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Subject: Laboratory Report DF 58 SL-211: Strain Cycling Tests on Large Specimens of AISI Type 347 Stainless Steel and 2-1/4 Croloy

As requested by Gary L. Stevens (NRC), GE-Hitachi Nuclear Energy Americas LLC (GEH) is providing a copy of the following General Electric laboratory report:

> Schmeider, A. K., and La Cagnina, J. J., Jr., "Strain Cycling Tests on Large Specimens of AISI Type 347 Stainless Steel and 2-1/4 Croloy," Materials and Processes Laboratory Report DF 58 SL-211, General Electric Company, February 1959.

This laboratory report is being provided to the NRC in support of the NRC's efforts in the area of environmentally assisted fatigue. Specifically, the NRC is collecting all references cited in NUREG/CR-6909 "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials." Reference 72 in NUREG/CR-0609 is a 1977 ASME paper (Jaske, C. E., and W. J. O'Donnell, "Fatigue Design Criteria for Pressure Vessel Alloys," Trans. ASME J. Pressure Vessel Technol. 99, 584–592, 1977.) which, in turn, cites the above General Electric laboratory report as Reference 13 of the paper.

If you have any questions, please contact me.

Sincerely,

James F. Harrison

James F. Harrison
Vice President, Fuels Licensing
Regulatory Affairs
GE-Hitachi Nuclear Energy Americas LLC

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Enclosure:

1. Laboratory Report DF 58 SL-211 – Non-Proprietary Information – Class I (Public)

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ENCLOSURE 1

MFN 13-009

Laboratory Report DF 58 SL-211

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TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO. / DATE
AK Schmieder JJ LaCagnina, Jr	Fatigue, Low Cycle AISI Type 347 Stainless Steel 2-1/4 Croloy	NO. DF58SL211 DATE Feb. 9, 1959

TITLE
STRAIN CYCLING TESTS ON LARGE SPECIMENS OF AISI TYPE 347 STAINLESS STEEL AND 2-1/4 CROLOY.

ABSTRACT
Twenty-one specimens one inch in diameter were tension-compression strain cycled to failure. Six specimens had transverse holes. Load-strain and load-time records were made. The unit strain ranges used were 0.026 and 0.009. The stainless steel specimens were tested at 662°F (350°C), the 2-1/4 Croloy specimens at 850°F.

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CONCLUSIONS

1. The cyclic life of a specimen with a hole can be predicted from smooth specimen tests by using the elastic stress concentration factor increased by 15%.

2. In the commonly used exponential relationship between cycles to failure (N) and strain range ($\Delta\epsilon_p$) $N^K \Delta\epsilon_p = c$; the material constants are:

   for AISI type 347 stainless steel; K = 0.50, c=0.42
   for 2-1/4 Croloy; K = 0.81, c=2.44

3. Comparing these tests with those made by others indicates that AISI Type 347 stainless steel exhibits a pronounced size effect. The cyclic life at the same plastic strain range is reduced to about one half as the specimen diameter is increased from 0.1875 to 1.0 inches. The size effect is negligible for 2-1/4 Croloy.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

For list of contents—drawings, photos, etc. and for distribution see next page (FN-610-2).

INFORMATION PREPARED FOR E. E. Baldwin, KAPL

TESTS MADE BY J. J. La Cagnina

COUNTERSIGNED D. P. Timo DIV. Electromechanical Engineering Unit

DIVISIONS M & P Laboratory LOCATION Schenectady, N. Y.

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I. INTRODUCTION

These tests subjected the specimens to successive tensile and compressive strains of equal magnitudes up to about 1%. A few tests were made holding the tensile and compressive load limits constant instead of strain limits. All tests were at elevated temperatures. The variation of load with time was recorded in some cases. Periodically load vs. strain was recorded for several cycles. Two series of tests were made, the first on AISI type 347 stainless steel, and the second on 2-1/4 Croloy. The report also contains values for some other mechanical properties of the materials.

II. DESCRIPTION OF THE SPECIMENS AND APPARATUS

The specimens were made according to Figure 1 unless otherwise noted. A few specimens differed in that the test section was rectangular in cross section or that drilled holes were added. The test section was finished by wet grinding with very light cuts. The values of surfaces roughness were obtained by using a recording profilometer after the cycling tests were completed.

The cycling tests were made using the 150,000 lb. capacity Baldwin machine type SR4UN1V. This machine is equipped with controls for automatically cycling between strain limits or load limits. Since standard strain gages could not be used at the elevated test temperature, a special extensometer was made. To avoid marking the gage length, the extensometer heads were attached to the shoulders of the specimen. One head was attached by three tightly fitted wedges driven into the groove shown in Figure 1. The other head was attached by tightly fitted pins inserted in the holes shown in Figure 1. Extension rods and tube attached to these heads passed through the bore hole in the specimen holders as shown in Figure 2. Above the furnace, two independent sets of displacement pickups were mounted between arms attached to the extension rod and tube. One displaced pickup consisted of the sensing elements of a standard SR4 extensometer. The signal from these operated the cycling control and one coordinate of the load strain records. The other independent displacement pickup consisted of a pair of Plunjets, one at the compression strain limit and the other at the tensile strain limit. Displacement was read by a dual Precisionaire whose float moves approximately 1 inch per .001 inch movement of the Plunjets. The Plunjets were used to set the strain limits and monitor them throughout the test. A micrometer head was placed in a series with each of four displaced transducers. These were used to adjust and calibrate the gages. During the second series of tests on 2-1/4 Croloy, a linear differential transformer was added and a strain time record made. The external parts of the strain measuring system without the transformer pickup are shown in Figure 3.

The specimens were held in threaded couplings which were securely bolted to the machine heads. The specimens and couplings were heated by the three zone furnace shown in Figure 2. Each zone was independently controlled by a thermocouple on the specimen. The accuracy of temperature control is estimated to be $\pm$ 10F°.

III. TEST RESULTS

The test results are summarized in Tables I, II and III except for the photomircographs shown in Figure 4.

