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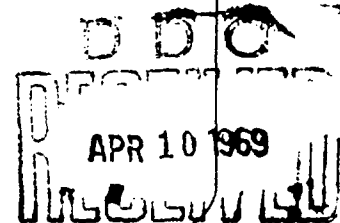
MECHANICAL PROPERTIES, INCLUDING FRACTURE
TOUGHNESS AND FATIGUE, CORROSION CHARACTERISTICS
AND FATIGUE-CRACK PROPAGATION RATES OF
STRESS-RELIEVED ALUMINUM ALLOY HAND FORGINGS

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Contract No. F33615-68-C-1385

Project No. 7381

Fourth Technical Management Report
November 15, 1968 - February 15, 1969



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ABSTRACT

All forty of the 2014-T652, 2024-T852, 7075-T7352 and 7079-T652 hand forgings scheduled for test under this contract have now been received. Chemical analyses have been made and indicate that the samples meet the composition requirements. Most of the tensile, compressive, shear and bearing properties have been determined for all but one of the forgings. Ratios among these properties have been calculated. Modulus, stress-strain and the remaining notch-bend fracture toughness tests will be made soon. The results of axial-stress fatigue tests (R=0.0) of smooth specimens are reported.

The results of the stress-corrosion tests of specimens from the 2, 3 and 5-in. thick hand forgings showed their performance, in general, to be typical or better than typical for these alloys and tempers. Accelerated exfoliation tests of specimens from the 2x8-in. hand forgings displayed very good resistance to exfoliation regardless of alloy.

The results of some tests to determine the effects of notch geometry on the rate of fatigue-crack propagation are presented. Additional tests are being initiated to determine if the uniformity of crack initiation can be improved by using a different notch and crack initiation procedure. Tests are in progress to determine whether it is feasible to change the load during a test to obtain crack-propagation rates at more than one stress level. (1)

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Fourth Technical Management Report

MECHANICAL PROPERTIES, INCLUDING FRACTURE TOUGHNESS AND FATIGUE, CORROSION CHARACTERISTICS AND FATIGUE-CRACK-PROPAGATION RATES OF STRESS-RELIEVED ALUMINUM ALLOY HAND FORGINGS

I. Introduction.

The design mechanical properties, fracture toughness, corrosion characteristics and fatigue-crack propagation rates are four of the most important factors involved in the selection and efficient design of aircraft structures. Such data are needed for aluminum alloy hand forgings for several reasons:

(1) much of the published design data has become obsolete by a change in the basis of specifying minimum properties, from one in which the length, width and thickness were considered, to one where only the thickness is involved; (2) the development of a technique of stress relief by cold work in compression has resulted in relatively new tempers (TX52) for many of the alloys; and (3) there have been some significant problems with forged parts in recent years that were related to fracture and stress-corrosion characteristics.

Accordingly, the properties of hand forgings of several aluminum alloys currently being used in aircraft structures are being determined under this contract. The tests are intended to provide statistically reliable data for deriving design mechanical properties for MIL-HDBK-5A, including stress-strain and compressive tangent-modulus curves. In

addition, data concerning the fracture toughness, axial-stress fatigue, stress-corrosion, exfoliation and fatigue-crack propagation rates are being obtained.

This Fourth Technical Management Report summarizes the results of tests carried out during the fourth quarter of the contract, and the general status of the program at this time.

II. Material.

All of the hand forgings scheduled for investigation have now been obtained.

The chemical compositions of the forgings are shown in Table I. The compositions are within the applicable limits specified in Federal Specification QQ-A-367g and The Aluminum Association, "Aluminum Standards and Data", April 1968. The hand forgings were solution heat treated, cold worked and artificially aged in accordance with Military Specification MIL-H-6088D and the recommendations given in The Aluminum Association, "Aluminum Standards and Data, April 1968. The 7075-T7352 hand forgings were stress-relieved and aged to meet the requirements of paragraph 4.10 of Federal Specification QQ-A-367g.

III. Procedure.

All of the specimens and test procedures were described in the First Technical Management Report, dated May 15, 1968.

IV. Progress During Quarter.

A. Mechanical Properties

A.1. Tensile, Compressive, Shear and Bearing

Tensile, compressive, shear and bearing tests have been made of 39 forgings, the results of which are summarized in Tables II through V. The ratios showing the relationships among these mechanical properties are summarized in Table VI. The tensile properties of the hand forgings meet the applicable minimum-property requirements shown in Table VII.

