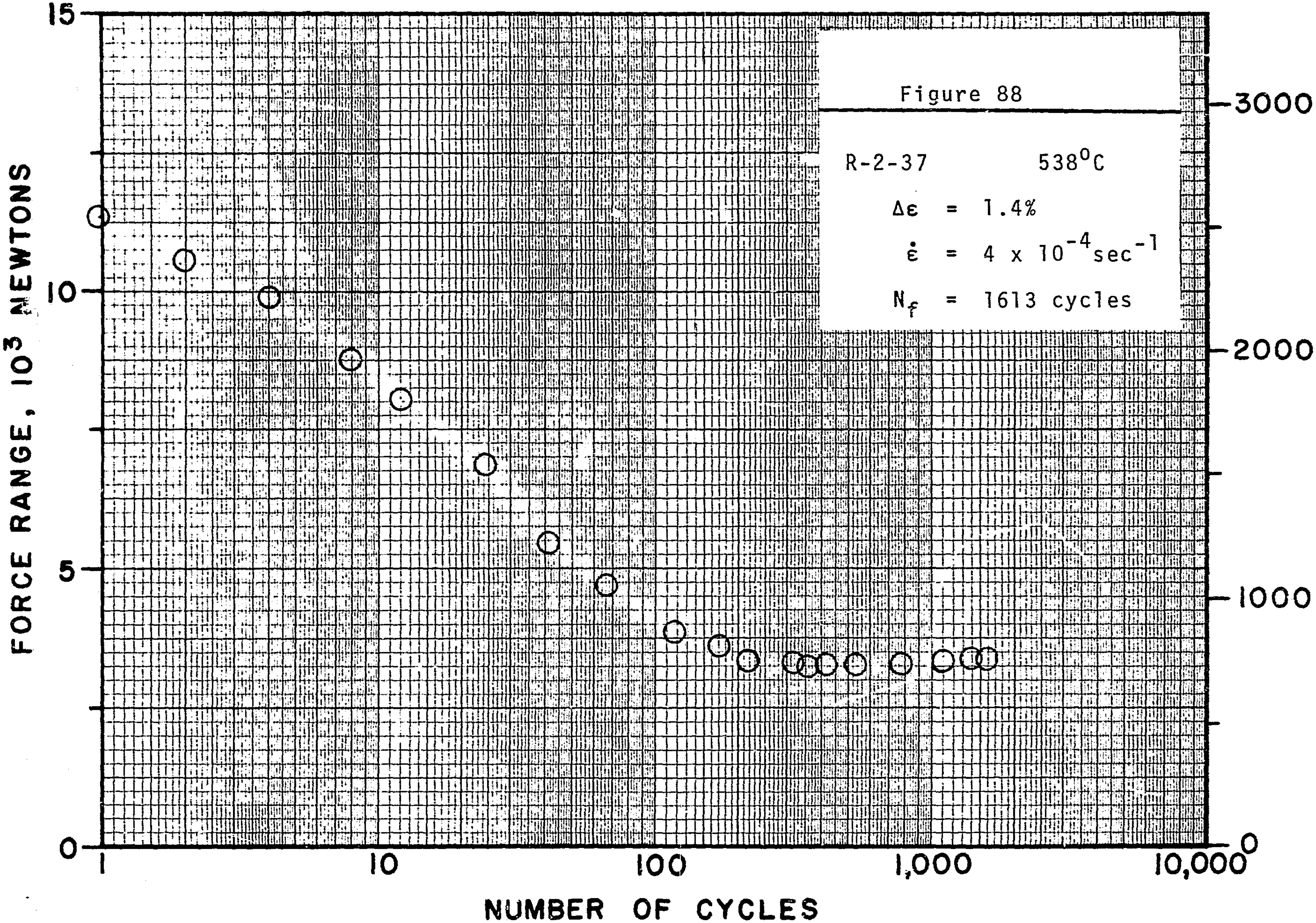

R-2-37 538°C
Δε = 1.4%
$\dot{\varepsilon}$ = 4 x 10^{-4} sec^{-1}
N_f = 1613 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 88

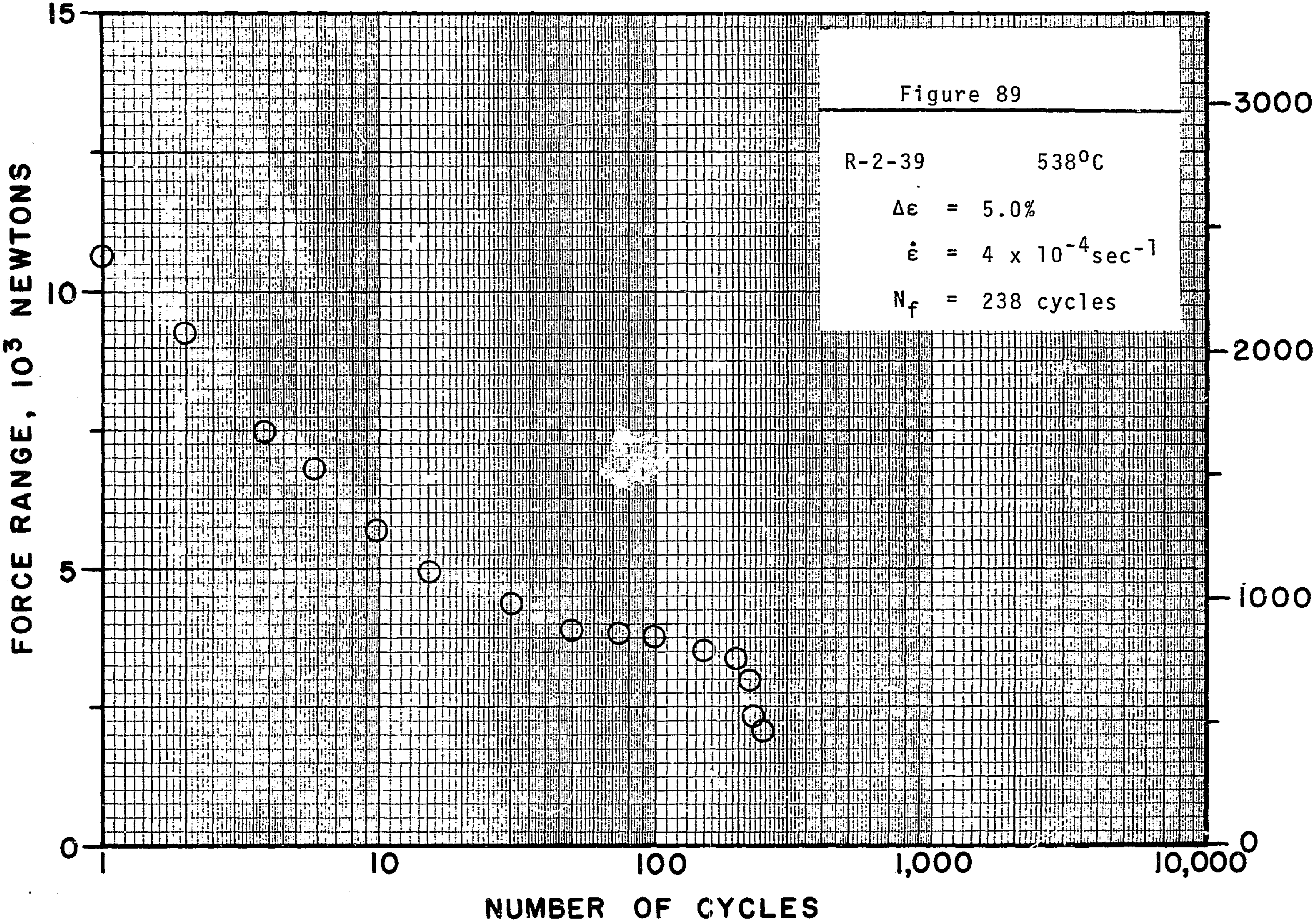


Figure 89
R-2-39 538°C
Δε = 5.0%
ε̇ = 4 x 10⁻⁴sec⁻¹
N_f = 238 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

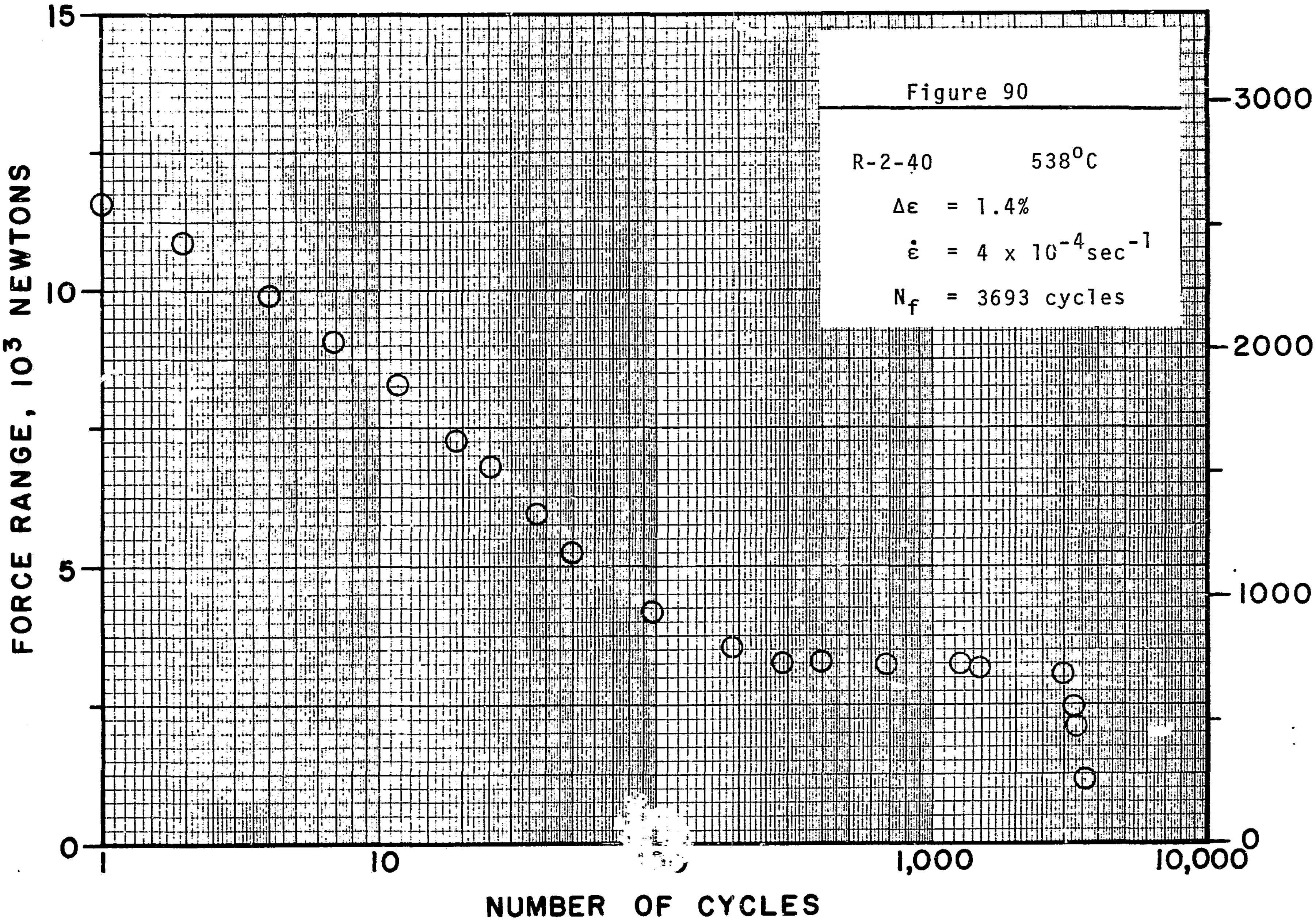


Figure 90
R-2-40 538°C
Δε = 1.4%
ε̇ = 4 x 10^-4 sec^-1
N_f = 3693 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
1,000
10,000

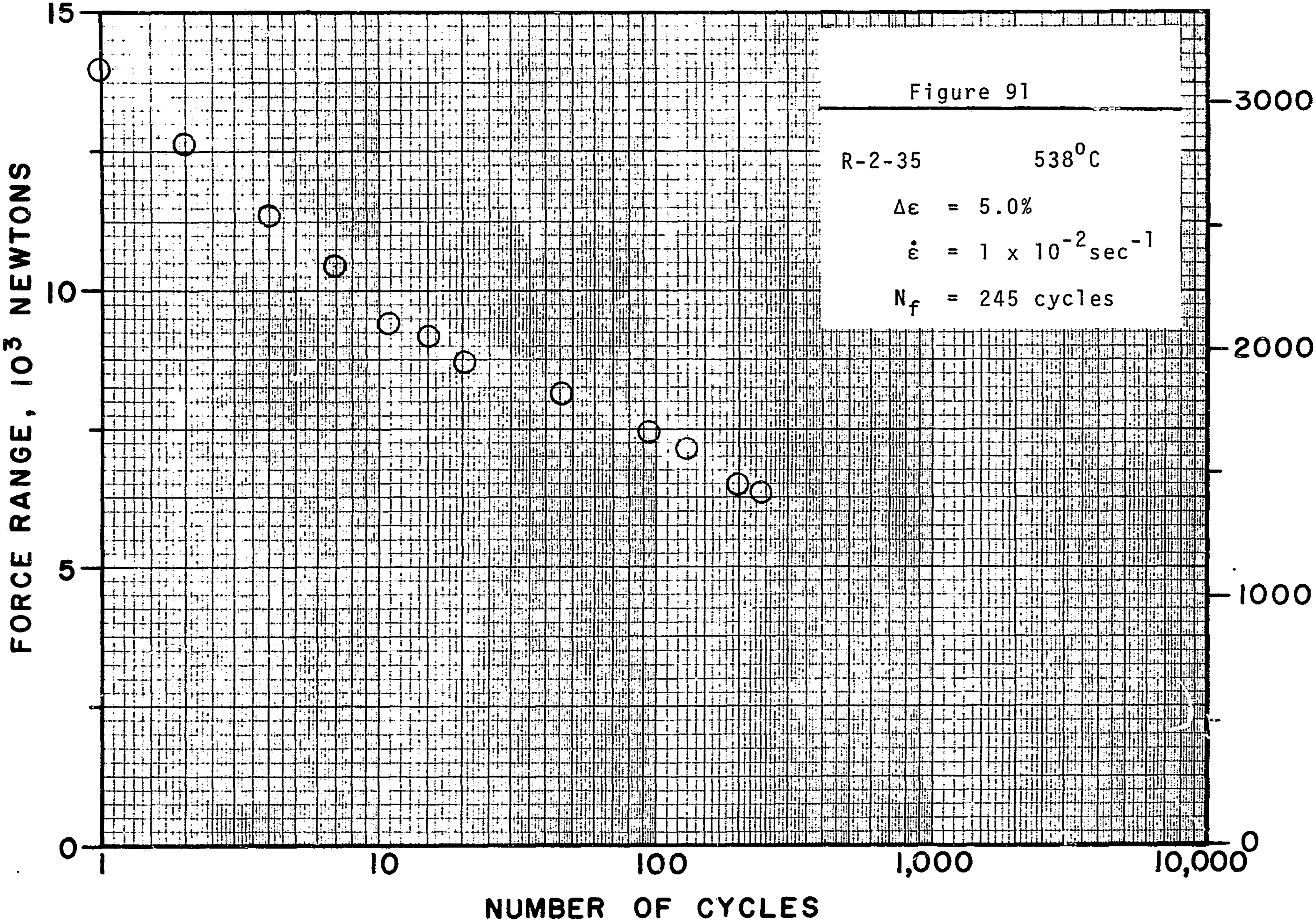


Figure 91
R-2-35 538°C
Δε = 5.0%
ε̇ = 1 x 10^-2 sec^-1
N_f = 245 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

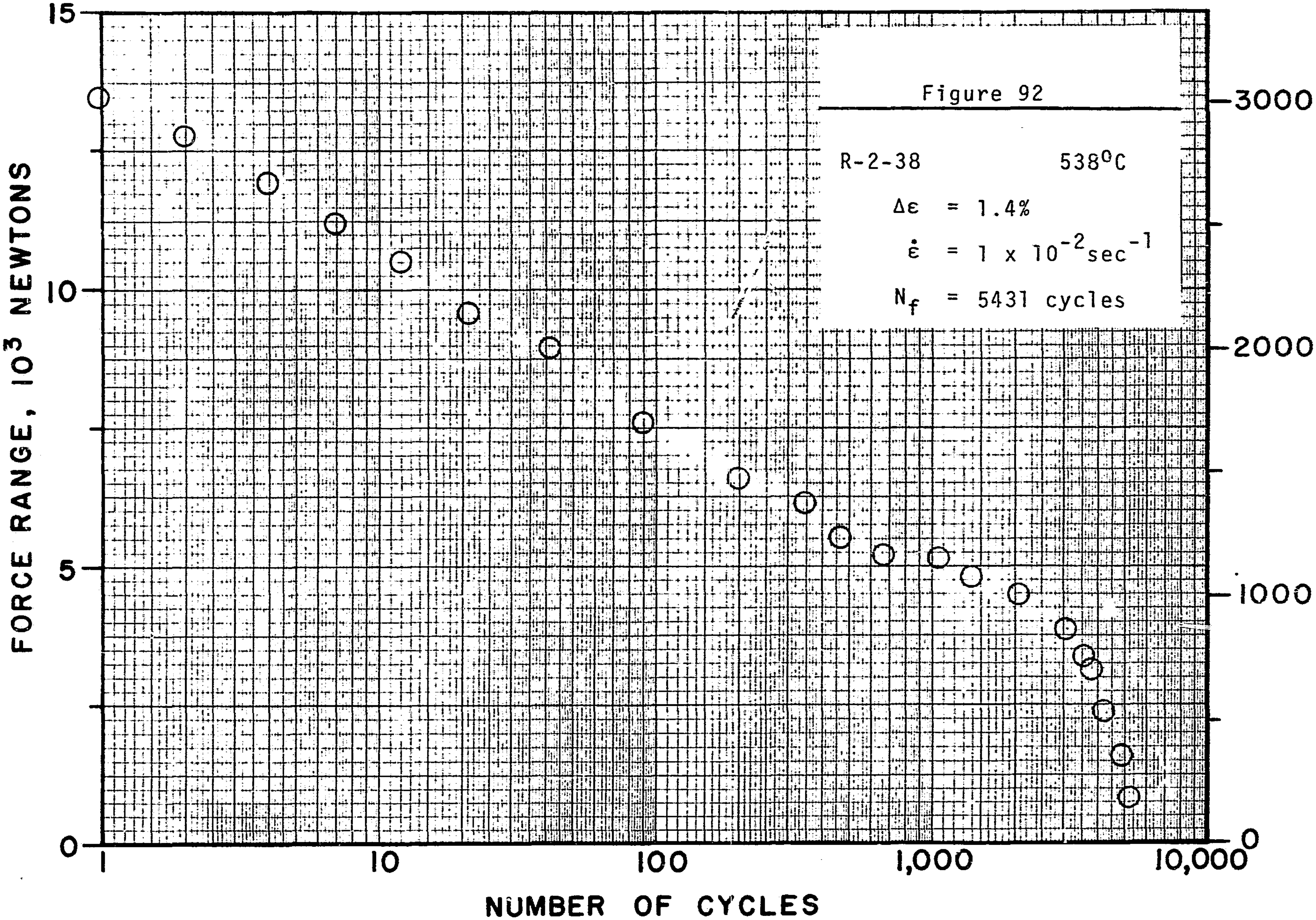


Figure 92
R-2-38
538°C
Δε = 1.4%
ε̇ = 1 x 10-2sec-1
Nf = 5431 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

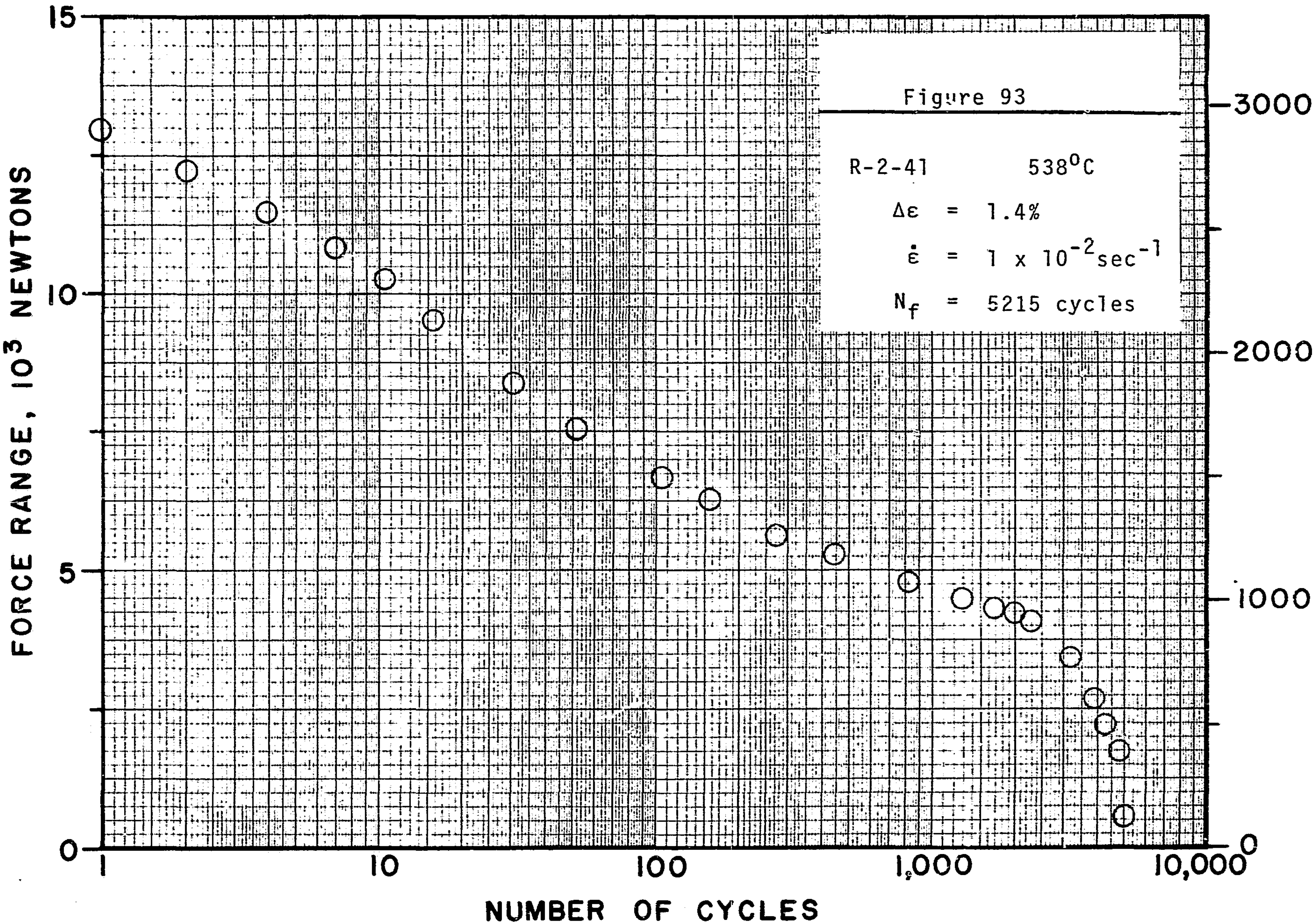

FORCE RANGE, 10^3 NEWTONS
15
10
5
0
1
10
100
1,000
10,000
NUMBER OF CYCLES
FORCE RANGE, LBS.
3000
2000
1000
0
R-2-41 538°C
$\Delta\varepsilon$ = 1.4%
$\dot{\varepsilon}$ = $1 \times 10^{-2} sec^{-1}$
N_f = 5215 cycles

Figure 93

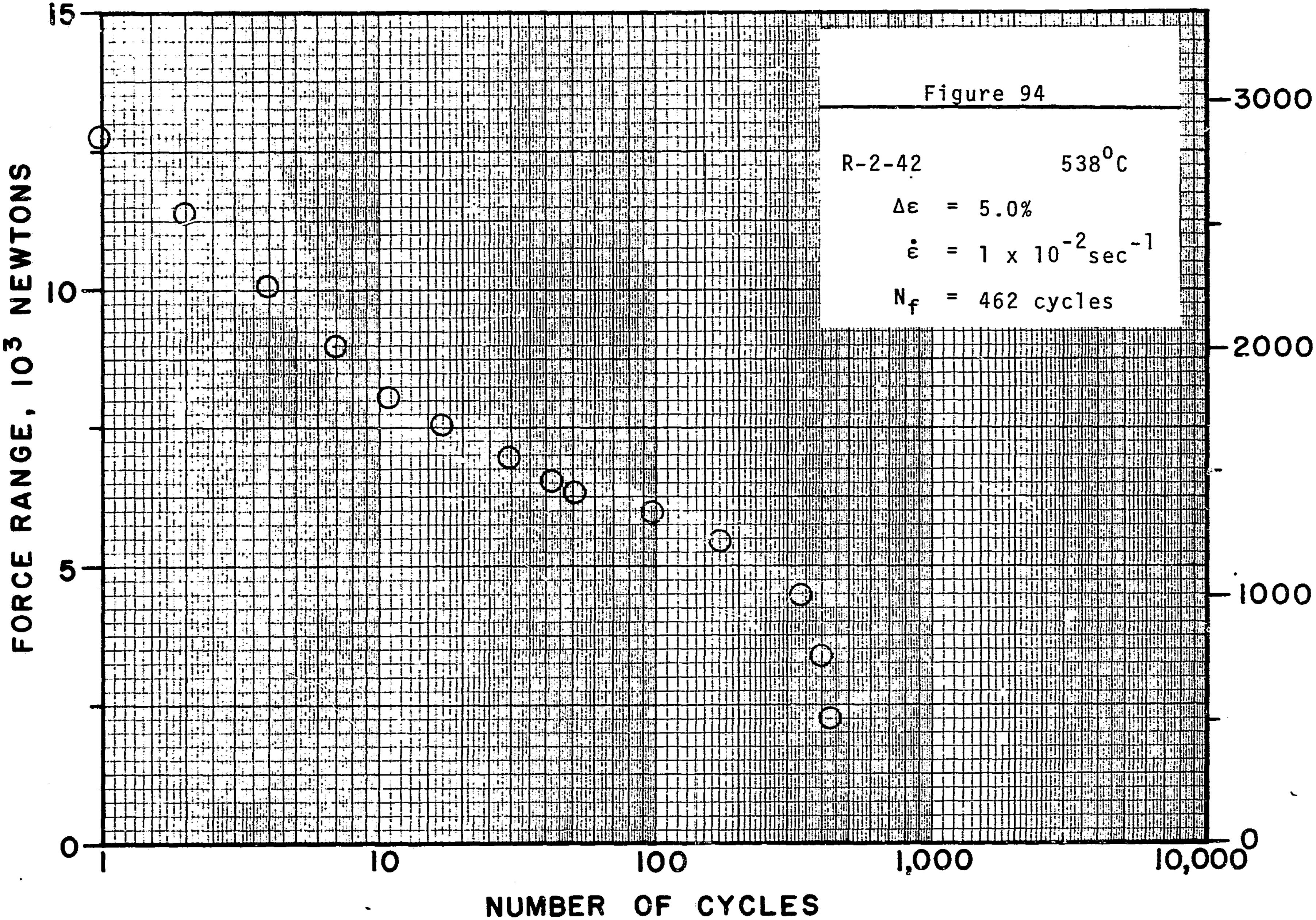


Figure 94

R-2-42 538°C

$\Delta\varepsilon$ = 5.0%

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

N_f = 462 cycles

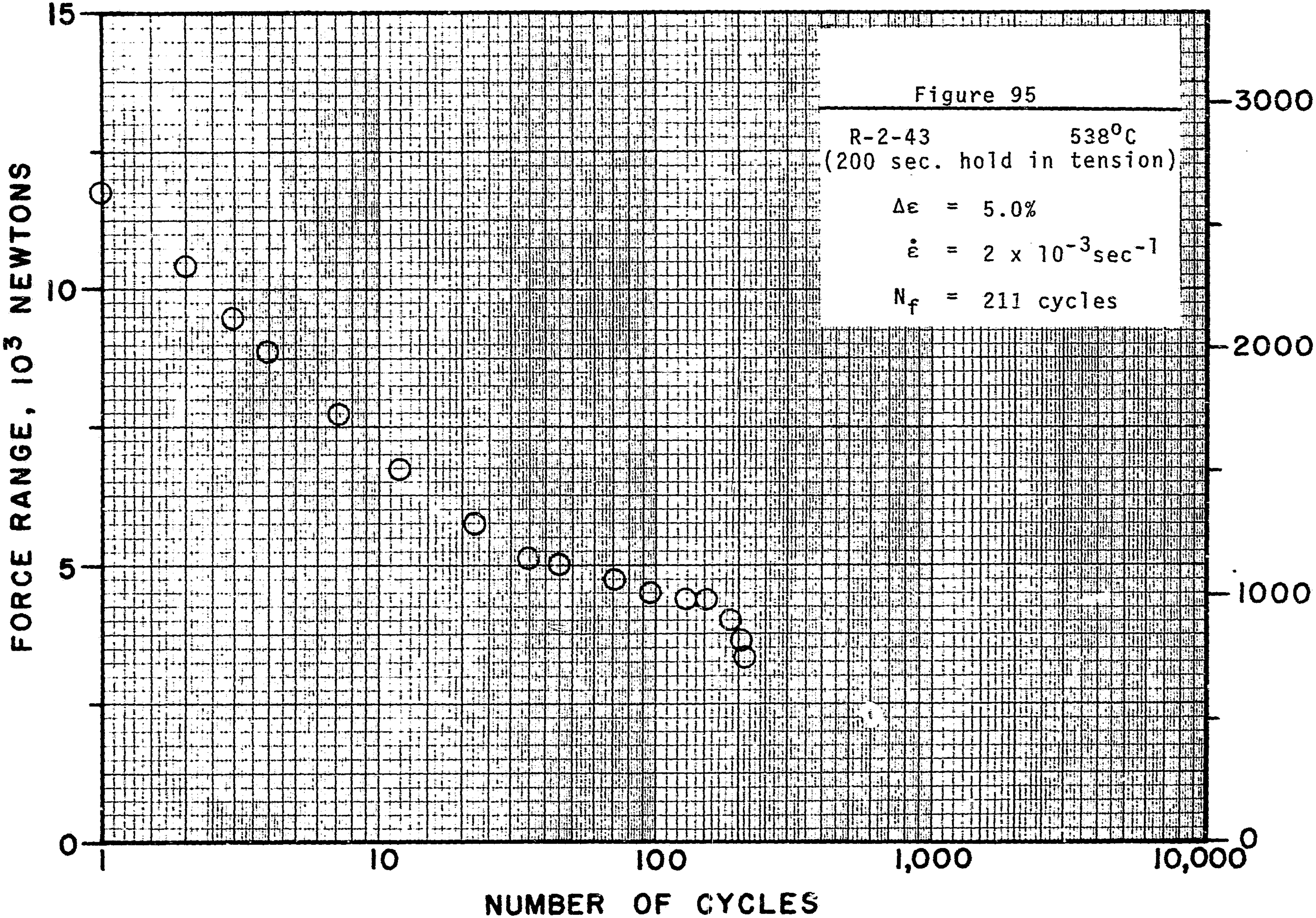


Figure 95

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

$\Delta\varepsilon$ = 5.0%

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

N_f = 211 cycles

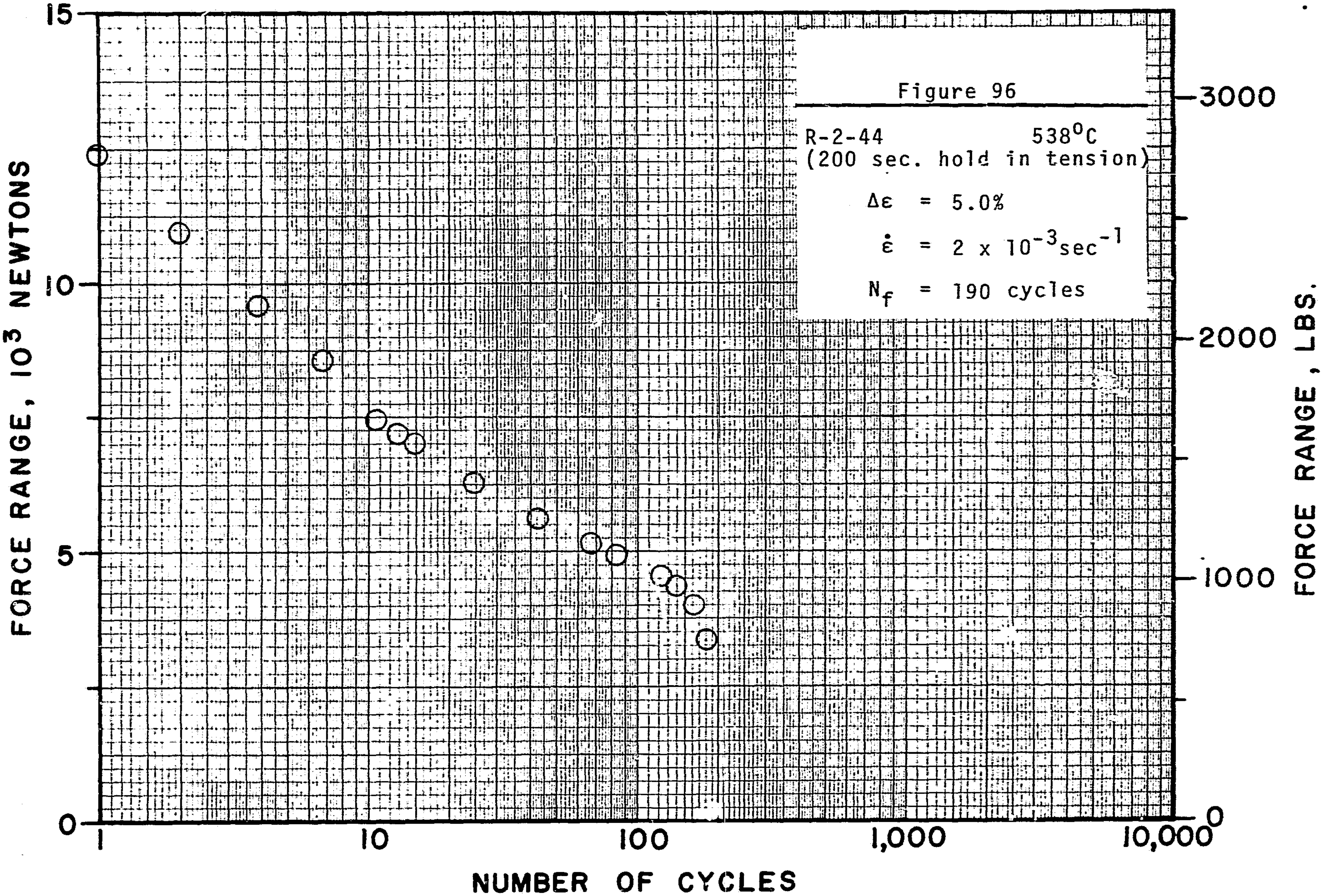


Figure 96
R-2-44 538°C
(200 sec. hold in tension)
Δε = 5.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 190 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

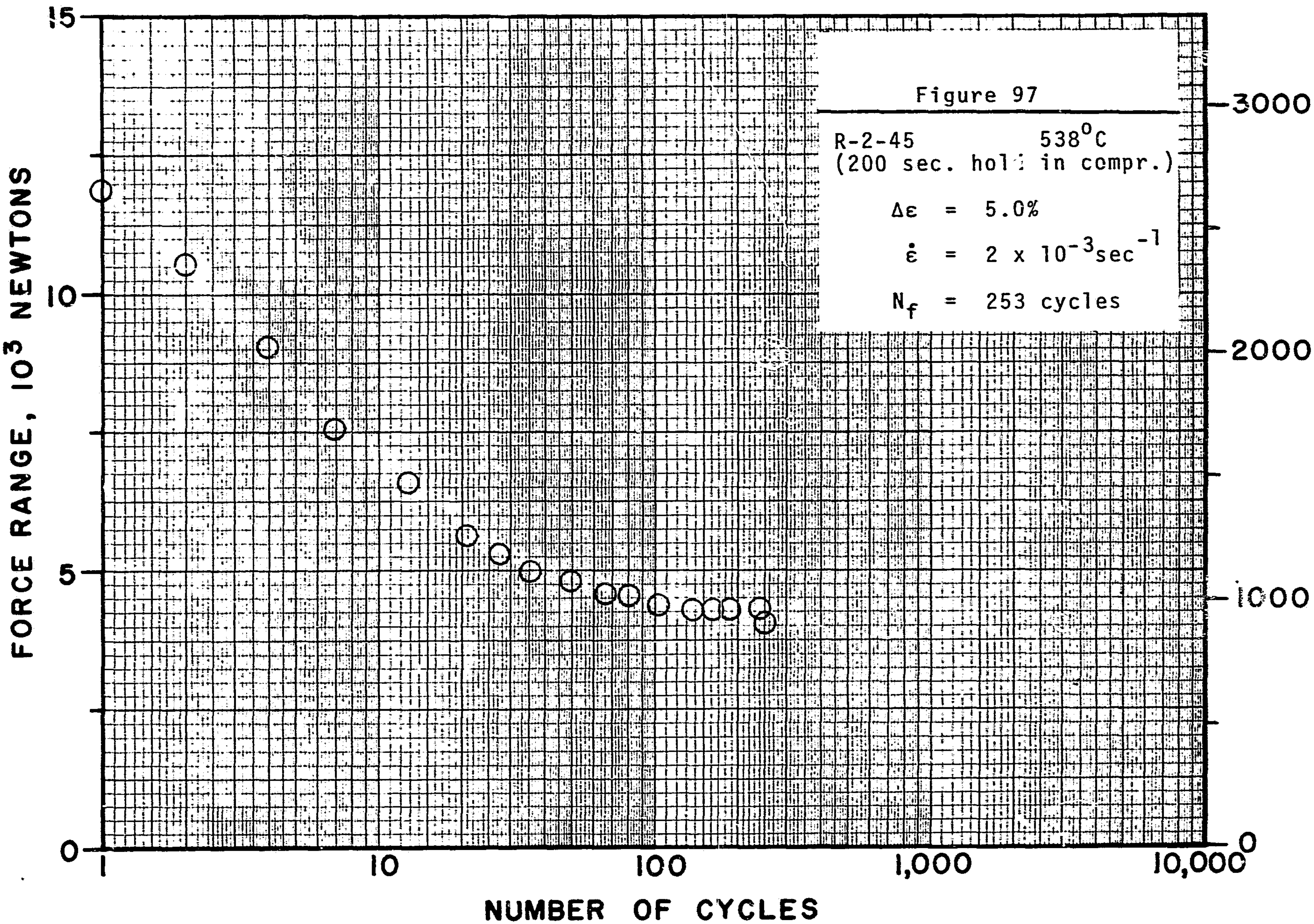


Figure 97
R-2-45 538°C
(200 sec. hold in compr.)
Δε = 5.0%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 253 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

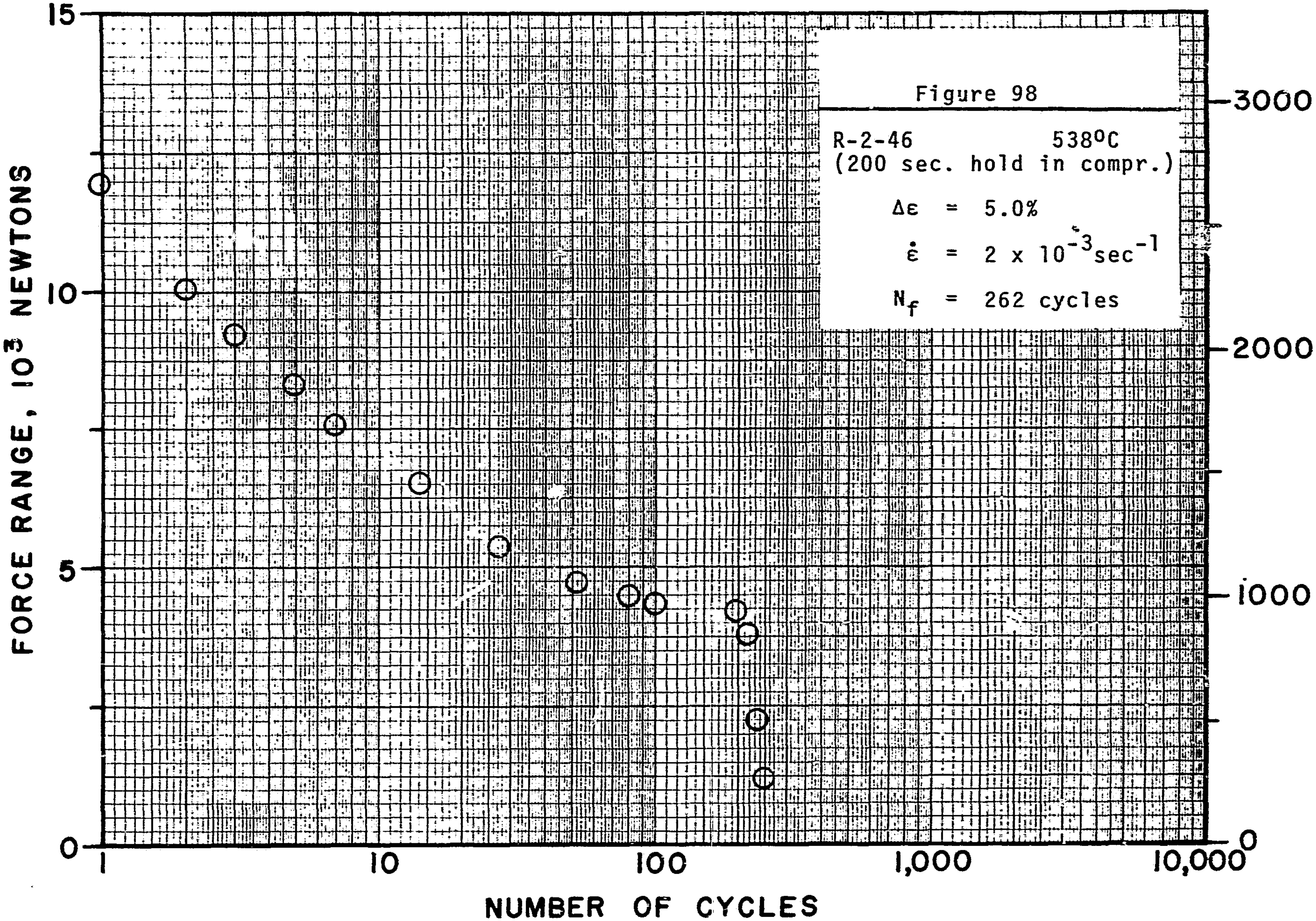


Figure 98
R-2-46 538°C
(200 sec. hold in compr.)
Δε = 5.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 262 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

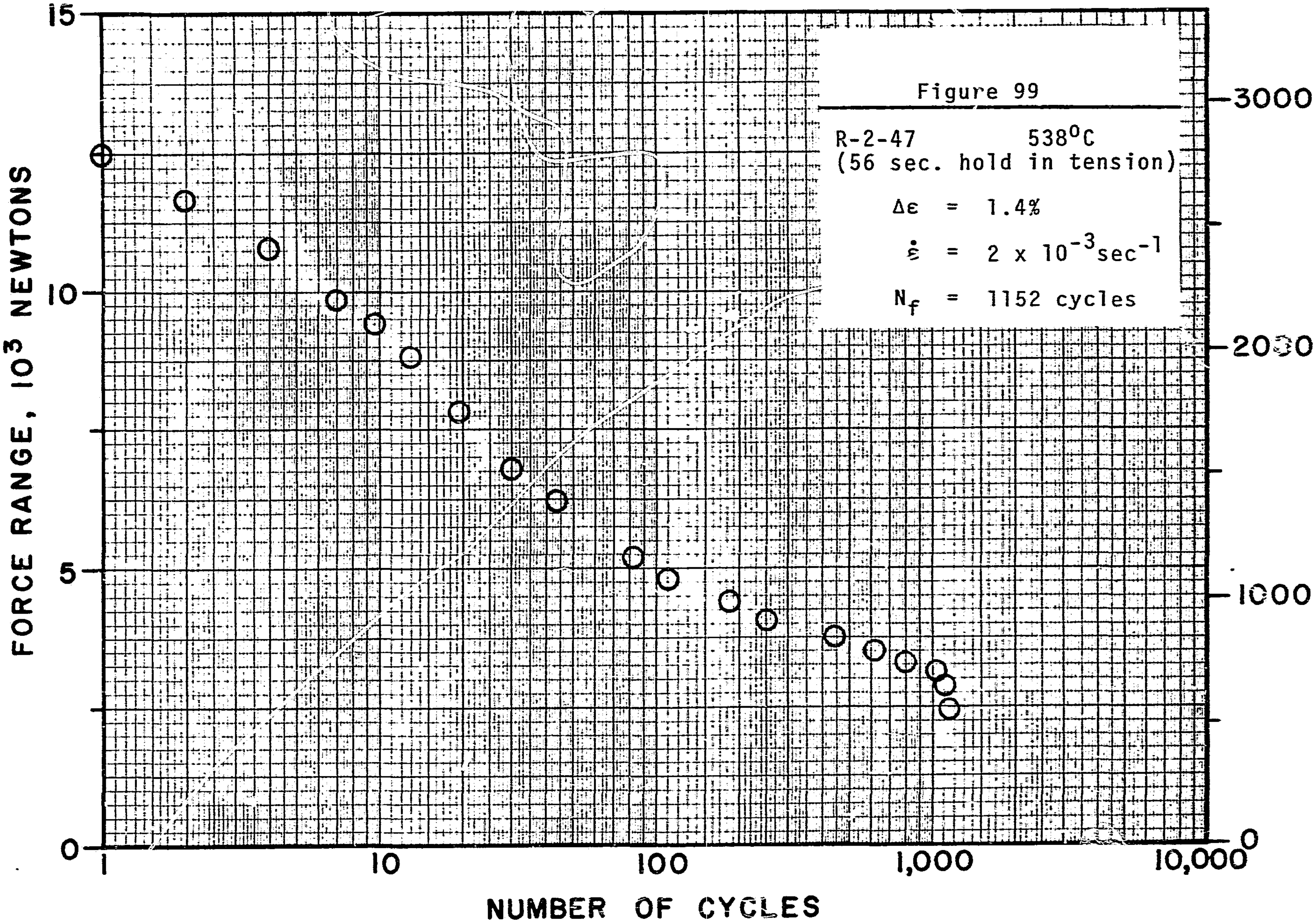


Figure 99
R-2-47 538°C
(56 sec. hold in tension)
Δε = 1.4%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1152 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

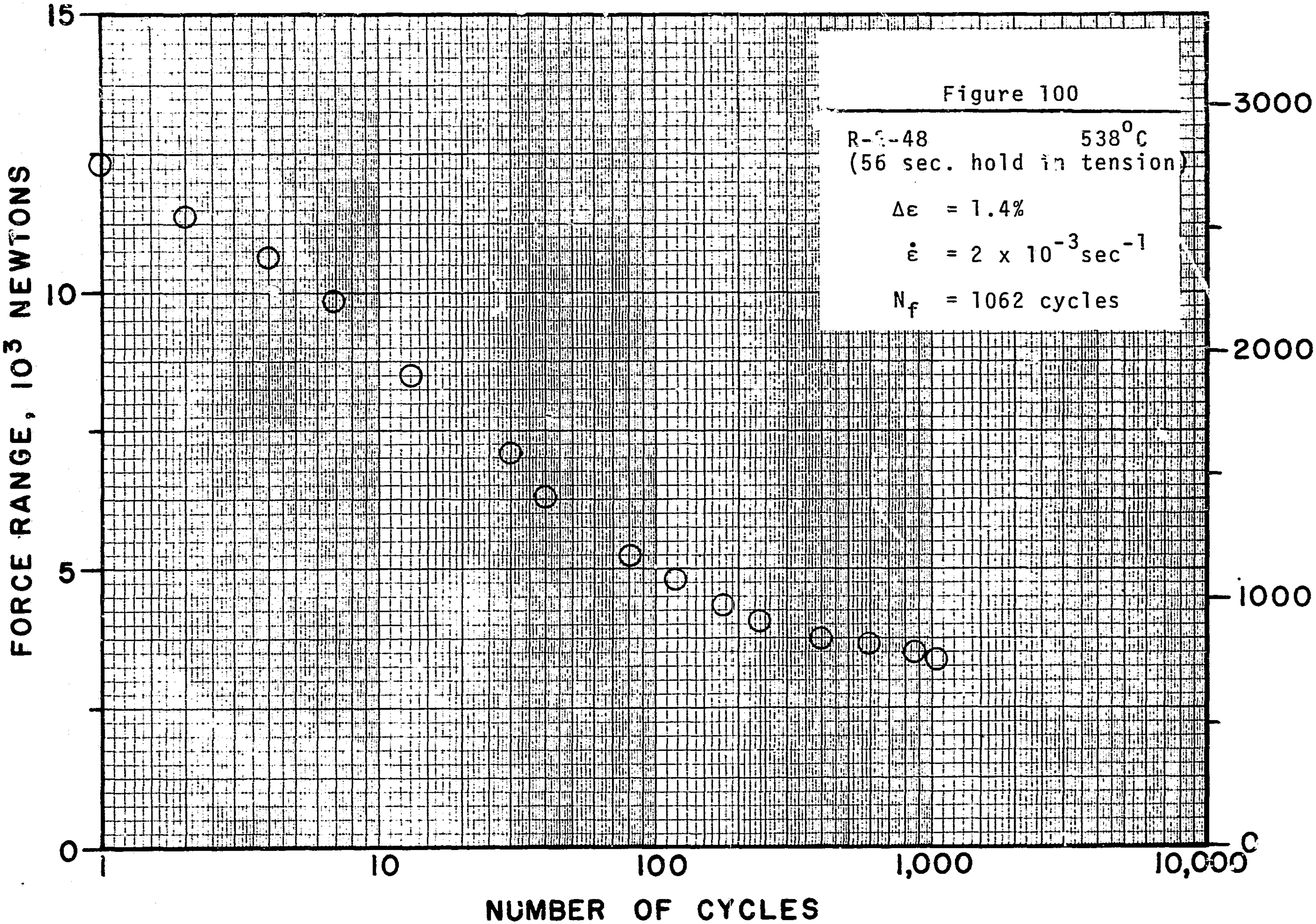


Figure 100

R-[illegible]-48 538°C
(56 sec. hold in tension)

$\Delta\varepsilon$ = 1.4%

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

N_f = 1062 cycles

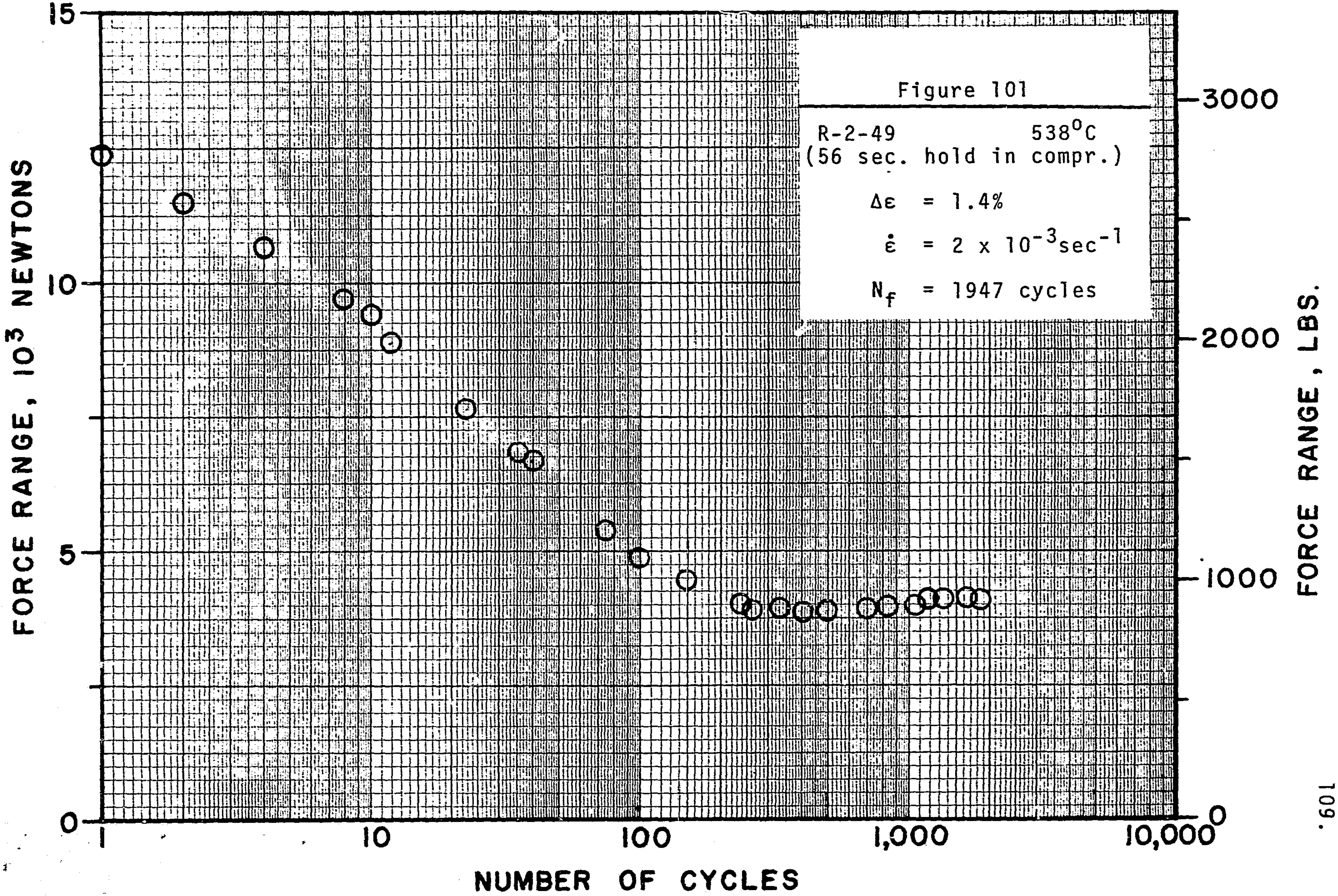

R-2-49 538°C
(56 sec. hold in compr.)
Δε = 1.4%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1947 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 101

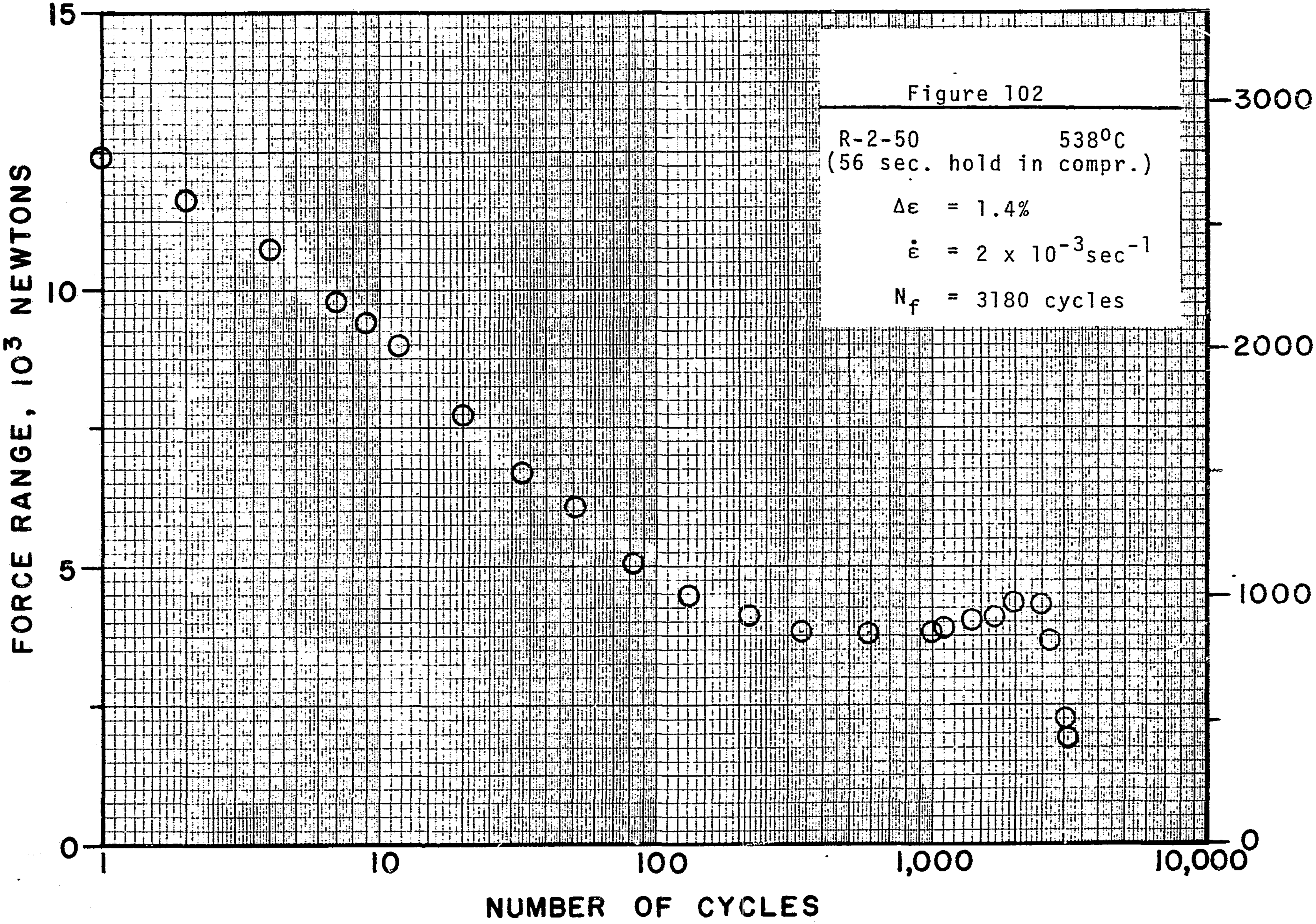


Figure 102
R-2-50 538°C
(56 sec. hold in compr.)
Δε = 1.4%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3180 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

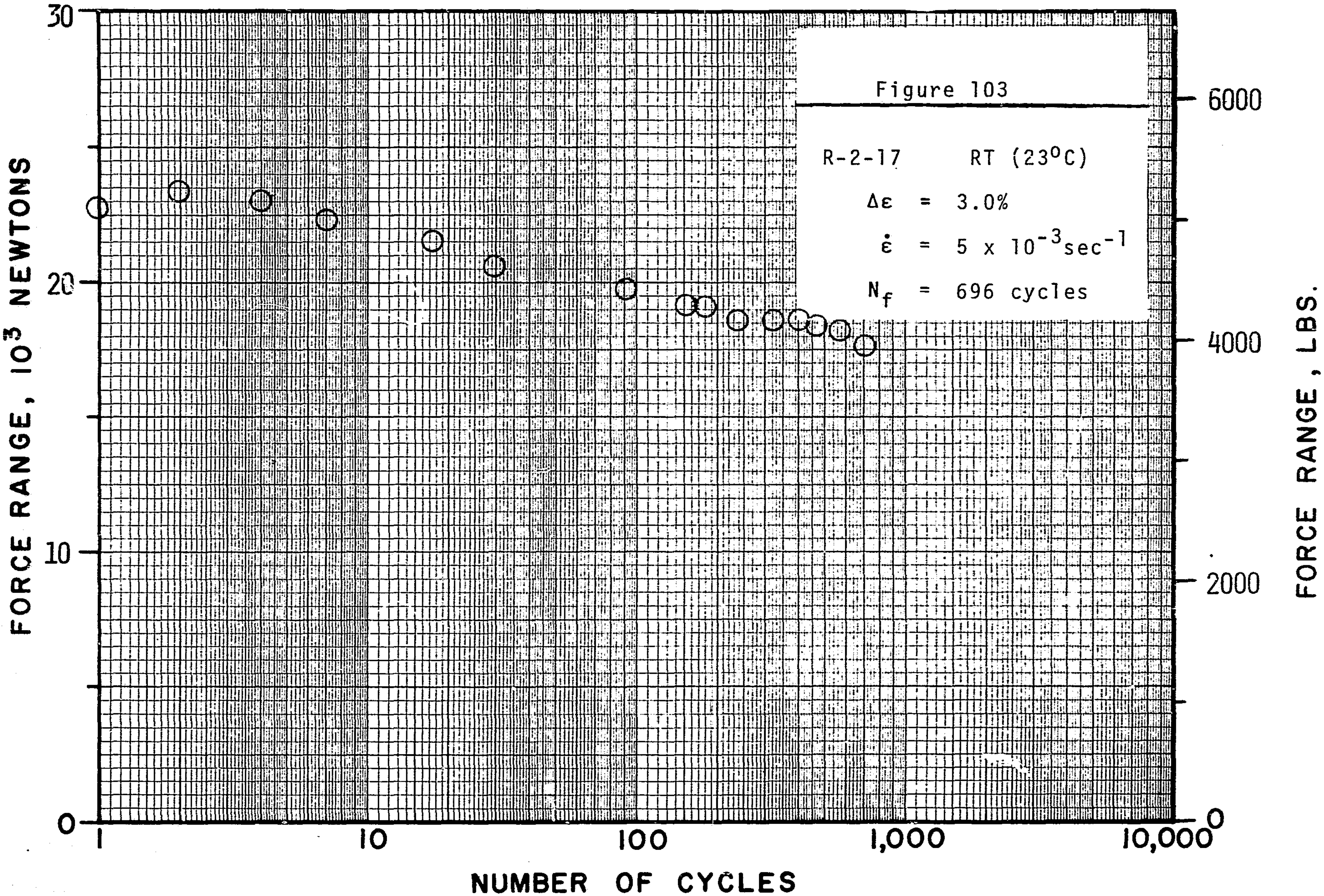


Figure 103
R-2-17 RT (23°C)
Δε = 3.0%
ε̇ = 5 x 10⁻³sec⁻¹
N_f = 696 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

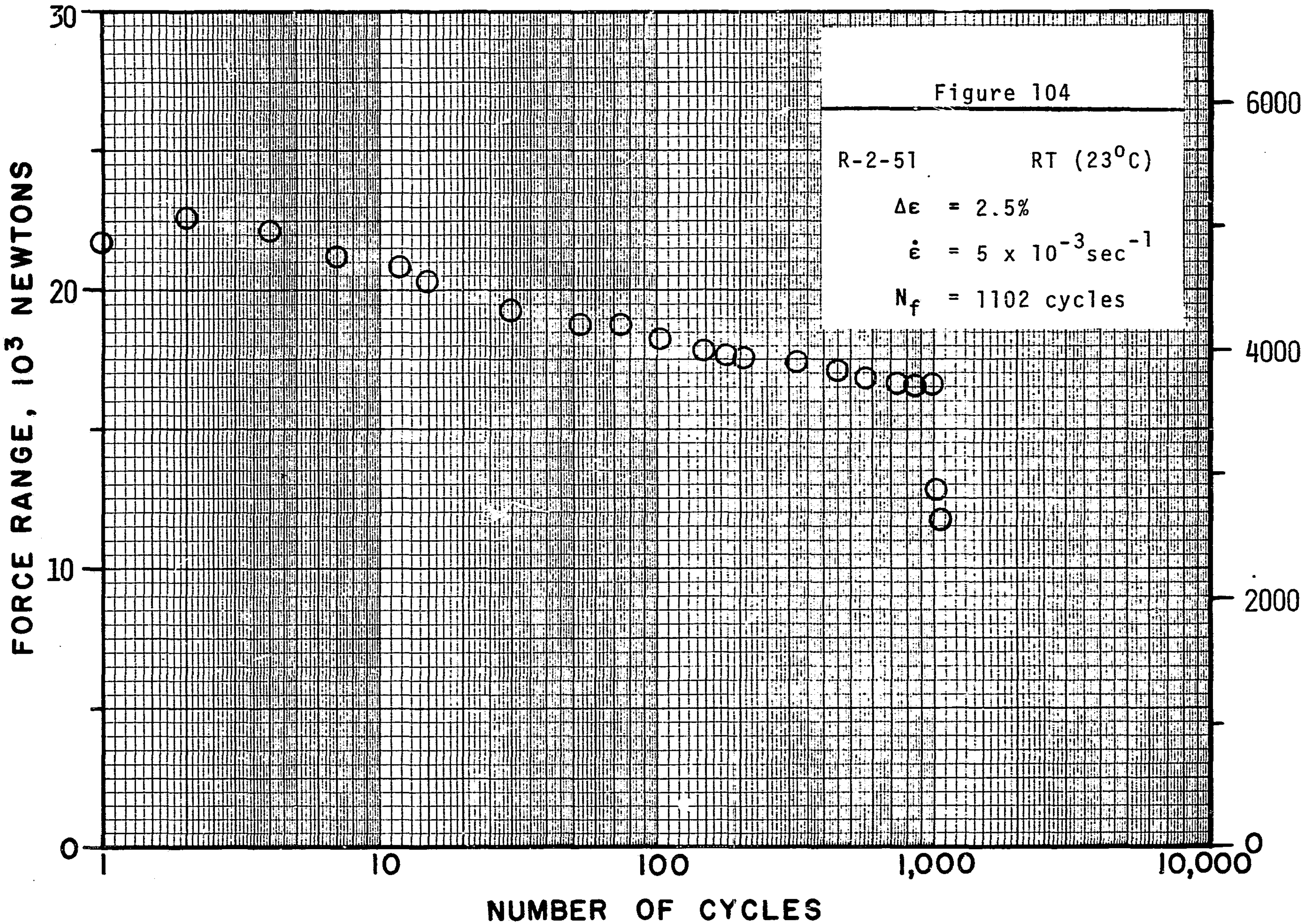


Figure 104
R-2-51
RT (23°C)
Δε = 2.5%
ε̇ = 5 x 10-3sec-1
Nf = 1102 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
30
20
10
0
6000
4000
2000
0
1
10
100
1,000
10,000

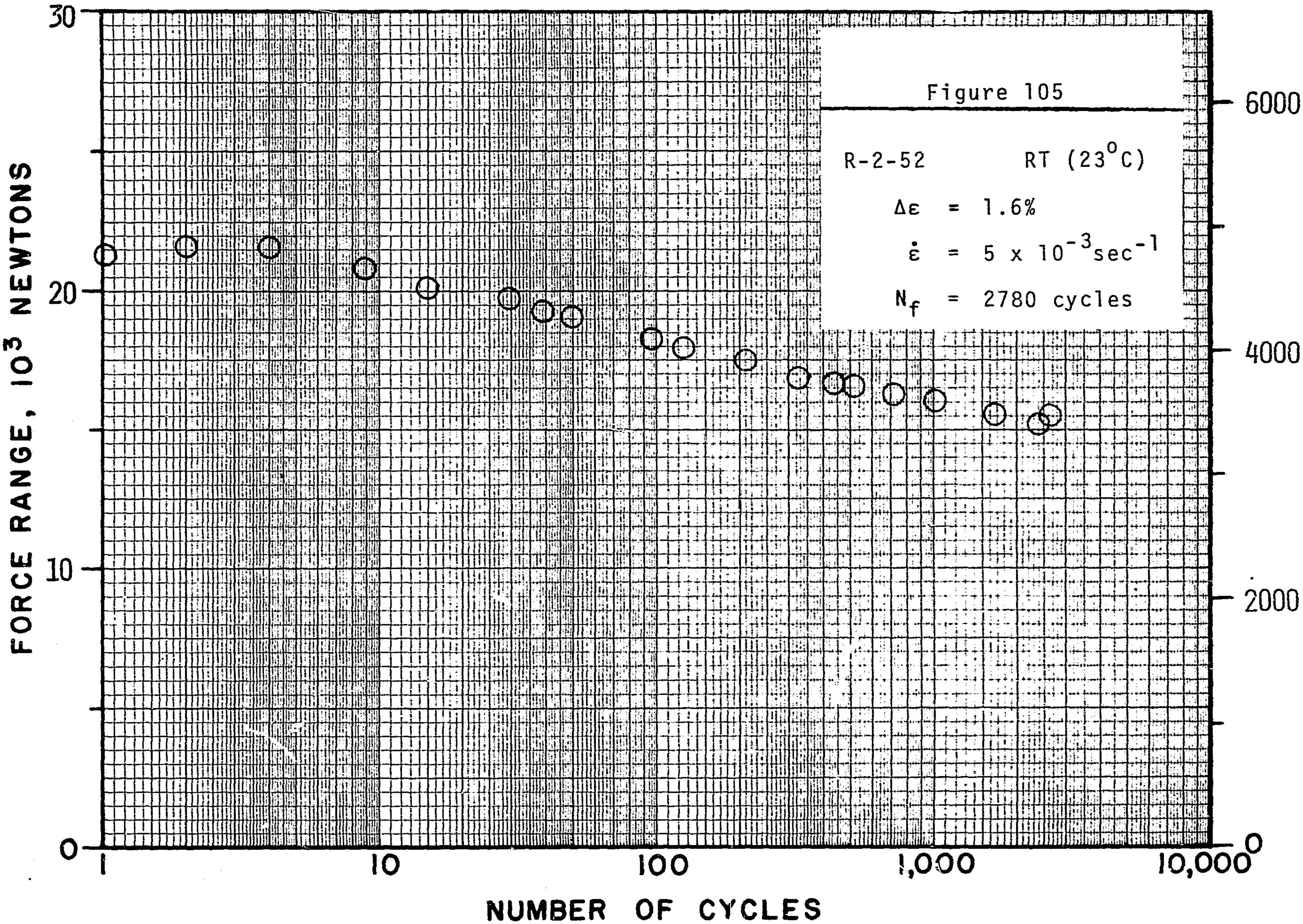


Figure 105
R-2-52 RT ($23^{o}C$)
$\Delta\varepsilon$ = 1.6%
$\dot{\varepsilon}$ = $5 \times 10^{-3} sec^{-1}$
N_f = 2780 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

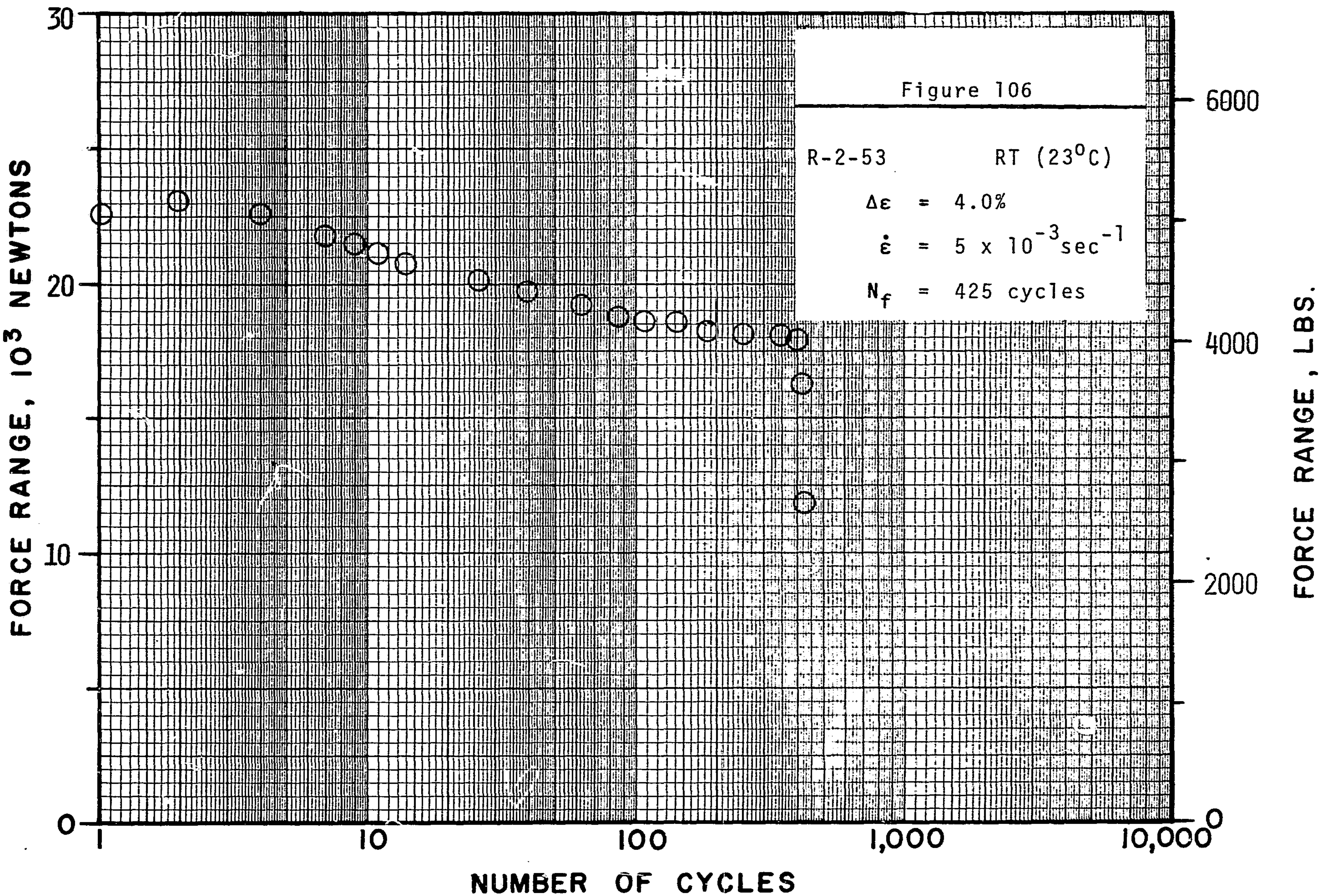


Figure 106

R-2-53 RT ($23^{o}C$)

$\Delta\varepsilon$ = 4.0%

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

N_f = 425 cycles

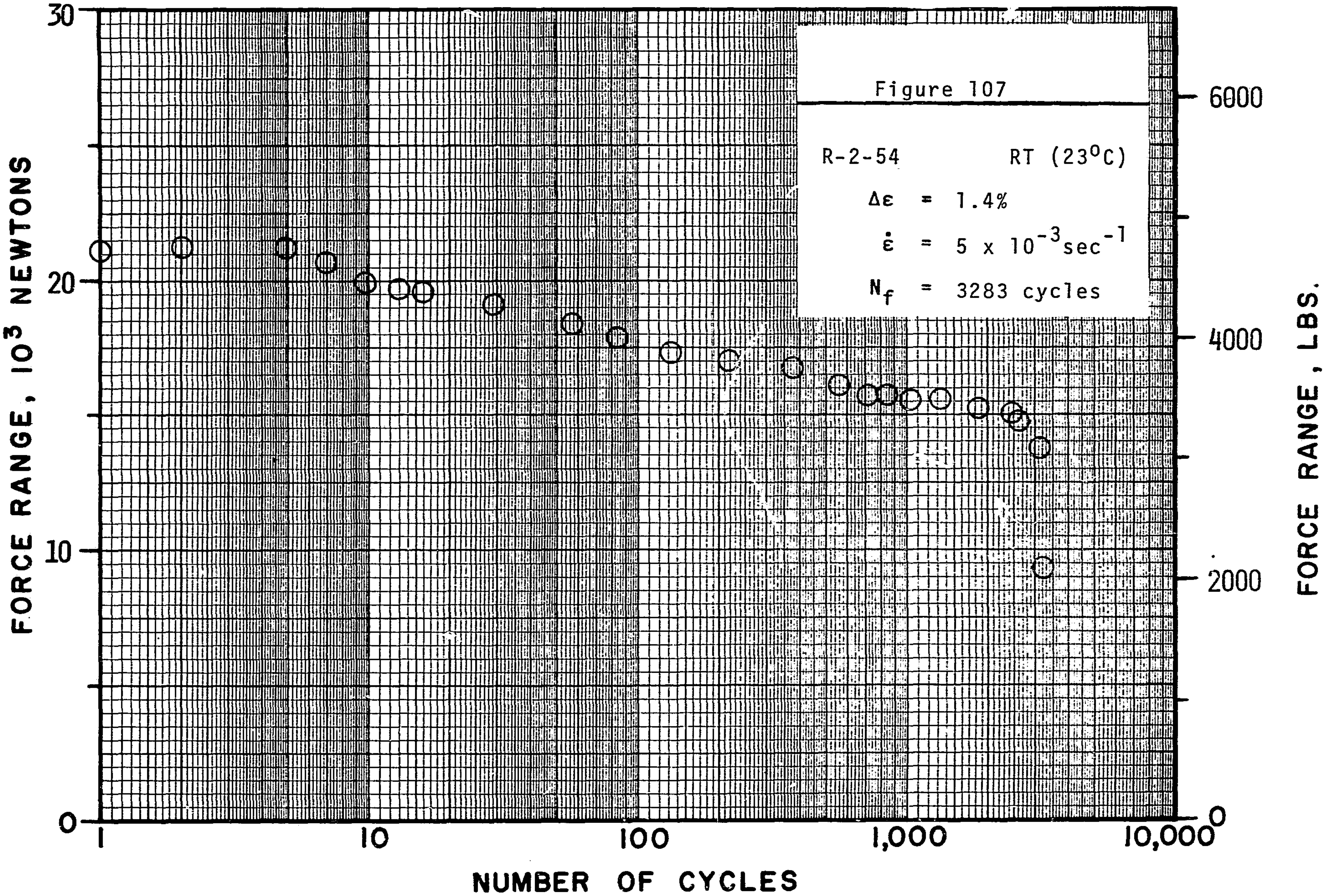


Figure 107
R-2-54
RT (23°C)
Δε = 1.4%
ε̇ = 5 x 10^-3 sec^-1
N_f = 3283 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
30
20
10
0
6000
4000
2000
0
1
10
100
1,000
10,000

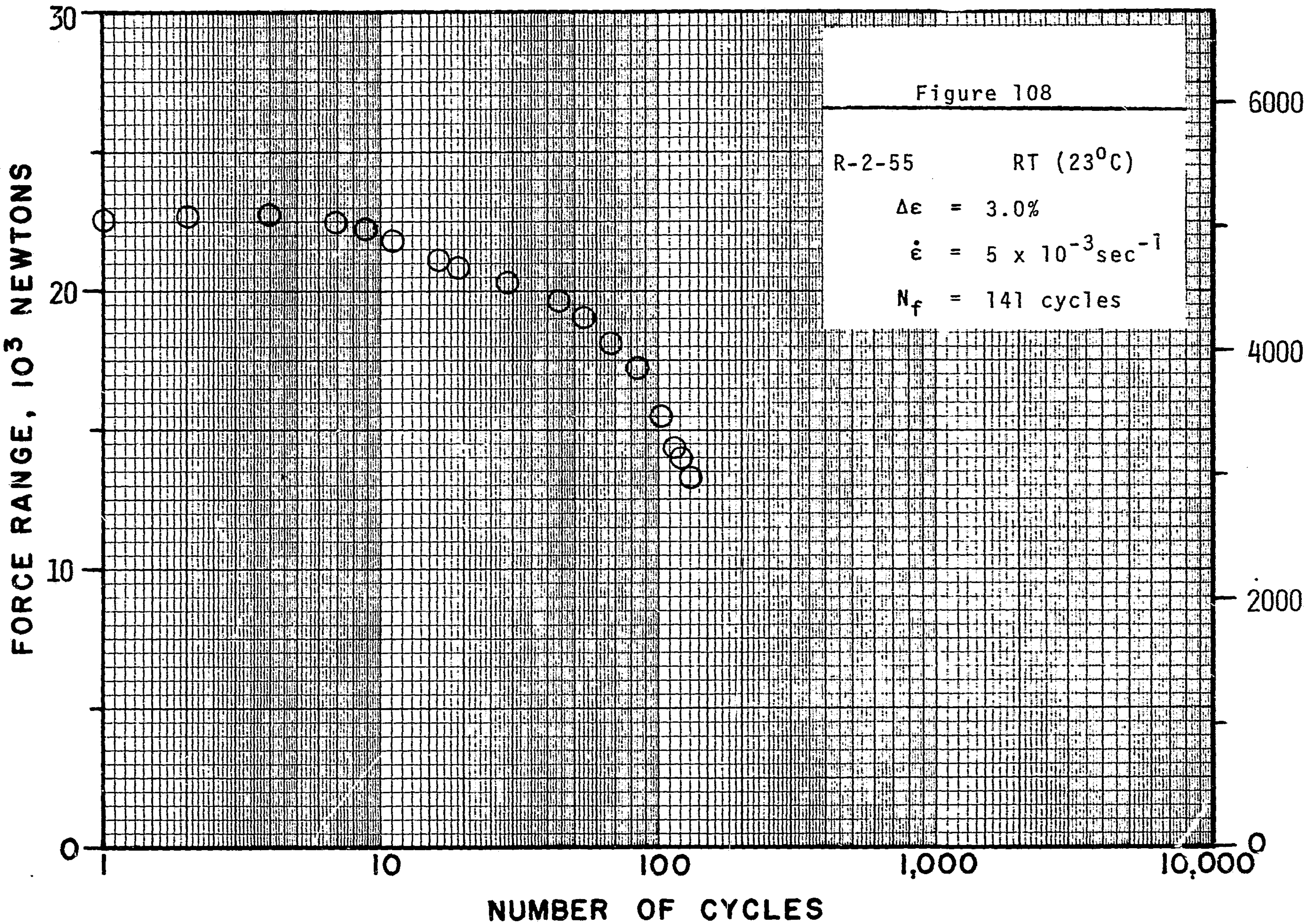

R-2-55
RT (23°C)
Δε = 3.0%
ε̇ = 5 x 10^-3 sec^-1
N_f = 141 cycles
FORCE RANGE, 10³ NEWTONS
0
10
20
30
FORCE RANGE, LBS.
0
2000
4000
6000
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 108

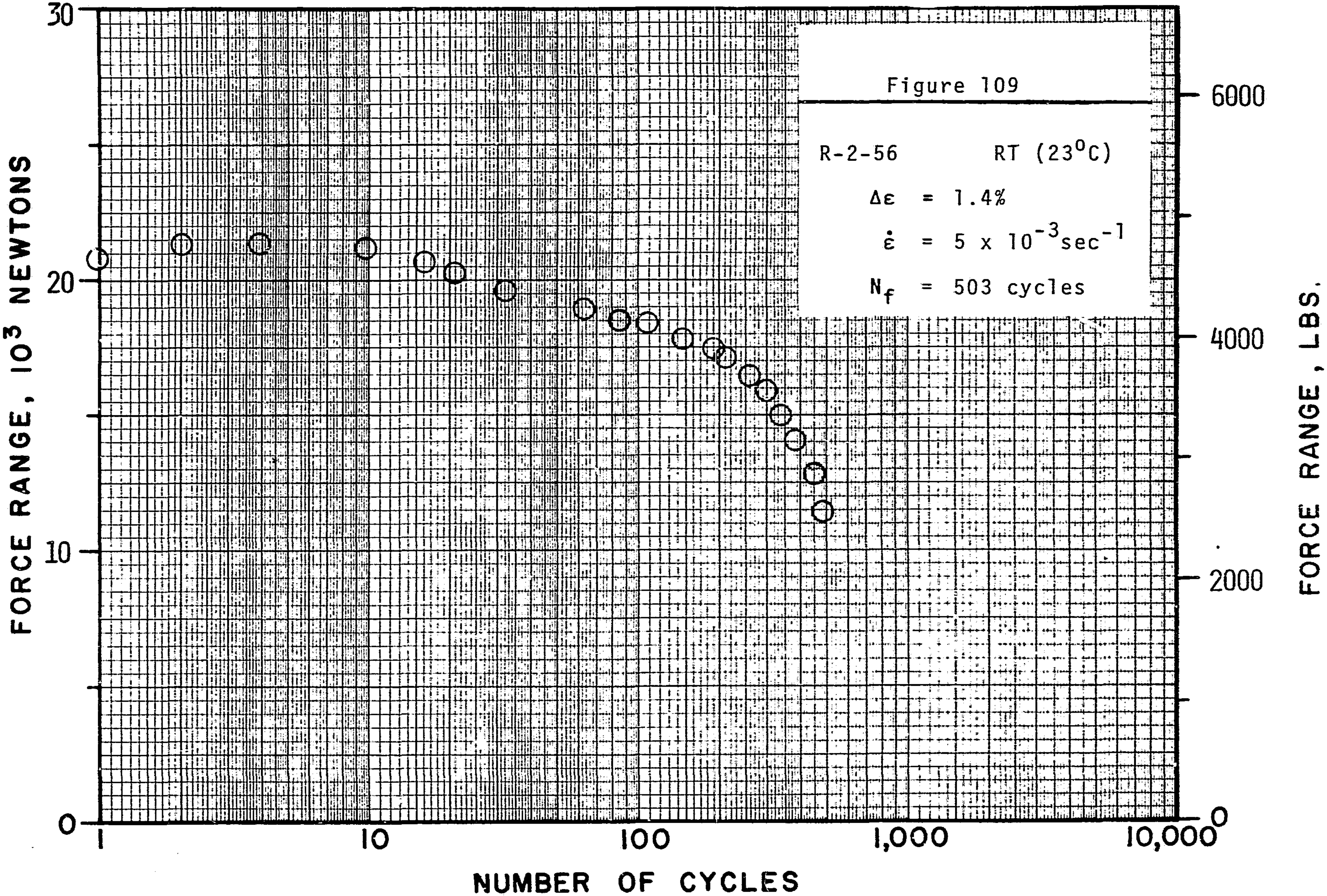


Figure 109
R-2-56 RT (23°C)
Δε = 1.4%
ε̇ = 5 x 10^-3 sec^-1
N_f = 503 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000

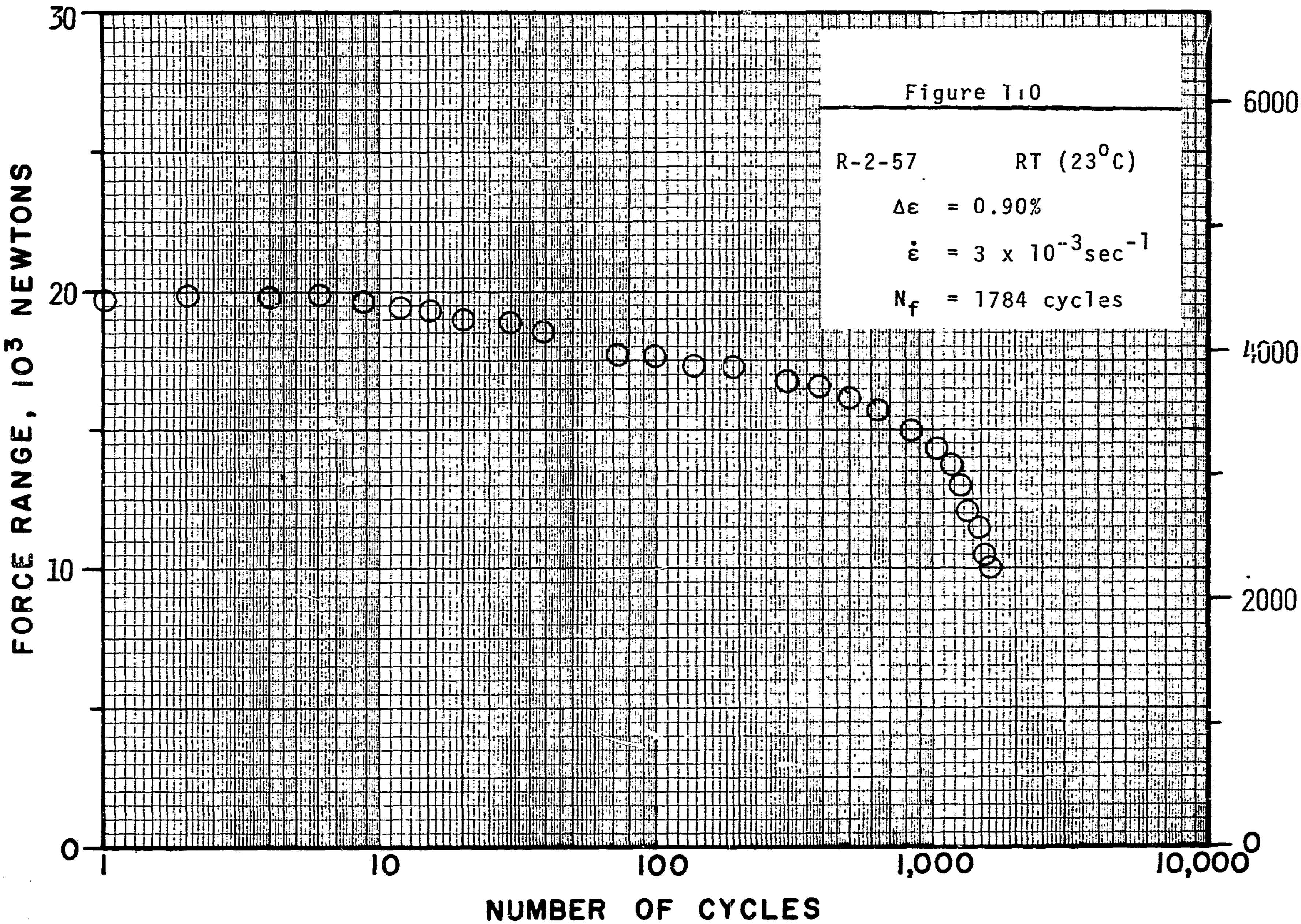


Figure 110
R-2-57 RT (23°C)
Δε = 0.90%
ε̇ = 3 x 10^-3 sec^-1
N_f = 1784 cycles
FORCE RANGE, 10^3 NEWTONS
30
20
10
0
FORCE RANGE, LBS.
6000
4000
2000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

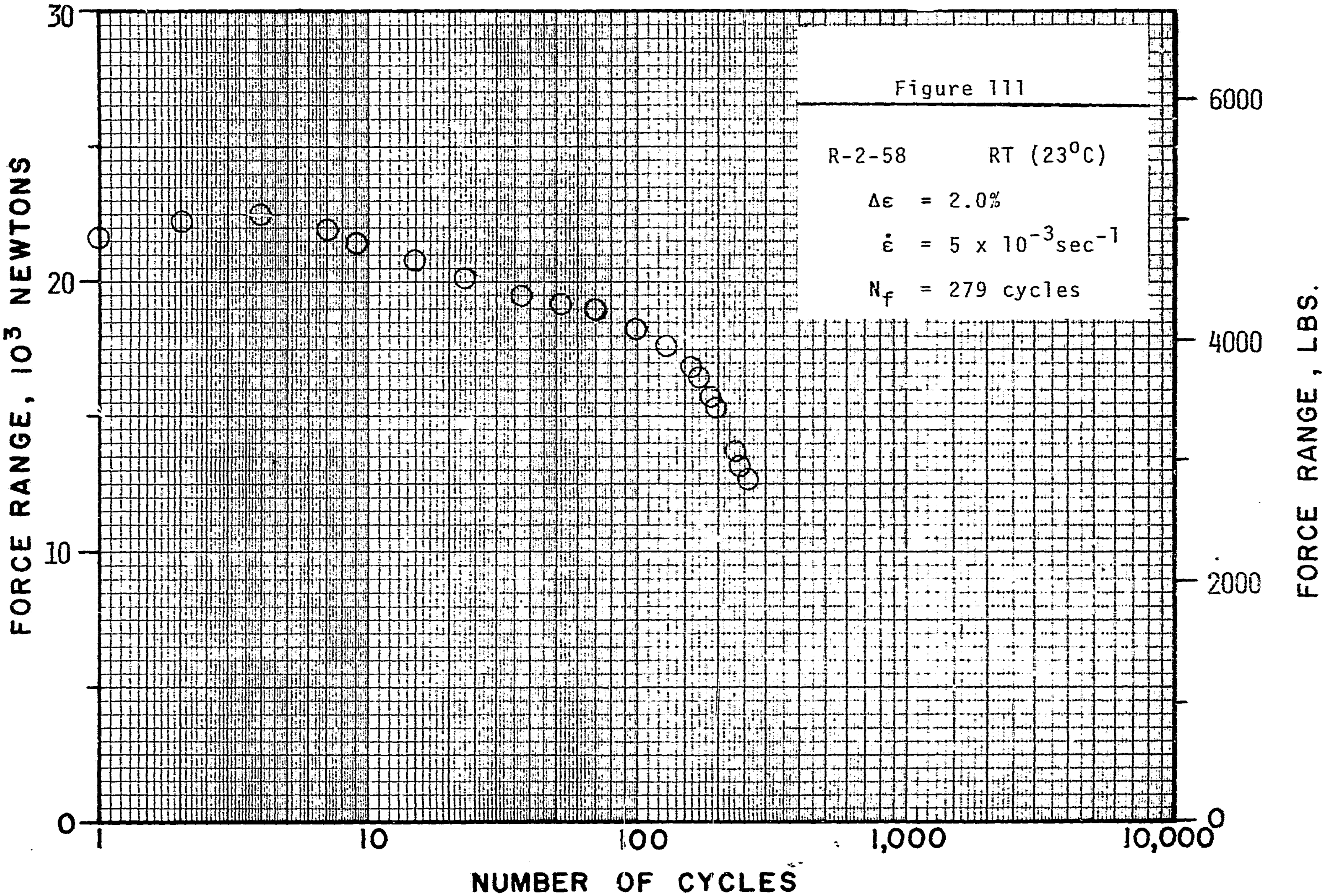


Figure 111
R-2-58 RT (23°C)
Δε = 2.0%
ε̇ = 5 x 10^-3 sec^-1
N_f = 279 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000

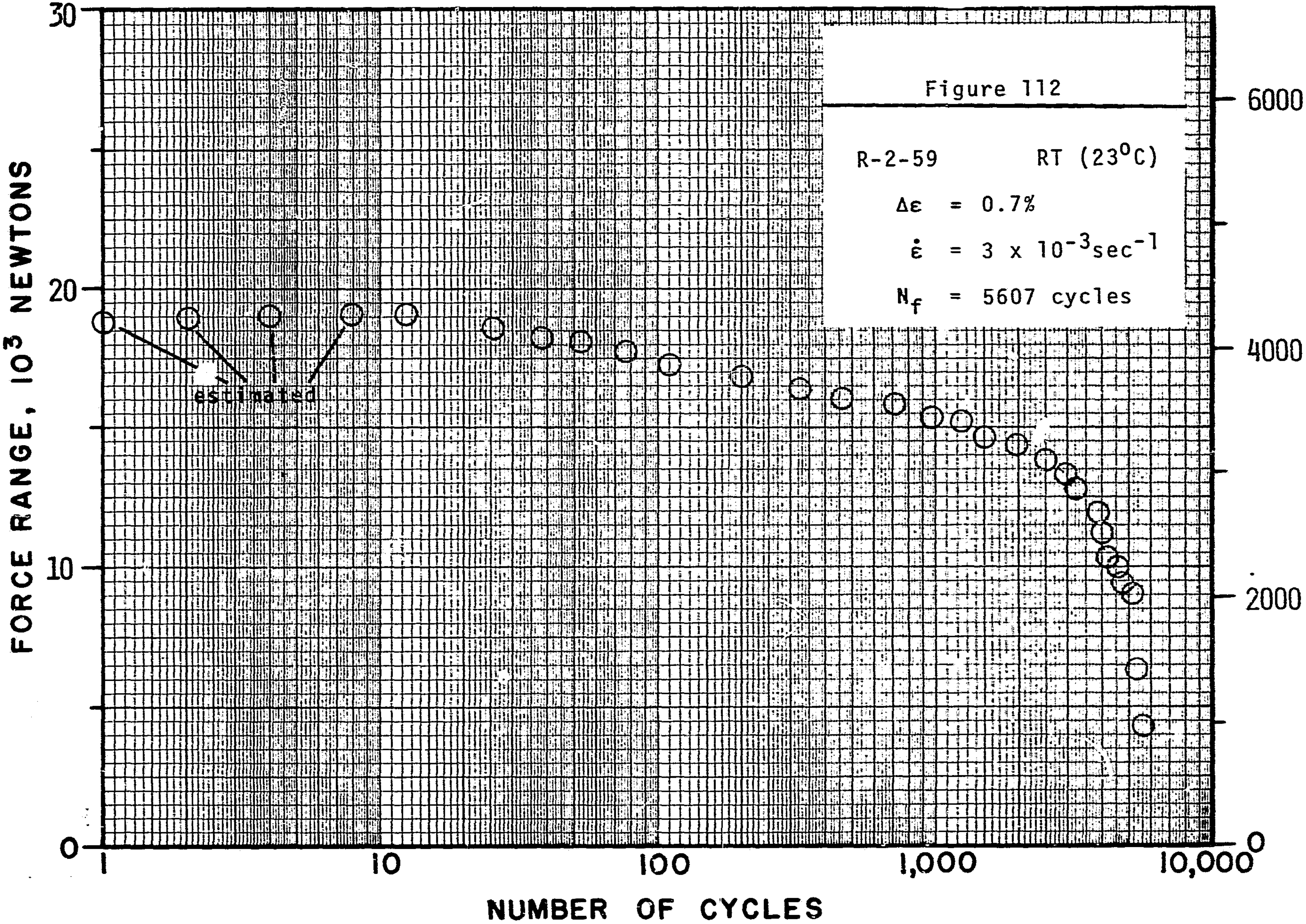


Figure 112
R-2-59 RT (23°C)
Δε = 0.7%
ε̇ = 3 x 10⁻³sec⁻¹
N_f = 5607 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