TABLE I MATERIAL PROPERTIES AND TEST RESULTS FOR AISI TYPE 347 STAINLESS STEEL

Specification, Mil-S-18170 Heat No. 81701 Manufacturer, Alleghany Ludlum Source of Supply KAPL-N-P-D-19919

Description, 3" diameter bar stock, mill annealled. Grain size A.S.T.M. No. 8

* Chemical Analysis	C	Ni	Cr	Cb	Co	Mn	Si	P	S	Ta
	.036	9.73	18.29	.41	.10	1.35	.31	.020	.015	.10

* Room temperature tensile properties: tensile strength 83,500 psi, .2% yield strength 40,750 psi, elongation 58.5% and reduction in area 74.5%

* Hardness: Brinell hardness number 149-159 Rockwell "A" hardness Bar No. 3 near surface 57, near center 50
Bar No. 4 near surface 61, near center 50

RESULTS OF CYCLIC LOAD TESTS AT 662°F (350°C)

Tests numbered 1 through 9 were on the smooth cylindrical specimens shown in Figure 1

Specimen No.	Bar No. (1) **	Set Strain Limits at the Shoulders, Inches	Calculated Unit Strain Range in Gage Length (6)	Average Speed, Cycles per Hour	Cycles to First Crack (3)	Cycles to Failure (3)	Ratio of Two Proceeding Columns	Most Frequent Max. Average Stress, Thousand Psi (4)	Foot Notes See Page 4	Surface Roughness Measurements Microinches rms Fillet (5)	Surface Roughness Measurements Microinches rms Gage Length (5)
1	4	± .040	0.0264	77	—	434	—	± 48		6	12
2	3	"	"	31	300	—	—	± 48		10	13
3	3	"	"	31	299	325	.92	± 48		5	9
4	3	"	"	168	—	181	—	± 53	(A)	14	8
5	3	"	"	216	340	370	.92	± 49		12	10
6	4	"	"	276	255	285	.89	± 49		8	13
7	3	± .016,?	—	278	2650	2709	.94	± 39,47	(B)	3	5
8	3	± .016	0.0092	325	3720	4055	.92	± 38		5.5	—
9	4	"	"	258	2359	2804	.84	± 37	(C)	5.2	7.4

Specimens 10, 11, 12 had rectangular cross sections approximately 1" X .75" with a .25" hole through the center of the wide face. The cycling was controlled by set loading limits.

Specimen No.	Bar No.	Set Strain Limits	Calculated Unit Strain Range	Average Speed	Cycles to First Crack	Cycles to Failure	Ratio	Most Frequent Max. Average Stress	Foot Notes	Fillet	Gage Length
10	4	± .0145	—	300		516		± 38		5	4
11	3	± .015	—	Approxi-		620		± 39		5.4	4
12	3	± .0155	—	mately		576		± 39		8	4.2

* Test results marked with an asterisk were supplied with the material.

** Numbers in parenthesis identify items which are discussed further on Page 5.

TABLE II MATERIAL PROPERTIES AND TEST RESULTS FOR 2-1/4 CROLOY

Manufacturer B & W. Heat No. 10834. Three, 3-1/2 inch bars, 90 inches long. Heat treatment 1658 ± 25°F, 1 hr. F.C. to R.T.

* Chemical Analysis	C	Mn	P	S	Si	Cr	Ni	Mo	Ca
	.110	.43	.016	.019	.36	2.21	.14	.96	.10

Room temperature tensile properties from standard .505" diameter specimens

Bar number	CS	CS	CS1	CS1
Tensile strength, psi	78,500	78,200	78,200	78,650
.2% Yield strength, psi	39,050	39,050	37,100	38,050
Elongation in 2", %	31.5	31.0	33.5	33.0
Reduction in Area, %	68.8	69.9	70.1	69.3

Hardness Rockwell "A" Bar CS 46.5 - 49.5 Bar CS1 49.5 - 51.0 Grain size ASTM No. 4-5

RESULTS OF CYCLIC LOADING TESTS AT 850°F, CONTROLLED BY STRAIN LIMITS

Tests on specimens numbered 1 through 6 were on the smooth cylindrical specimens shown in Figure 1

Specimen No	Set Strain Limits at the Shounders, Inches	Calculated Unit Strain Range in Gage Length	Average Speed, Cycles per Hr.	Cycles to First Crack	Cycles to Failure	Ratio of Two Proceeding Columns	Most Frequent Max. Average Stress, Thousand Psi	Surface Roughness Measurements Microinches, rms (5) Fillet	Gage Length
C-1	± .040	0.0264	82	311	371	0.84	± 51	40	40
C-2	"	"	82	230	271	0.85	± 52	20	20
C-3	"	"	82	320	342	0.93	± 53	32	—
C-4 (2)	± .016	0.0084	116	880	1065	0.83	± 53	25	13
C-5	"	0.0092	131	1500	1760	0.85	± 43	40	30
C-6	"	"	144	1300	1670	0.78	± 42	48	17

Tests numbered 7 through 9 were on similar specimens except that a diametral hole was made by a 0.0595 inch diameter drill in the center of the gage length.

Specimen No	Set Strain Limits	Calculated Unit Strain Range	Average Speed	Cycles to First Crack	Cycles to Failure	Ratio	Max. Average Stress	Fillet	Gage Length
C-7	± .016	—	131	228	280	0.81	± 48	40	14
C-8	± .016	—	131	264	317	0.83	± 45	34	23
C-9	± .016	—	131	253	296	0.85	± 48	58	24

TABLE III

EXAMPLES OF STRAIN HARDENING DURING THE FIRST CYCLES

Stainless Steel, Specimen 6, 2.64% Strain Range

Cycle	1	2	3	4	5	6	Stabilized
Max. Tension, 10^3 psi	34.2	41.2	45.0	46.2	48.1	48.7	49
Max. Compression, 10^3 psi	40.1	43.5	45.9	47.4	48.1	48.1	49

AISI Type 347 Stainless Steel Specimen 8, 0.92% Strain Range

Cycle	1	2	3	5	10	30	Stabilized
Max. Tension, 10^3 psi	33.4	35.0	36.0	36.3	38.8	39.1	38
Max. Compression, 10^3 psi	34.4	35.0	36.6	37.5	38.8	39.4	38

2-1/4 Croloy Specimen 2, 2.64% Strain Range

Cycle	1	2	5	Stabilized
Max. Tension, 10^3 psi	38.2	48.6	52.1	52
Max. Compression, 10^3 psi	44.7	51.0	51.6	52

2-1/4 Croloy Specimen 5, 0.92% Strain Range

Cycle	1	2	3	4	5	Stabilized
Max. Tension, 10^3 psi	30.2	35.4	--	39.5	41.1	43
Max. Compression, 10^3 psi	33.8	37.3	--	41.1	41.8	43

FIRST FOUR LOADINGS AND HARDNESS, ALL 2-1/4 CROLOY SPECIMENS (2)

Specimen No.	1	2	3	4	5	6	7	8	9
1st Tension, 10^3 psi	37.1	38.2	39.7	33.1	30.2	28.4	32.1	31.6	32.6
1st Compression, 10^3 psi	41.4	44.7	48.3	38.2	33.8	31.1	37.1	39.6	37.7
2nd Tension, 10^3 psi	47.0	48.6	50.6	39.5	35.4	33.9	39.3	35.4	40.3
2nd Compression, 10^3 psi	51.1	50.9	54.4	--	37.3	34.8	42.0	41.9	41.8
Rockwell A on Shoulders (Average of six measurements made after cycling tests)	47.7	48.5	50.3	51.2	48.6	48.8	49.1	48.6	49.0

FOOTNOTES FOR TABLE I

(A) Overloaded to 60,000 psi tension for the tenth cycle only.

(B) Cycled at ± 47,000 psi for the last 200 cycles, strain unknown.

(C) Overloaded to ± 47,000 psi during the 1225th cycle.