Check tests were made in several instances where the values or ratios seemed to be inconsistent with the other data. In such cases where the check test values indicated that a possible error had been made in the testing or in the identification of the original test specimens, the original values have been discarded; where the original values and check test values were in good agreement, the original values have been retained.

Tensile and compressive stress-strain tests, including modulus determinations, will be started soon. The Tuckerman optical instrument to be used in making the strain measurements has been calibrated and meets the ASTM requirements of a Class A extensometer.

A.2. Fracture Toughness

To date, notch-bend fracture toughness tests have been made of only two of the twenty hand forgings scheduled for test. The results of the completed tests were reported in the Third Technical Management Report, dated November 15, 1968.

Specimens from all but one hand forging have been fatigue cracked and will be tested soon.

A.3. Axial-Stress Fatigue

Axial-stress fatigue ($R=0.0$) tests of specimens from all except the 6x12-in. 7075-T7352 hand forging have been completed. The results of the axial-stress fatigue tests are shown in Table VIII and plotted in Figs. 1 through 4.

B. Corrosion Characteristics

B.1. Resistance to Stress-Corrosion Cracking

All of the stress-corrosion test specimens from the 2x8-in., 3x12-in. and 5x20-in. hand forgings were exposed to the 3.5% NaCl alternate immersion test during this quarter.

The remaining 4x10-in. hand forging designated for stress-corrosion testing was received, and specimens were prepared. Specimens are currently being stressed, and tests should begin in late February or early March.

Specimens have been prepared from the 6x24-in. 2024-T852 and 7079-T652 hand forgings; specimens are being prepared from the 7075-T7352 hand forging recently received. Tests will be initiated as soon as specimens from the latter forging are obtained.

Table IX lists the stress-corrosion data, to date, for longitudinal and long-transverse specimens, and Table X shows data for the short-transverse specimens.

Thus far, no longitudinal specimen has failed, which tends to confirm the expected high resistance of all items stressed in this direction.

Long-transverse failures have occurred with 2014-T652 and 7079-T652 specimens stressed at 75% of the yield strength. Microscopic examination of a representative failure in alloy 2014-T652 confirmed that failure was caused by stress-corrosion cracking (Figs. 5 and 6). A similar examination will be made of some 7079-T652 specimens. These failures indicate that some stress-corrosion susceptibility may be expected when 2014-T652 and 7079-T652 forgings are highly stressed in the long-transverse direction, while 2024-T352 and 7075-T7352 forgings should be highly resistant. These data are in good agreement with existing stress-corrosion guidelines for these products.

Failure occurred with short-transverse specimens from each of the four alloys tested. However, with each alloy, failure occurred in only one of three forgings tested, and the various alloys did not fail consistently for any one forging size.

Failure occurred at a stress of 22.5 ksi with specimens from the 3-in. thick 2014-T652 and 5-in. thick 7079-T652 forgings. Microscopic examination of a representative 2014-T652 failure confirmed that failure was due to stress-corrosion cracking (Fig. 7). A similar examination will be made with the 7079-T652 specimens. The performance of these materials was

better than that typically observed with forgings of these alloys, but was within the bounds of existing stress-corrosion data for these materials.

The performance of the 2024-T352 forgings was about as anticipated with only one isolated stress-corrosion failure (Figs. 8 and 9) occurring at 75% of the yield strength with a specimen from the 2-in. thick forging.

The failure of specimens from the 3-in. thick 7075-T7352 forging was totally unexpected, since this alloy and temper have been shown to provide excellent resistance to stress-corrosion cracking. All test failures were therefore examined microscopically and found to be typical intergranular stress-corrosion failures (Figs. 10 and 11). The electrical conductivity of the 3-in. forging, 38.4 to 38.7% IACS, was only slightly above the specified minimum of 38% IACS [MIL-A-22771B (ASG)], and might indicate a marginal aging treatment for this item. Specimens are currently being obtained for retests to confirm the apparently anomalous behavior of this forging.

B.2. Exfoliation Resistance

Accelerated exfoliation tests of specimens from the 2x8-in. forgings were completed during this quarter.

Specimens from the 2-in. thick forgings displayed very good resistance to exfoliation regardless of alloy, and as shown in Figs. 12 and 13 no significant differences were observed between specimens from different regions (T/10, T/2) relative to the forging thickness.