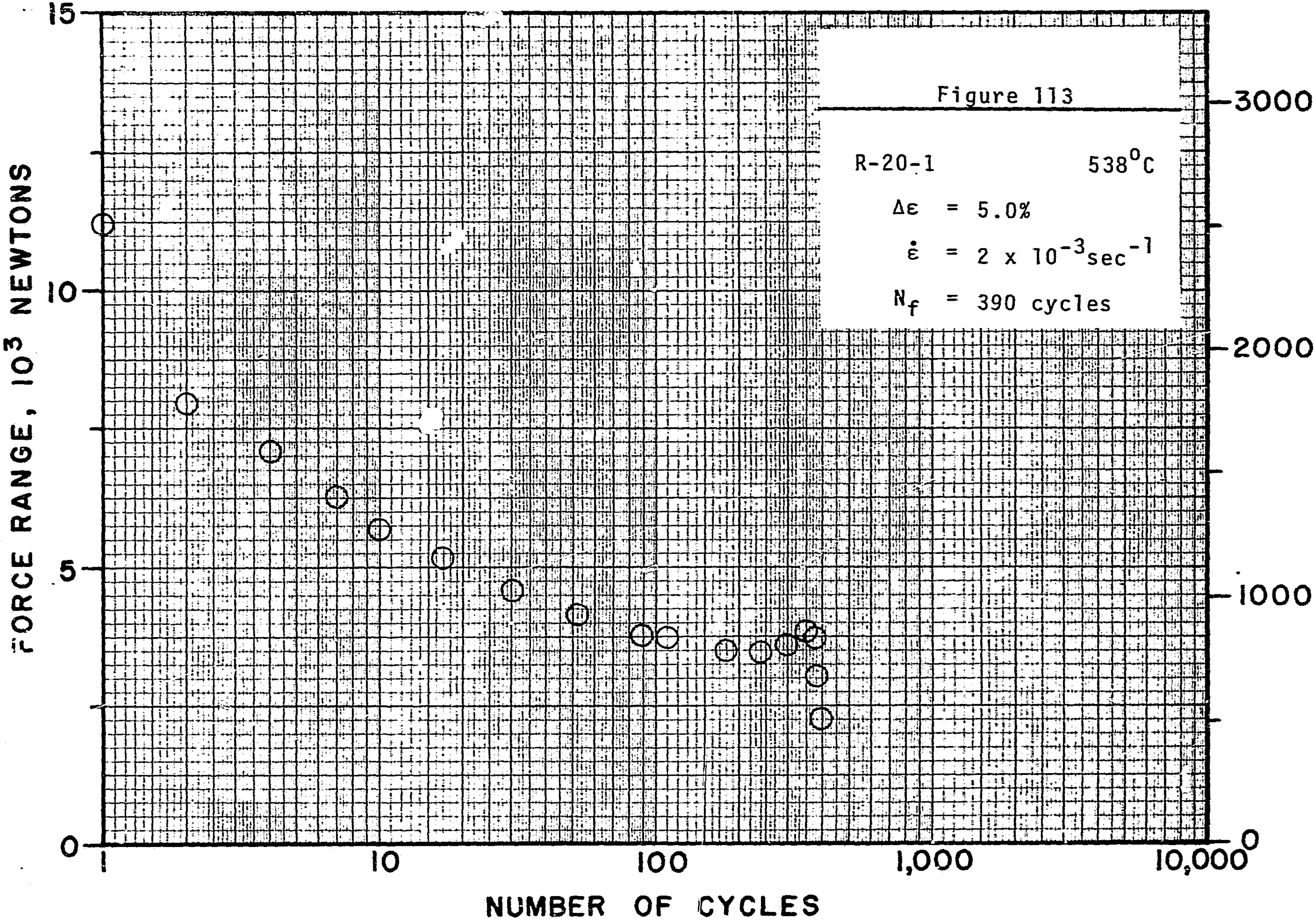


Figure 113
R-20-1
538°C
Δε = 5.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 390 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

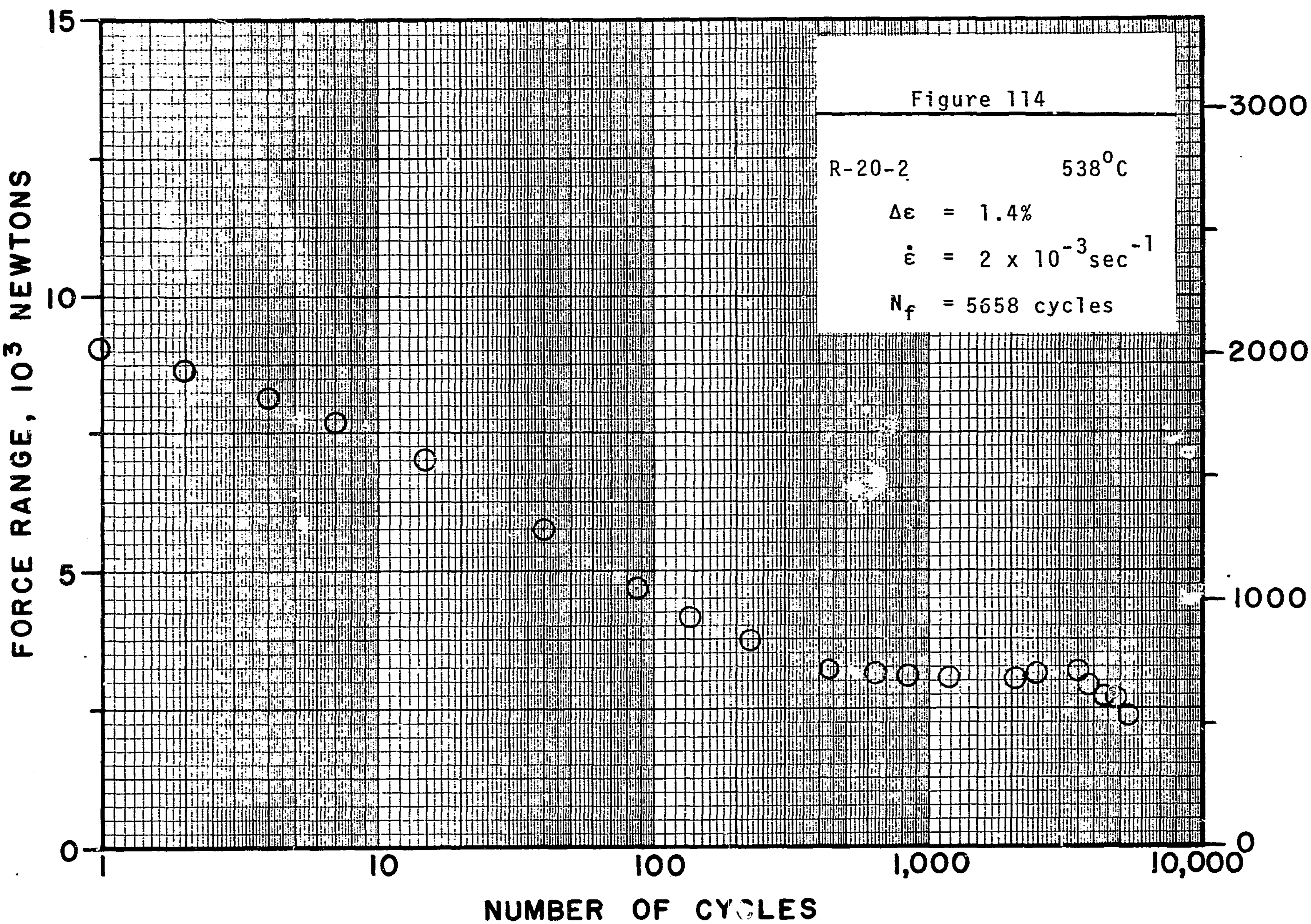


Figure 114
R-20-2
538°C
Δε = 1.4%
ε̇ = 2 x 10^-3 sec^-1
N_f = 5658 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

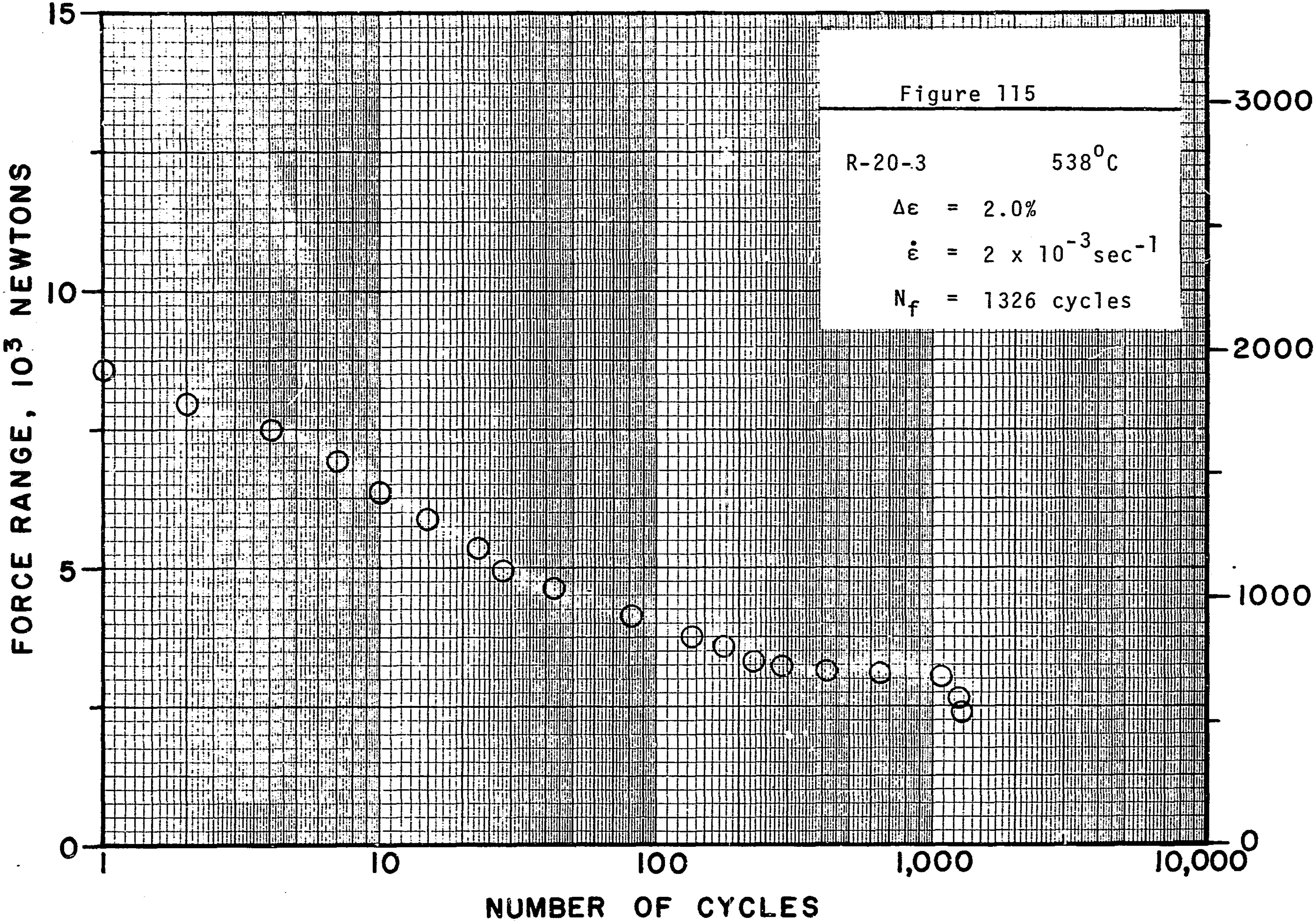


Figure 115
R-20-3 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
Nf = 1326 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

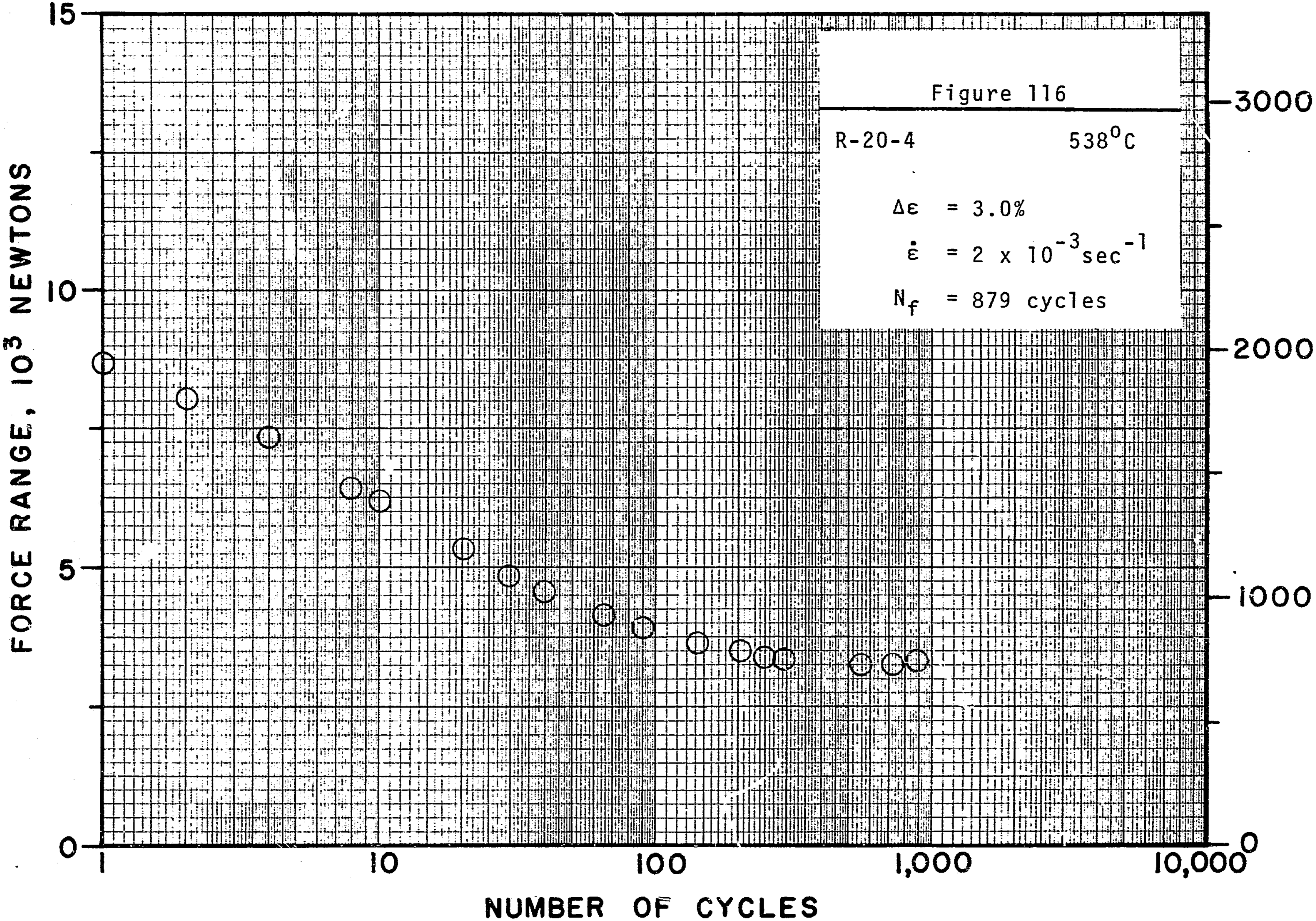


Figure 116
R-20-4
538°C
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 879 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

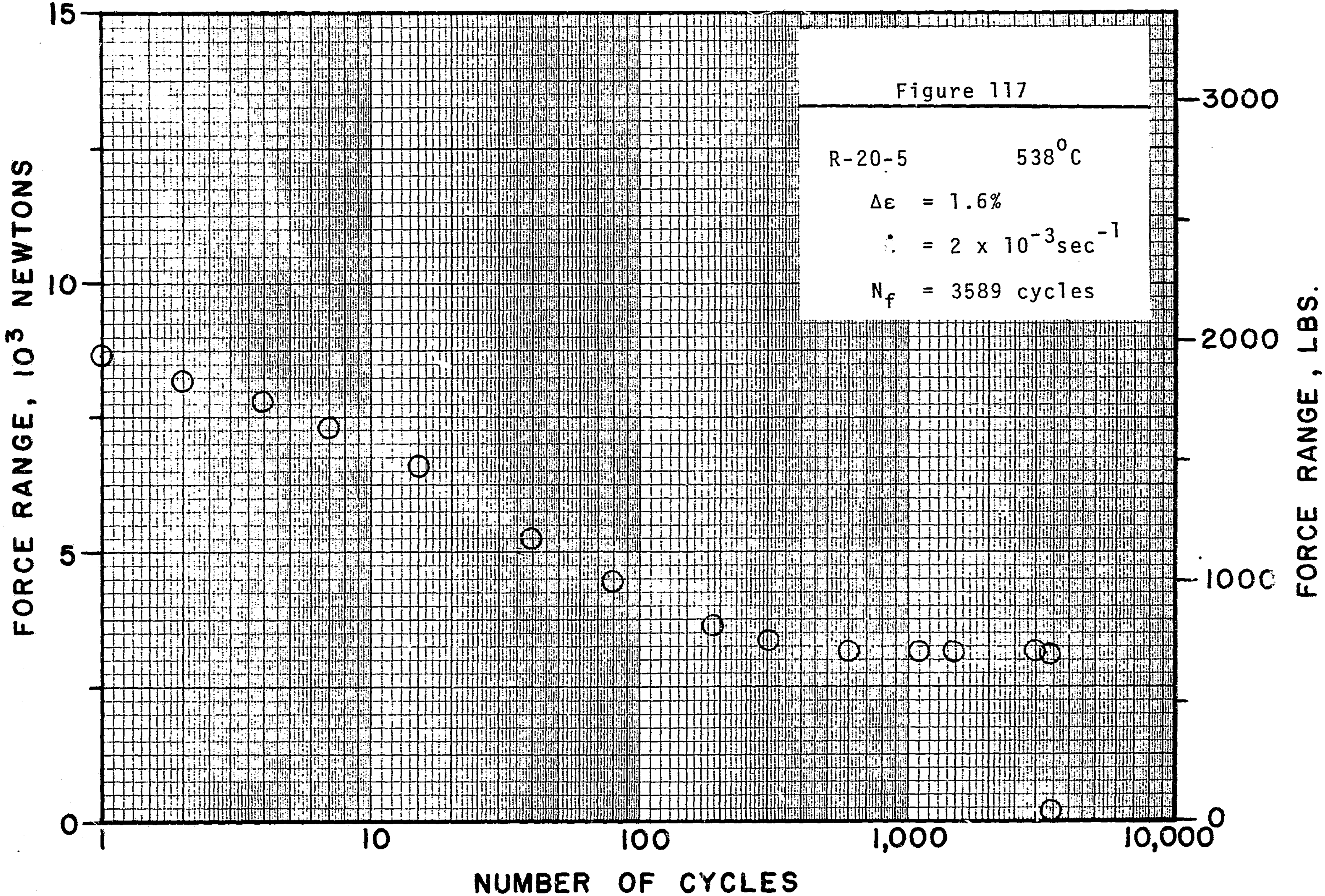

R-20-5
538°C
$\Delta\varepsilon$ = 1.6%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 3589 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
1
10
100
1,000
10,000
3000
2000
1000
0

Figure 117

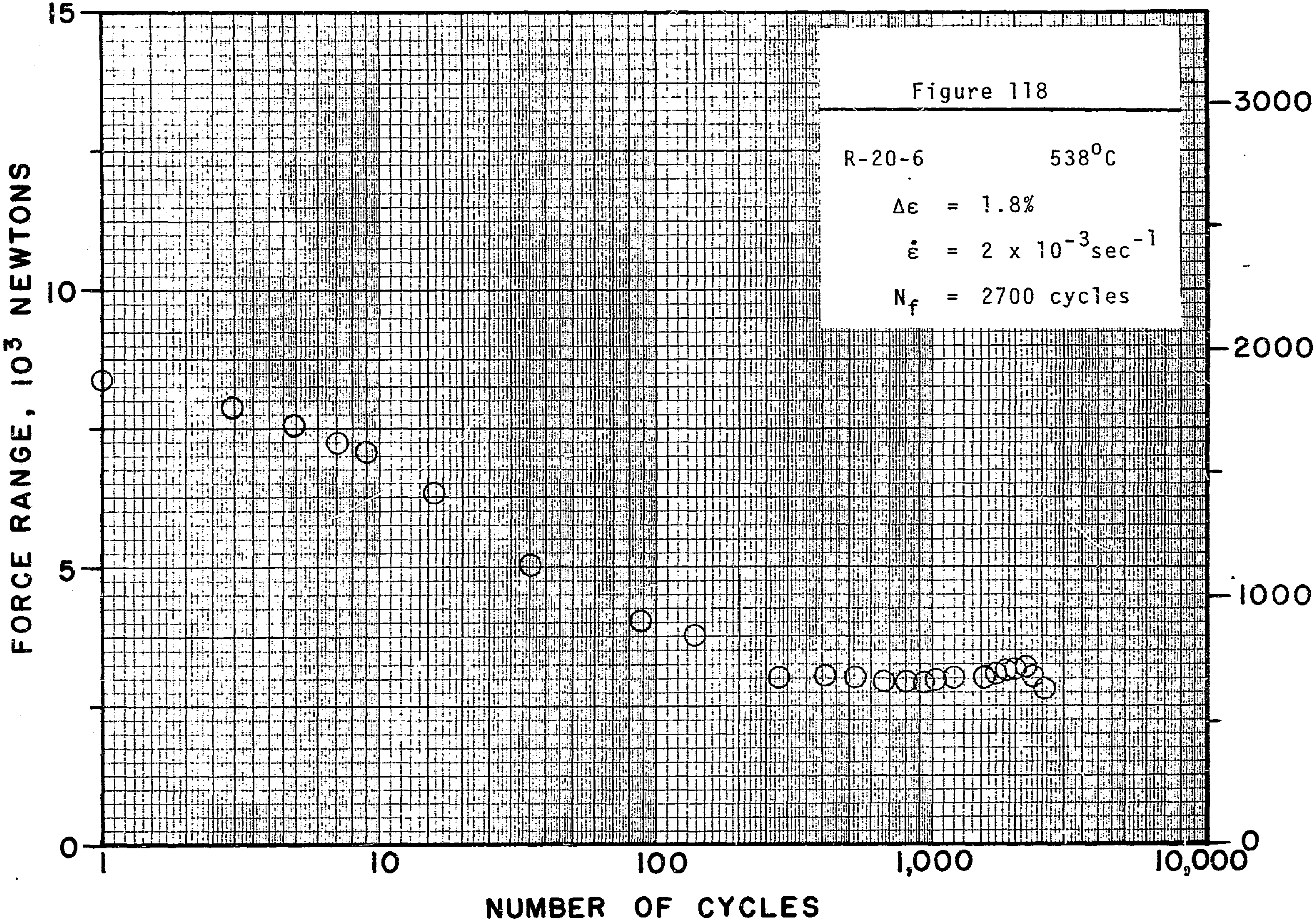


Figure 118
R-20-6
538°C
Δε = 1.8%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2700 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

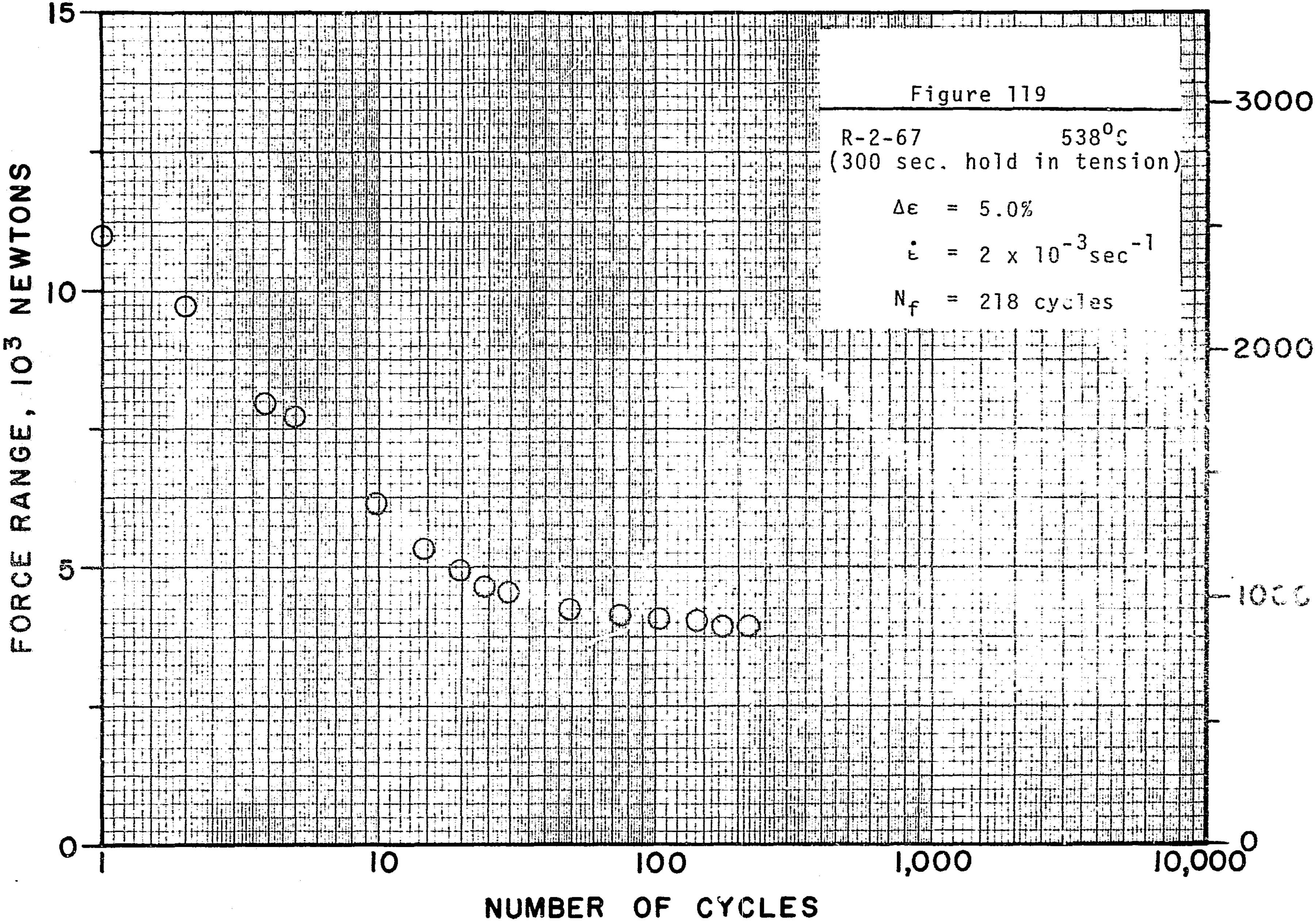


Figure 119

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

$\Delta\varepsilon = 5.0\%$

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

N_f = 218 cycles

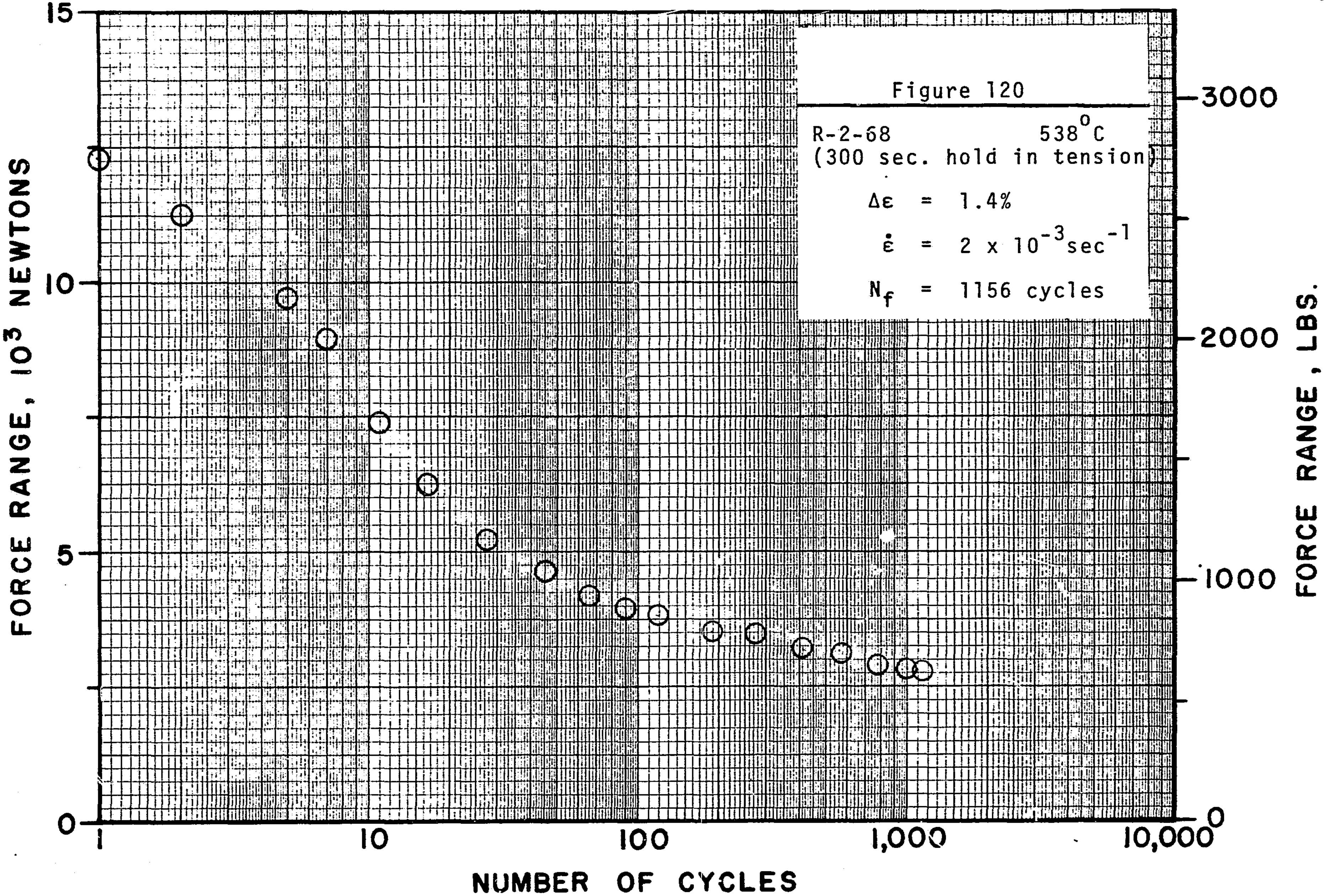


Figure 120
R-2-68 538°C
(300 sec. hold in tension)
Δε = 1.4%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1156 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

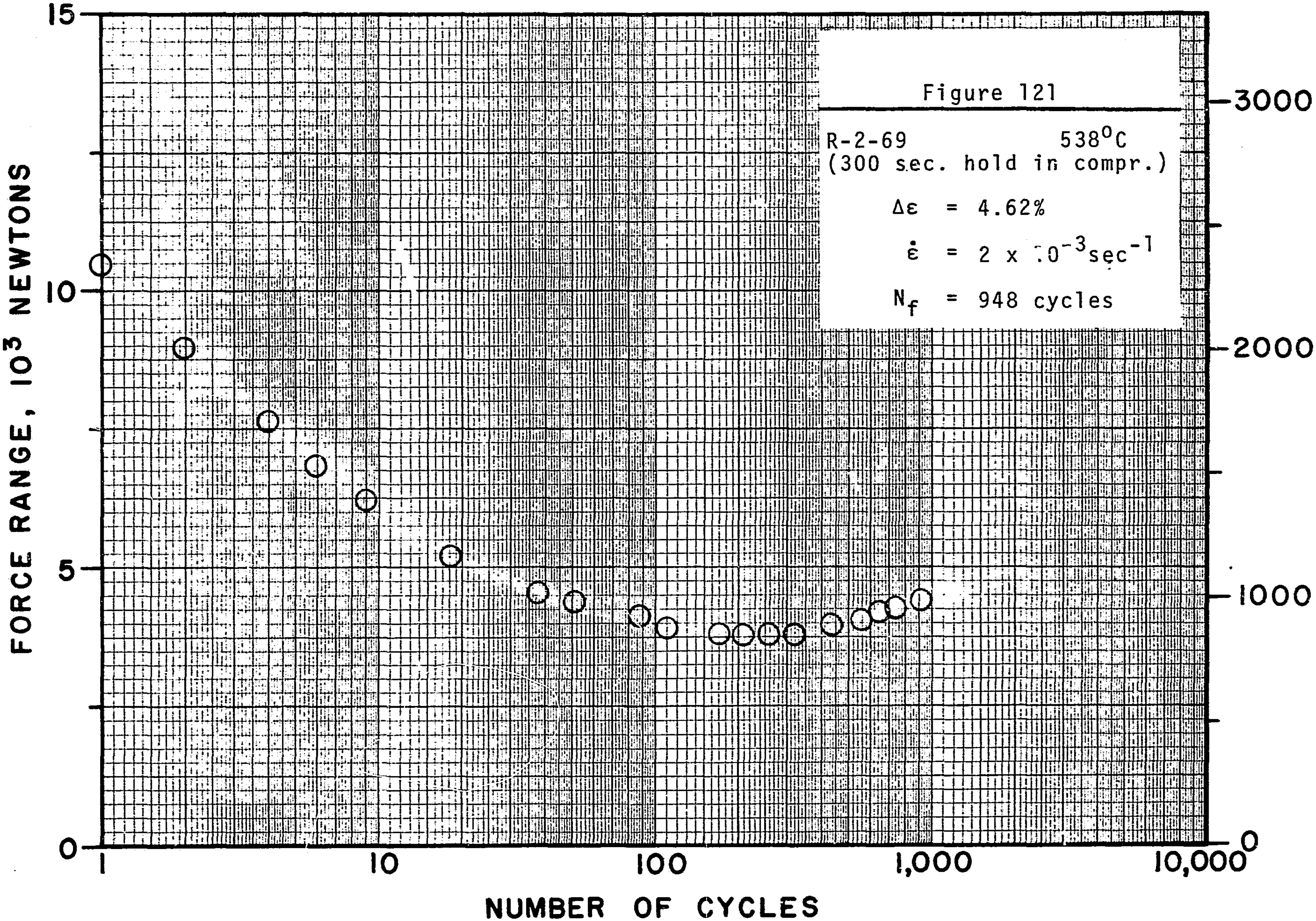


Figure 121
R-2-69 538°C
(300 sec. hold in compr.)
Δε = 4.62%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 948 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

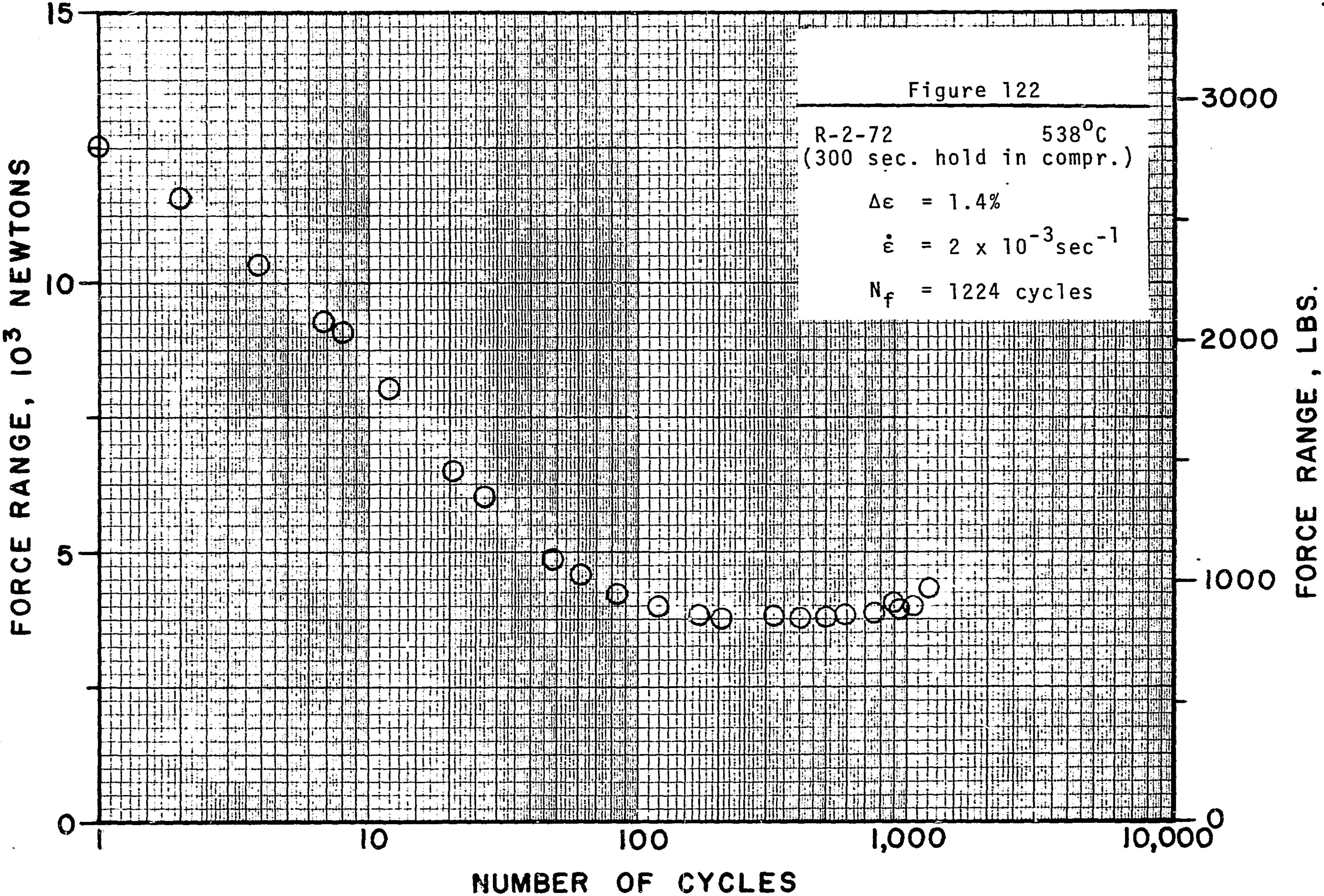


Figure 122
R-2-72 538°C
(300 sec. hold in compr.)
Δε = 1.4%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 1224 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

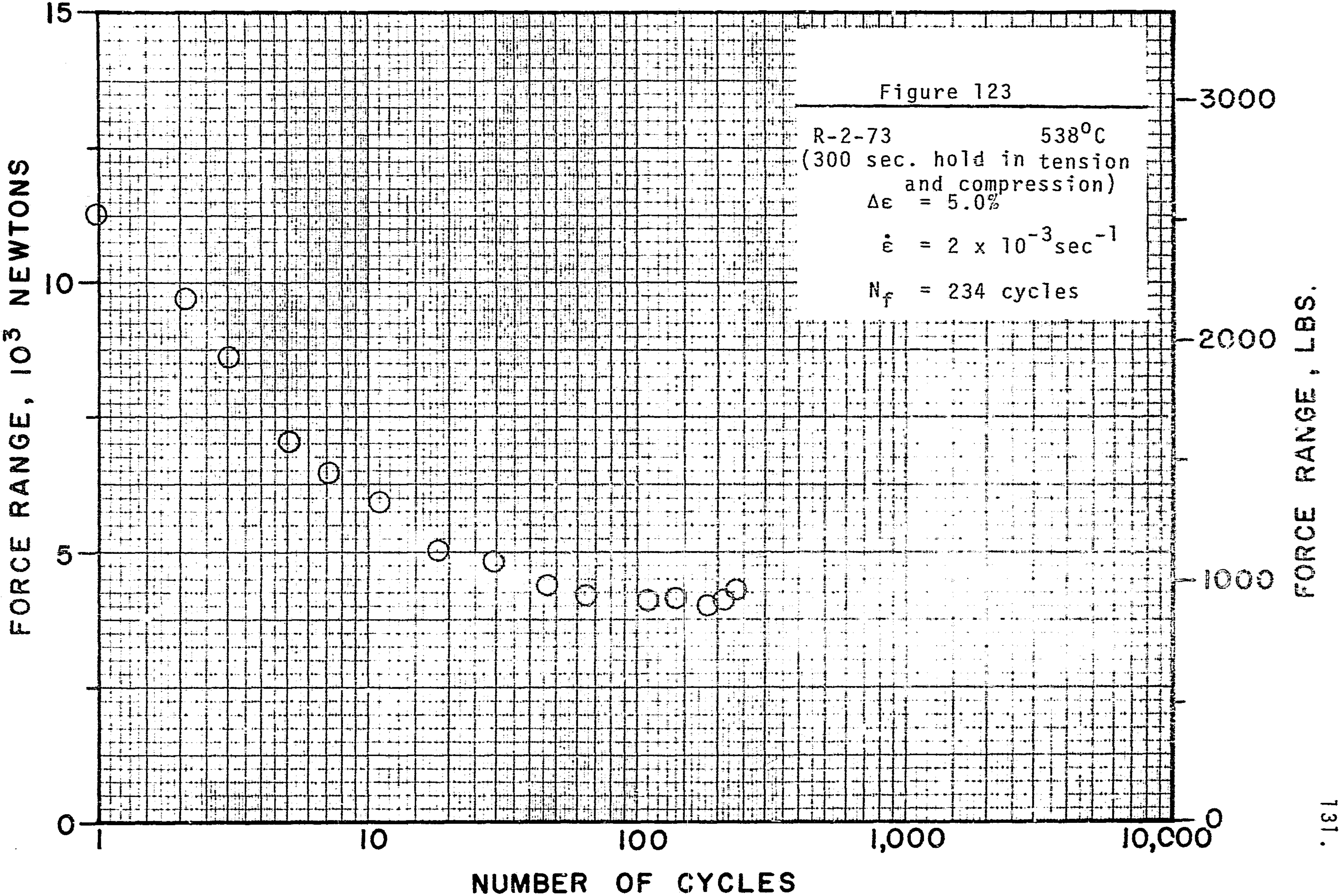


Figure 123
R-2-73 538°C
(300 sec. hold in tension and compression)
Δε = 5.0%
ε̇ = 2 x 10⁻³sec⁻¹
Nf = 234 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

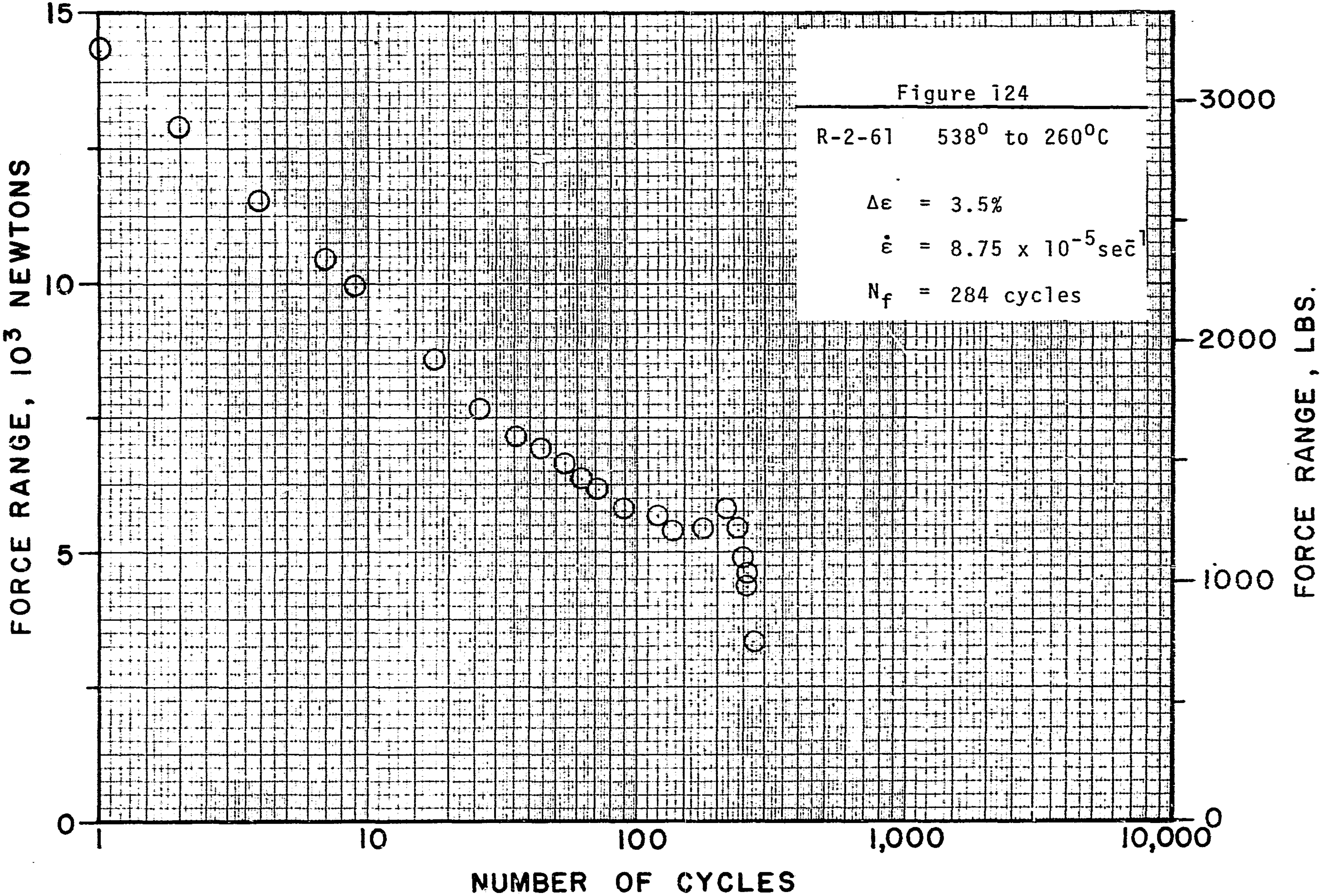


Figure 124
R-2-61 538° to 260°C
Δε = 3.5%
ε̇ = 8.75 x 10⁻⁵ sec⁻¹
N_f = 284 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

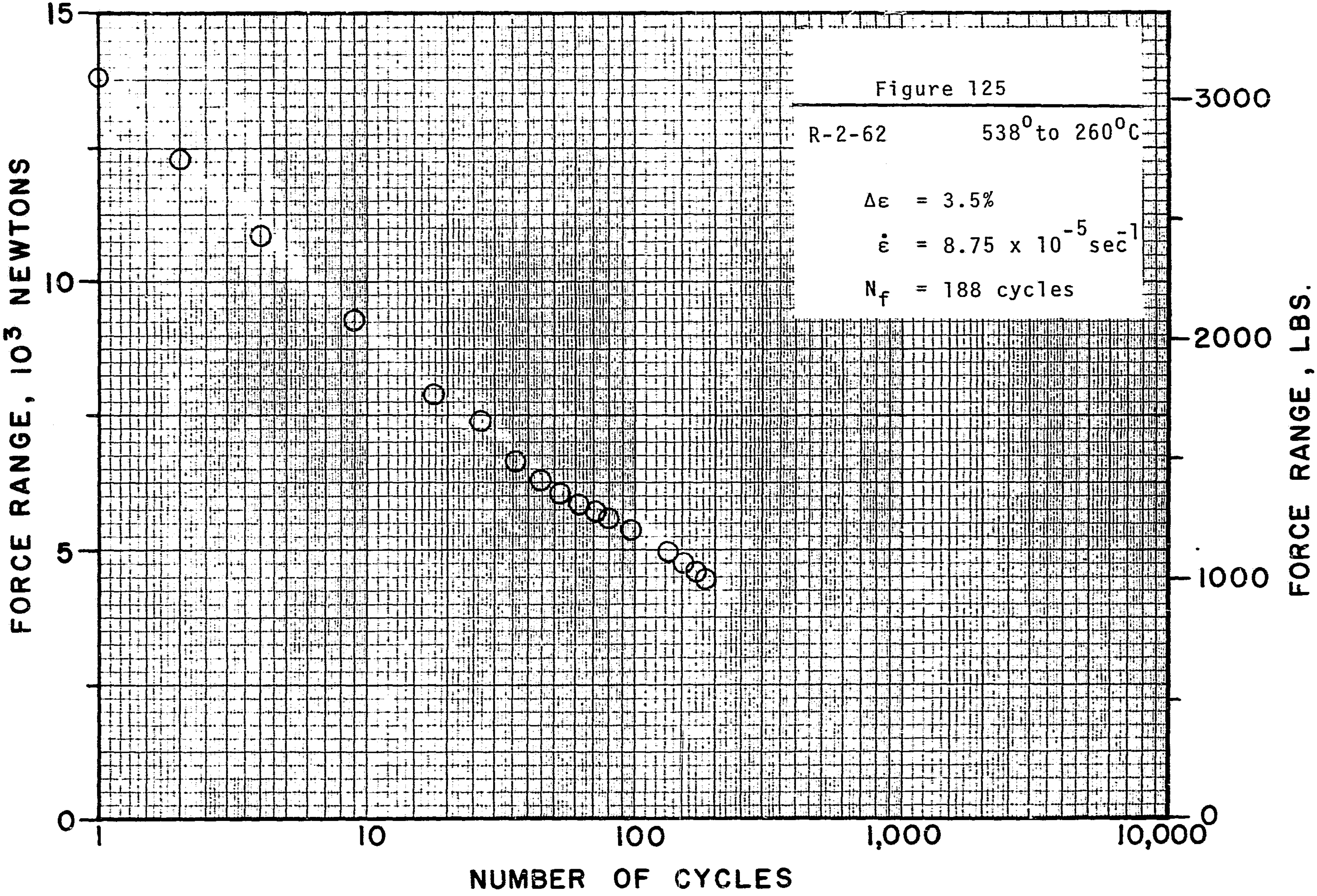


Figure 125
R-2-62
538°to 260°C
Δε = 3.5%
ε̇ = 8.75 x 10^-5 sec^-1
N_f = 188 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
1
10
100
1,000
10,000
NUMBER OF CYCLES
FORCE RANGE, LBS.
3000
2000
1000
0

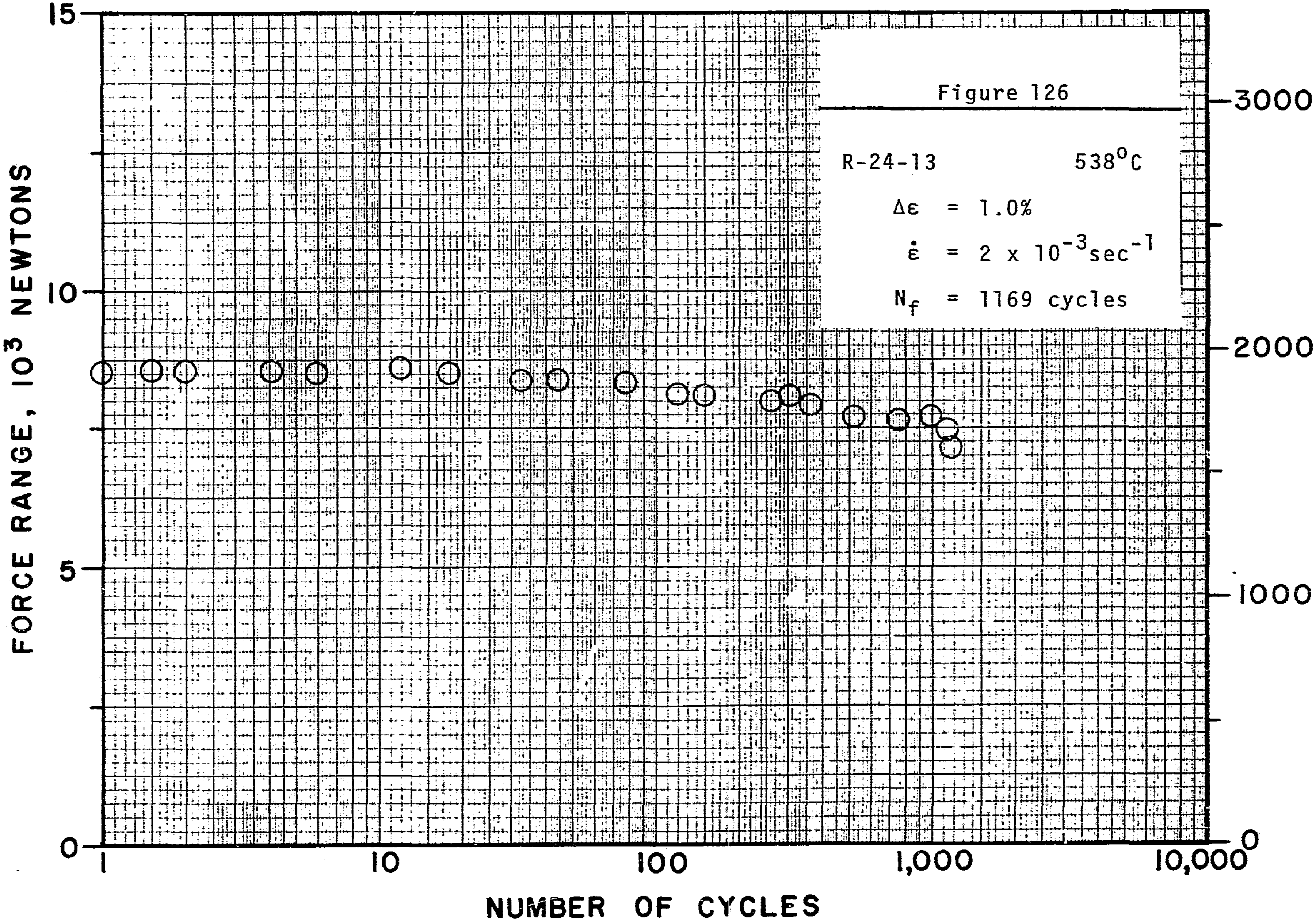


Figure 126
R-24-13 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1169 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

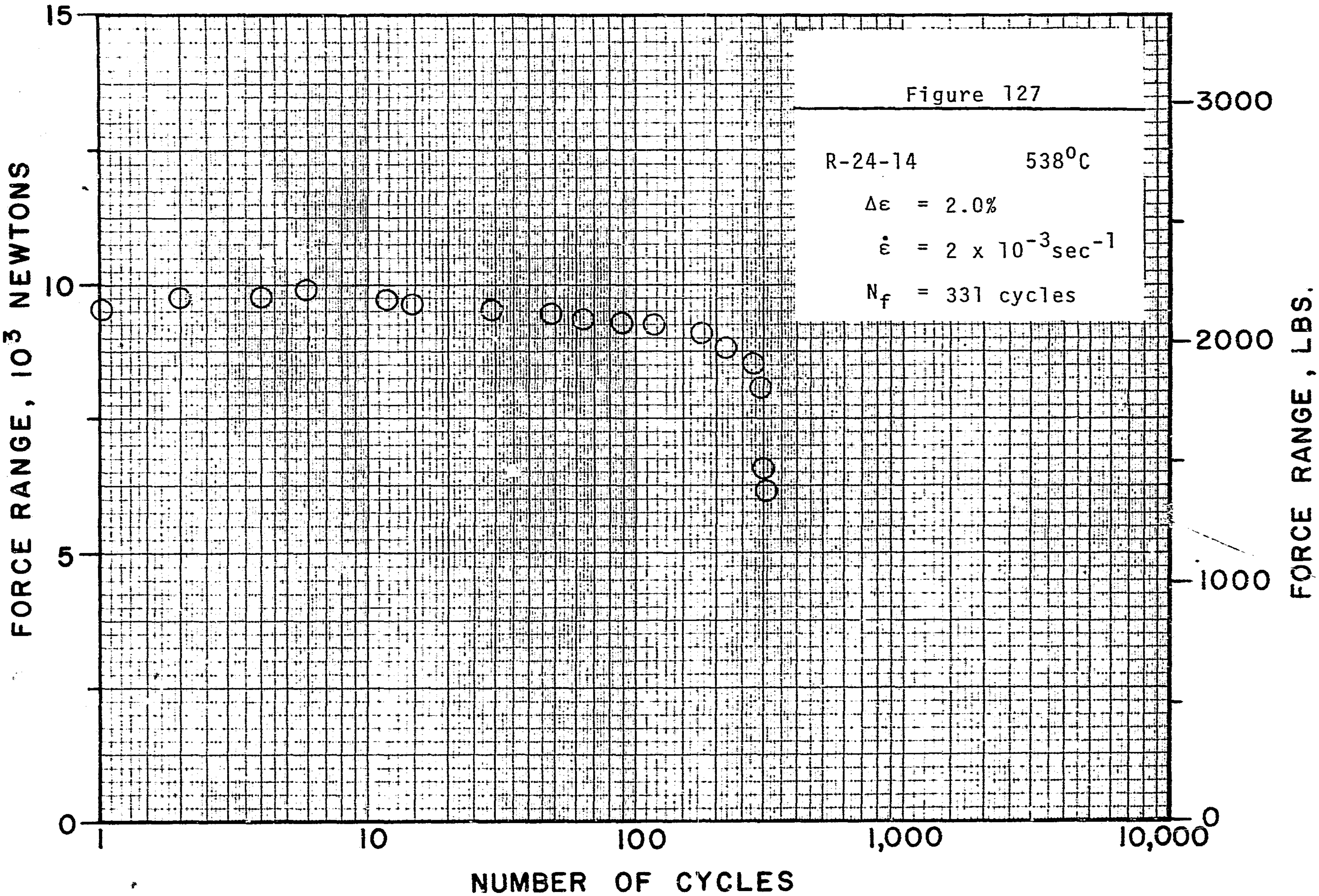


Figure 127
R-24-14
538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 331 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

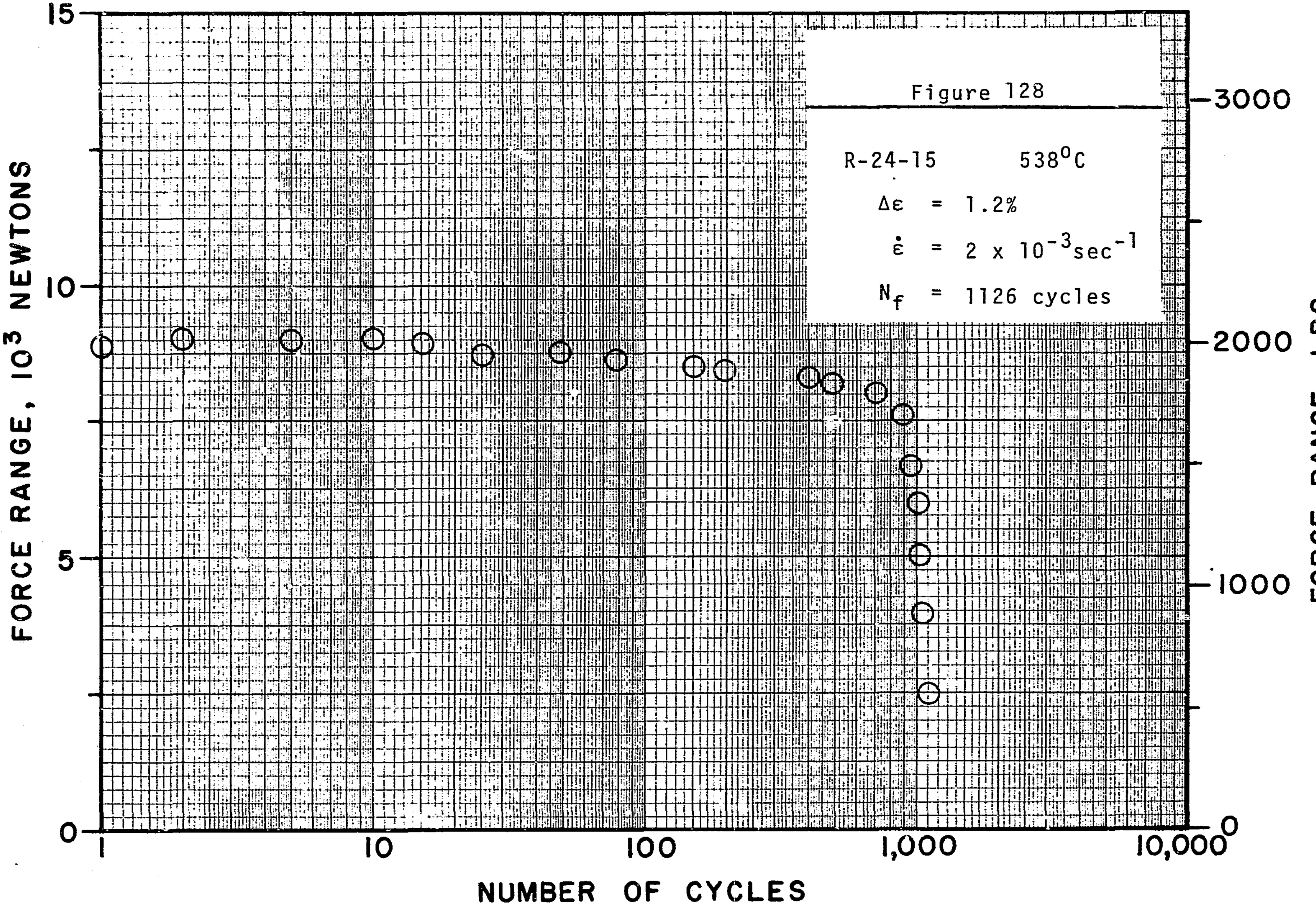

R-24-15 538°C
Δε = 1.2%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1126 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 128

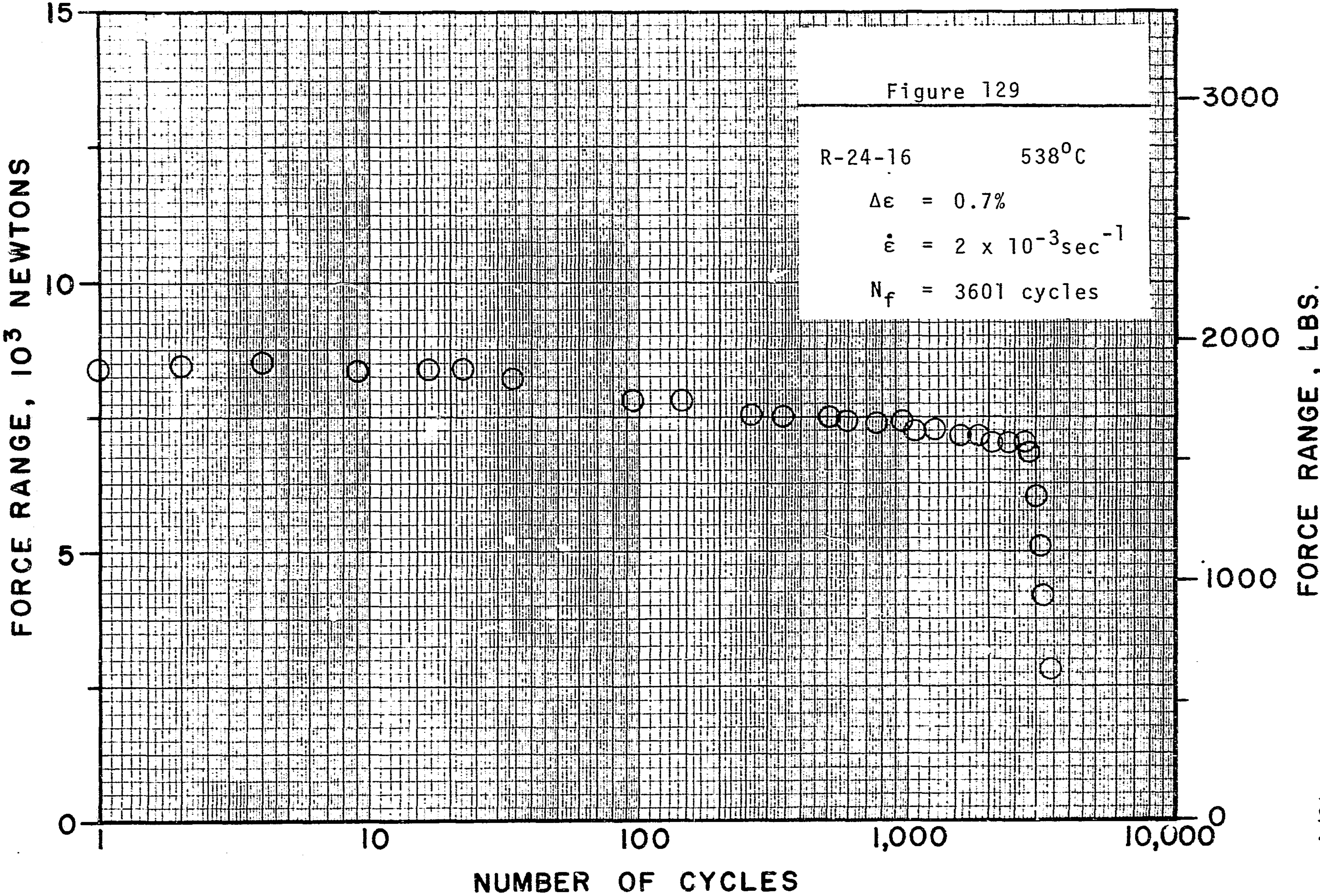


Figure 129
R-24-16 538°C
Δε = 0.7%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3601 cycles
15
10
5
0
FORCE RANGE, 10^3 NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

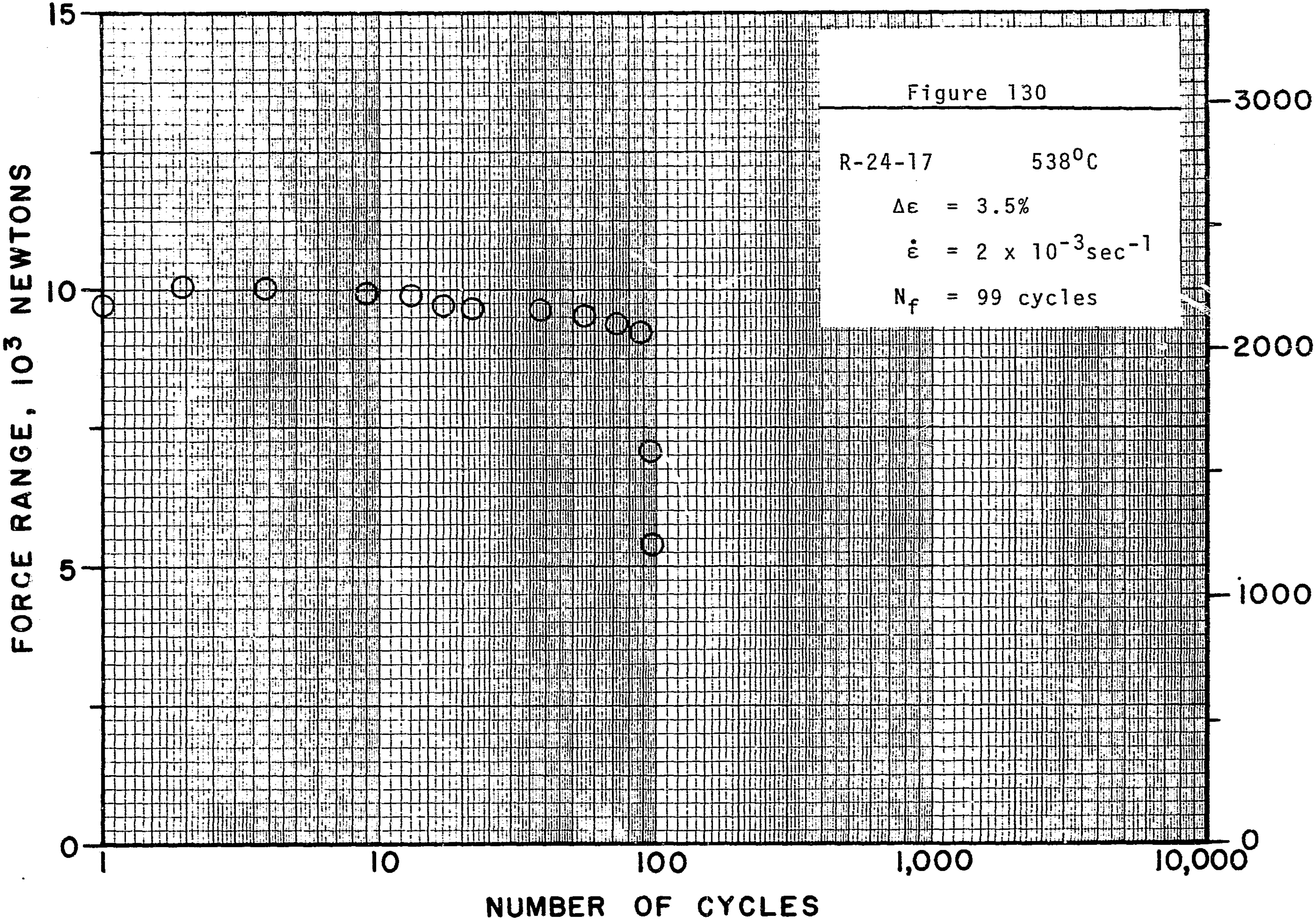


Figure 130
R-24-17 538°C
Δε = 3.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 99 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

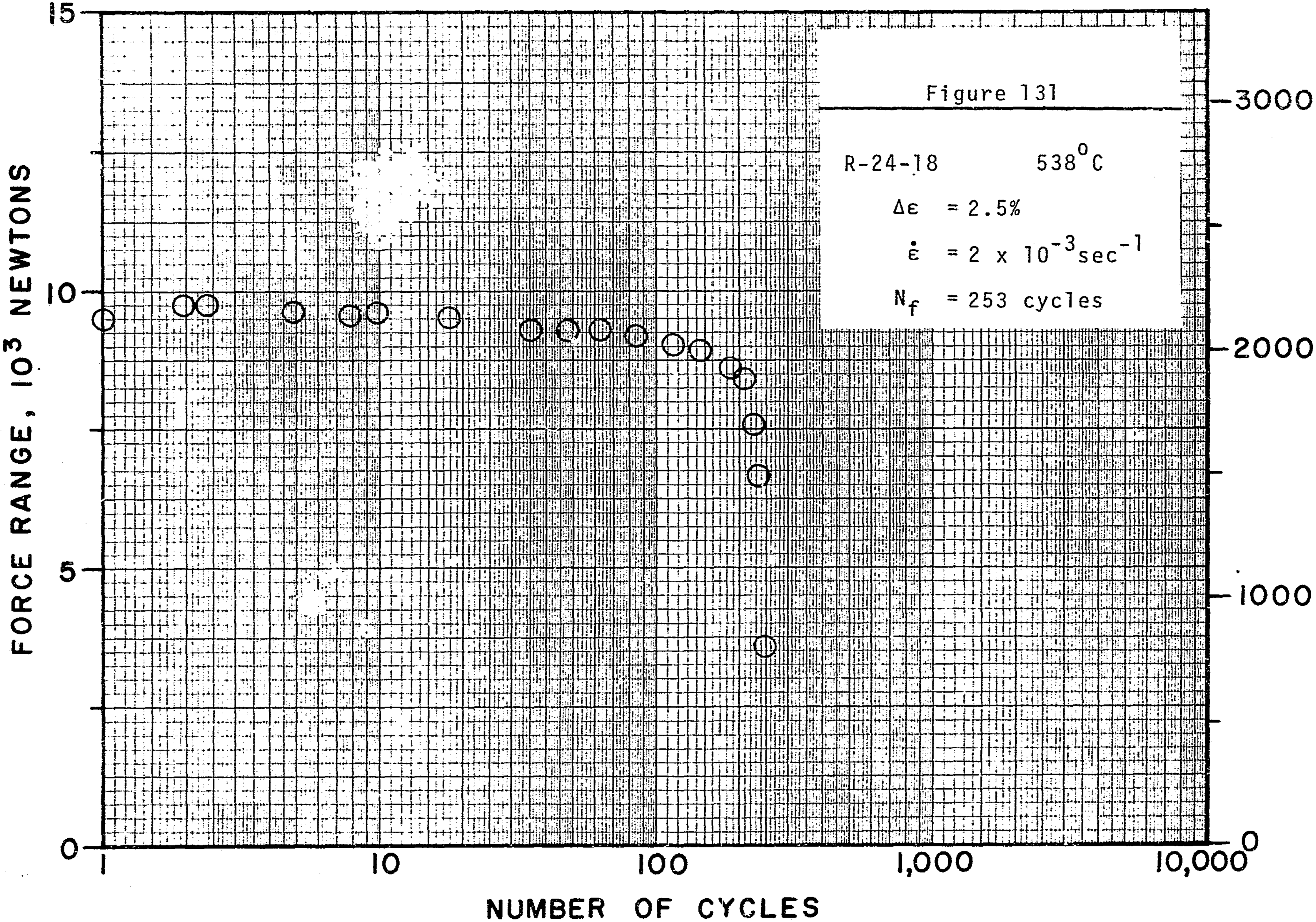


Figure 131
R-24-18 538°C
Δε = 2.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 253 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

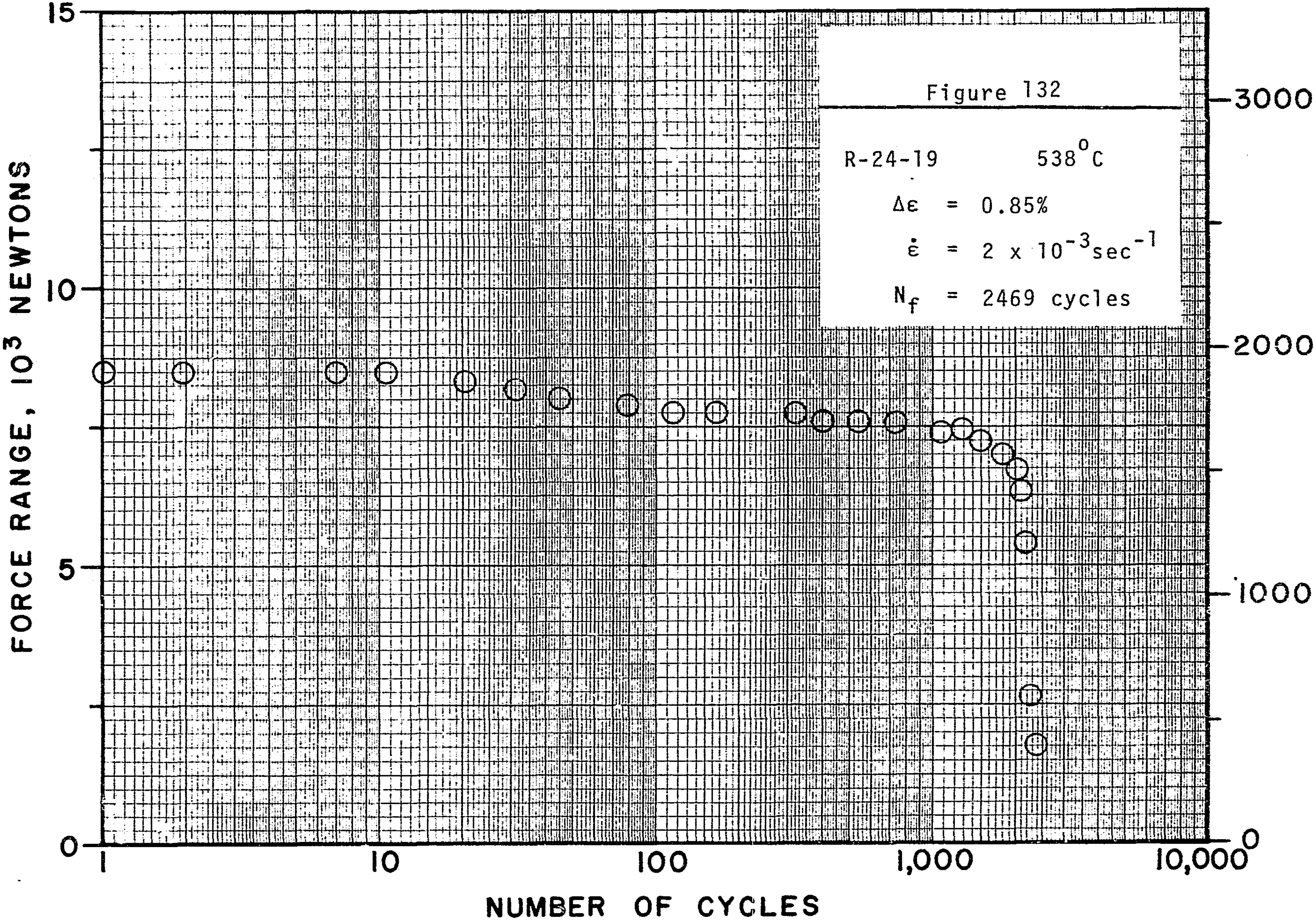


Figure 132
R-24-19 538°C
Δε = 0.85%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2469 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

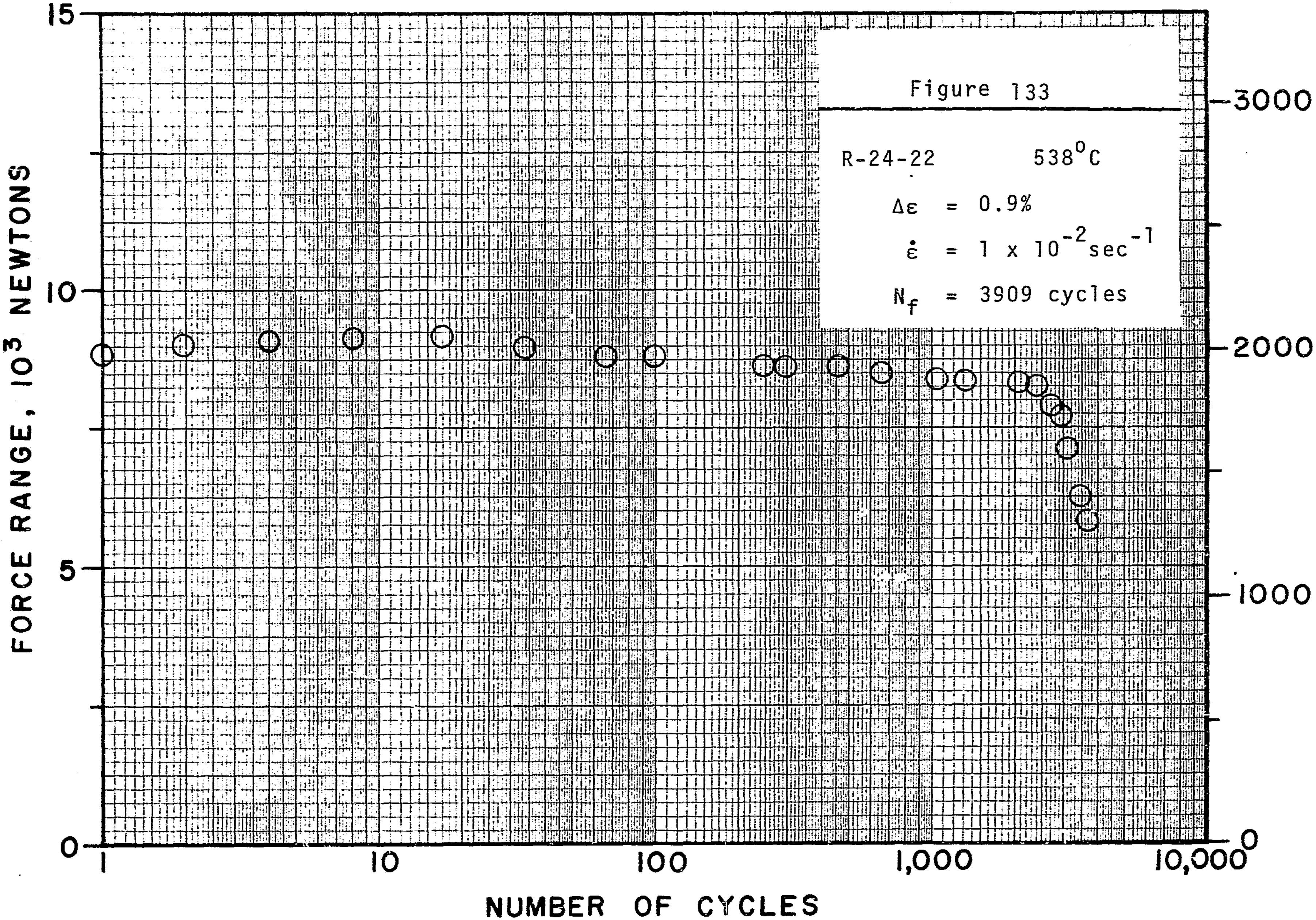


Figure 133
R-24-22 538°C
Δε = 0.9%
ε̇ = 1 x 10^-2 sec^-1
N_f = 3909 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

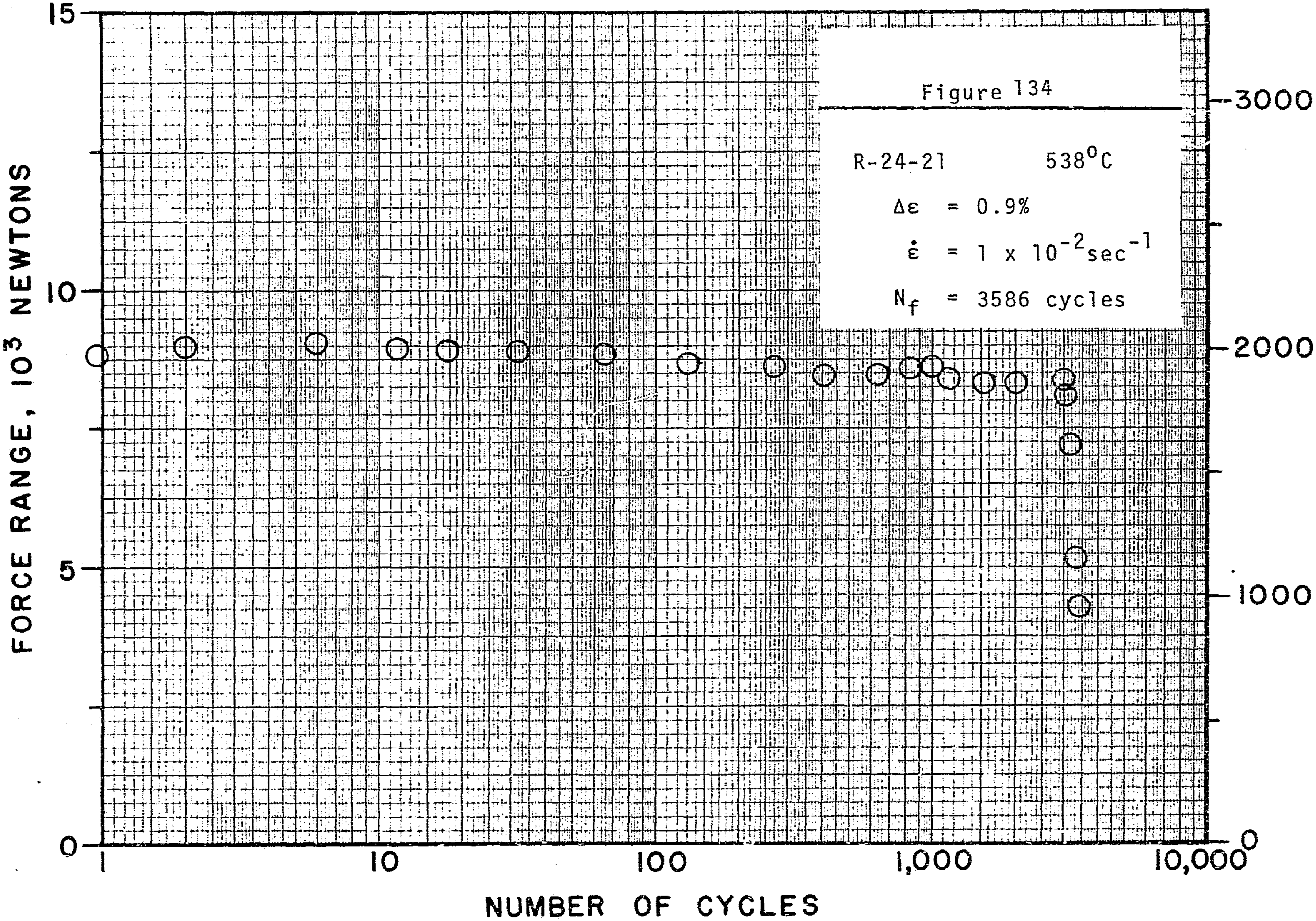

R-24-21 538°C
Δε = 0.9%
$\dot{\varepsilon}$ = 1 x 10^{-2}sec^{-1}
N_f = 3586 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 134

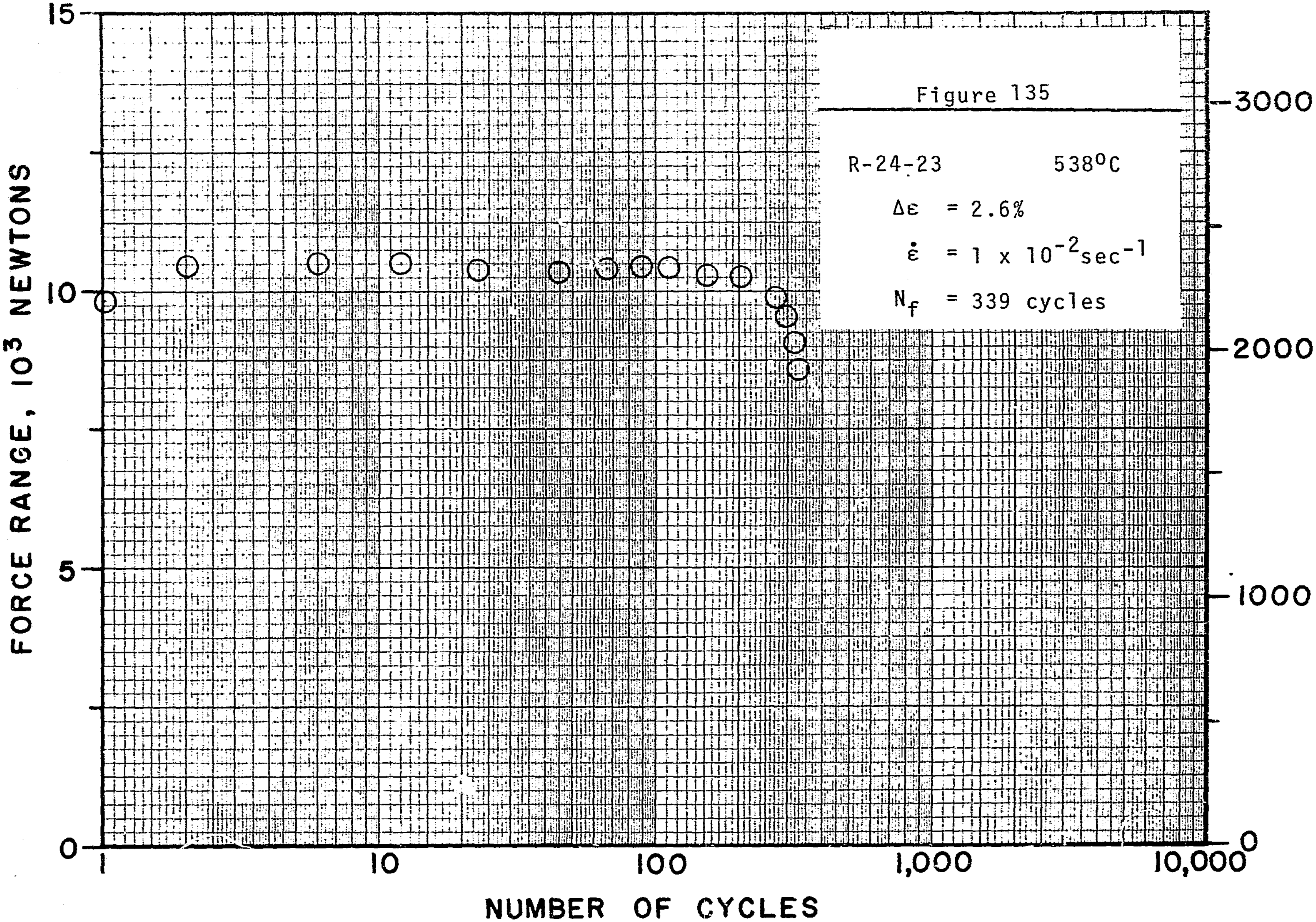


Figure 135
R-24-23
538°C
Δε = 2.6%
ε̇ = 1 x 10⁻² sec⁻¹
N_f = 339 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

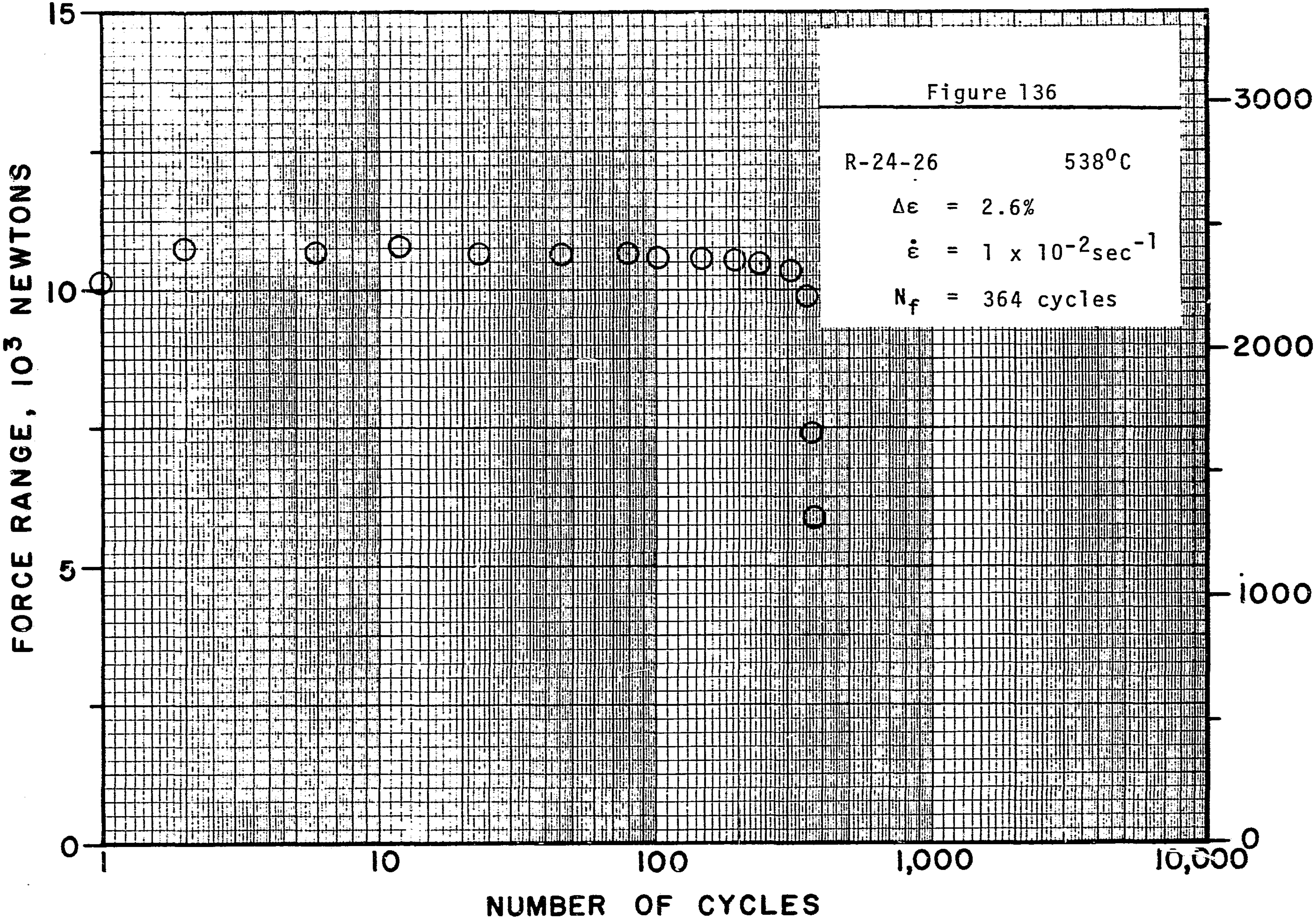


Figure 136
R-24-26
538°C
Δε = 2.6%
ε̇ = 1 x 10⁻² sec⁻¹
N_f = 364 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

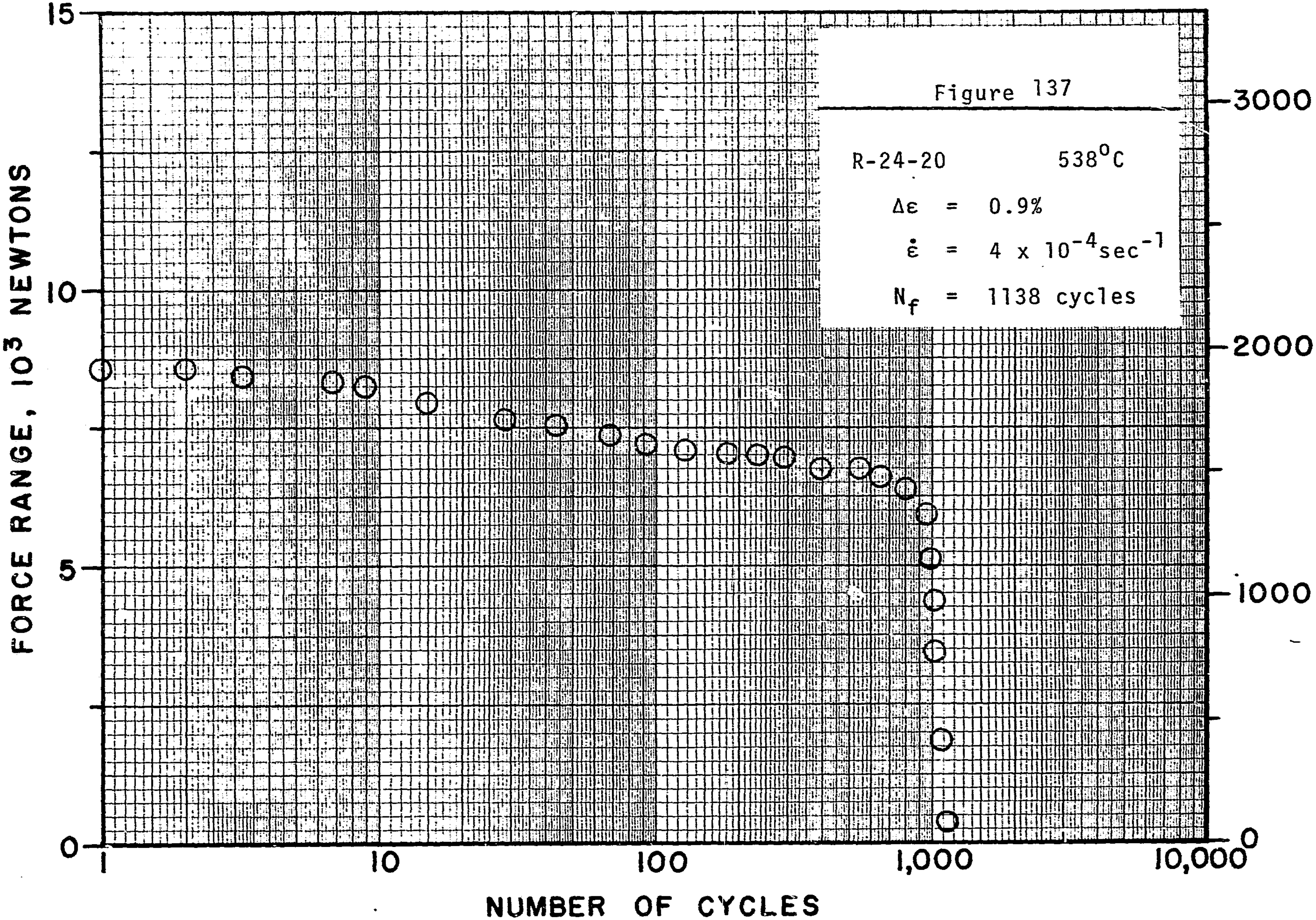

R-24-20 538°C
Δε = 0.9%
ε̇ = 4 x 10⁻⁴ sec⁻¹
N_f = 1138 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1000
2000
3000
1
10
100
1,000
10,000

Figure 137

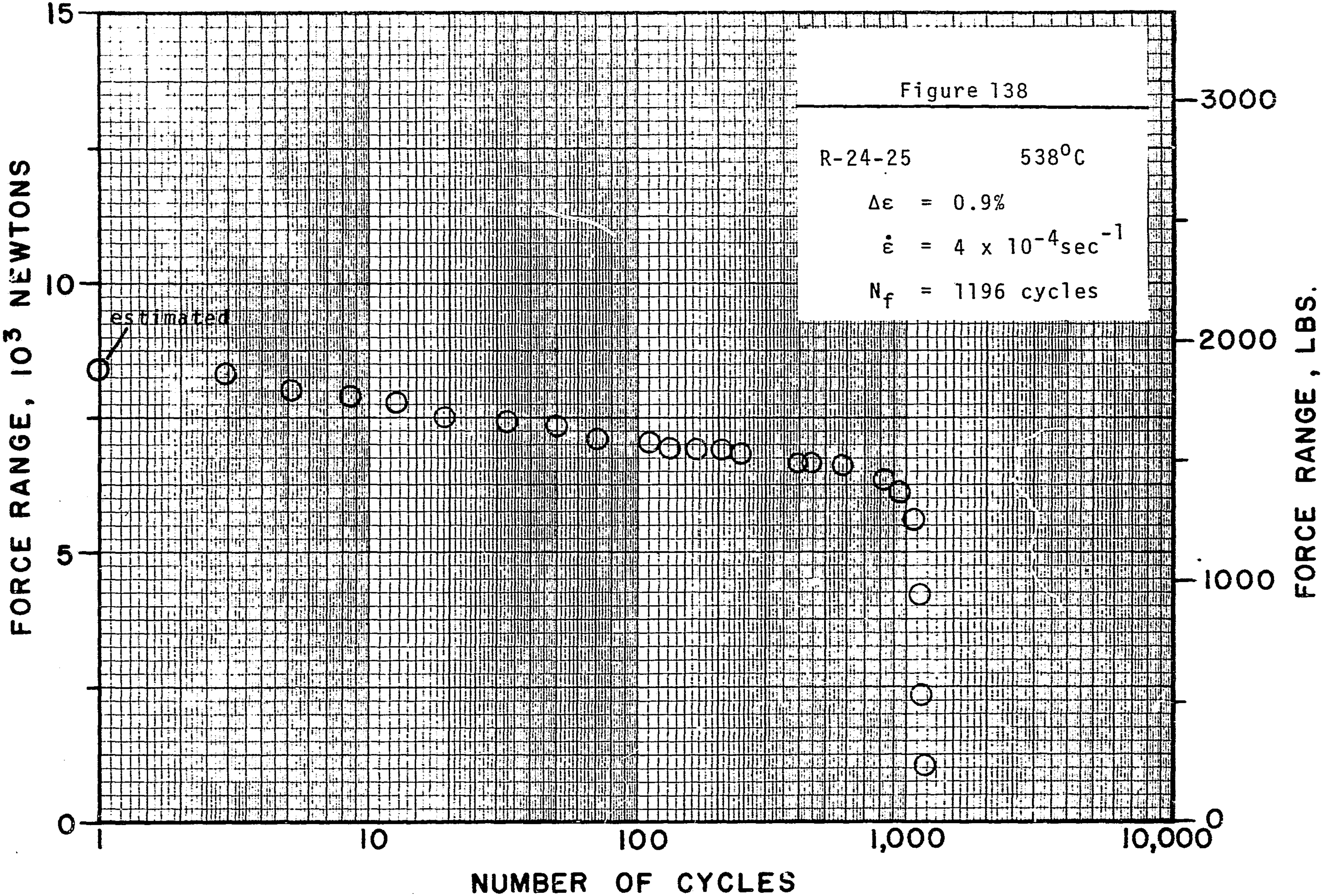

R-24-25 538^{o}C
$\Delta\varepsilon$ = 0.9%
$\dot{\varepsilon}$ = 4 x 10^{-4}sec^{-1}
N_f = 1196 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