IV. NOTES ON TEST AND RESULTS

(1) The stainless steel specimens were made from two bars and each specimen was stamped with its bar number.

(2) The Croloy specimens were also made from two or more pieces of bar stock but the specimens were not identified with their parent bar. The length of the parent bar and the specimen length indicates that five specimens were taken from one bar and four from the other. The tensile test results indicate that the two bars were different. Using load during the first cycles at ± .016 shoulder strain to separate the specimens, Specimens No. 1, 2, 5 and 6 seems to be taken from one bar and 4, 7, 8 and 9 from another. Specimen No. 3 is less clearly catagorized; but, since its cyclic life is median in its testing group, it is averaged with its group. The difference in cyclic life of the material from the two bars is in excellent agreement with the difference due to heat treatment reported by Sokal in an unpublished report referred to later. Visual spectroscopic analysis of Specimens 1, 4 and 5 indicated that their chemical compositions are similar. In later analysis of the results of the tests on Croloy specimens, comparisons will be restricted to specimens from the same bar as grouped above.

(3) The bar was considered to have cracked when the load-time record showed a decrease in load at the strain limit. It was considered failed when the tensile load carrying capacity was zero.

(4) The envelope of the load-time record shows an increasing load for approximately ten cycles, then an approximately constant load for 80 to 90% of the specimens life in test. This approximately constant load divided by the cross-section area (minus the projected area of any holes) is called the most frequent maximum average stress.

(5) The measured surface roughness of the Croloy specimens may be greater than that of the stainless steel specimens due to the former having rusted after testing but before surface roughness measurements were made. All the specimens were finished by the same machinist and machine.

(6) The unit strain in the gage length was calculated from the strain at the shoulders by assuming that each differential length of the filleted portion acts elastically and plastically as would a uniform bar of the same diameter. The uniform diameter, shoulder portion was assumed to be the same diameter as the bottom of the groove. The equivalent elastic gage length* calculated this way is 4.55 inches. The modulus of elasticity of the Croloy specimens calculated using this equivalent gage length and the slope of the linear portion of the load-strain record is 25.5×10^6 psi. This is in good agreement with published values for similar material. Calculations were applied only to Record 4 of the test on Croloy Specimen No. 4 shown in Figure 5. The results are plotted on Figure 6 and used to determine the equivalent gage length from the plastic strain and total

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* The equivalent gage length is the length which multiplied by the unit strain in the uniform section equals the total strain measured at the shoulders.

strain measured from the load-strain record for the Croloy specimens. For example, Figure 5 shows that the ratio of total to plastic strain for Specimen No. C-1 is 1.3. The corresponding value from the ordinate of Figure 6 is 0.7 therefore, the equivalent gage length is 3.1 inches. The unit strain range is 0.040 x 2 ÷ 3.1 = 0.026 and the plastic strain range is 0.026 ÷ 1.3 = 0.02.

The stainless steel specimens had about the same ratio of total to plastic strain as the Croloy, at each of the two levels tested so the equivalent gage lengths were assumed to be the same.

V. DESCRIPTION OF FRACTURE

Failure of all the specimens without holes seemed to consist of three stages. The first stage started with a crack in a cross-section plane. This crack progressed until it covered 10-30% of the area. Since the load curves did not show a sudden drop as failure was approached, it seems that the initial, transverse crack spread gradually. This impression is strengthened by the presence of other similar cracks of all sizes in unbroken parts of some specimens. Most of the transverse portion of the cracks are roughly sectors of the circular area.

The second stage of failure was a crack on a 45° plane (shear crack) which started at the boundary of the tensile crack. Beach marks in some specimens clearly indicated a gradual crack progression. The final stage of failure completed the shear crack in one loading. This final process involved 10% or less of the original resisting area.

The specimens with holes followed similar stages of failure. The transverse crack area was larger than for solid specimens being approximately 30-50% of the resisting area. For the stainless steel (rectangular) specimens, the transverse crack area was a rectangle symetrical about the hole and extending the whole length of the hole. For the Croloy (cylindrical) specimens, the transverse crack area was football shaped with the points at the ends of the hole. A dye check showed no crossed, 45° cracks at the outer surface. This indicates that the crack progression was principally from the center out. The almost perfect symetry of the transverse crack areas about perpendicular axes indicates that no significant eccentricity of loading existed.

Photographs of four typical failed specimen are shown in Figure 7.

The load-time records shows that the tensile and compressive forces at maximum strain are still equal until the cracks start. After the cracks start, the maximum load decreases at an increasing rate. The compressive load does not drop to zero because the broken ends can be pressed together and sustain load. Typical records of load-time and of load-strain during failure are shown in Figure 8.

VI. DISCUSSION OF RESULTS

Most published reports of tests of this type* indicate that strain and cycles to failure are related as

$$N^{1/2} \Delta\epsilon_p = c$$

where

- N is the number of cycles to produce fracture.
- $\Delta\epsilon_p$ is the plastic strain range.
- c is a constant for most materials and a measure of the material resistance to failure.

Values of "c" calculated for the tests on specimens without a hole, excluding the overload specimens are:

Specimen No	Strain Range	Plastic Strain Range	c	Specimen No	Strain Range	Plastic Strain Range	c
1	2.64%	2.26%	.47	C-1	2.64%	2.24%	.43
2	"	"	.41	C-2	"	2.23	.37
3	"	"	.41	C-3	"	2.22	.41
5	"	2.25	.43	C-4	0.84	.42	.14
6	"	"	.38	C-5	0.92	.58	.24
8	0.92	0.62	.39	C-6	0.92	.59	.24

The results of tests on the stainless steel seem normal in that the value of "c" for high and low strains is not significantly different, indicating that the exponent is one half. The average value of "c" is significantly less than the 0.70 obtained by Baldwin** et al. for a similar material at the same temperature but with 0.1875 inch diameter specimens. These values indicate that at equal plastic strain ranges the cycle life of the large specimens is 36% of that of the small specimens. When the Specimen No. 8 and the referenced tests are compared on the basis of equal stress range, the difference in cyclic life is insignificant. No other tests are available for comparisons at the high strain range for either of the materials reported here. Some of the apparent decrease in "c" for the large specimens may be due to differences in speed of testing or method of calculating plastic strain range. These are not described in the reference. But even assuming the strain in the fillets to be zero, the value of "c" for the tests reported here would only be 0.52.

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* A Compilation and Interpretation of Cyclic-Strain Fatigue Tests on Metals By J. F. Tavernelli and L. F. Coffin, Jr. Report No. 57RL1847, November, 1957.

** Cyclic Strain Fatigue Studies on AISI Type 347 Stainless Steel By E. E. Baldwin, G. J. Sokol and L. F. Coffin, Jr. presented at the Sixtieth Annual Meeting ASTM, June 1957.

The tests on stainless steel Specimens No. 4 and 9 indicate the even one over-strain cycle can produce a considerable decrease in life, so overstrained specimens are excluded from their group averages.