C. Fatigue Crack Propagation
Preliminary Investigation

The fatigue tests studying the effect of the notch types shown in Figs. 14 and 15 have been completed. Two specimens of each type were tested at maximum gross stresses of 8.2 and 12.3 ksi. As would be expected, crack initiation was more uniform at the higher stress; there was a slight advantage for the sharper notch. At a stress of 8.2 ksi, cracks did not initiate at one side of a mildly notched specimen until two cracks reached lengths of 1/2 in. The cracking was not as eccentric in either of the two specimens having the sharper notch shown in Fig. 15. However, one of these specimens did not crack at all four corners until another crack measured 1/4 in. long.

Although crack initiation is somewhat more uniform for the sharper notch, it is still not as even as desired, particularly for the portions of this program which call for the moist atmospheres or changes in the load as the crack progresses. To determine if another notch would do better, 1/2-in. long clox notches were made in several 7178-T7651 specimens from another program. Crack initiation at 8.2 ksi was improved but was still not uniform enough in all specimens. To improve the uniformity of initiation, the procedure will be changed as follows:

1. A central 0.20-in. long elox notch (Fig. 16) will be made in the test section of the remaining specimens; only the 2014-T652 specimens have been notched.

2. Because crack initiation is more uniform at higher stresses, the cracks will be initiated at net stresses of about 20 ksi. When cracks are visible at all four corners of the notch, the load will be reduced to produce the desired gross stress and the cracks will be propagated to a total "original notch" length of 0.50 in. before test readings are taken. Thus, before crack propagation measurements are made, each crack will be propagated about 0.15 in.; this should put the cracks well beyond any plastic zone produced by the higher initial loading.

The above outlined test procedure is similar to that used for obtaining cracks in fracture toughness specimens.

Consideration will be given to having a few replacement 2014-T652 specimens notched and cracked as described above.

Computer plots of the crack propagation data and rates of crack propagation are shown in Figs. 17 and 18 for the specimens stressed to 8.2 ksi. The long life of specimen MT⁴ is attributable to the nonuniformity of crack initiation. Consequently, its rate of crack propagation was slower in the earlier stages. Beyond the earlier stages, the type of notch does not appear to have affected the rate of propagation.

Tests are now in progress to determine whether it is feasible to change the load during the test to obtain crack propagation rates at more than one stress level.

V. Summary.

All of the 40 hand forgings scheduled for test have been received. The chemical compositions of the hand forgings meet the applicable specified limits shown in Table I.

The tensile, compressive, shear and bearing properties determined for 39 of the forgings are shown in Tables II through V. The tensile properties of the hand forgings meet the applicable minimum-property requirements shown in Table VII. Ratios among the properties are shown in Table VI.

The results of the axial-stress fatigue tests completed to date are summarized in Table VIII and plotted in Figs. 1 through 4.

The current status of stress-corrosion tests is shown in Tables IX and X. The performance of the 2014-T652 and 7079-T652 forgings was better than that typical of these materials, but not unexpected. The performance of the 2024-T852 forging was typical of that expected of this alloy and temper. The 2-in. and 5-in. thick 7075-T7352 forgings also performed typically, i.e., were highly resistant, but unexpected failures were encountered with the 3-in. thick 7075-T7352 forging; retests will be made to investigate this anomalous behavior.

Fatigue tests of the 6x24-in. 2014-T652 hand forging at two stress levels indicate that the rates of crack propagation were not affected appreciably by the shape of the notch. However, to improve the uniformity of crack initiation, a different notch and crack initiation procedure will be used for

the other three alloys. Tests of 2014-T652 specimens have been initiated to determine if it is feasible to change loads during a test to obtain crack propagation rates at more than one stress level.

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VI. Tables and Figures.

TABLE I

CHEMICAL COMPOSITIONS OF STRESS-RELIEVED ALUMINUM ALLOY HAND FORGINGS
(F35615-68-C-1385)