Figure 138

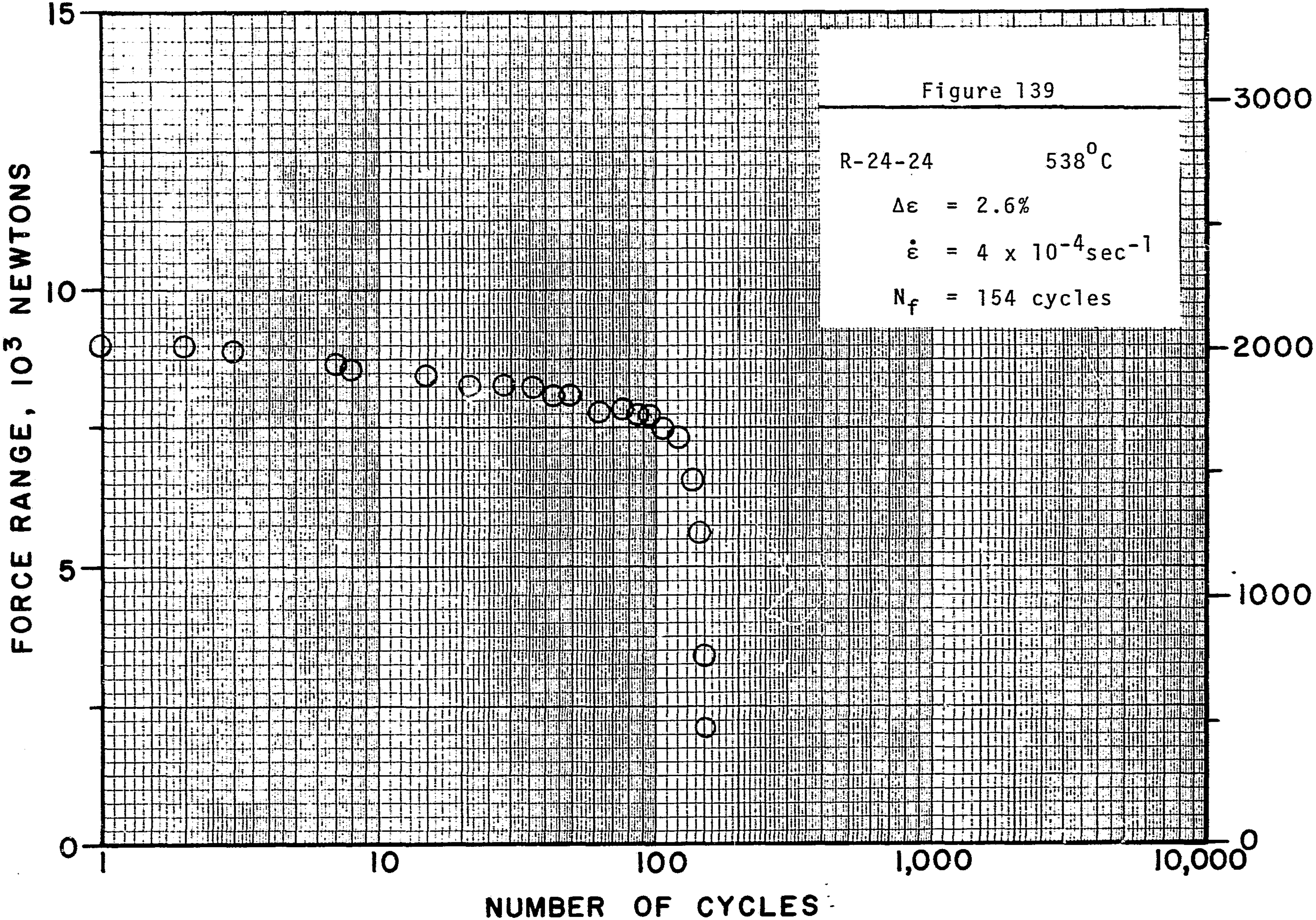


Figure 139
R-24-24 538°C
Δε = 2.6%
ε̇ = 4 x 10⁻⁴sec⁻¹
N_f = 154 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

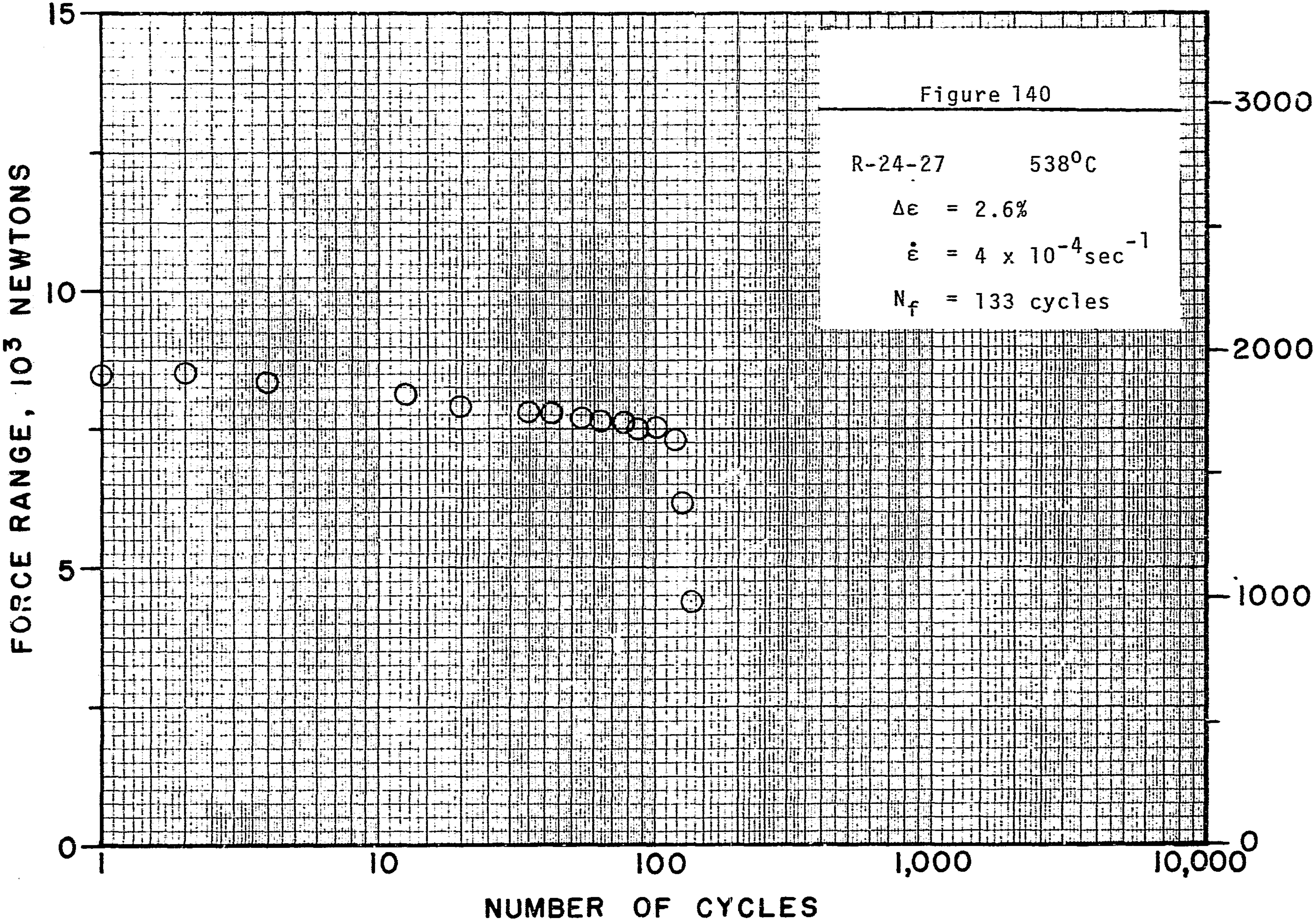


Figure 140
R-24-27 538^{o}C
$\Delta\varepsilon$ = 2.6%
$\dot{\varepsilon}$ = 4 x 10^{-4} sec^{-1}
N_f = 133 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

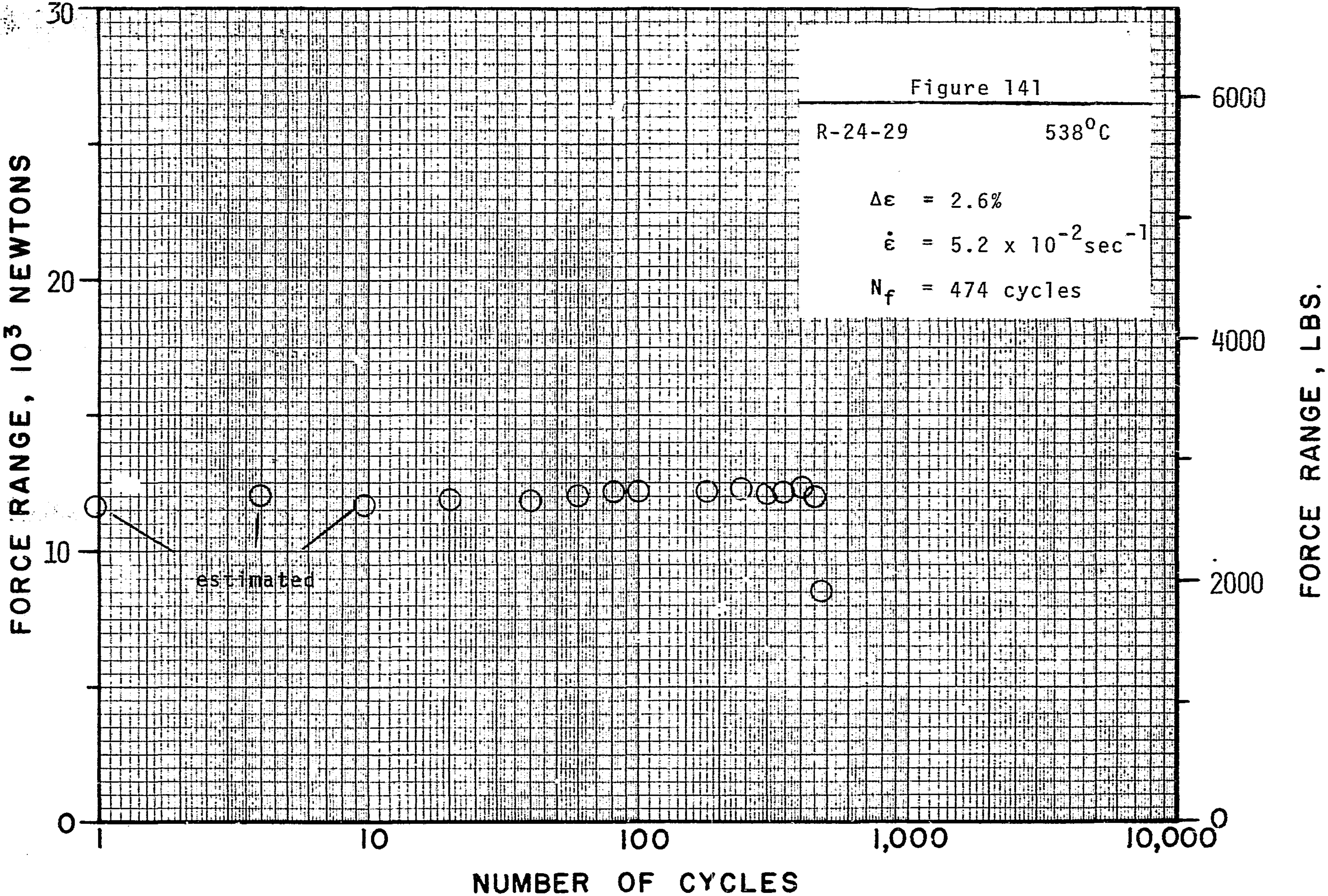


Figure 141
R-24-29
$538^{o}C$
$\Delta\varepsilon$ = 2.6%
$\dot{\varepsilon}$ = $5.2 \times 10^{-2} sec^{-1}$
N_f = 474 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

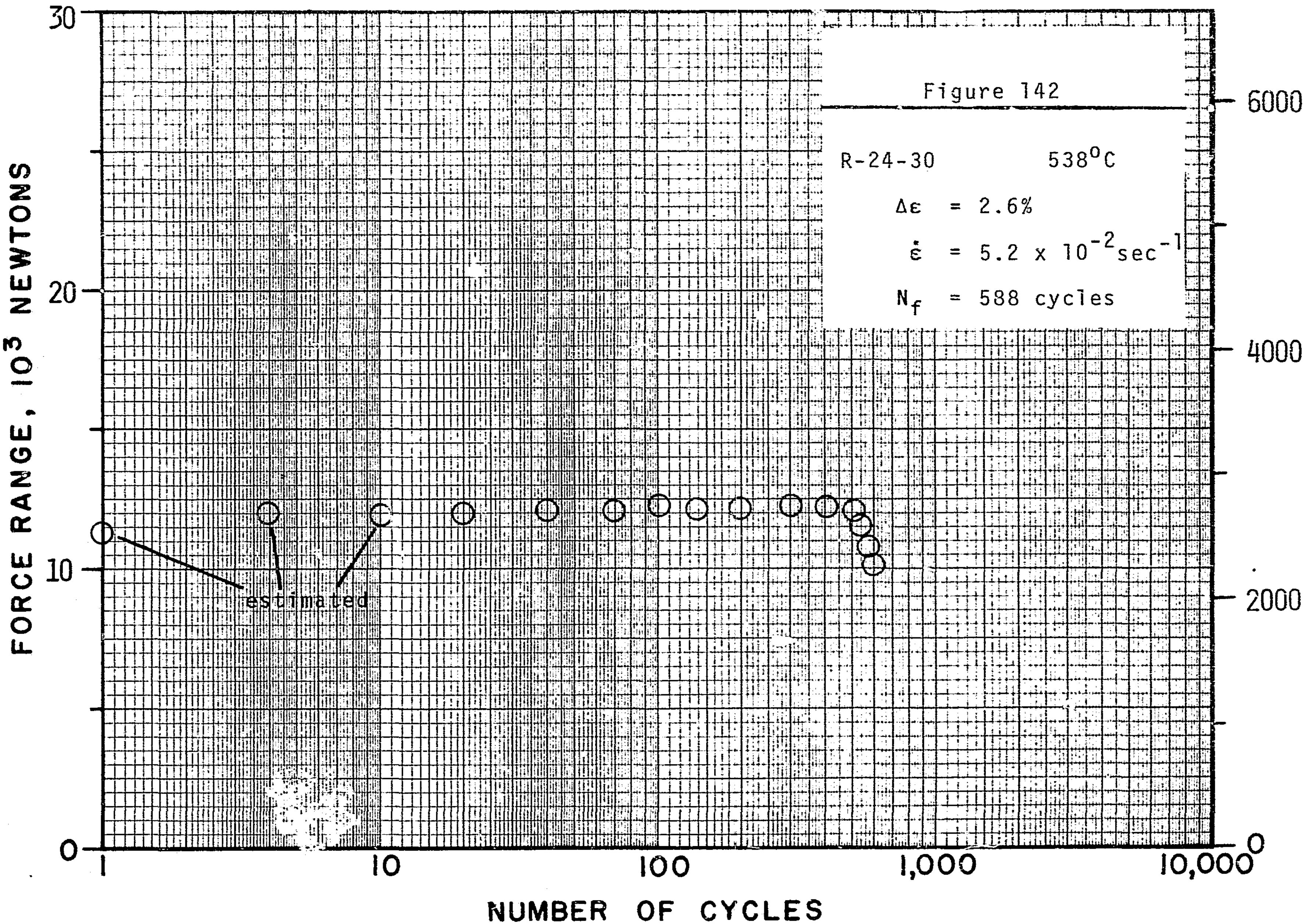


Figure 142
R-24-30
538°C
Δε = 2.6%
ε̇ = 5.2 x 10⁻² sec⁻¹
Nf = 588 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
2000
4000
6000
1
10
100
1,000
10,000

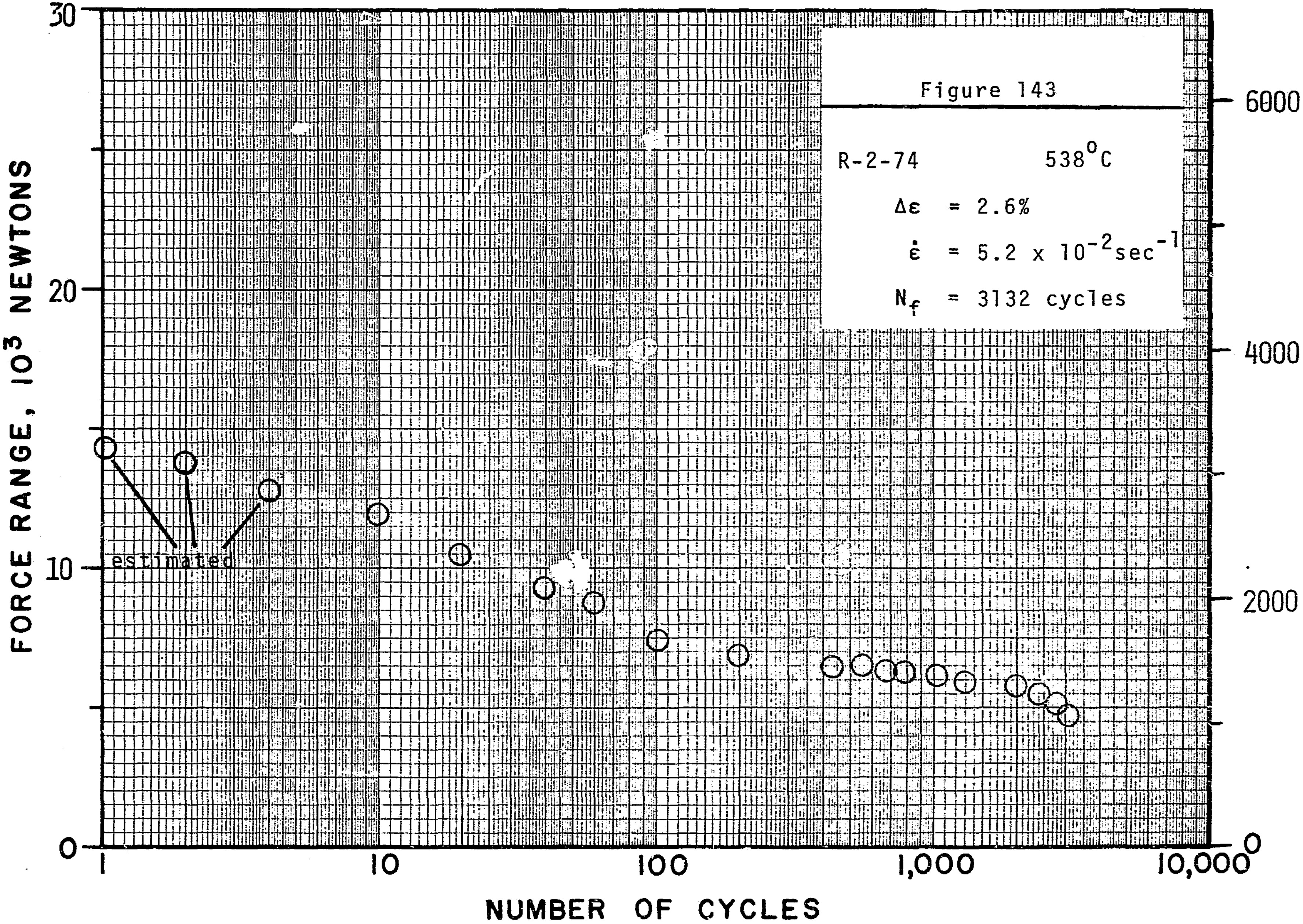


Figure 143
R-2-74 538°C
Δε = 2.6%
ε̇ = 5.2 x 10^-2 sec^-1
N_f = 3132 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
0
2000
4000
6000
1
10
100
1,000
10,000

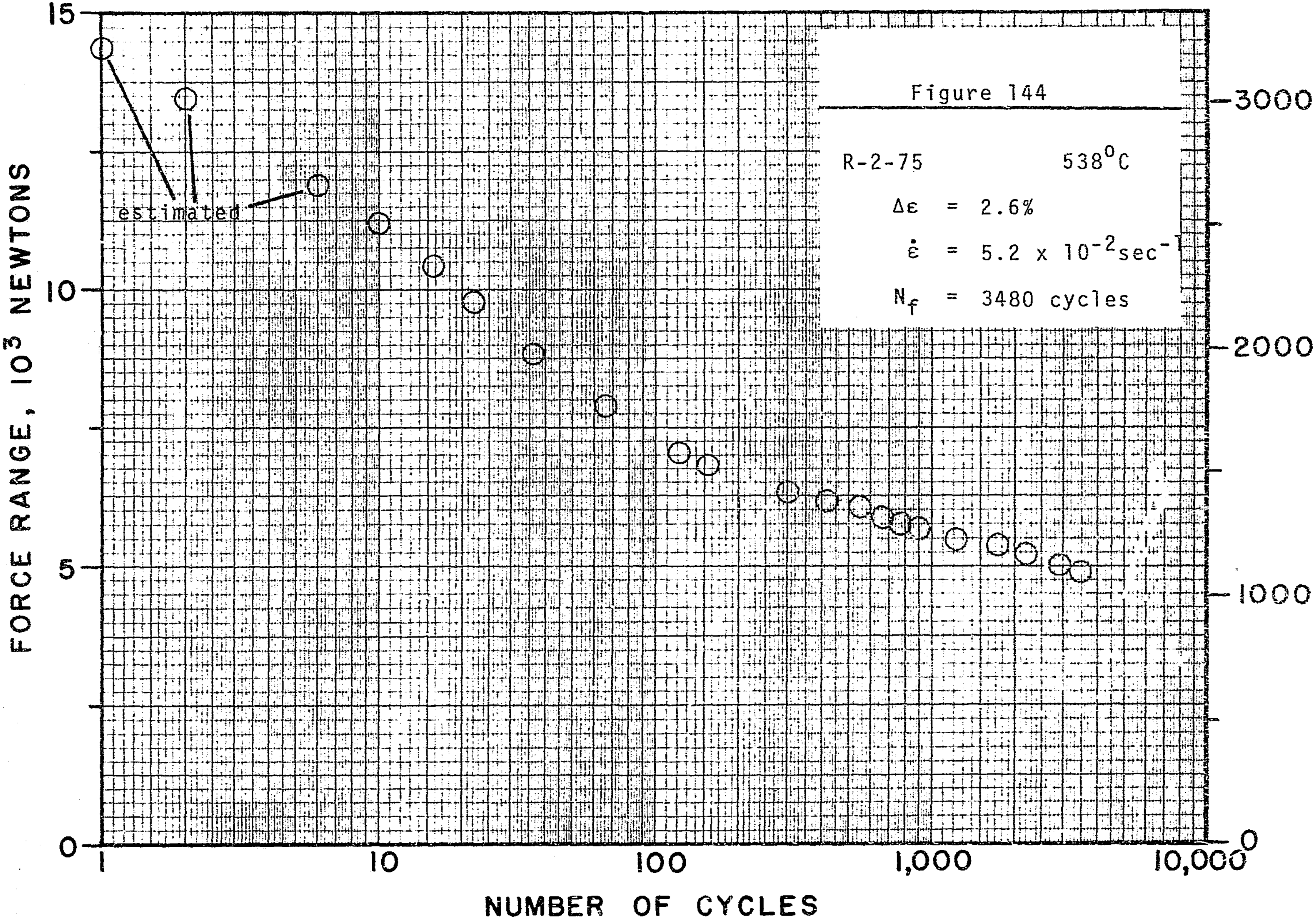


Figure 144
R-2-75 538°C
Δε = 2.6%
ε̇ = 5.2 x 10⁻² sec⁻¹
N_f = 3480 cycles
estimated
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

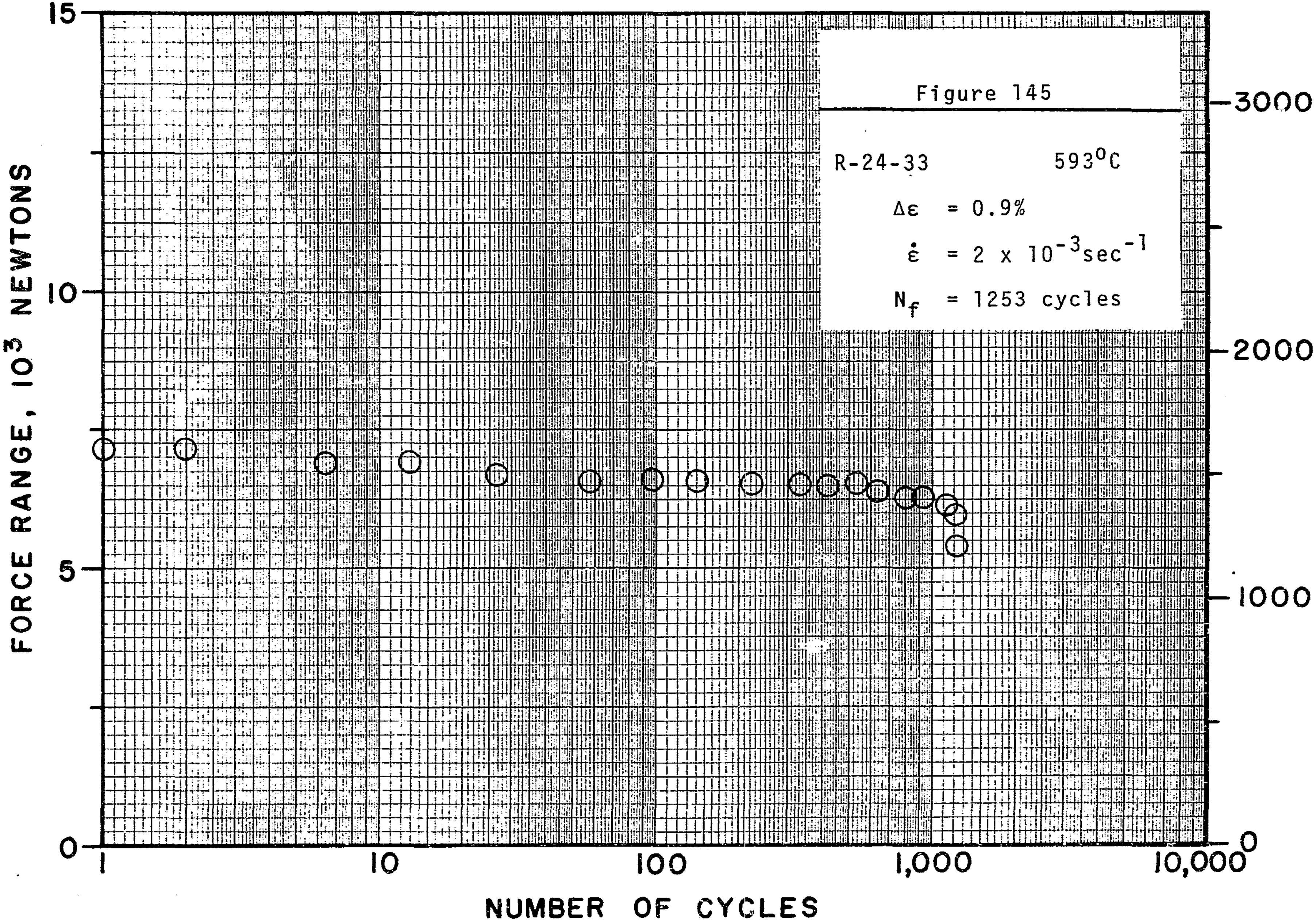

R-24-33
593°C
Δε = 0.9%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1253 cycles
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

Figure 145

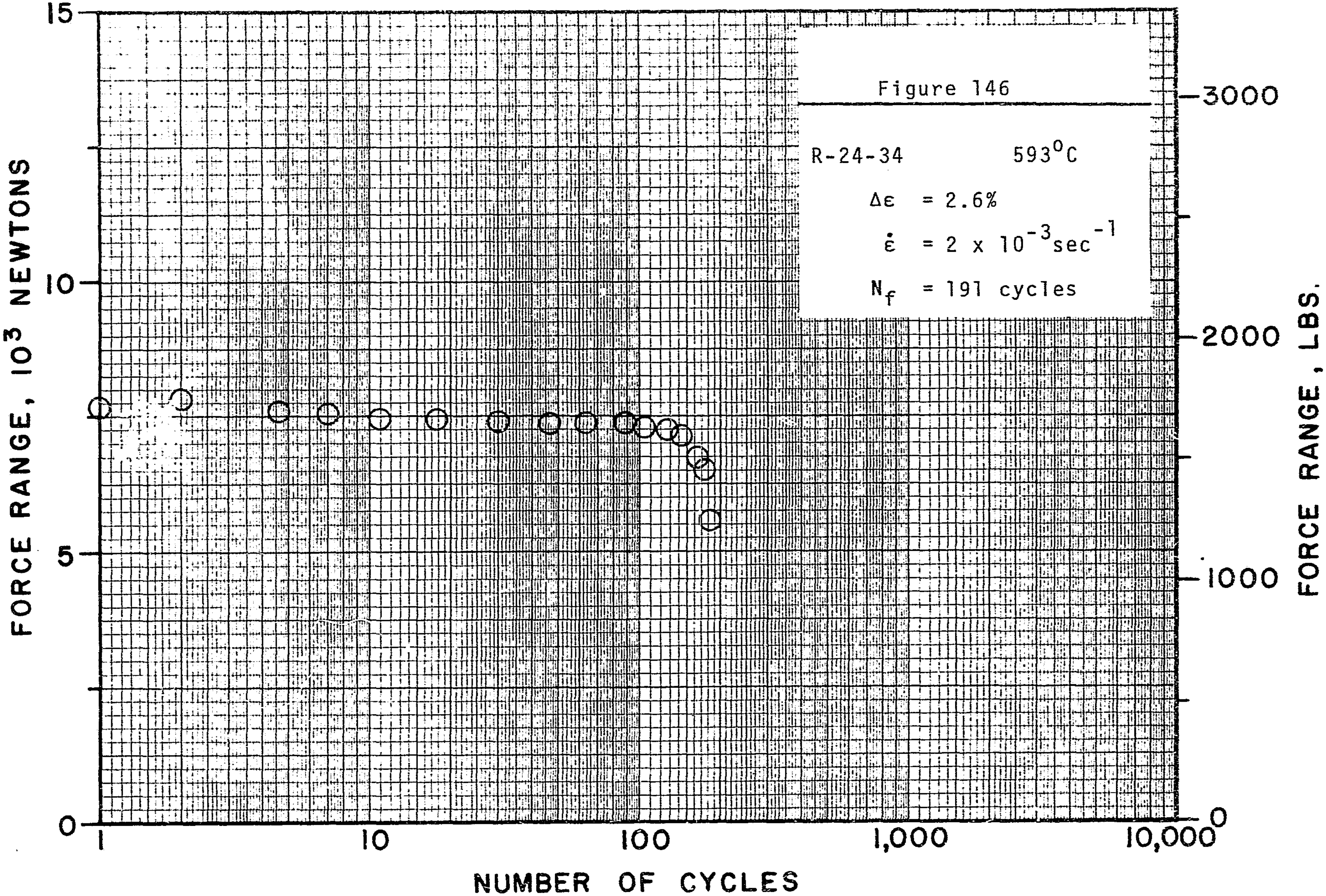


Figure 146
R-24-34 593°C
Δε = 2.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 191 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

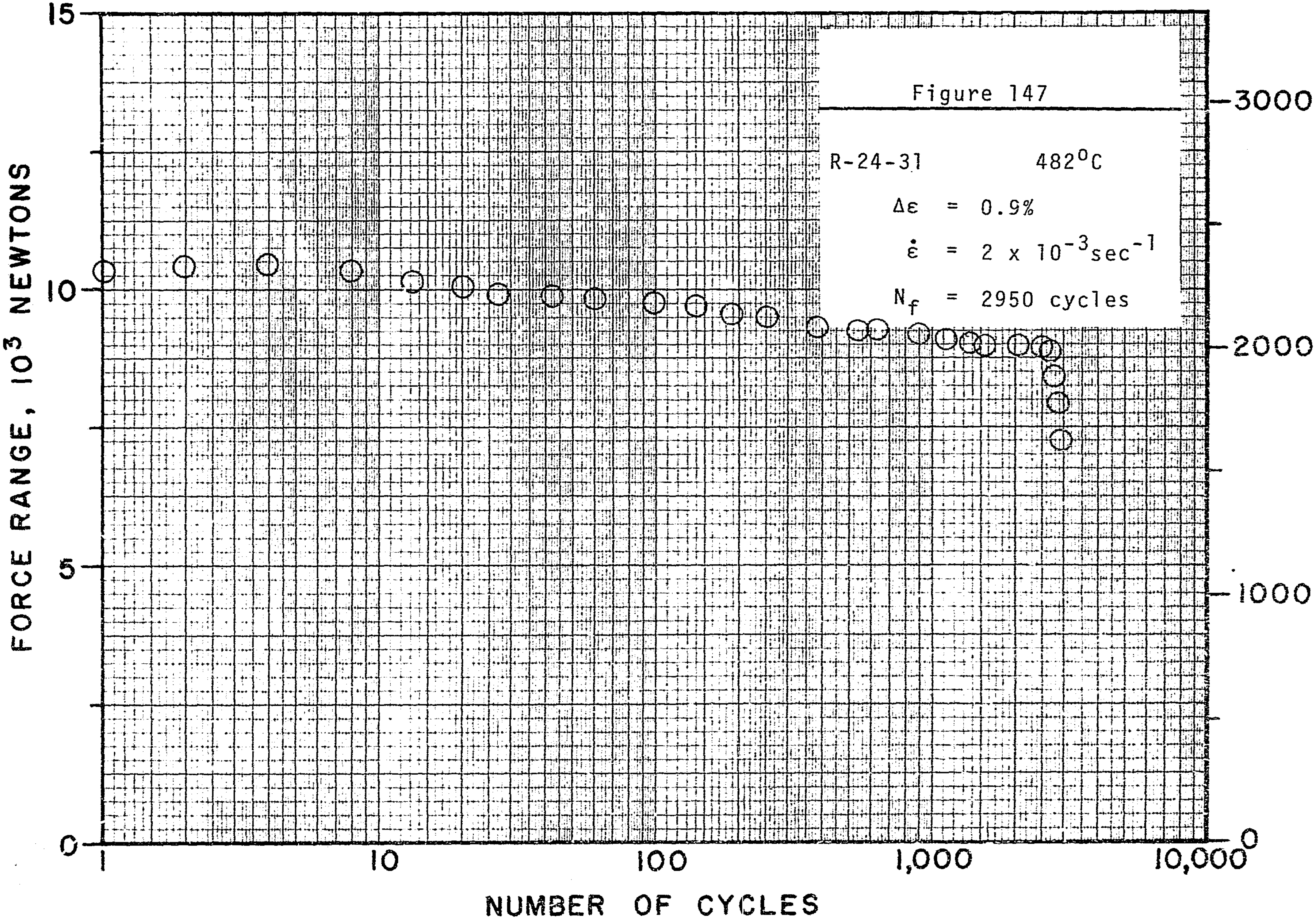


Figure 147
R-24-31 482°C
Δε = 0.9%
ε̇ = 2 x 10^-3 sec^-1
N_f = 2950 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

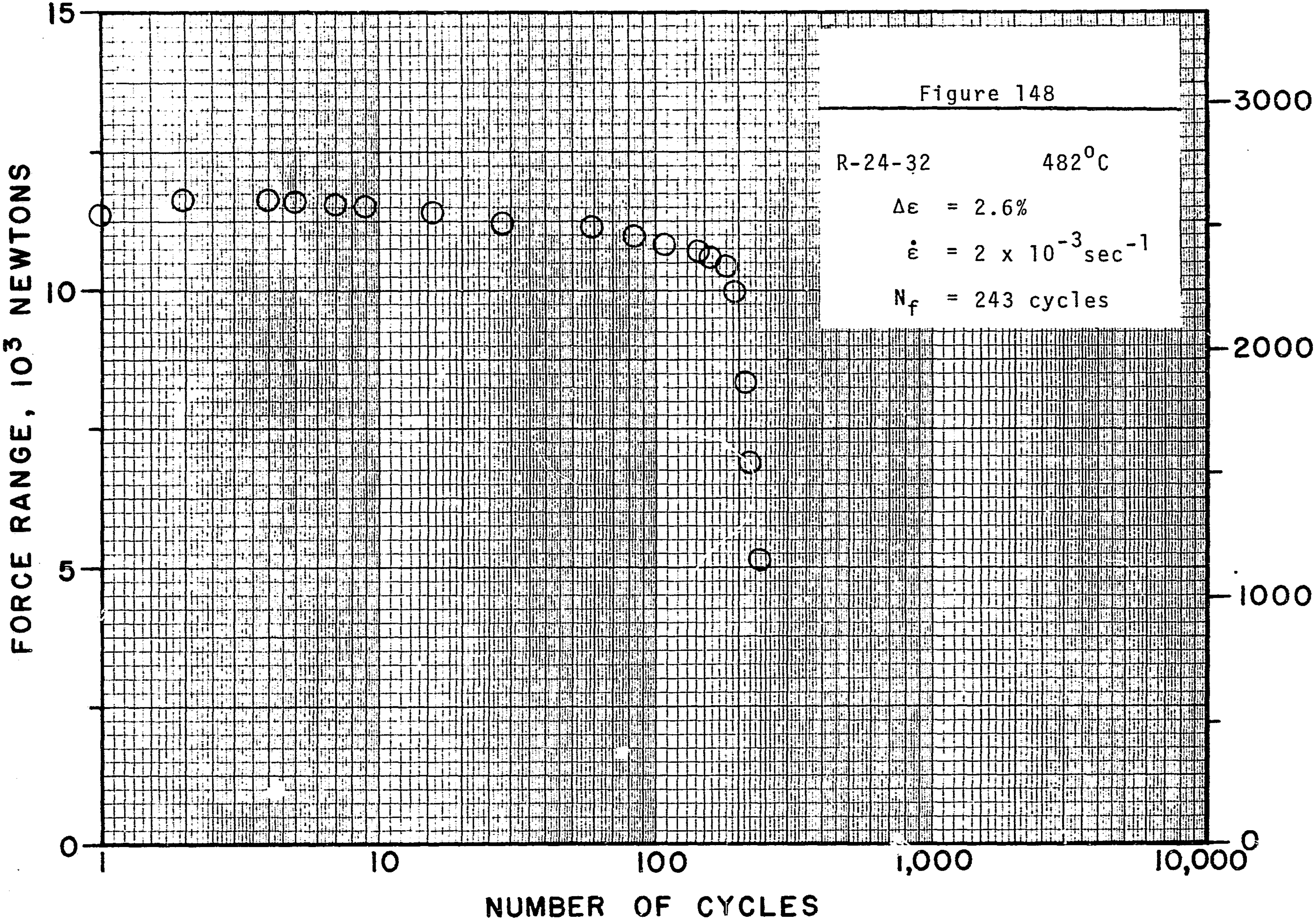


Figure 148
R-24-32 482°C
Δε = 2.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 243 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

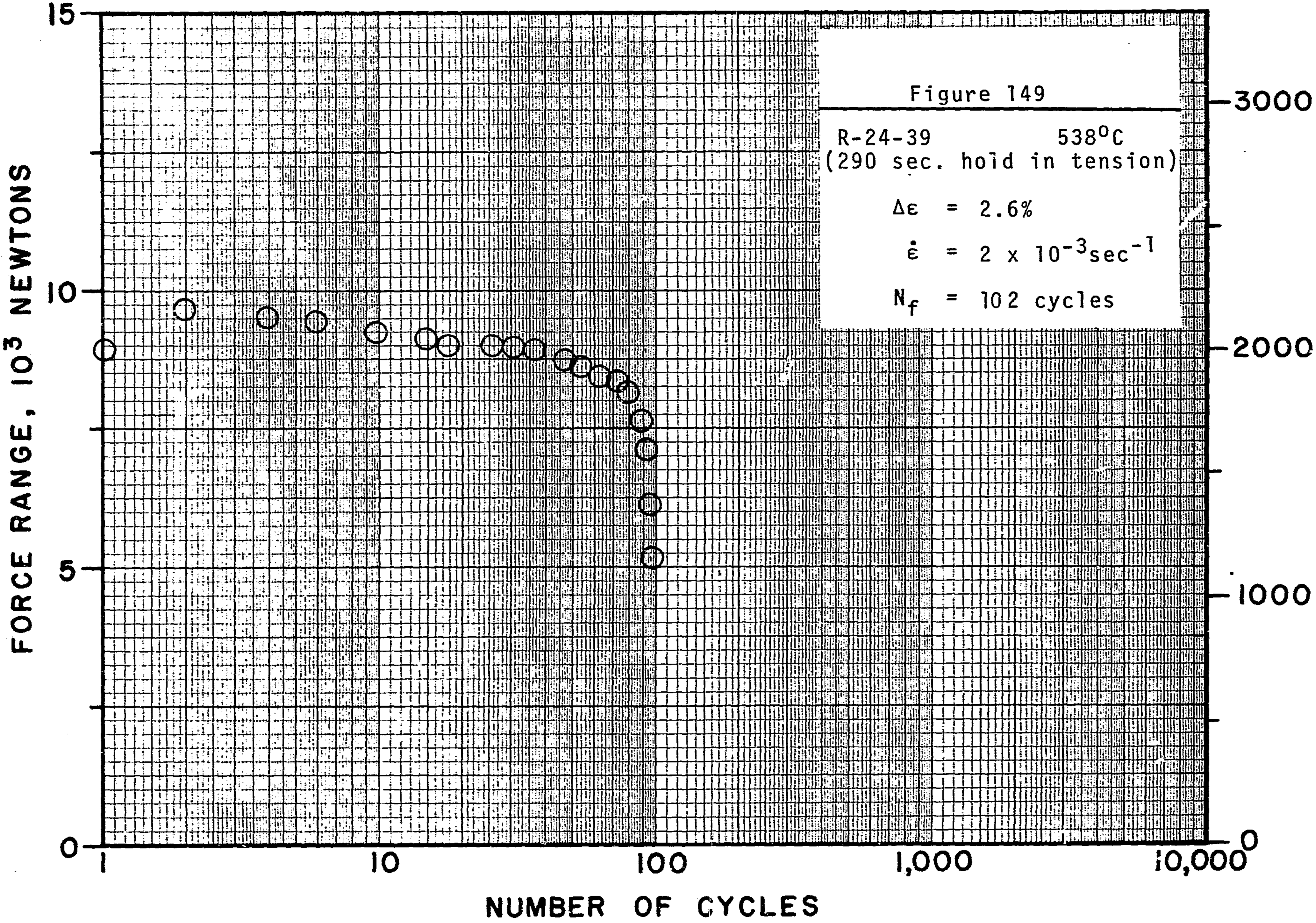

R-24-39 538°C
(290 sec. hold in tension)
Δε = 2.6%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 102 cycles
15
10
5
0
FORCE RANGE, 10³ NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 149

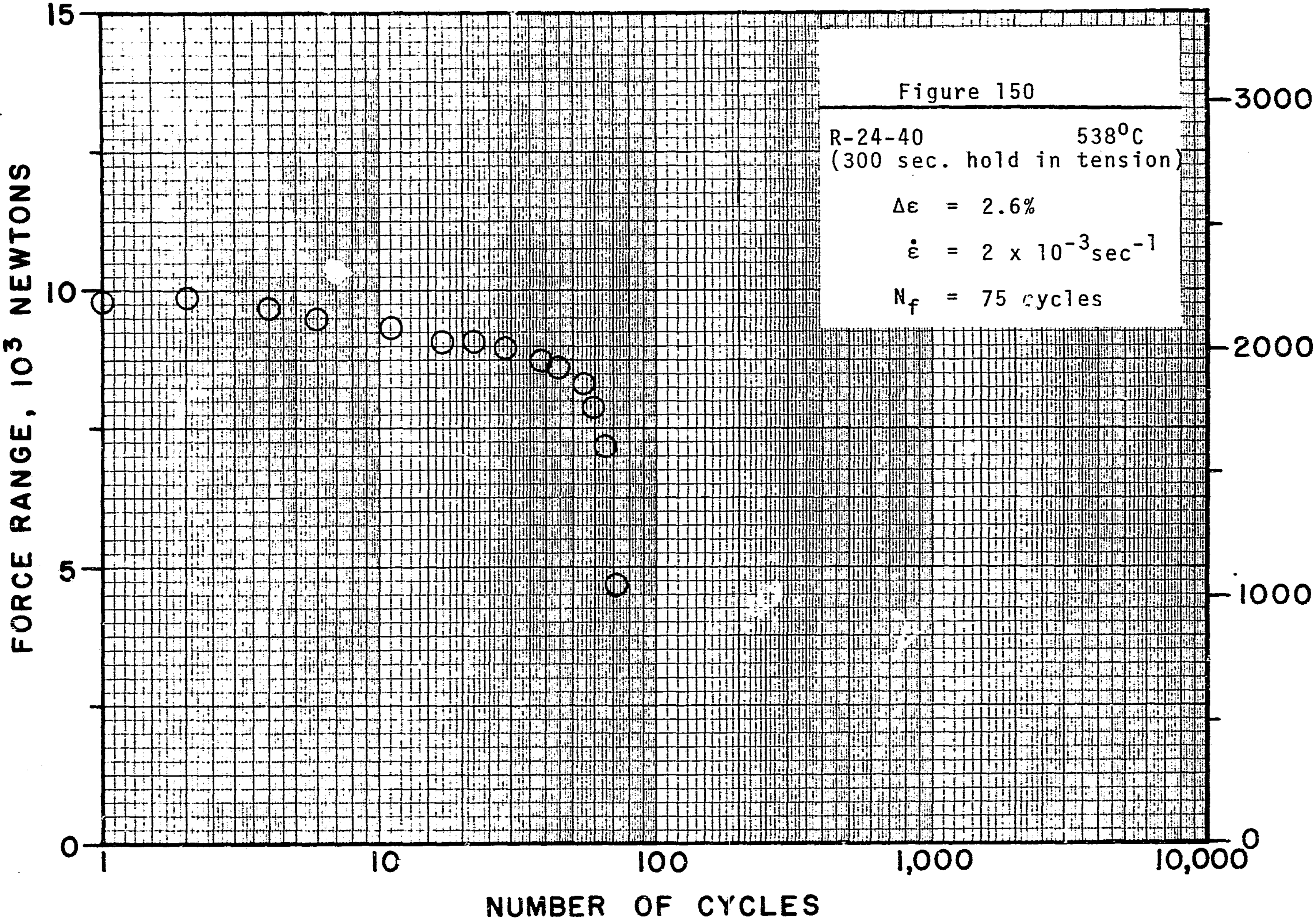

R-24-40
538°C
(300 sec. hold in tension)
Δε = 2.6%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 75 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 150

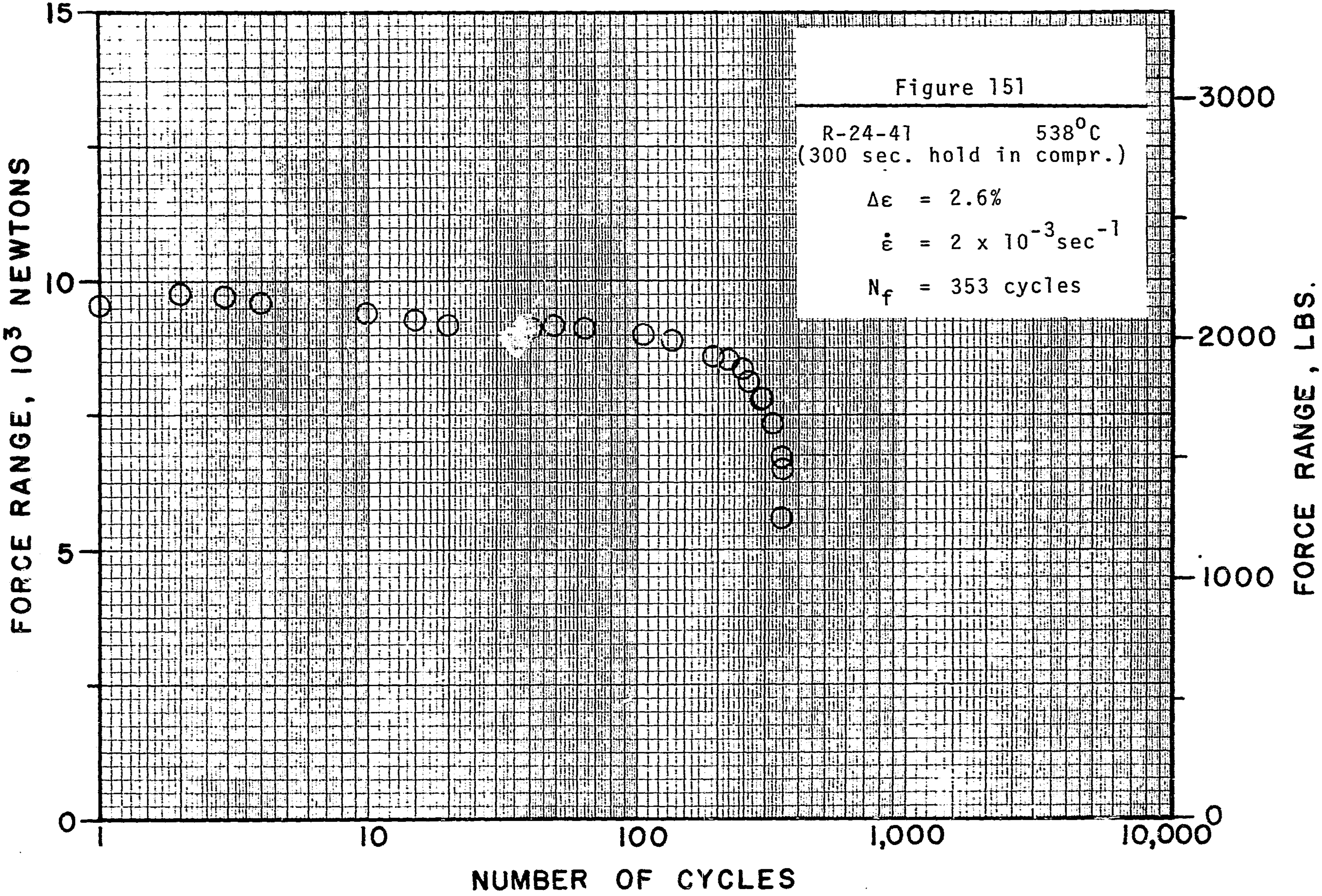


Figure 151
R-24-41 538°C
(300 sec. hold in compr.)
Δε = 2.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 353 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

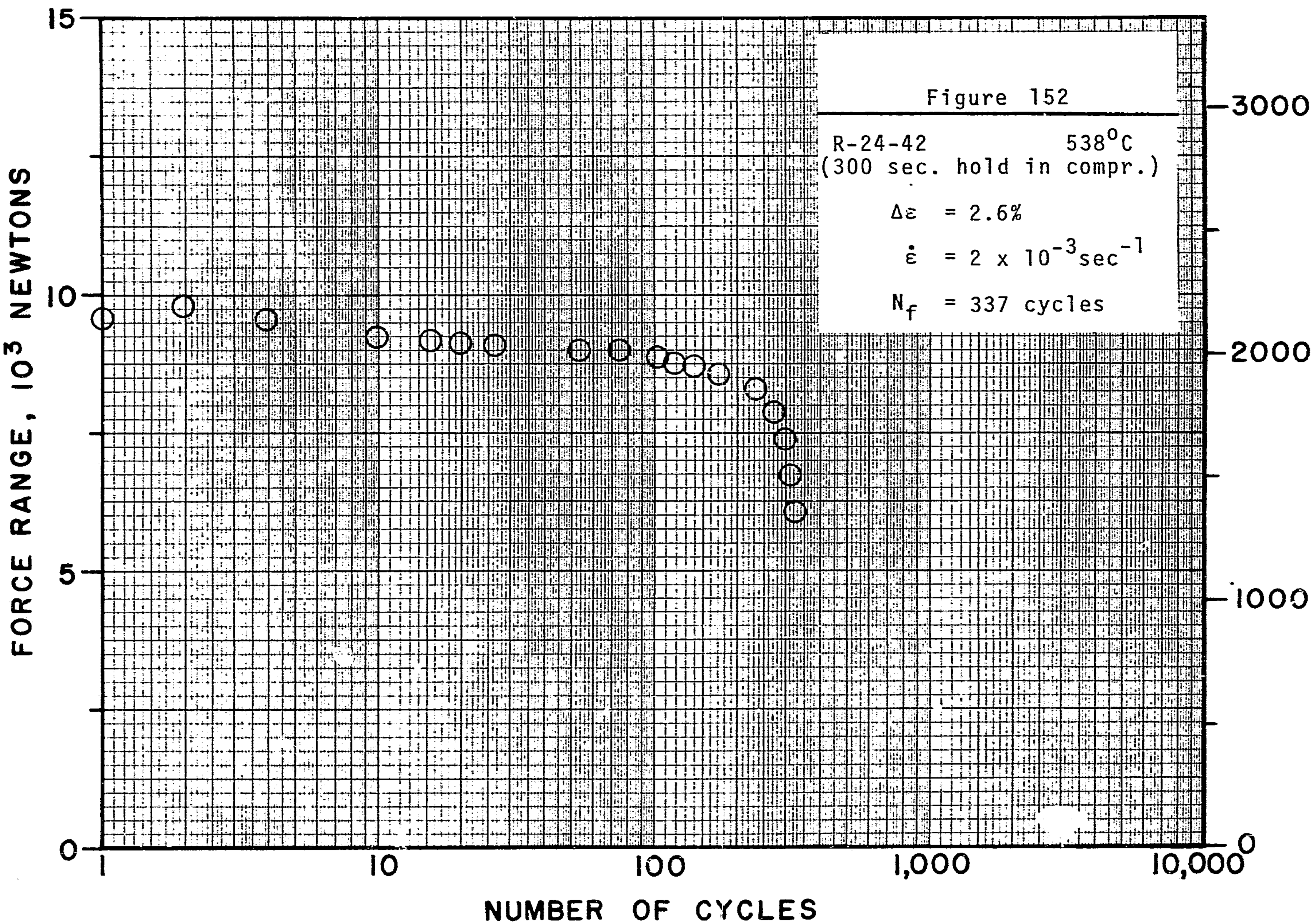


Figure 152
R-24-42 538°C
(300 sec. hold in compr.)
Δε = 2.6%
ε̇ = 2 x 10^-3 sec^-1
N_f = 337 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

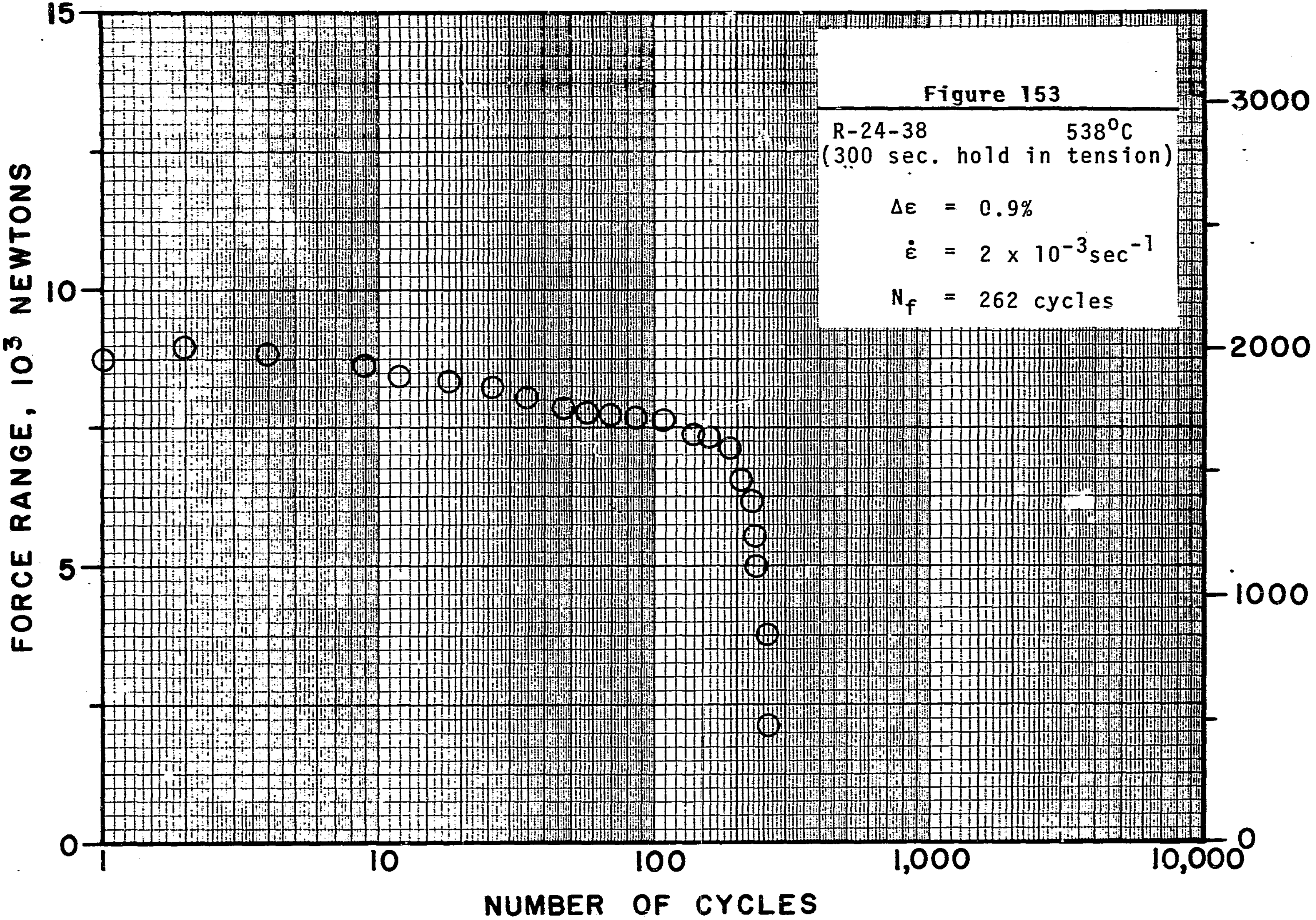


Figure 153
R-24-38 538°C
(300 sec. hold in tension)
Δε = 0.9%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 262 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

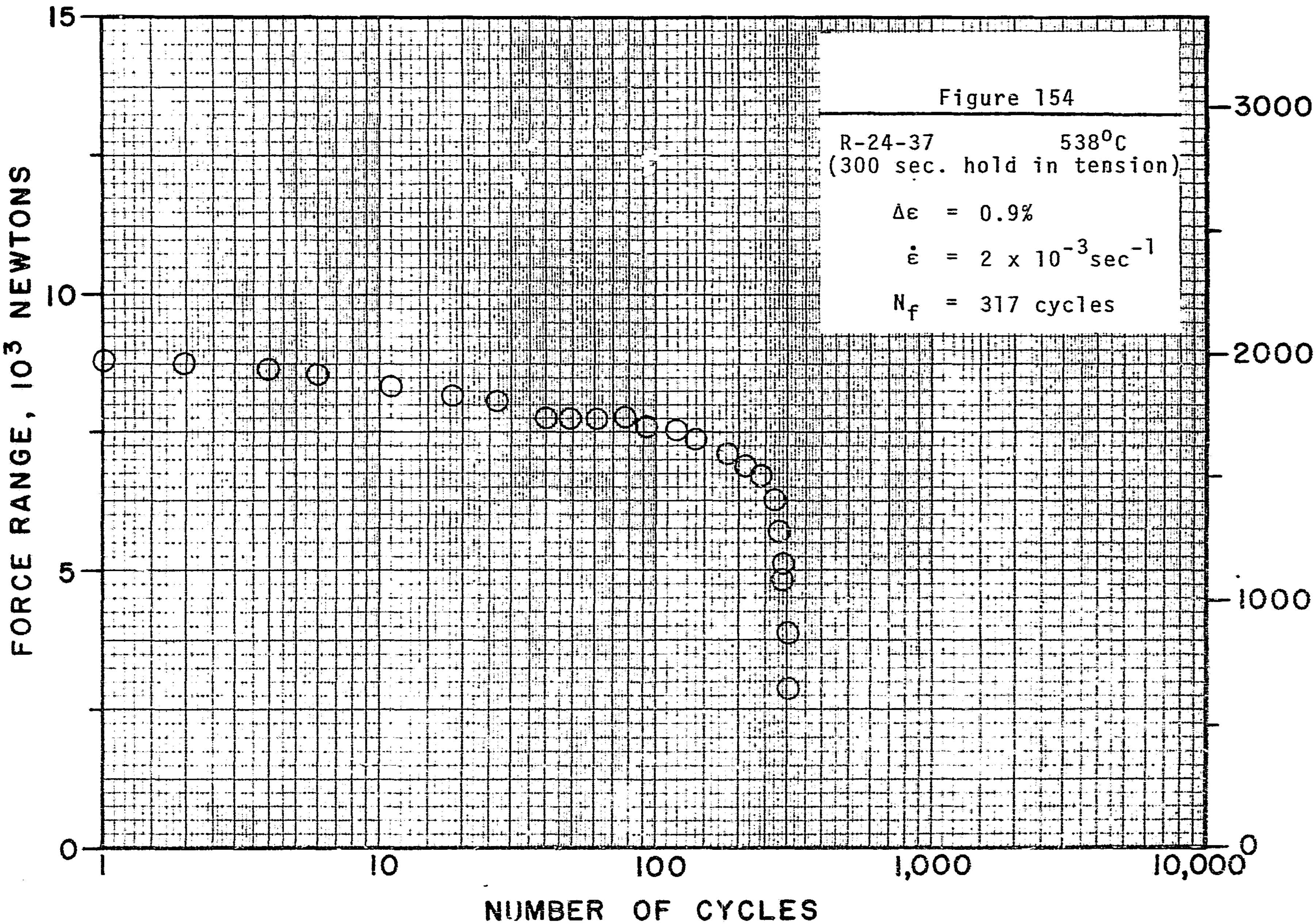

R-24-37 538°C
(300 sec. hold in tension)
Δε = 0.9%
ε̇ = 2 x 10^-3 sec^-1
N_f = 317 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 154

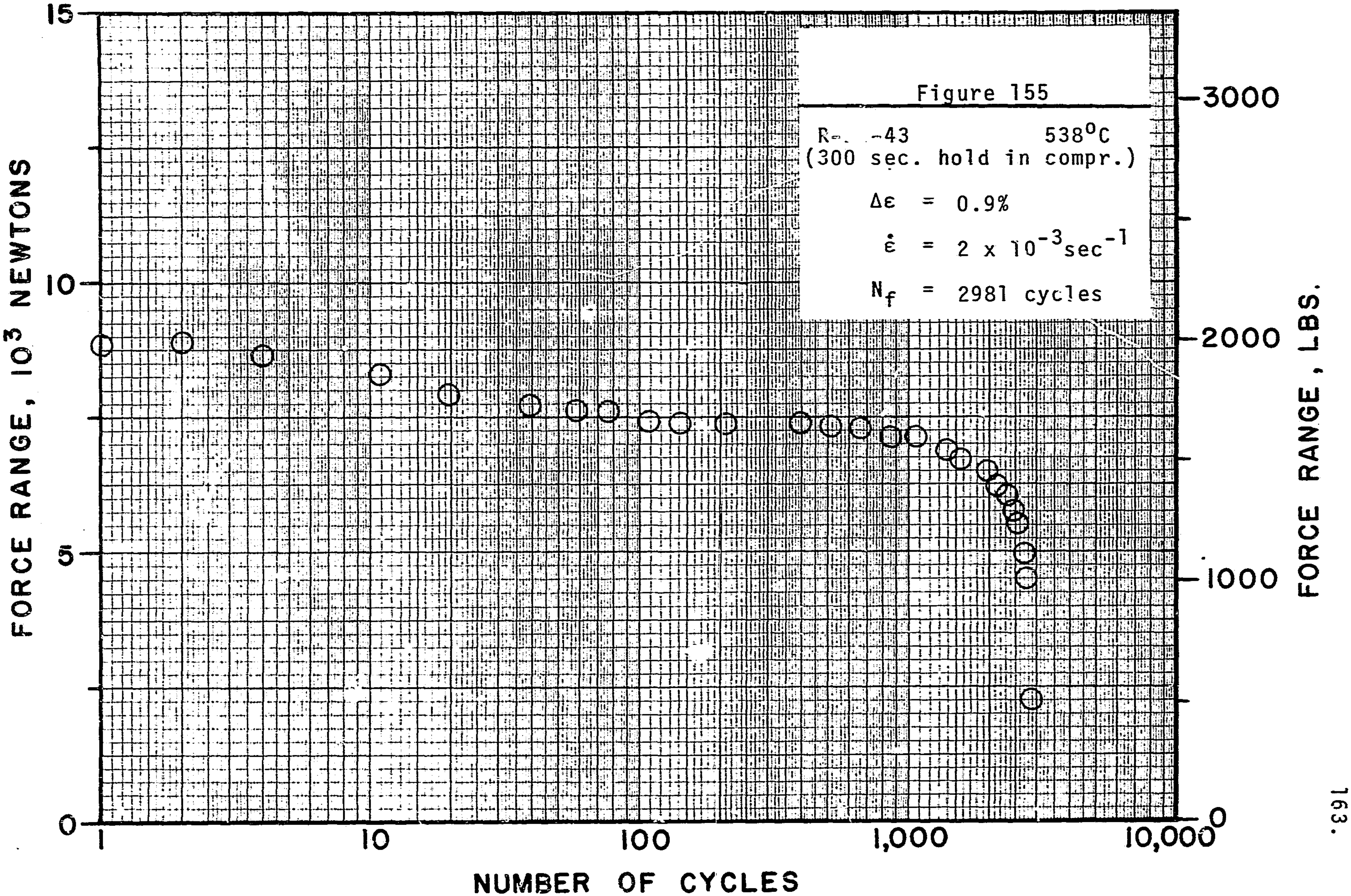


Figure 155
R-. -43 538°C
(300 sec. hold in compr.)
Δε = 0.9%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2981 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

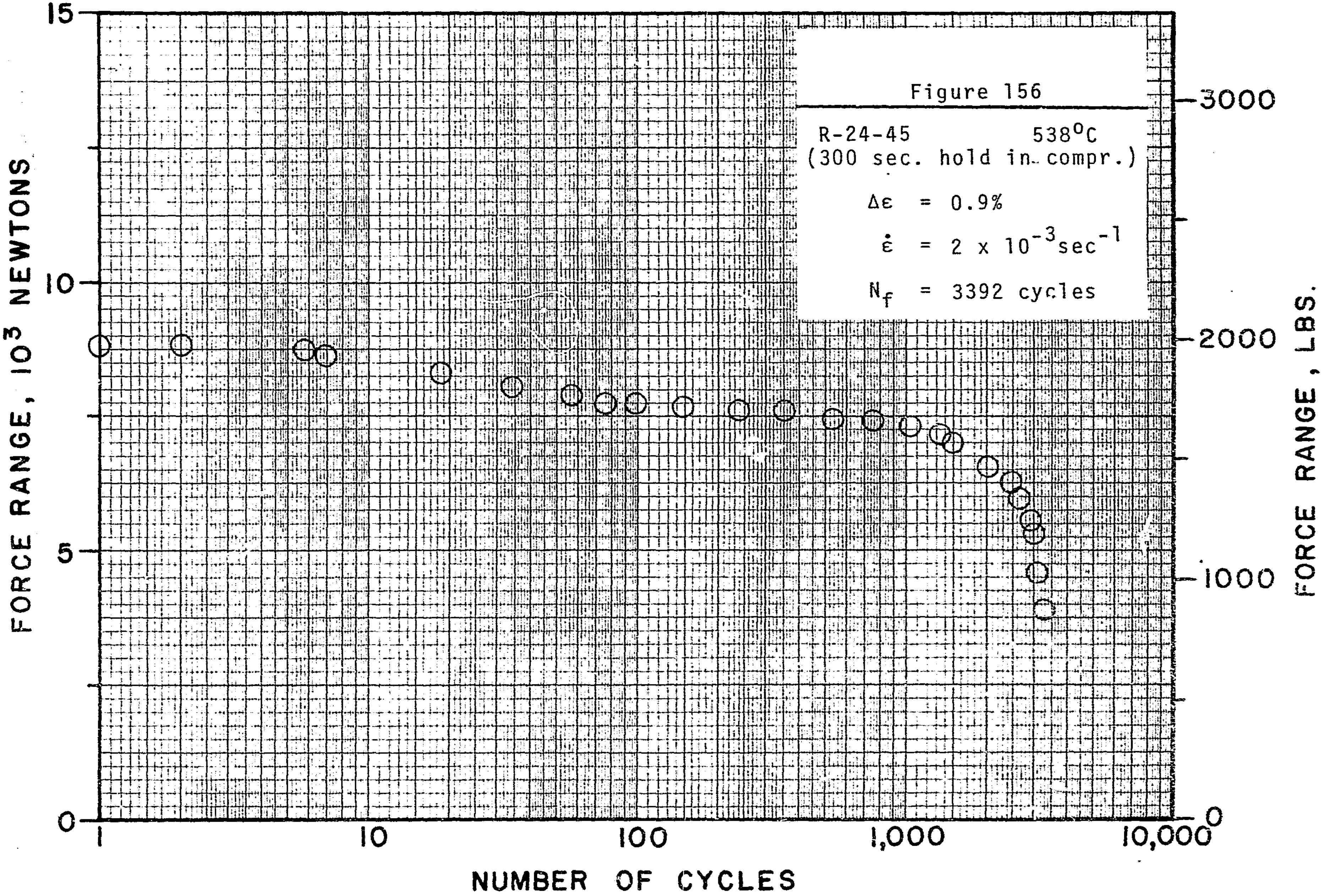


Figure 156
R-24-45 538°C
(300 sec. hold in compr.)
Δε = 0.9%
ε̇ = 2 x 10^-3 sec^-1
N_f = 3392 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

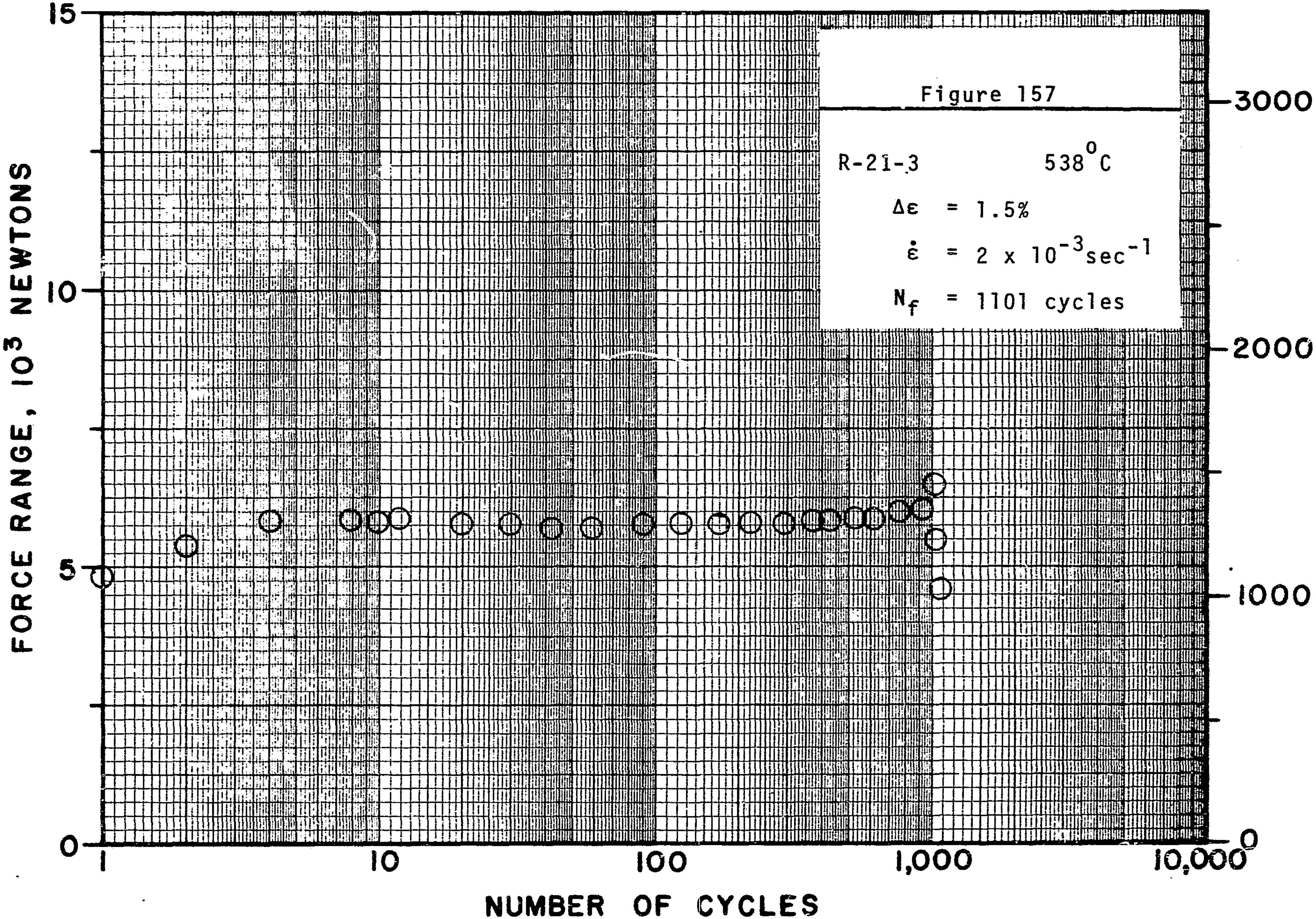


Figure 157
R-21-3
538°C
Δε = 1.5%
ε̇ = 2 x 10⁻³ sec⁻¹
Nf = 1101 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

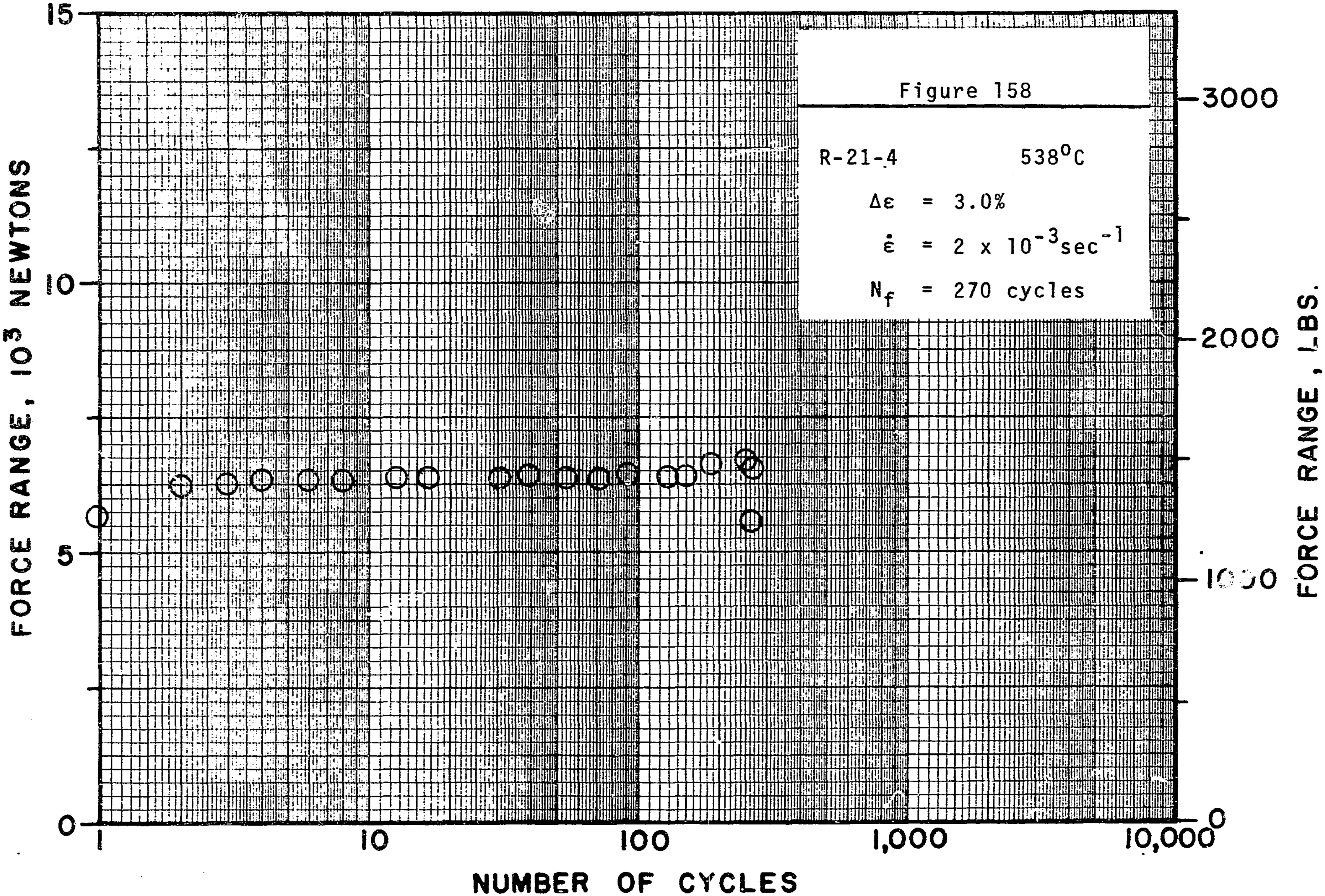

R-21-4 538°C
Δε = 3.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 270 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

Figure 158

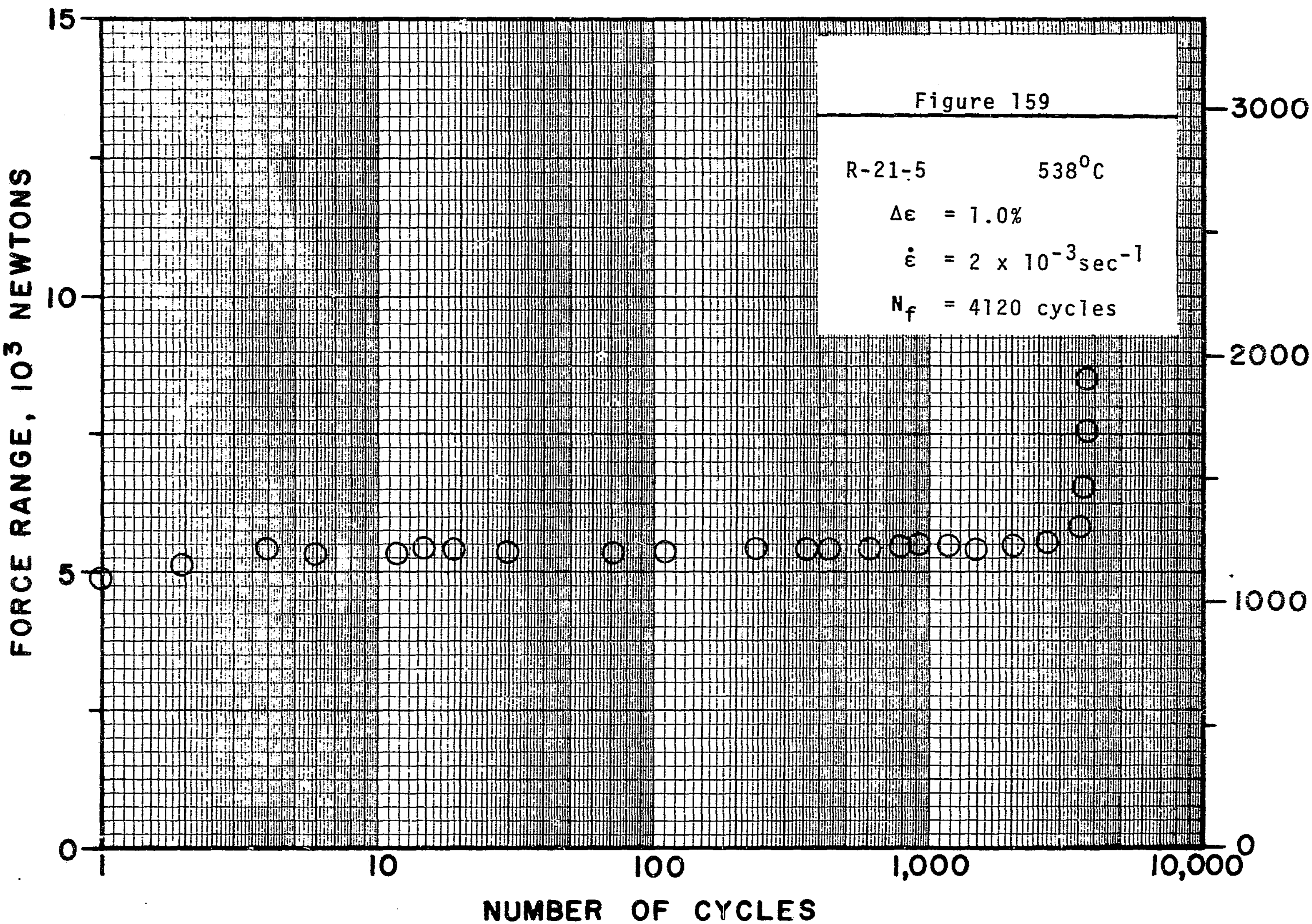

R-21-5 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 4120 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

Figure 159

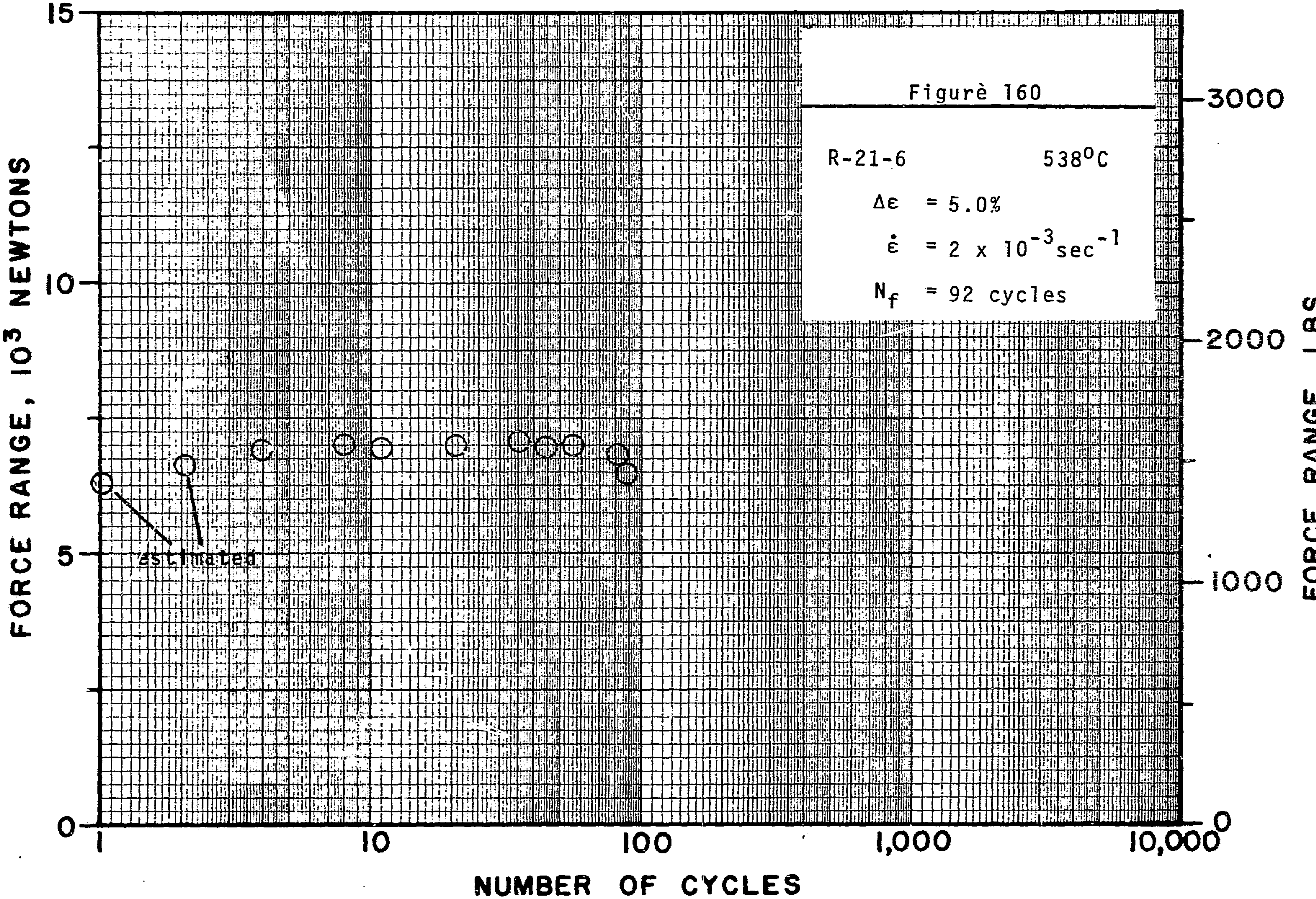

R-21-6 538°C
Δε = 5.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 92 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
0
5
10
15
FORCE RANGE, LBS.
0
1000
2000
3000
NUMBER OF CYCLES
1
10
100
1,000
10,000

Figure 160

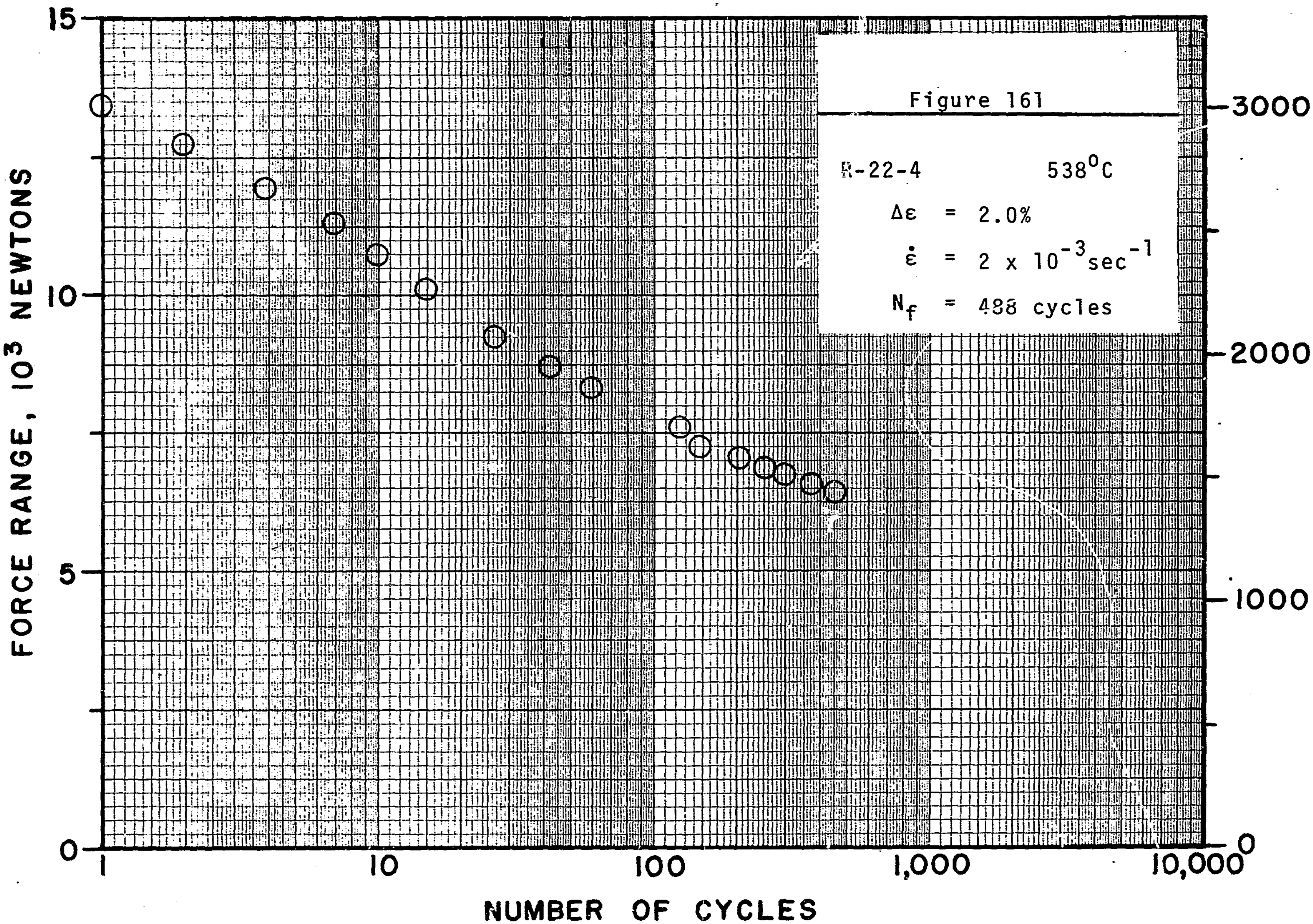


Figure 161
R-22-4
538°C
Δε = 2.0%
ε̇ = 2 x 10⁻³ sec⁻¹
Nf = 488 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

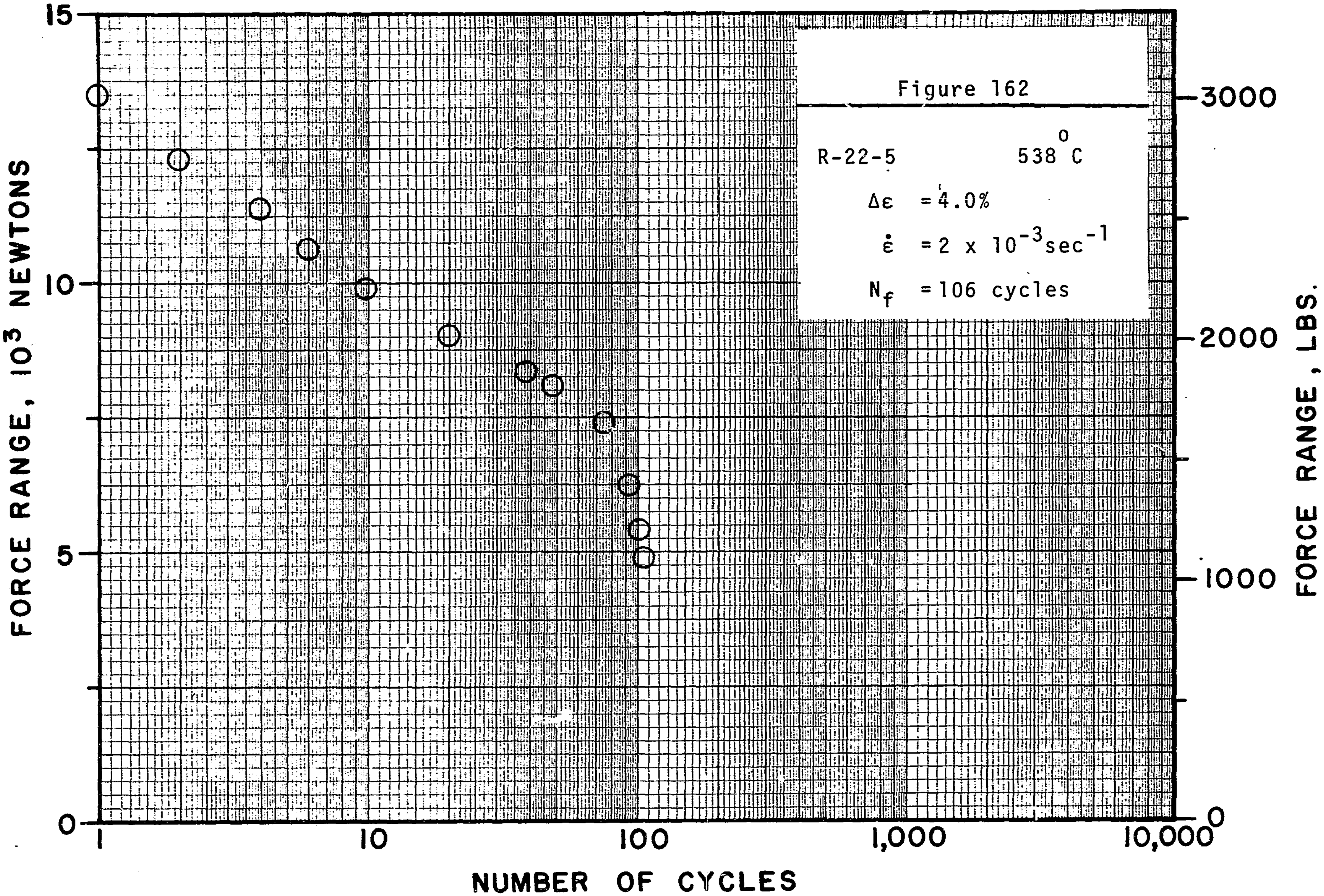


Figure 162
R-22-5
538 °C
Δε = 4.0%
ε̇ = 2 x 10-3 sec-1
Nf = 106 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

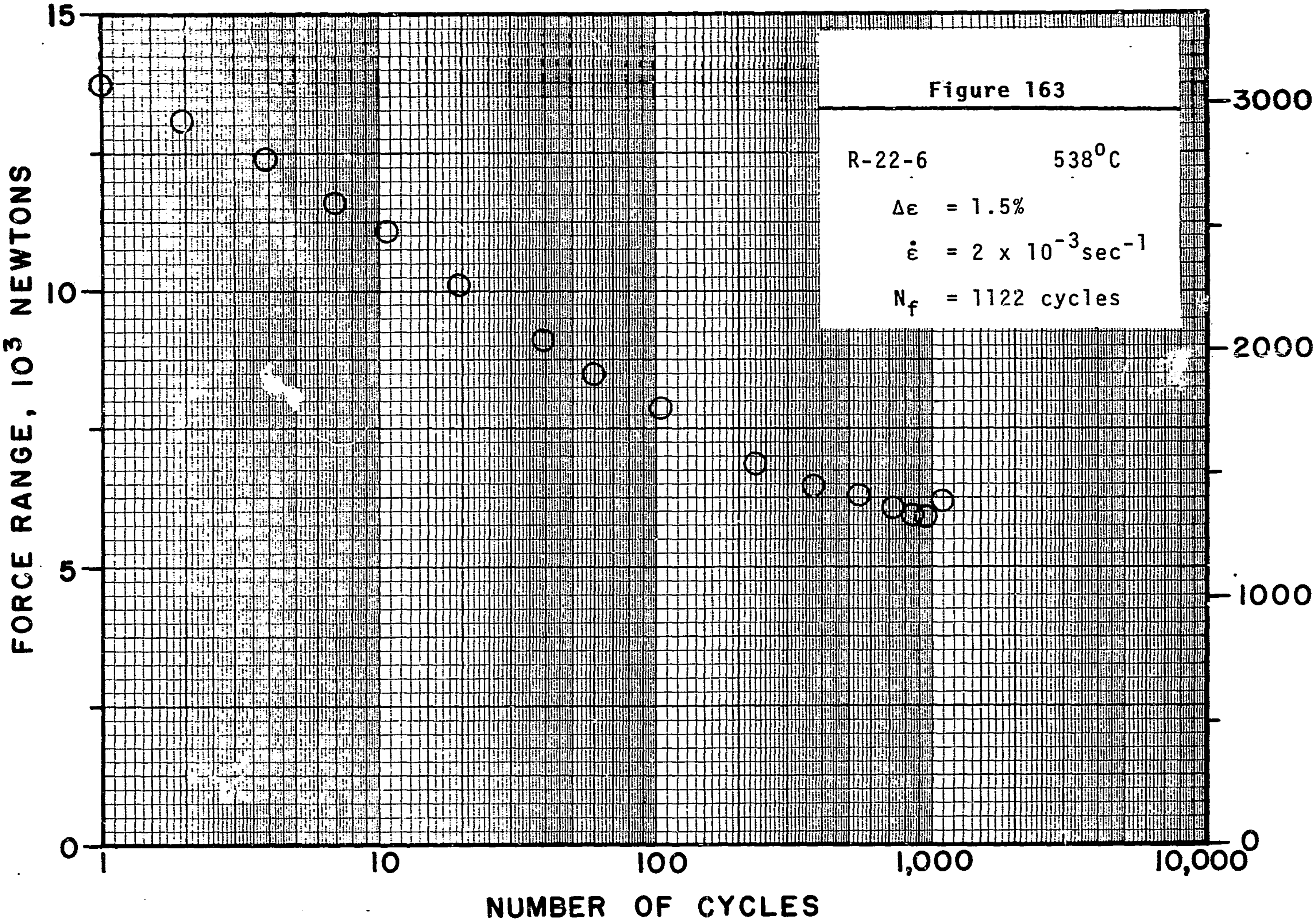


Figure 163
R-22-6
538°C
Δε = 1.5%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1122 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