The values of "c" for 2-1/4 Croloy seem less normal in that the usual 1/2 power relationship does not accurately predict the effect on cyclic life of changing the strain range. Excluding Specimen No. C-4, the data fits a similar relationship where the exponent is 0.81. Unpublished data by G. J. Sokol for small specimens of a similar material tested at the same temperature show an exponent of 0.73 for material normalized at 1650 - 1700°F, A. C., and tempered at 1200 - 1250°F; and an exponent of 0.85 for annealed material, both at the same plastic strain range (0.0058) as the least strained group reported here. The cyclic life of Specimens C-5 and C-6 is almost identical to that reported by Sokol for the normalized material and is about three quarters of that for the annealed material. When the stress range vs. cycles are compared, Specimens C-1, C-2, C-3, C-5 and C-6 fall on Sokol's curve for the annealed material and C-4 falls on the curve for normalized material.

The stainless steel specimens with holes had only one-eighth the cyclic life of a specimen without a hole tested at the same nominal stress range. If the one half power exponential relationship is assumed to be valid, the calculated plastic strain concentration factor is 2.8. The elastic stress (or strain) concentration factor for the same configuration is 2.4*.

Similarly comparing the Croloy specimens with holes to Specimen No. C-4 without a hole, the cyclic life is reduced to 28%. With the exponent taken as 0.81 in the exponential relationship, the plastic strain concentration factor equals 2.8. The corresponding elastic strain concentration factor is 2.5**. This comparison is not as rigorous as that for the stainless specimens because the specimen without a hole was cycled at the same shoulder strain, therefore less stress, than those with holes.

The constancy of the ratio of cycles during cracking to total cycles is striking when the difference in strain range, holes and materials are considered.

No significant effect of testing speed was established.

VII. CONCLUSIONS

1. The cyclic life of a specimen with a hole can be predicted from smooth specimen tests by using the elastic stress concentration factor increased by 15%.

2. In the commonly used exponential relationship between cycles to failure (N) and strain range ($\Delta\epsilon_p$), $N^K \Delta\epsilon_p = c$; the material constants are:

   for AISI Type 347 stainless steel; $K = 0.50$, $c = 0.42$

   for 2-1/4 Croloy; $K = 0.81$, $c = 2.44$

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* "Stress concentration design factors" By R. E. Peterson published by John Wiley and Sons, Inc., New York.

** "Machine Design" 3rd Edition By V. L. Maleev and J. B. Hartman, published by International Textbook Co., Scranton, Pennsylvania.

3. Comparing these tests with those made by others indicates that AISI Type 347 stainless steel exhibits a pronounced size effect. The cyclic life at the same plastic strain range is reduced to about one half as the specimen diameter is increased from 0.1875 to 1.0 inches. The size effect is negligible for 2-1/4 Croloy.

A. K. Schmieder

A. K. Schmieder

J. J. La Cagnina

J. J. La Cagnina

Countersigned by:

D P Timo

D. P. Timo

NOTE: THREADS MUST BE CONCENTRIC TO GAGE DIA. WITHIN ±.002. ENDS MUST BE SQUARE WITH ℄ WITHIN .005 AT 10".