Alloy and Temper	Sample Cross-Section Size, in.	Number	Element, Percent						
			Cu	Si	Fe	Mn	Mg	Zn	Cr
2014-T652	2x8	341007	4.41	0.97	0.24	0.73	0.50	0.14	0.01
	3x12	341008	4.47	0.98	0.22	0.70	0.69	0.11	0.01
	4x8	341009	4.27	0.94	0.20	0.69	0.57	0.10	0.01
	4x16	341010	4.58	0.94	0.22	0.72	0.59	0.08	0.01
	5x5	341011	4.27	0.89	0.20	0.69	0.57	0.10	0.01
	5x10	341012	4.28	0.91	0.22	0.68	0.55	0.08	0.01
	5x20	341013	4.25	0.93	0.24	0.70	0.60	0.08	0.01
	6x6	341014	4.27	0.89	0.20	0.69	0.57	0.10	0.01
	6x12	341015	4.53	0.94	0.25	0.74	0.53	0.12	0.02
	6x24	341016	4.41	1.00	0.22	0.69	0.57	0.09	0.01
2024-T852	Limits*		3.9-5.0	0.50-1.2	1.0	0.40-1.2	0.20-0.8	0.25	0.10
	2x8	341017	4.63	0.11	0.15	0.53	1.54	0.07	0.00
	3x12	341018	4.51	0.11	0.15	0.53	1.54	0.07	0.00
	4x8	341019	4.51	0.13	0.19	0.57	1.72	0.24	0.02
	4x16	341020	4.51	0.11	0.17	0.57	1.58	0.07	0.01
	5x5	341021	4.51	0.13	0.19	0.57	1.72	0.24	0.02
	5x10	341022	4.48	0.10	0.12	0.52	1.52	0.02	0.01
	5x20	341023	4.51	0.13	0.15	0.57	1.72	0.24	0.02
	6x6	341024	4.45	0.12	0.15	0.57	1.54	0.07	0.00
	6x12	341025	4.48	0.10	0.12	0.52	1.52	0.02	0.01
7075-T7352	Limits*		3.8-4.9	0.50	0.50	0.30-0.9	1.2-1.8	0.25	0.10
	2x8	341027	1.60	0.10	0.13	0.02	2.50	5.55	0.19
	3x12	341028	1.52	0.11	0.16	0.02	2.20	5.43	0.20
	4x8	341029	1.48	0.07	0.16	0.02	2.54	5.77	0.20
	4x16	341030	1.52	0.12	0.15	0.02	2.53	5.62	0.19
	5x5	341031	1.50	0.07	0.13	0.02	2.50	5.87	0.20
	5x10	341032	1.53	0.11	0.14	0.03	2.57	5.82	0.19
	5x20	341033	1.48	0.12	0.16	0.02	2.60	5.72	0.20
	6x6	341034	1.71	0.12	0.20	0.04	2.42	5.68	0.19
	6x12	341035	1.65	0.17	0.20	0.04	2.45	5.88	0.20
7079-T652	Limits*		1.2-2.0	0.50	0.7	0.30	2.1-2.9	5.1-6.1	0.18-0.40
	2x8	341037	0.76	0.11	0.18	0.18	3.48	4.57	0.14
	3x12	341038	0.75	0.11	0.18	0.18	3.48	4.57	0.14
	4x8	341039	0.70	0.10	0.16	0.19	3.66	4.74	0.14
	4x16	341040	0.63	0.08	0.14	0.18	3.51	4.40	0.15
	5x5	341041	0.70	0.08	0.16	0.17	3.38	4.42	0.14
	5x10	341042	0.72	0.10	0.15	0.18	3.45	4.54	0.15
	5x20	341043	0.65	0.11	0.18	0.18	3.45	4.77	0.15
	6x6	341044	0.55	0.09	0.17	0.17	3.20	4.16	0.15
	6x12	341045	0.70	0.10	0.16	0.19	3.60	4.74	0.14
7079-T652	Limits*		0.40-0.8	0.30	0.40	0.10-0.30	2.9-3.7	3.8-4.8	0.10-0.25
	6x24	341046	0.72	0.10	0.16	0.17	3.55	4.60	0.15

* Federal Specification QQ-A-367g

† The Aluminum Association, "Aluminum Standards and Data", April 1968

Maximum unless a range is shown.