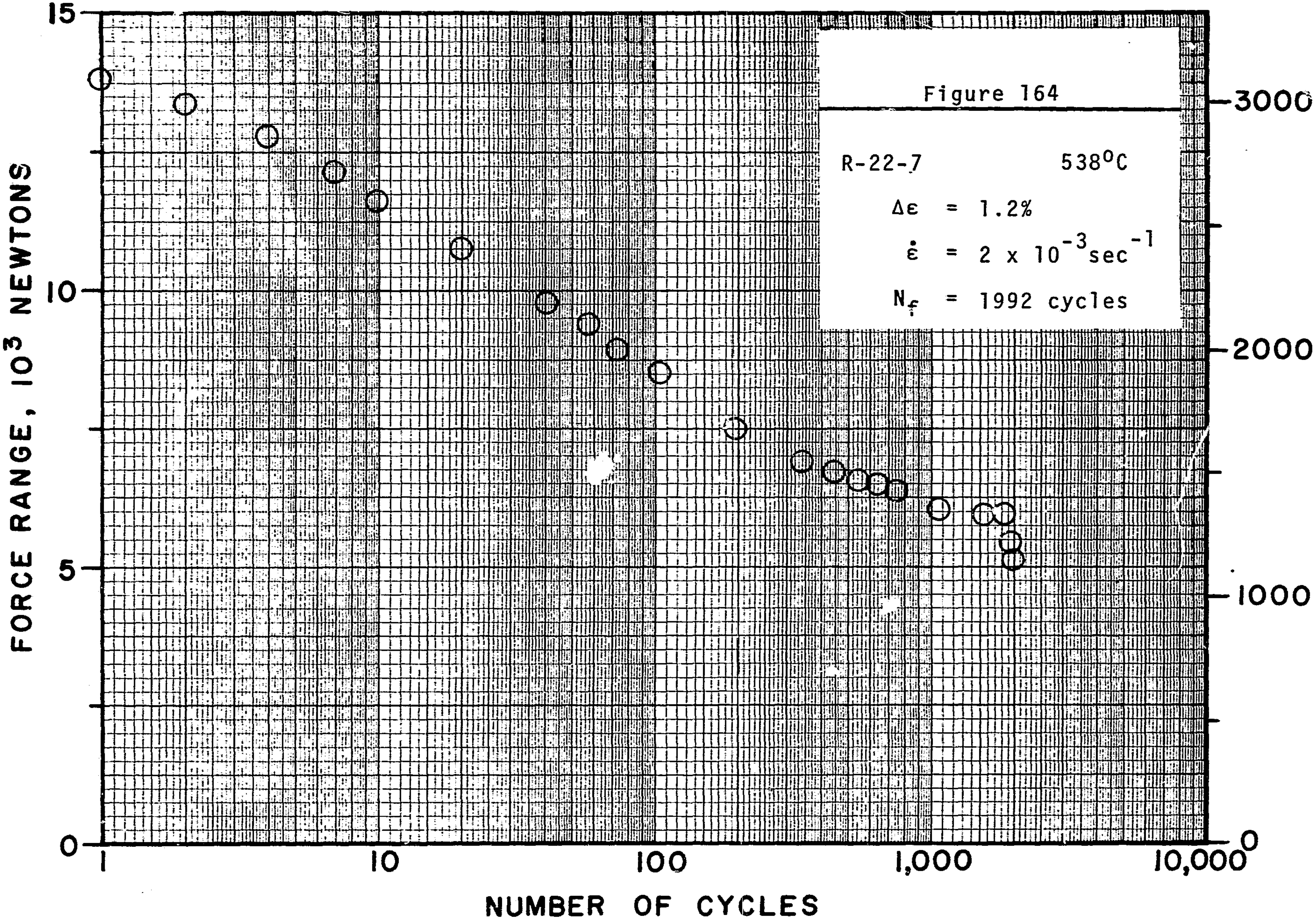

R-22-7
538°C
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 1992 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

Figure 164

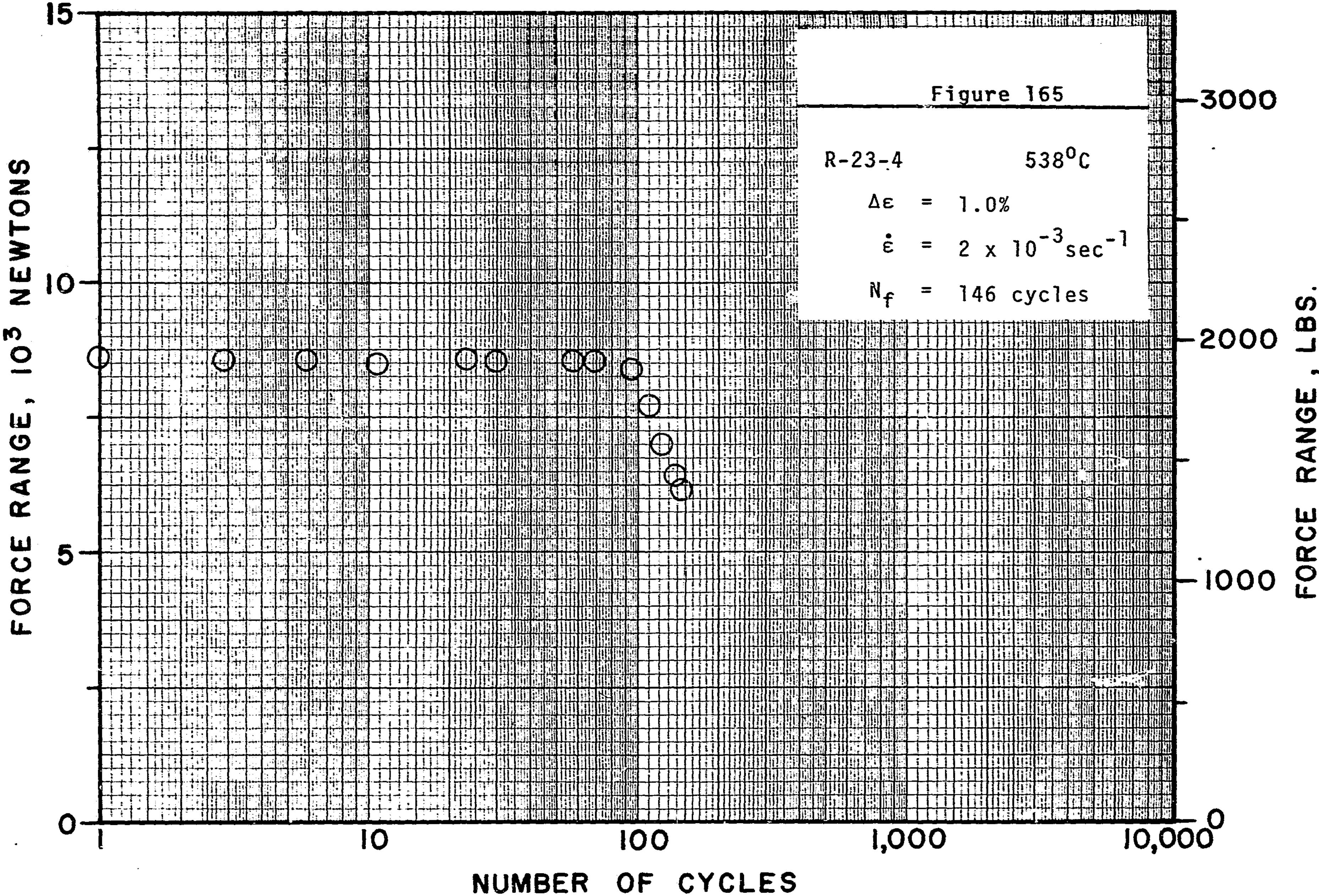


Figure 165
R-23-4 538°C
Δε = 1.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 146 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

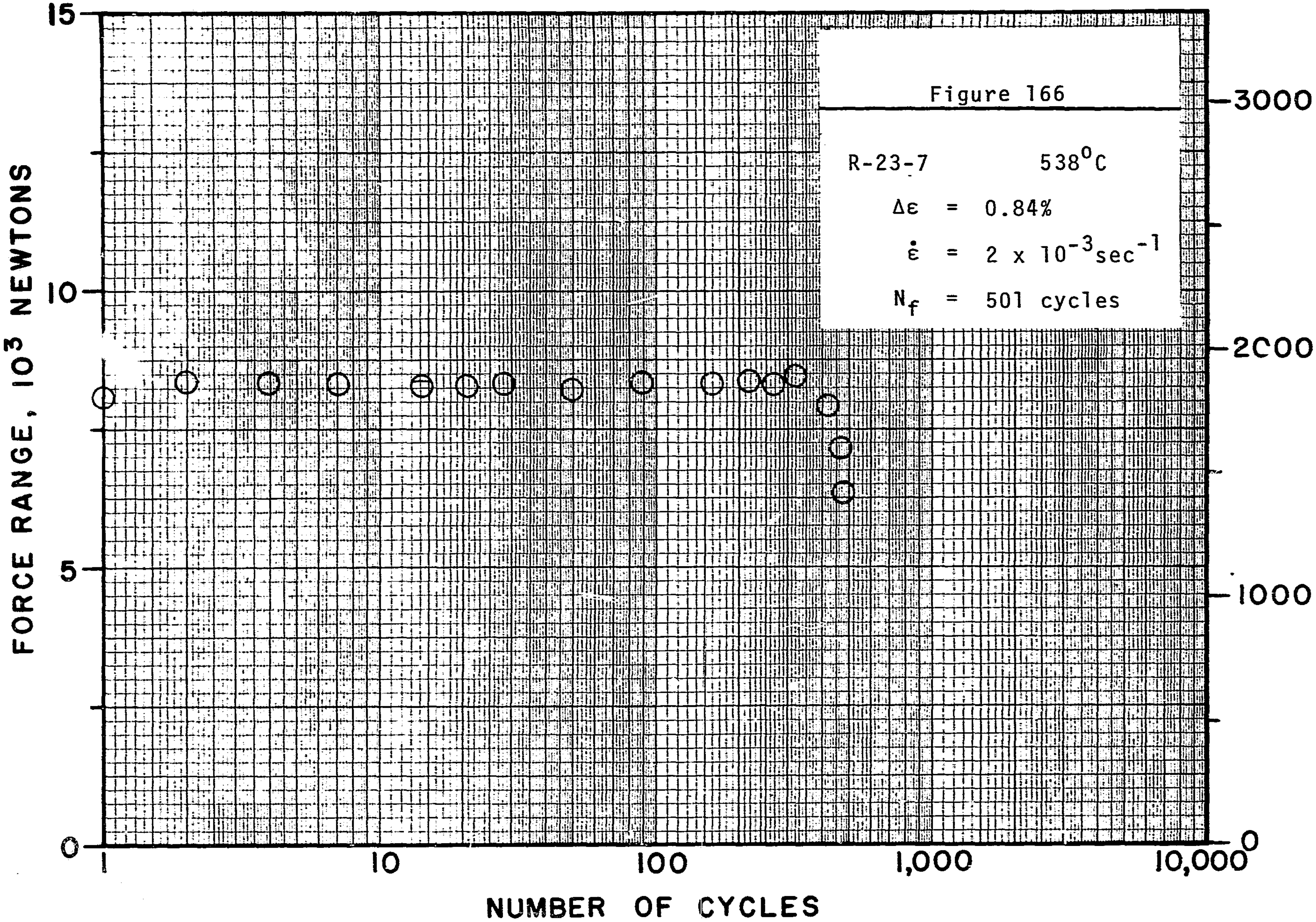


Figure 166
R-23-7 538°C
Δε = 0.84%
ε̇ = 2 x 10⁻³ sec⁻¹
N_f = 501 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

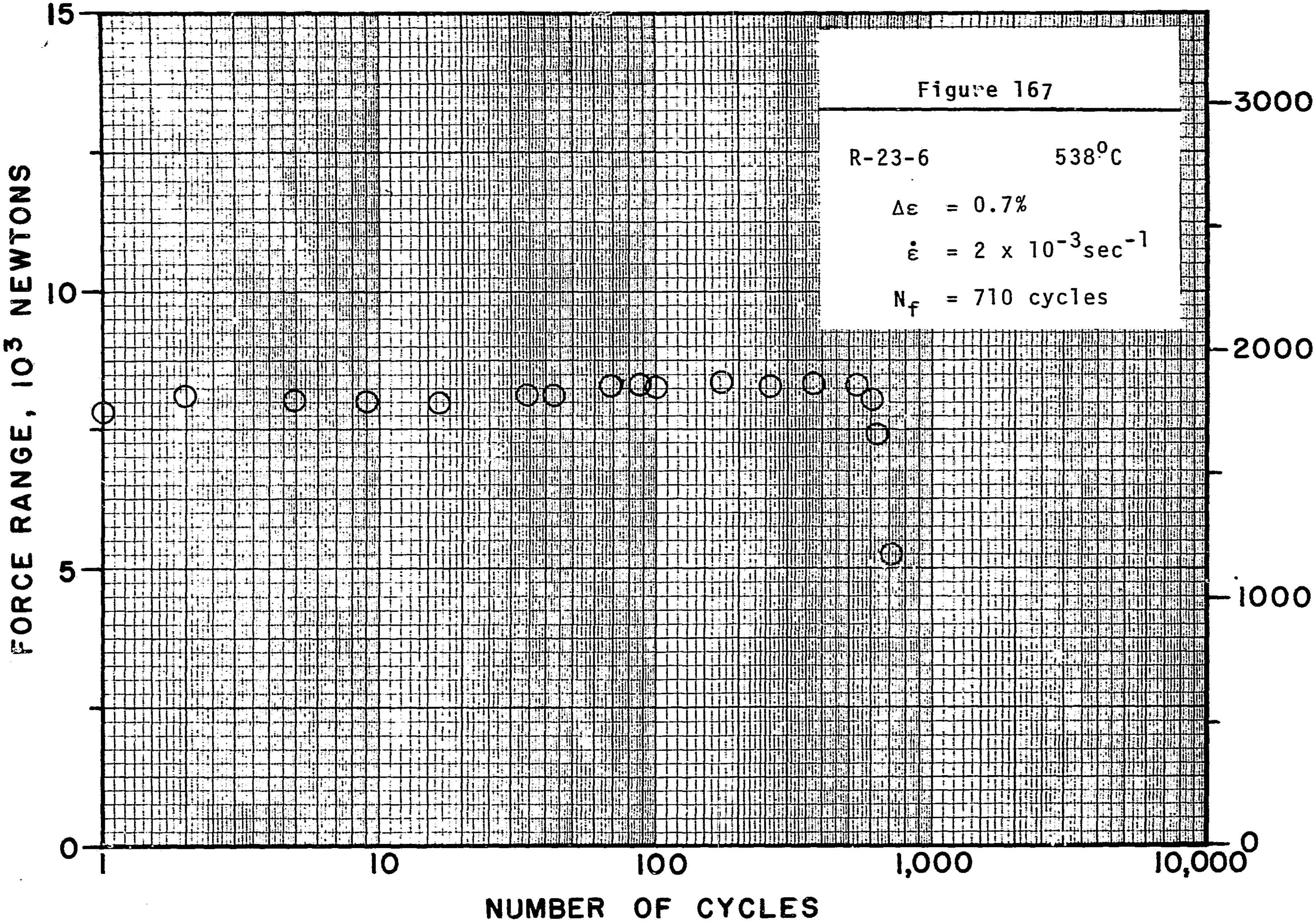

FORCE RANGE, 10³ NEWTONS
15
10
5
0
1
10
100
1,000
10,000
NUMBER OF CYCLES
FORCE RANGE, LBS.
3000
2000
1000
0
R-23-6 538°C
Δε = 0.7%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 710 cycles

Figure 167

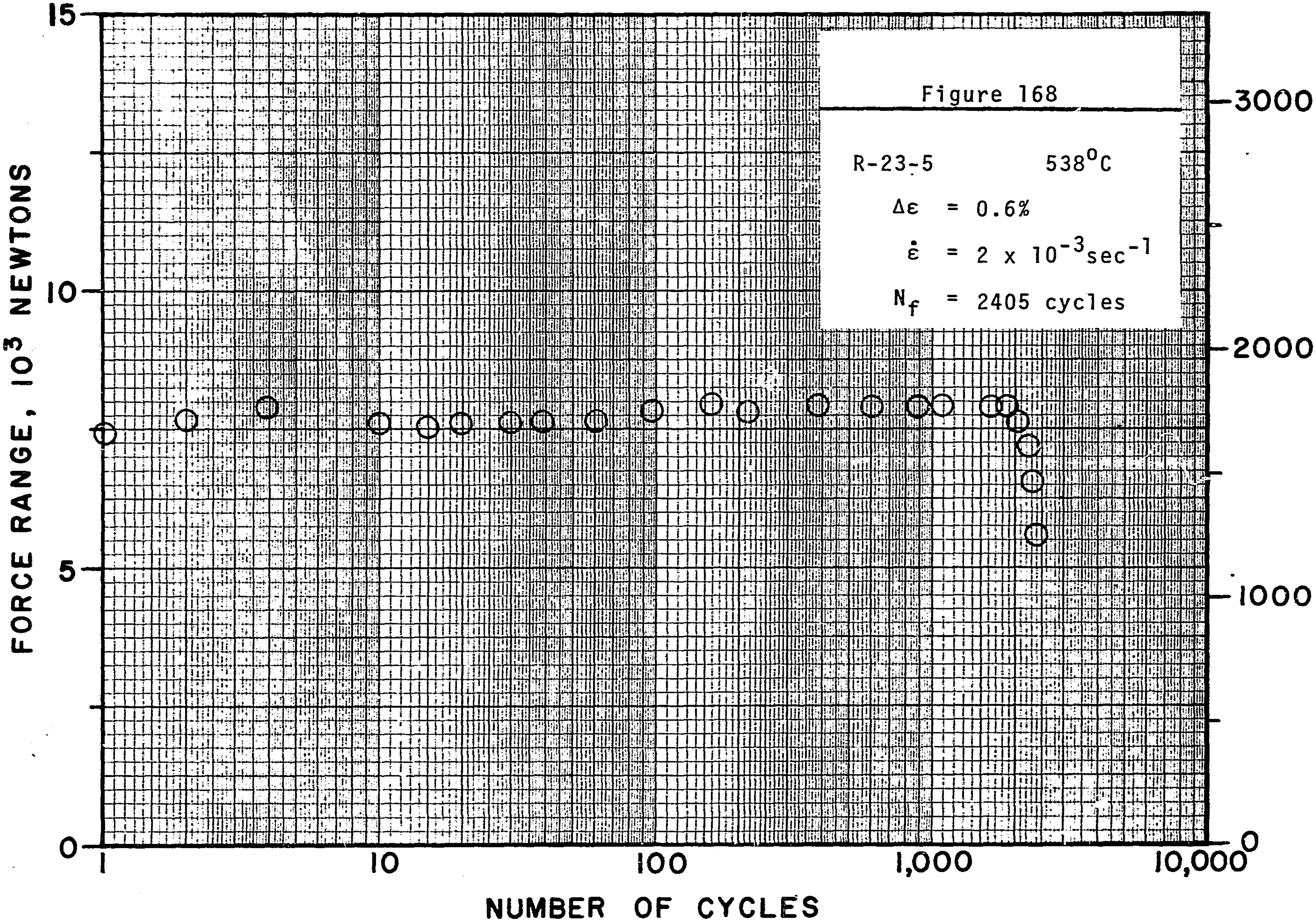


Figure 168
R-23-5 538°C
Δε = 0.6%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 2405 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

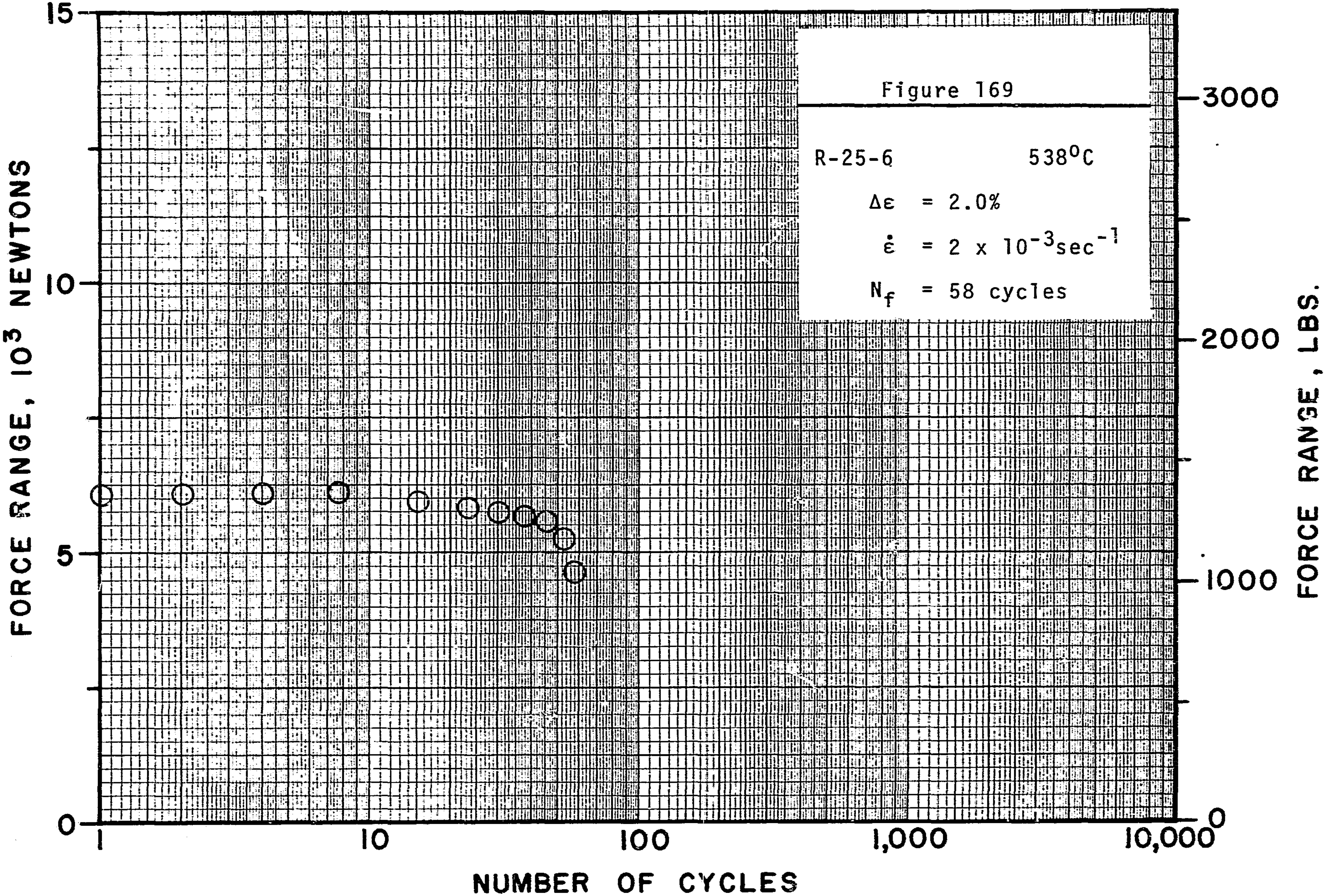


Figure 169
R-25-6
538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 58 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

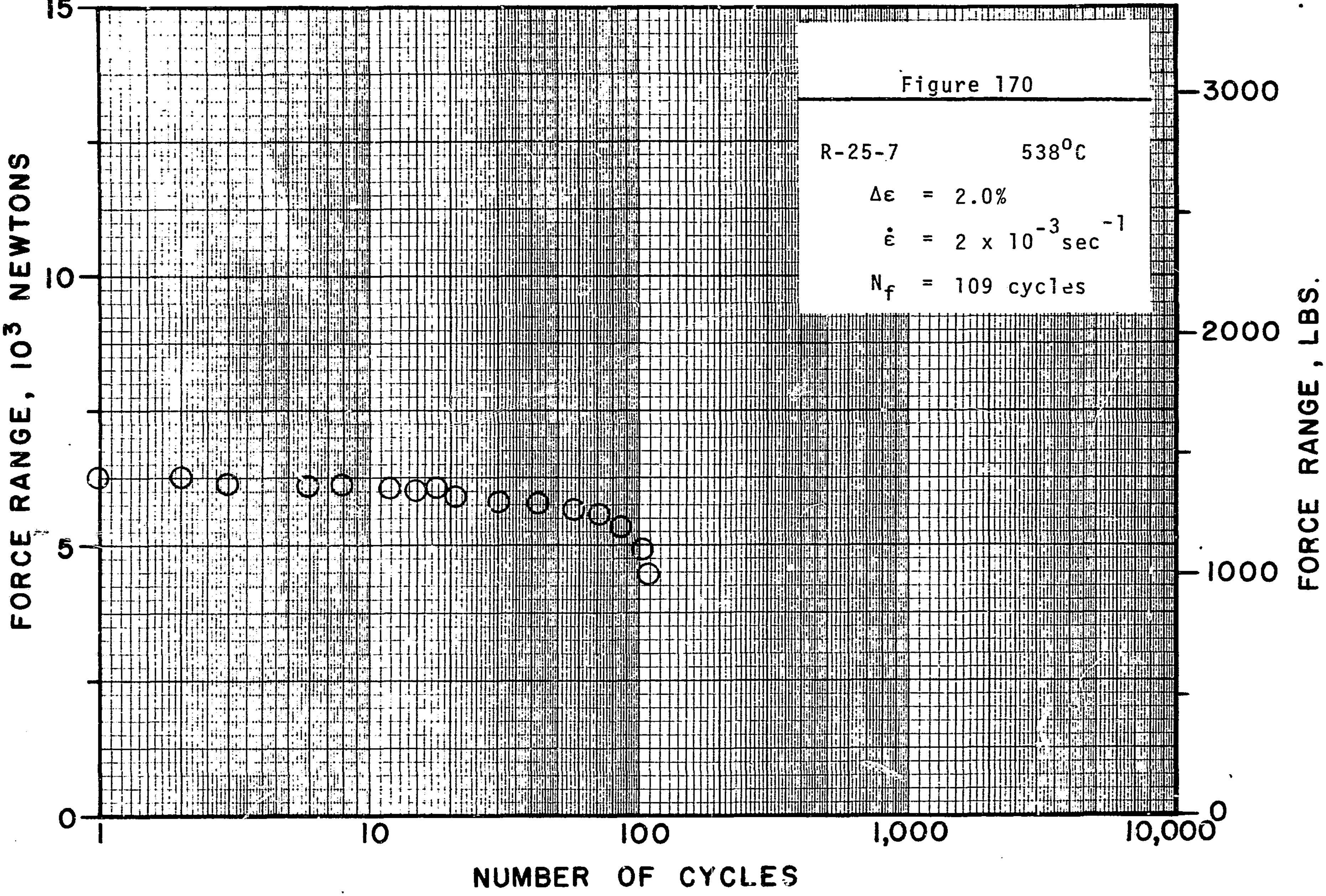

R-25-7 538^{0}C
$\Delta\varepsilon$ = 2.0%
$\dot{\varepsilon}$ = 2 x 10^{-3} sec^{-1}
N_f = 109 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 170

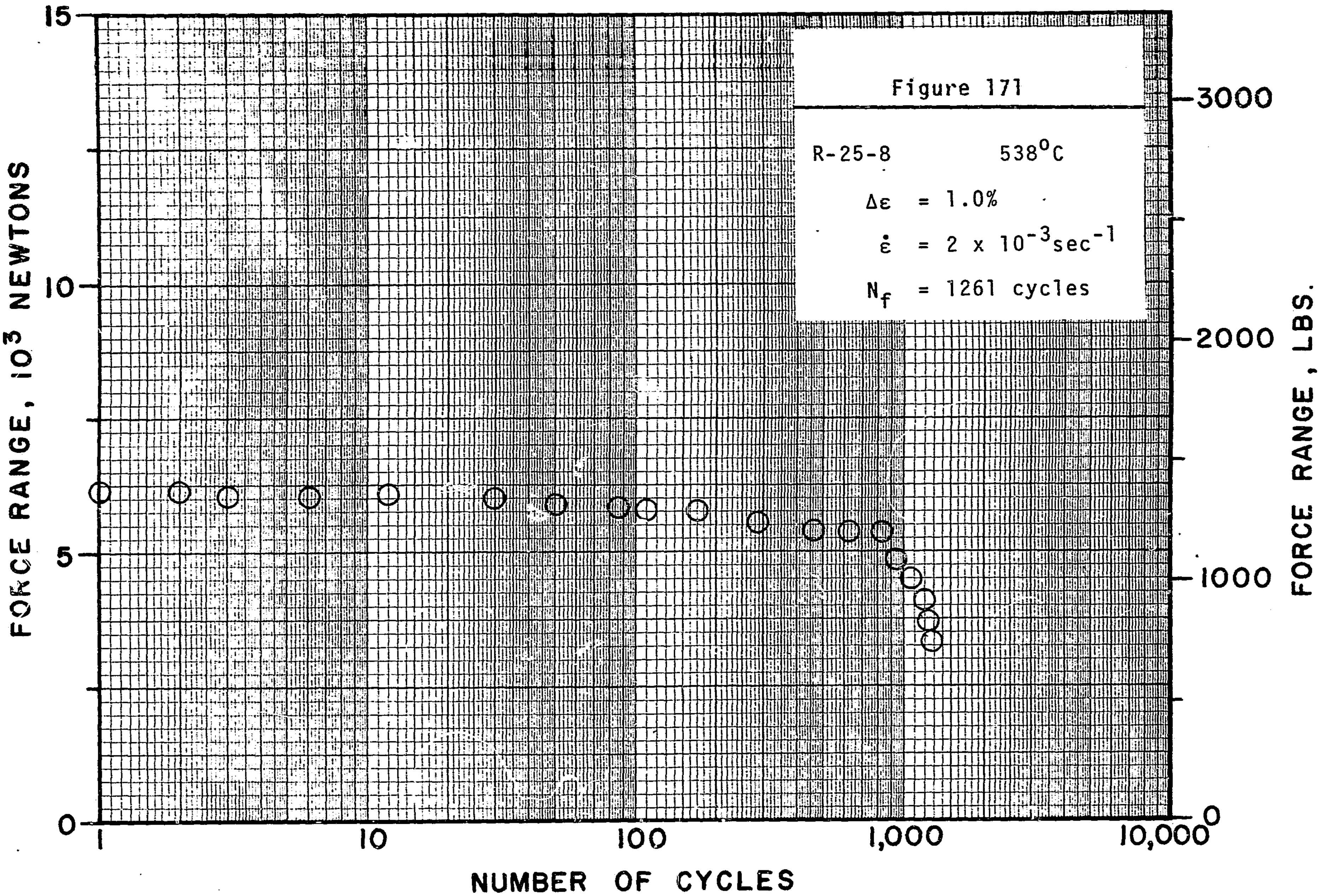

R-25-8 538°C
Δε = 1.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 1261 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

Figure 171

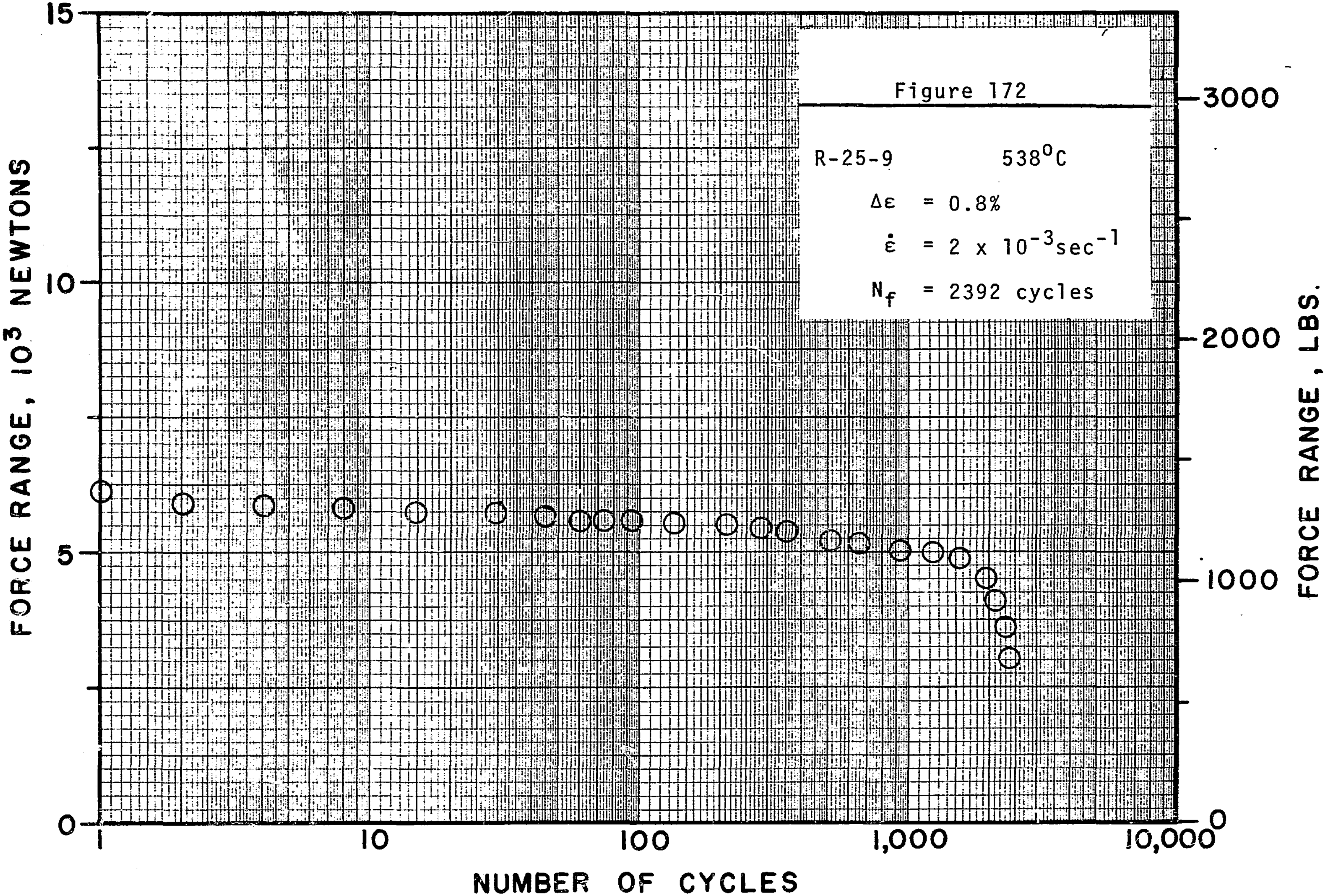


Figure 172
R-25-9 538°C
Δε = 0.8%
ε̇ = 2 x 10⁻³sec⁻¹
Nf = 2392 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

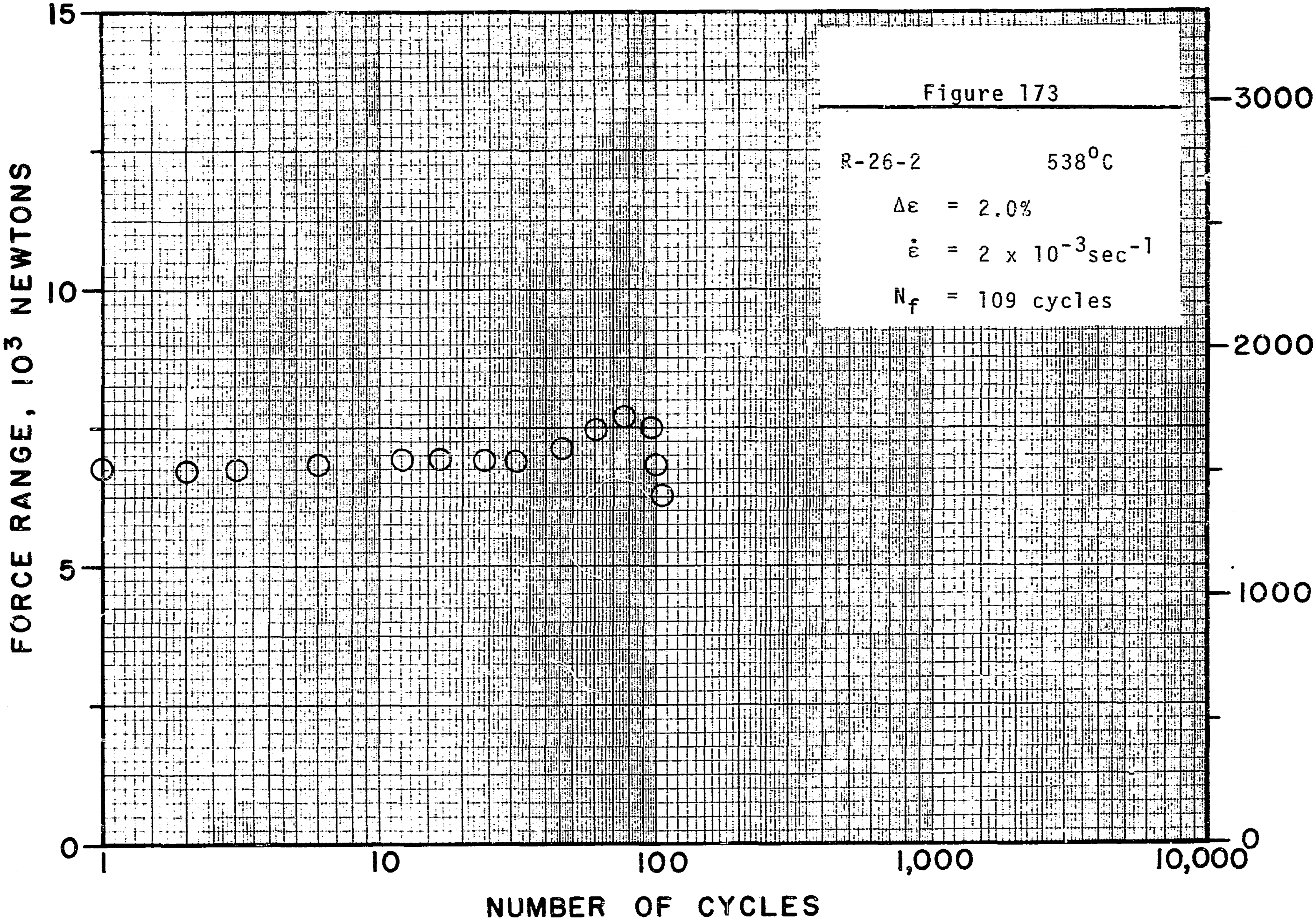


Figure 173
R-26-2 538°C
Δε = 2.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 109 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

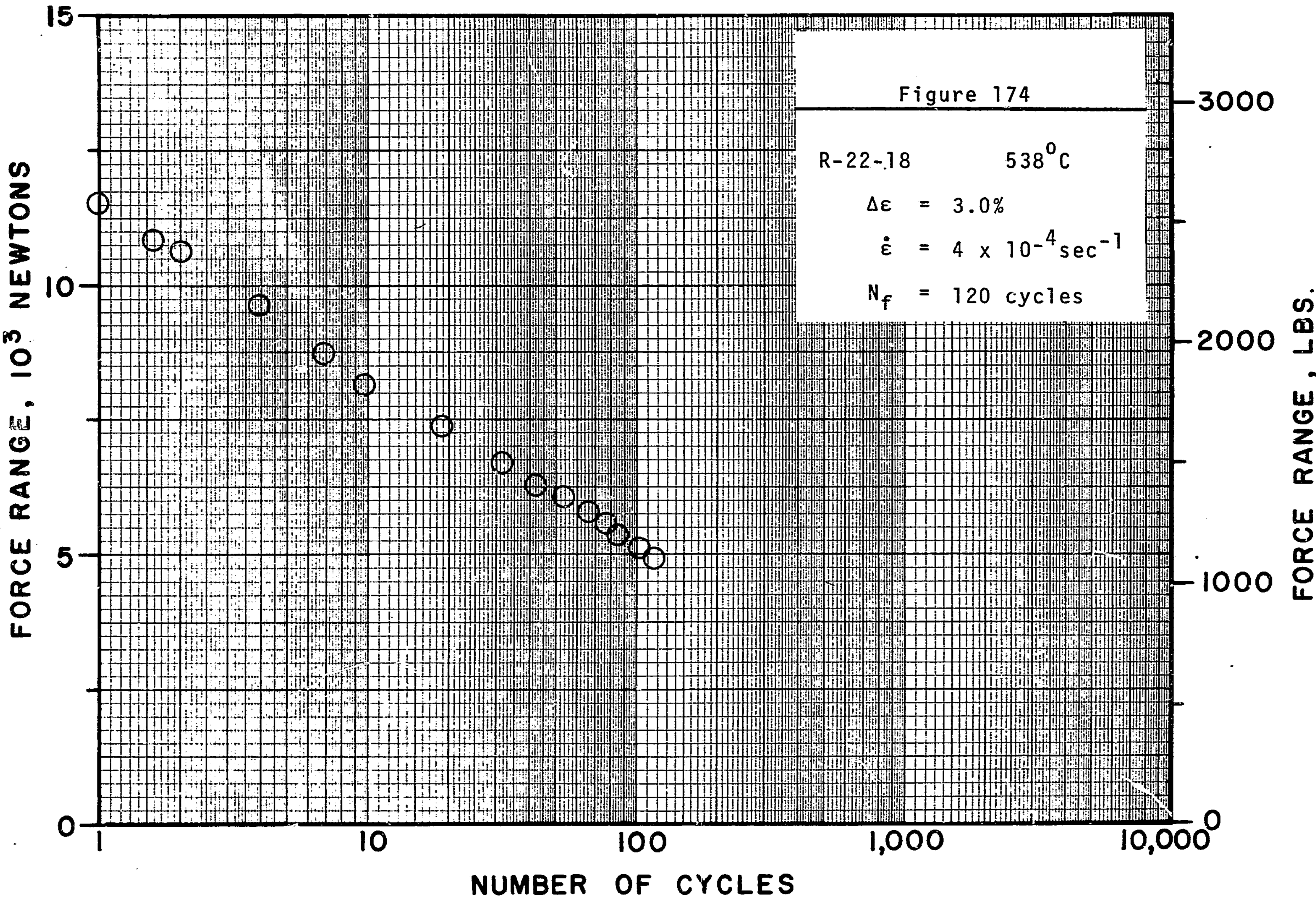


Figure 174
R-22-18 538°C
Δε = 3.0%
ε̇ = 4 x 10^-4 sec^-1
N_f = 120 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

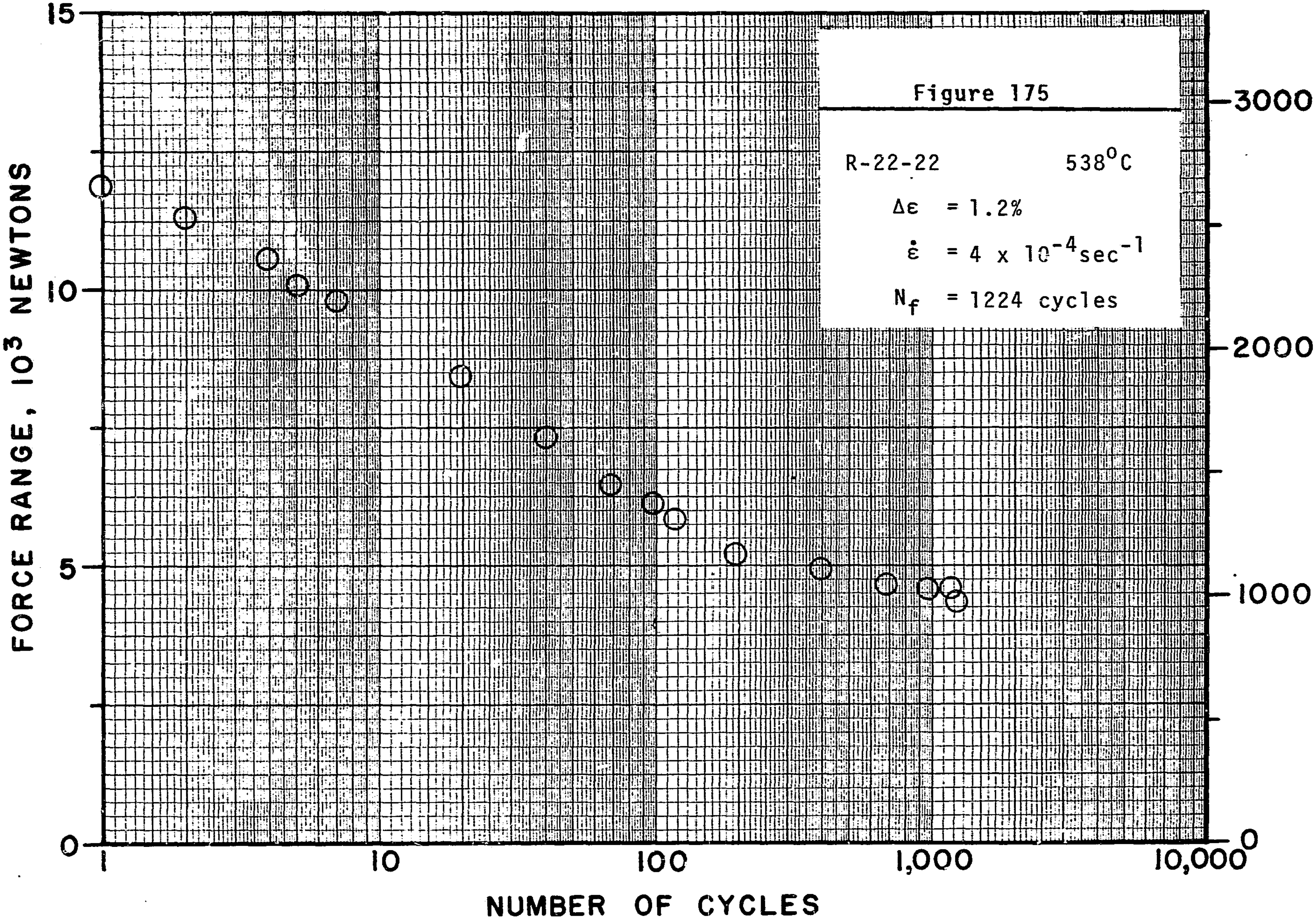


Figure 175
R-22-22 538°C
Δε = 1.2%
ε̇ = 4 x 10⁻⁴sec⁻¹
N_f = 1224 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

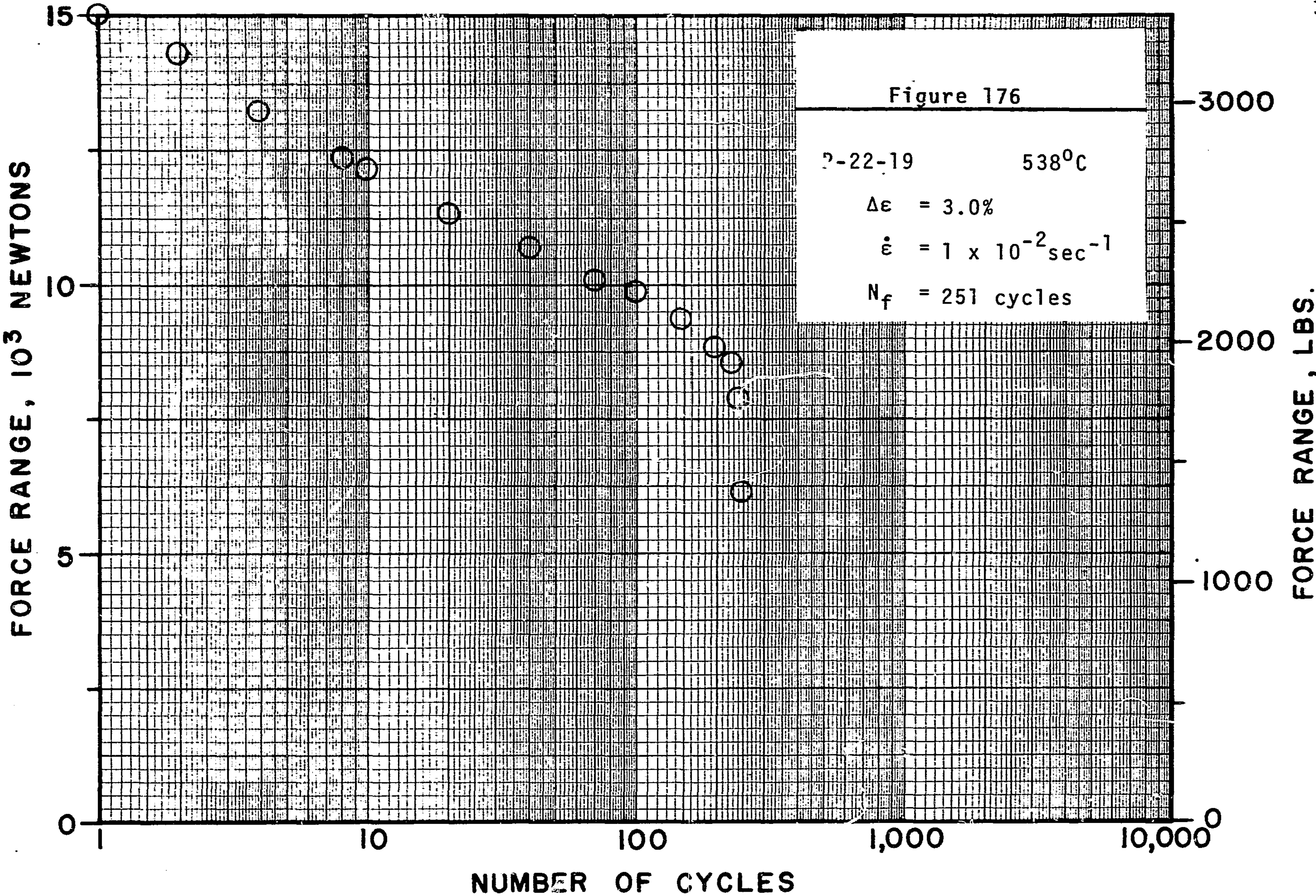


Figure 176
2-22-19 538^{0}C
$\Delta\varepsilon$ = 3.0%
$\dot{\varepsilon}$ = 1 x 10^{-2}sec^{-1}
N_f = 251 cycles
FORCE RANGE, 10^3 NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

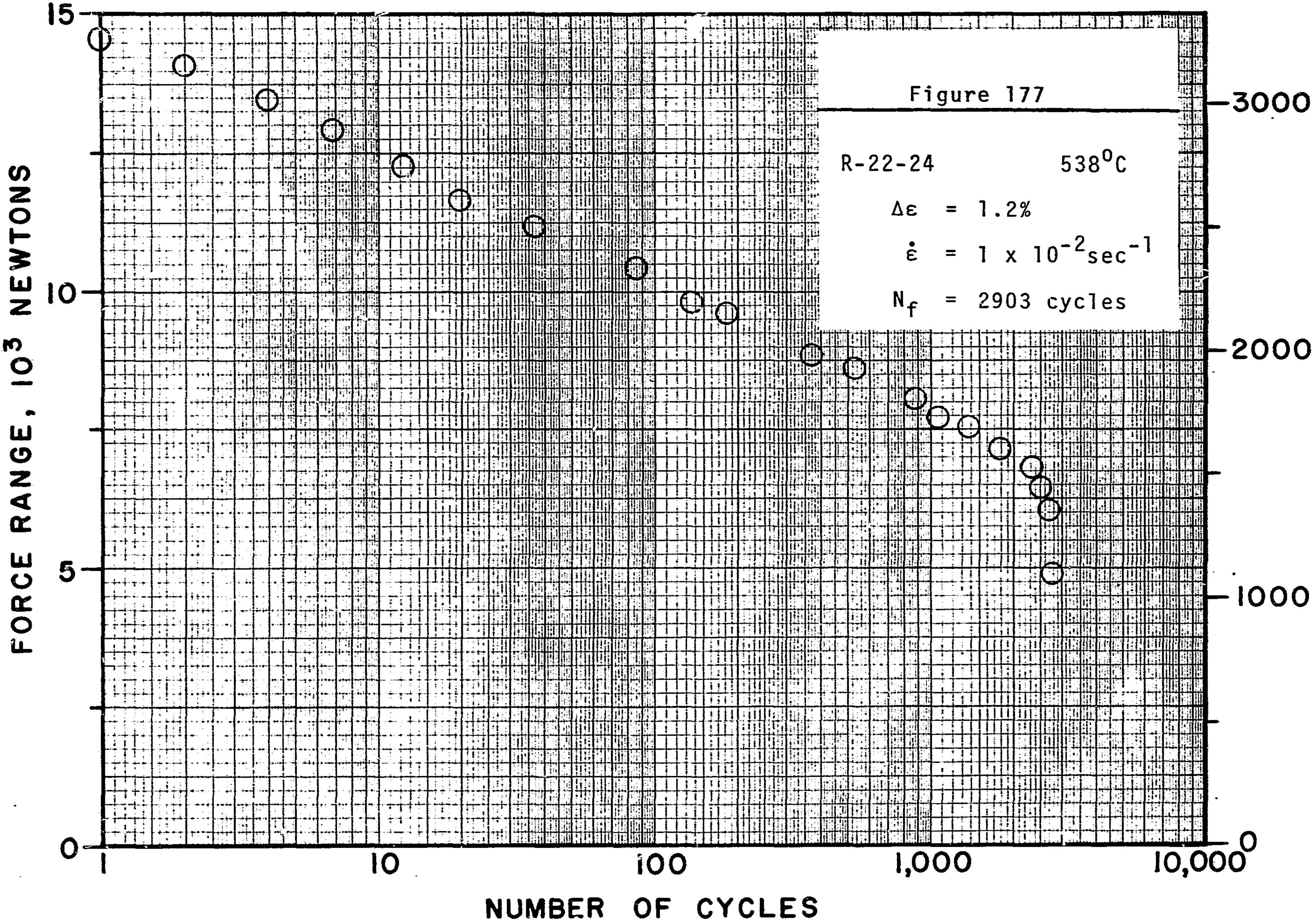


Figure 177
R-22-24 538°C
Δε = 1.2%
ε̇ = 1 x 10⁻² sec⁻¹
N_f = 2903 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
1
10
100
1,000
10,000
0
1000
2000
3000

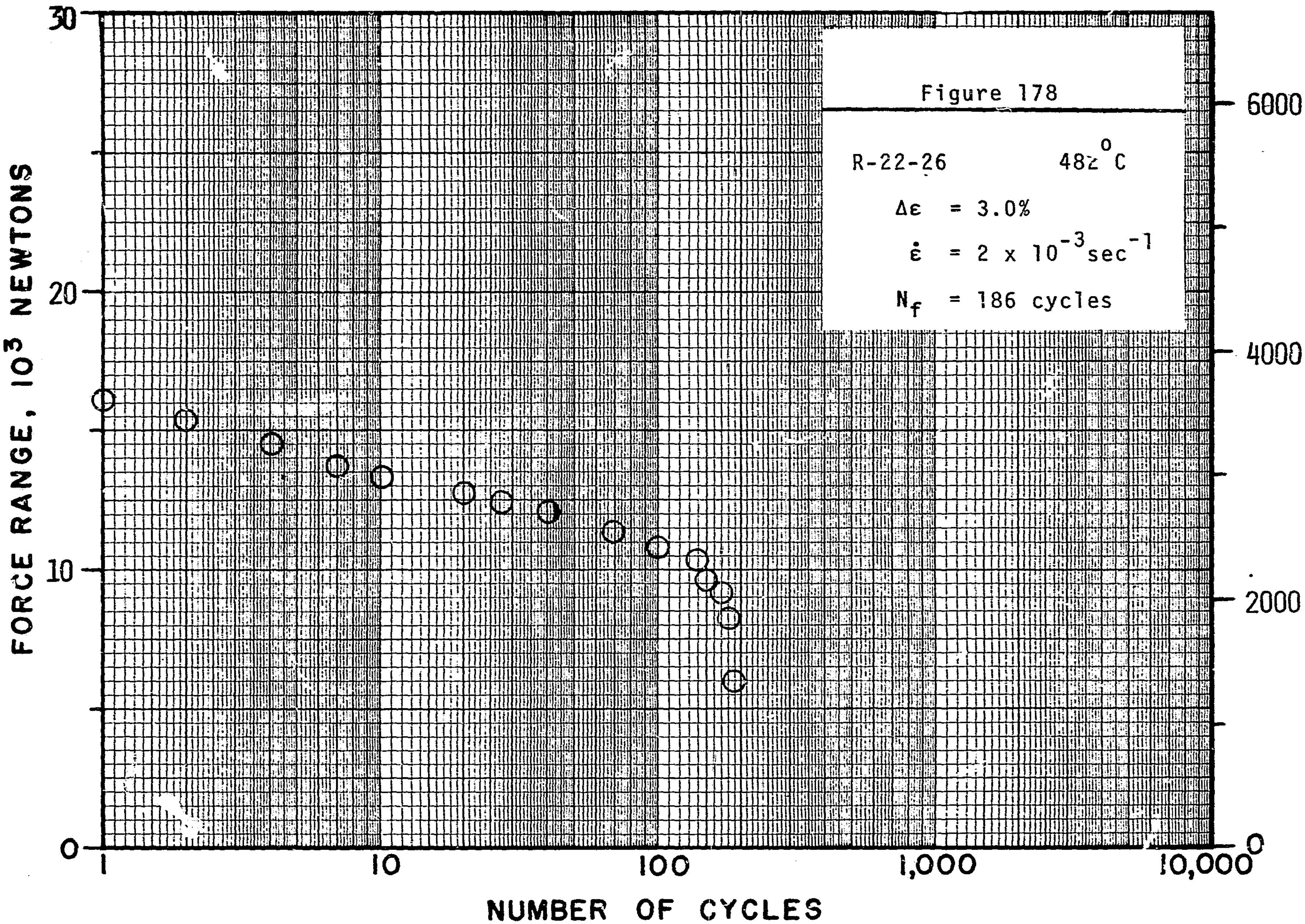
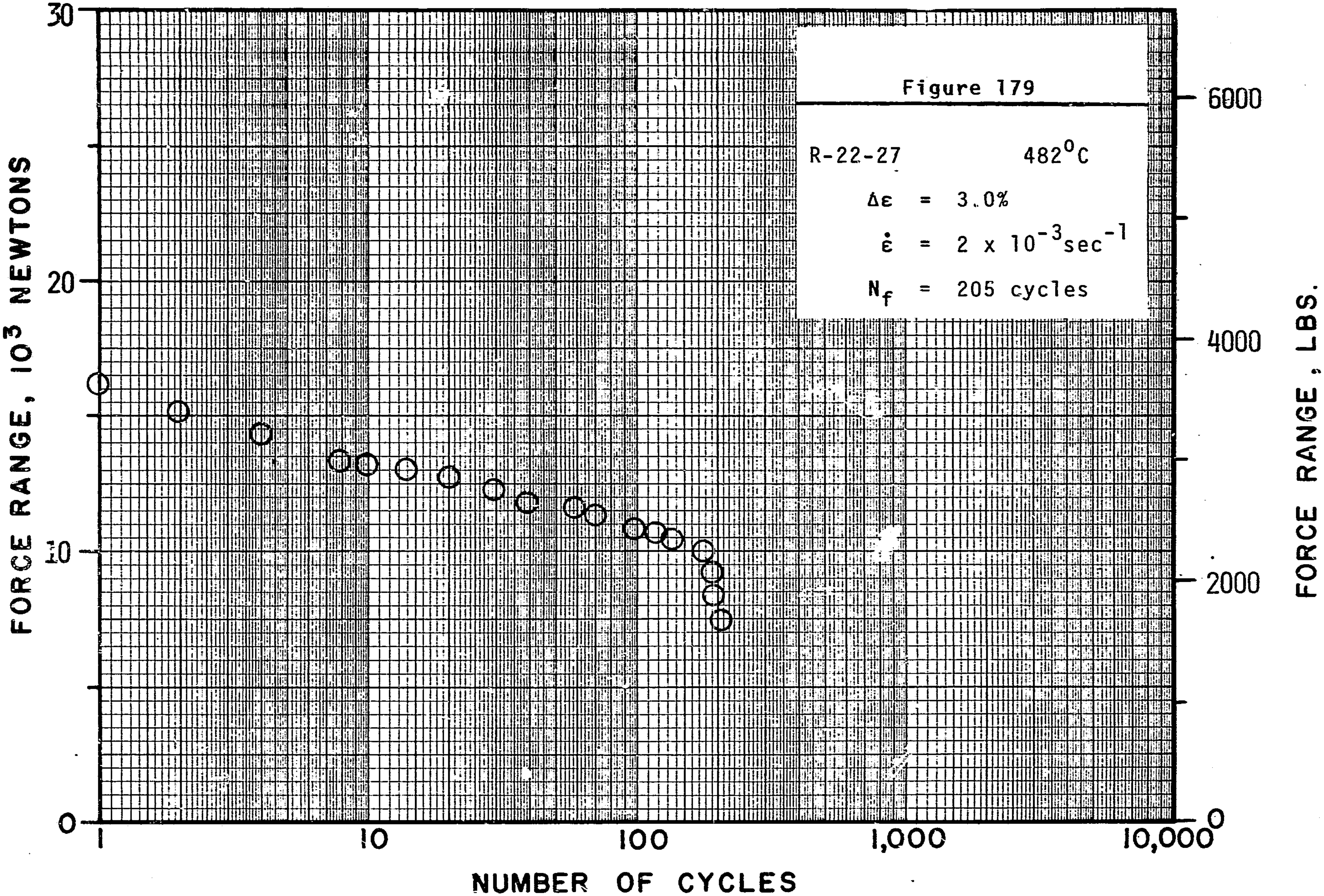


Figure 178
R-22-26 482°C
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 186 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
10
20
30
1
10
100
1,000
10,000
0
2000
4000
6000


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
R-22-27
$482^{o}C$
$\Delta\varepsilon$ = 3.0%
$\dot{\varepsilon}$ = $2 \times 10^{-3} sec^{-1}$
N_f = 205 cycles
Figure 179

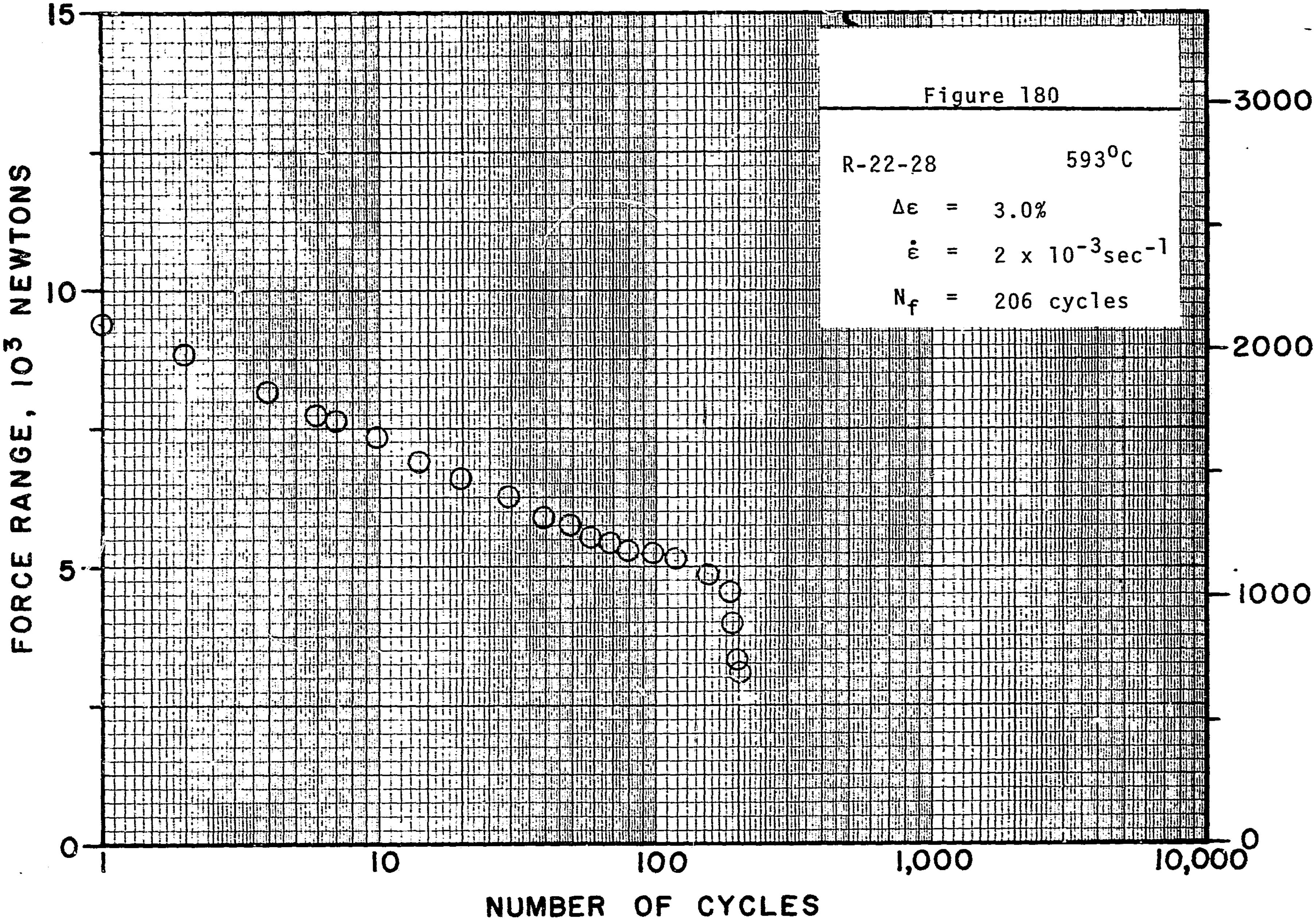

R-22-28
593°C
Δε = 3.0%
ε̇ = 2 x 10⁻³sec⁻¹
N_f = 206 cycles
FORCE RANGE, 10³ NEWTONS
15
10
5
0
FORCE RANGE, LBS.
3000
2000
1000
0
1
10
100
1,000
10,000
NUMBER OF CYCLES

Figure 180

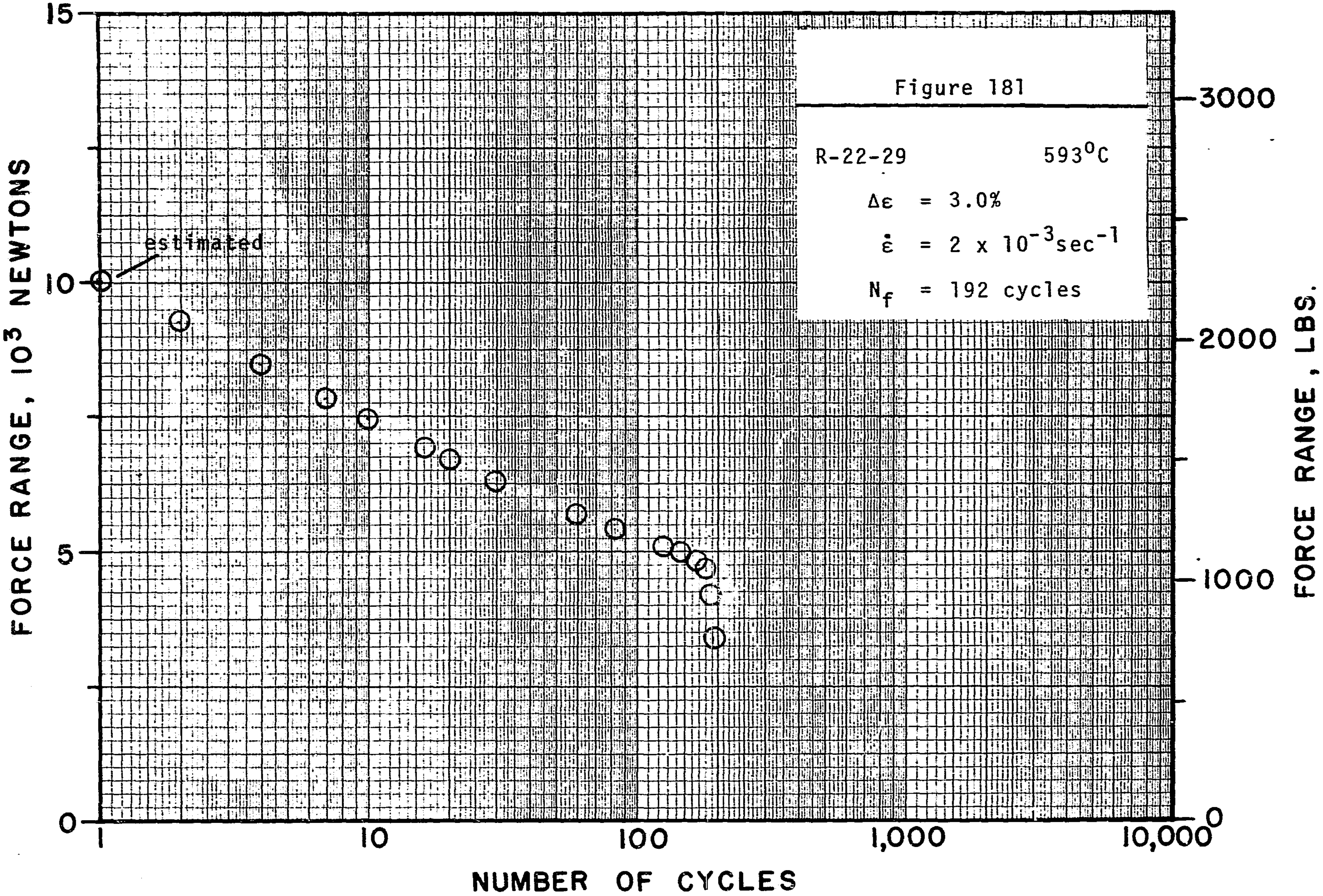


Figure 181
R-22-29
593°C
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 192 cycles
estimated
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

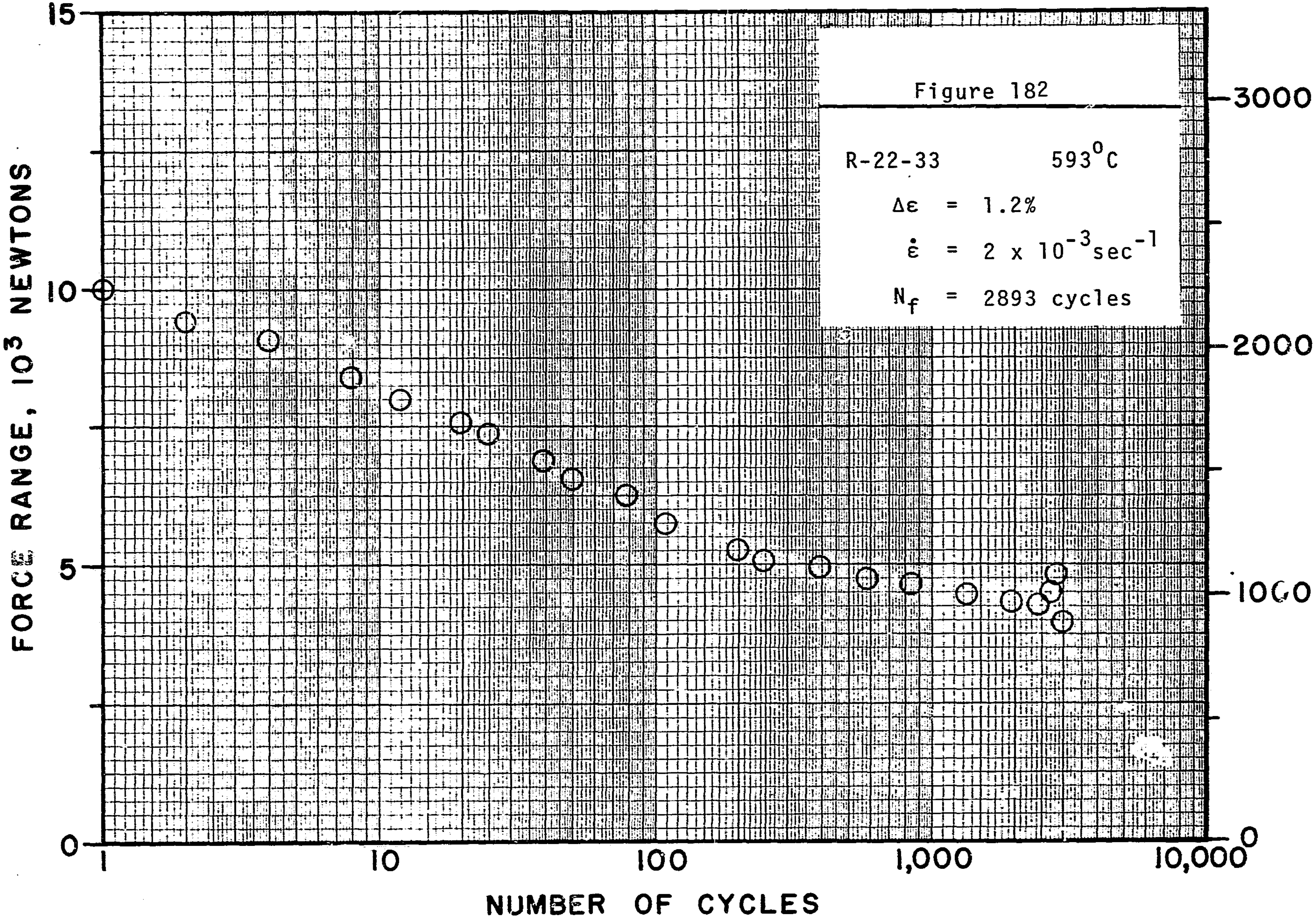


Figure 182
R-22-33 593°C
Δε = 1.2%
ε̇ = 2 x 10⁻³ sec⁻¹
Nf = 2893 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
0
5
10
15
0
1000
2000
3000
1
10
100
1,000
10,000

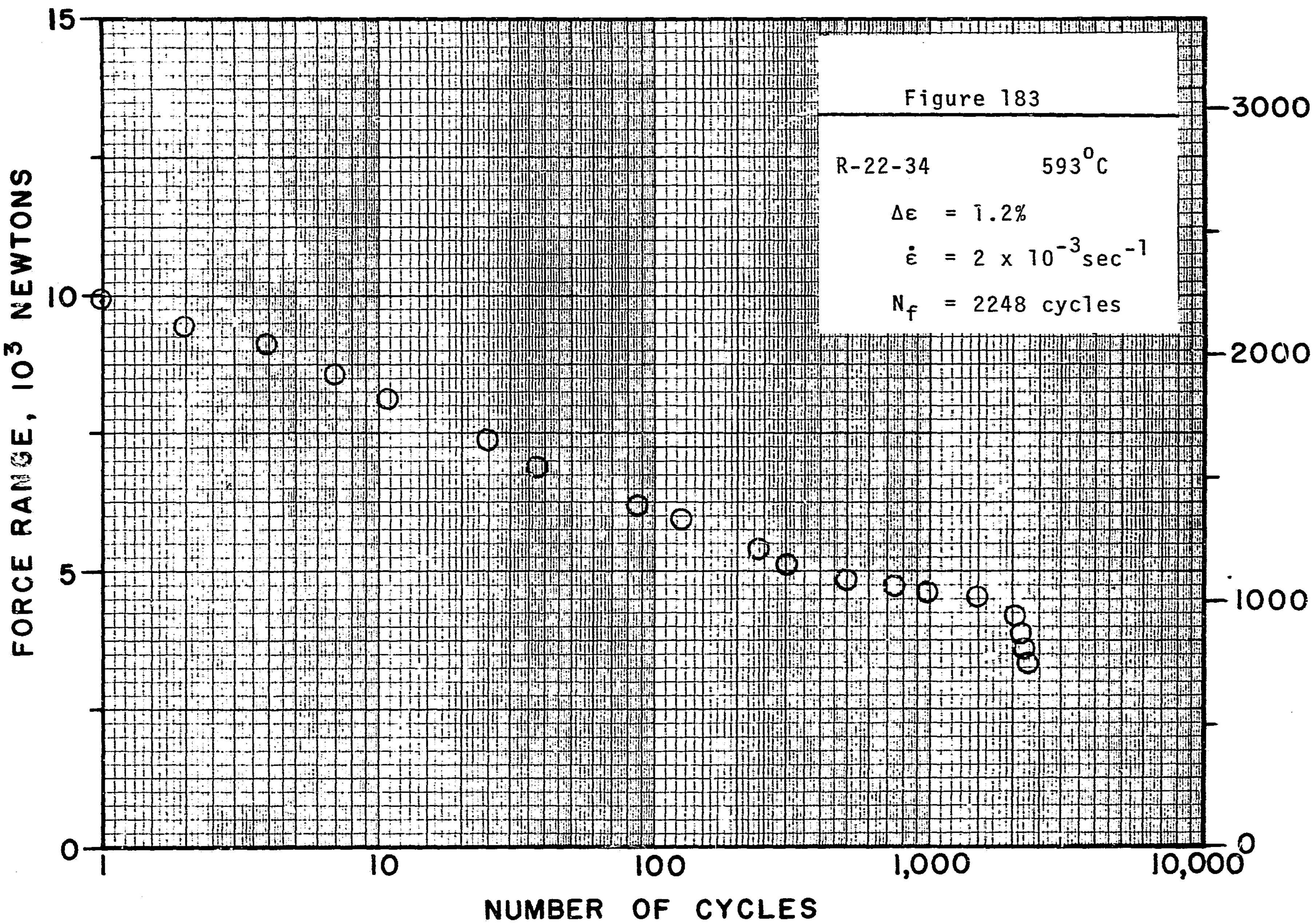


Figure 183
R-22-34 593^{o}C
$\Delta\varepsilon$ = 1.2%
$\dot{\varepsilon}$ = 2 x 10^{-3}sec^{-1}
N_f = 2248 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

C-3

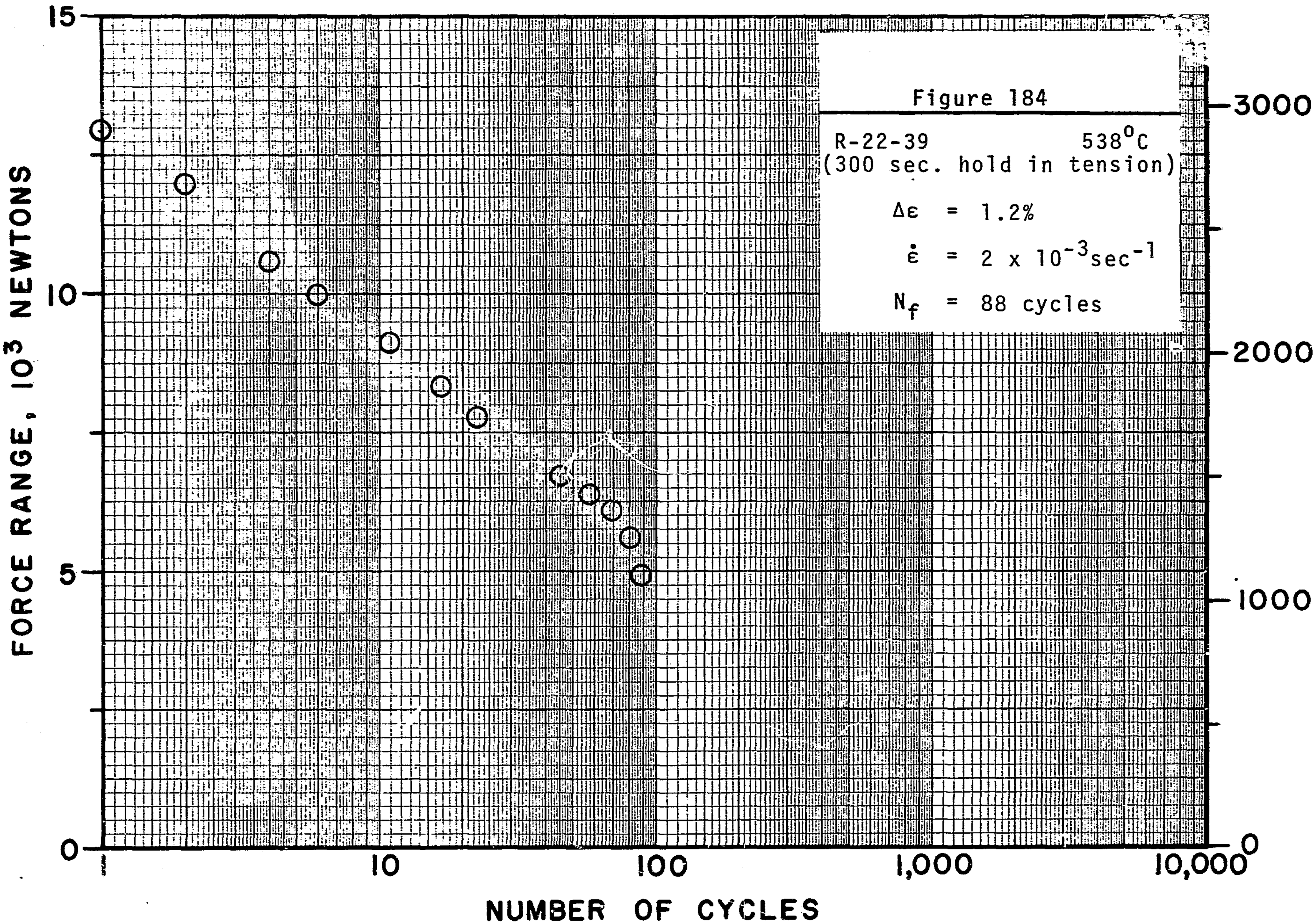


Figure 184

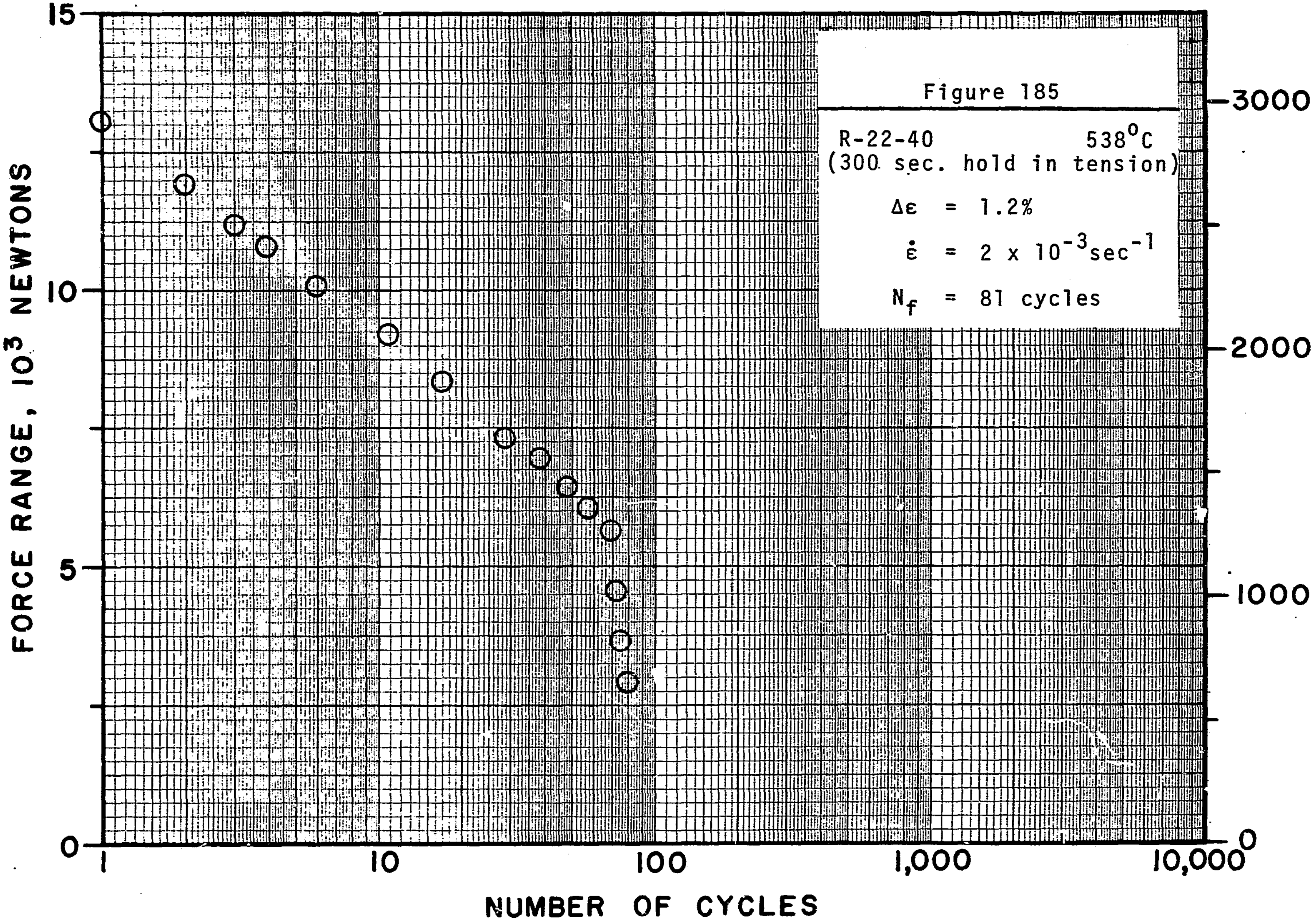


Figure 185
R-22-40 538°C
(300 sec. hold in tension)
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 81 cycles
15
10
5
0
FORCE RANGE, 10^3 NEWTONS
3000
2000
1000
0
FORCE RANGE, LBS.
1
10
100
1,000
10,000
NUMBER OF CYCLES

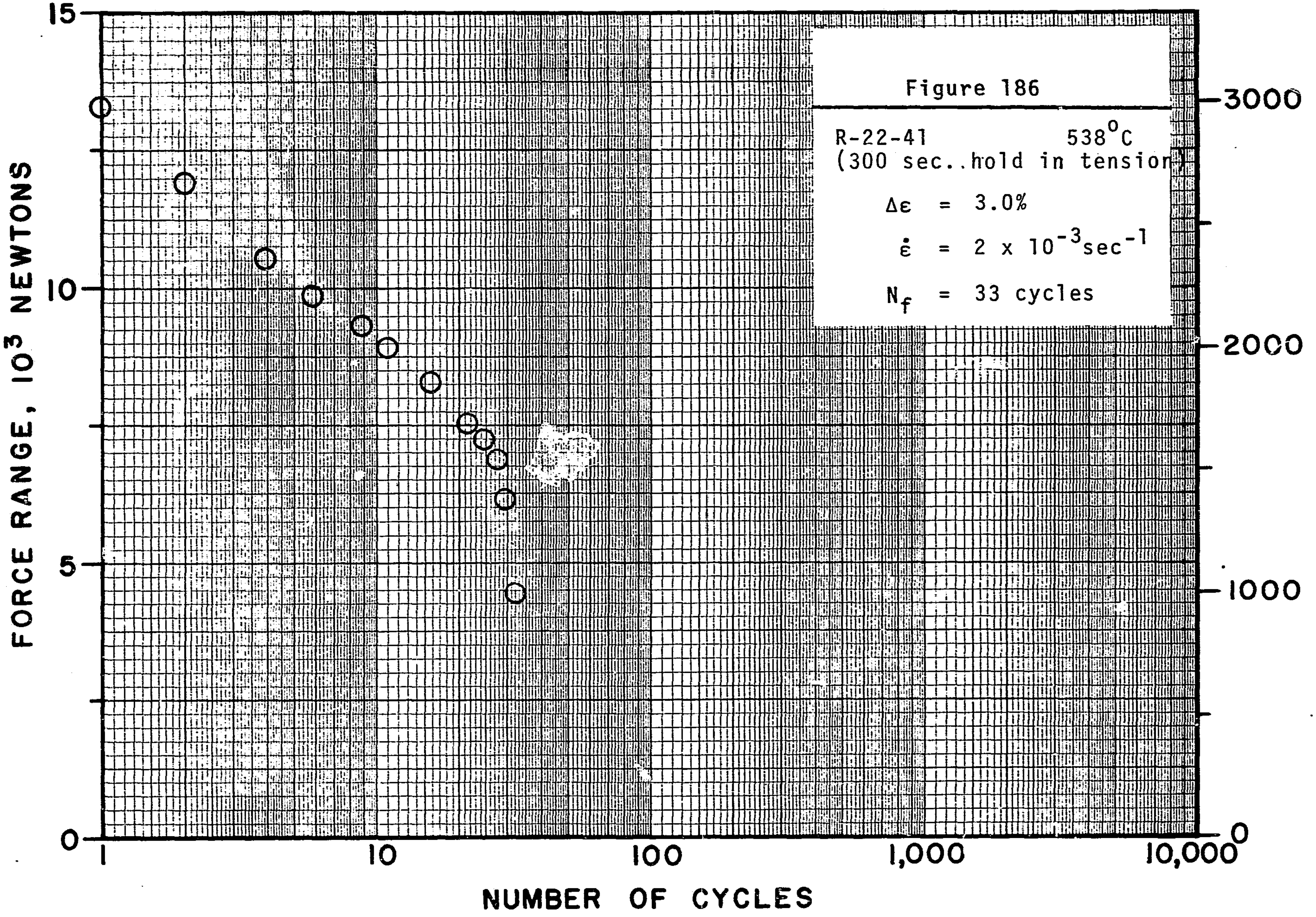
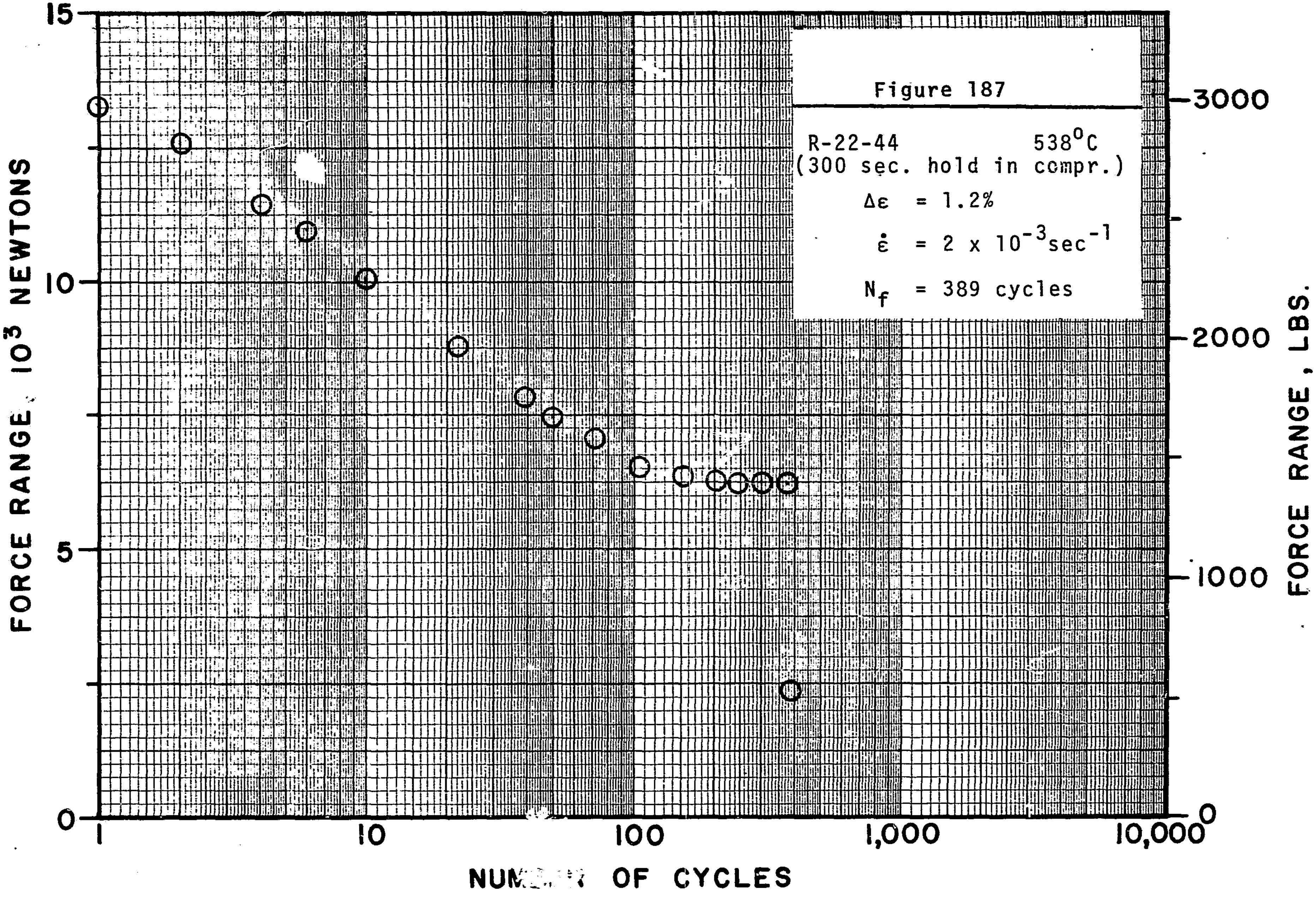


Figure 186
R-22-41 538°C
(300 sec. hold in tension)
Δε = 3.0%
ε̇ = 2 x 10-3sec-1
Nf = 33 cycles
FORCE RANGE, 10³ NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000



R-22-44 538°C
(300 sec. hold in compr.)
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 389 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 187

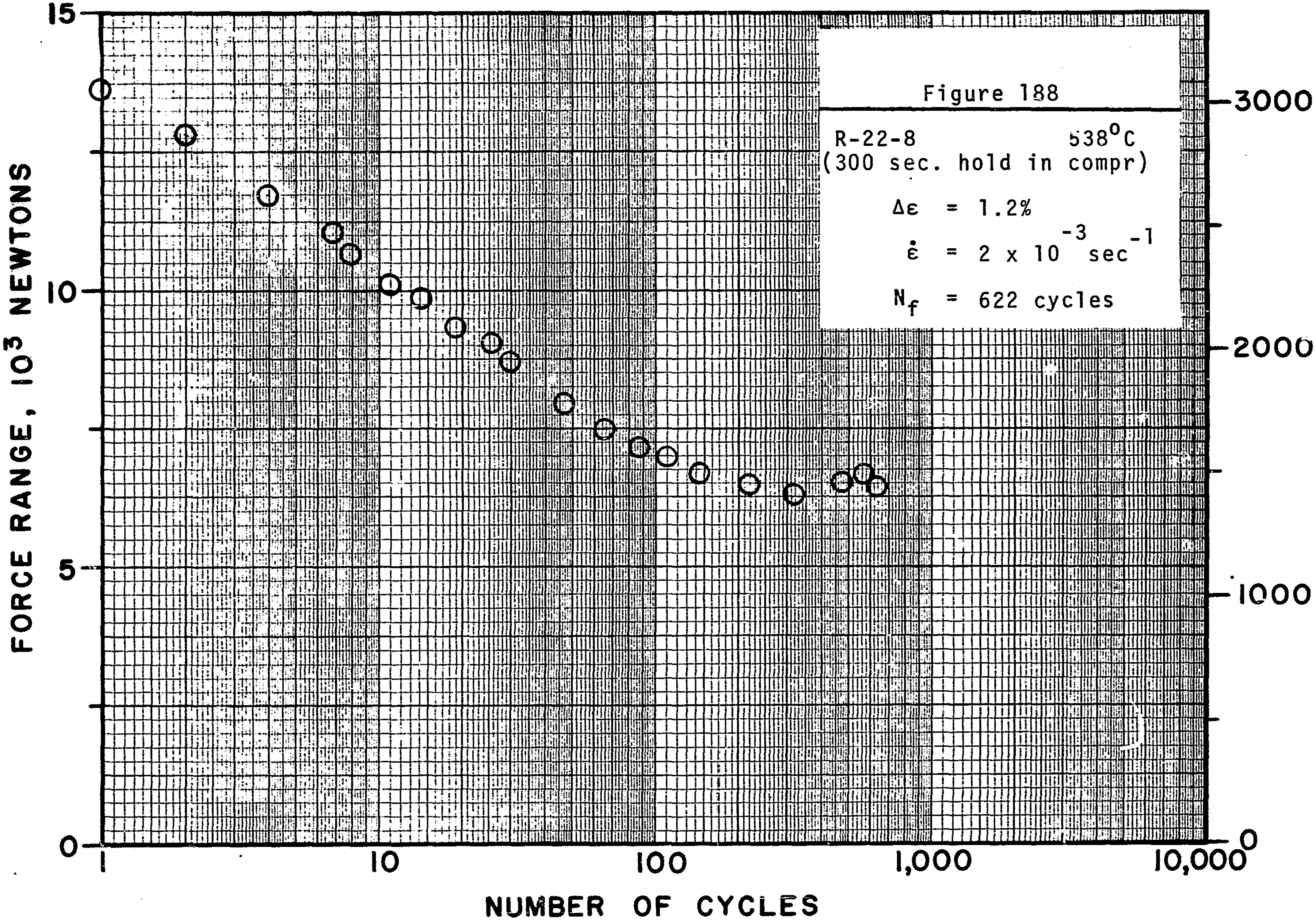


Figure 188
R-22-8 538°C
(300 sec. hold in compr)
Δε = 1.2%
ε̇ = 2 x 10^-3 sec^-1
N_f = 622 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

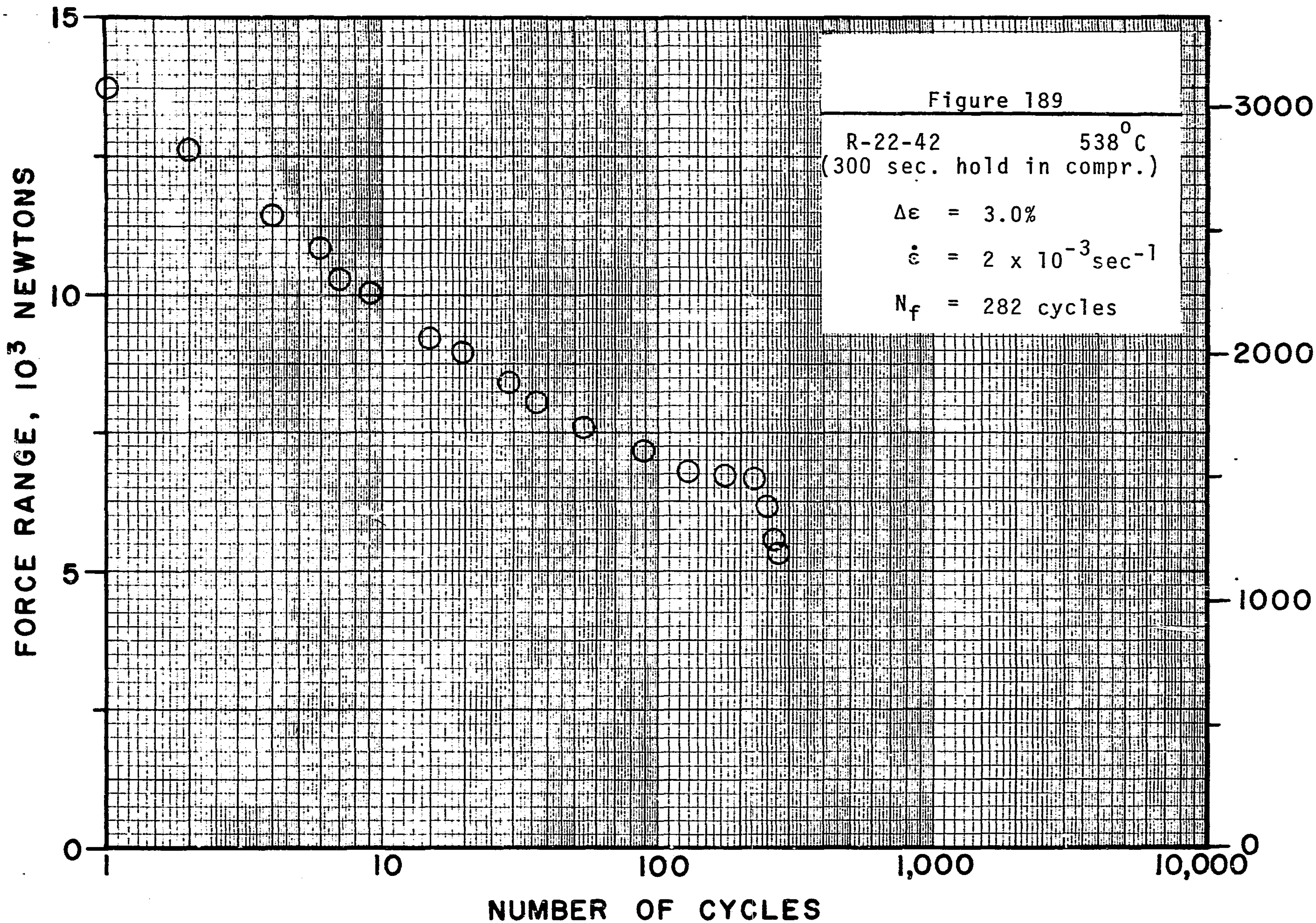


Figure 189
R-22-42 538°C
(300 sec. hold in compr.)
Δε = 3.0%
ε̇ = 2 x 10^-3 sec^-1
N_f = 282 cycles
FORCE RANGE, 10^3 NEWTONS
FORCE RANGE, LBS.
NUMBER OF CYCLES
15
10
5
0
3000
2000
1000
0
1
10
100
1,000
10,000

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.