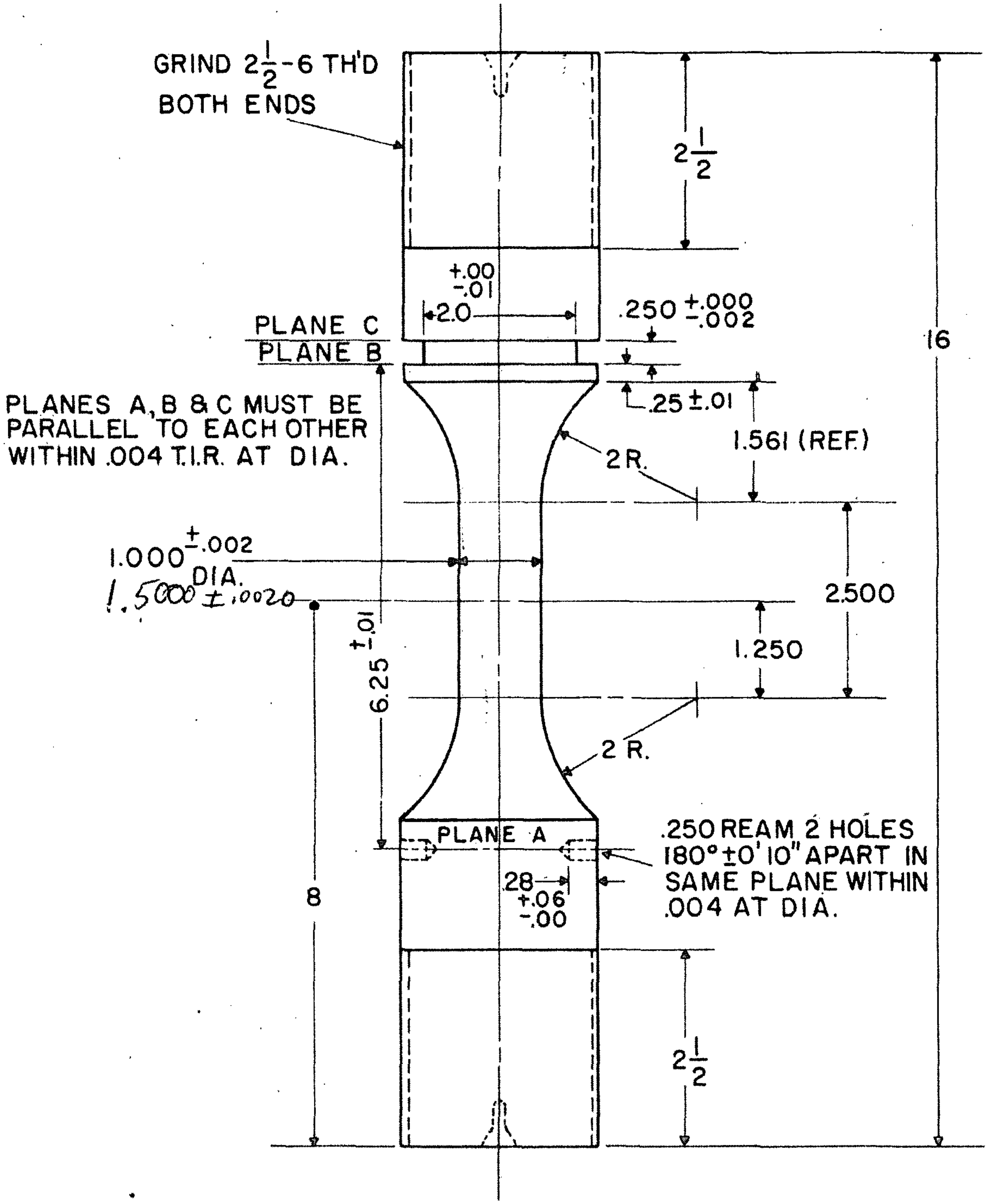

FIGURE 1 – STRAIN CYCLING SPECIMEN

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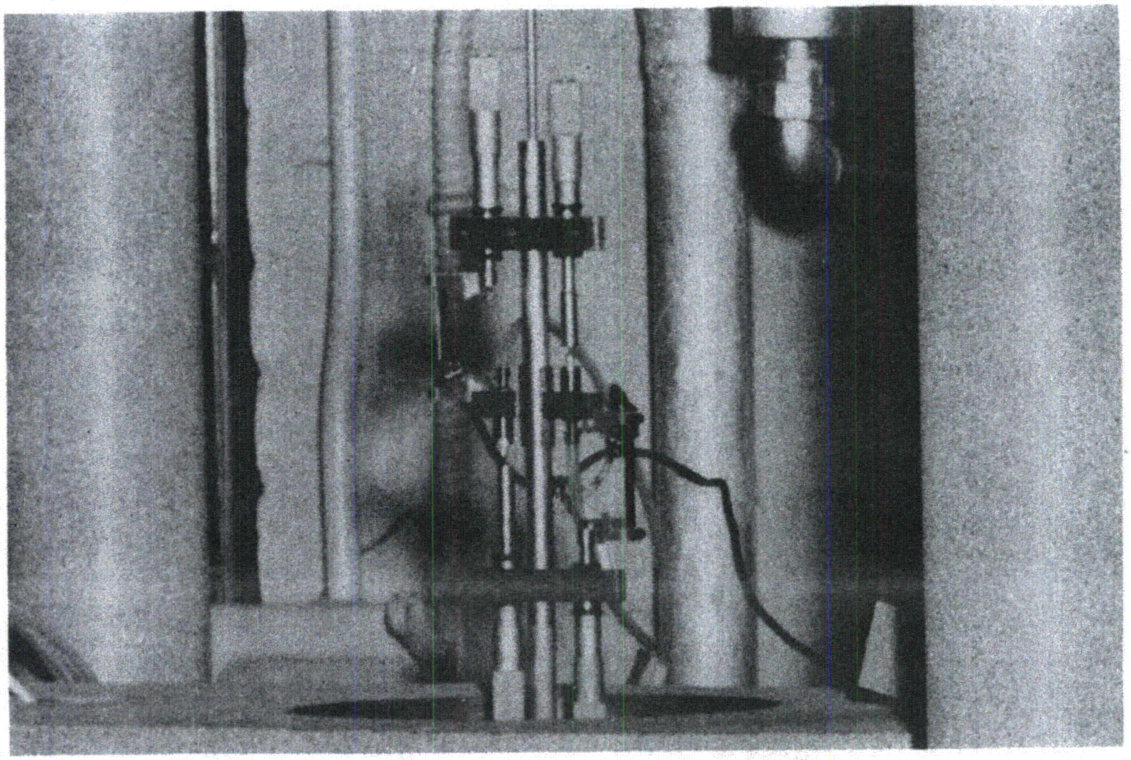


FIGURE 3 EXTERNAL PARTS OF EXTENSOMETER

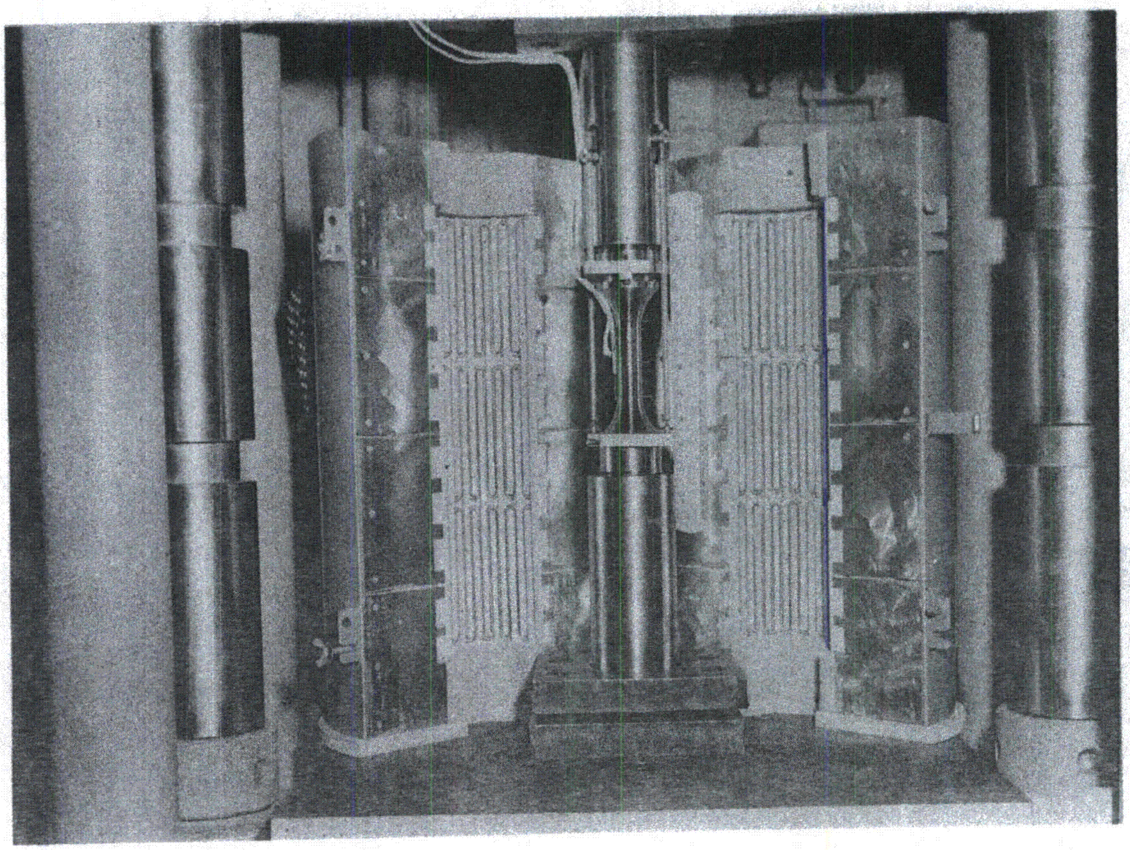
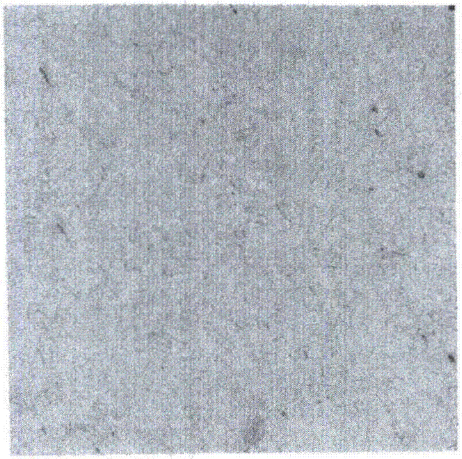
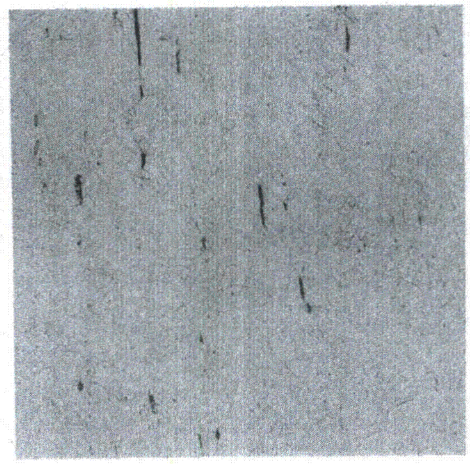