TABLE II

MECHANICAL PROPERTIES OF STRESS-RELIEVED 2014-T652 ALUMINUM ALLOY HAND FORGINGS
(F33615-68-C-1385)

SAMPLE CROSS- SECTIONAL NUMBER SIZE, IN.	DIREC- TION§	TENSILE			RED. OF AREA, %	COMP.	SHEAR	HEARING# EDGEWISE	
		ULT. STRESS, PSI	YIELD STRESS,* PSI	ELONG. IN 2 IN. OR 4D, %				ULT. STRESS, PSI	YIELD STRESS† PSI
2X 8	L	71 600	66 500	11.5	30	69 200	44 200	101 000	122 500
	LT	71 700	64 900	6.0	9	70 300	43 600	101 000	130 100
	ST	66 400	61 400	9.4	34	68 700	---	---	---
3X12	L	71 800	66 200	10.5	28	68 400	42 200	102 300	132 500
	LT	71 000	65 100	7.5	12	69 800	41 800	97 100	126 900
	ST	69 700	62 200	5.0	7	69 700	41 300	---	---
4X 8	L	70 300	64 200	12.5	29	66 400	40 400	89 300	123 700
	LT	69 900	63 000	7.5	12	65 100	40 600	90 700	121 700
	ST	66 900	59 500	2.5	4	69 300	39 900	---	---
4X16	L	69 100	62 500	11.5	26	60 200	38 700	88 600	123 900
	LT	66 600	59 200	6.0	8	61 500	38 800	---	114 900
	ST	65 800	57 000	6.0	6	61 900	38 900	---	---
5X 5	L	68 600	63 200	12.0	28	65 300	41 800	88 200	117 300
	LT	67 500	61 200	4.0	5	62 500	40 700	87 200	118 400
	ST	65 200	58 800	2.0	4	66 500	41 200	---	---
5X10	L	68 800	61 600	11.5	27	63 000	40 600	93 400	117 400
	LT	67 300	60 200	5.5	9	61 700	40 300	88 700	123 400
	ST	64 600	57 400	3.0	6	65 300	39 700	---	---
5X20	L	68 500	60 700	11.5	24	61 200	38 800	90 100	113 500
	LT	64 700	57 300	5.0	7	63 500	38 400	86 600	117 500
	ST	63 900	56 100	3.7	7	62 800	37 300	---	---
6X 6	L	67 700	62 700	12.0	31	64 000	42 400	97 400	114 200
	LT	64 900	59 500	3.5	5	60 400	40 700	89 300	121 100
	ST	64 200	55 900	2.8	1	65 700	40 500	---	---
6X12	L	66 200	59 500	11.0	27	60 300	40 200	91 100	120 100
	LT	64 200	58 400	3.5	6	61 900	38 800	87 700	119 000
	ST	63 900	55 900	3.5	2	61 900	38 700	---	---
6X24	L	63 000	55 900	9.5	19	57 900	42 500	89 500	118 100
	LT	66 600	57 700	6.0	6	62 400	38 800	86 300	117 900
	ST	62 600	54 000	6.0	14	59 300	39 000	---	---

* OFFSET EQUALS 0.2 PER CENT

† OFFSET EQUALS 2 PER CENT OF PIN DIAMETER

‡ SPECIMENS AND FIXTURES CLEANED ULTRASONICALLY

§ L, LONGITUDINAL; LT, LONG TRANSVERSE; ST, SHORT TRANSVERSE

Table II

Table III

TABLE III

MECHANICAL PROPERTIES OF STRESS-RELIEVED 2024-T852 ALUMINUM ALLOY HAND FORGINGS
(F33615-68-C-1395)