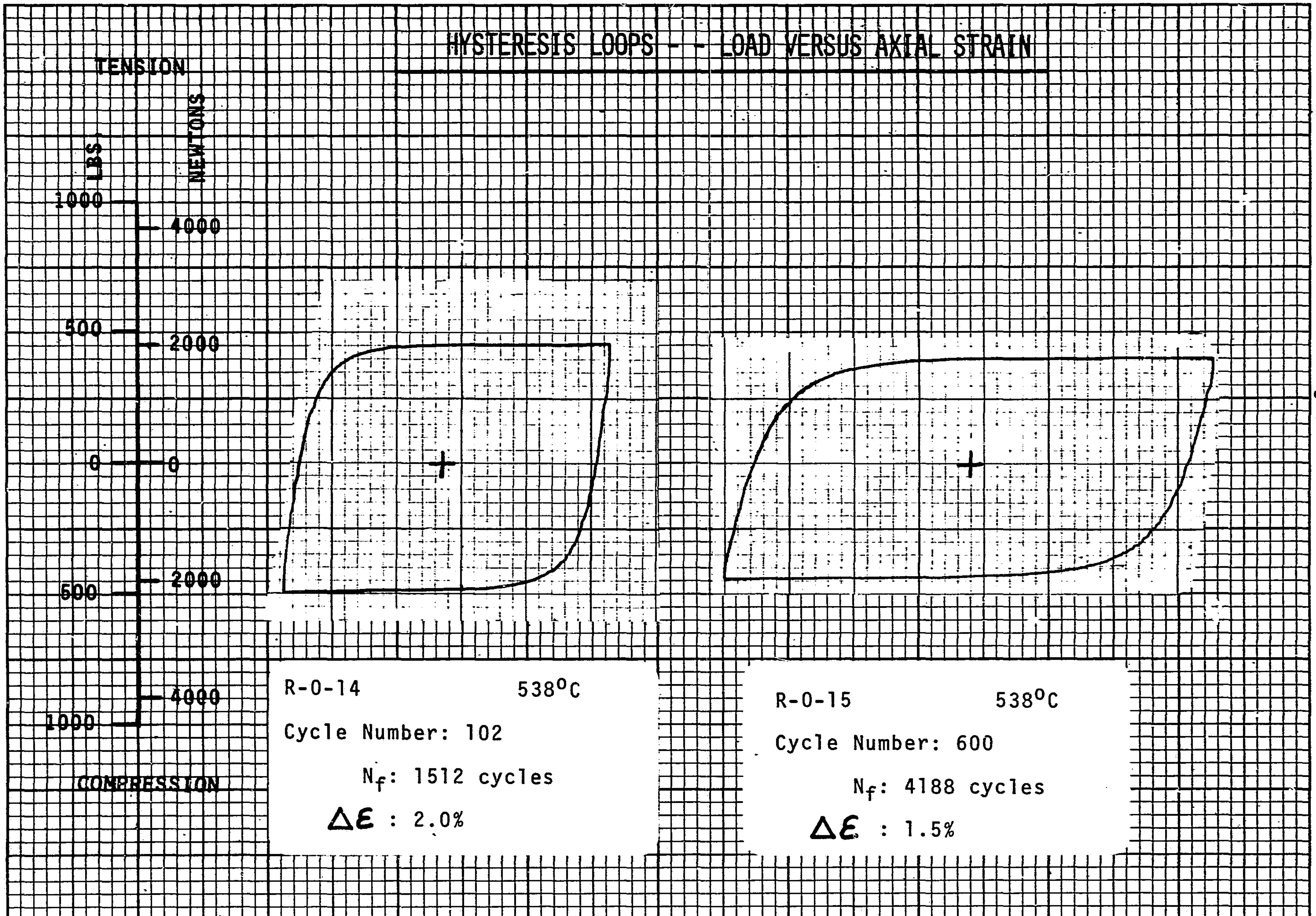
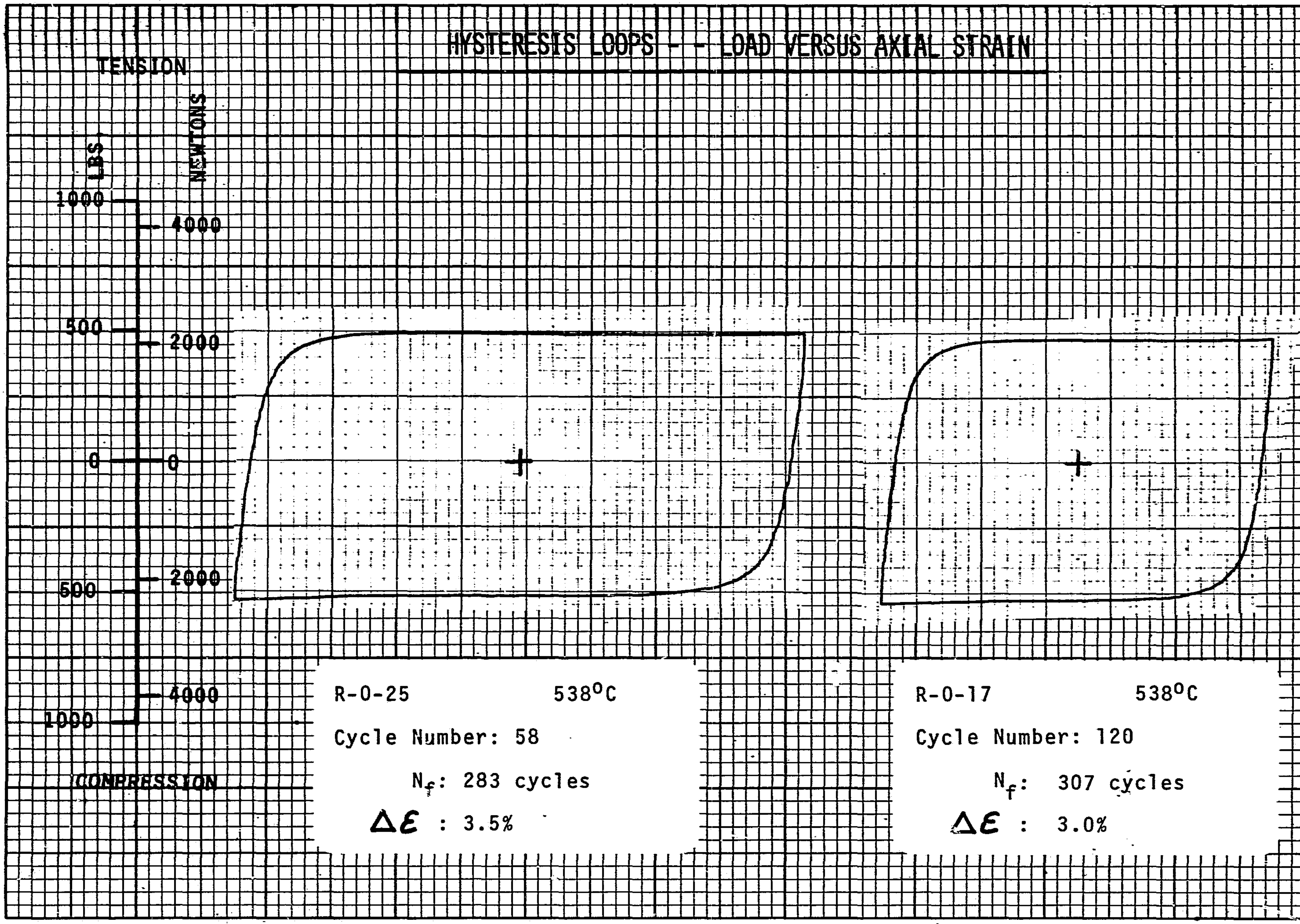

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-0-14
538°C
Cycle Number: 102
N_f: 1512 cycles
Δε : 2.0%
R-0-15
538°C
Cycle Number: 600
N_f: 4188 cycles
Δε : 1.5%

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
Nf: 283 cycles
Δε : 3.5%
R-0-17
538°C
Cycle Number: 120
Nf: 307 cycles
Δε : 3.0%

Figure 191

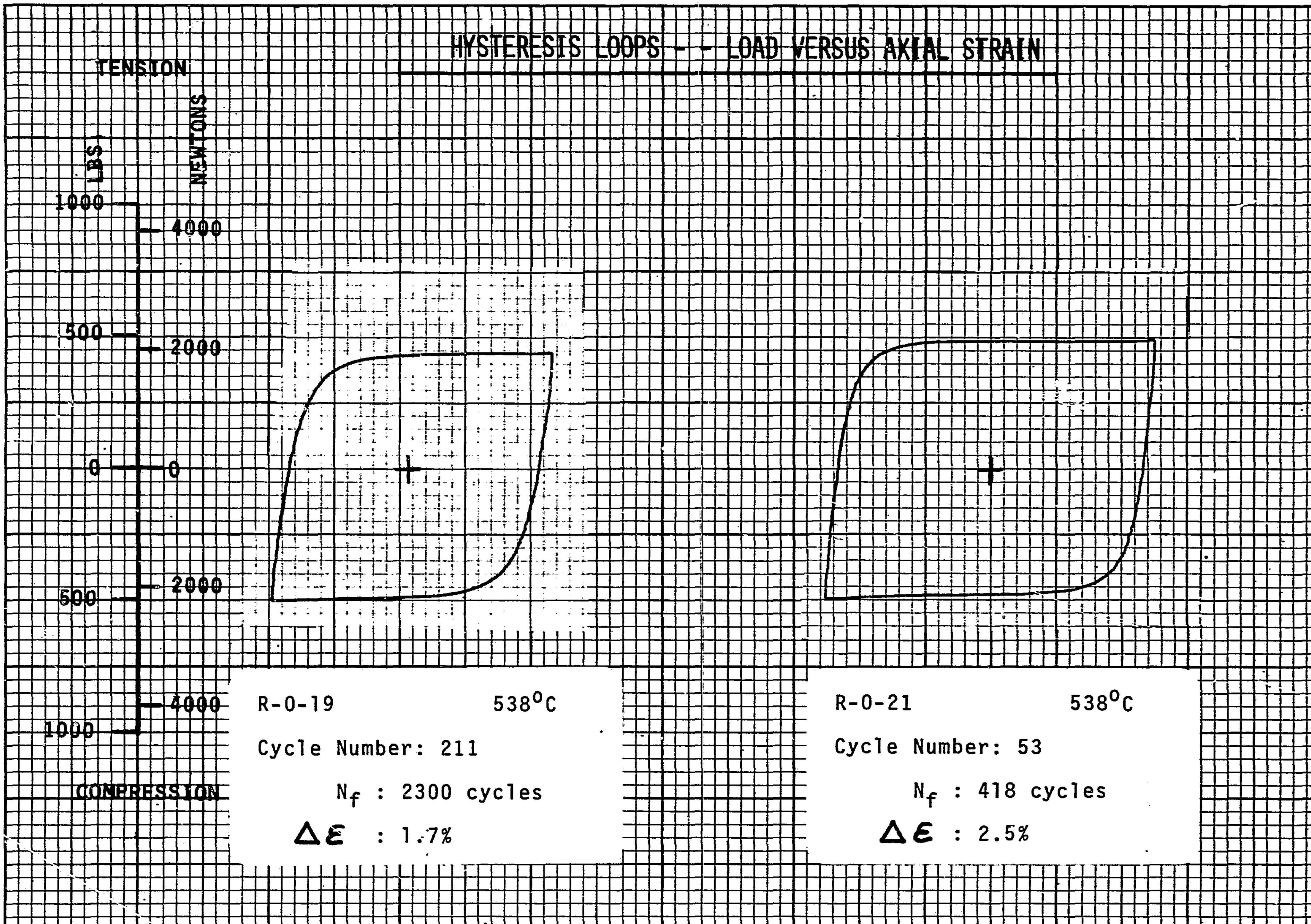

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-0-19
538°C
Cycle Number: 211
Nf : 2300 cycles
ΔƐ : 1.7%
R-0-21
538°C
Cycle Number: 53
Nf : 418 cycles
ΔƐ : 2.5%

Figure 192

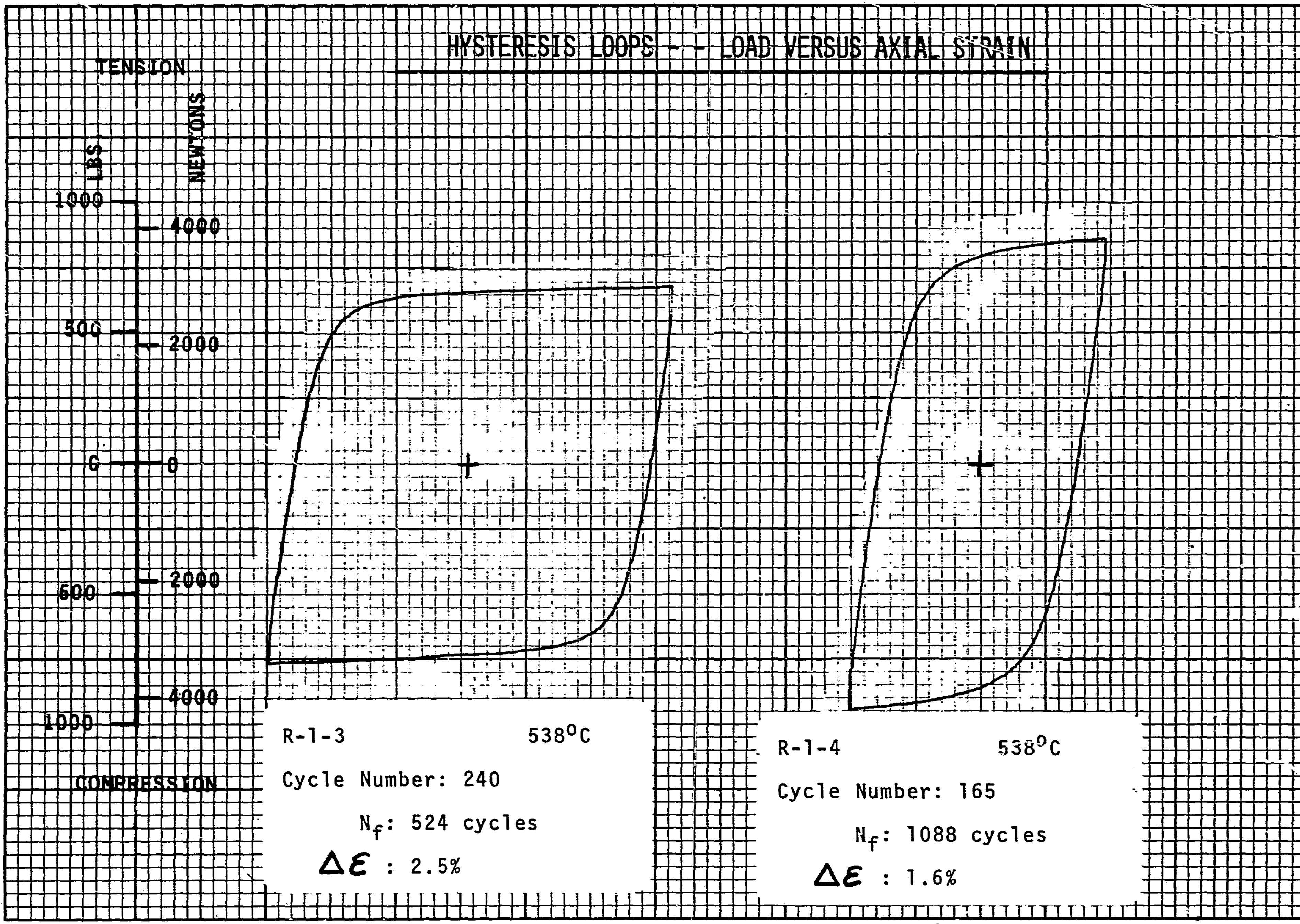

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-3
538°C
Cycle Number: 240
Nf: 524 cycles
ΔΕ : 2.5%
R-1-4
538°C
Cycle Number: 165
Nf: 1088 cycles
ΔΕ : 1.6%

Figure 193

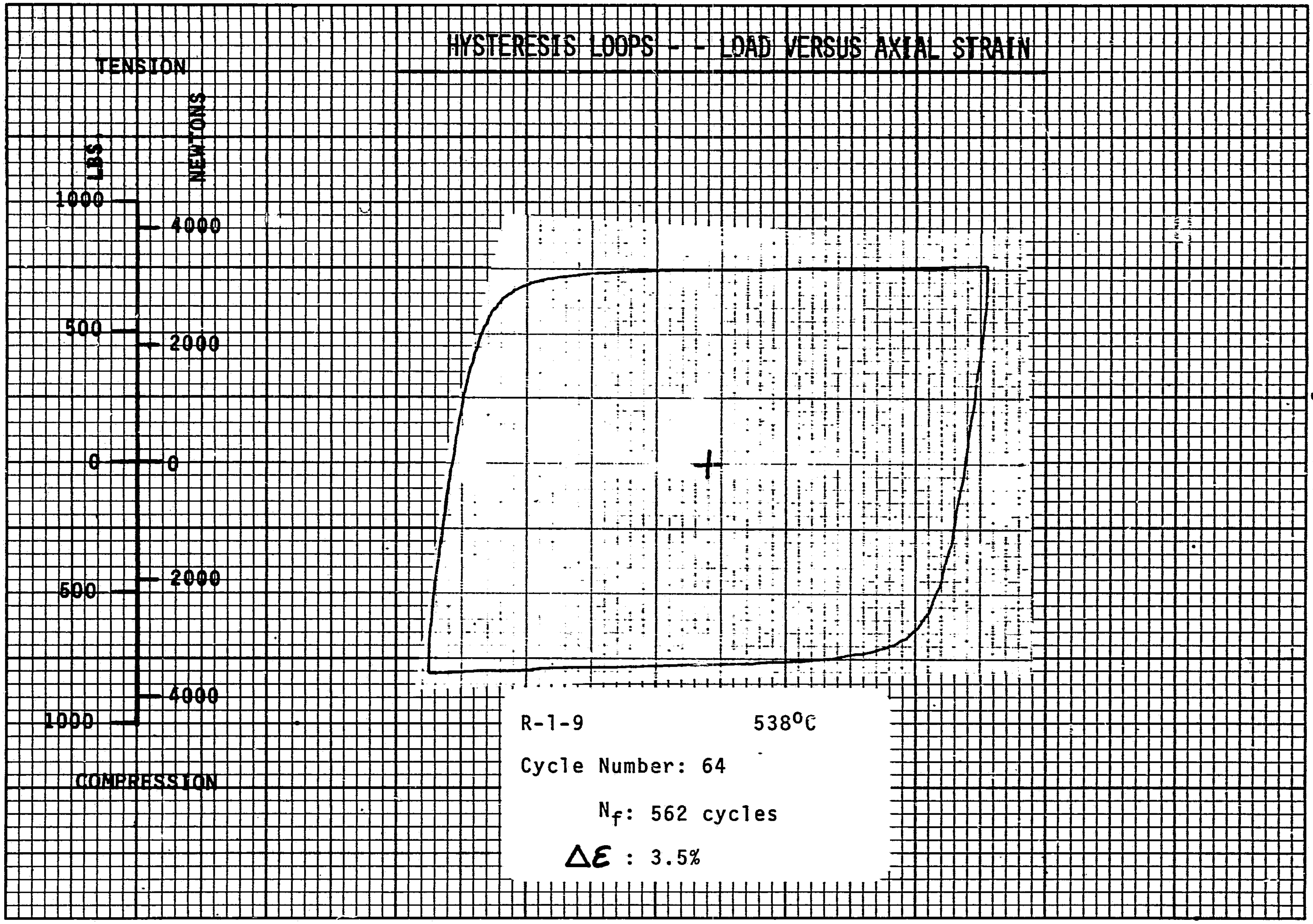

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-9
538°C
Cycle Number: 64
N_f: 562 cycles
ΔE : 3.5%

Figure 194

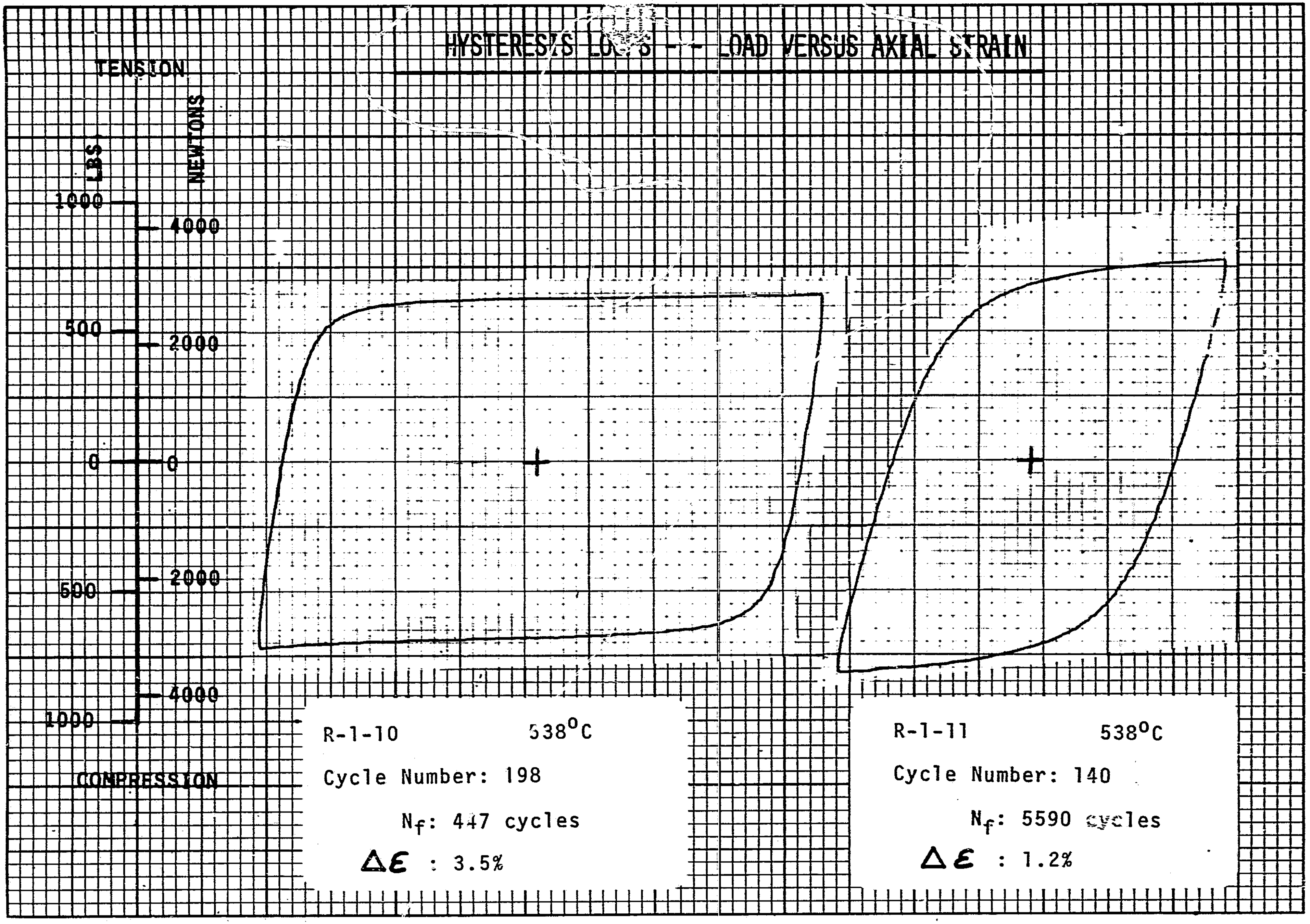

HYSTERESIS LOOPS -- LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-1-10 538°C
Cycle Number: 198
Nf: 447 cycles
ΔΕ : 3.5%
R-1-11 538°C
Cycle Number: 140
Nf: 5590 cycles
ΔΕ : 1.2%

Figure 195

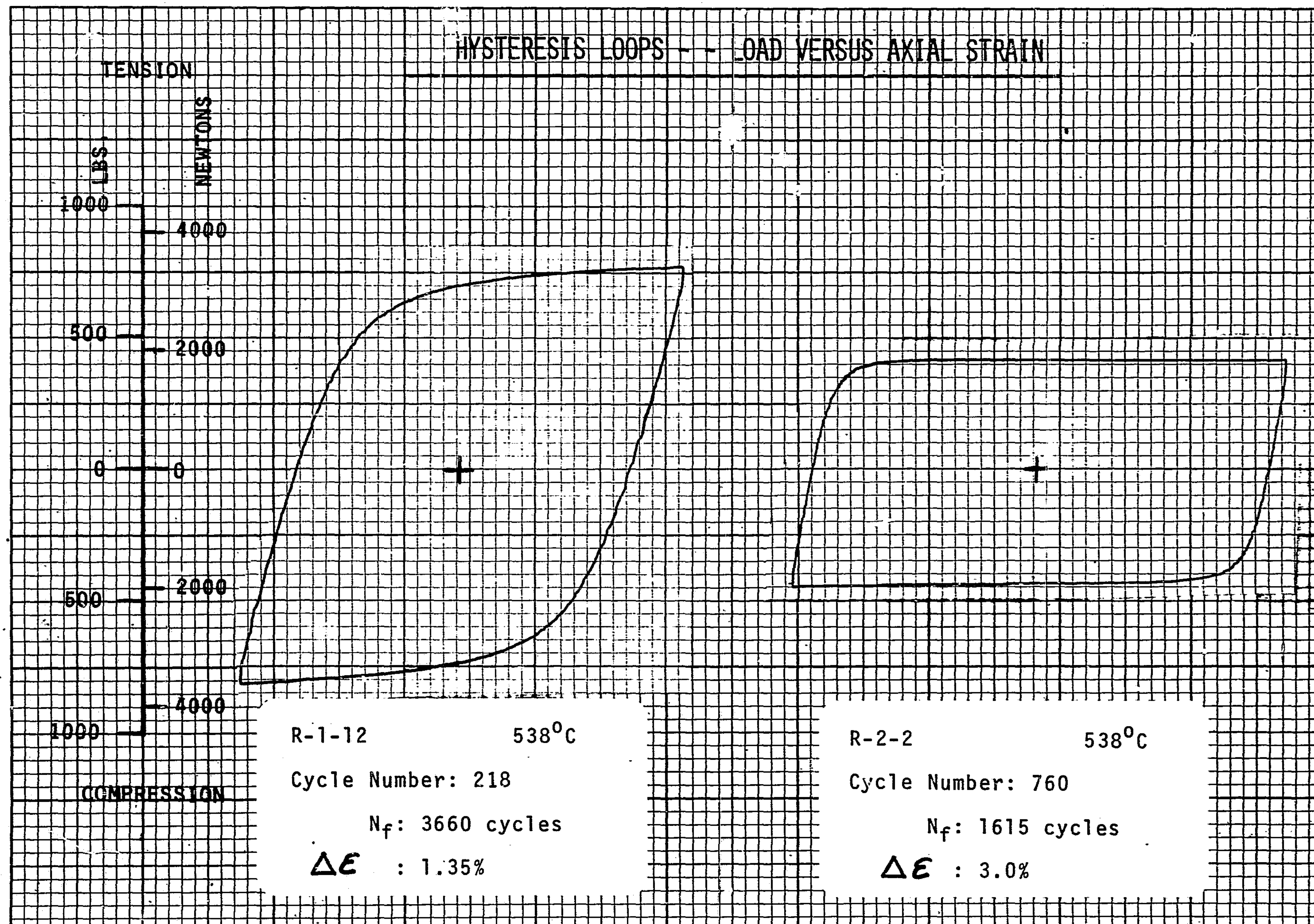

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-1-12
538°C
Cycle Number: 218
N_f: 3660 cycles
Δε : 1.35%
R-2-2
538°C
Cycle Number: 760
N_f: 1615 cycles
Δε : 3.0%

Figure 196

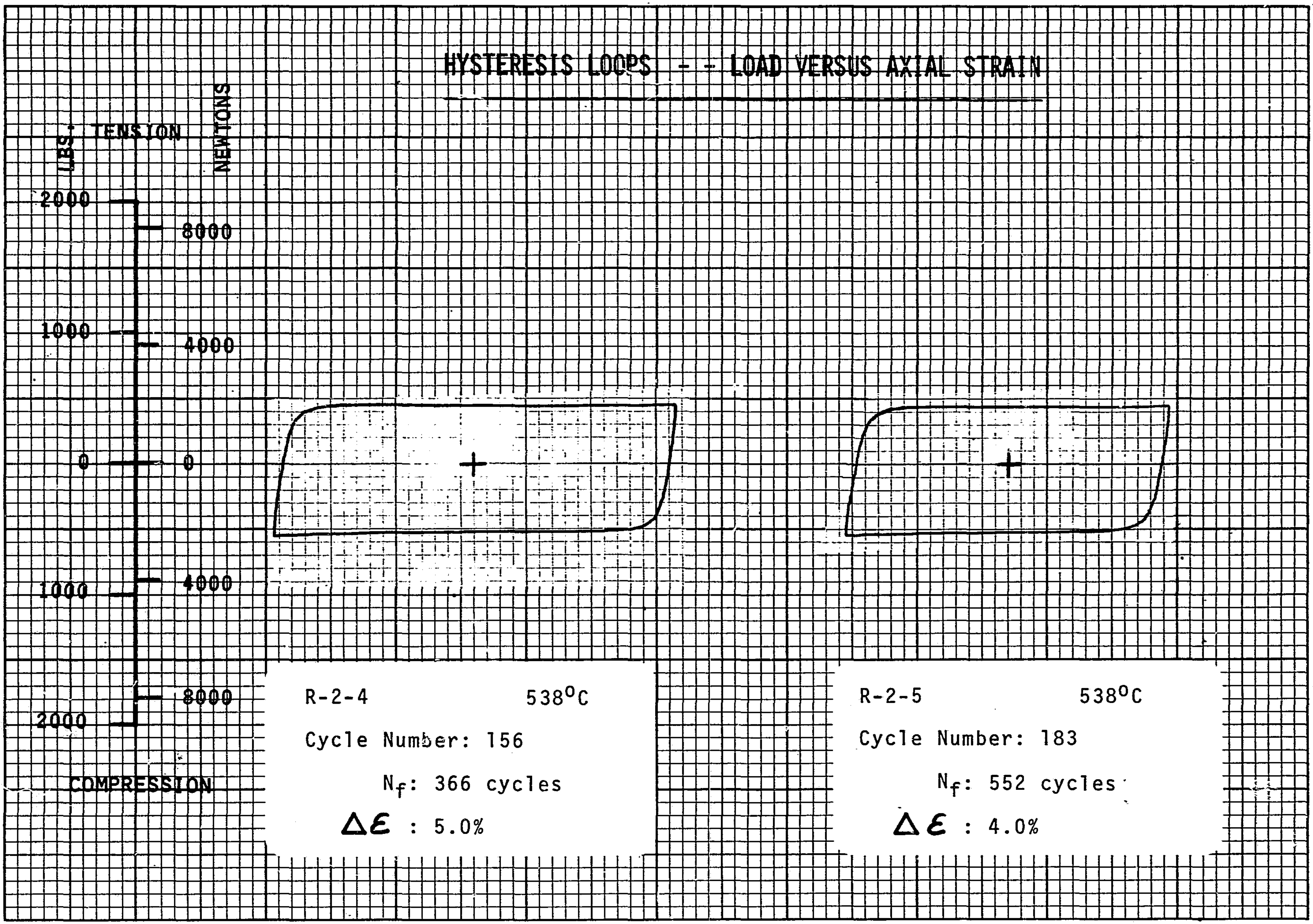

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
4000
1000
8000
2000
COMPRESSION
R-2-4
538°C
Cycle Number: 156
N_f: 366 cycles
$\Delta\varepsilon$: 5.0%
R-2-5
538°C
Cycle Number: 183
N_f: 552 cycles
$\Delta\varepsilon$: 4.0%

Figure 197

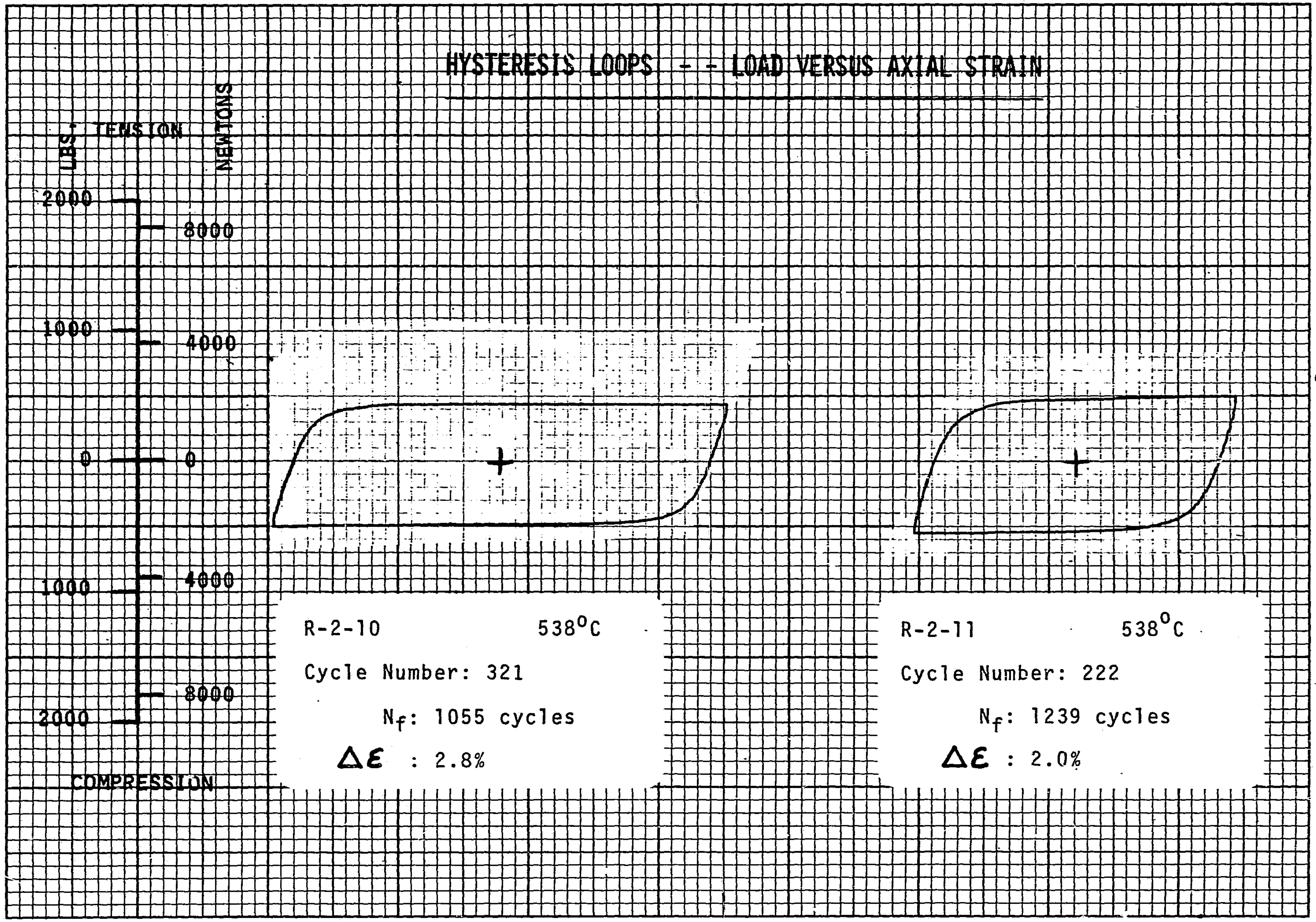

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-10 538°C
Cycle Number: 321
N_f: 1055 cycles
ΔE : 2.8%
R-2-11 538°C
Cycle Number: 222
N_f: 1239 cycles
ΔE : 2.0%

Figure 198

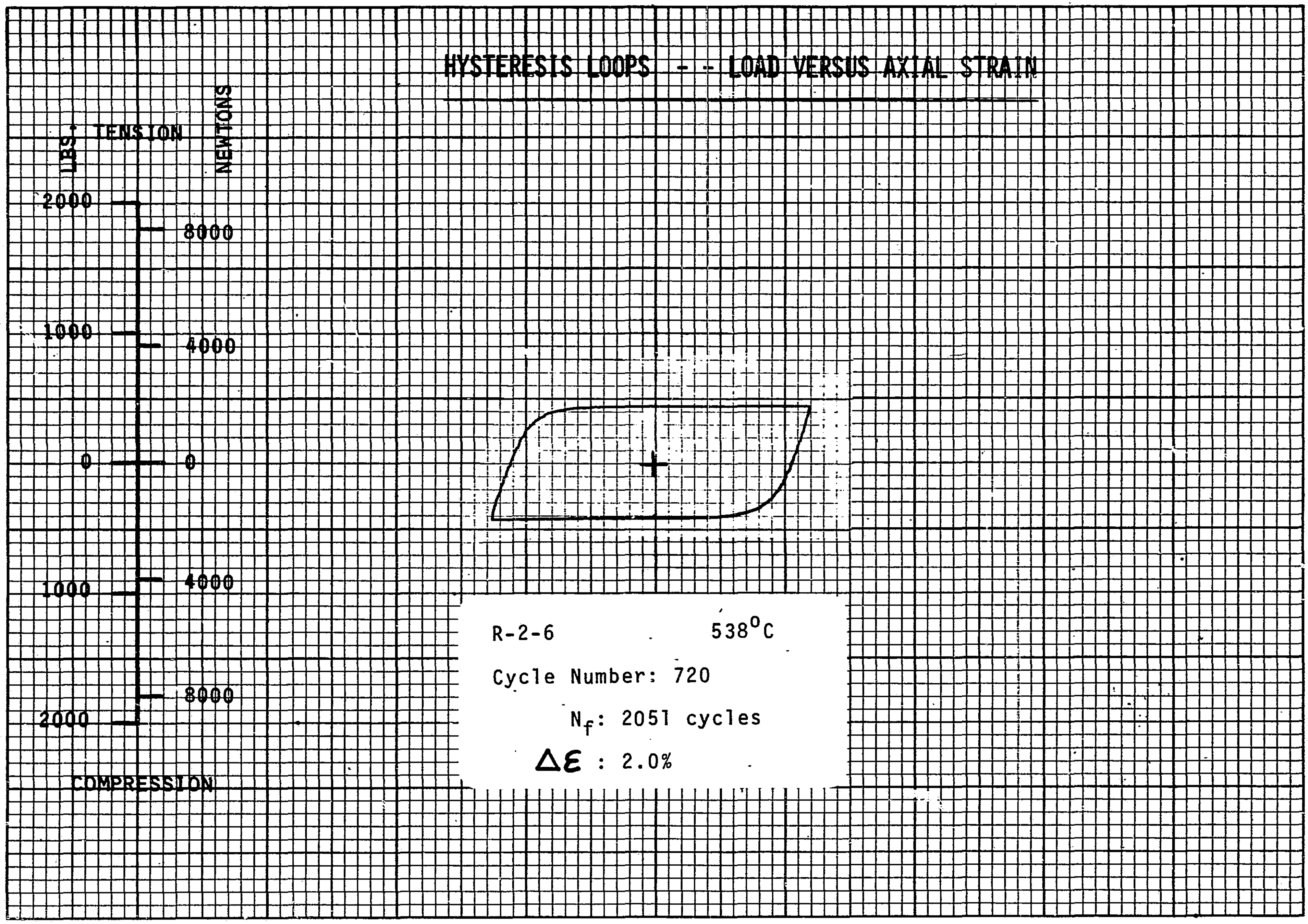

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-6
538°C
Cycle Number: 720
Nf: 2051 cycles
Δε : 2.0%

Figure 199

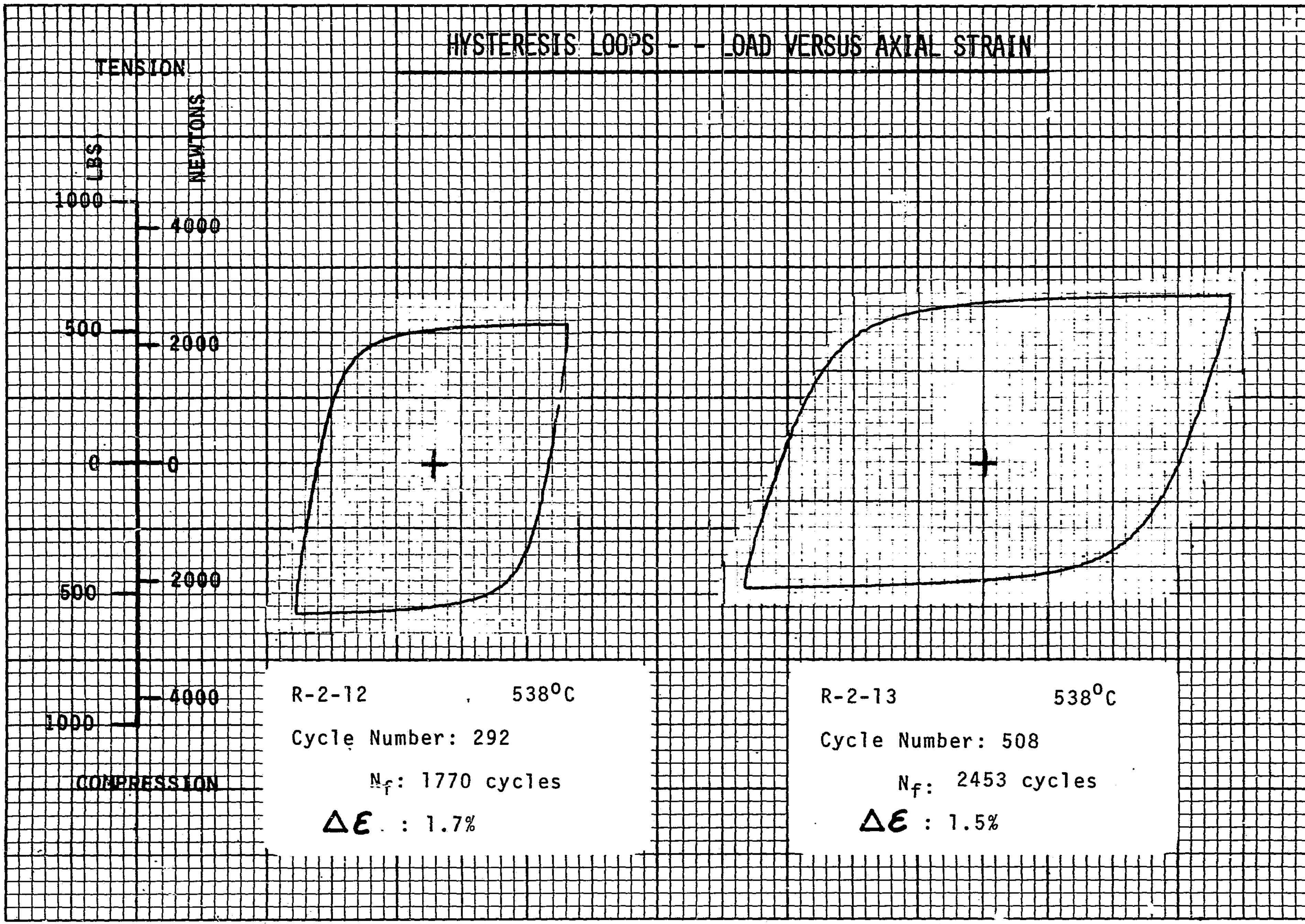

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-2-12 538°C
Cycle Number: 292
Nf: 1770 cycles
Δε : 1.7%
R-2-13 538°C
Cycle Number: 508
Nf: 2453 cycles
Δε : 1.5%

Figure 200

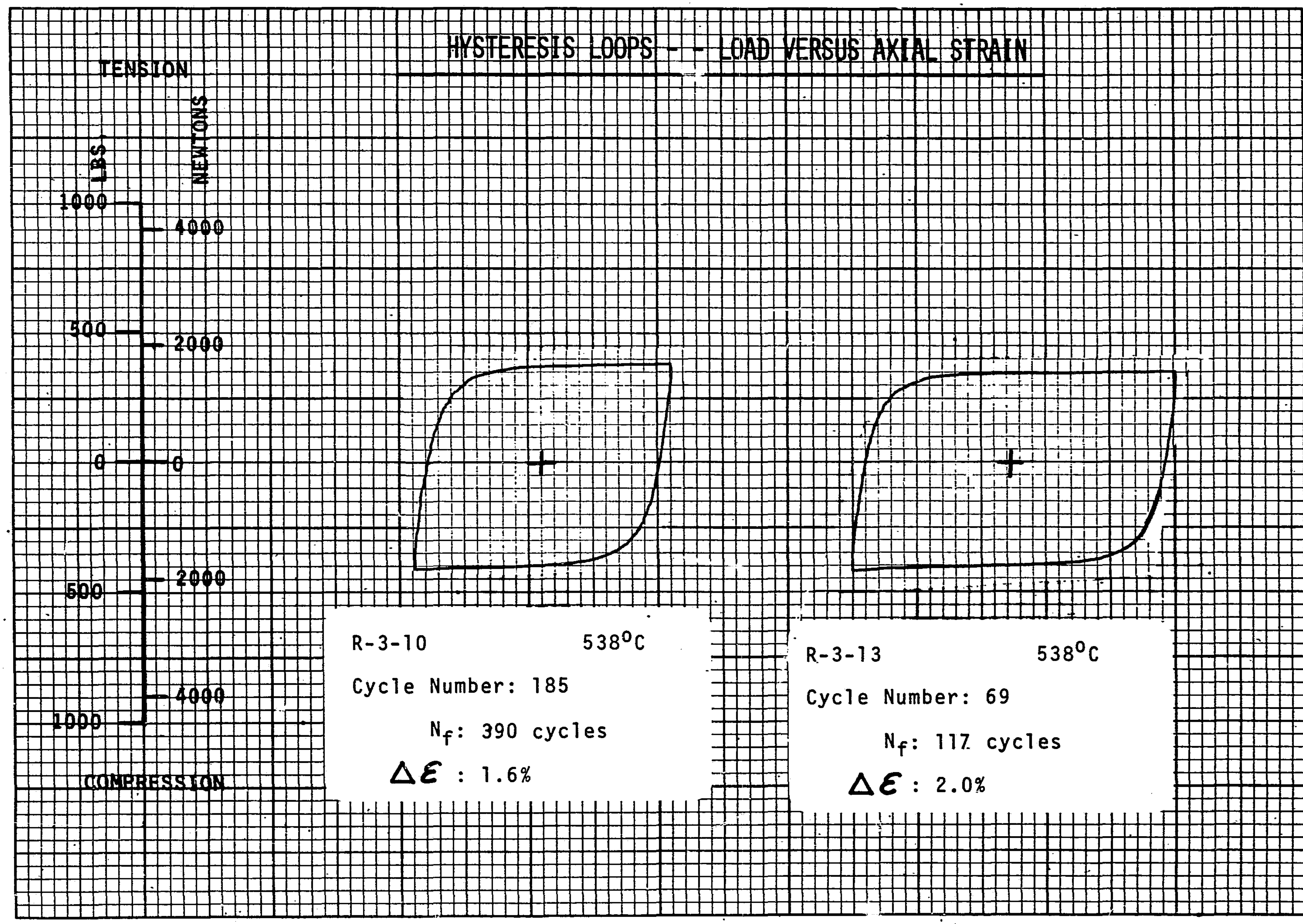

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-3-10 538^{o}C
Cycle Number: 185
N_f: 390 cycles
$\Delta\varepsilon$: 1.6%
R-3-13 538^{o}C
Cycle Number: 69
N_f: 117 cycles
$\Delta\varepsilon$: 2.0%

Figure 201

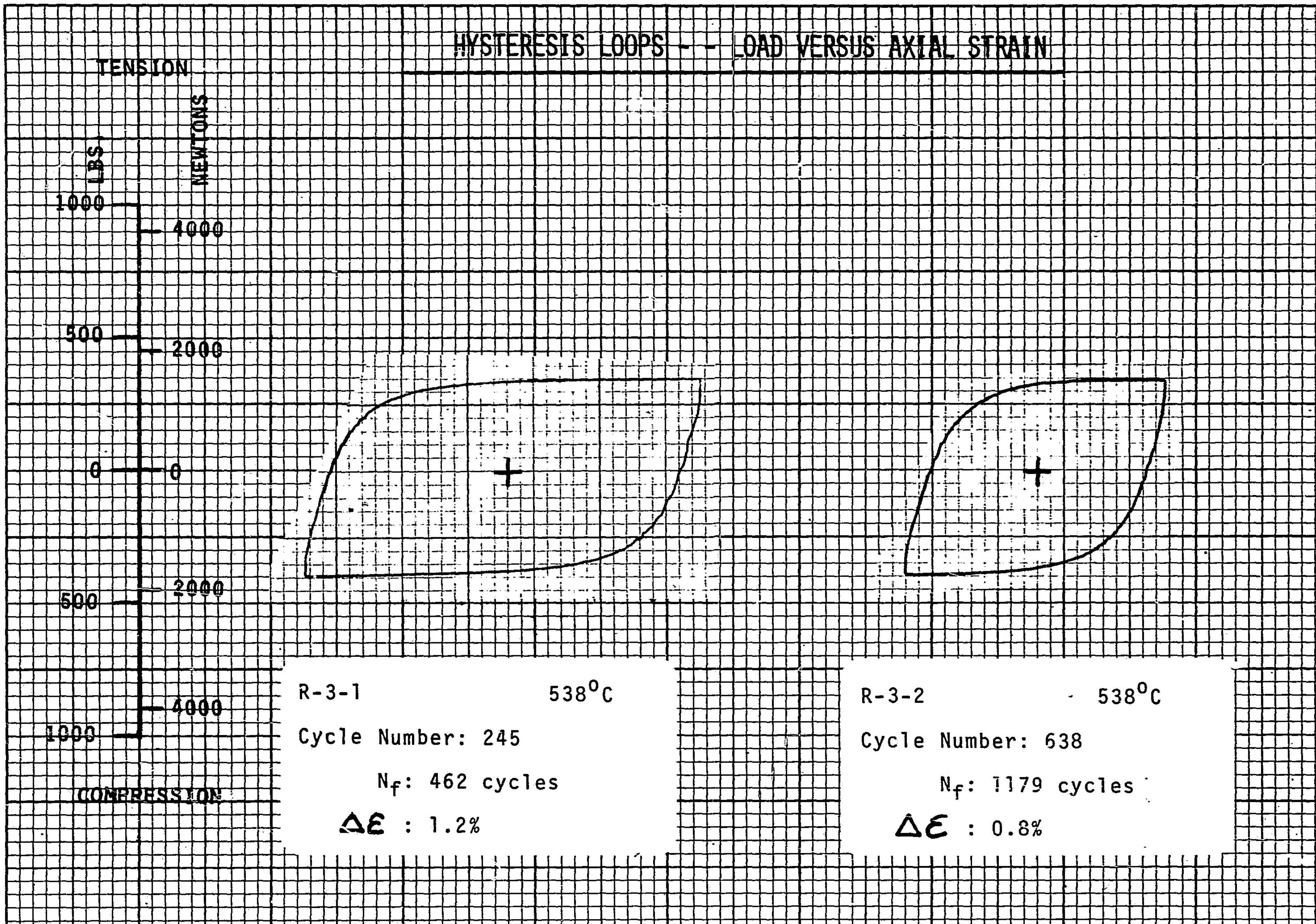

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-3-1
538°C
Cycle Number: 245
N_f: 462 cycles
ΔΕ : 1.2%
R-3-2
538°C
Cycle Number: 638
N_f: 1179 cycles
ΔΕ : 0.8%

Figure 202

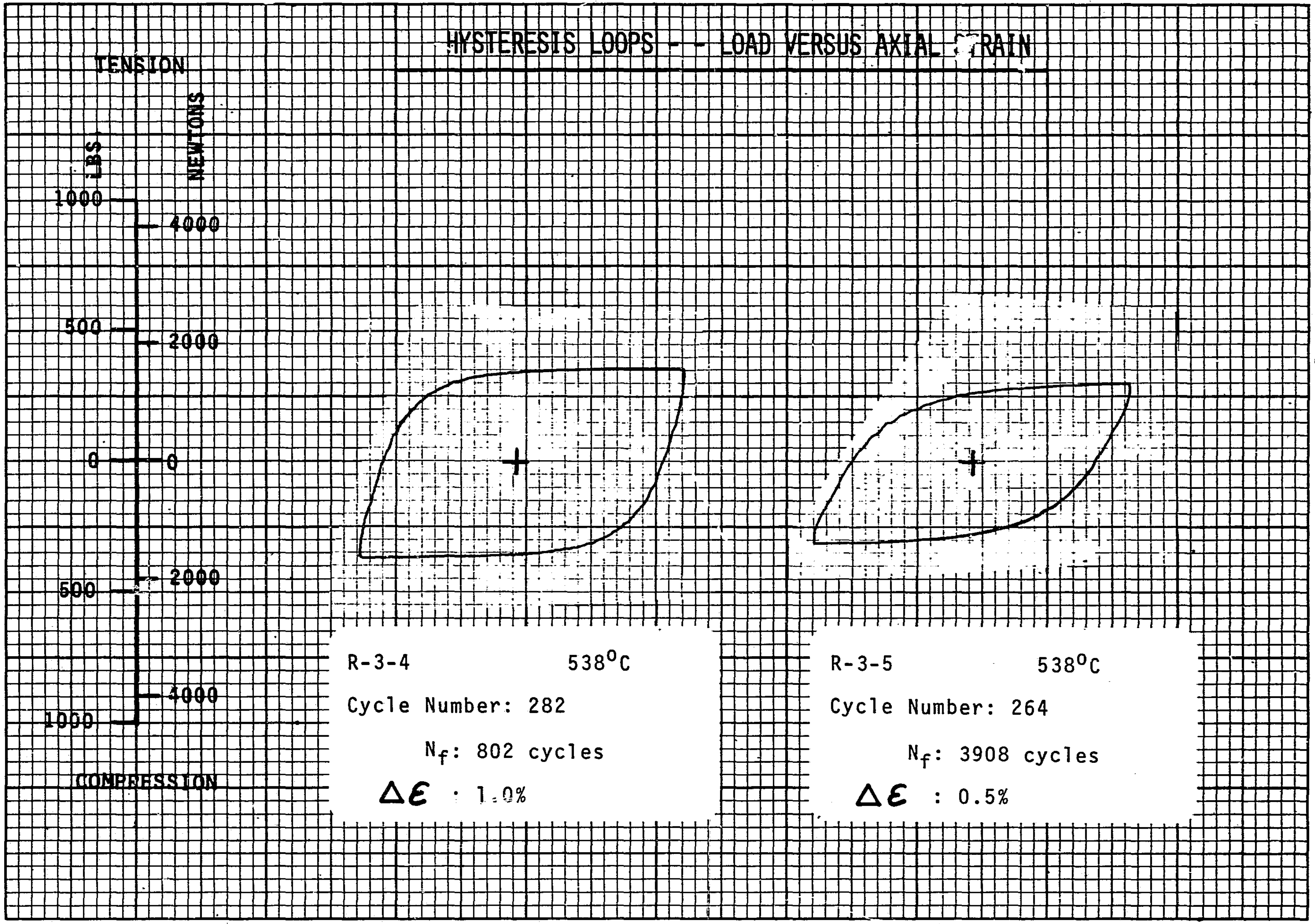

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-3-4 538°C
Cycle Number: 282
Nf: 802 cycles
Δε : 1.0%
R-3-5 538°C
Cycle Number: 264
Nf: 3908 cycles
Δε : 0.5%

Figure 203

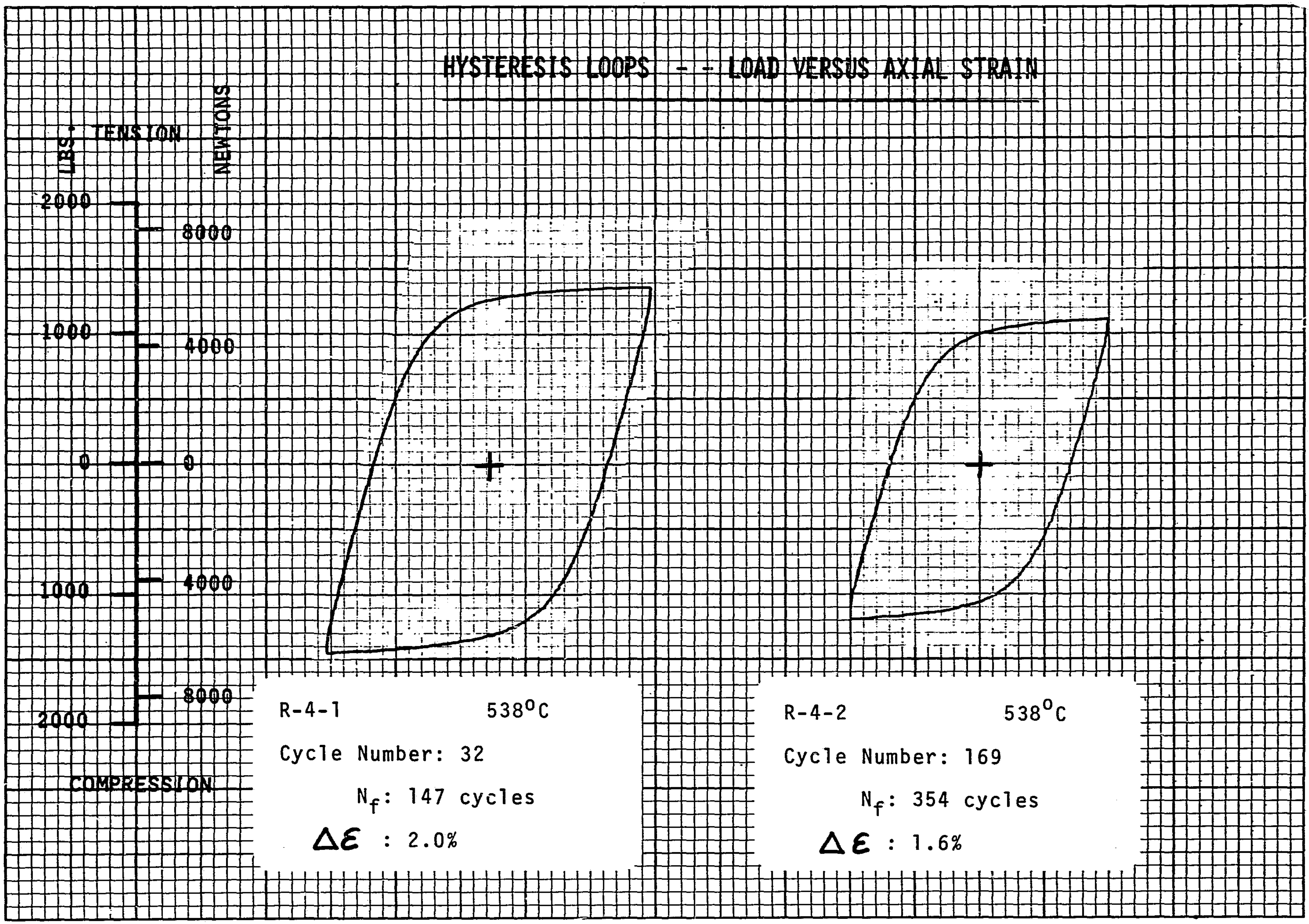

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-4-1 538°C
Cycle Number: 32
N$_f$: 147 cycles
$\Delta\varepsilon$: 2.0%
R-4-2 538°C
Cycle Number: 169
N$_f$: 354 cycles
$\Delta\varepsilon$: 1.6%

Figure 204

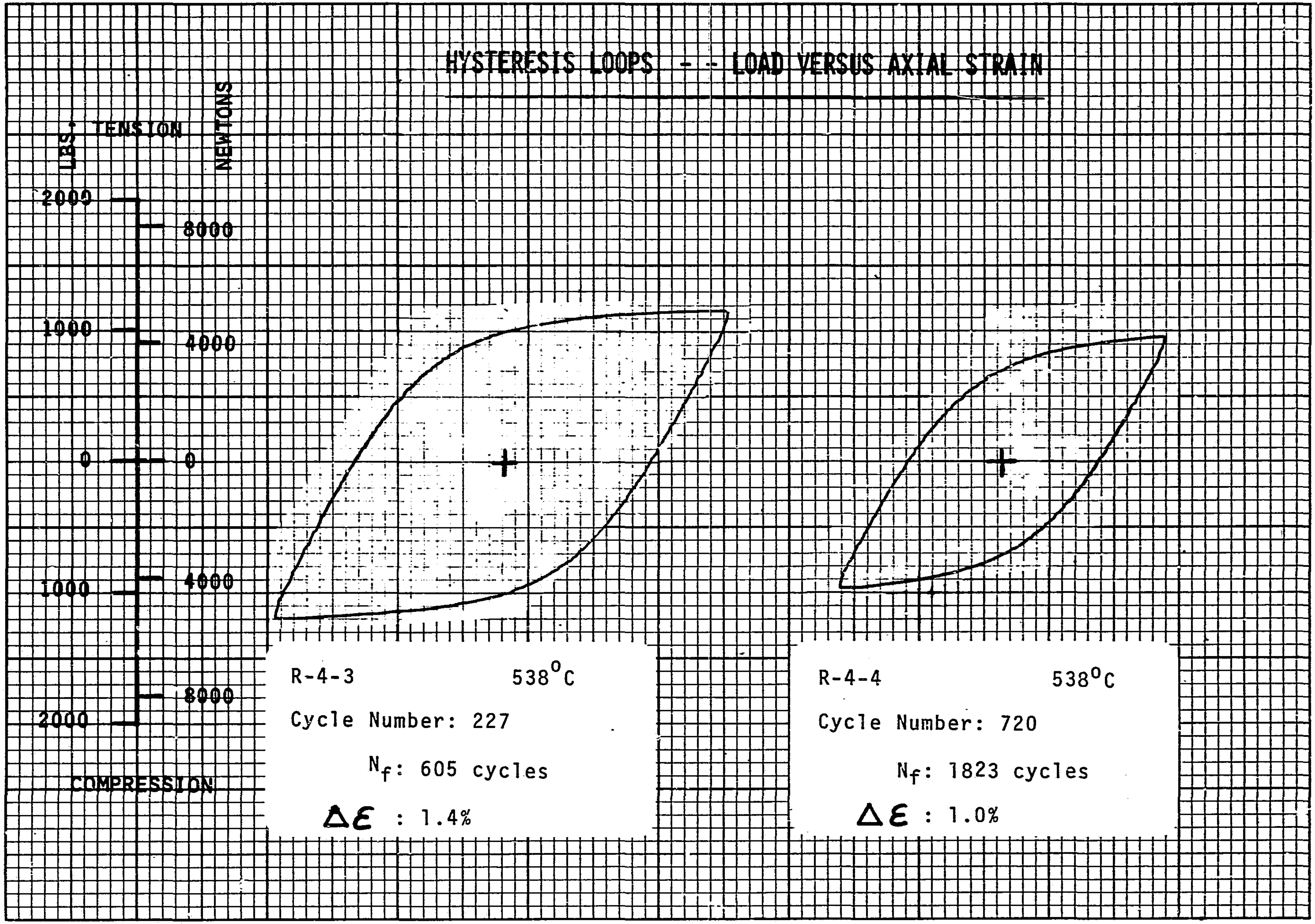

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-4-3 538°C
Cycle Number: 227
Nf: 605 cycles
ΔE : 1.4%
R-4-4 538°C
Cycle Number: 720
Nf: 1823 cycles
ΔE : 1.0%

Figure 205

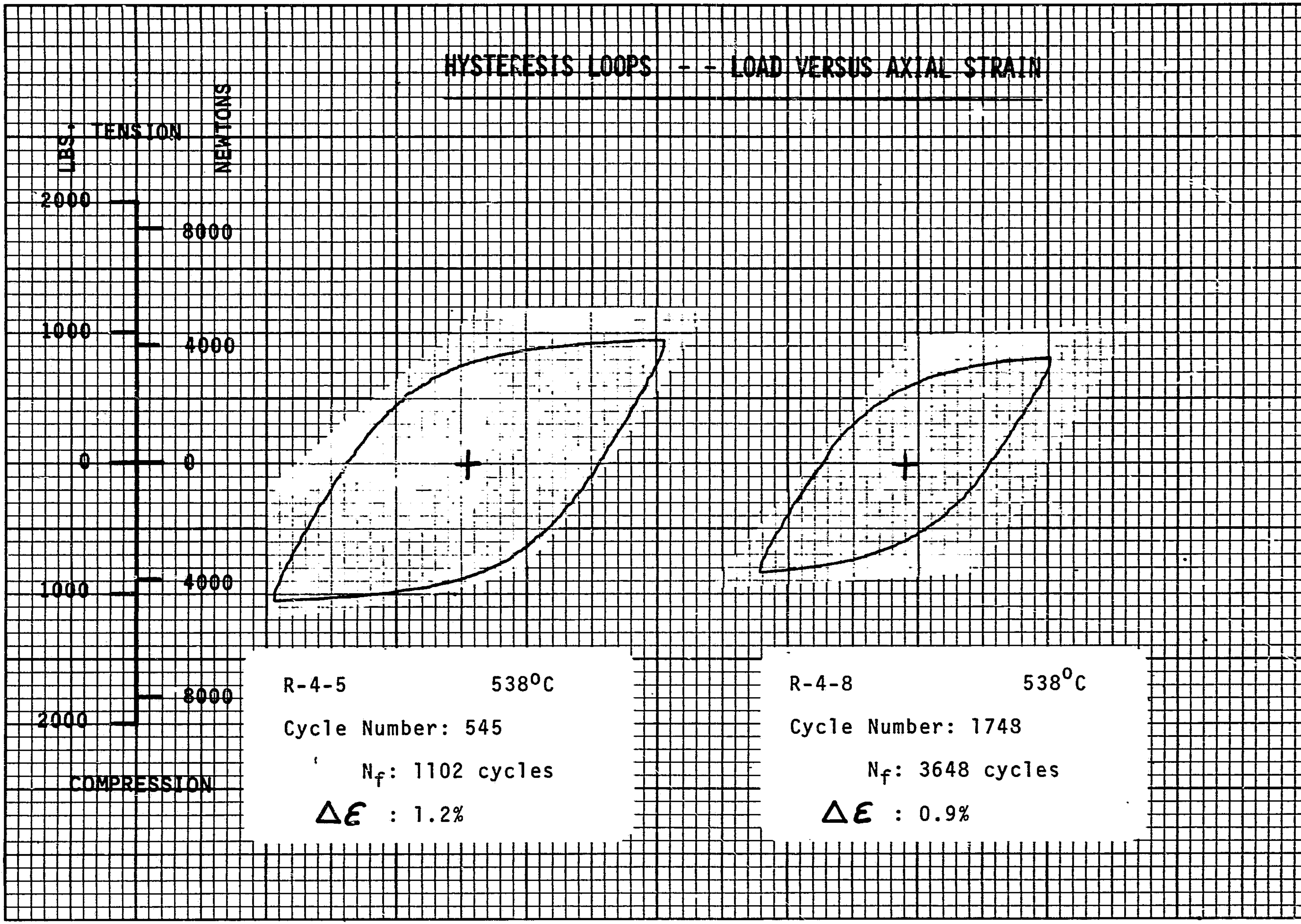

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-4-5
538°C
Cycle Number: 545
N_f: 1102 cycles
$\Delta\varepsilon$: 1.2%
R-4-8
538°C
Cycle Number: 1748
N_f: 3648 cycles
$\Delta\varepsilon$: 0.9%

Figure 206

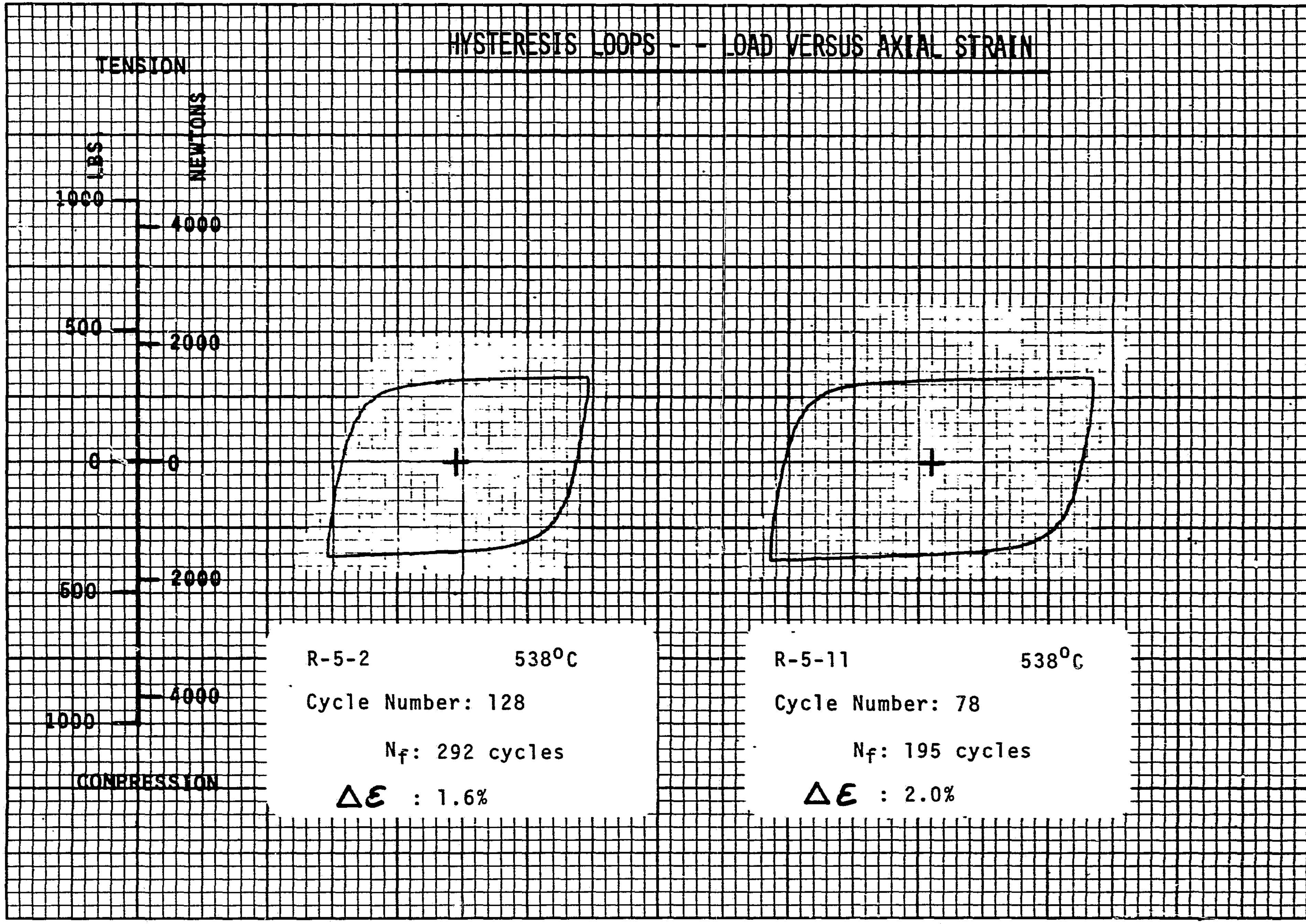

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-5-2
538°C
Cycle Number: 128
Nf: 292 cycles
ΔE : 1.6%
R-5-11
538°C
Cycle Number: 78
Nf: 195 cycles
ΔE : 2.0%

Figure 207

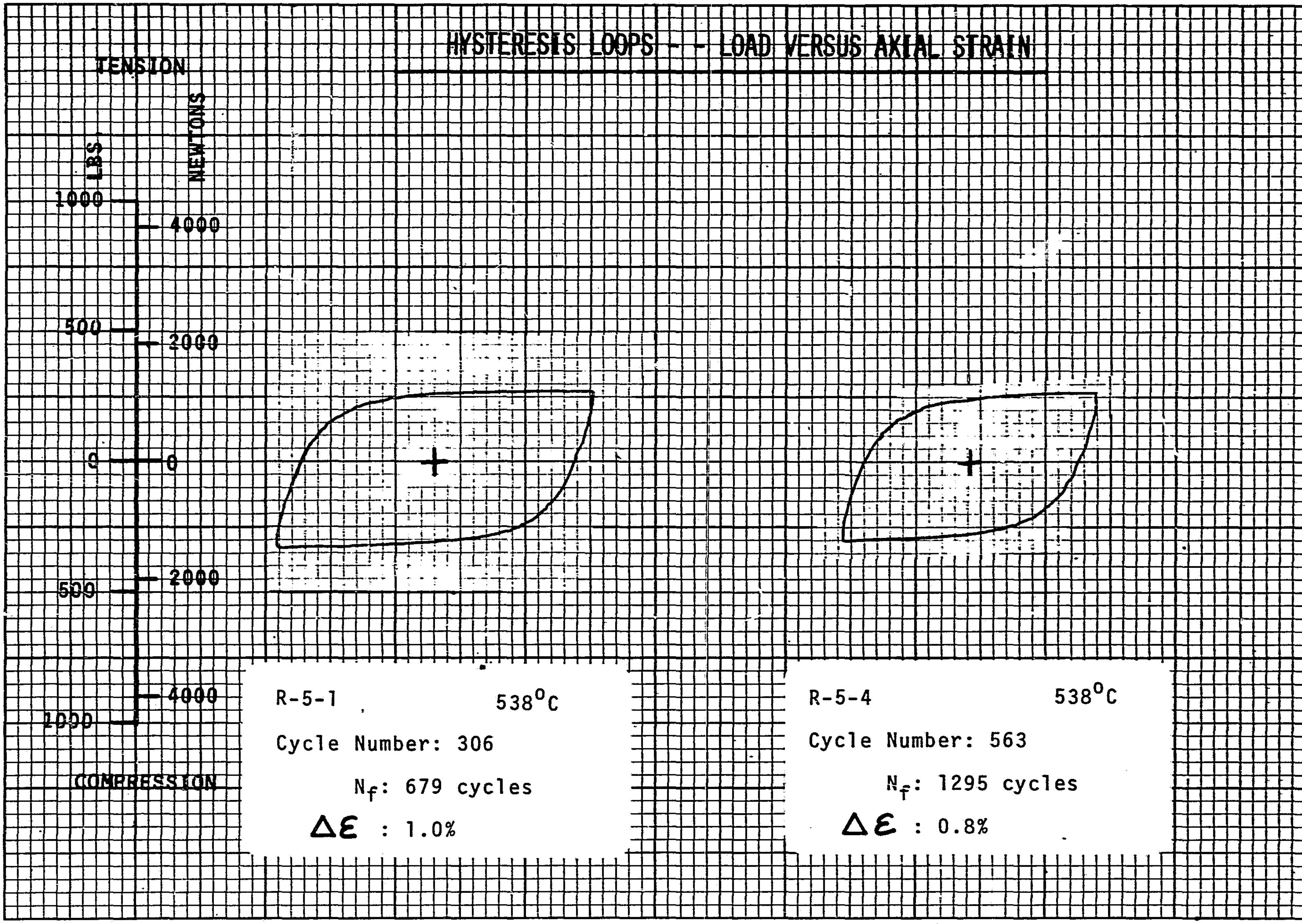

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-5-1 538°C
Cycle Number: 306
N_f: 679 cycles
Δε : 1.0%
R-5-4 538°C
Cycle Number: 563
N_f: 1295 cycles
Δε : 0.8%

Figure 208

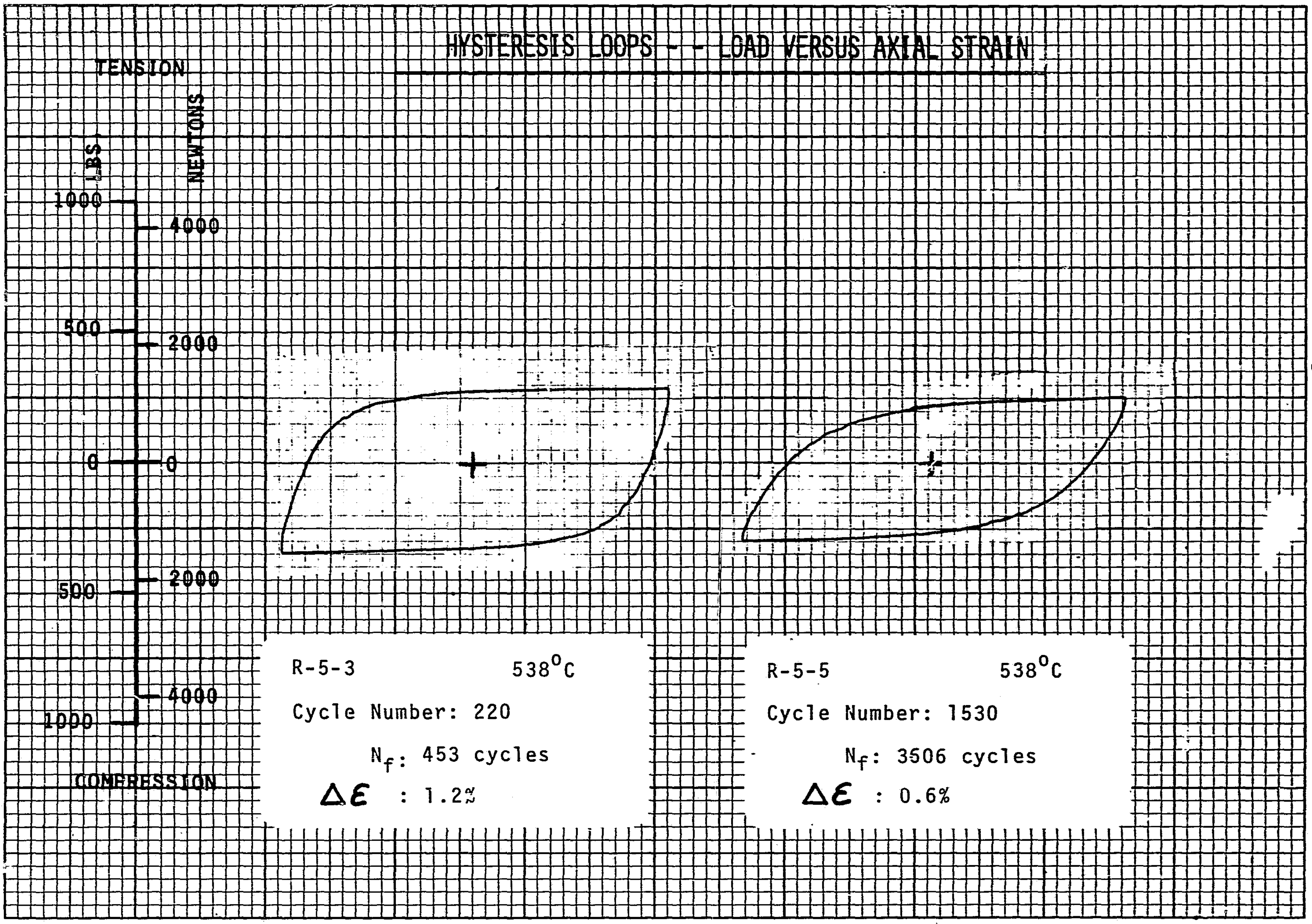

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-5-3
538°C
Cycle Number: 220
N_f: 453 cycles
Δε : 1.2%
R-5-5
538°C
Cycle Number: 1530
N_f: 3506 cycles
Δε : 0.6%

Figure 209

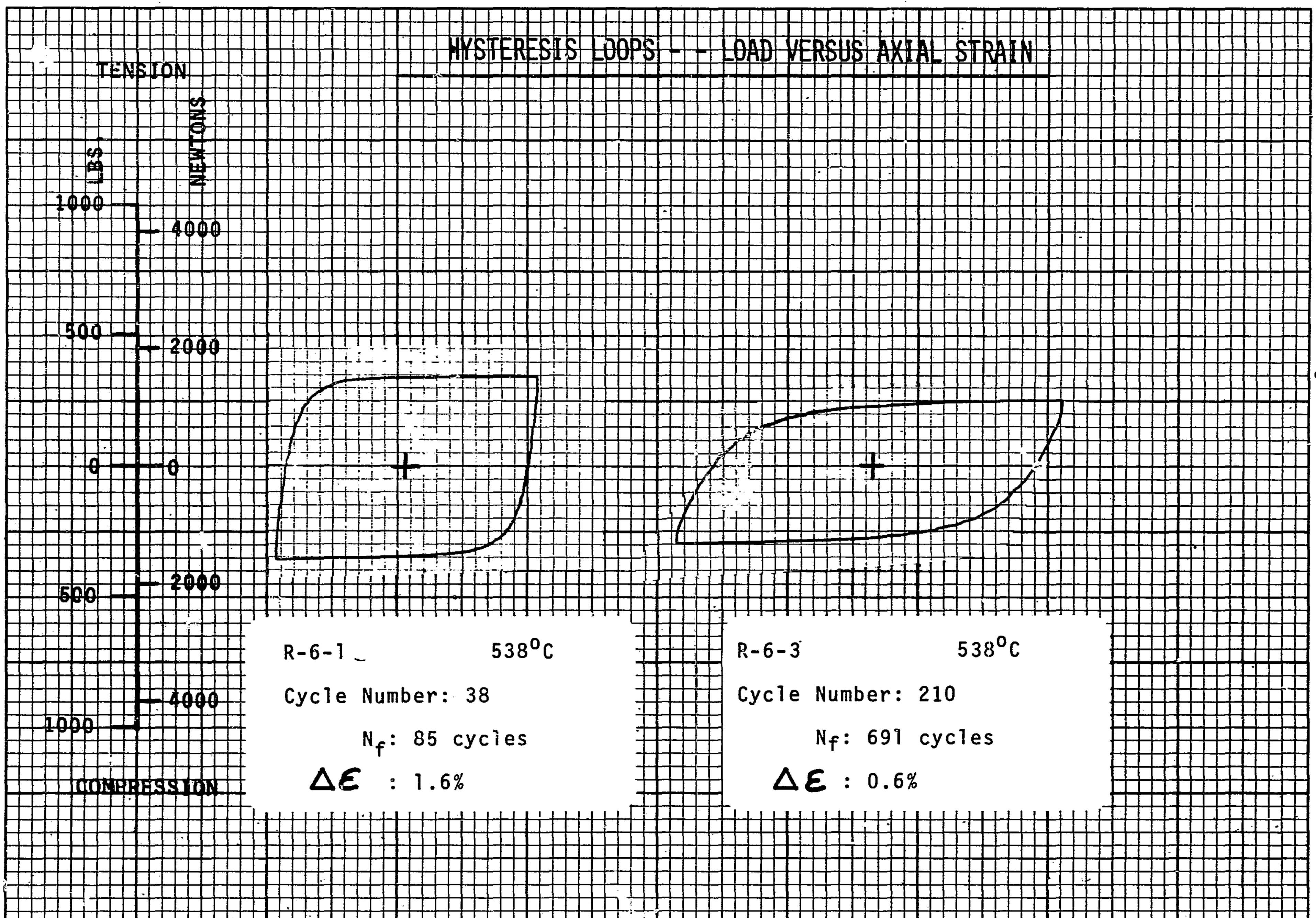

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-1
538°C
Cycle Number: 38
Nf: 85 cycles
ΔΕ : 1.6%
R-6-3
538°C
Cycle Number: 210
Nf: 691 cycles
ΔΕ : 0.6%

Figure 210

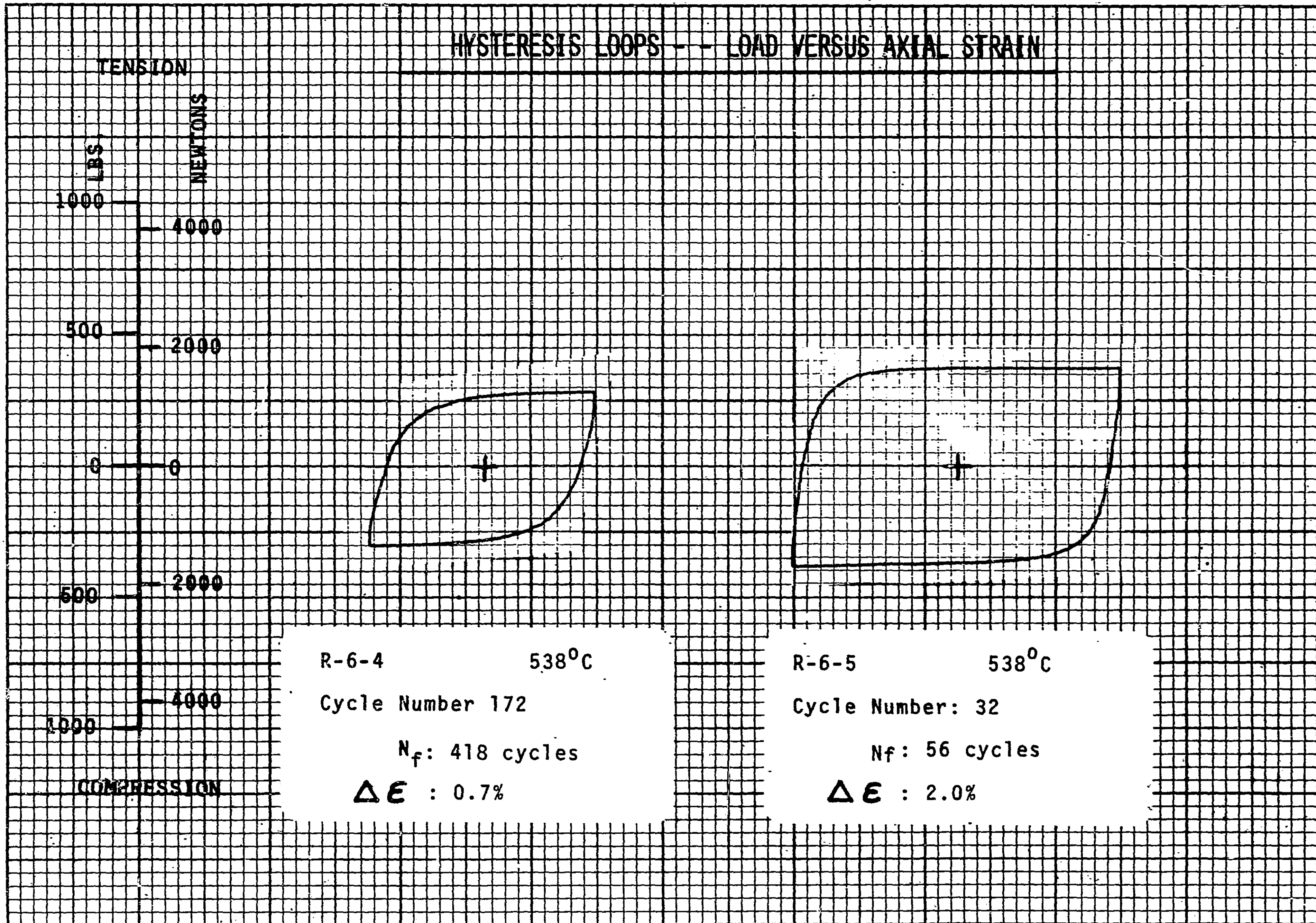

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-6-4 538°C
Cycle Number 172
Nf: 418 cycles
Δε : 0.7%
R-6-5 538°C
Cycle Number: 32
Nf: 56 cycles
Δε : 2.0%

Figure 211

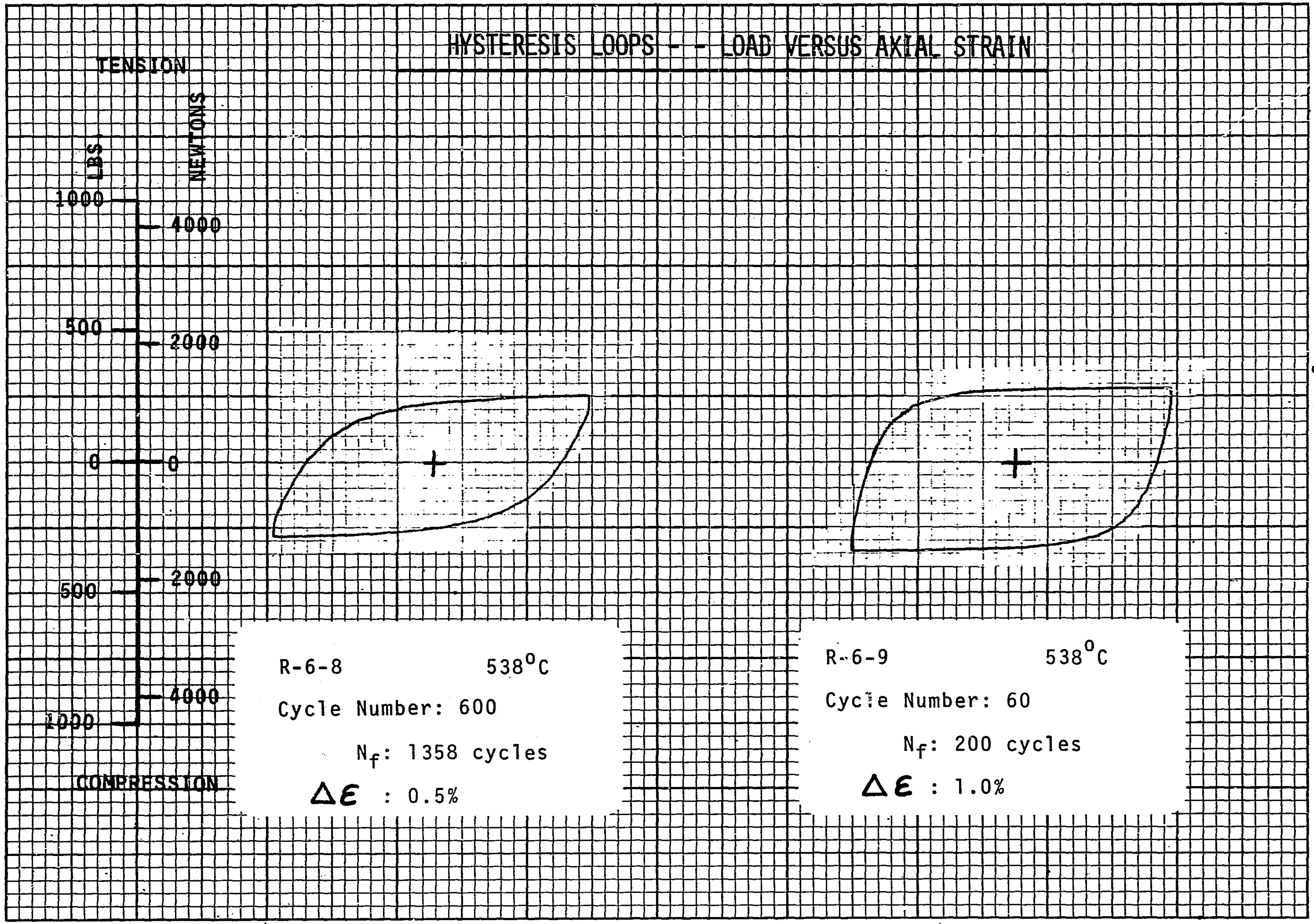

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-8 538°C
Cycle Number: 600
N_f: 1358 cycles
$\Delta\varepsilon$: 0.5%
R-6-9 538°C
Cycle Number: 60
N_f: 200 cycles
$\Delta\varepsilon$: 1.0%

Figure 212

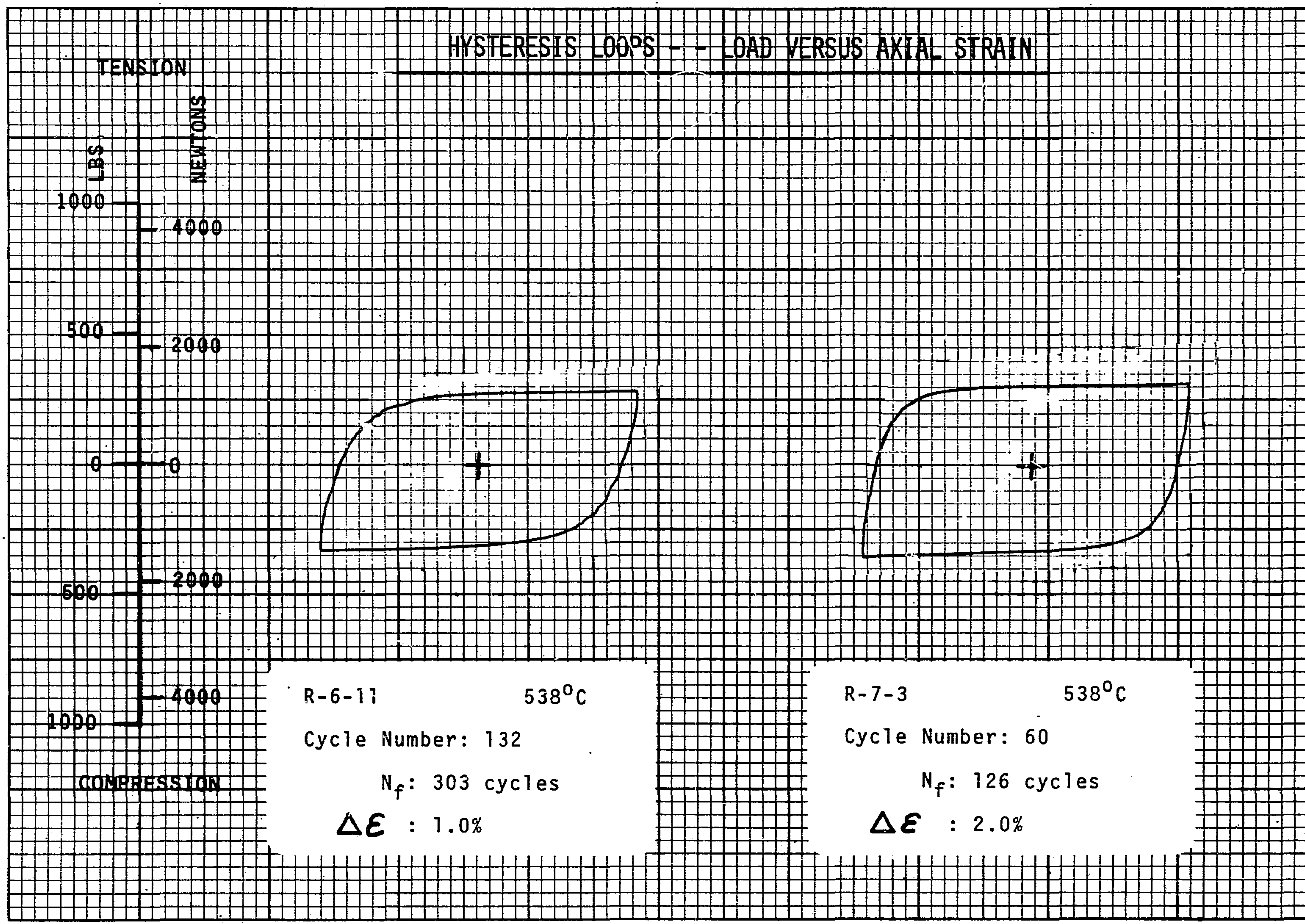

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-6-11
538°C
Cycle Number: 132
Nf: 303 cycles
ΔE : 1.0%
R-7-3
538°C
Cycle Number: 60
Nf: 126 cycles
ΔE : 2.0%

Figure 213

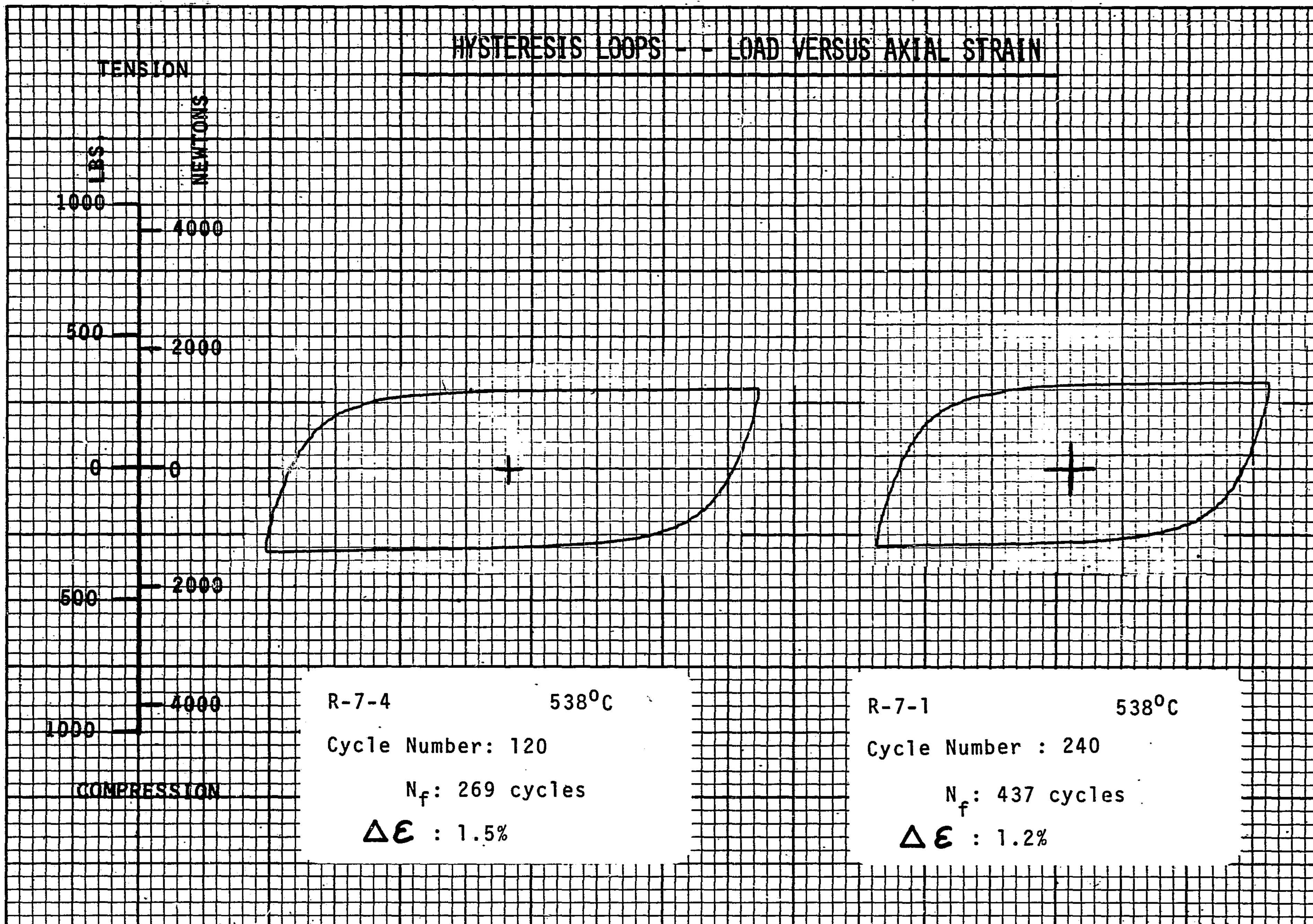

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-7-4
538^{o}C
Cycle Number: 120
N_f: 269 cycles
$\Delta\varepsilon$: 1.5%
R-7-1
538^{o}C
Cycle Number : 240
N_f: 437 cycles
$\Delta\varepsilon$: 1.2%