FIGURE 2 SPECIMEN IN HOLDERS

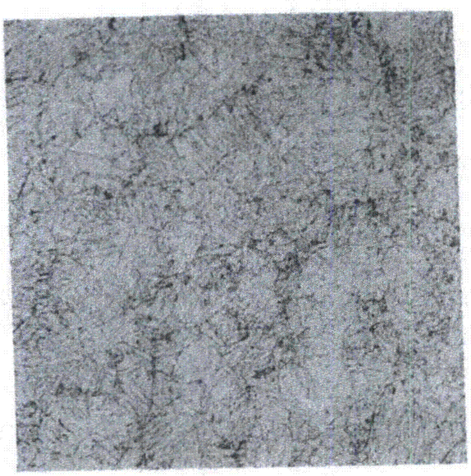


Bar 3A
KAPL Specimen No. 7240



Bar 4A
KAPL Specimen No. 7241

Type 347 Stainless Steel, AL Heat 81701, Magnification 100X

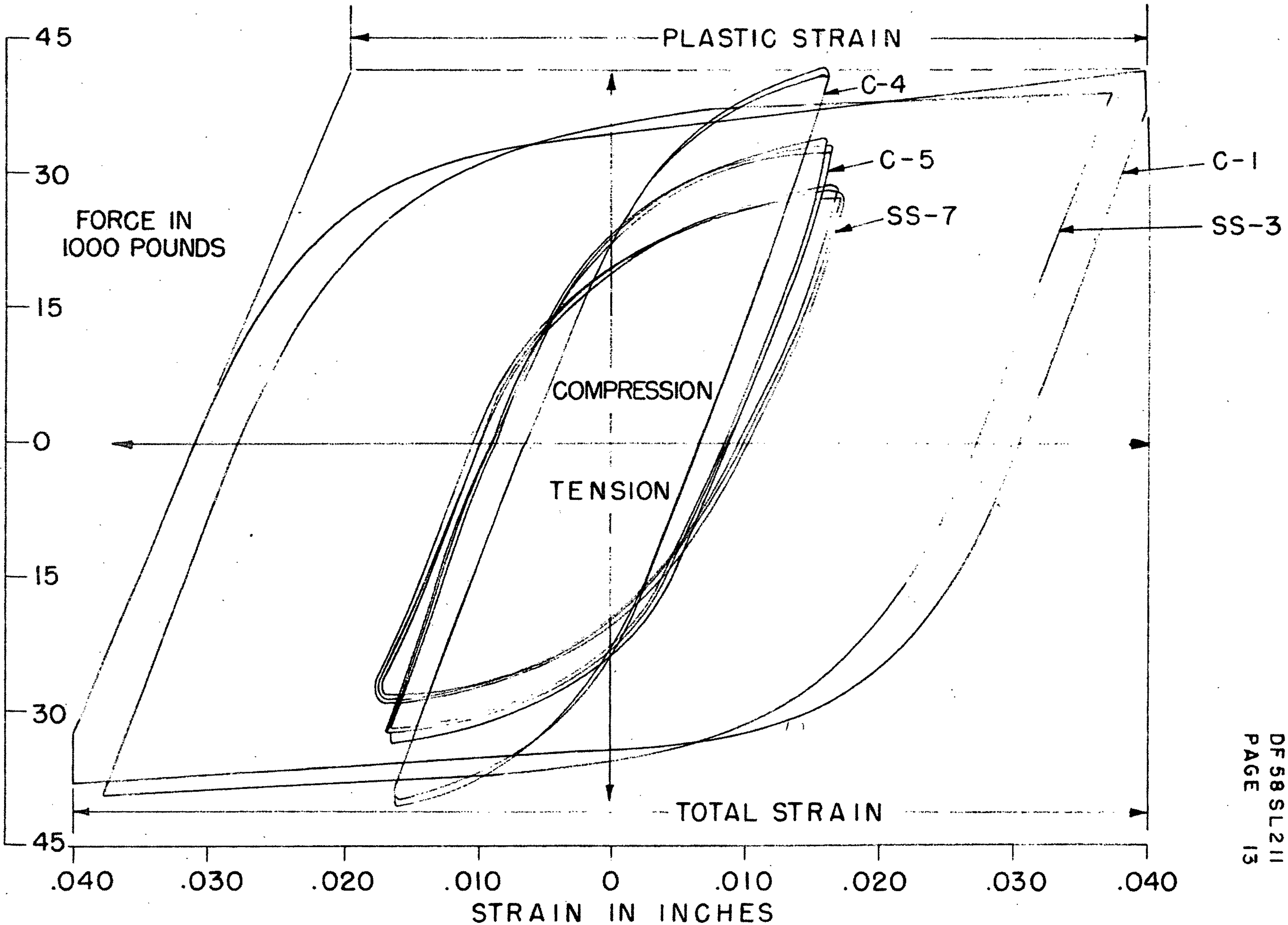


Bar CS
M&P Lab Specimen No. 3247SA

Bar CS1
M&P Lab Specimen No. 3247SA

2-1/2 Croloy, Magnification 100X, Nital Etchant