SAMPLE CROSS- SECTIONAL NUMBER DIREC- TION\$ SIZE, IN.	TENSILE				RED. OF AREA, %	COMP. YIELD STRESS,* PSI	SHEAR ULT. STRESS, PSI	BEARING #			
	ULT. STRESS, PSI	YIELD STRESS,* PSI	ELONG. IN 2 IN. OR 4D, %	EDGEWISE							
				ULT. STRESS, PSI e/D=1.5				YIELD STRESS, † PSI e/D=2.0			
2X 8	L	70 800	64 600	7.0	28	70 200	42 700	97 700	133 100	95 500	116 300
	LT	72 300	63 800	9.0	17	72 700	41 800	94 500	125 900	89 500	114 200
	ST	67 400	64 000	1.6	3	74 600	---	---	---	---	---
3X12	L	72 200	66 700	5.5	18	70 000	42 400	94 900	123 400	93 700	109 300
	LT	73 700	69 000	3.0	2	75 800	42 000	94 500	126 100	93 500	113 300
	ST	68 100	64 400	1.0	2	72 200	40 200	---	---	---	---
4X 8	L	68 900	61 100	9.0	26	62 200	40 500	91 900	117 900	82 500	100 500
	LT	70 400	63 200	5.0	8	63 500	39 500	88 800	119 400	82 800	101 000
	ST	65 700	57 200	3.2	4	65 500	38 600	---	---	---	---
4X16	L	71 400	65 400	6.5	23	66 600	41 100	92 100	124 000	87 400	104 800
	LT	71 000	65 200	5.0	8	71 500	40 200	91 500	127 100	90 500	108 200
	ST	70 100	60 600	2.4	6	70 200	39 900	---	---	---	---
5X 5	L	69 000	62 000	8.5	29	63 400	40 800	93 500	125 200	89 900	105 100
	LT	68 400	62 100	3.0	1	63 100	40 700	89 100	121 600	84 400	101 100
	ST	66 500	56 000	2.8	4	64 700	39 600	---	---	---	---
5X10	L	68 400	61 000	8.5	25	63 000	40 300	89 100	114 300	87 700	96 800
	LT	69 100	61 500	6.0	8	64 800	39 700	89 500	120 200	85 100	99 600
	ST	66 100	59 800	1.5	4	68 400	38 800	---	---	---	---
5X20	L	65 200	55 100	9.0	16	57 800	38 800	83 600	112 600	79 300	94 400
	LT	62 800	56 700	3.0	4	60 700	38 000	84 900	114 600	82 500	98 000
	ST	63 200	54 500	3.0	3	59 400	37 000	---	---	---	---
6X 6	L	69 100	61 600	9.0	28	63 700	41 500	95 300	123 900	89 800	102 200
	LT	68 800	60 600	6.5	10	61 500	40 600	92 000	123 200	86 900	102 700
	ST	69 400	58 500	2.3	3	67 600	39 800	---	---	---	---
6X12	L	67 000	58 700	8.0	22	59 700	39 600	84 700	117 100	82 400	100 500
	LT	67 400	60 200	3.2	4	63 500	38 400	85 700	113 400	81 400	95 700
	ST	65 300	55 100	2.9	3	63 000	37 400	---	---	---	---
6X24	L	64 300	56 100	7.5	20	56 000	37 100	---	111 700	---	95 000
	LT	65 400	57 800	5.0	8	57 500	36 100	---	98 600	---	90 600
	ST	58 200	53 600	1.5	2	58 000	34 900	---	---	---	---

* OFFSET EQUALS 0.2 PER CENT

† OFFSET EQUALS 2 PER CENT OF PIN DIAMETER

‡ SPECIMENS AND FIXTURES CLEANED ULTRASONICALLY

§ L, LONGITUDINAL; LT, LONG TRANSVERSE; ST, SHORT TRANSVERSE

Table IV

TABLE IV

MECHANICAL PROPERTIES OF STRESS-RELIEVED 7075-T7352 ALUMINUM ALLOY HAND FORGINGS
(F33615-68-C-1385)

SAMPLE CROSS- SECTIONAL NUMBER DIREC- TION, IN.		TENSILE				RED. OF AREA, %	COMP.	SHEAR	BEARING [‡] EDGE-WISE			
		ULT. STRESS,* PSI	YIELD STRESS, PSI	ELONG. IN 2 IN. OR 40, %	YIELD STRESS,* PSI				ULT. STRESS, PSI	ULT. STRESS, PSI e/D=1.5 e/D=2.0	YIELD STRESS,* PSI e/D=1.5 e/D=2.0	
2X 8	341027	L	73 700	65 300	13.5	43	69 300	46 800	111 900	147 200	93 700	111 200
		LT	74 900	65 300	13.5	29	68 800	44 300	110 600	146 300	92 700	106 500
		ST	73 100	61 800	6.3	9	69 300	---	---	---	---	---
3X12	341028	L	76 400	66 200	11.5	27	66 900	42 400	103 100	136 100	89 000	103 800
		LT	71 400	59 300	8.0	11	65 300	42 600	98 300	135 100	89 800	110 300
		ST	73 000	60 800	4.2	5	69 300	42 900	---	---	---	---
4X 8	341029	L	68 400	57 300	15.0	42	60 200	39 800	95 100	130 000	83 500	98 600
		LT	65 100	53 000	10.0	17	57 600	38 400	98 500	127 100	81 400	99 000
		ST	64 500	50 600	6.4	10	57 500	38 200	---	---	---	---
4X16	341030	L	70 000	59 500	13.0	34	57 400	40 600	95 300	126 000	82 900	95 800
		LT	67 600	55 200	12.0	25	59 700	40 700	94 200	125 500	82 600	99 200
		ST	64 800	52 500	6.4	7	58 600	39 100	---	---	---	---
5X 5	341031	L	68 400	56 700	14.0	39	59 400	41 500	104 400	131 600	84 300	99 000
		LT	67 200	55 100	10.5	20	56 600	40 600	98 000	131 800	83 500	100 700
		ST	63 800	51 700	4.0	6	59 500	41 500	---	---	---	---
5X10	341032	L	65 200	52 700	14.0	37	53 400	39 600	95 900	124 600	82 300	91 900
		LT	64 000	51 400	9.0	17	53 800	38 500	97 700	127 100	80 100	97 000
		ST	64 200	49 500	7.0	9	58 000	39 400	---	---	---	---
5X20	341033	L	64 800	52 500	14.5	35	52 200	38 800	94 100	120 300	76 800	89 100
		LT	64 000	50 700	11.0	25	54 400	38 300	91 500	119 400	77 100	92 600
		ST	63 700	49 300	6.5	10	54 900	38 000	---	---	---	---
6X 6	341034	L	62 400	51 100	15.0	44	54 000	41 300	99 300	131 200	82 100	94 400
		LT	63 800	52 100	10.0	23	53 000	40 100	97 400	128 400	81 600	96 100
		ST	63 400	49 700	8.0	14	55 300	39 000	---	---	---	---
6X12	341035	L	63 300	52 600	12.5	34	---	---	---	---	---	---
		LT	63 400	50 900	9.0	14	---	---	---	---	---	---
		ST	60 800	49 800	6.5	9	---	---	---	---	---	---
6X24	341036	L	---	---	---	---	---	---	---	---	---	---
		LT	---	---	---	---	---	---	---	---	---	---
		ST	---	---	---	---	---	---	---	---	---	---