Figure 214

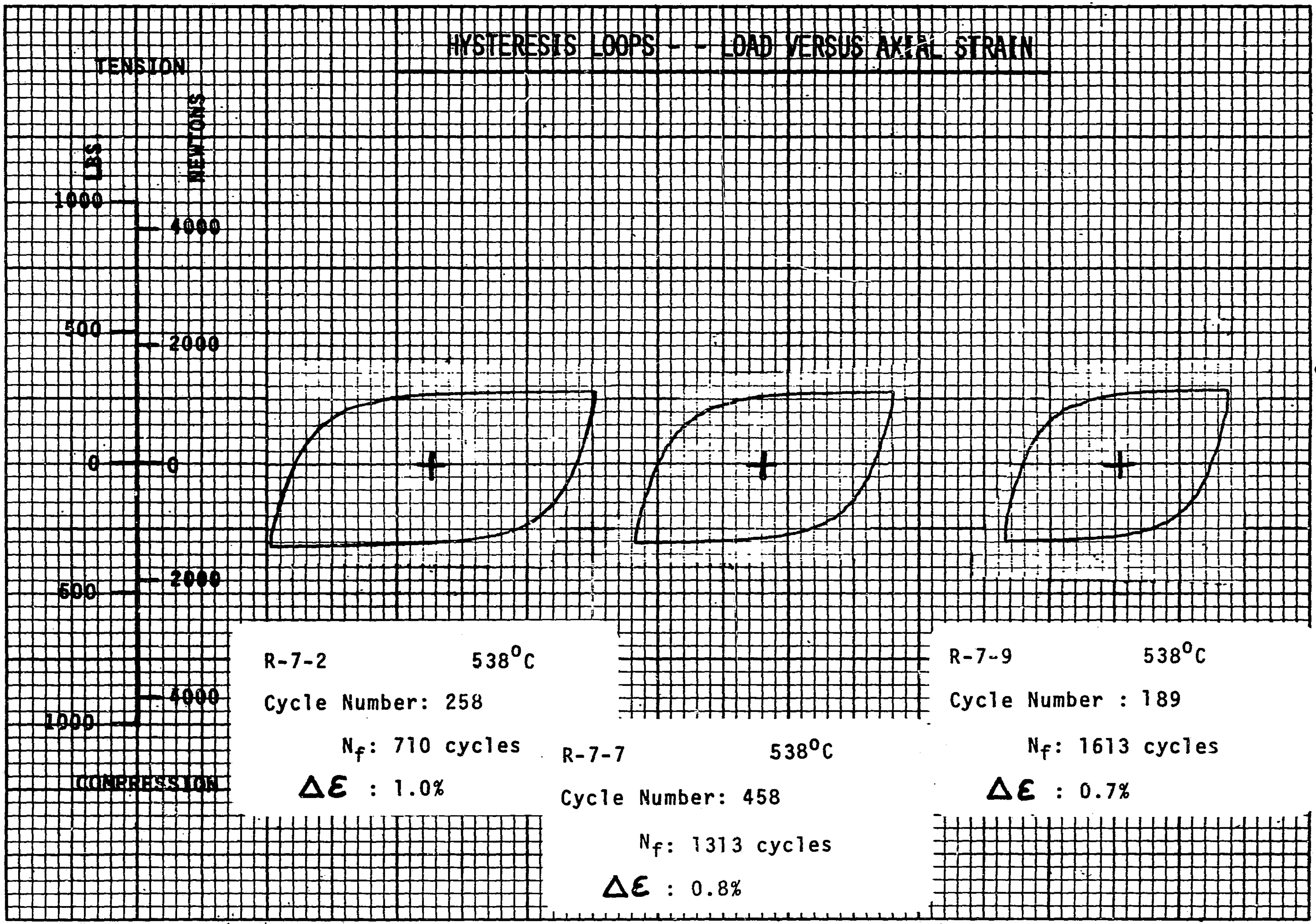

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-7-2 538°C
Cycle Number: 258
Nf: 710 cycles
Δε : 1.0%
R-7-7 538°C
Cycle Number: 458
Nf: 1313 cycles
Δε : 0.8%
R-7-9 538°C
Cycle Number : 189
Nf: 1613 cycles
Δε : 0.7%

Figure 215

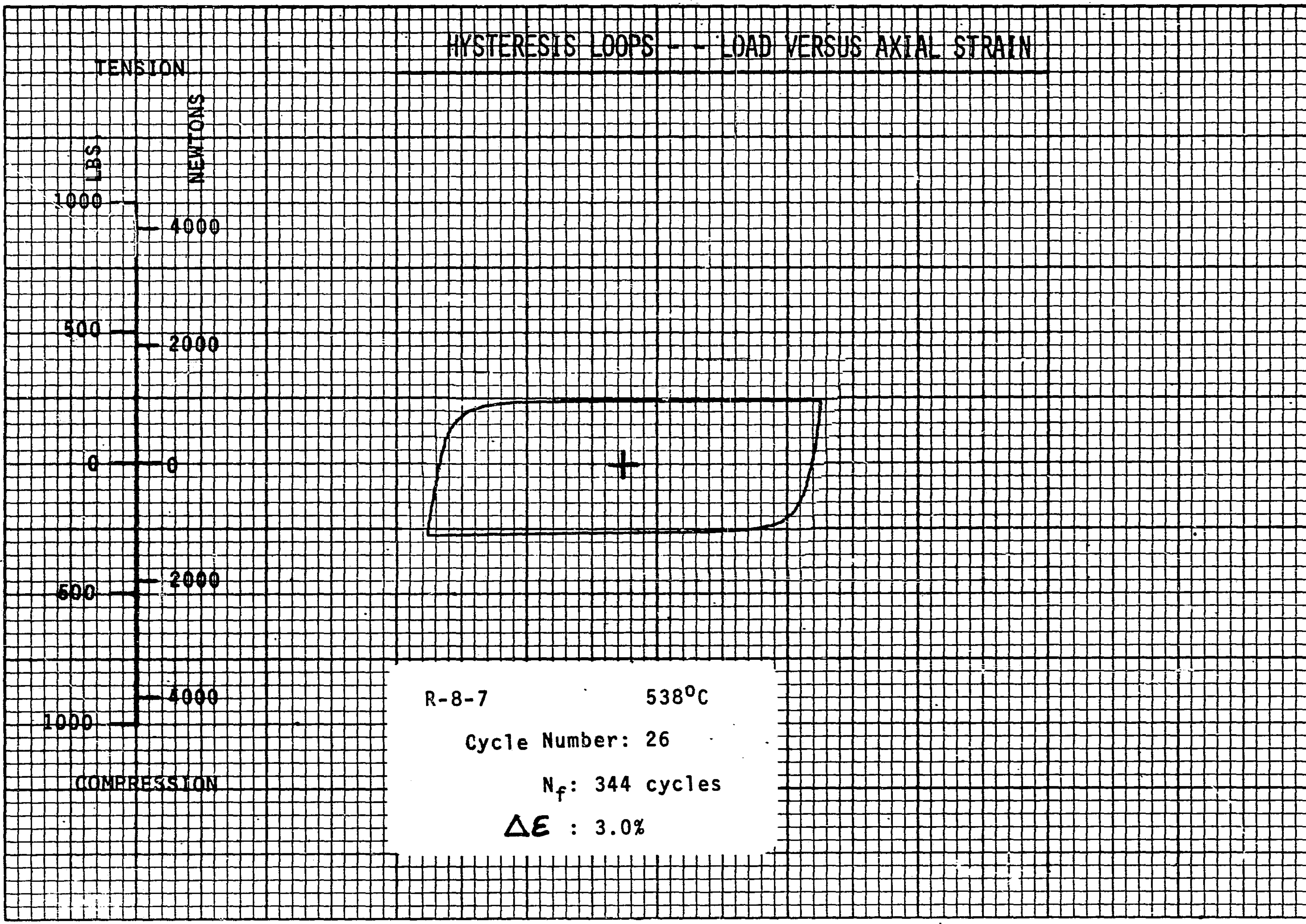

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-8-7
538°C
Cycle Number: 26
Nf: 344 cycles
ΔE : 3.0%

Figure 216

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 0780

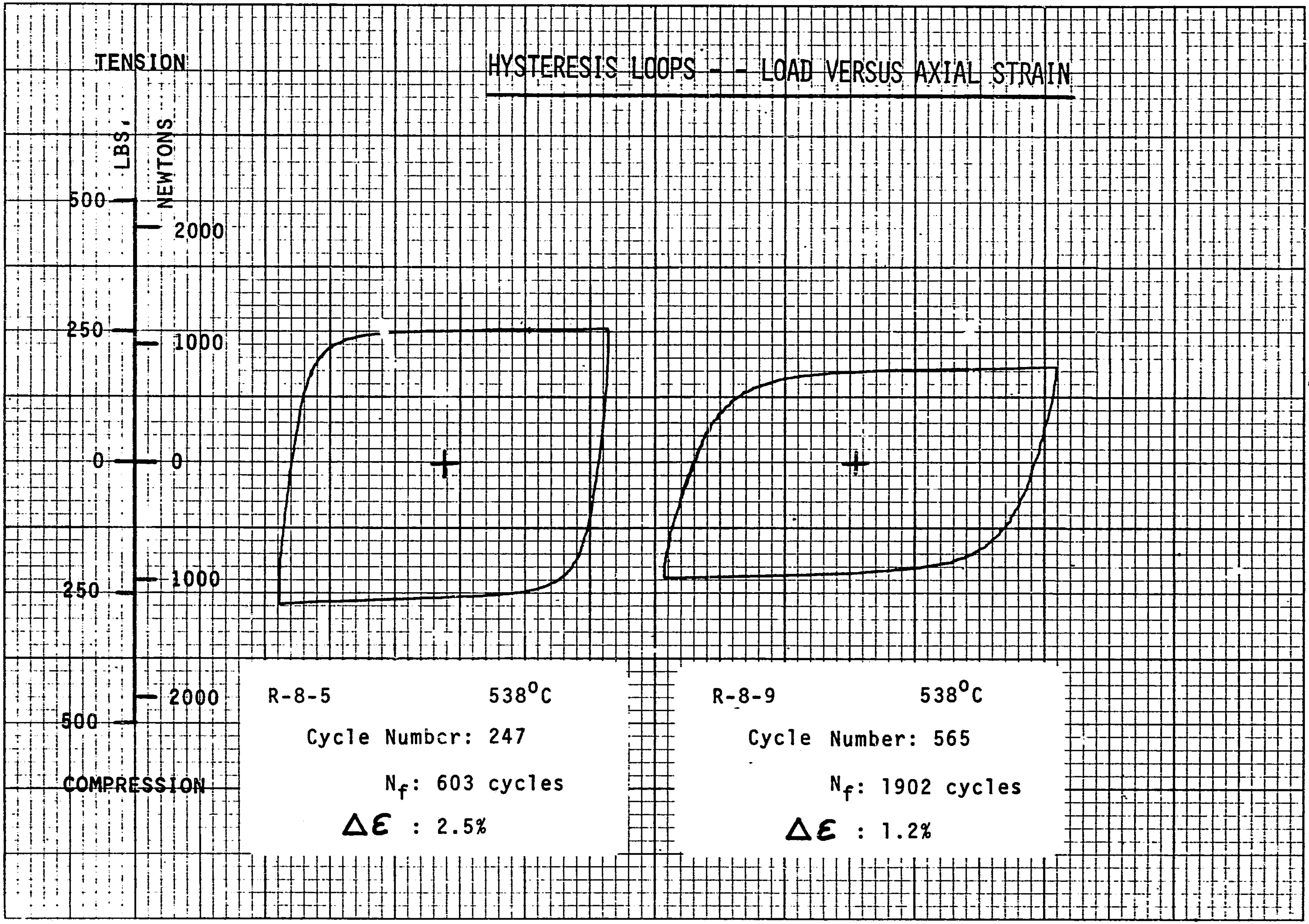


Figure 217

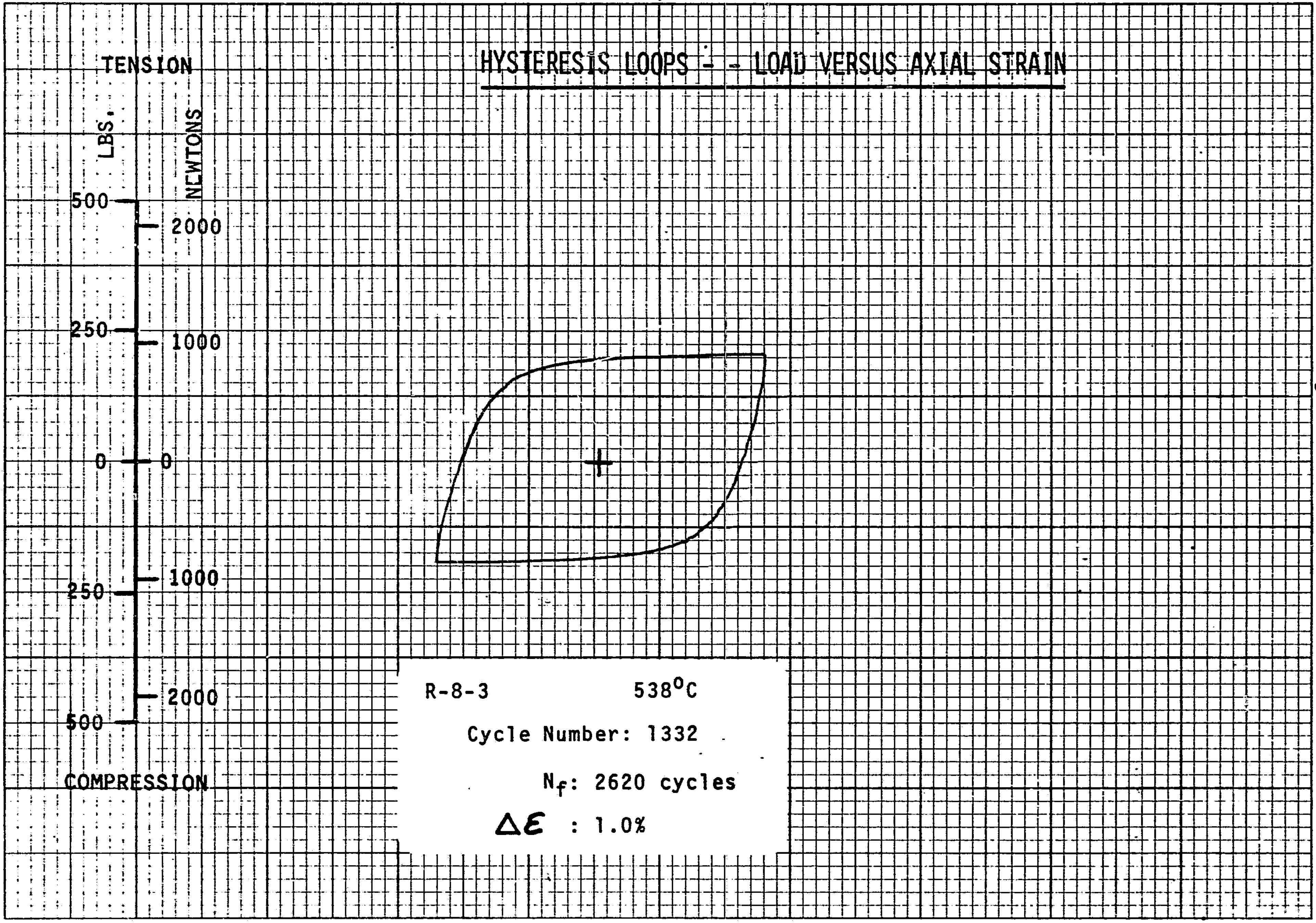

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
500
2000
250
1000
0
0
1000
250
2000
500
COMPRESSION
R-8-3
538°C
Cycle Number: 1332
N_f: 2620 cycles
ΔE : 1.0%

Figure 218

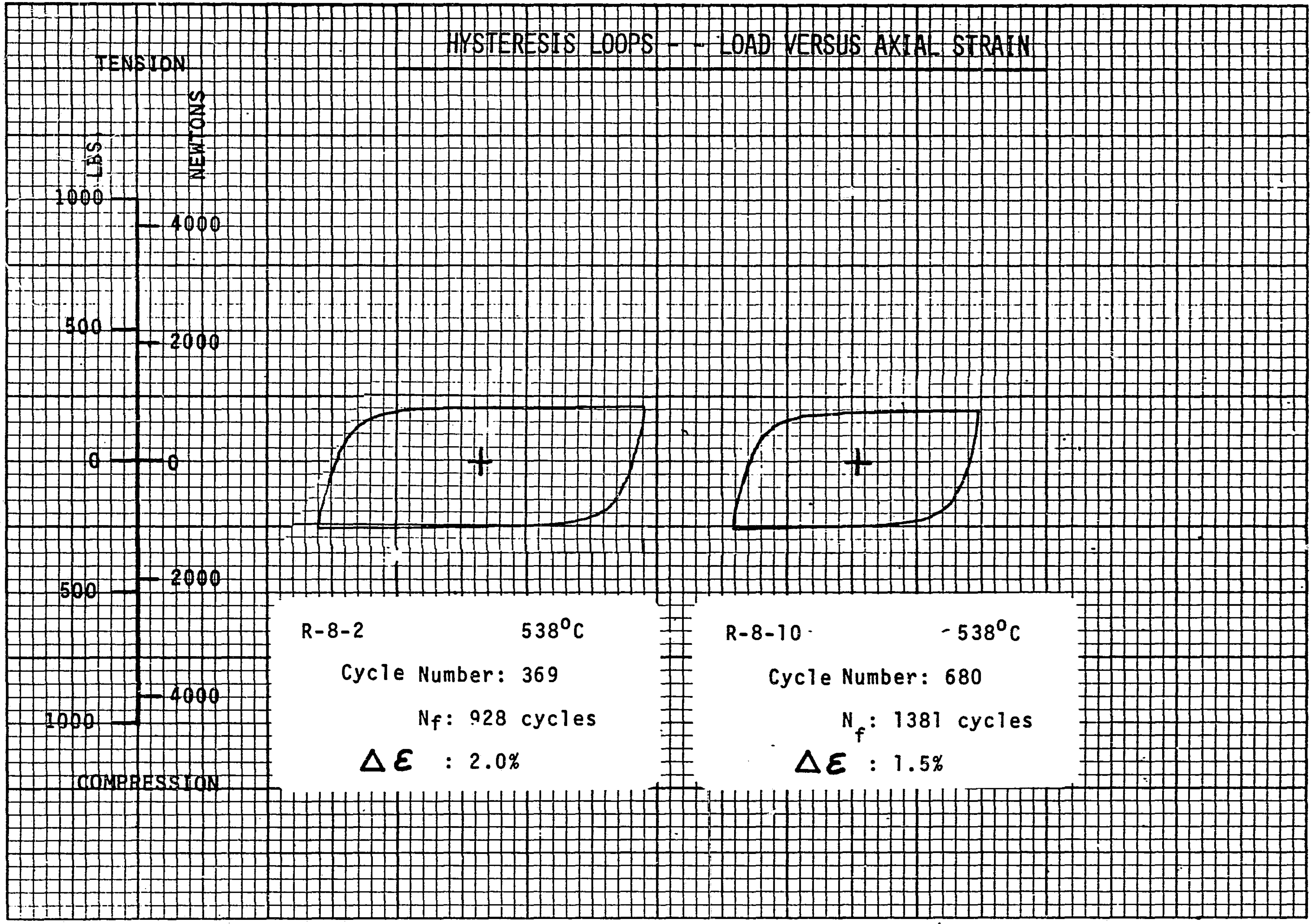

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-8-2
538°C
Cycle Number: 369
Nf: 928 cycles
Δε : 2.0%
R-8-10
538°C
Cycle Number: 680
Nf: 1381 cycles
Δε : 1.5%

Figure 219

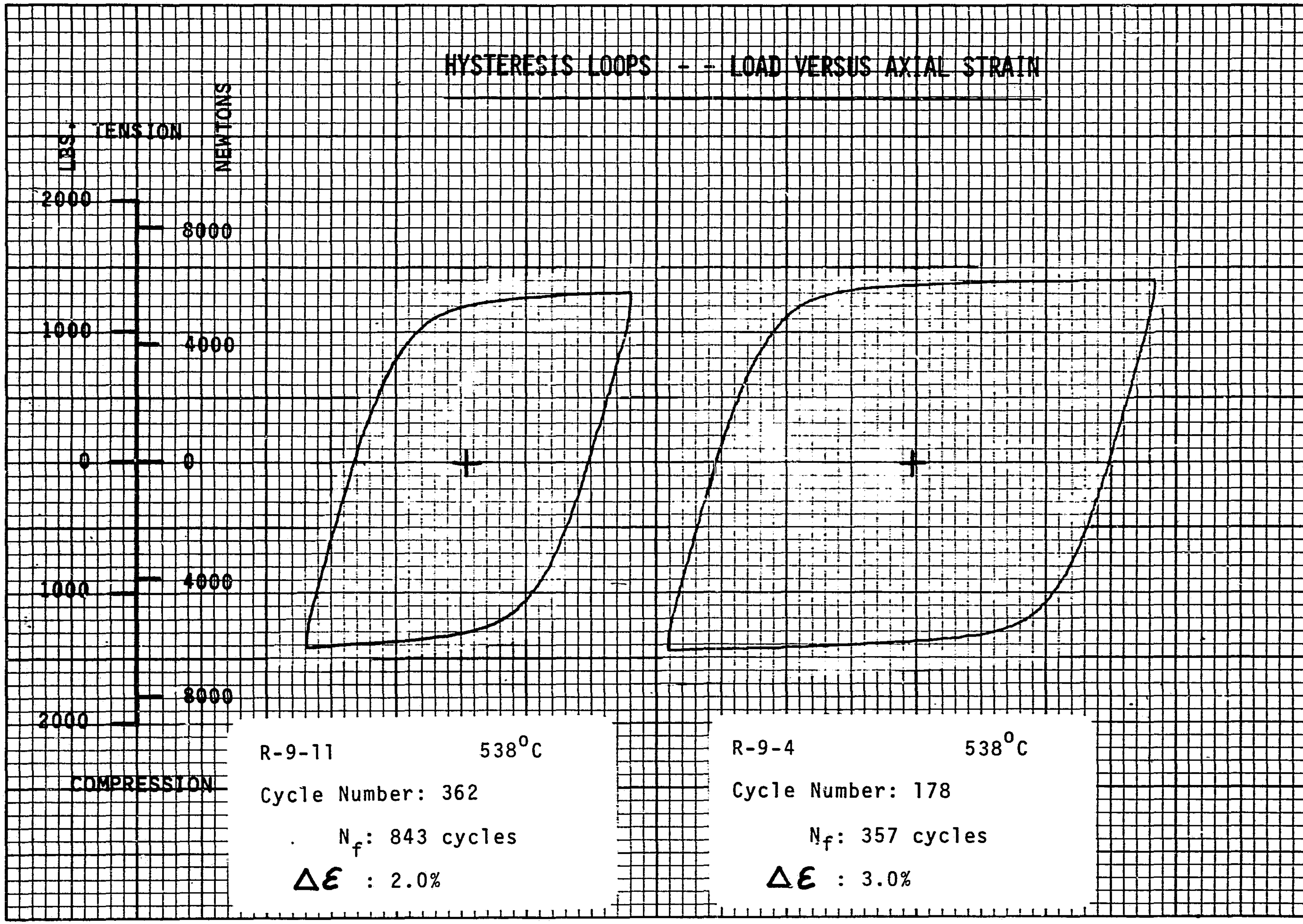

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-9-11 538°C
Cycle Number: 362
N_f: 843 cycles
Δε : 2.0%
R-9-4 538°C
Cycle Number: 178
N_f: 357 cycles
Δε : 3.0%

Figure 220

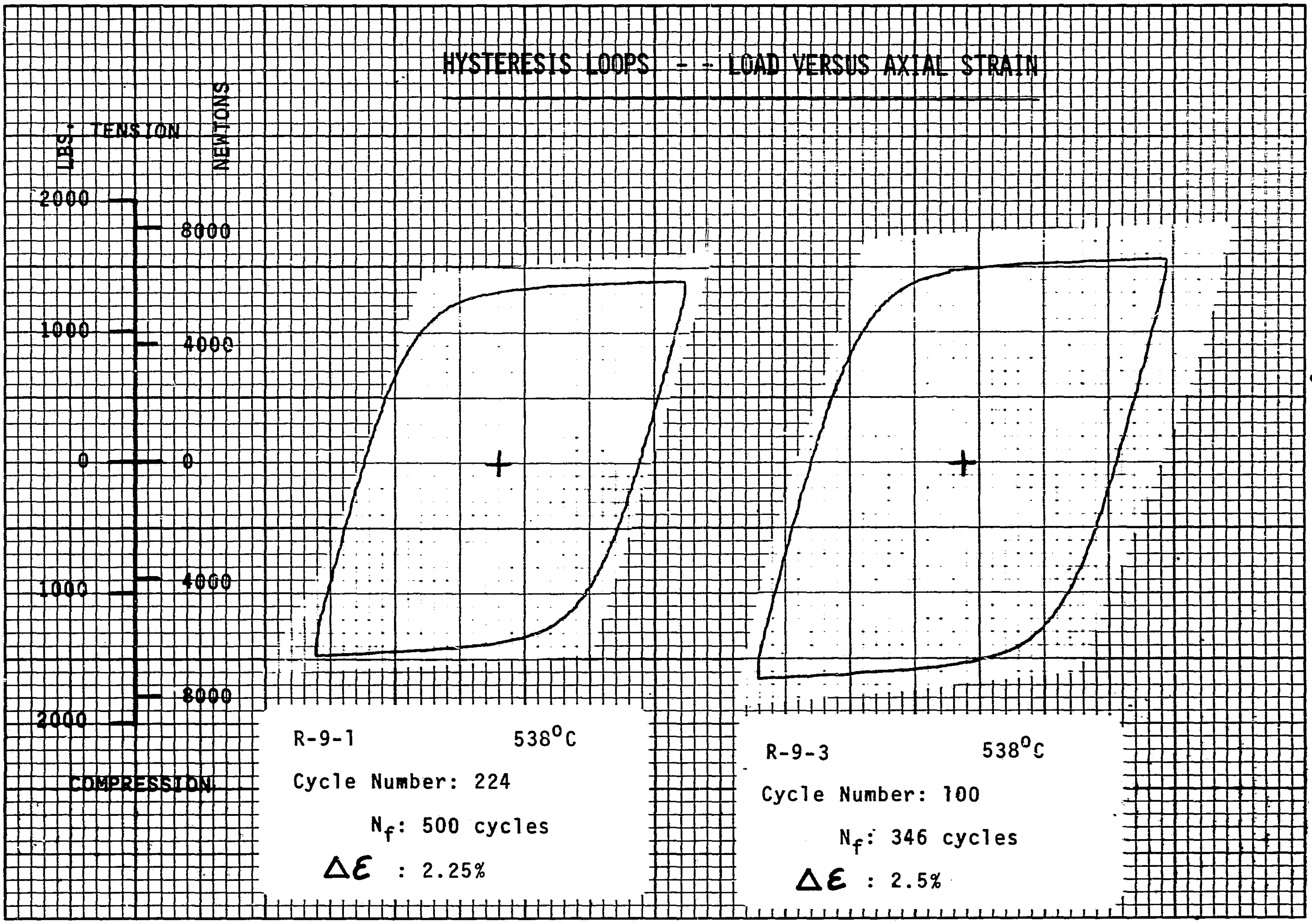

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-9-1
538°C
Cycle Number: 224
Nf: 500 cycles
Δε : 2.25%
R-9-3
538°C
Cycle Number: 100
Nf: 346 cycles
Δε : 2.5%

Figure 221

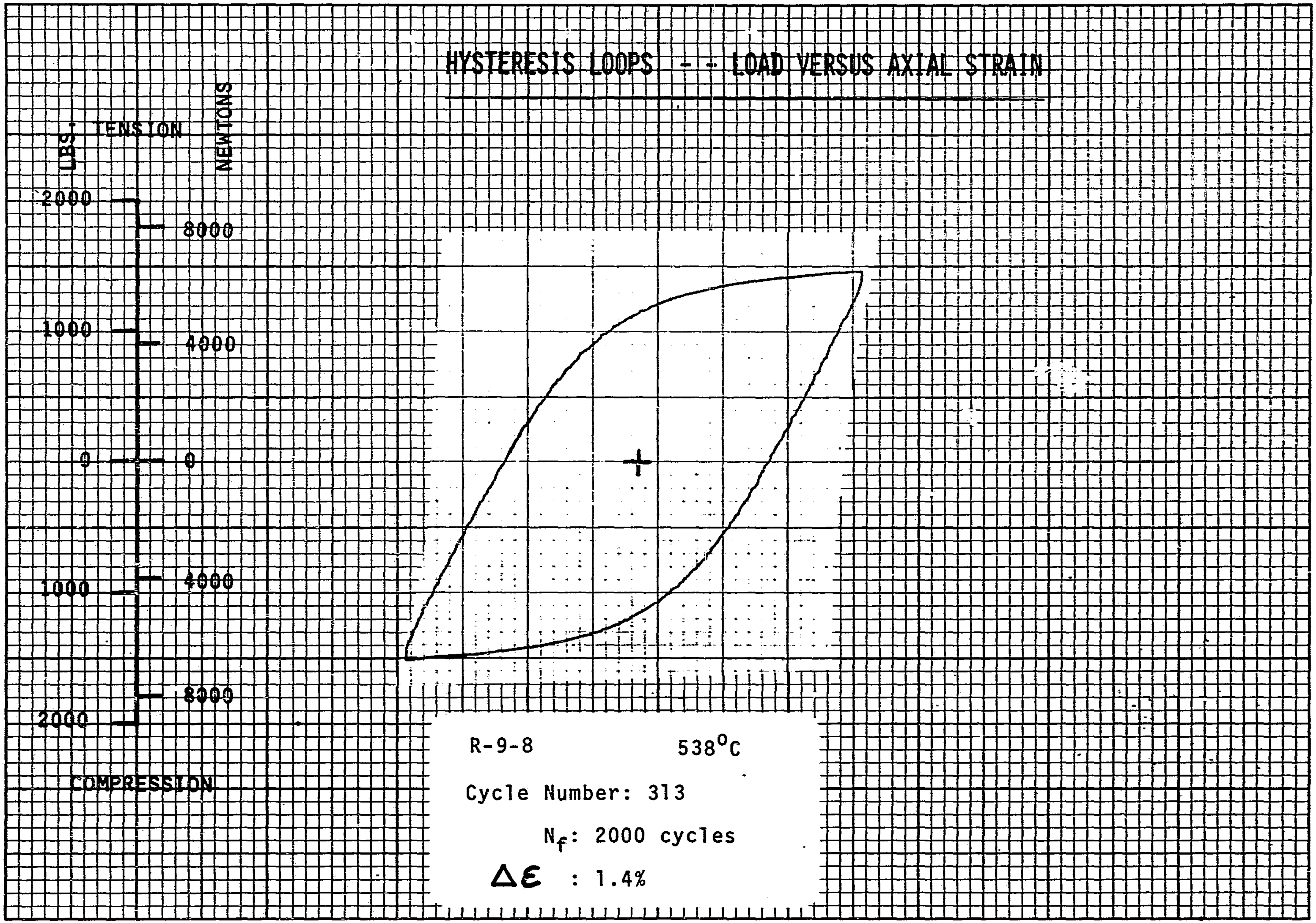

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-9-8
538°C
Cycle Number: 313
Nf: 2000 cycles
Δε : 1.4%

Figure 222

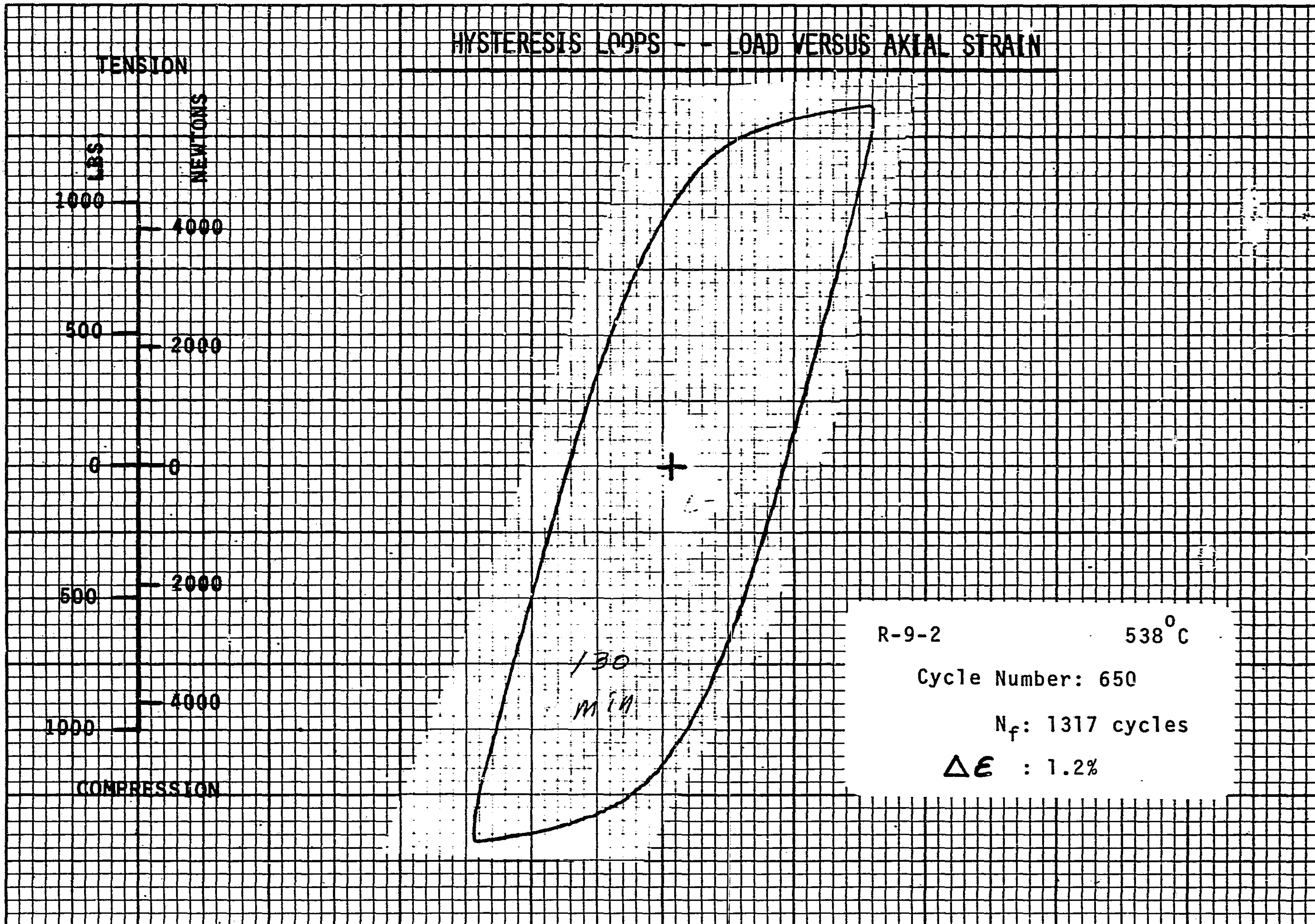

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
130
min
R-9-2
538°C
Cycle Number: 650
Nf: 1317 cycles
Δε : 1.2%

Figure 223

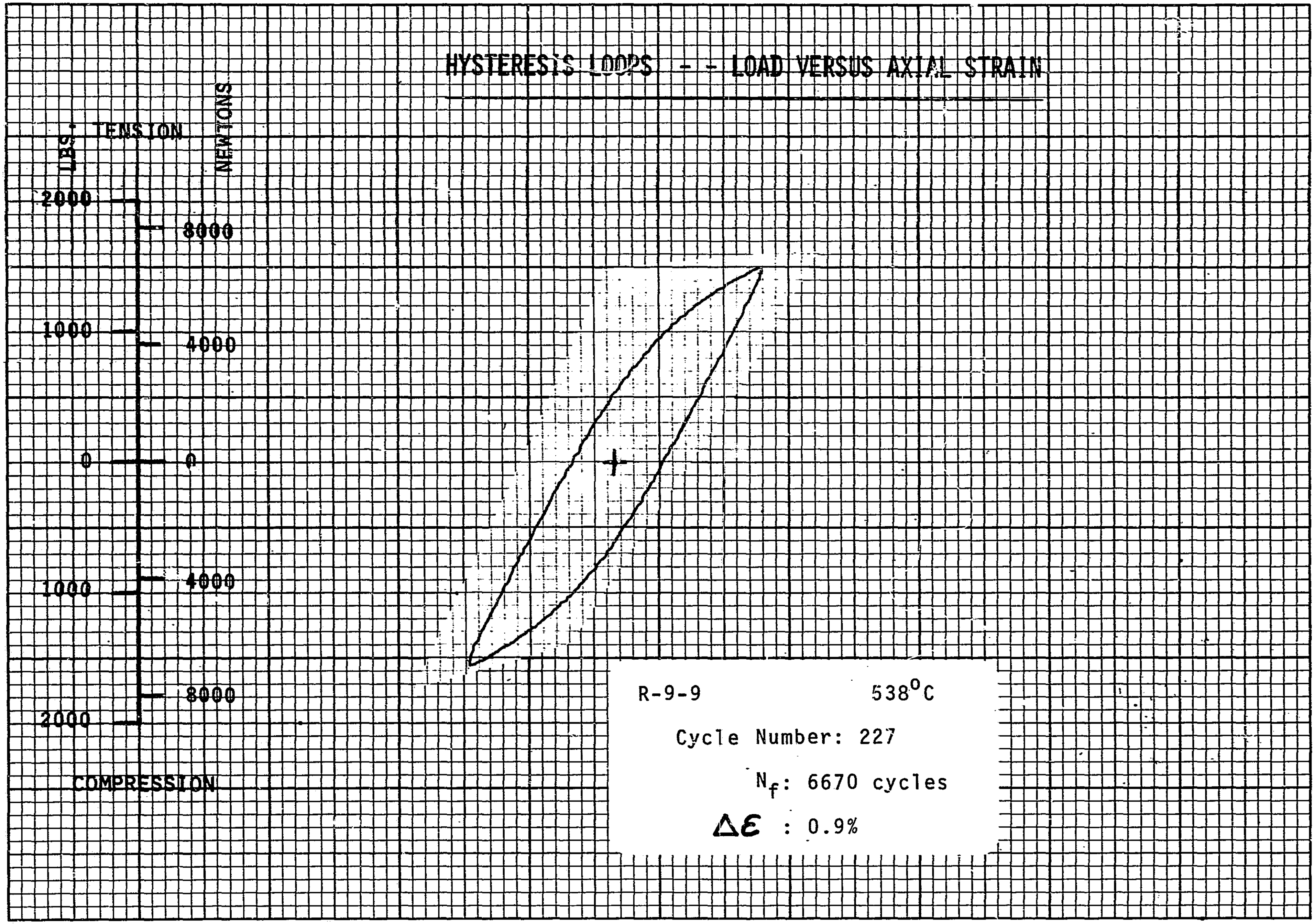

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-9-9
538°C
Cycle Number: 227
Nf: 6670 cycles
ΔE : 0.9%

Figure 224

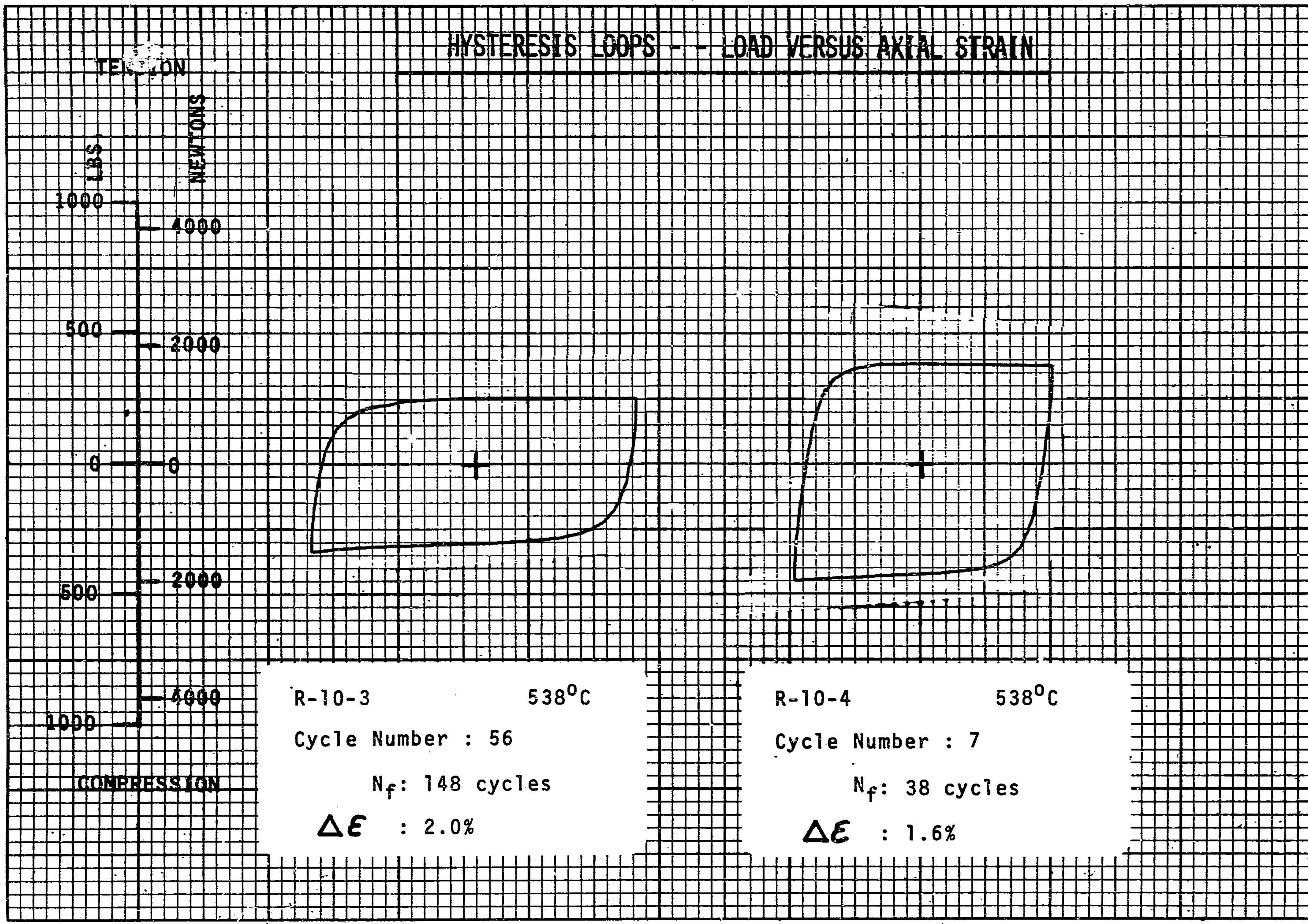

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-10-3 538°C
Cycle Number : 56
N_f: 148 cycles
Δε : 2.0%
R-10-4 538°C
Cycle Number : 7
N_f: 38 cycles
Δε : 1.6%

Figure 225

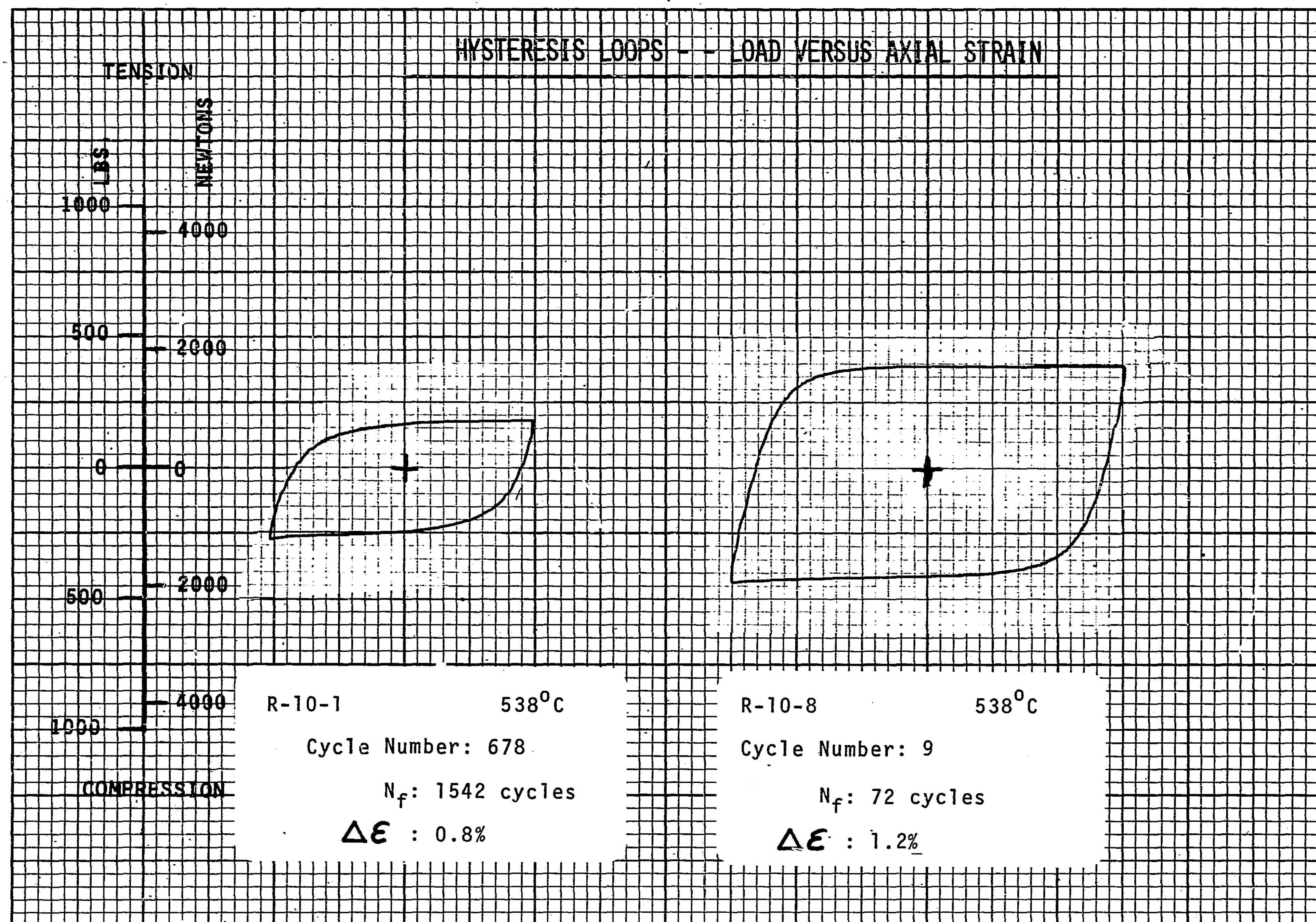

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-10-1
538°C
Cycle Number: 678
Nf: 1542 cycles
Δε : 0.8%
R-10-8
538°C
Cycle Number: 9
Nf: 72 cycles
Δε : 1.2%

Figure 226

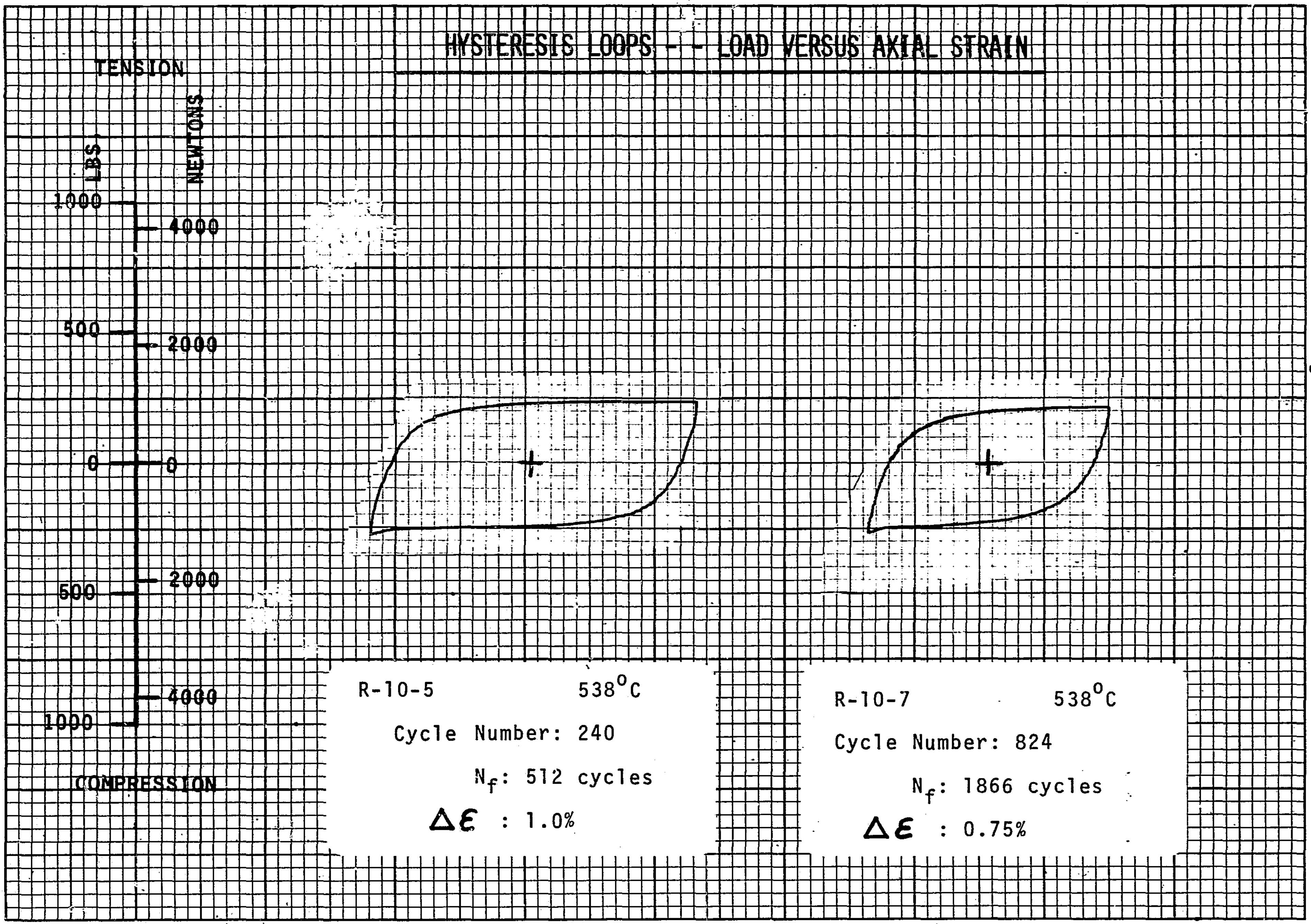

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-10-5
538°C
Cycle Number: 240
N_f: 512 cycles
Δε : 1.0%
R-10-7
538°C
Cycle Number: 824
N_f: 1866 cycles
Δε : 0.75%

Figure 227

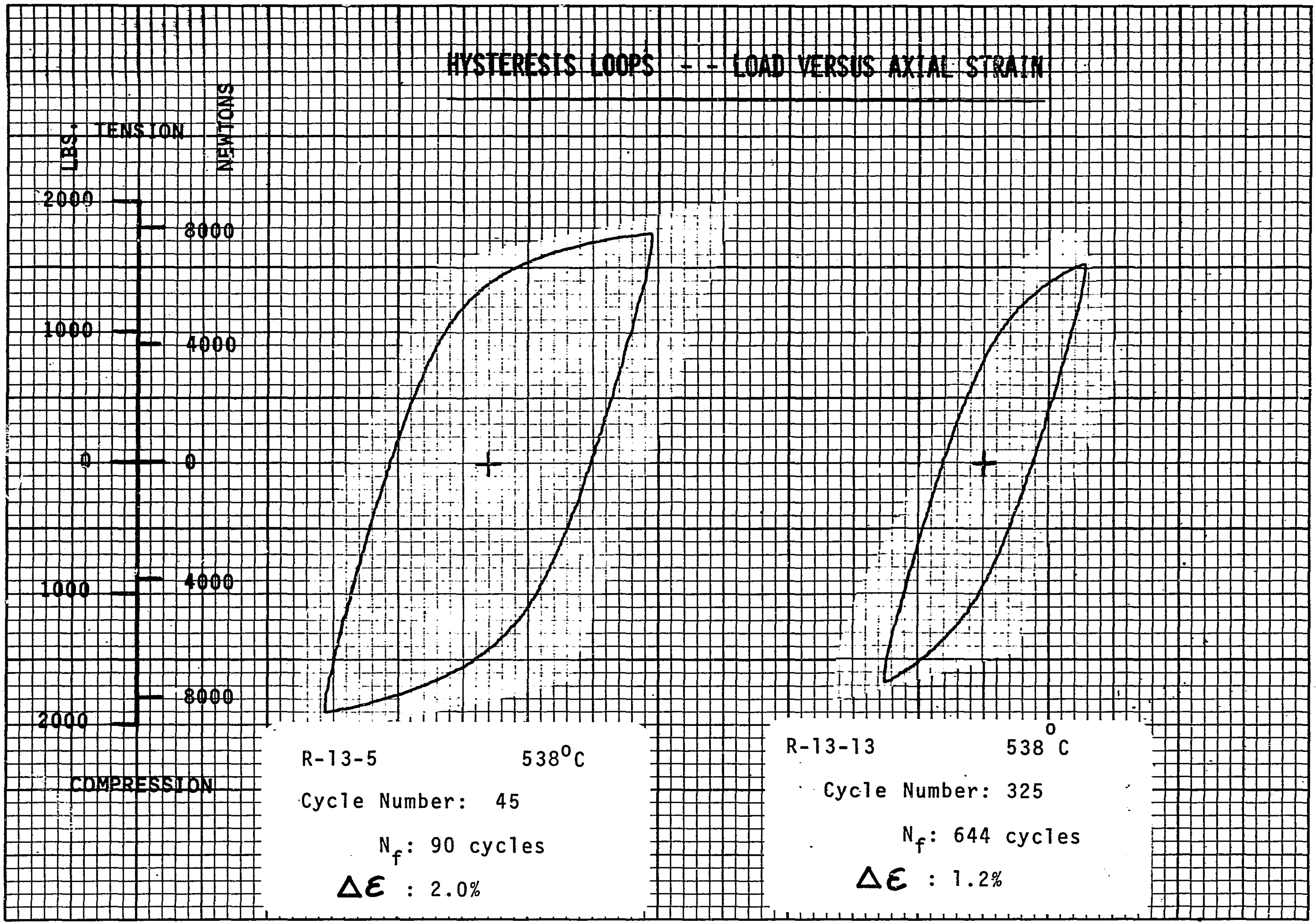

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-13-5 538°C
Cycle Number: 45
Nf: 90 cycles
Δε : 2.0%
R-13-13 538°C
Cycle Number: 325
Nf: 644 cycles
Δε : 1.2%

Figure 228

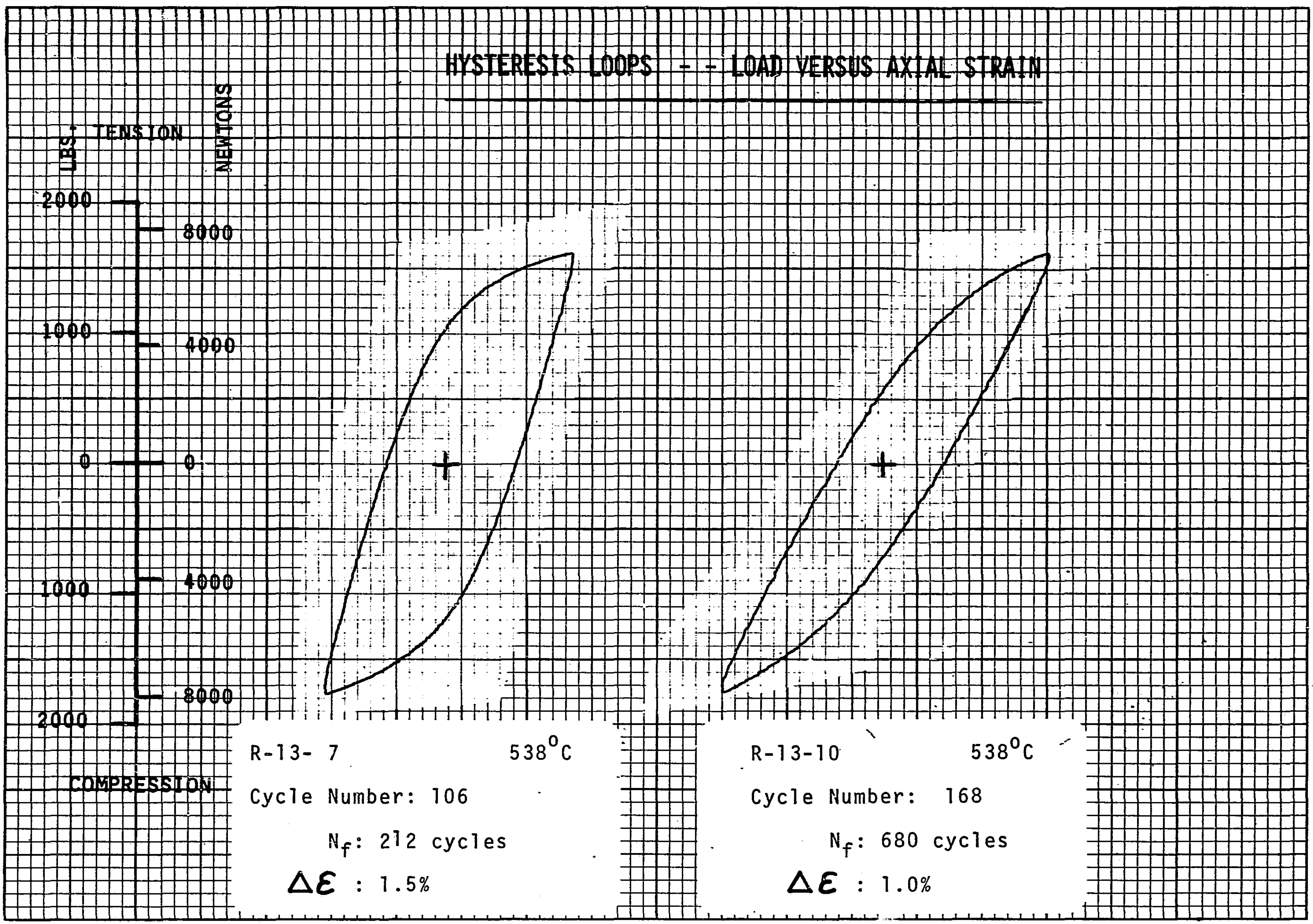

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-13- 7 538°C
Cycle Number: 106
N_f: 212 cycles
ΔΕ : 1.5%
R-13-10 538°C
Cycle Number: 168
N_f: 680 cycles
ΔΕ : 1.0%

Figure 229

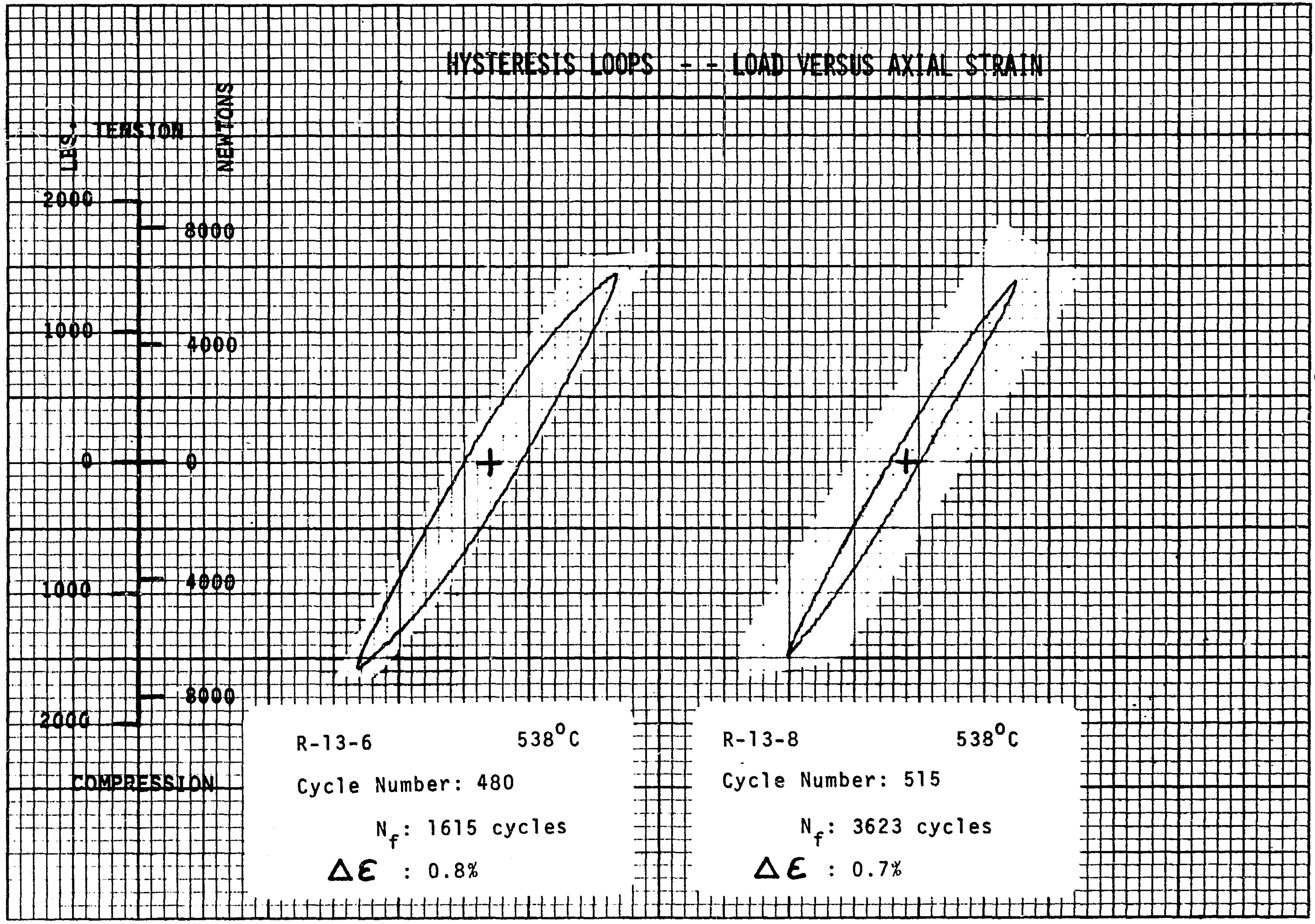

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-13-6 538°C
Cycle Number: 480
Nf: 1615 cycles
ΔΕ : 0.8%
R-13-8 538°C
Cycle Number: 515
Nf: 3623 cycles
ΔΕ : 0.7%

Figure 230

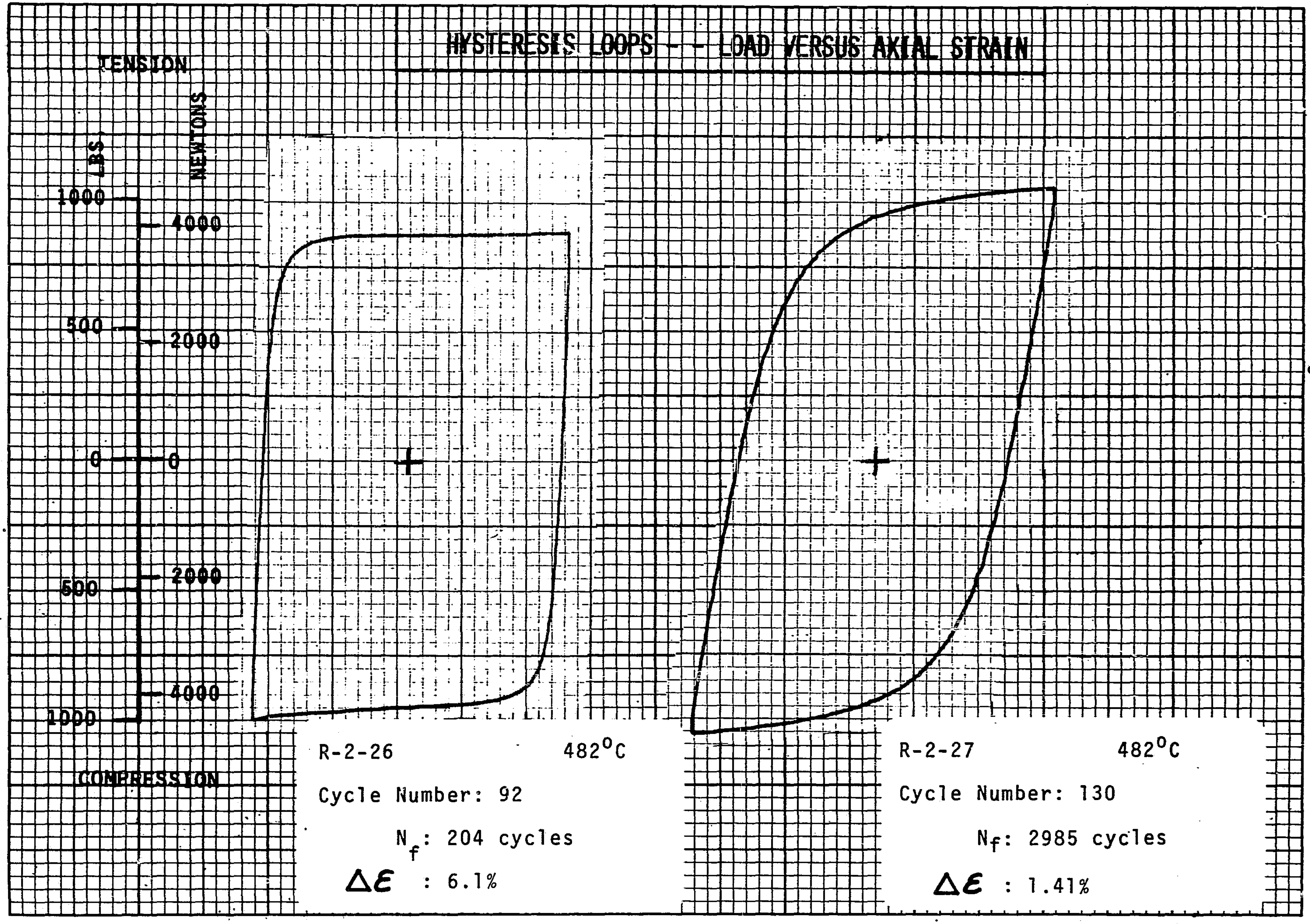

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-26
482°C
Cycle Number: 92
N_f: 204 cycles
Δε : 6.1%
R-2-27
482°C
Cycle Number: 130
N_f: 2985 cycles
Δε : 1.41%

Figure 231

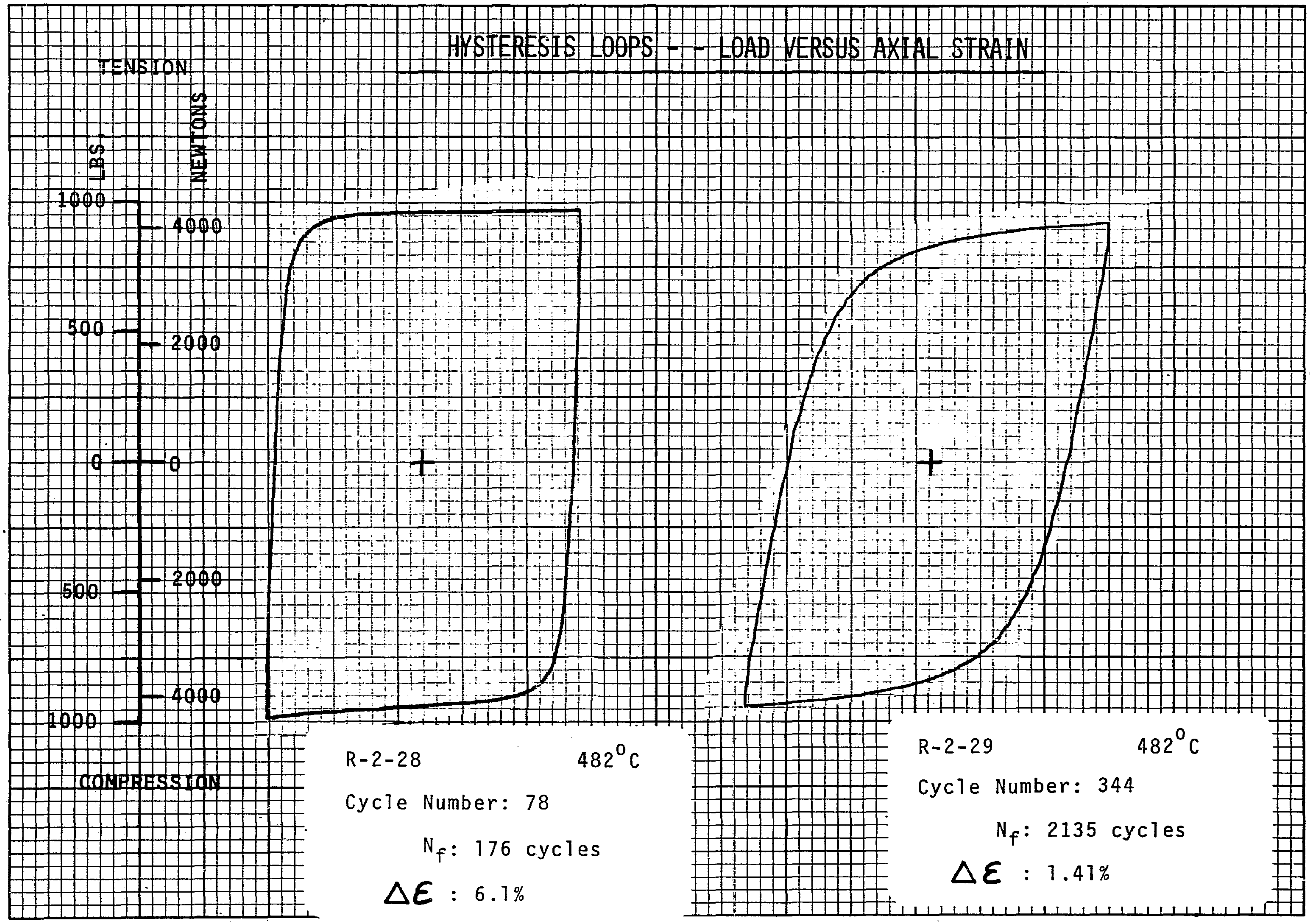

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-28
482°C
Cycle Number: 78
N_f: 176 cycles
$\Delta\varepsilon$: 6.1%
R-2-29
482°C
Cycle Number: 344
N_f: 2135 cycles
$\Delta\varepsilon$: 1.41%

Figure 232

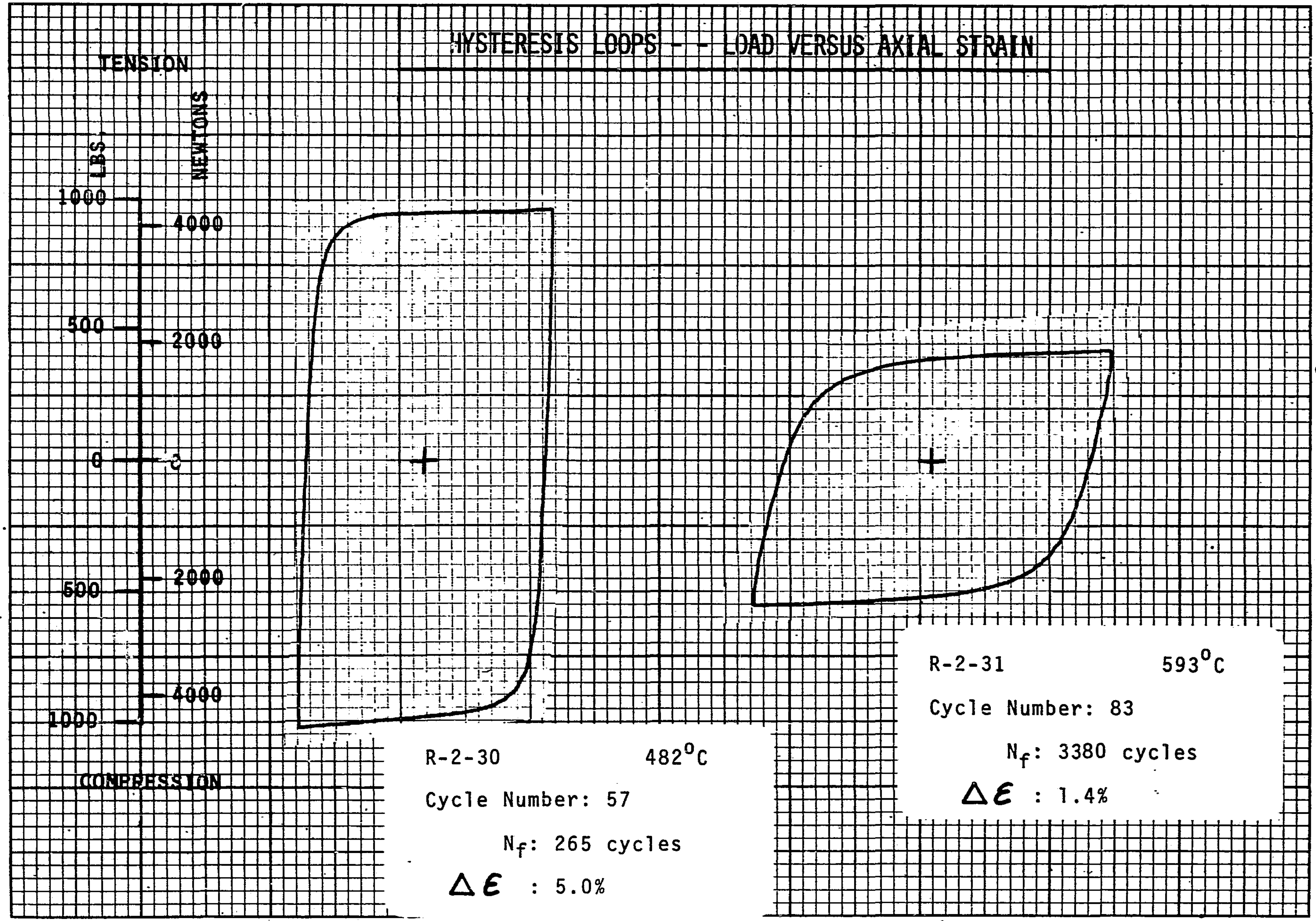

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-30 482°C
Cycle Number: 57
Nf: 265 cycles
ΔΕ : 5.0%
R-2-31 593°C
Cycle Number: 83
Nf: 3380 cycles
ΔΕ : 1.4%

Figure 233

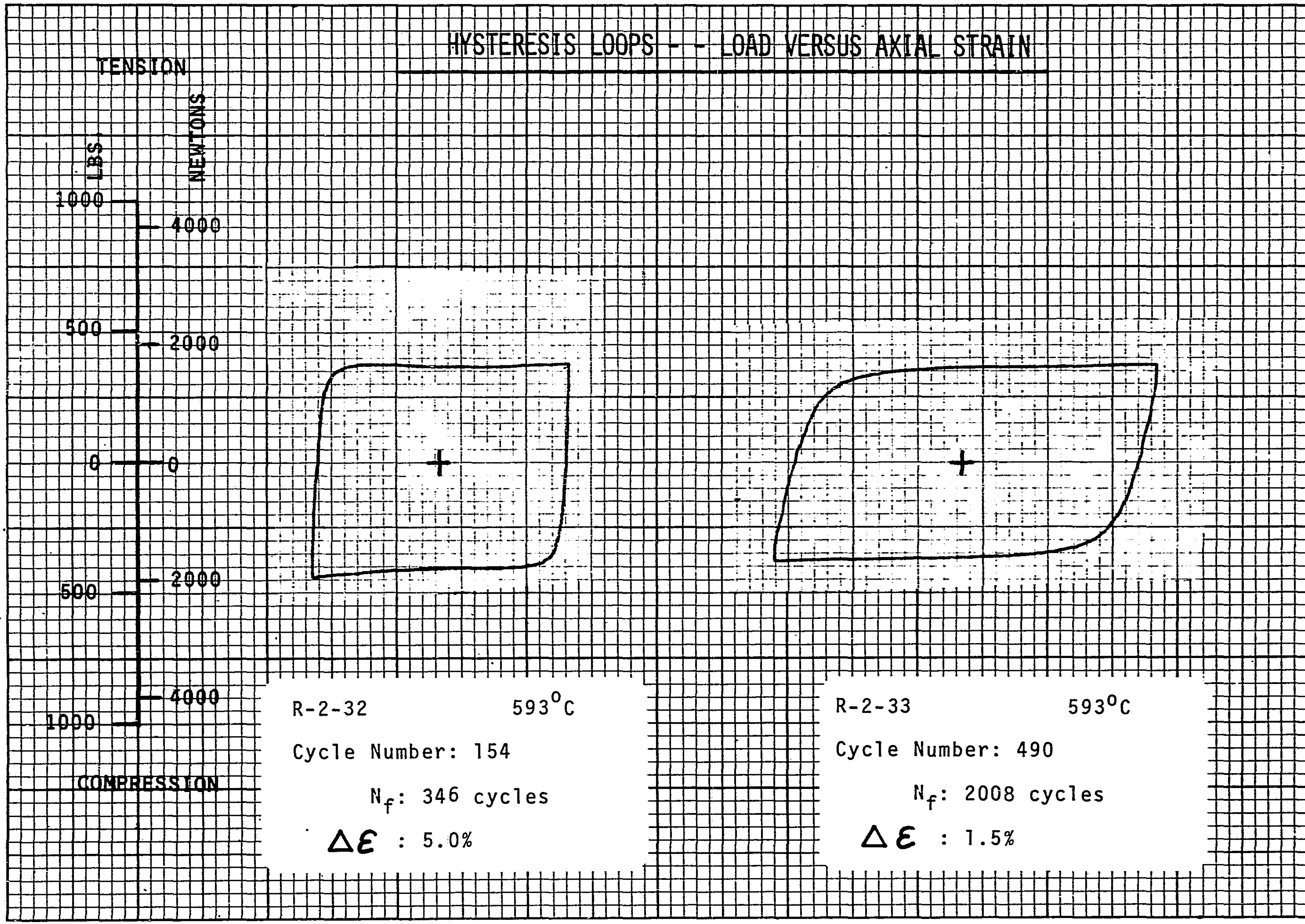

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-32
593°C
Cycle Number: 154
Nf: 346 cycles
Δε : 5.0%
R-2-33
593°C
Cycle Number: 490
Nf: 2008 cycles
Δε : 1.5%

Figure 234

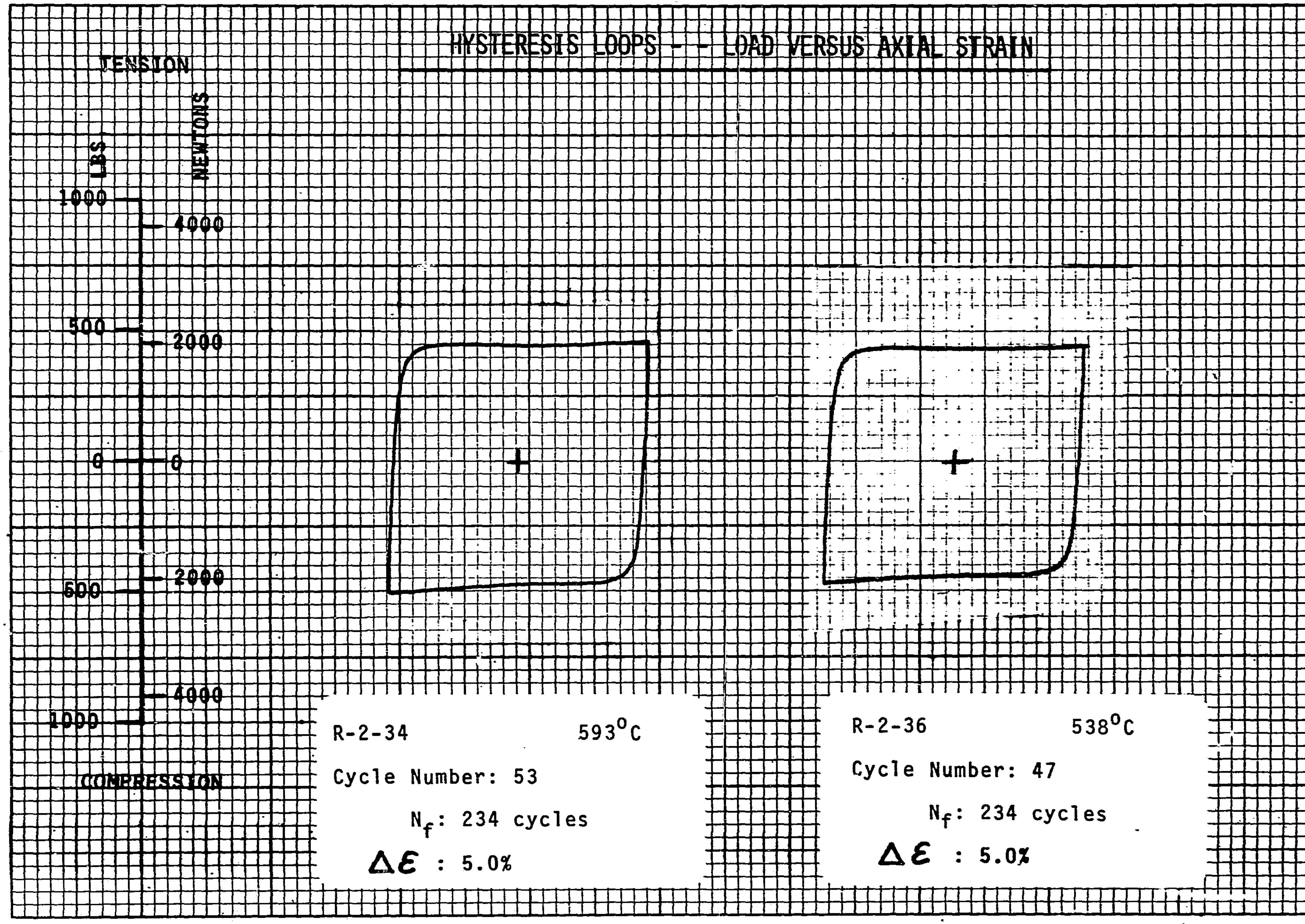

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-34
593°C
Cycle Number: 53
Nf: 234 cycles
ΔE : 5.0%
R-2-36
538°C
Cycle Number: 47
Nf: 234 cycles
ΔE : 5.0%

Figure 235

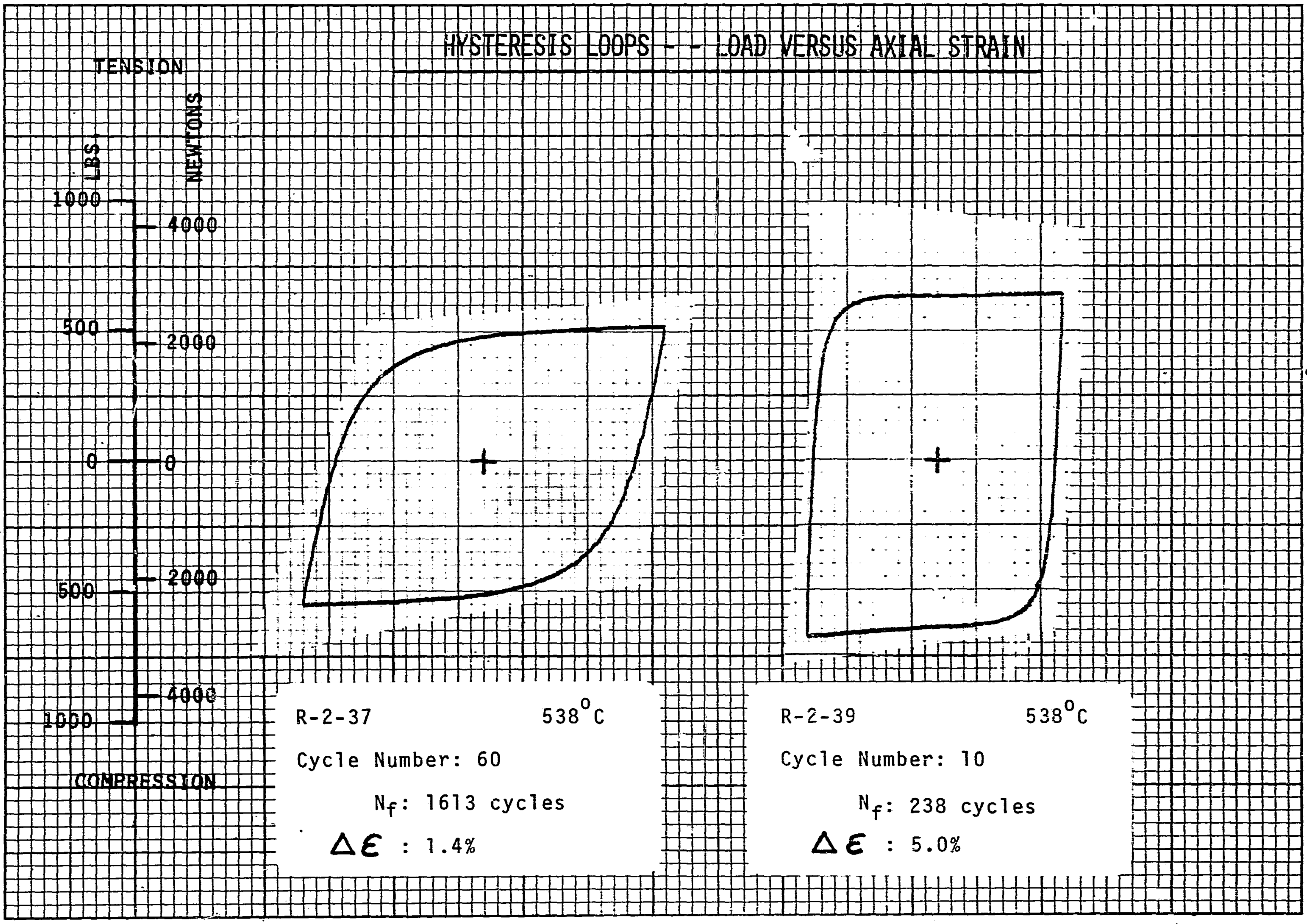

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-37
538°C
Cycle Number: 60
Nf: 1613 cycles
Δε : 1.4%
R-2-39
538°C
Cycle Number: 10
Nf: 238 cycles
Δε : 5.0%

Figure 236

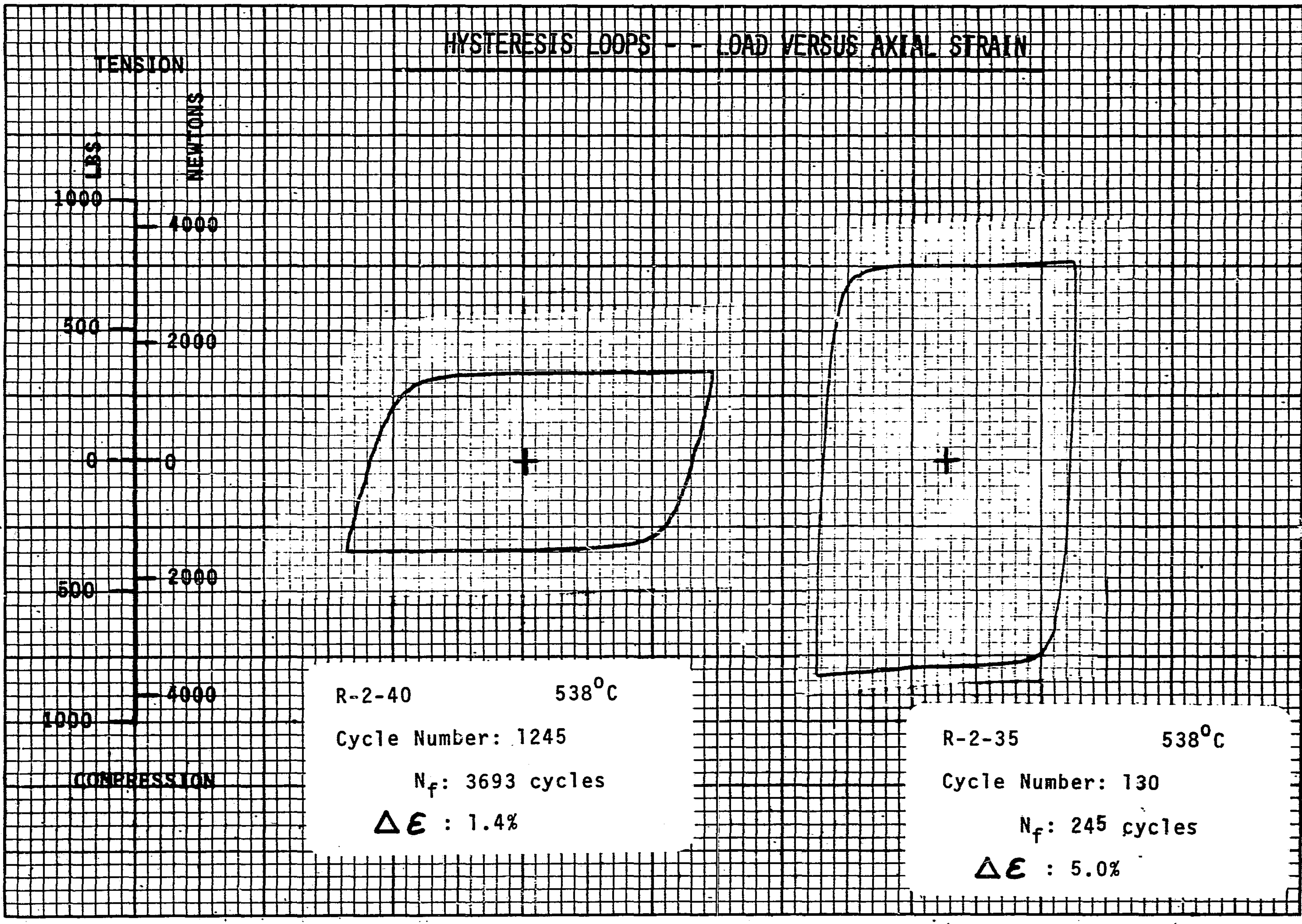

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-40 538°C
Cycle Number: 1245
Nf: 3693 cycles
ΔE : 1.4%
R-2-35 538°C
Cycle Number: 130
Nf: 245 cycles
ΔE : 5.0%

Figure 237

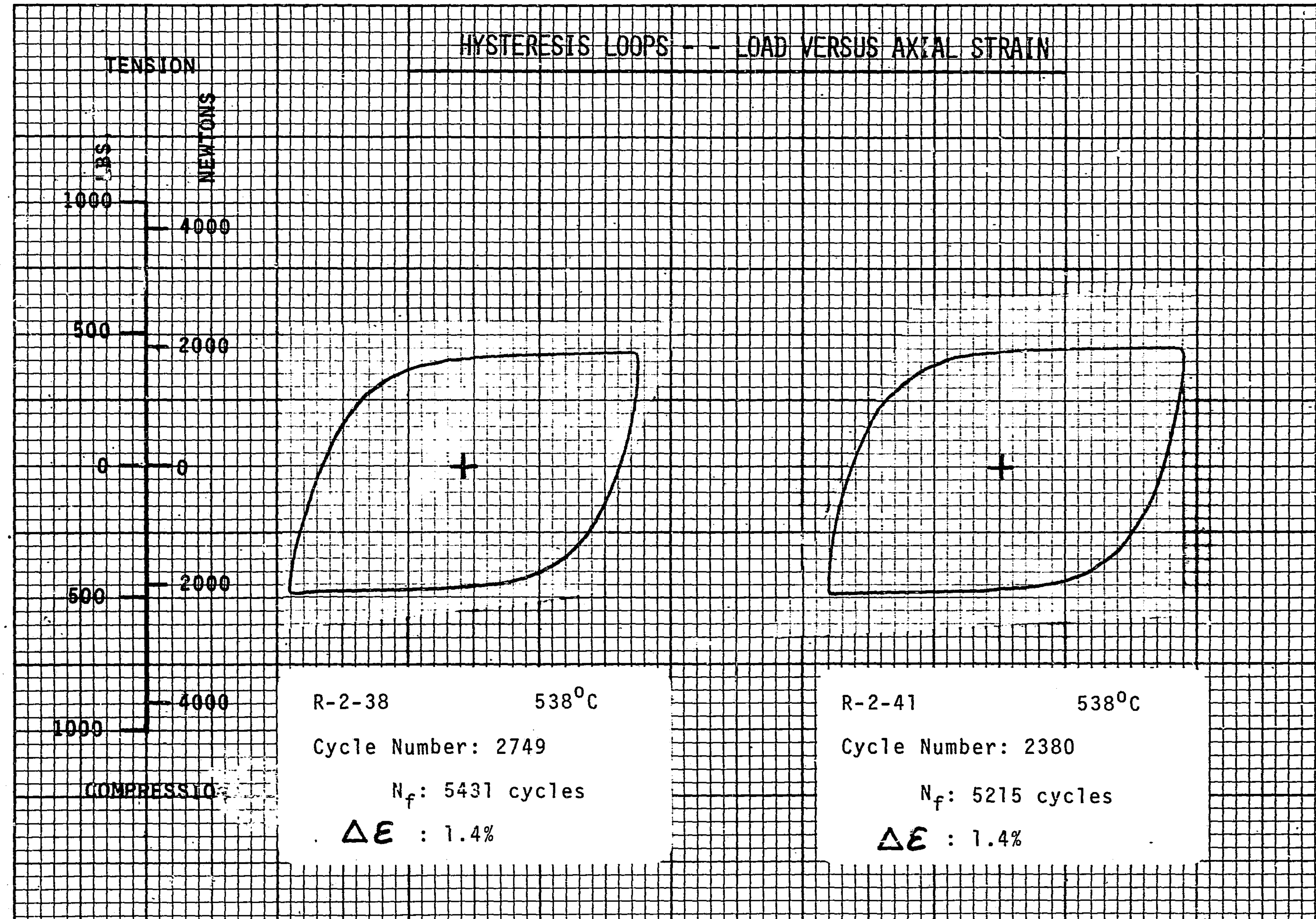

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSIO
R-2-38
538°C
Cycle Number: 2749
N_f: 5431 cycles
Δε : 1.4%
R-2-41
538°C
Cycle Number: 2380
N_f: 5215 cycles
Δε : 1.4%

Figure 238

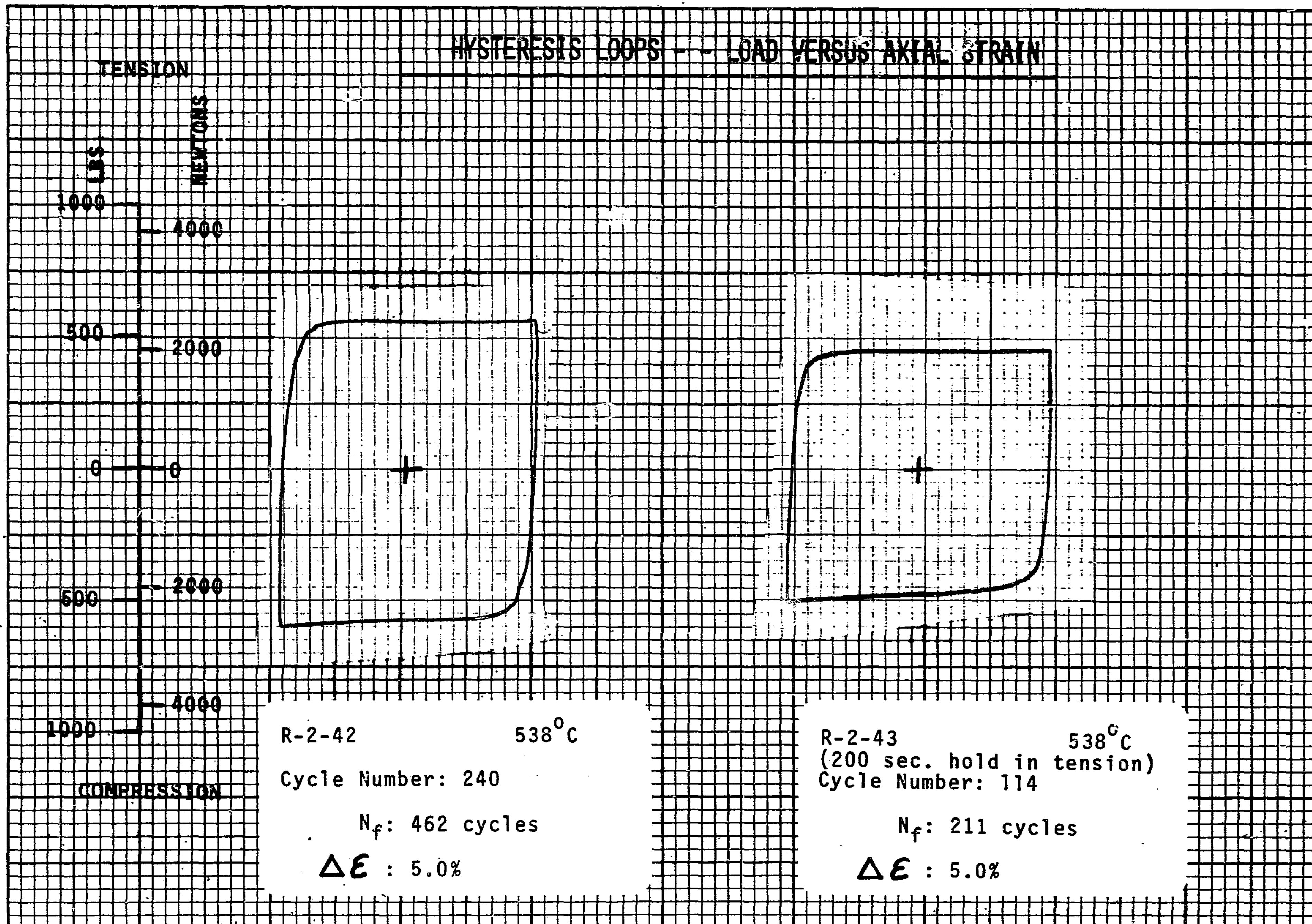

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-42
538°C
Cycle Number: 240
N_f: 462 cycles
Δε : 5.0%
R-2-43
538°C
(200 sec. hold in tension)
Cycle Number: 114
N_f: 211 cycles
Δε : 5.0%