FIGURE 4 PHOTOMICROGRAPHS OF BAR STOCK



MATERIAL	IDENTIFICATION	CYCLE NO.
STAINLESS STEEL	SS-3	14
STAINLESS STEEL	SS-7	3

MATERIAL	IDENTIFICATION	CYCLE NO.
CROLOY	C-1	19
CROLOY	C-4	201
CROLOY	C-5	270

FIGURE 5 - TYPICAL LOAD-STRAIN RECORD

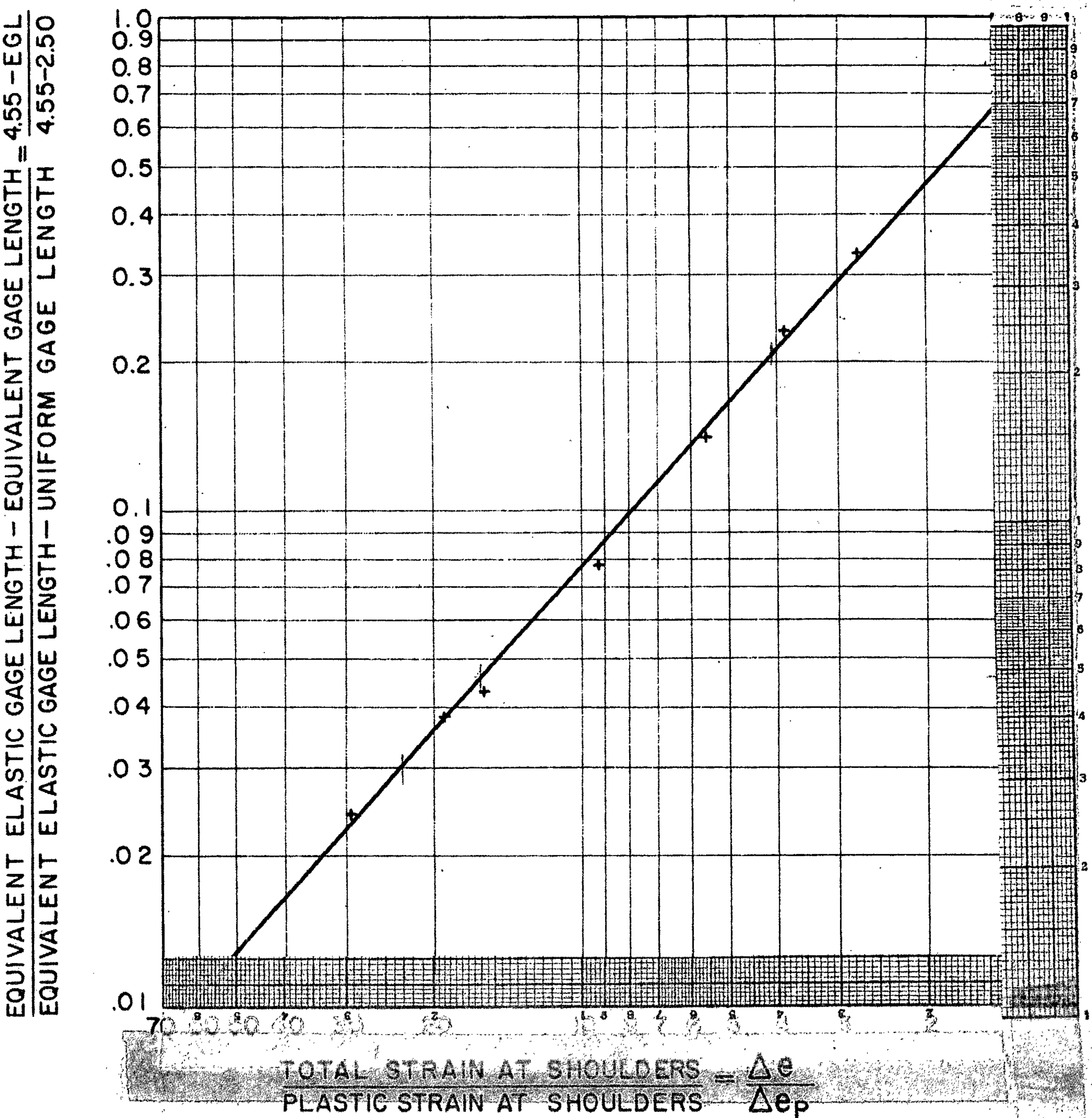
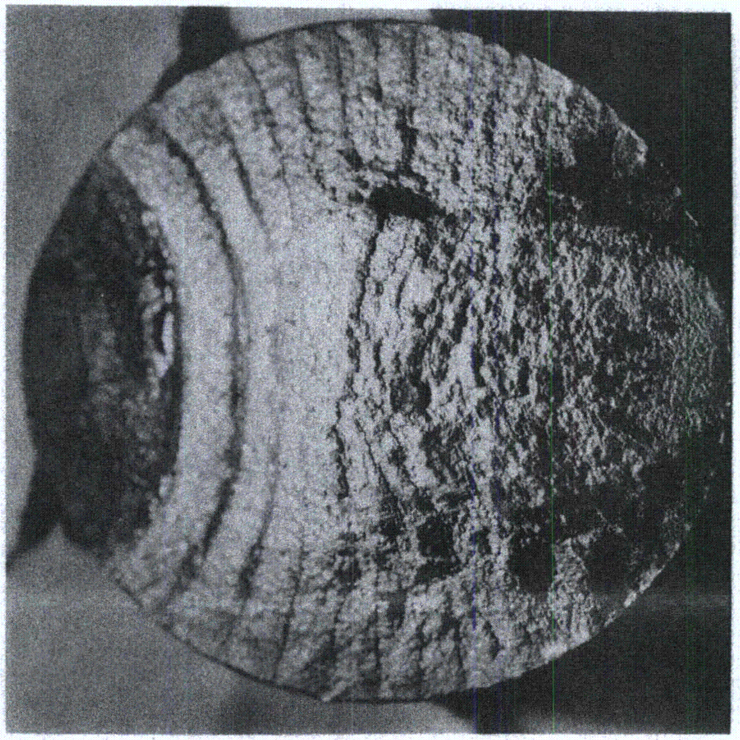
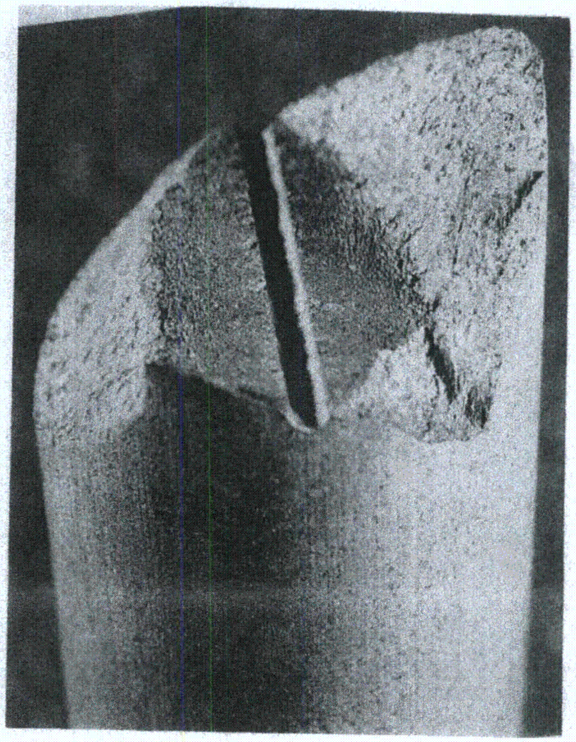