* OFFSET EQUALS 0.2 PER CENT

† OFFSET EQUALS 2 PER CENT OF PIN DIAMETER

‡ SPECIMENS AND FIXTURES CLEANED ULTRASONICALLY

§ L, LONGITUDINAL; LT, LONG TRANSVERSE; ST, SHORT TRANSVERSE

TABLE V

MECHANICAL PROPERTIES OF STRESS-RELIEVED 7079-T652 ALUMINUM ALLOY HAND FORGINGS
(F33615-68-C-1385)

SAMPLE CROSS- SECTIONAL NUMBER OR PREC- SIZE, IN.	TENSILE					RED. OF AREA, %	COMP. YIELD STRESS,* PSI	SHEAR ULT. STRESS, PSI	PEARLING [†] EDGWISE			
	ULT. STRESS, PSI	YIELD STRESS,* PSI	ELONG. IN 2 IN. OR 4D, %	YIELD STRESS,* PSI	ULT. STRESS, PSI				EDGWISE			
									ULT. STRESS, PSI e/D=1.5	YIELD STRESS, PSI e/D=2.0	YIELD STRESS, PSI e/D=1.5	ULT. STRESS, PSI e/D=2.0
2X 8	341037	L	78 600	71 000	14.0	34	73 300	48 700	115 100	154 700	99 100	114 400
		LT	76 100	64 900	12.0	20	73 200	46 500	114 500	149 100	98 000	113 400
		ST	76 000	63 700	7.8	10	74 200	---	---	---	---	---
3X12	341038	L	77 500	68 700	13.0	26	71 300	46 400	113 200	148 800	94 800	112 900
		LT	76 100	65 700	12.0	26	70 700	46 100	116 600	149 100	97 900	114 600
		ST	73 700	61 400	8.0	11	71 800	45 400	---	---	---	---
4X 8	341039	L	78 800	69 600	11.0	21	72 800	48 900	111 500	148 300	99 400	115 200
		LT	77 500	66 500	11.5	24	72 900	48 200	117 100	148 700	102 300	117 200
		ST	74 300	62 800	5.0	6	73 200	47 300	---	---	---	---
4X16	341040	L	77 900	68 000	12.0	22	70 100	46 600	113 000	145 900	95 200	110 300
		LT	74 600	63 000	9.5	18	66 800	45 700	107 500	144 400	94 000	105 700
		ST	74 000	62 900	7.9	17	70 600	44 900	---	---	---	---
5X 5	341041	L	75 600	67 600	13.0	27	69 700	47 900	112 600	149 900	94 400	108 900
		LT	72 900	63 000	8.5	12	67 000	45 900	105 200	143 600	92 100	107 800
		ST	71 300	59 500	7.0	10	68 400	46 300	---	---	---	---
5X10	341042	L	76 100	68 000	13.0	27	68 800	45 700	108 200	140 900	92 800	107 000
		LT	74 100	62 600	10.5	19	69 300	45 900	108 300	141 300	94 300	109 100
		ST	73 000	61 300	5.5	5	72 200	44 400	---	---	---	---
5X20	341043	L	76 900	65 600	13.0	24	67 000	46 200	104 600	135 900	91 600	106 400
		LT	73 300	61 400	11.0	19	65 700	46 400	103 300	136 900	89 800	105 400
		ST	71 300	58 300	6.0	7	68 300	44 000	---	---	---	---
6X 6	341044	L	73 600	63 800	15.0	37	68 900	48 400	112 200	148 100	95 600	105 400
		LT	72 600	61 400	9.0	16	69 700	47 900	111 000	146 000	96 700	109 400
		ST	71 700	61 800	8.5	14	67 100	47 300	---	---	---	---
6X12	341045	L	75 200	65 700	11.0	25	67 500	46 300	109 000	139 300	93 800	107 500
		LT	72 800	62 100	7.5	12	66 200	45 500	104 000	140 700	92 300	107 600
		ST	72 400	58 800	6.0	7	69 300	44 700	---	---	---	---
6X24	341046	L	73 900	63 900	12.0	22	63 300	43 800	94 300	128 300	85 200	98 100
		LT	69 100	57 500	10.0	22	62 900	42 000	87 700	123 300	83 300	97 200
		ST	69 300	58 100	4.5	6	67 300	42 000	---	---	---	---