Figure 239

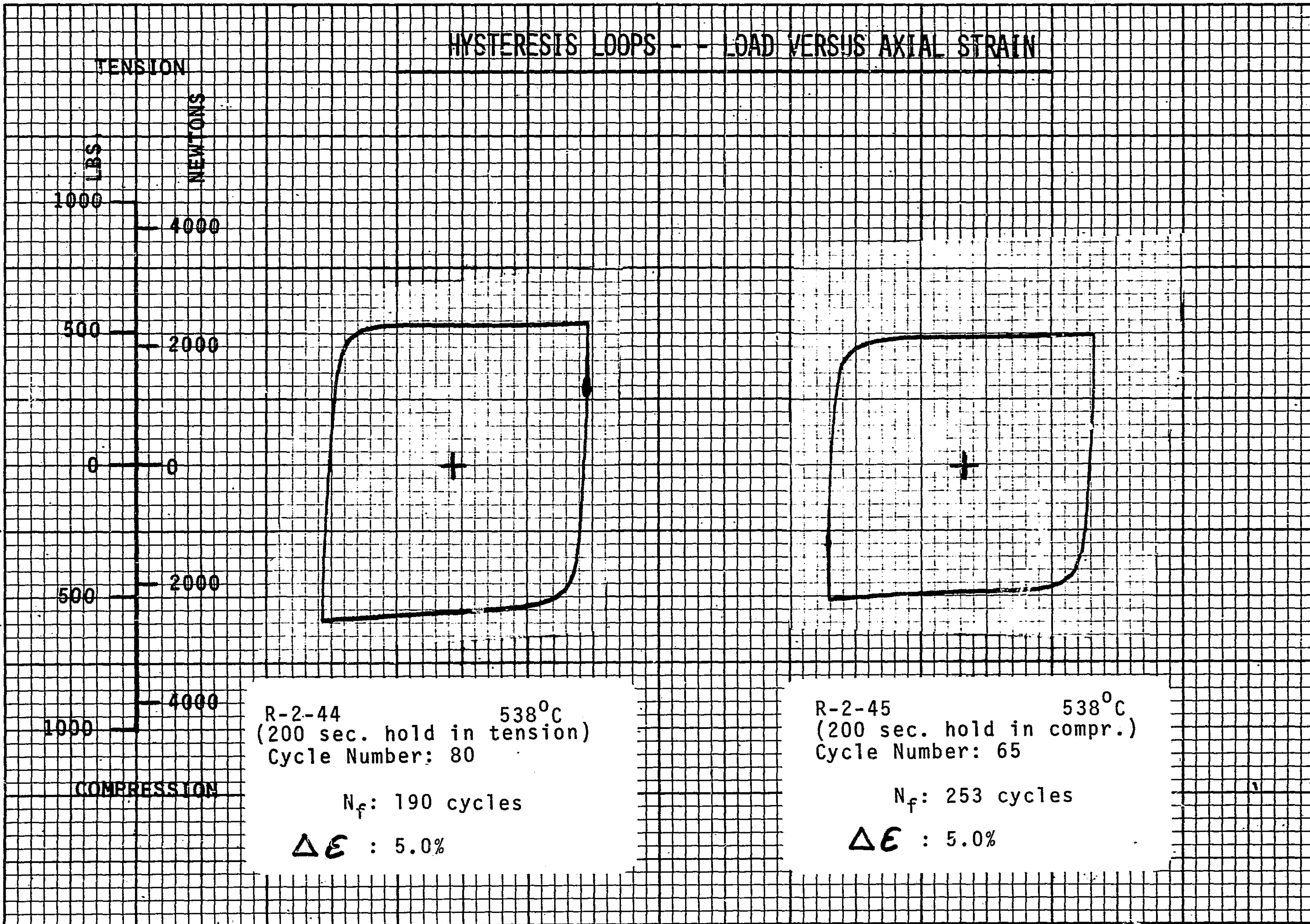

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-2-44 538°C
(200 sec. hold in tension)
Cycle Number: 80
Nf: 190 cycles
Δε : 5.0%
R-2-45 538°C
(200 sec. hold in compr.)
Cycle Number: 65
Nf: 253 cycles
Δε : 5.0%

Figure 240

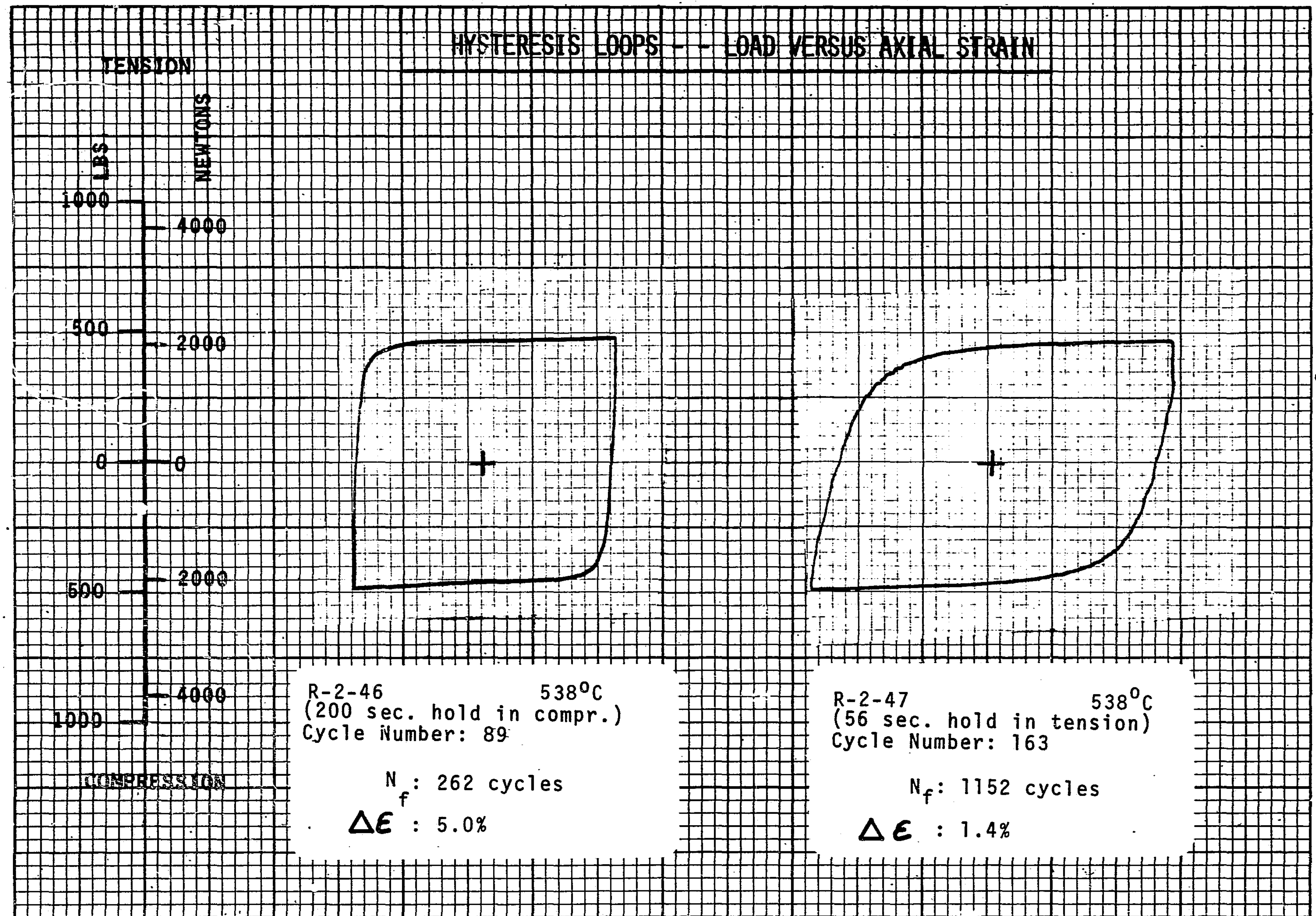

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-2-46 538°C
(200 sec. hold in compr.)
Cycle Number: 89
N f : 262 cycles
Δε : 5.0%
R-2-47 538°C
(56 sec. hold in tension)
Cycle Number: 163
N f : 1152 cycles
Δε : 1.4%

Figure 241

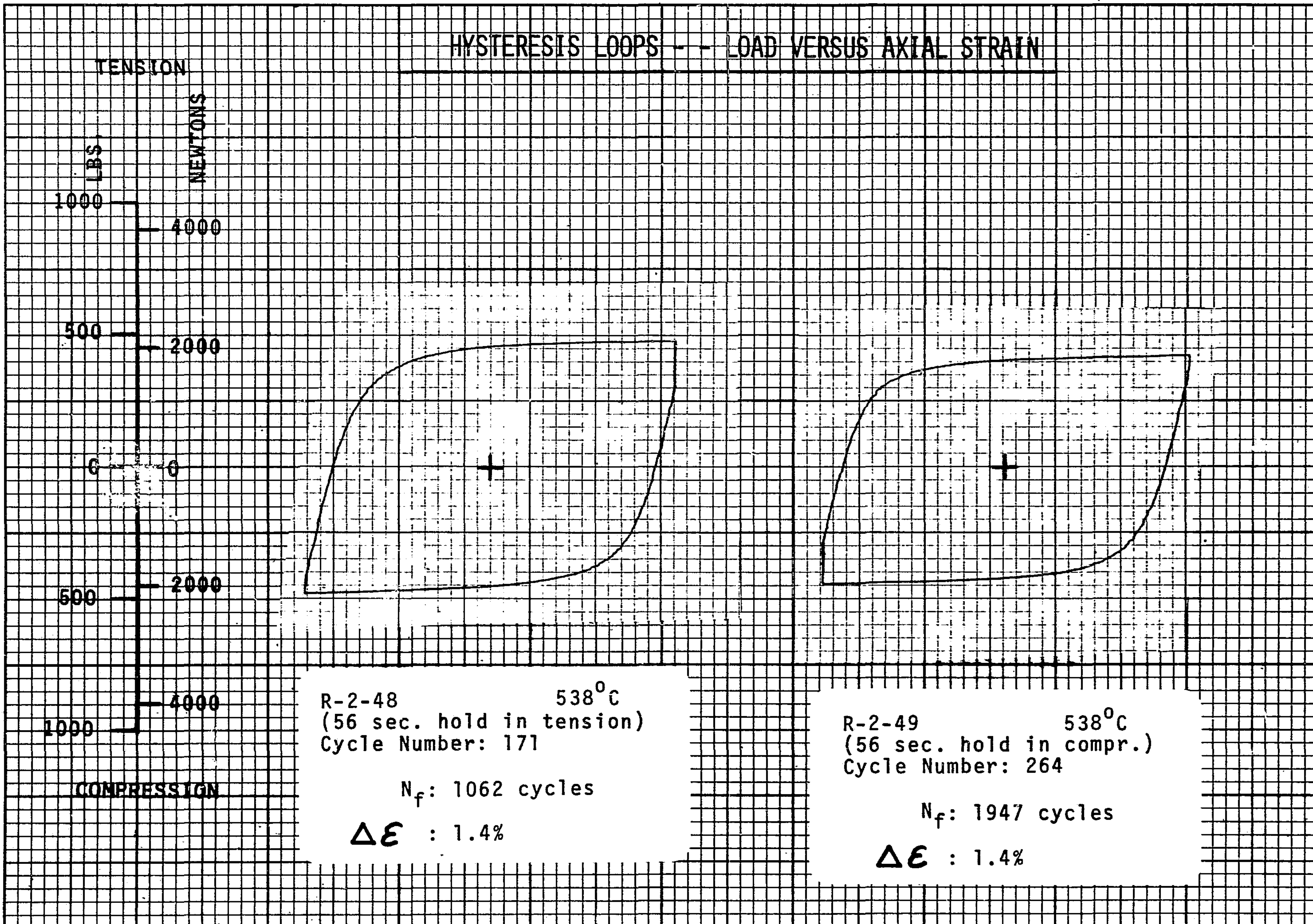

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-48 538°C
(56 sec. hold in tension)
Cycle Number: 171
N$_f$: 1062 cycles
$\Delta\varepsilon$: 1.4%
R-2-49 538°C
(56 sec. hold in compr.)
Cycle Number: 264
N$_f$: 1947 cycles
$\Delta\varepsilon$: 1.4%

Figure 242

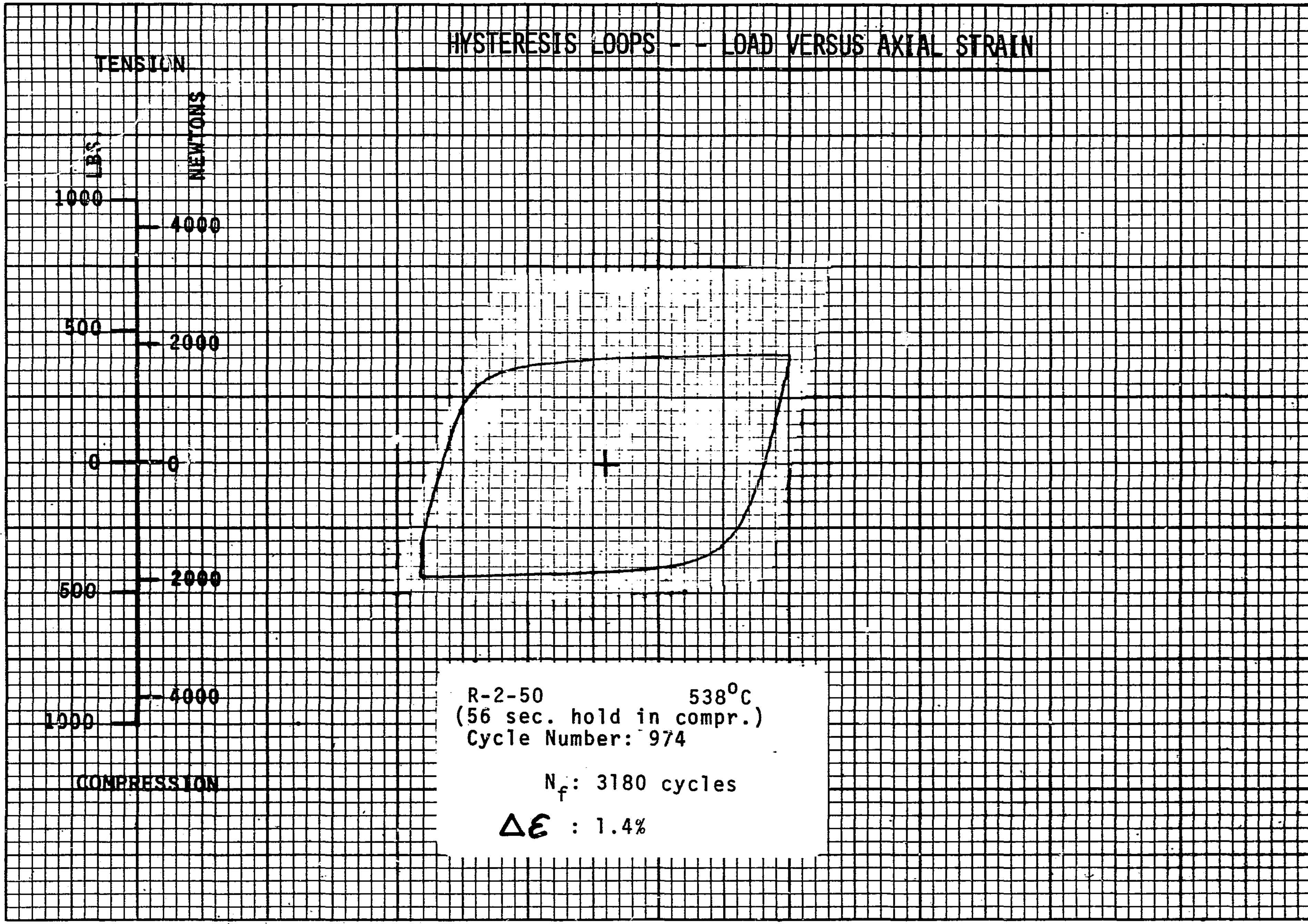

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-2-50 538°C
(56 sec. hold in compr.)
Cycle Number: 974
N_f: 3180 cycles
$\Delta\varepsilon$: 1.4%

Figure 243

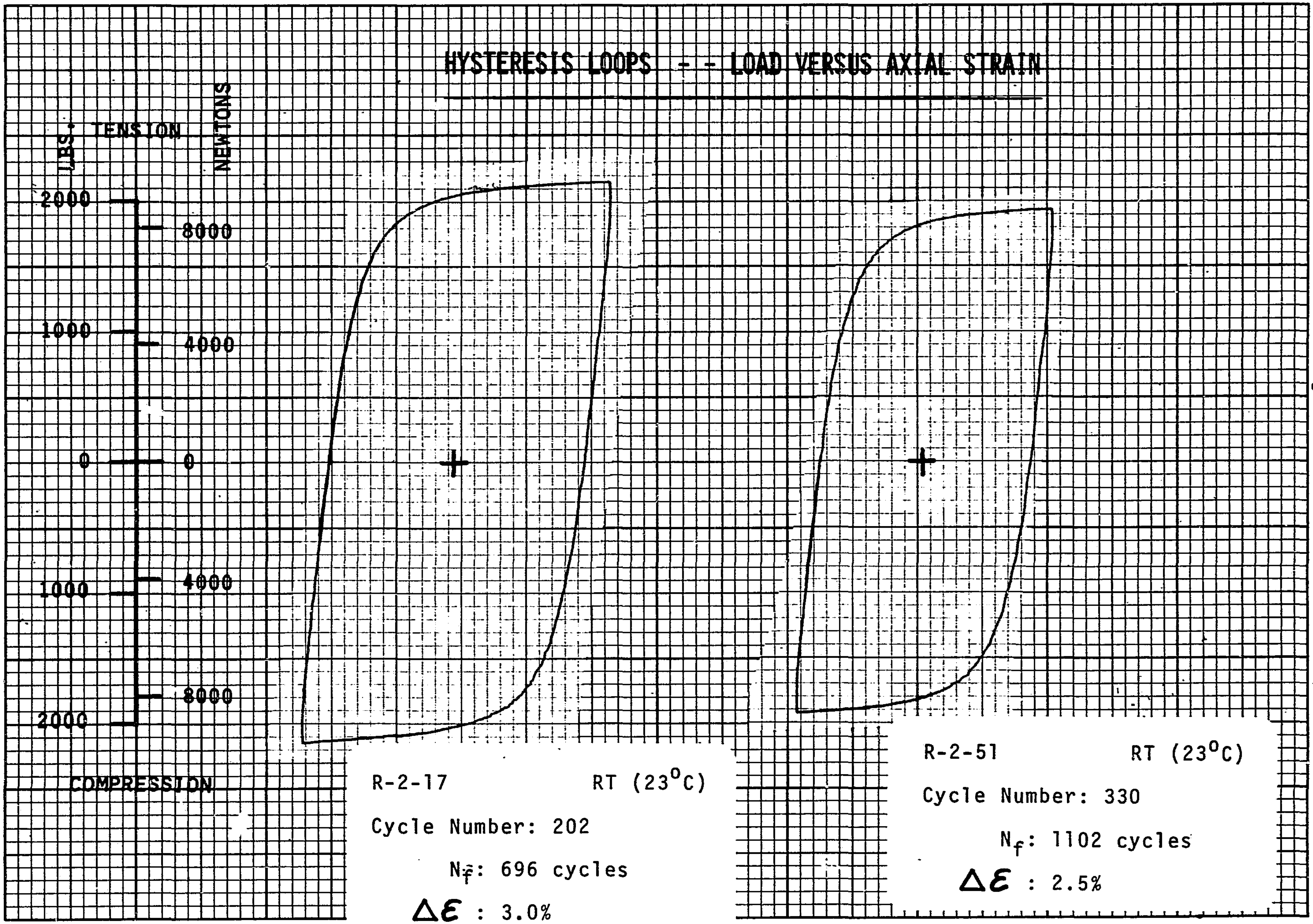

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-17 RT (23°C)
Cycle Number: 202
Nf: 696 cycles
Δε : 3.0%
R-2-51 RT (23°C)
Cycle Number: 330
Nf: 1102 cycles
Δε : 2.5%

Figure 244

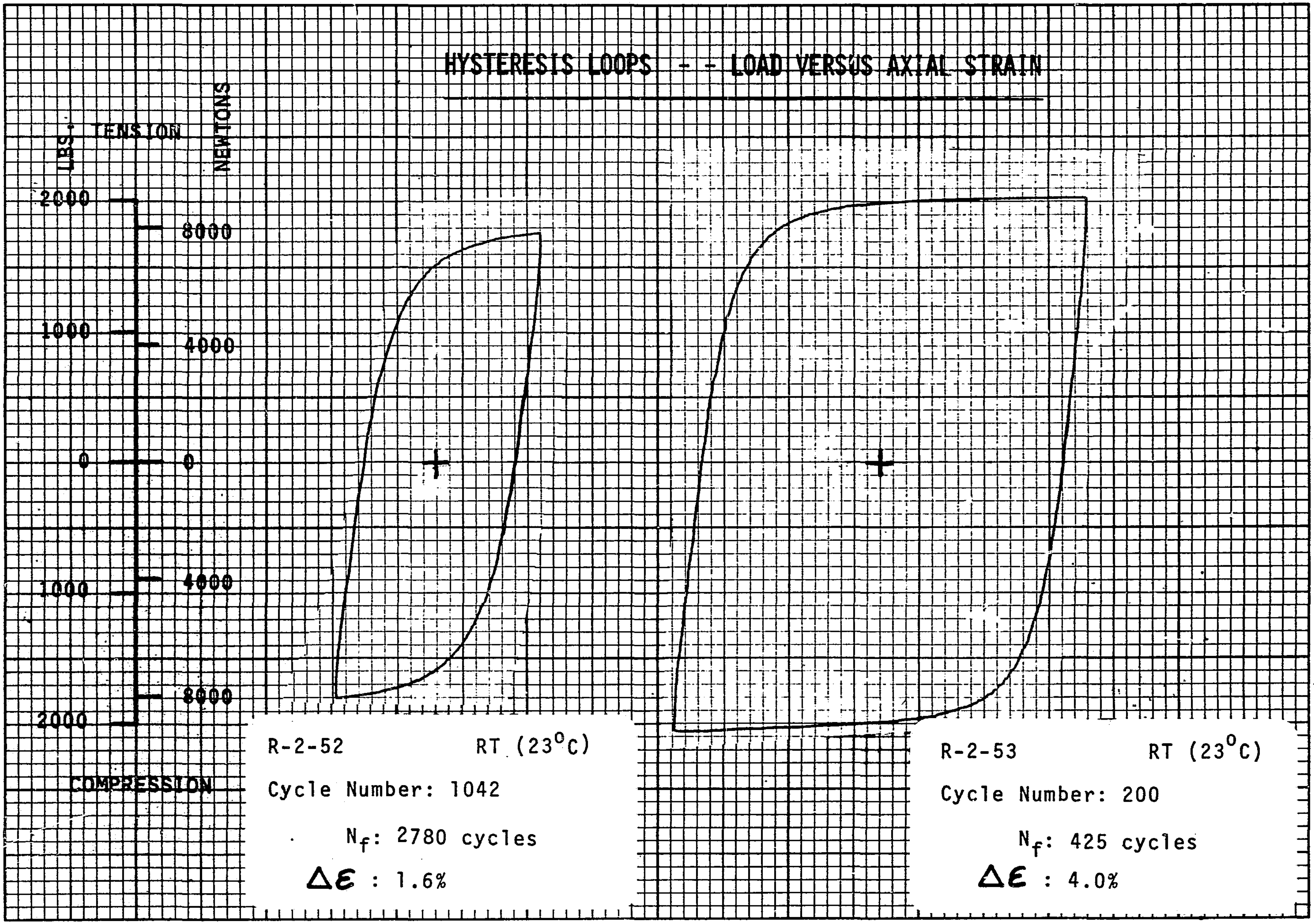

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-2-52
RT (23°C)
Cycle Number: 1042
N_f: 2780 cycles
Δε : 1.6%
R-2-53
RT (23°C)
Cycle Number: 200
N_f: 425 cycles
Δε : 4.0%

Figure 245

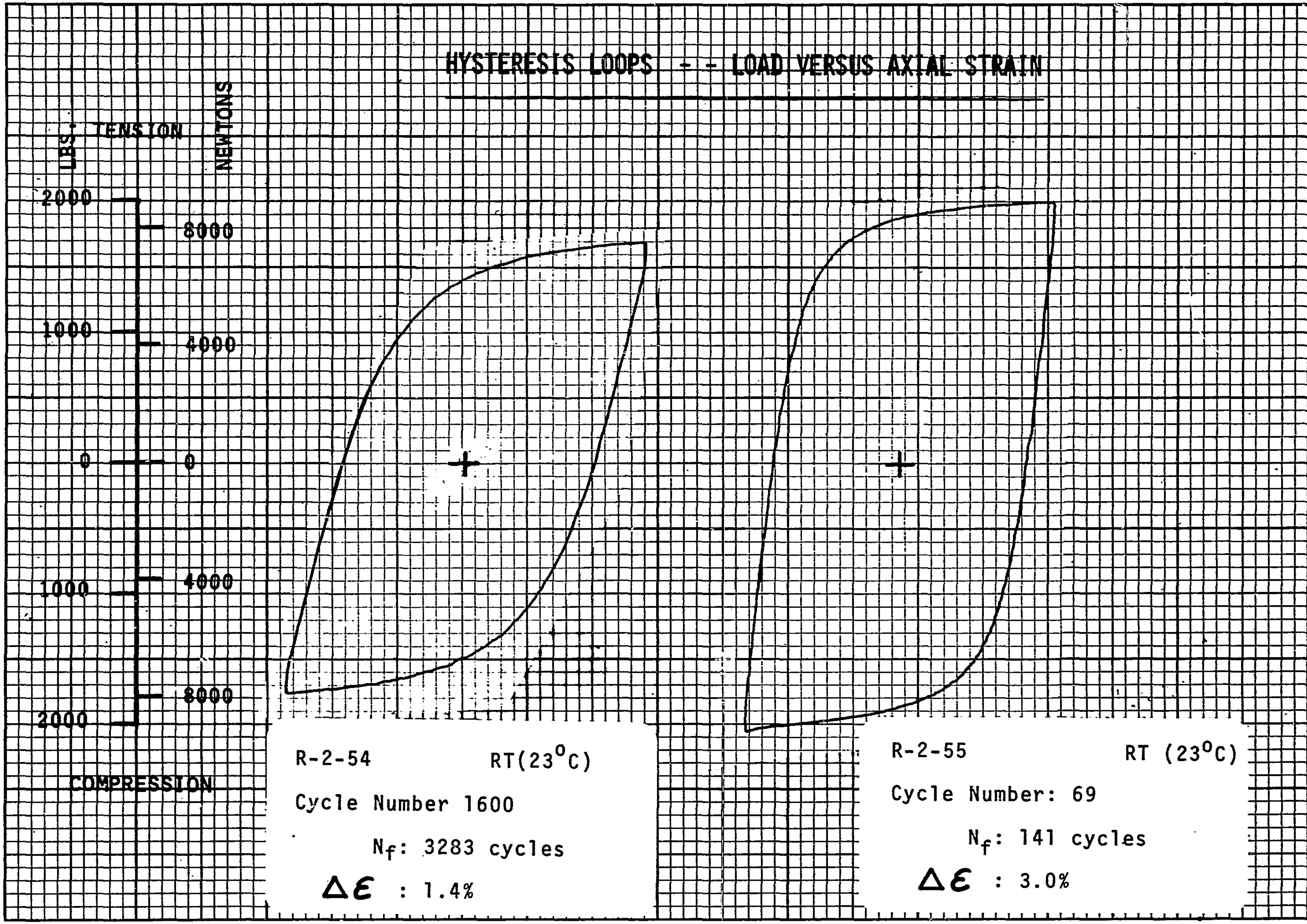

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-54 RT(23°C)
Cycle Number 1600
Nf: 3283 cycles
ΔƐ : 1.4%
R-2-55 RT (23°C)
Cycle Number: 69
Nf: 141 cycles
ΔƐ : 3.0%

Figure 246

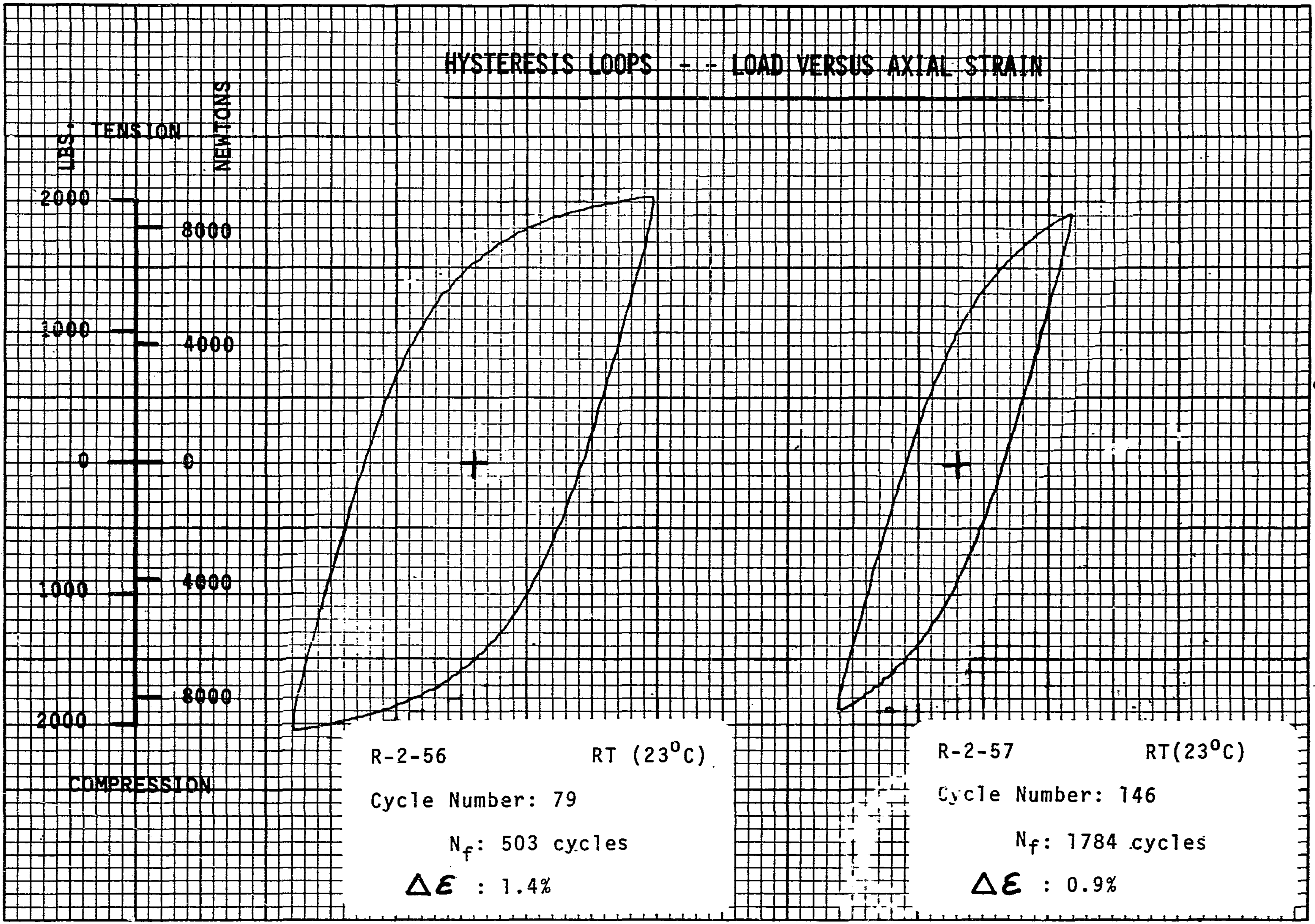

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION
NEWTONS
2000
8000
1000
4000
0
0
1000
4000
2000
8000
COMPRESSION
R-2-56 RT (23°C)
Cycle Number: 79
N_f: 503 cycles
ΔE : 1.4%
R-2-57 RT(23°C)
Cycle Number: 146
N_f: 1784 cycles
ΔE : 0.9%

Figure 247

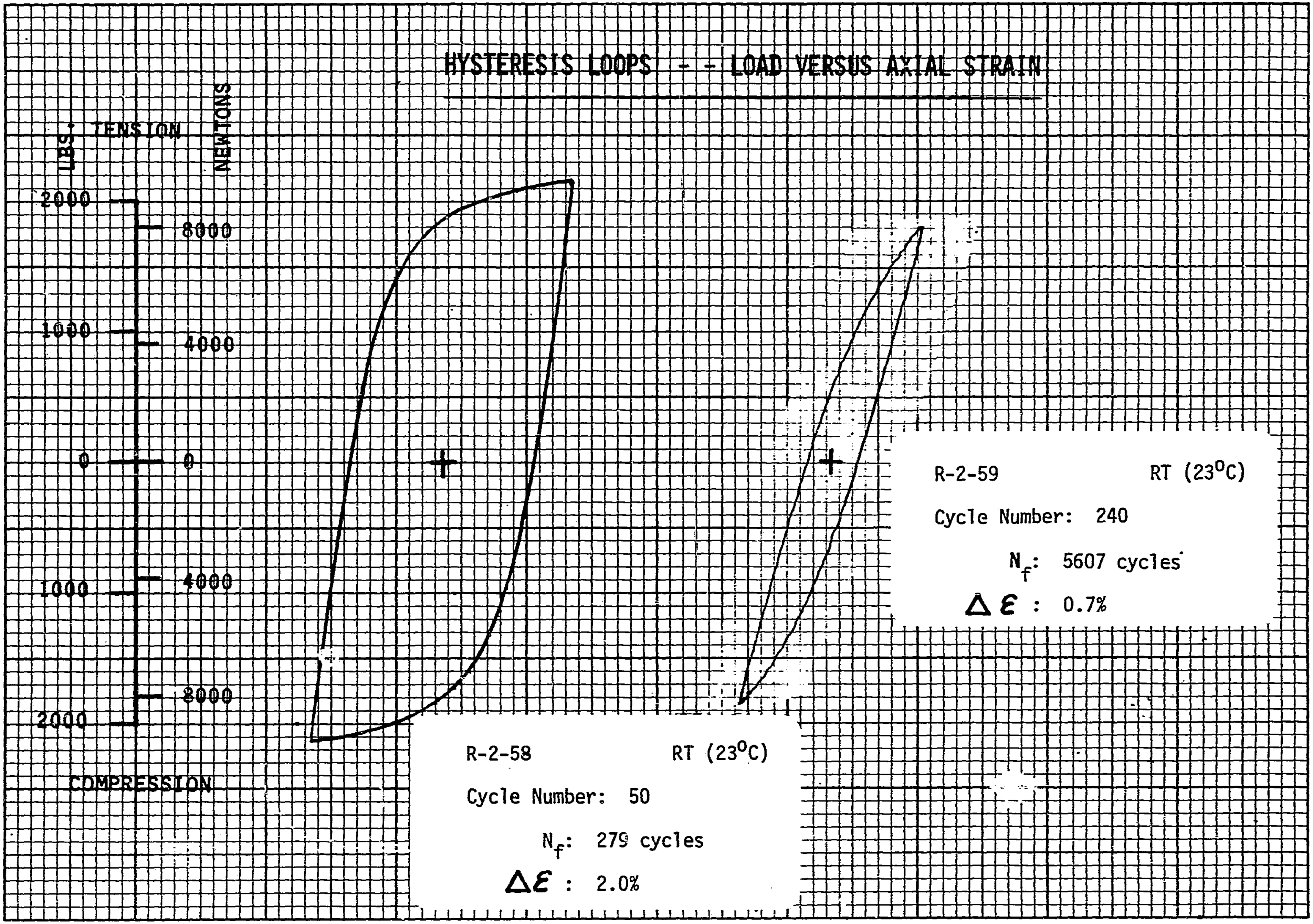

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION NEWTONS
2000
8000
1000
4000
0
0
1000
4000
8000
2000
COMPRESSION
R-2-59 RT (23°C)
Cycle Number: 240
Nf: 5607 cycles
Δε : 0.7%
R-2-58 RT (23°C)
Cycle Number: 50
Nf: 279 cycles
Δε : 2.0%

Figure 248

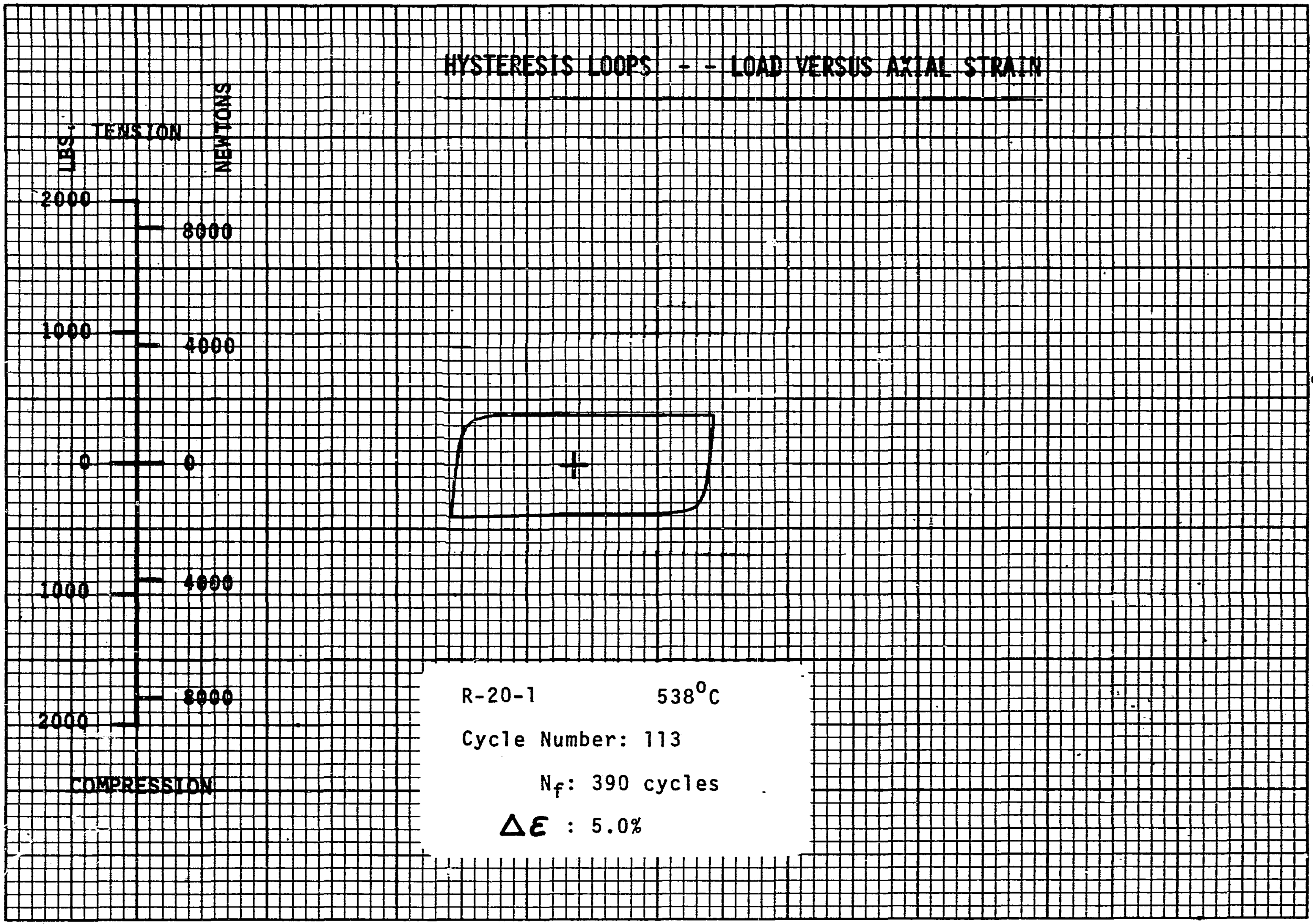

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS. TENSION NEWTONS
2000
8000
1000
4000
0
0
4000
1000
8000
2000
COMPRESSION
R-20-1 538^{o}C
Cycle Number: 113
N_f: 390 cycles
$\Delta\varepsilon$: 5.0%

Figure 249

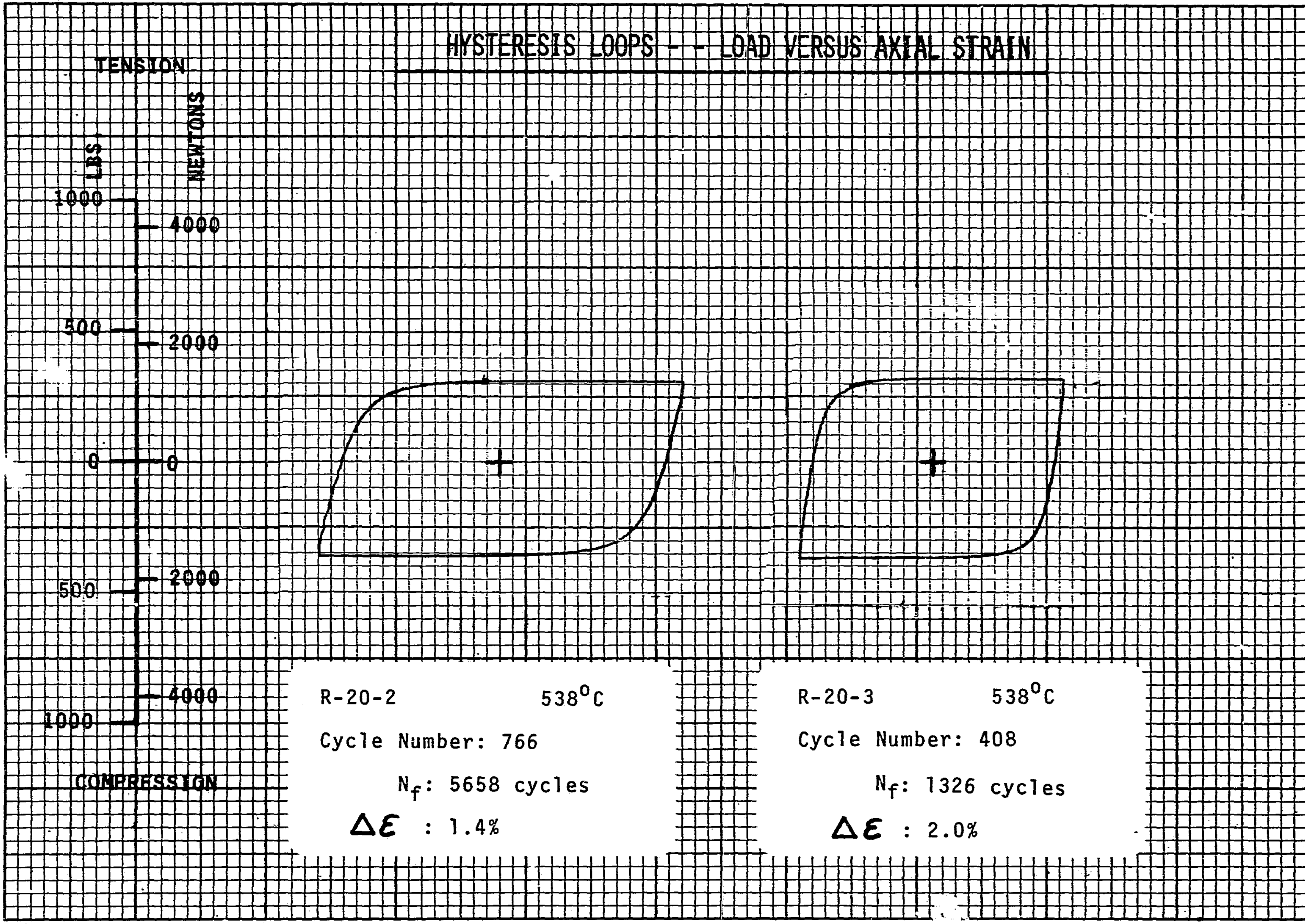

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-20-2
538°C
Cycle Number: 766
N_f: 5658 cycles
Δε : 1.4%
R-20-3
538°C
Cycle Number: 408
N_f: 1326 cycles
Δε : 2.0%

Figure 250

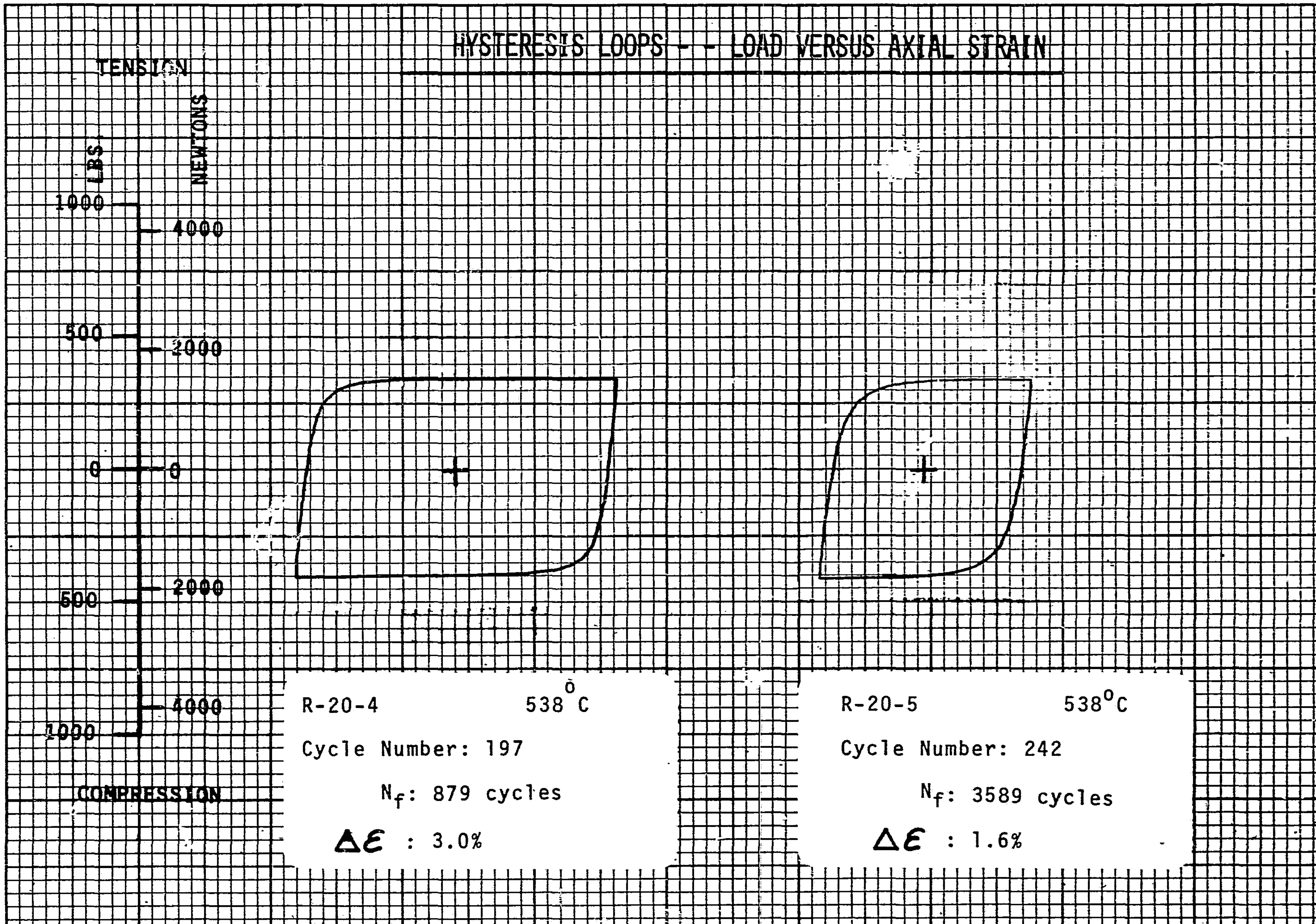

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-20-4 538°C
Cycle Number: 197
N_f: 879 cycles
$\Delta\varepsilon$: 3.0%
R-20-5 538°C
Cycle Number: 242
N_f: 3589 cycles
$\Delta\varepsilon$: 1.6%

Figure 251

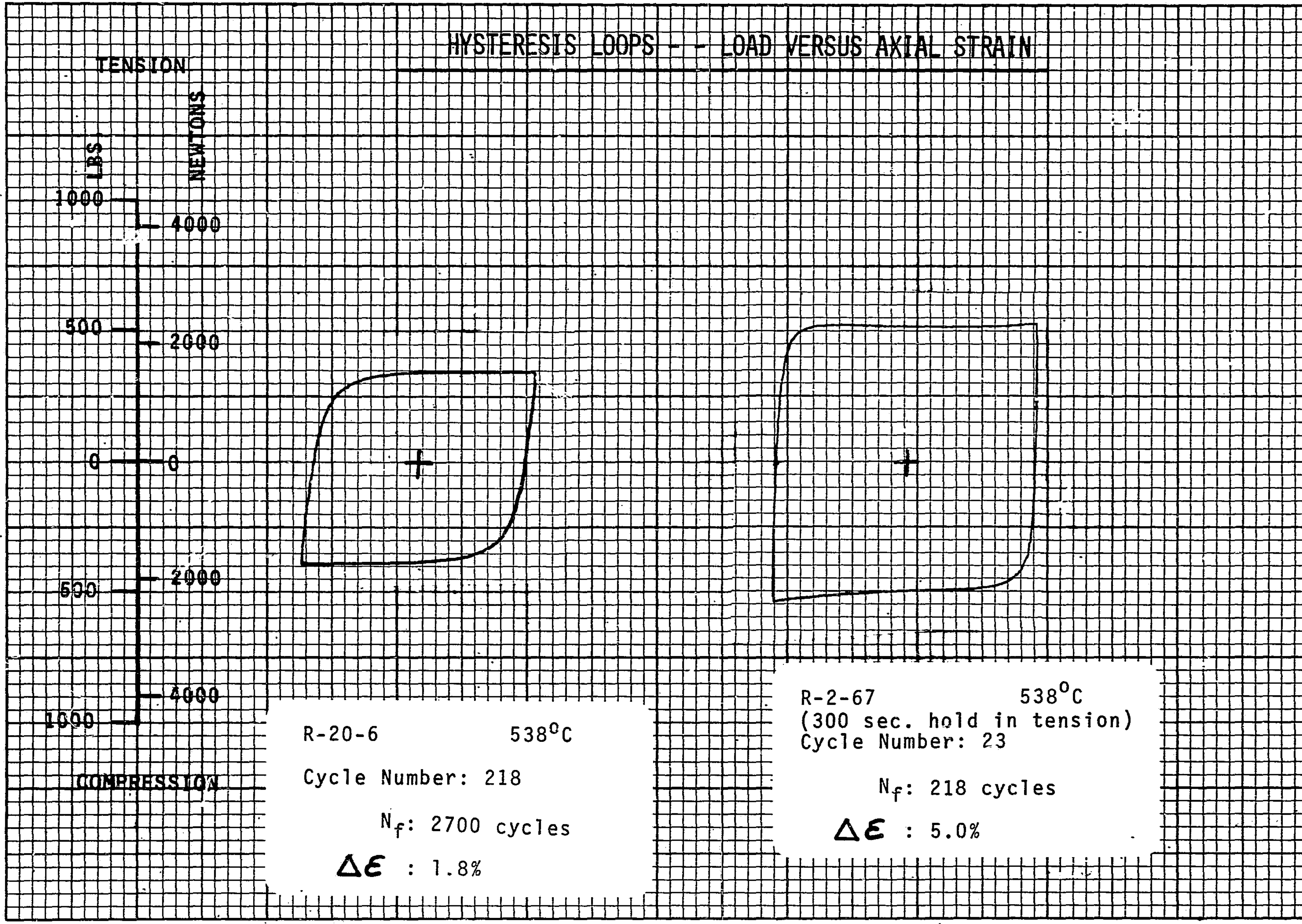

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-20-6 538°C
Cycle Number: 218
N_f: 2700 cycles
Δε : 1.8%
R-2-67 538°C
(300 sec. hold in tension)
Cycle Number: 23
N_f: 218 cycles
Δε : 5.0%

Figure 252

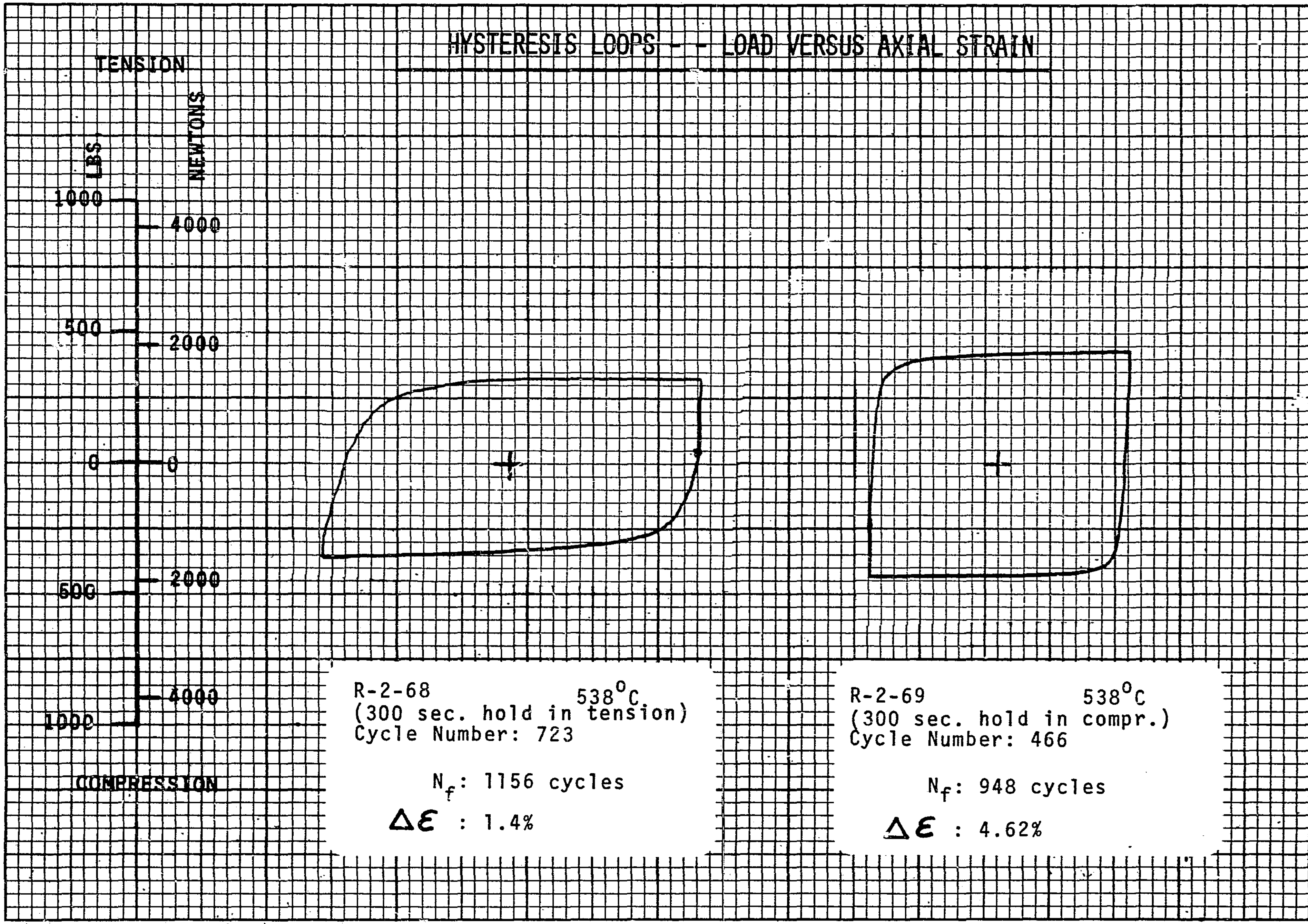

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
2000
500
4000
1000
COMPRESSION
R-2-68 538°C
(300 sec. hold in tension)
Cycle Number: 723
Nf: 1156 cycles
Δε : 1.4%
R-2-69 538°C
(300 sec. hold in compr.)
Cycle Number: 466
Nf: 948 cycles
Δε : 4.62%

Figure 253

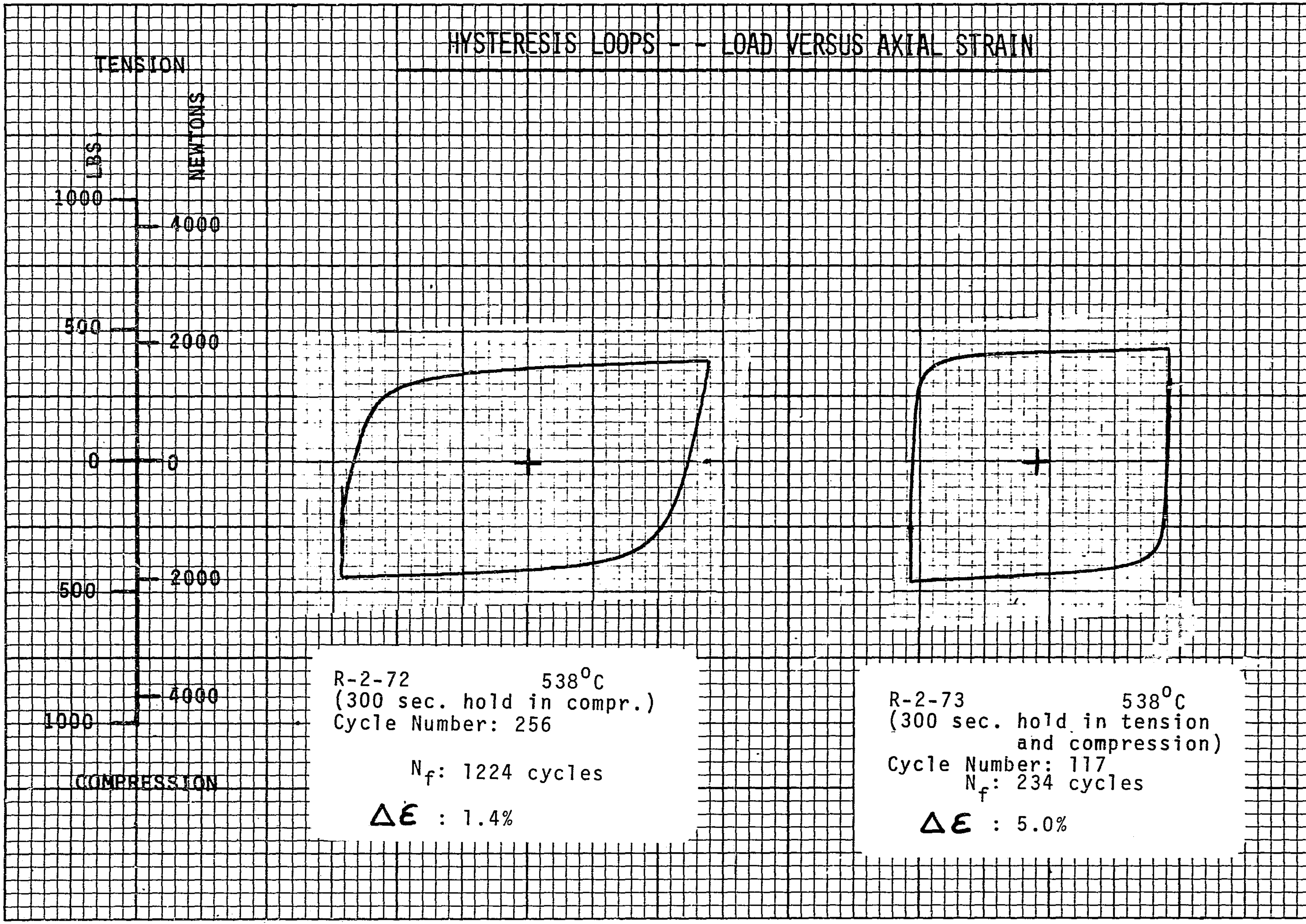

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-72 538°C
(300 sec. hold in compr.)
Cycle Number: 256
Nf: 1224 cycles
Δε : 1.4%
R-2-73 538°C
(300 sec. hold in tension
and compression)
Cycle Number: 117
Nf: 234 cycles
Δε : 5.0%

Figure 254

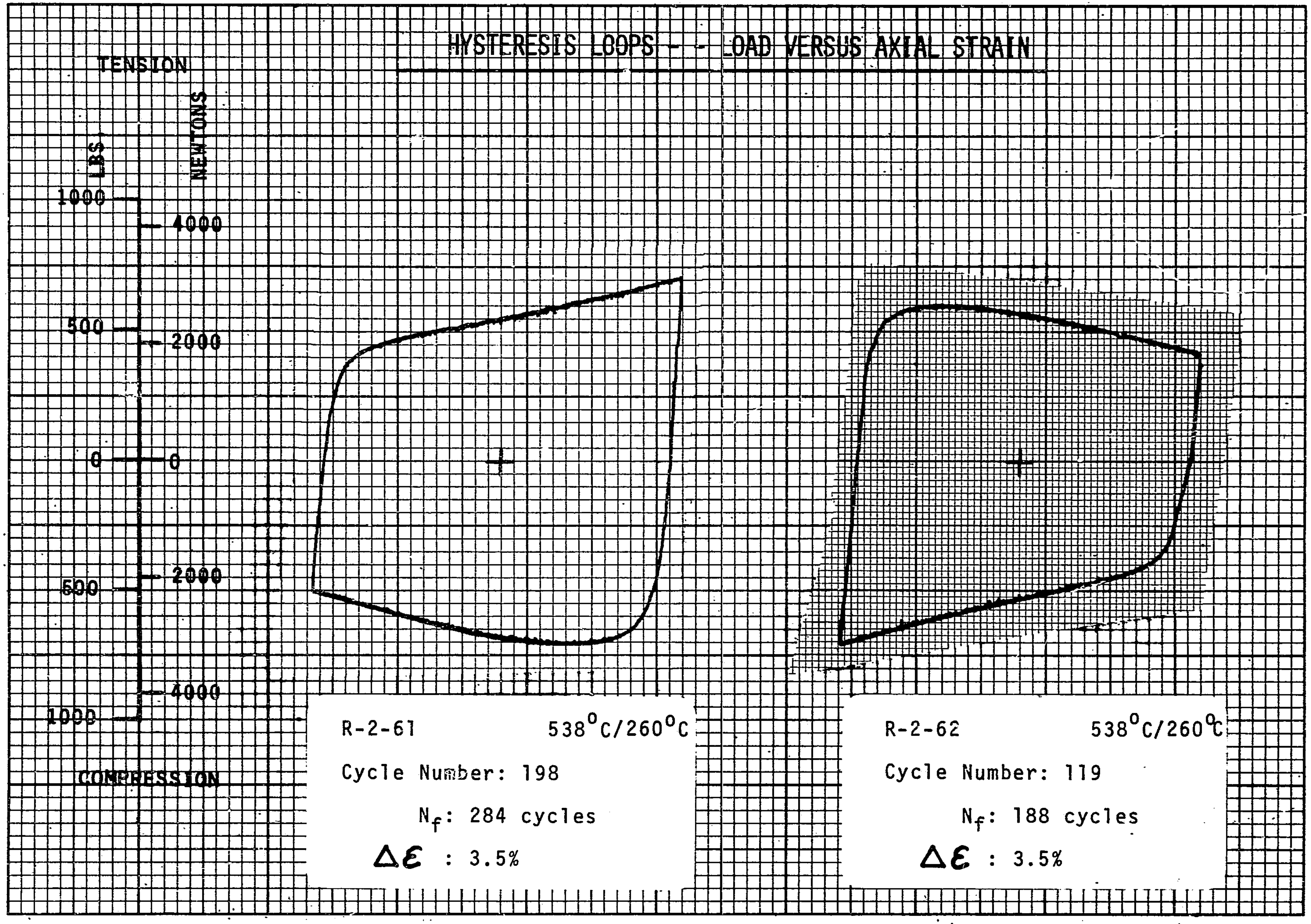

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-2-61 538°C/260°C
Cycle Number: 198
Nf: 284 cycles
Δε : 3.5%
R-2-62 538°C/260°C
Cycle Number: 119
Nf: 188 cycles
Δε : 3.5%

Figure 255

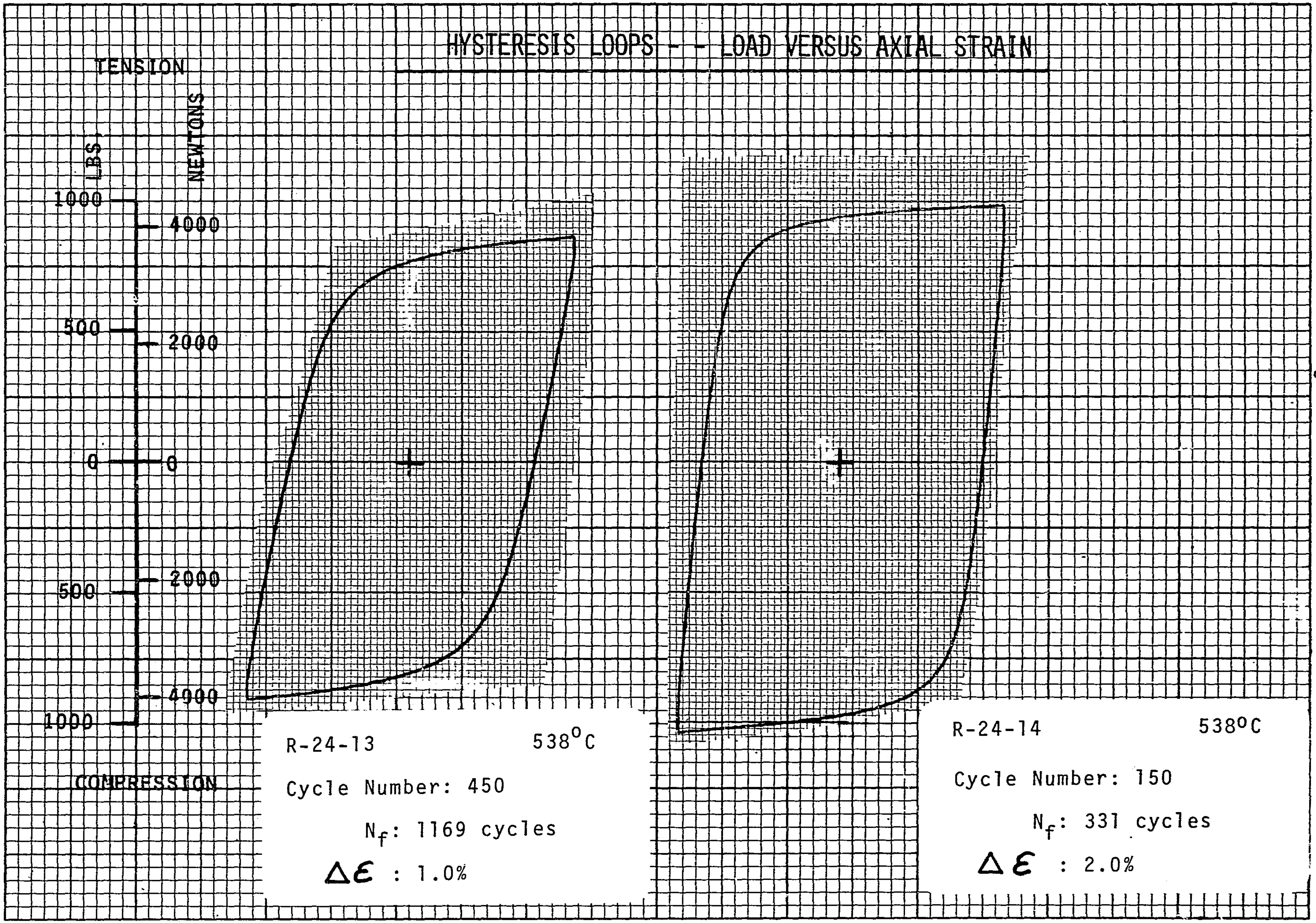

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-13
538°C
Cycle Number: 450
N_f: 1169 cycles
ΔƐ : 1.0%
R-24-14
538°C
Cycle Number: 150
N_f: 331 cycles
ΔƐ : 2.0%

Figure 256

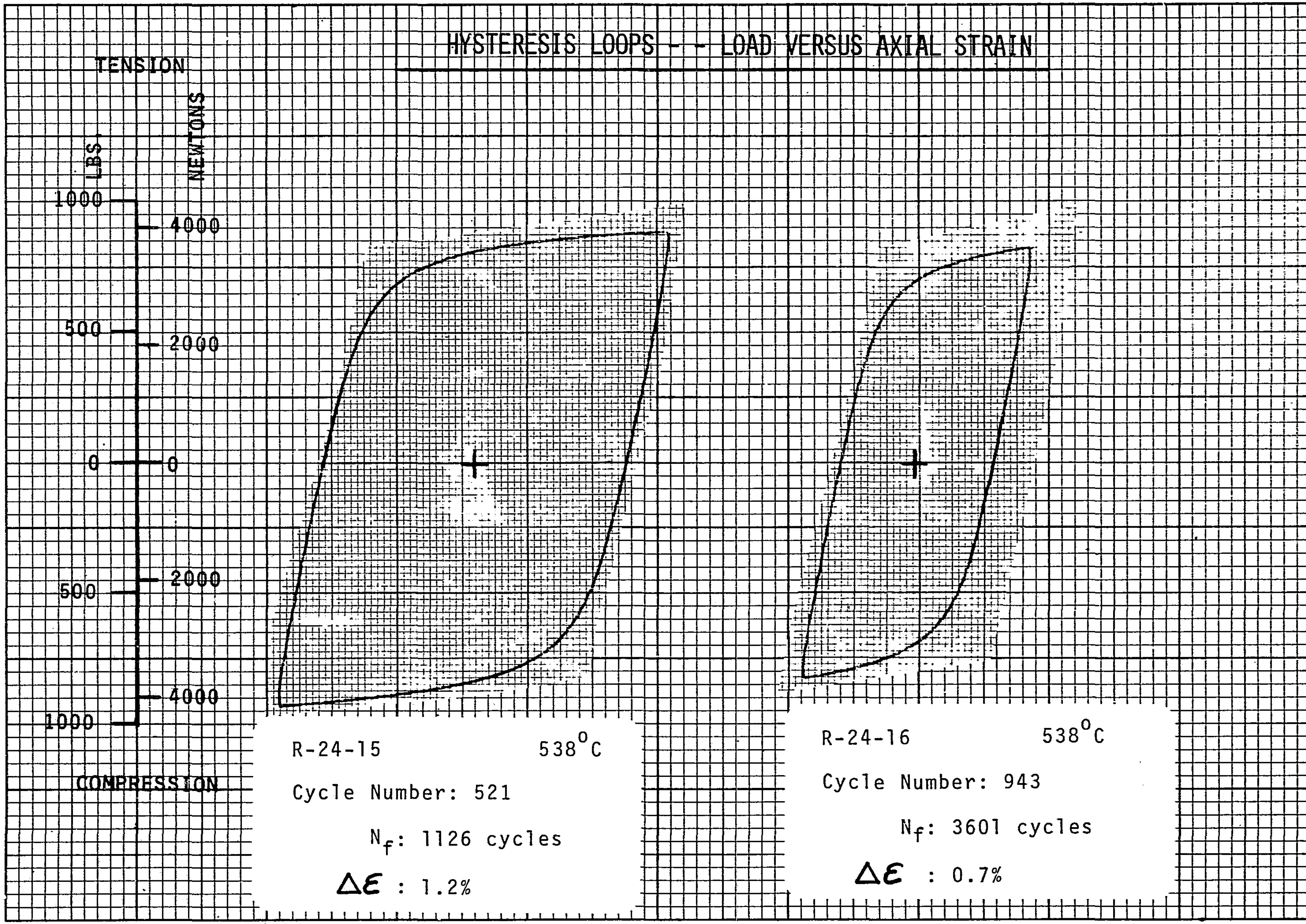

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-15
538°C
Cycle Number: 521
Nf: 1126 cycles
ΔE : 1.2%
R-24-16
538°C
Cycle Number: 943
Nf: 3601 cycles
ΔE : 0.7%

Figure 257

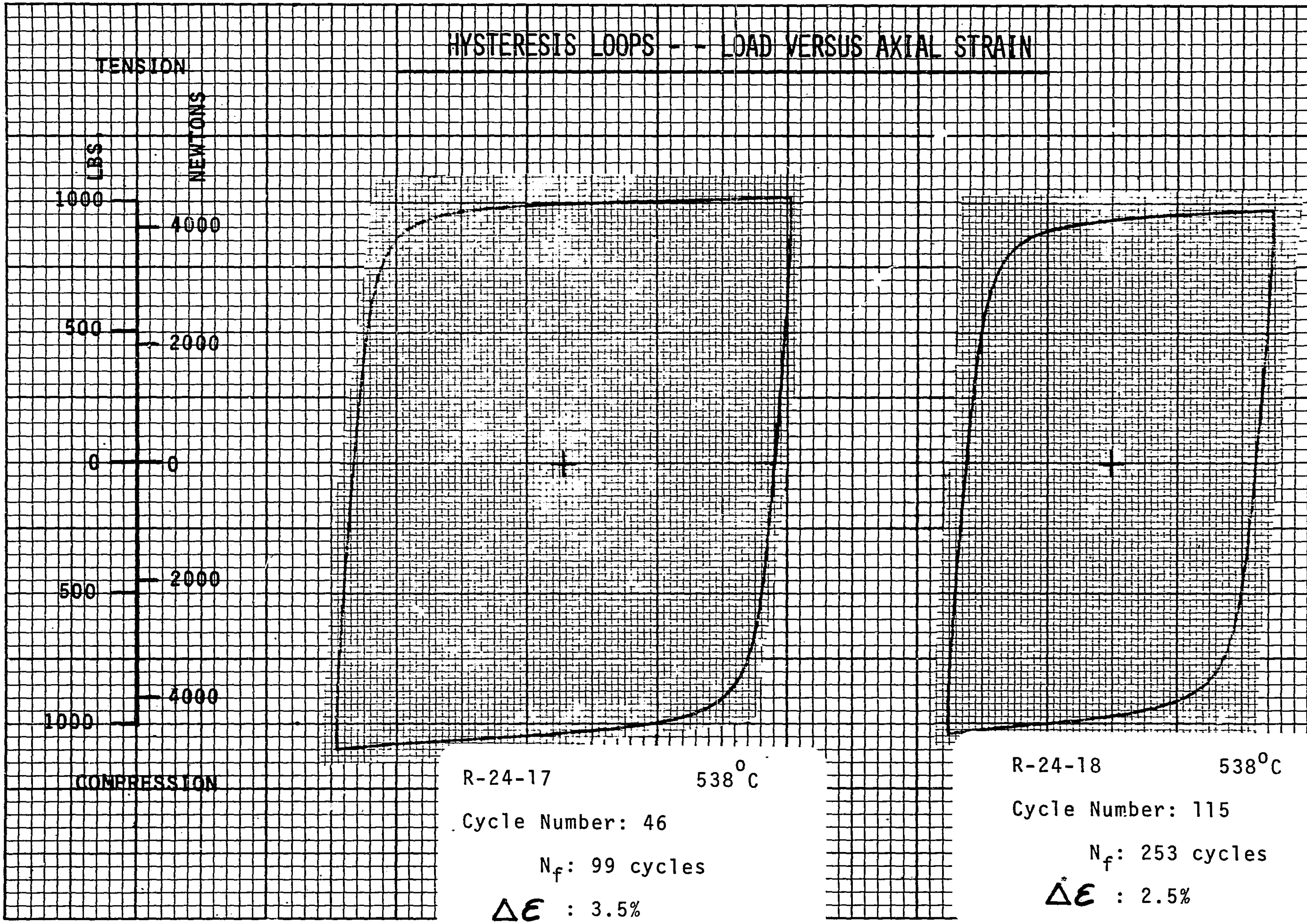

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-17
538°C
Cycle Number: 46
N_f: 99 cycles
$\Delta\varepsilon$: 3.5%
R-24-18
538°C
Cycle Number: 115
N_f: 253 cycles
$\Delta\varepsilon$: 2.5%

Figure 258

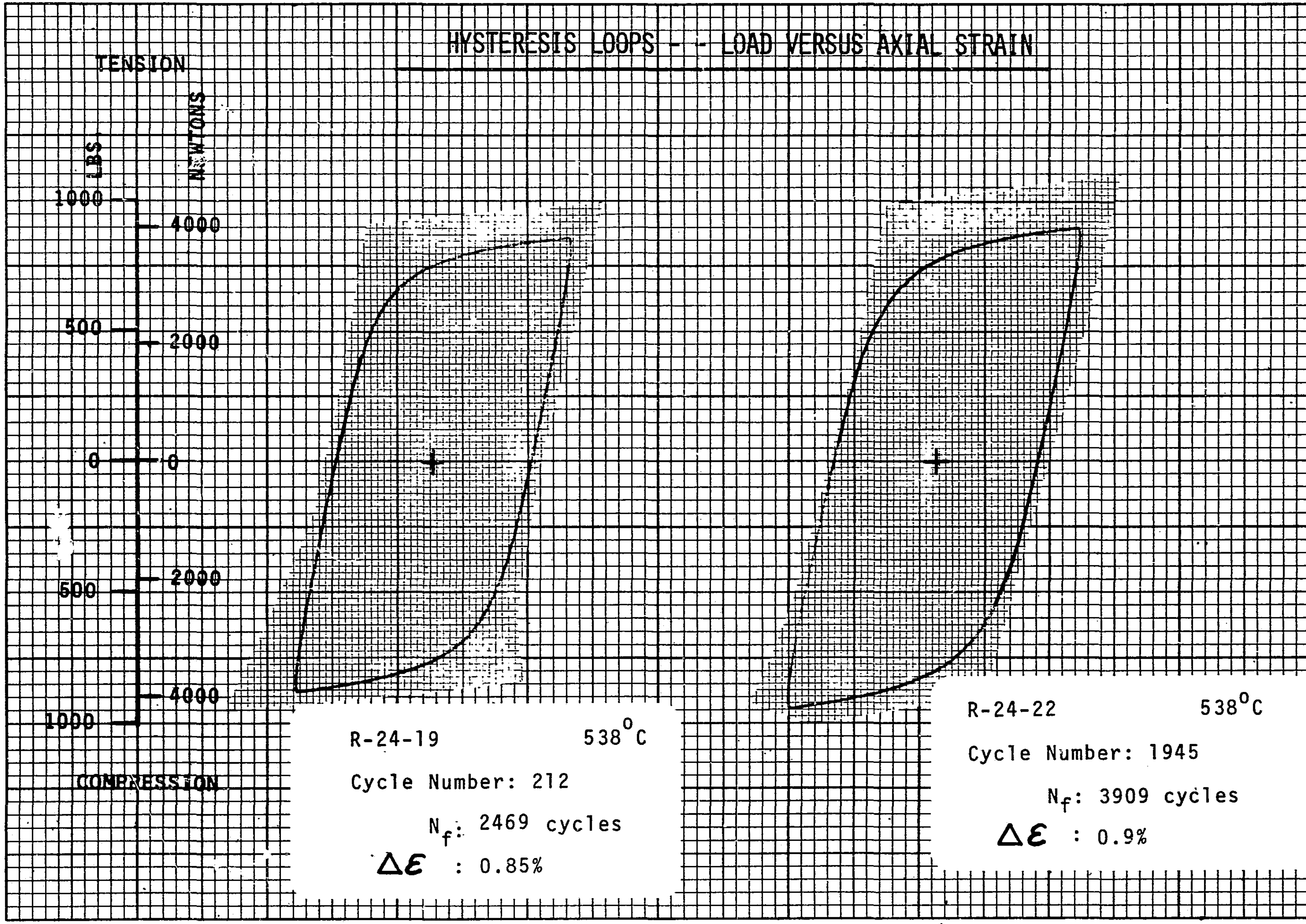

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
500
0
500
1000
4000
2000
0
2000
4000
COMPRESSION
R-24-19 538°C
Cycle Number: 212
N_f: 2469 cycles
Δε : 0.85%
R-24-22 538°C
Cycle Number: 1945
N_f: 3909 cycles
Δε : 0.9%

Figure 259

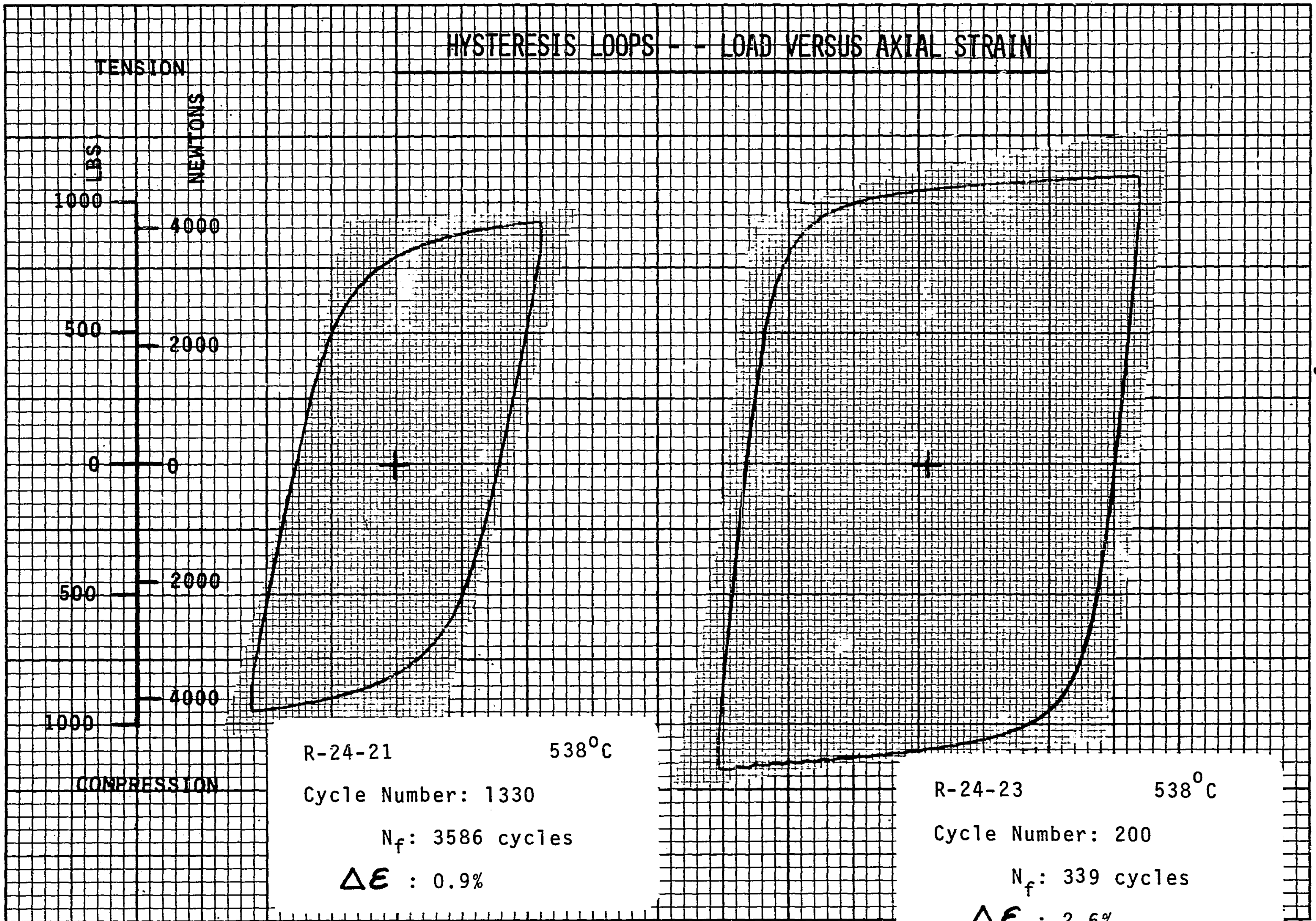

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-21 538°C
Cycle Number: 1330
N_f: 3586 cycles
Δε : 0.9%
R-24-23 538°C
Cycle Number: 200
Nf: 339 cycles
Δε : 2.6%

Figure 260

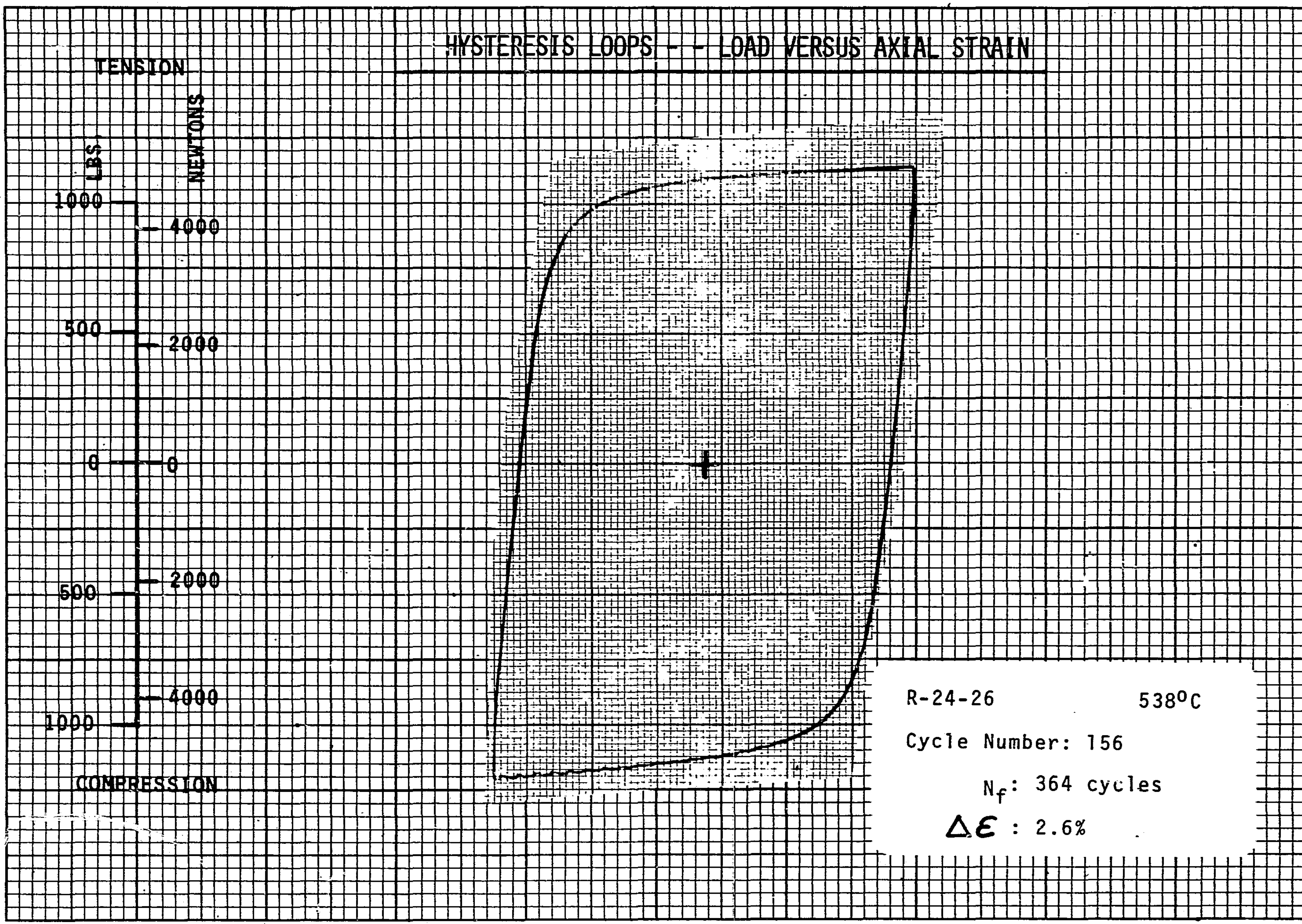

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-24-26
538°C
Cycle Number: 156
Nf: 364 cycles
Δε : 2.6%

Figure 261

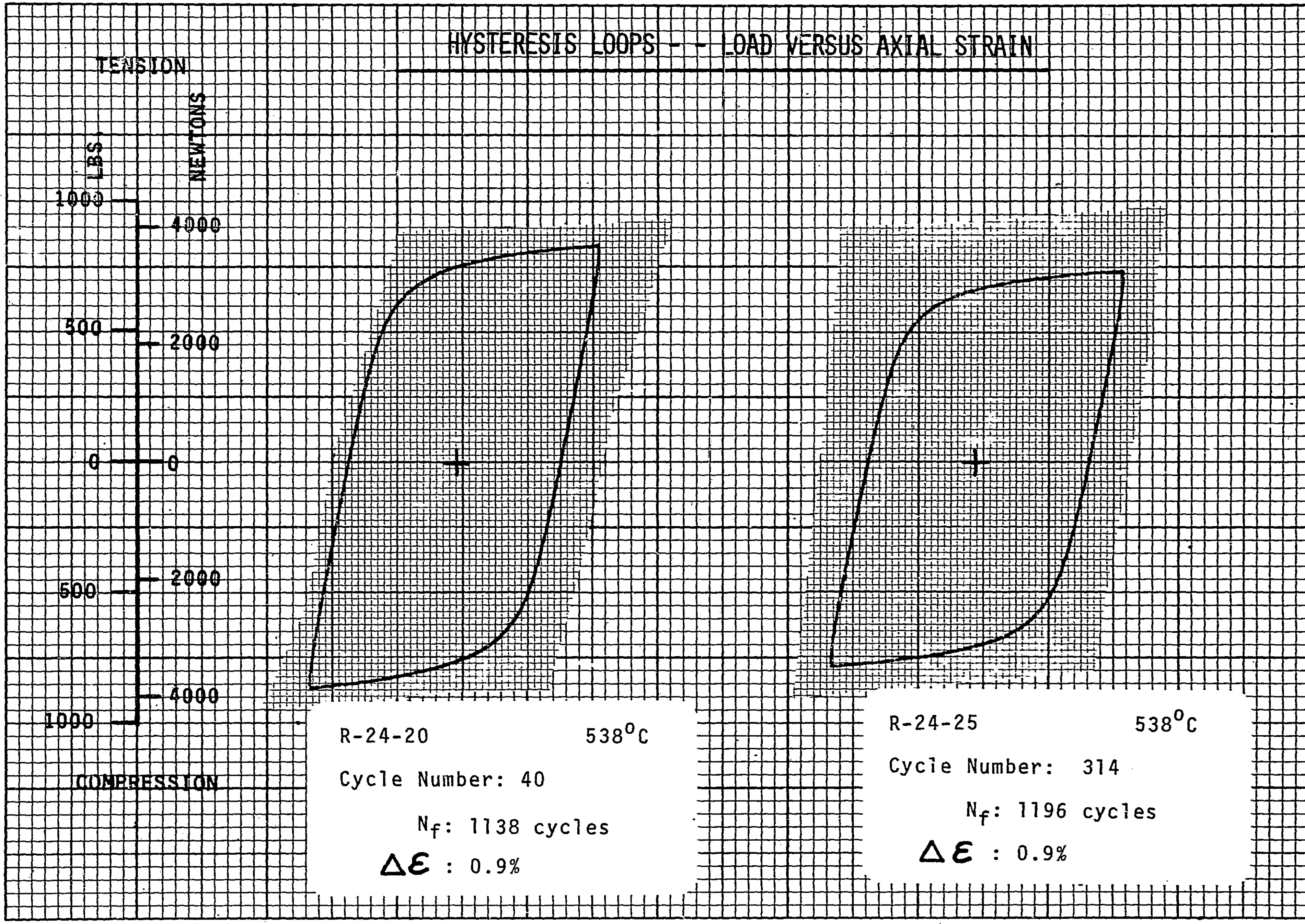

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-20
538°C
Cycle Number: 40
Nf: 1138 cycles
Δε : 0.9%
R-24-25
538°C
Cycle Number: 314
Nf: 1196 cycles
Δε : 0.9%

Figure 262

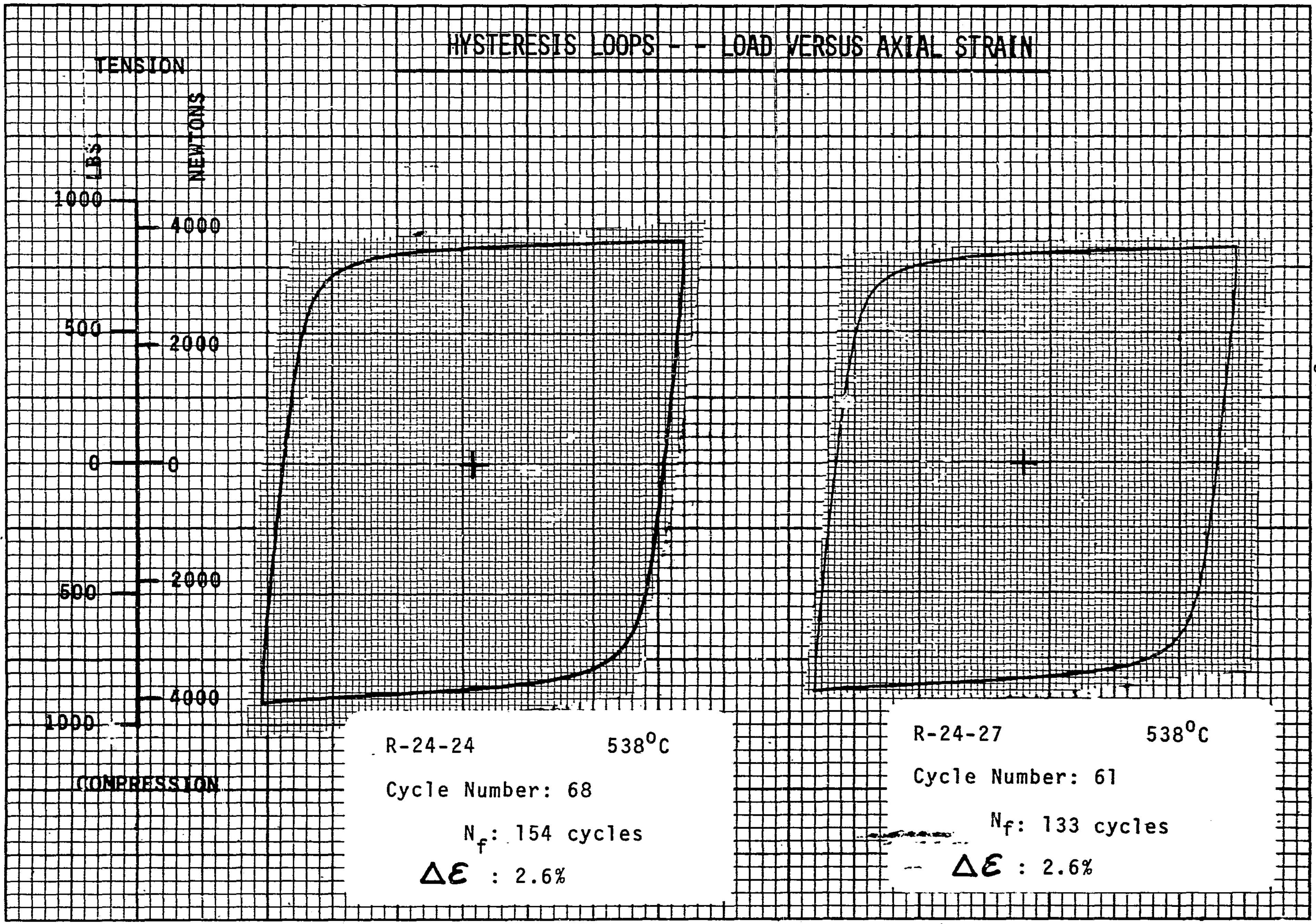

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-24-24 538°C
Cycle Number: 68
N_f: 154 cycles
$\Delta\varepsilon$: 2.6%
R-24-27 538°C
Cycle Number: 61
N_f: 133 cycles
$\Delta\varepsilon$: 2.6%