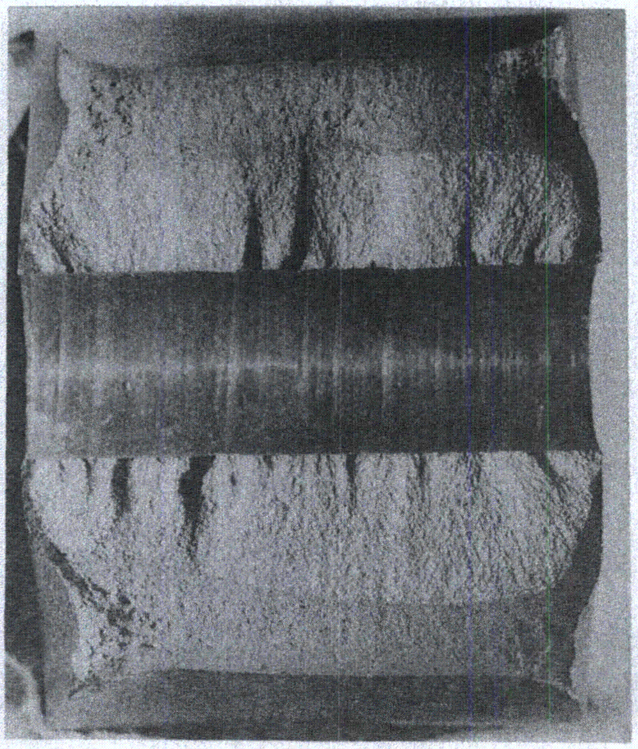
FIGURE 6 – PLOT FOR ESTIMATING EQUIVALENT GAGE LENGTH



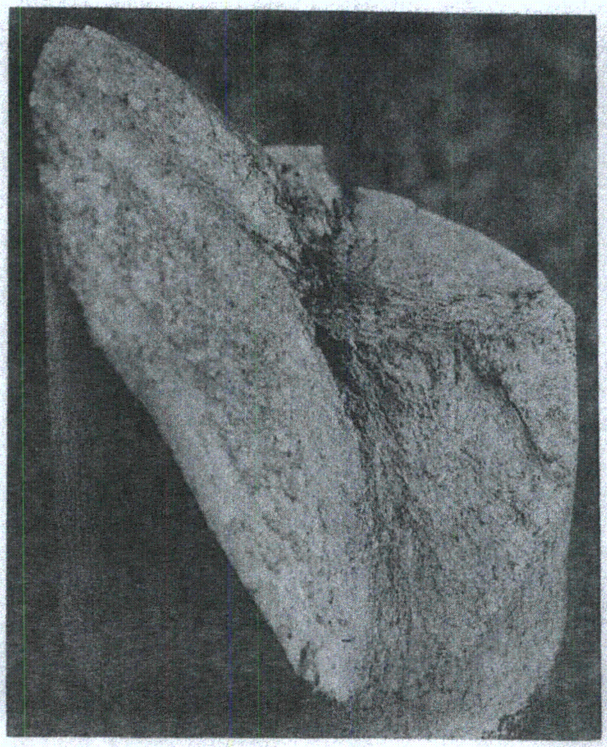
Type 347 S. S. Specimen Number 3



Croloy Specimen No. 9



Type 347 S. S. Specimen No. 11



Croloy Specimen No. 2

FIGURE 7 PHOTOGRAPHS OF FRACTURE SURFACES

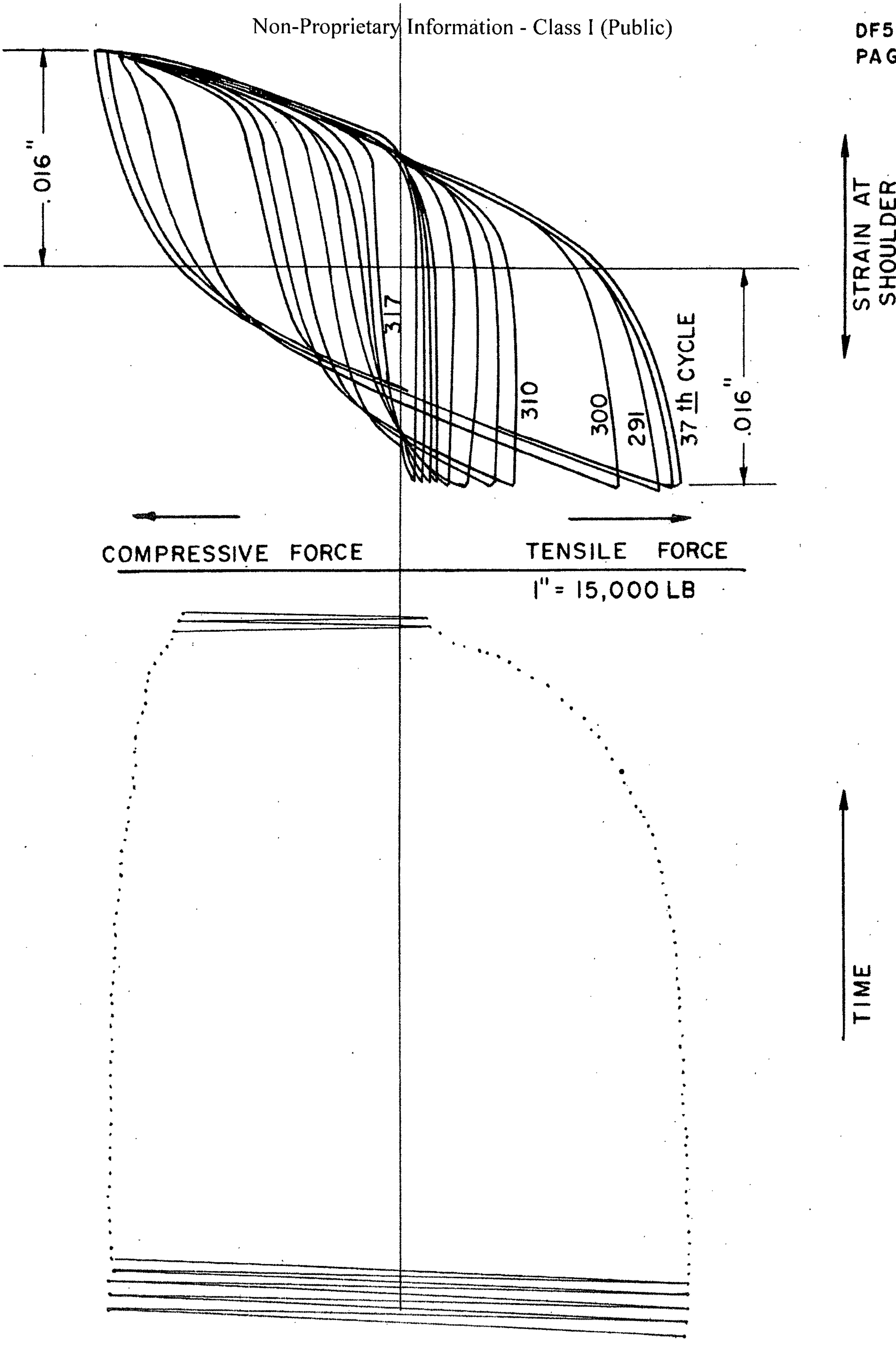


FIGURE 8 LOAD TIME AND LOAD-STRAIN RECORDS DURING FAILURE OF CROLOY SPECIMEN 8