Figure 263

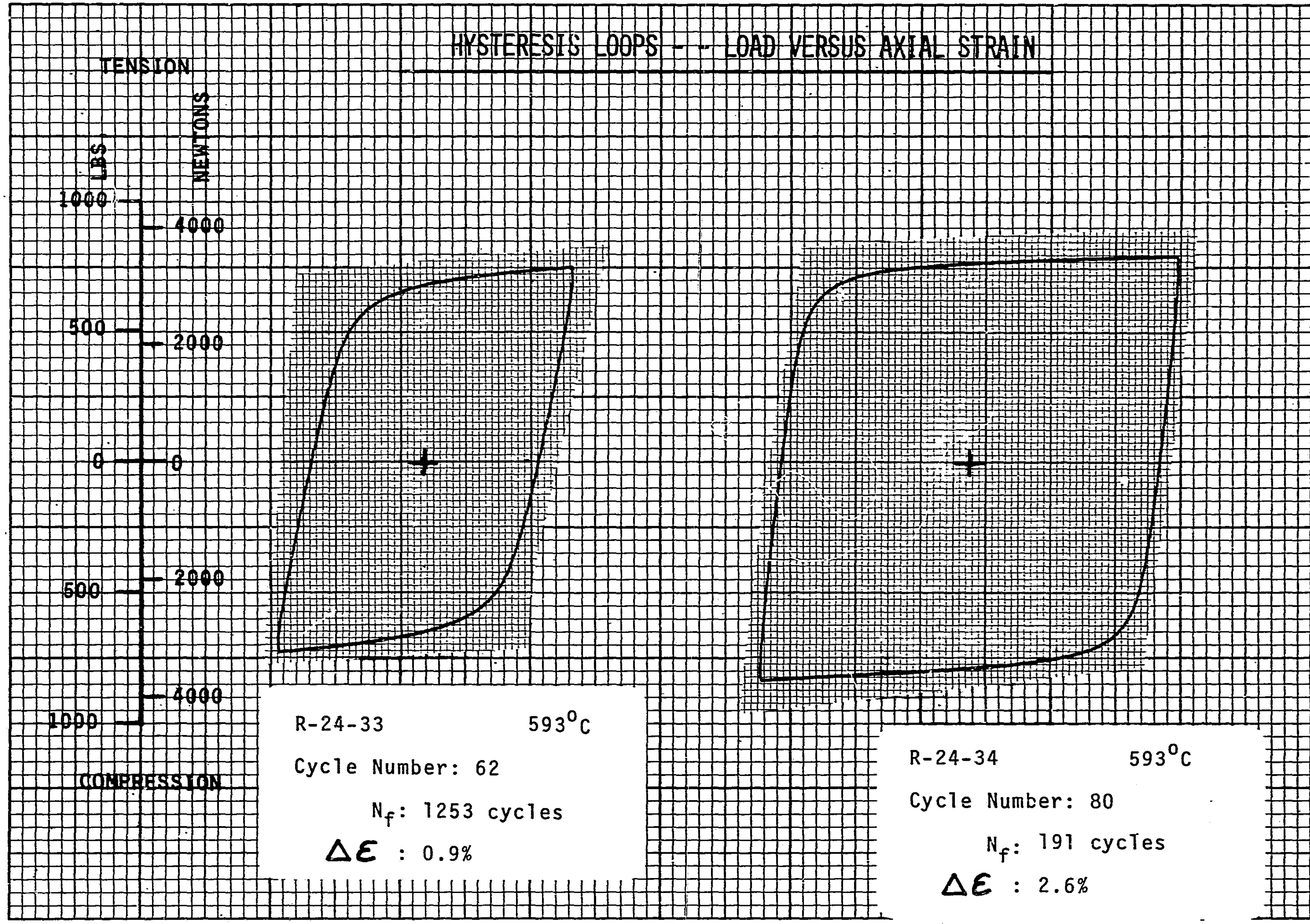

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-33 593°C
Cycle Number: 62
N_f: 1253 cycles
ΔE : 0.9%
R-24-34 593°C
Cycle Number: 80
N_f: 191 cycles
ΔE : 2.6%

Figure 264

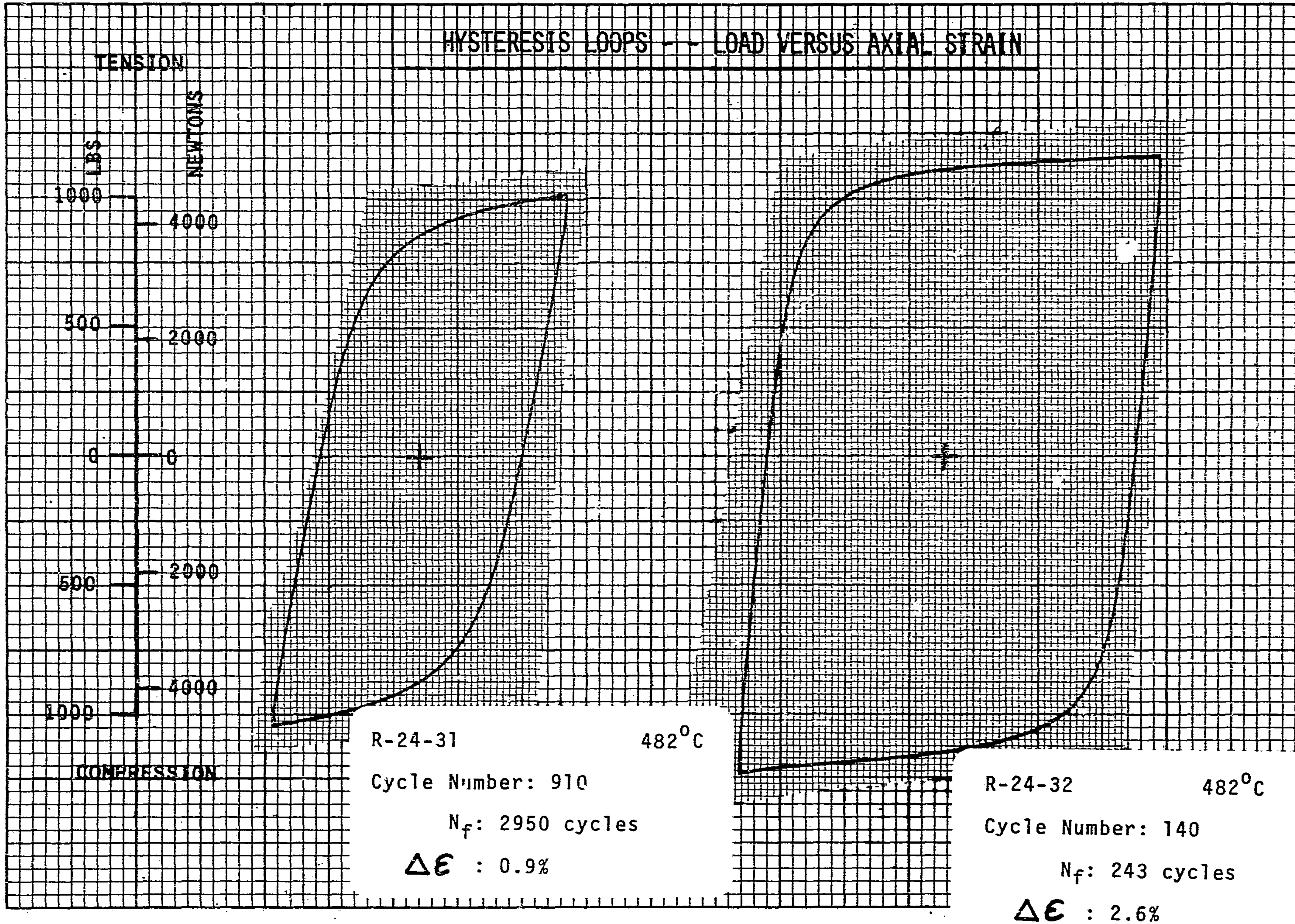

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-24-31 482°C
Cycle Number: 910
Nf: 2950 cycles
Δε : 0.9%
R-24-32 482°C
Cycle Number: 140
Nf: 243 cycles
Δε : 2.6%

Figure 265

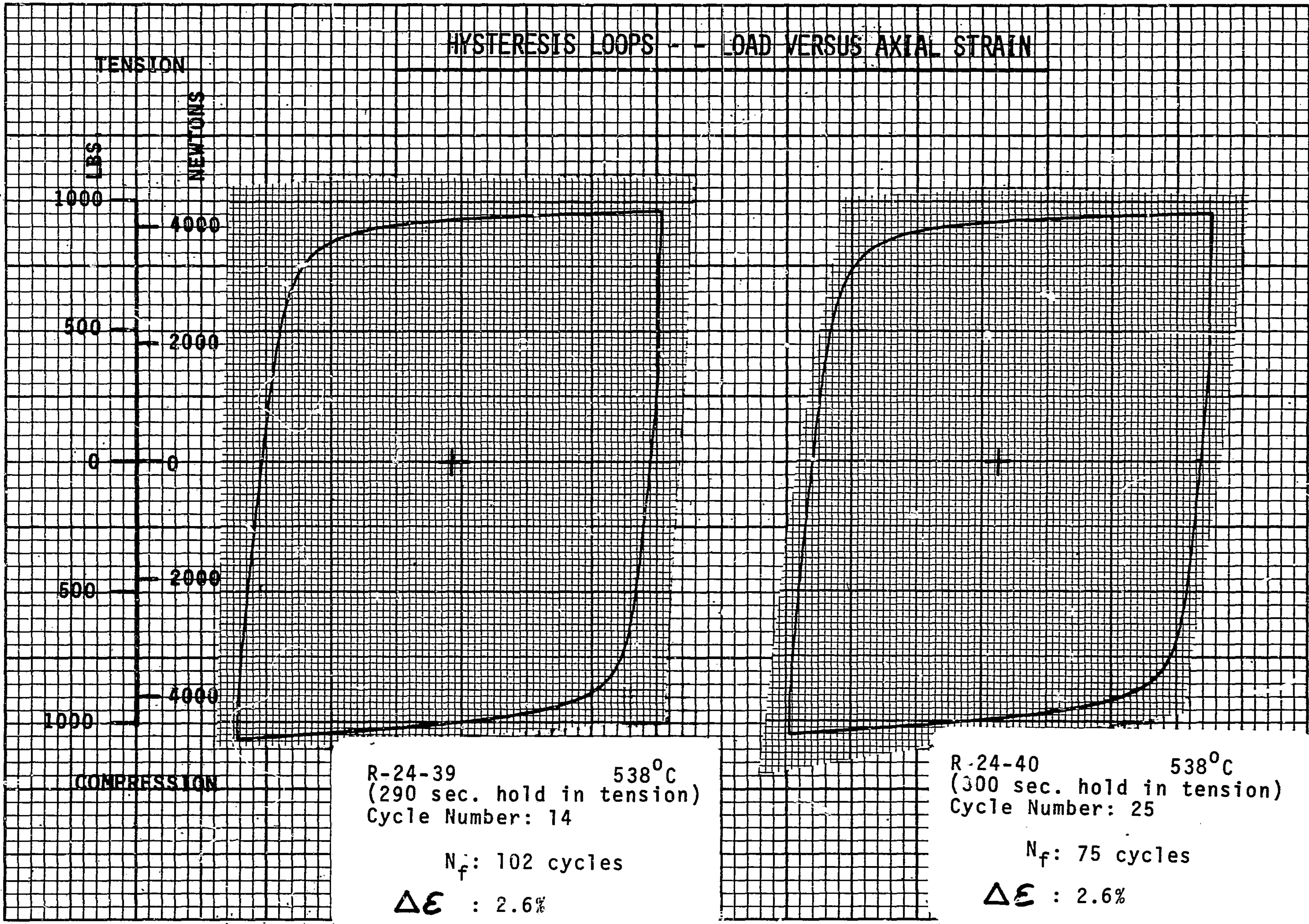

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-39 538°C
(290 sec. hold in tension)
Cycle Number: 14
N_f: 102 cycles
ΔΕ : 2.6%
R-24-40 538°C
(300 sec. hold in tension)
Cycle Number: 25
N_f: 75 cycles
ΔΕ : 2.6%

Figure 266

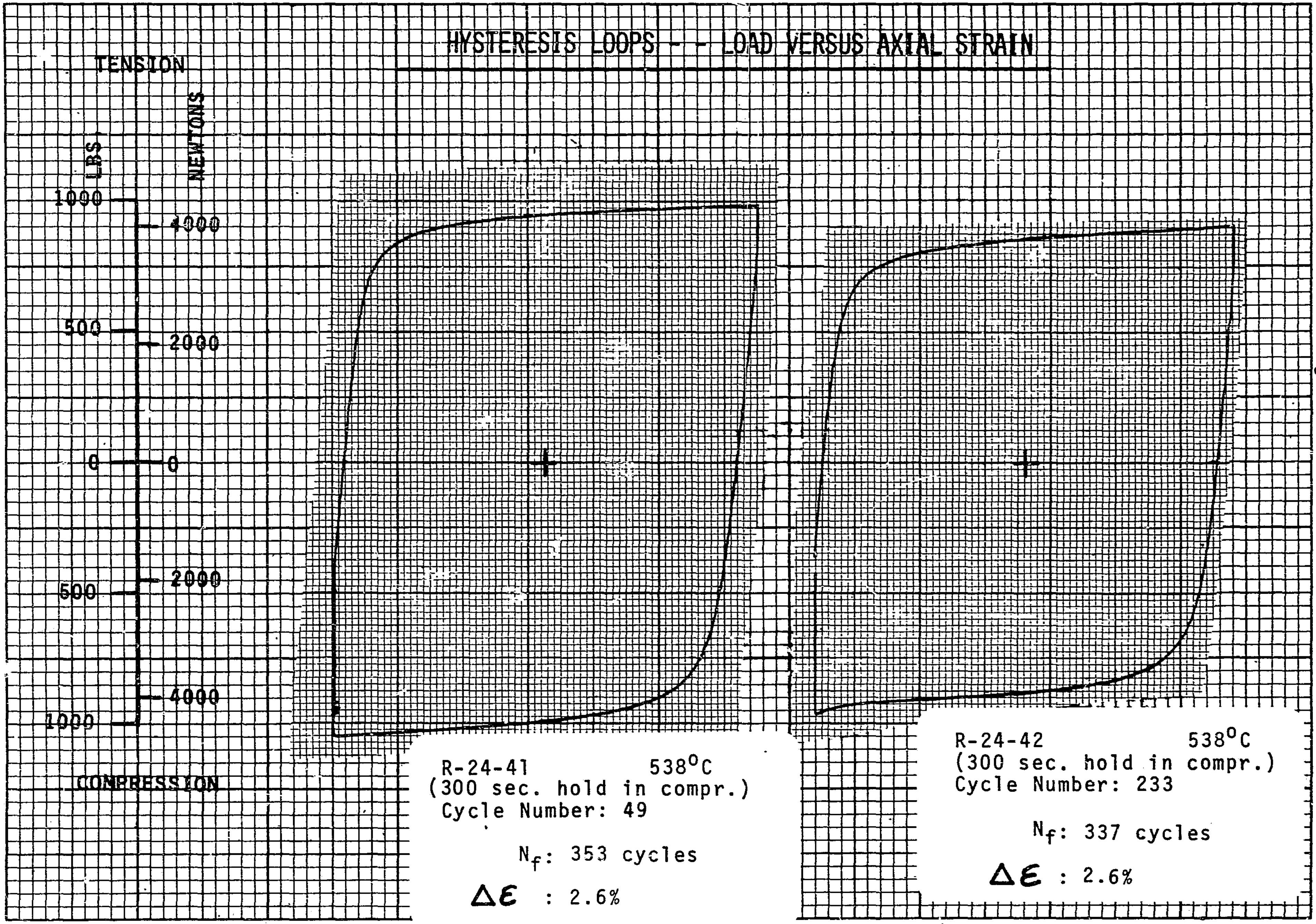

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-24-41 538°C
(300 sec. hold in compr.)
Cycle Number: 49
Nf: 353 cycles
Δε : 2.6%
R-24-42 538°C
(300 sec. hold in compr.)
Cycle Number: 233
Nf: 337 cycles
Δε : 2.6%

Figure 267

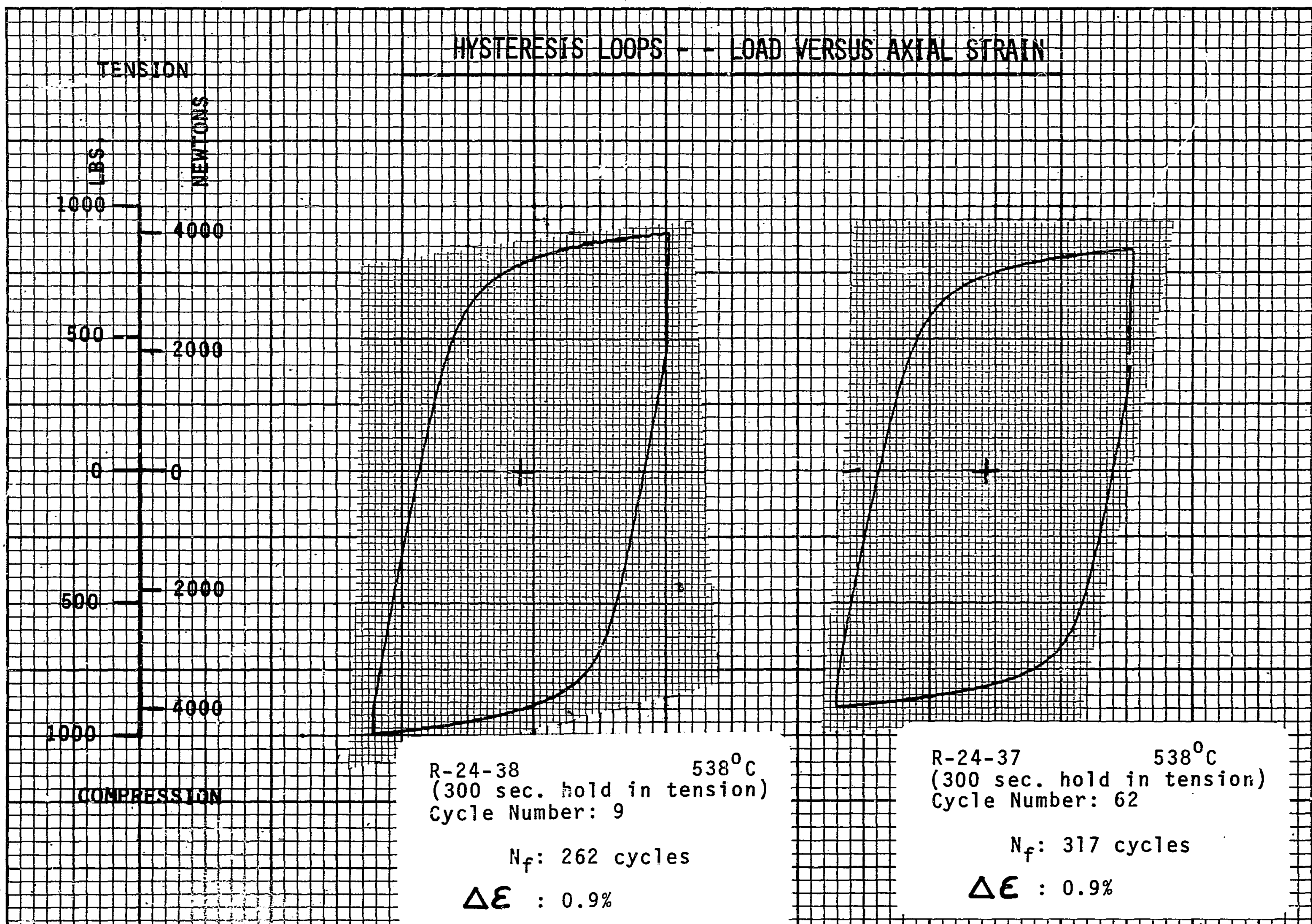

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-24-38 538°C
(300 sec. hold in tension)
Cycle Number: 9
N_f: 262 cycles
ΔE : 0.9%
R-24-37 538°C
(300 sec. hold in tension)
Cycle Number: 62
N_f: 317 cycles
ΔE : 0.9%

Figure 268

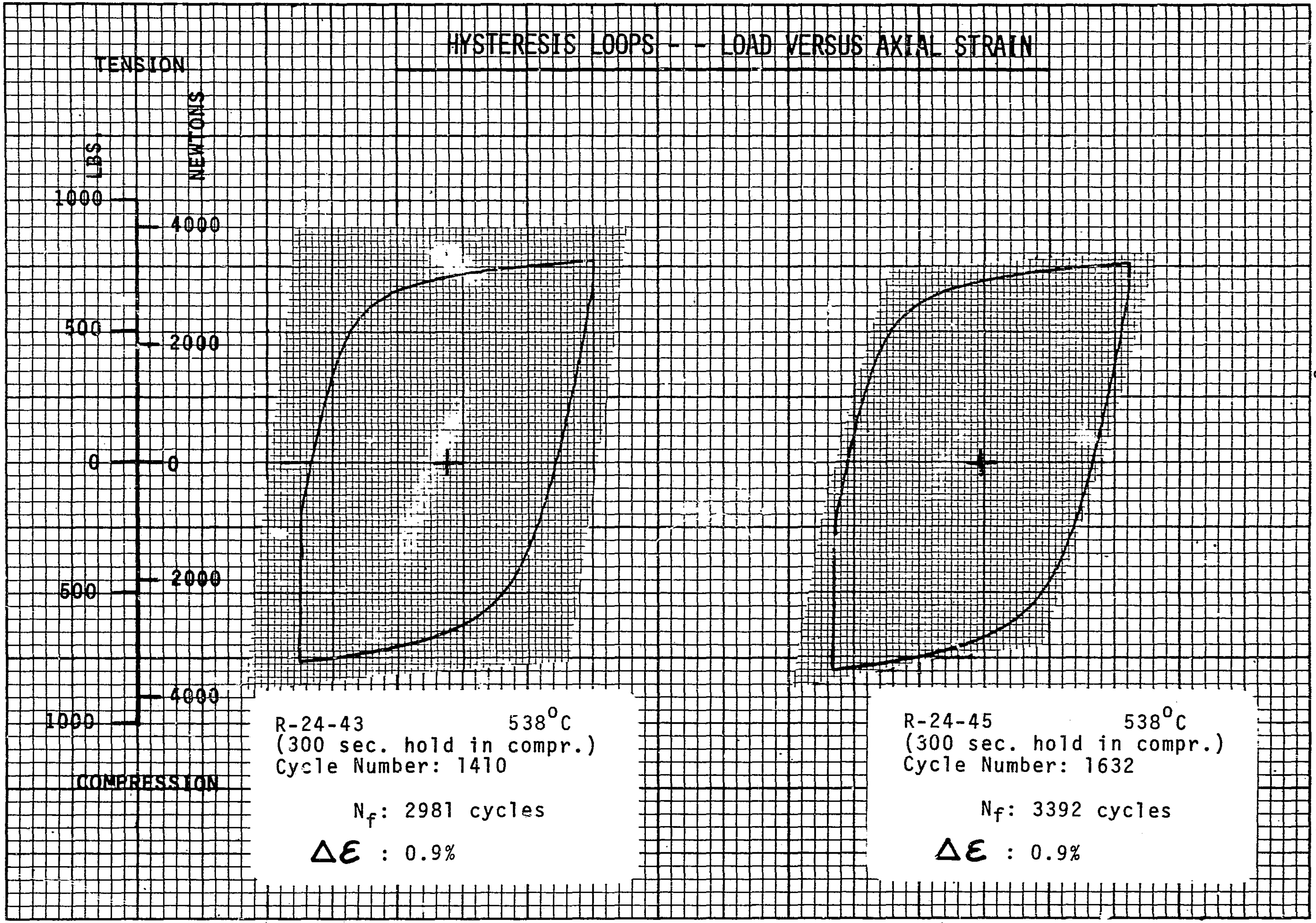
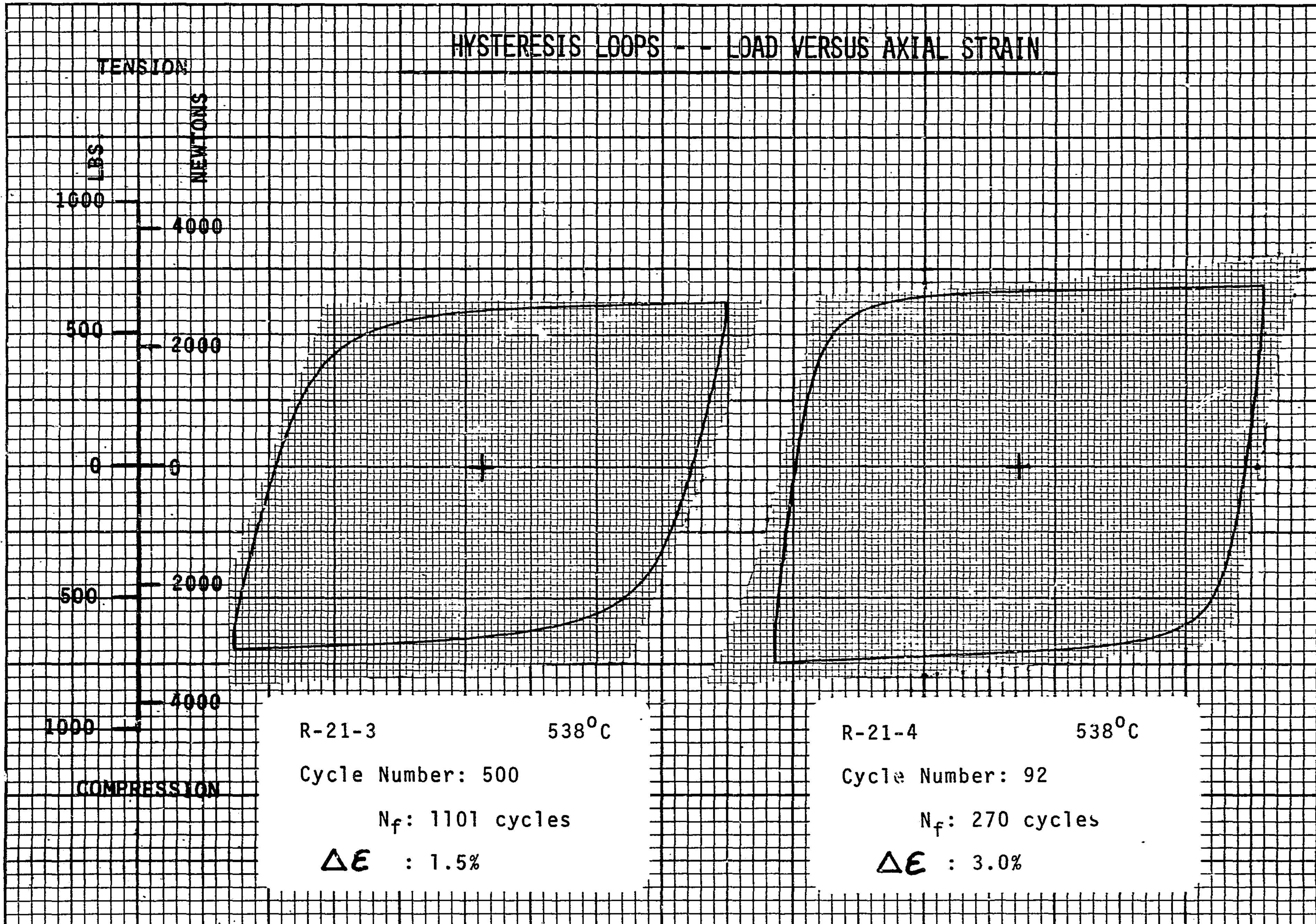

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-24-43 538°C
(300 sec. hold in compr.)
Cycle Number: 1410
N_f: 2981 cycles
ΔE : 0.9%
R-24-45 538°C
(300 sec. hold in compr.)
Cycle Number: 1632
N_f: 3392 cycles
ΔE : 0.9%

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
$\Delta\varepsilon$: 1.5%
R-21-4
538°C
Cycle Number: 92
N_f: 270 cycles
$\Delta\varepsilon$: 3.0%

Figure 270

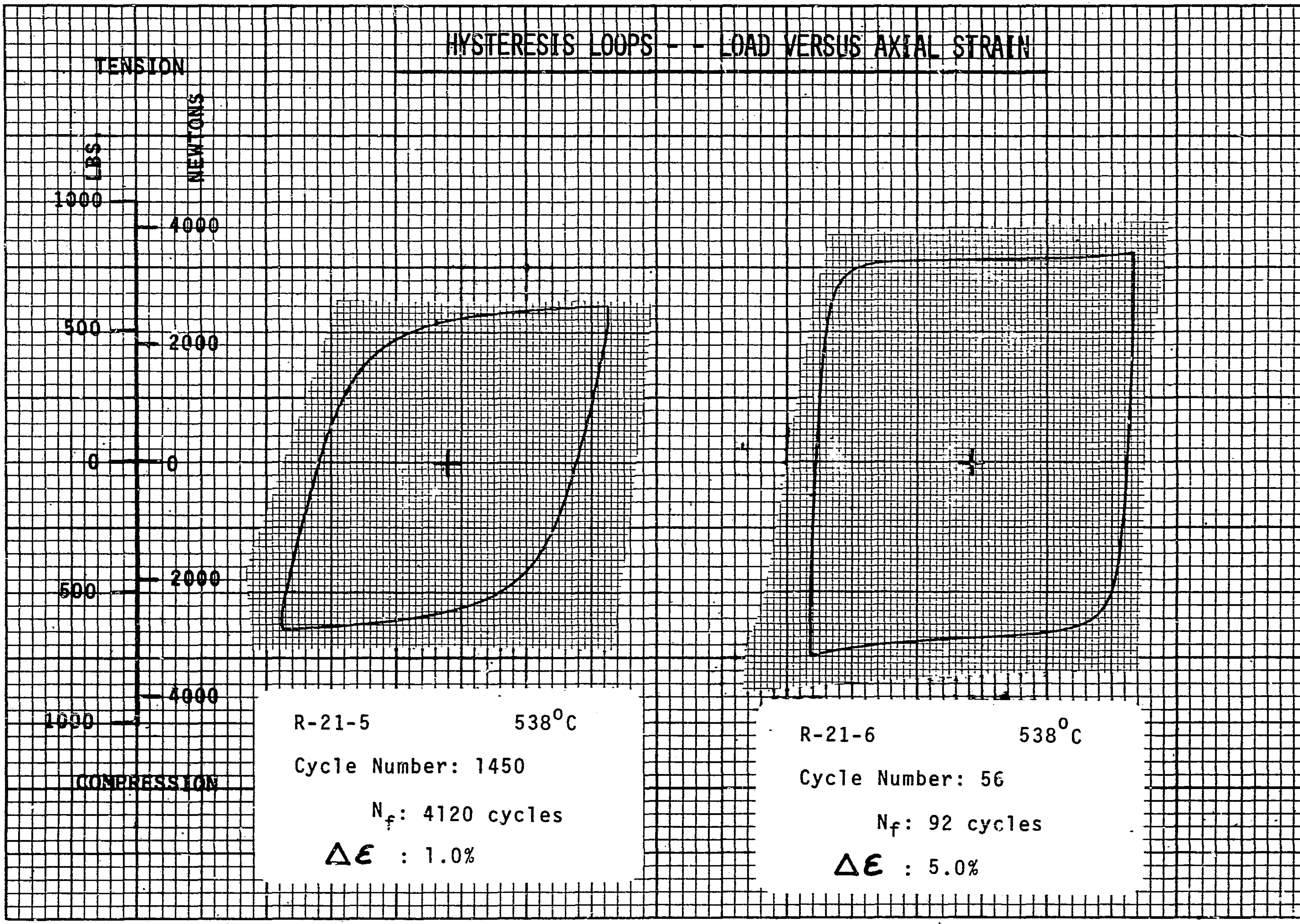

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-21-5
538°C
Cycle Number: 1450
N_f: 4120 cycles
$\Delta\varepsilon$: 1.0%
R-21-6
538°C
Cycle Number: 56
N_f: 92 cycles
$\Delta\varepsilon$: 5.0%

Figure 271

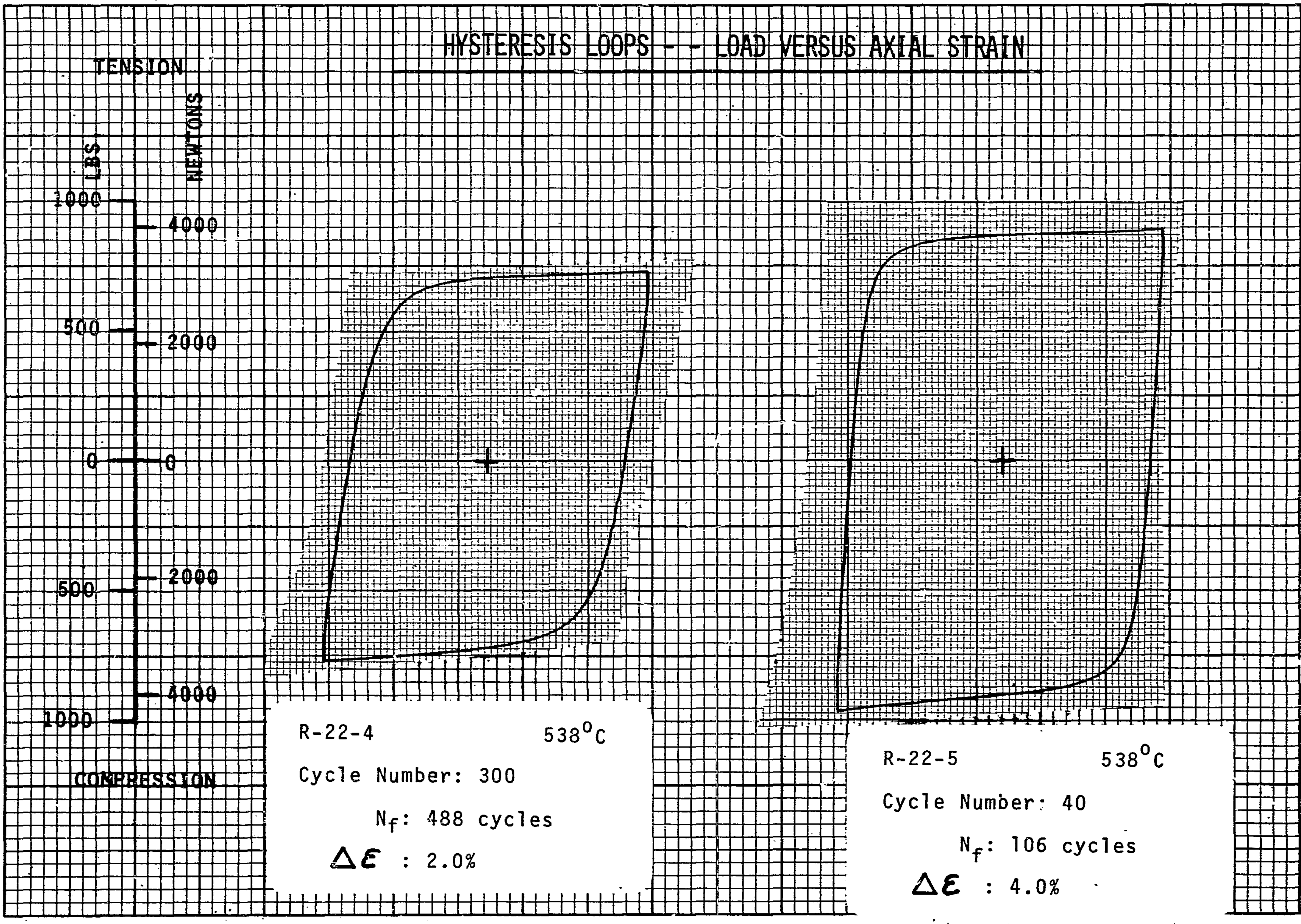

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-4
538°C
Cycle Number: 300
Nf: 488 cycles
ΔE : 2.0%
R-22-5
538°C
Cycle Number: 40
Nf: 106 cycles
ΔE : 4.0%

Figure 272

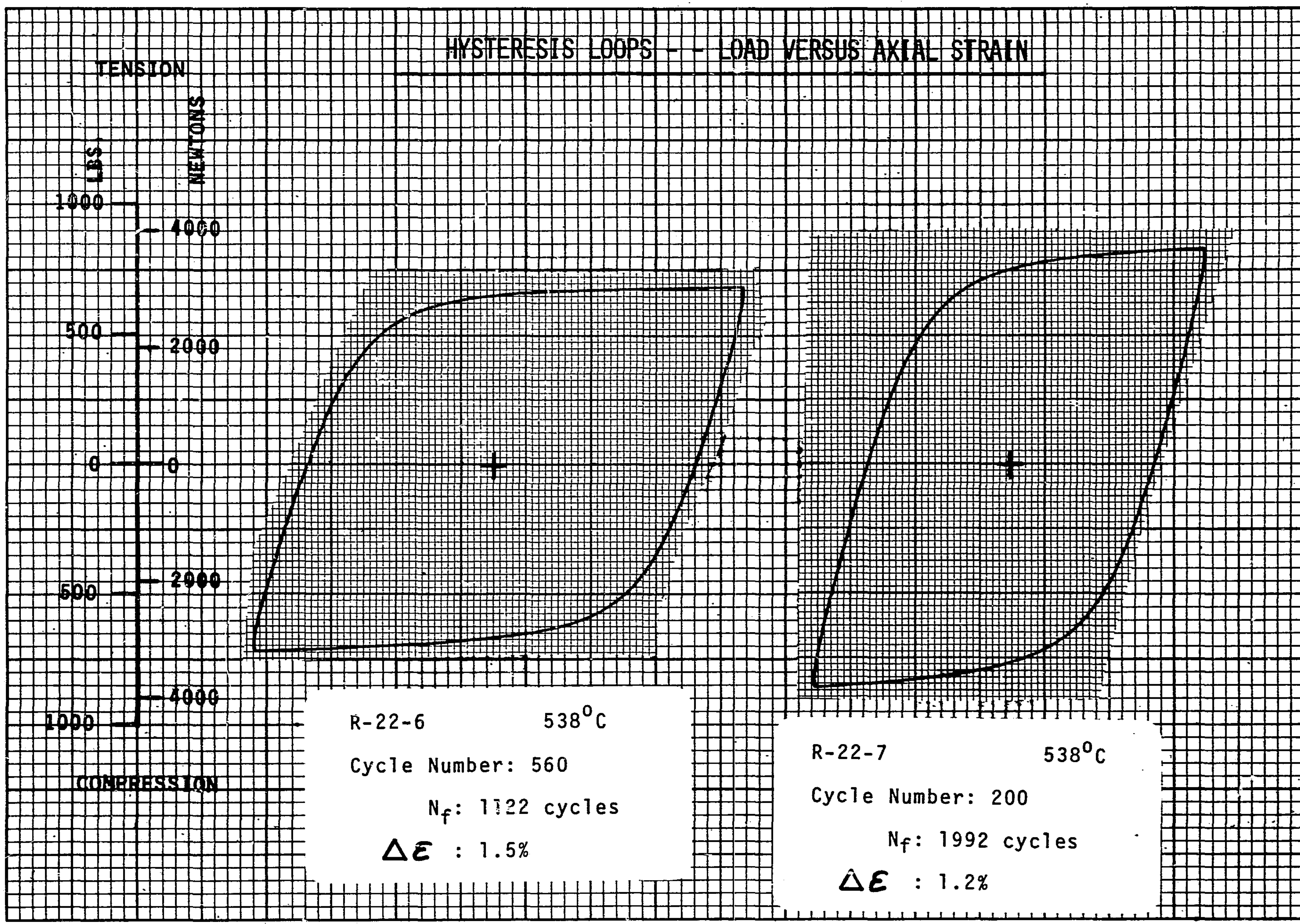

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-6 538°C
Cycle Number: 560
Nf: 1122 cycles
ΔE : 1.5%
R-22-7 538°C
Cycle Number: 200
Nf: 1992 cycles
ΔE : 1.2%

Figure 273

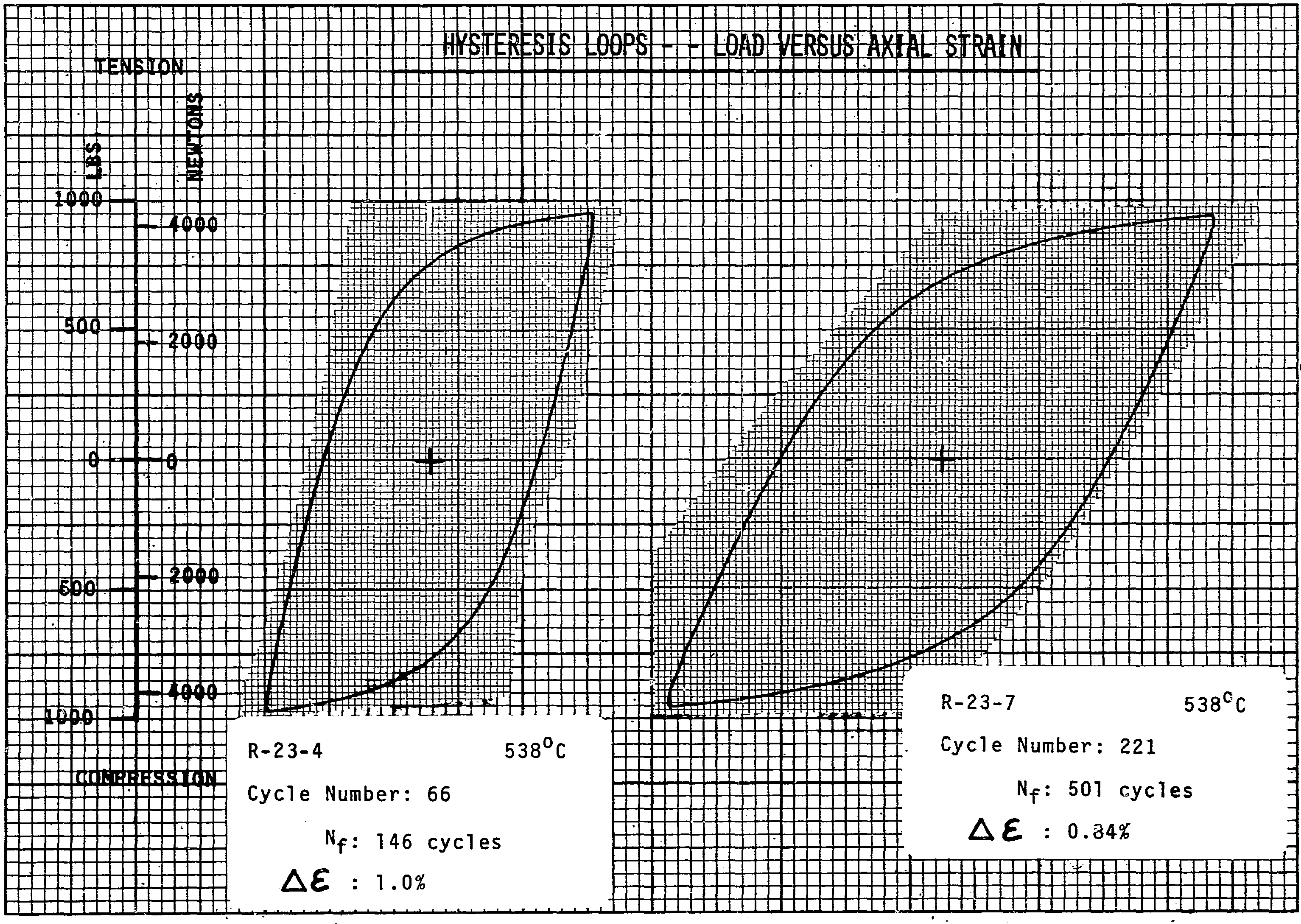

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-23-4
538°C
Cycle Number: 66
N_f: 146 cycles
ΔE : 1.0%
R-23-7
538°C
Cycle Number: 221
N_f: 501 cycles
ΔE : 0.34%

Figure 274

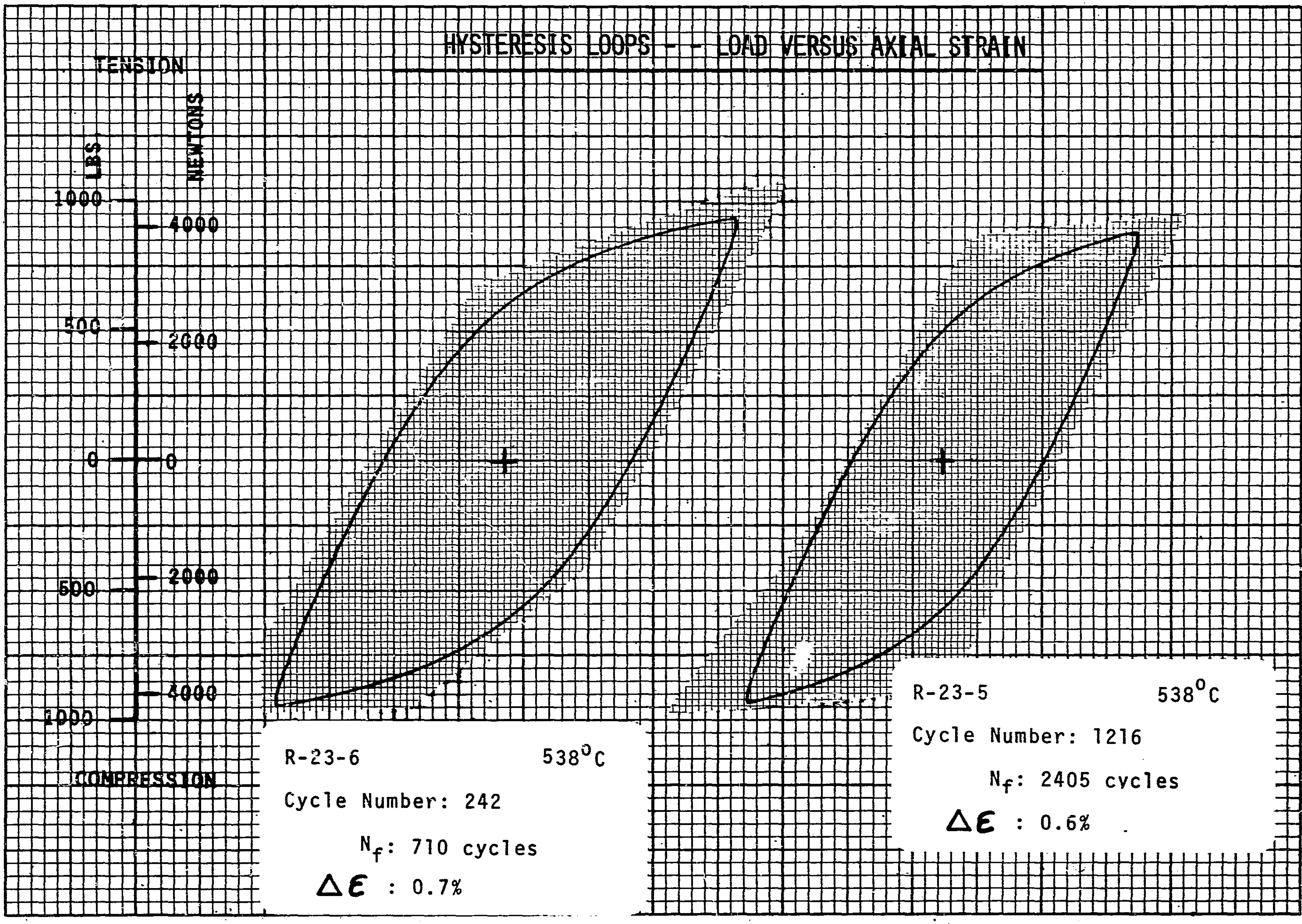
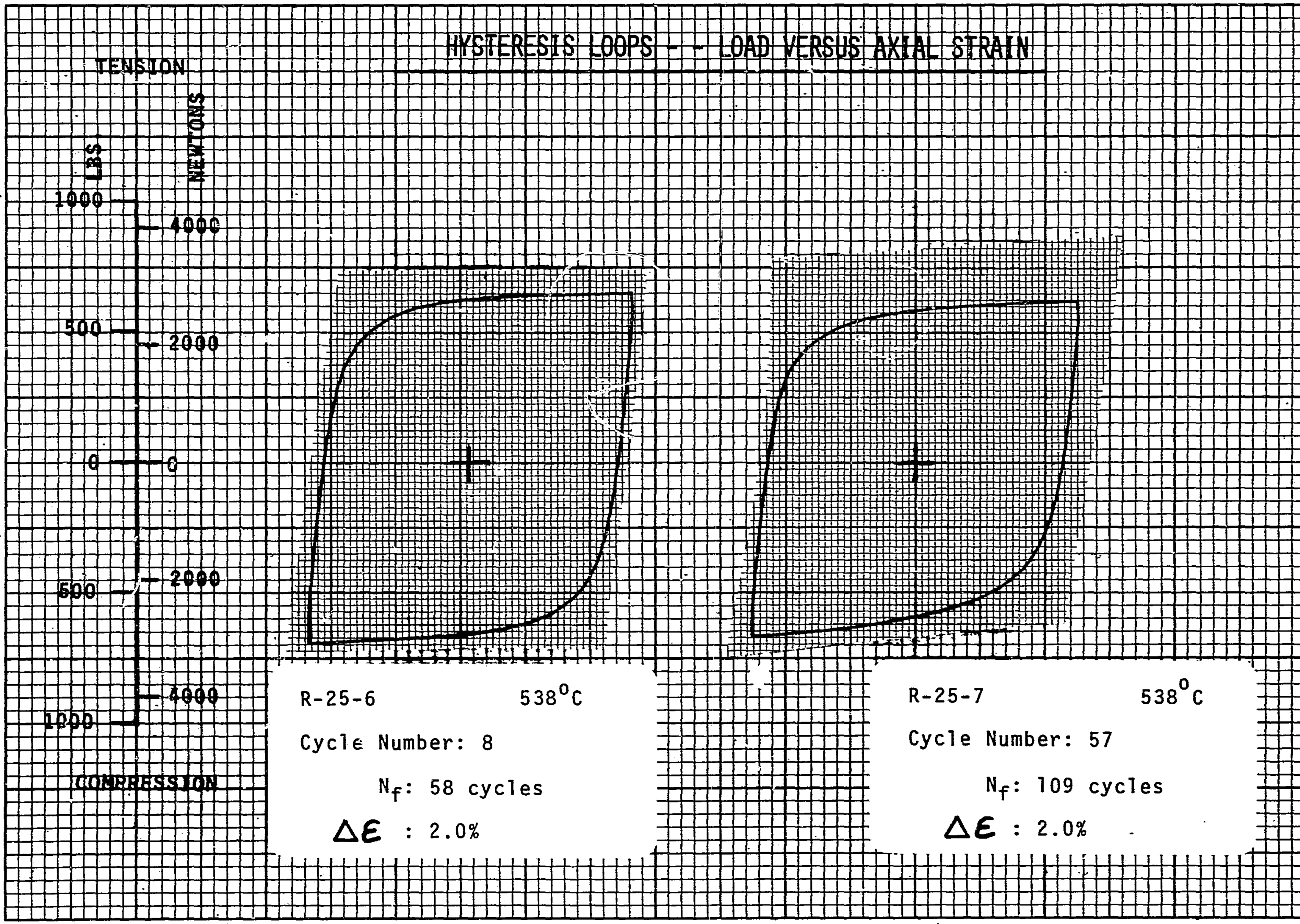

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-23-6
538°C
Cycle Number: 242
N_f: 710 cycles
Δε : 0.7%
R-23-5
538°C
Cycle Number: 1216
N_f: 2405 cycles
Δε : 0.6%

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
Nf: 58 cycles
ΔE : 2.0%
R-25-7
538°C
Cycle Number: 57
Nf: 109 cycles
ΔE : 2.0%

Figure 276

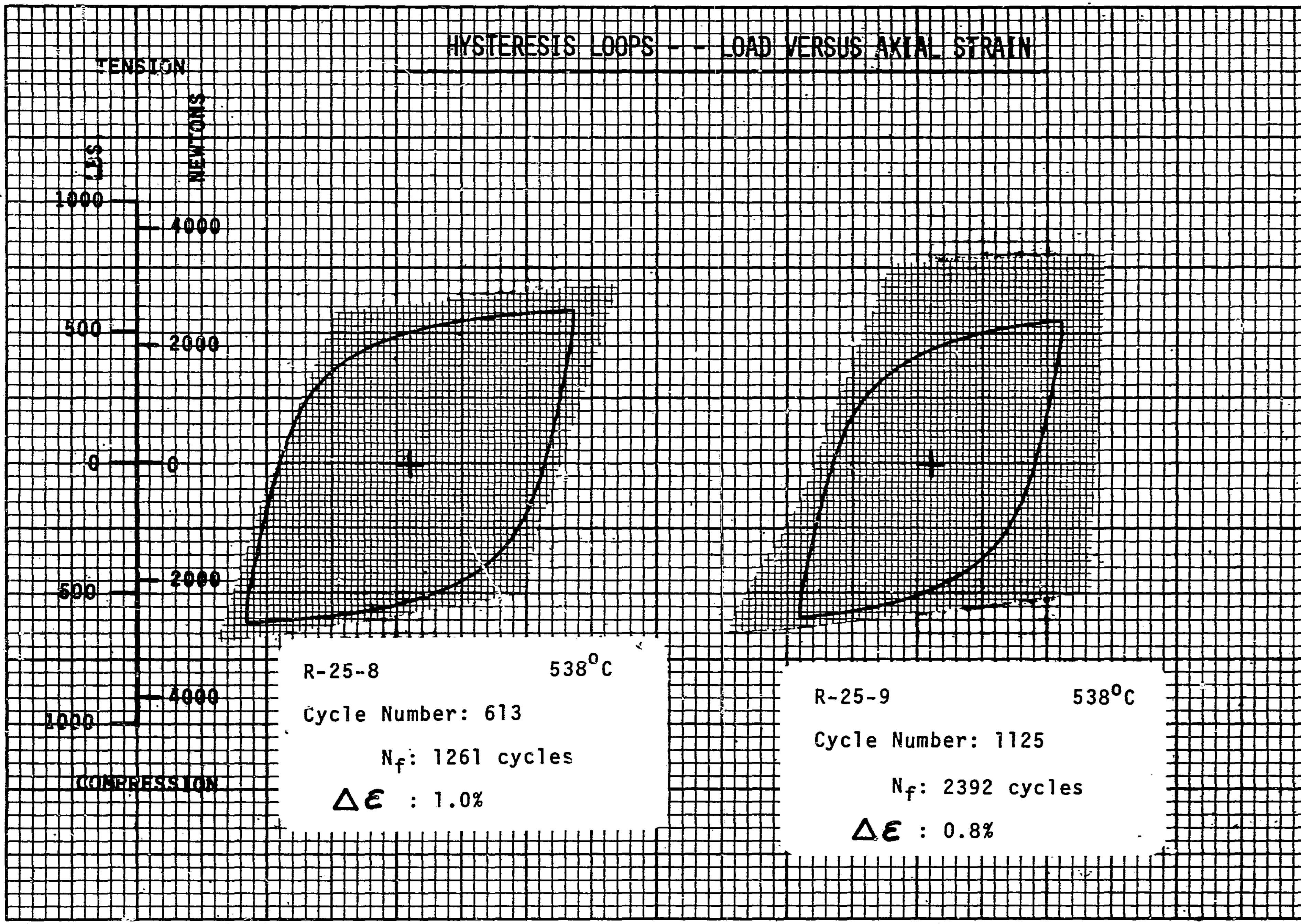

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-25-8
538°C
Cycle Number: 613
Nf: 1261 cycles
Δε : 1.0%
R-25-9
538°C
Cycle Number: 1125
Nf: 2392 cycles
Δε : 0.8%

Figure 277

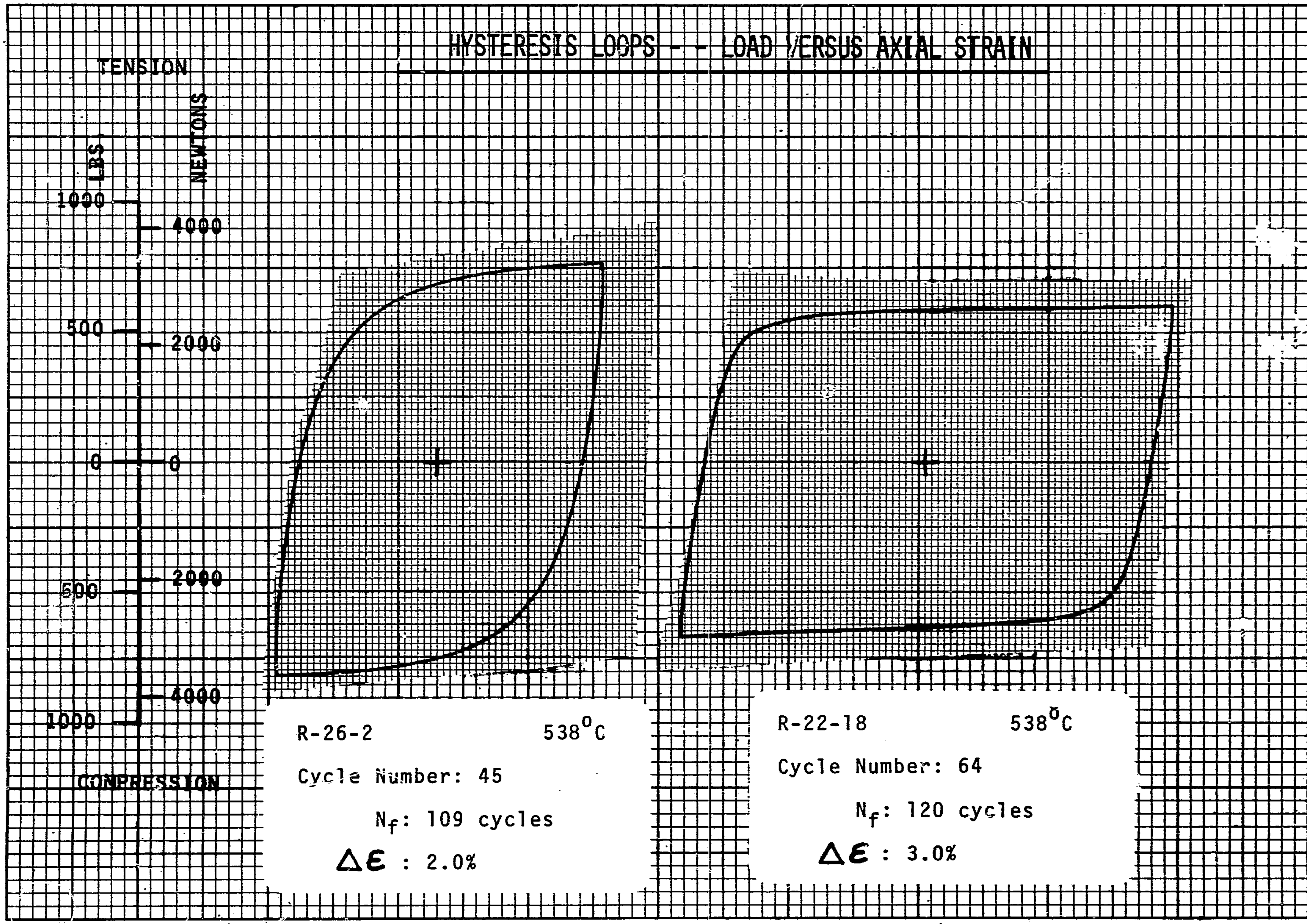

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-26-2
538°C
Cycle Number: 45
N_f: 109 cycles
ΔE : 2.0%
R-22-18
538°C
Cycle Number: 64
N_f: 120 cycles
ΔE : 3.0%

Figure 278

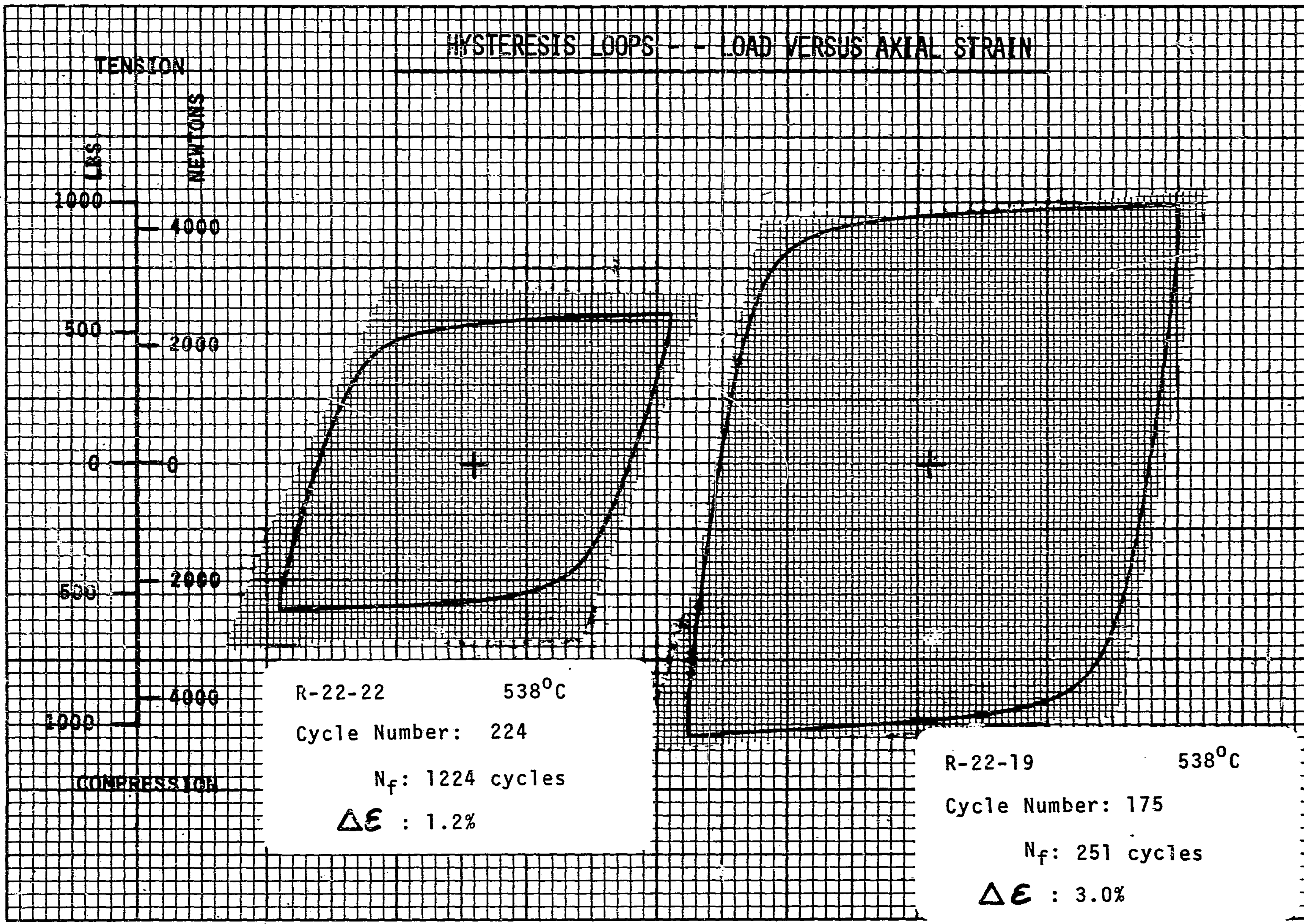

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-22 538°C
Cycle Number: 224
Nf: 1224 cycles
ΔΕ : 1.2%
R-22-19 538°C
Cycle Number: 175
Nf: 251 cycles
ΔΕ : 3.0%

Figure 279

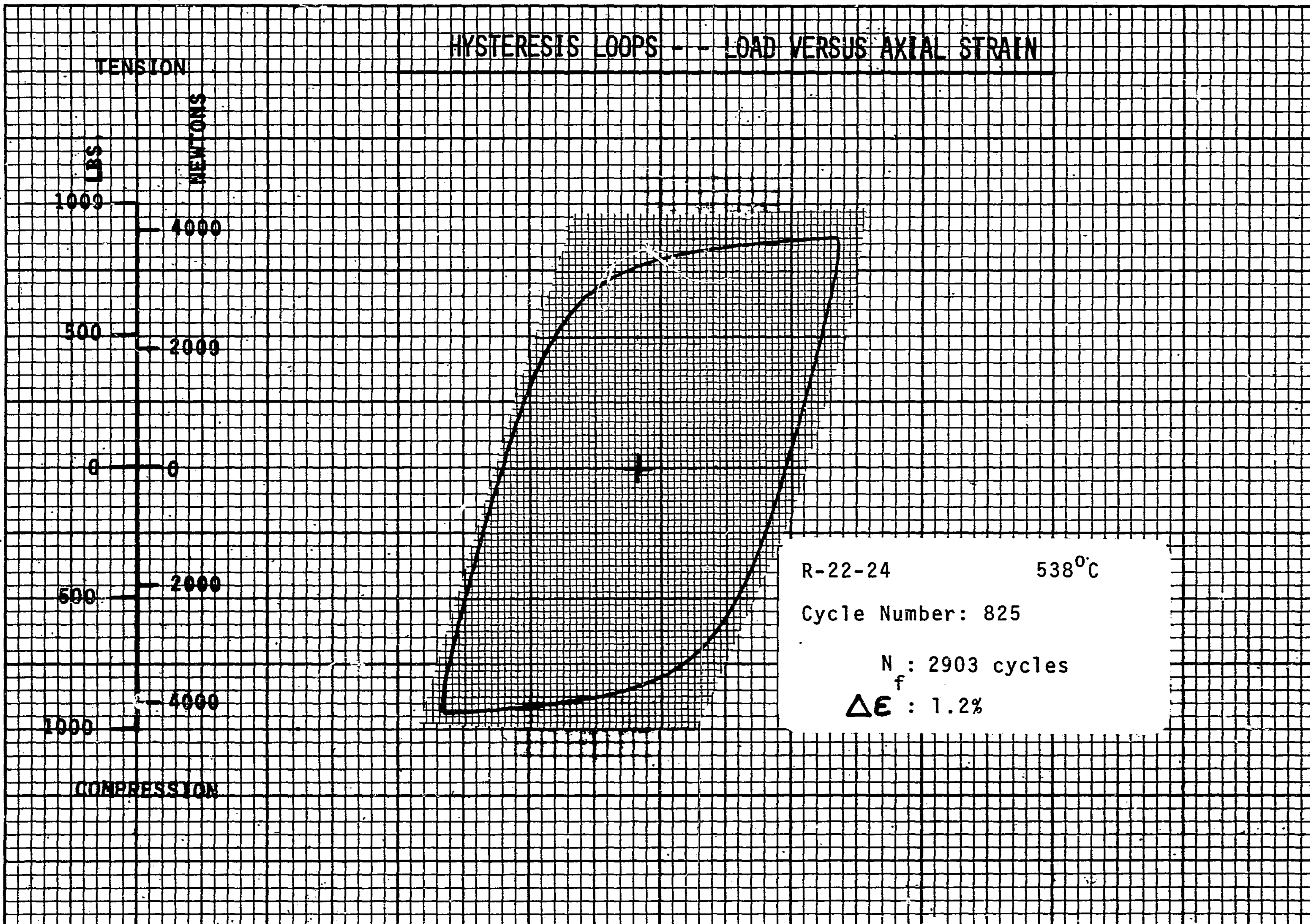

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
1000
4000
COMPRESSION
R-22-24
538°C
Cycle Number: 825
N_f : 2903 cycles
Δε : 1.2%

Figure 280

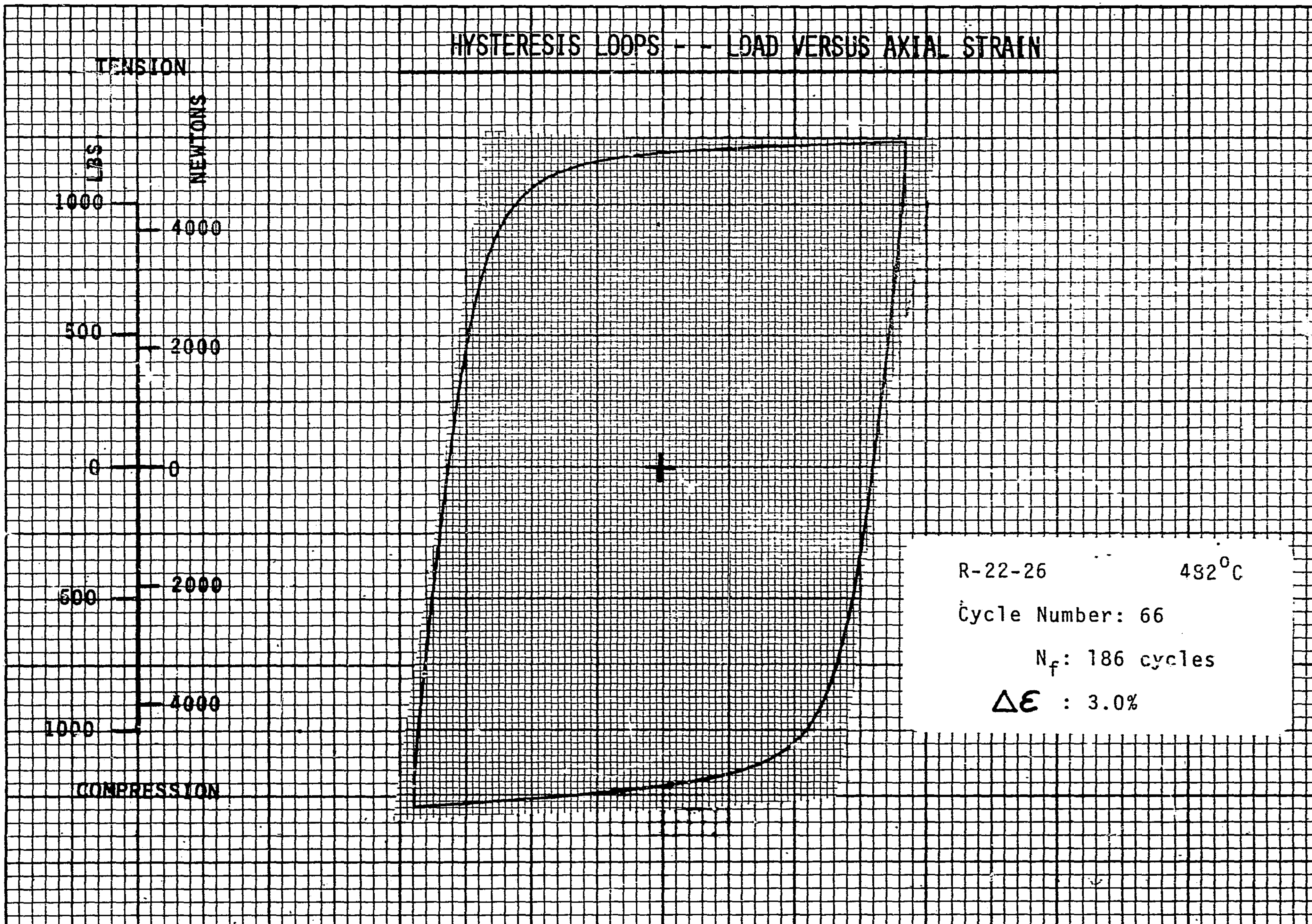

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-26
482°C
Cycle Number: 66
N_f: 186 cycles
ΔƐ : 3.0%

Figure 281

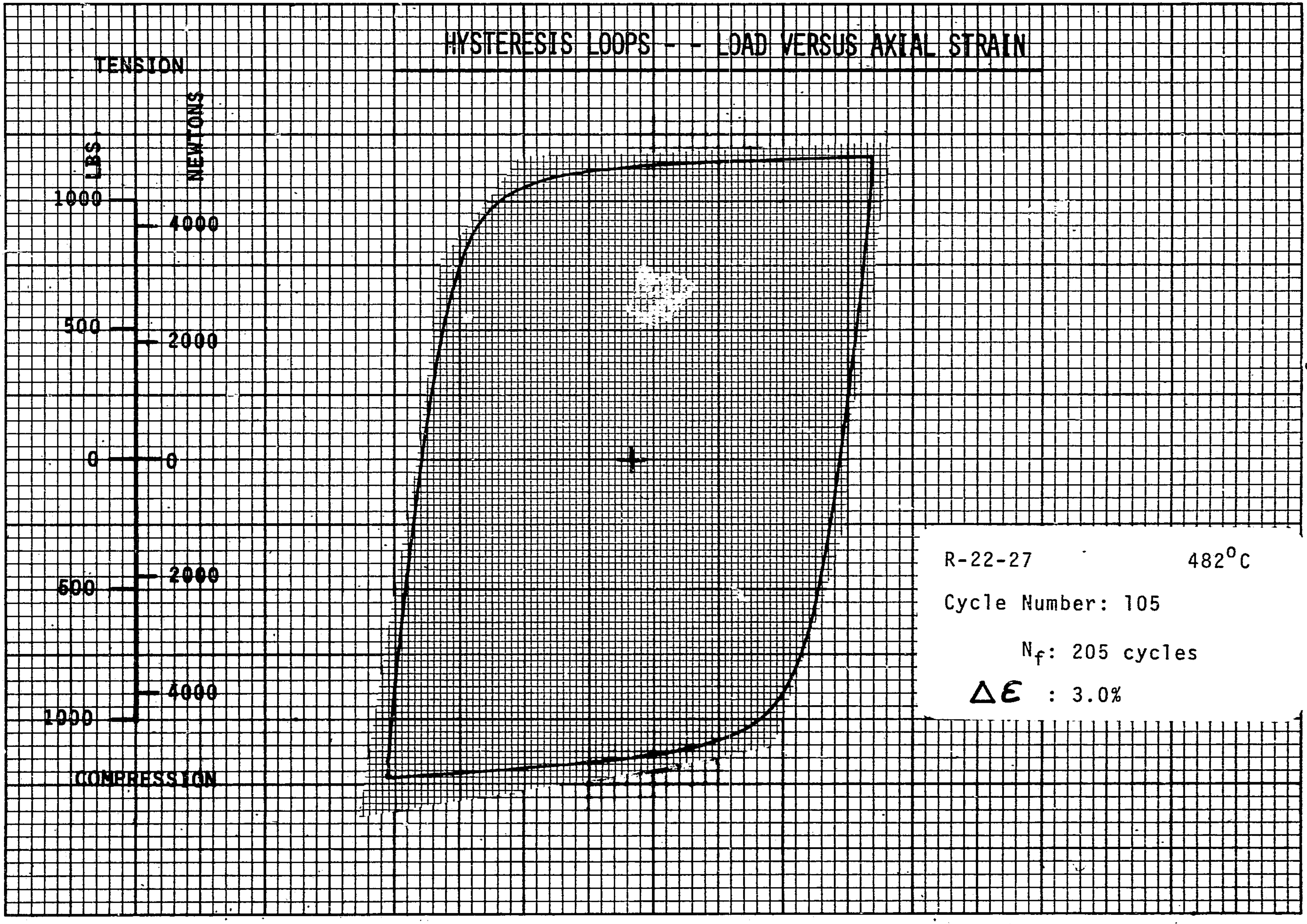

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-27
482°C
Cycle Number: 105
Nf: 205 cycles
ΔƐ : 3.0%

Figure 282

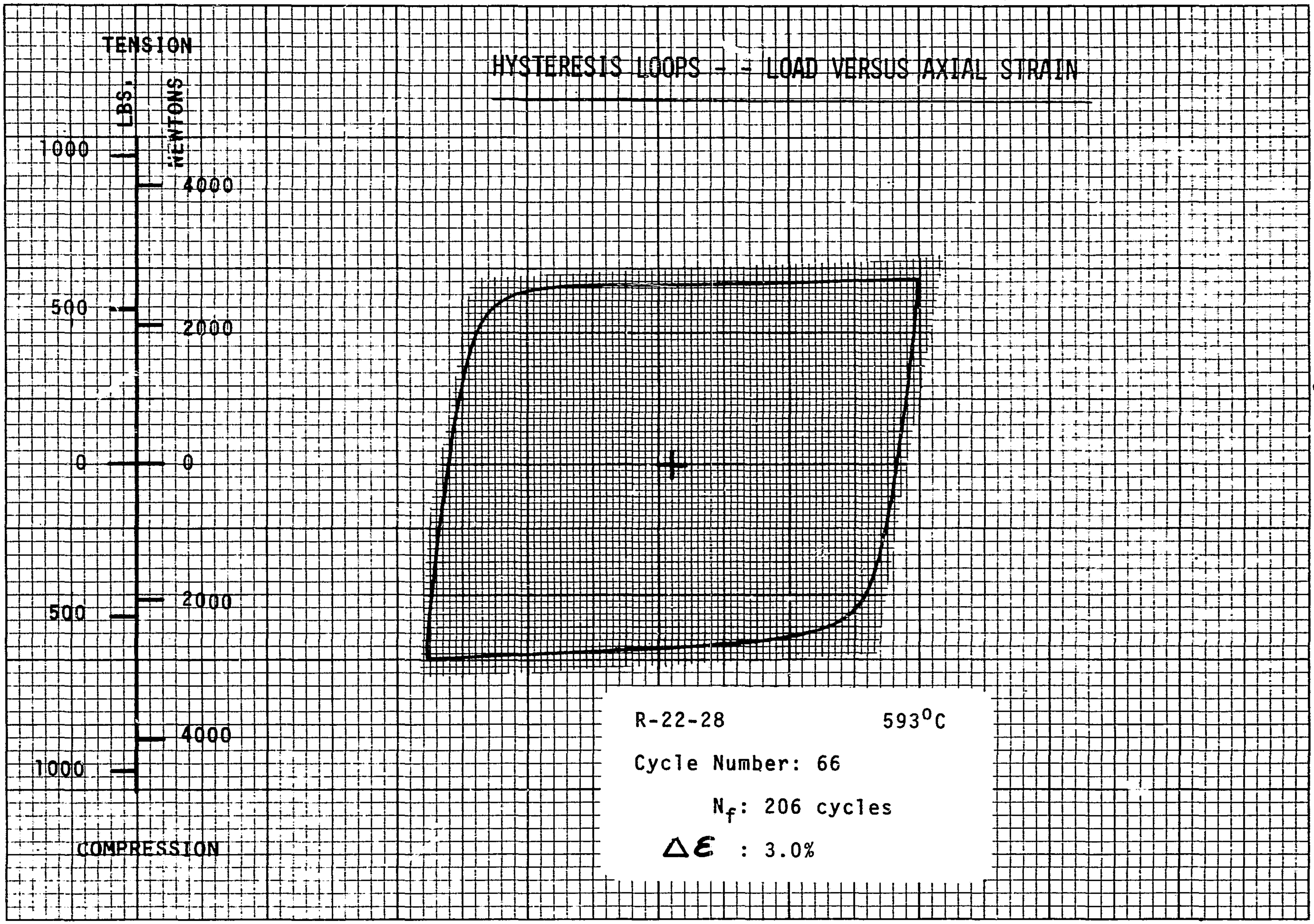

TENSION
HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-28
593^{0}C
Cycle Number: 66
N_f: 206 cycles
$\Delta\varepsilon$: 3.0%

Figure 283

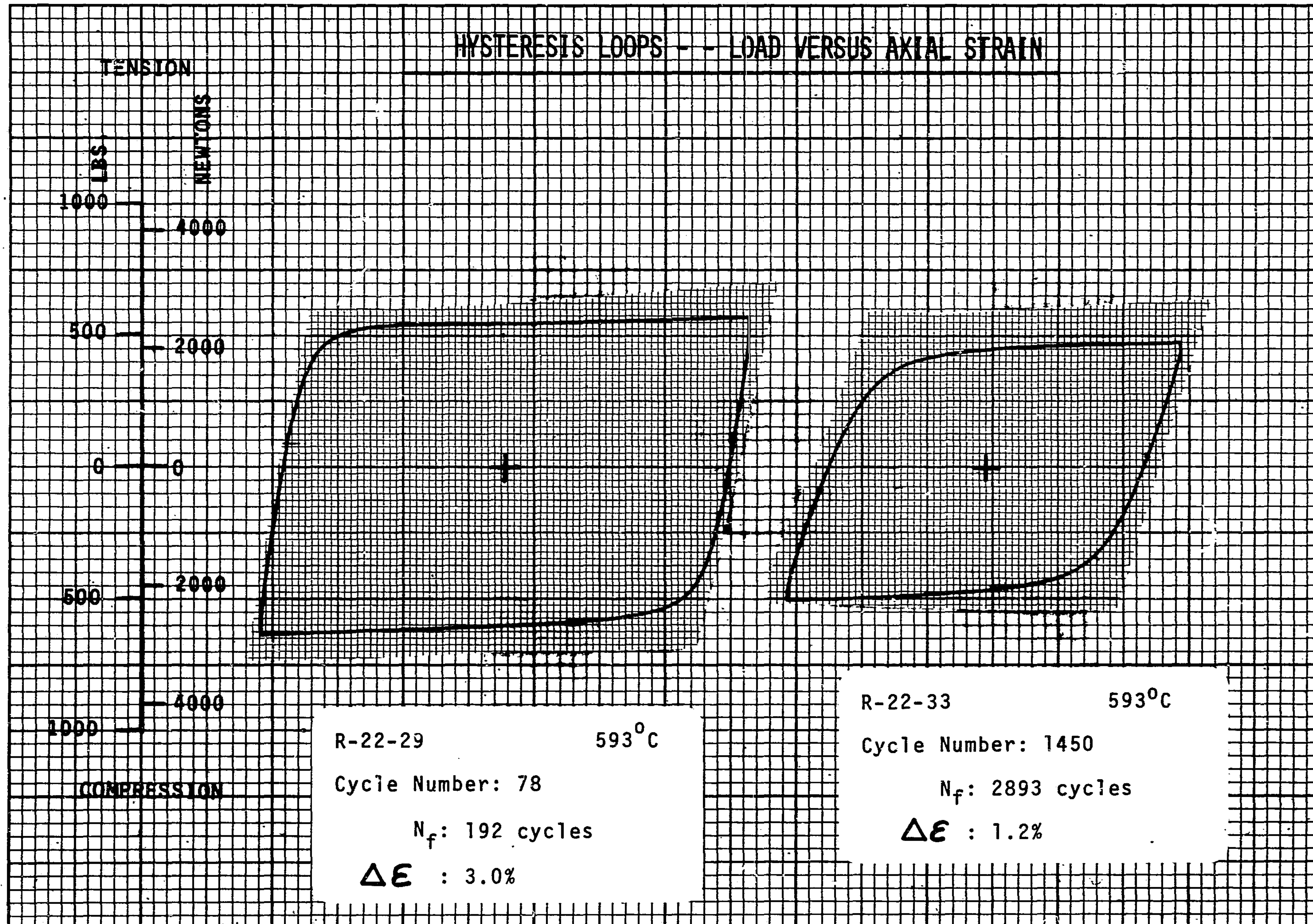

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-29 593°C
Cycle Number: 78
Nf: 192 cycles
ΔE : 3.0%
R-22-33 593°C
Cycle Number: 1450
Nf: 2893 cycles
ΔE : 1.2%

Figure 284

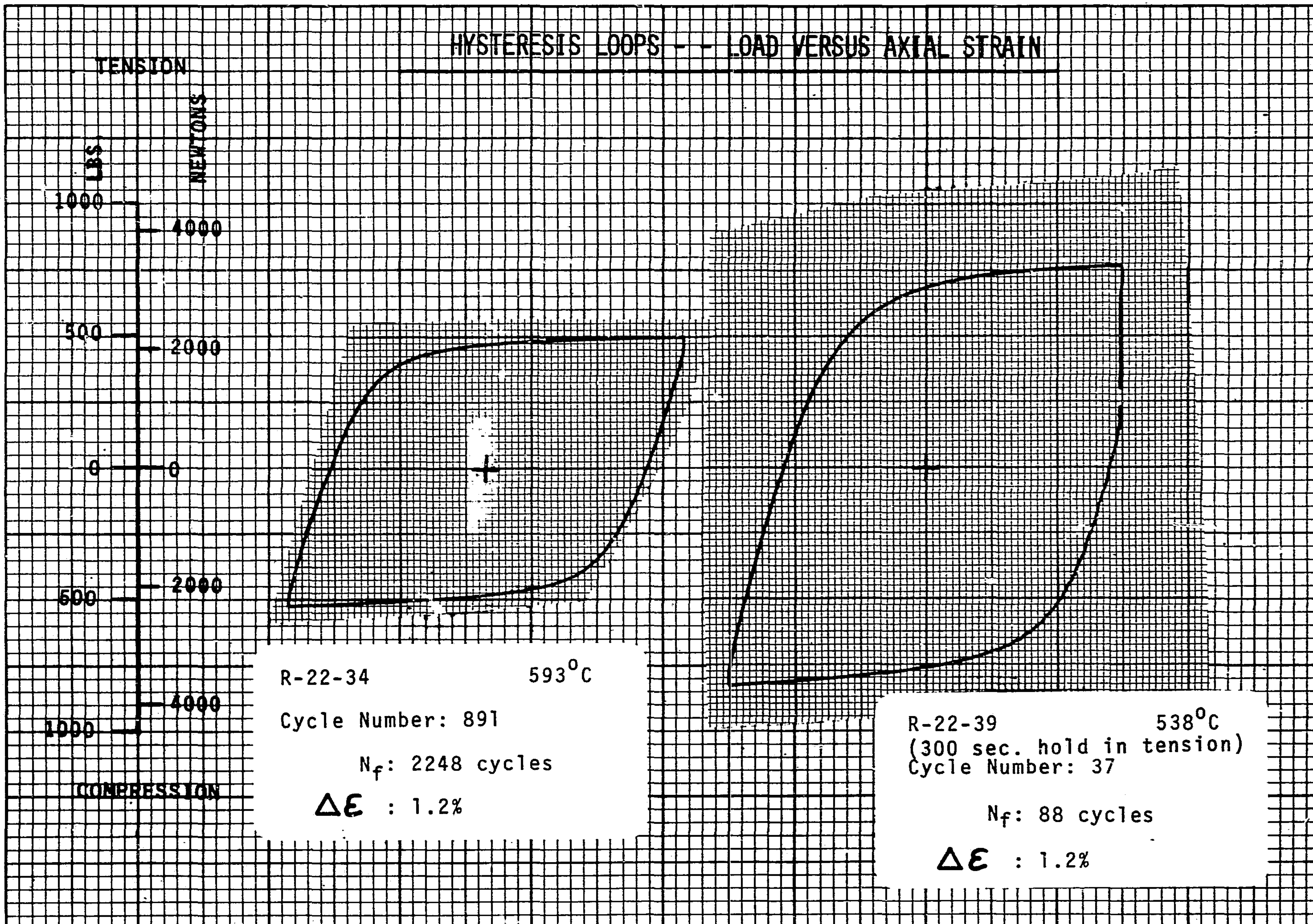

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-34 593^{o}C
Cycle Number: 891
N_f: 2248 cycles
$\Delta\varepsilon$: 1.2%
R-22-39 538^{o}C
(300 sec. hold in tension)
Cycle Number: 37
N_f: 88 cycles
$\Delta\varepsilon$: 1.2%

Figure 285

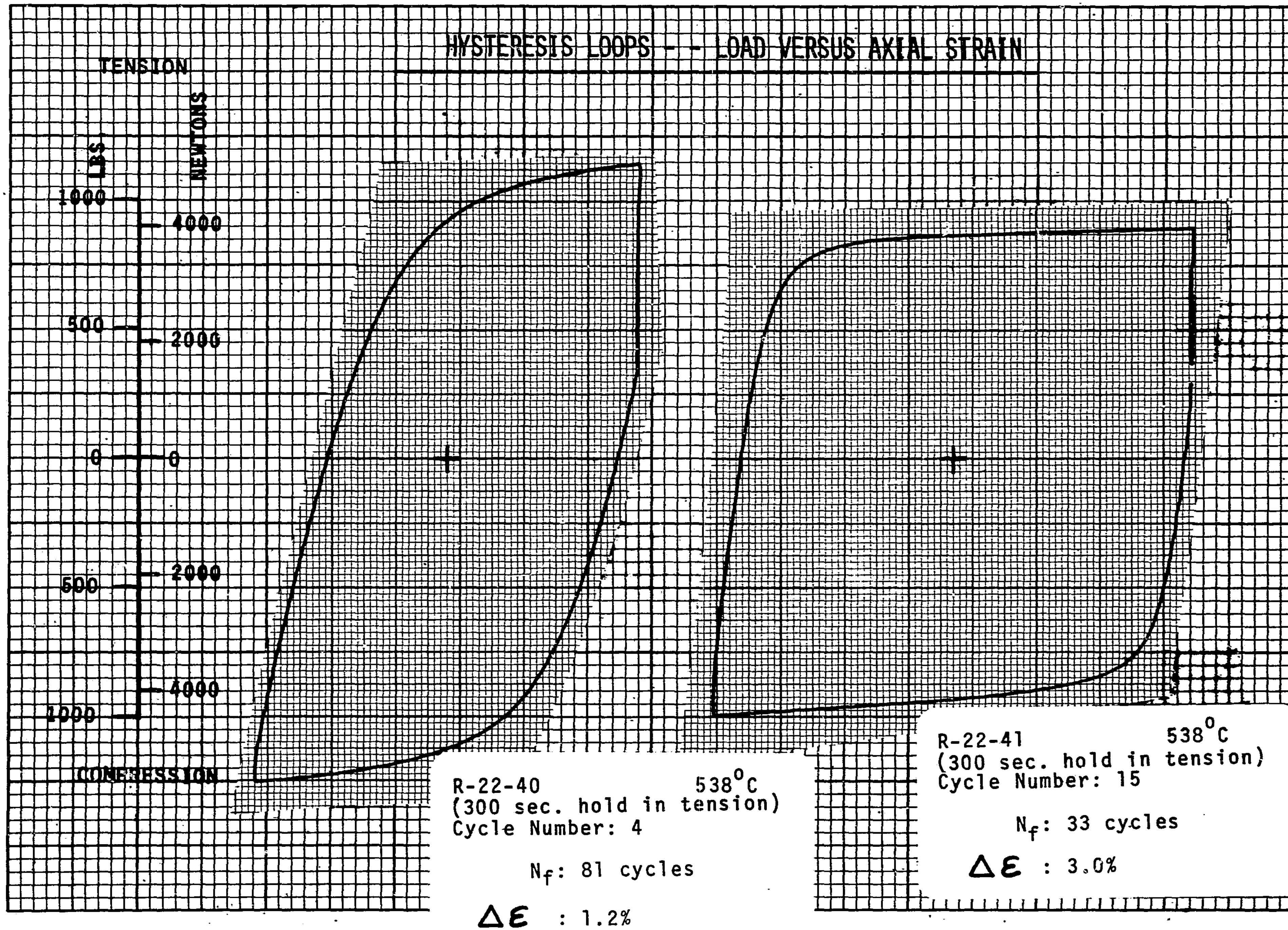

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-40 538°C
(300 sec. hold in tension)
Cycle Number: 4
N_f: 81 cycles
ΔE : 1.2%
R-22-41 538°C
(300 sec. hold in tension)
Cycle Number: 15
N_f: 33 cycles
ΔE : 3.0%

Figure 286

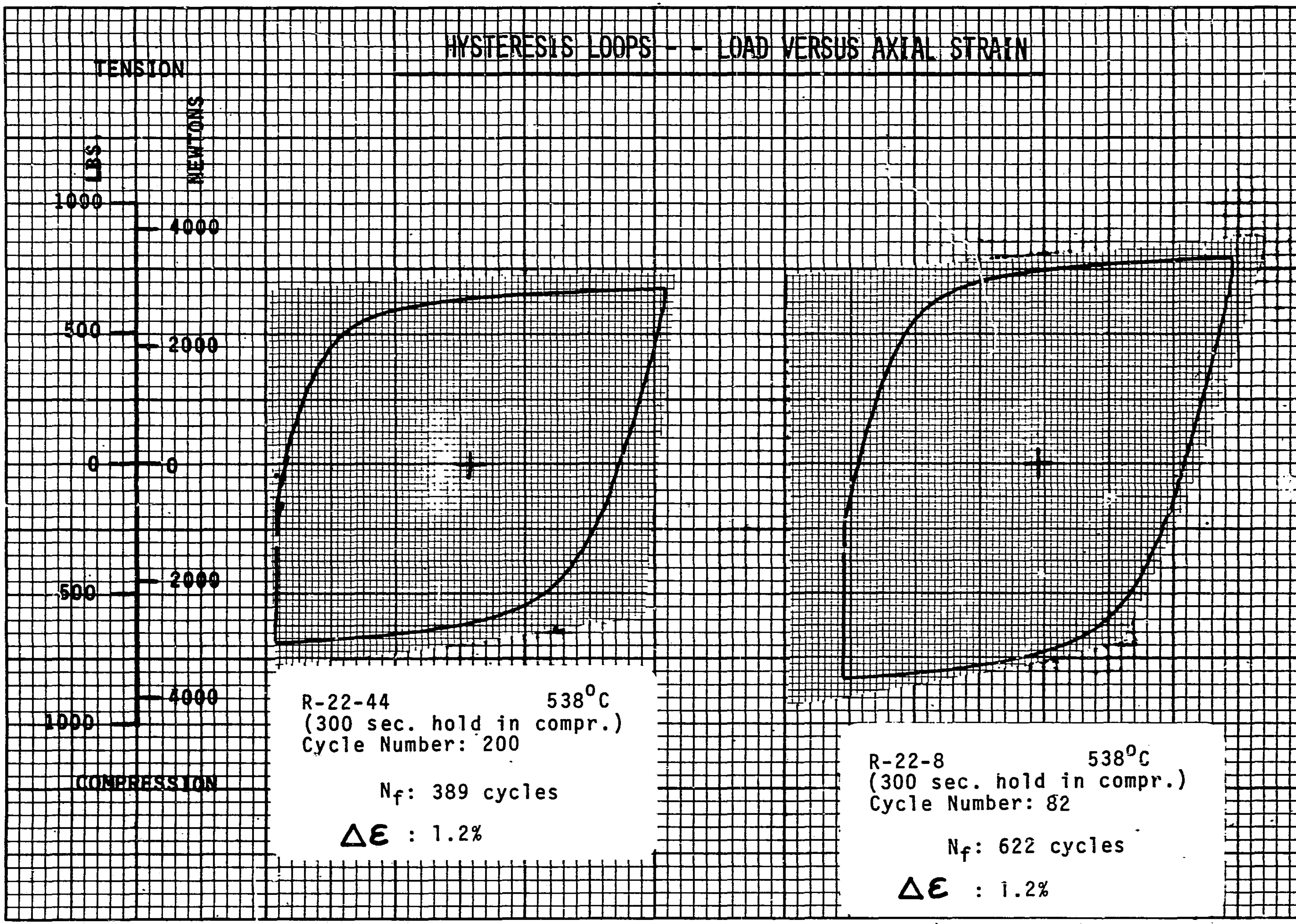

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-44 538°C
(300 sec. hold in compr.)
Cycle Number: 200
Nf: 389 cycles
Δε : 1.2%
R-22-8 538°C
(300 sec. hold in compr.)
Cycle Number: 82
Nf: 622 cycles
Δε : 1.2%

Figure 287

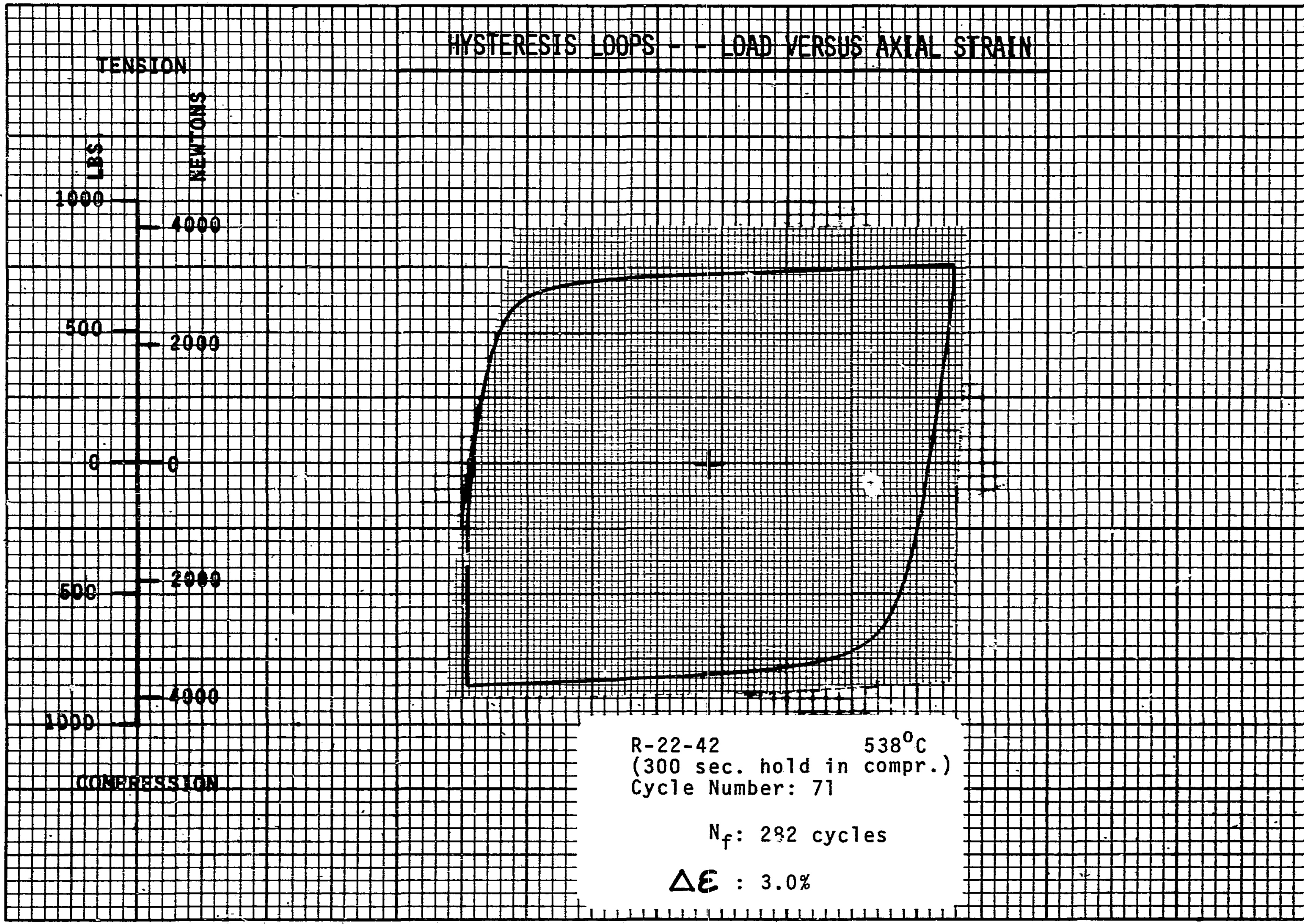

HYSTERESIS LOOPS - - LOAD VERSUS AXIAL STRAIN
TENSION
LBS.
NEWTONS
1000
4000
500
2000
0
0
500
2000
4000
1000
COMPRESSION
R-22-42
538°C
(300 sec. hold in compr.)
Cycle Number: 71
Nf: 282 cycles
ΔE : 3.0%

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

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., °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