* OFFSET EQUALS 0.2 PER CENT

† OFFSET EQUALS 2 PER CENT OF PIN DIAMETER

‡ SPECIMENS AND FIXTURES CLEANED ULTRASONICALLY

§ L, LONGITUDINAL; LT, LONG TRANSVERSE; ST, SHORT TRANSVERSE

Table VI

TABLE VI

RATIOS AMONG THE TENSILE, COMPRESSIVE, SHEAR AND BEARING PROPERTIES
OF STRESS-RELIEVED ALUMINUM ALLOY HAND FORGINGS
(F33615-68-C-1365)

ALLOY AND TEMPER	CROSS SECT. SIZE, NUMBER IN.	SAMPLE	TENSILE				COMPRESSIVE				SHEAR				BEARING			
			TS (L)		YS (L)		TS (L)		YS (L)		TS (L)		YS (L)		TS (L)		YS (L)	
			C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	C/D= 2.0	
2014-T652	2X 8	341007	1.04	1.08	1.12	0.62	0.61	---	1.41	1.71	1.35	1.56	1.41	1.61	1.38	1.54		
	3X12	341008	1.03	1.07	1.12	0.59	0.59	0.50	1.44	1.87	1.38	1.65	1.37	1.70	1.36	1.56		
	4X 8	341009	1.03	1.03	1.17	0.58	0.59	0.57	1.28	1.77	1.36	1.63	1.30	1.74	1.34	1.62		
	4X16	341010	0.96	1.04	1.08	0.58	0.58	0.58	1.33	1.86	1.34	1.65	1.33	1.73	1.34	1.59		
	5X 5	341011	1.03	1.02	1.13	0.62	0.60	0.61	1.31	1.74	1.40	1.65	1.29	1.75	1.40	1.44		
	5X10	341012	1.02	1.02	1.14	0.60	0.60	0.57	1.29	1.74	1.37	1.65	1.32	1.81	1.39	1.64		
	5X20	341013	1.01	1.11	1.12	0.60	0.59	0.59	1.39	1.75	1.38	1.65	1.34	1.82	1.34	1.65		
	6X 6	341014	1.03	1.02	1.18	0.65	0.63	0.62	1.58	1.76	1.46	1.64	1.38	1.87	1.41	1.78		
	6X12	341015	1.01	1.05	1.12	0.63	0.60	0.60	1.42	1.87	1.48	1.64	1.37	1.95	1.34	1.78		
	6X24	341016	1.04	1.08	1.10	0.64	0.58	0.59	1.34	1.77	1.41	1.73	1.30	1.77	1.34	1.71		
2024-T852	2X 8	341017	1.09	1.14	1.17	0.59	0.58	---	1.35	1.84	1.50	1.82	1.31	1.74	1.49	1.79		
	3X12	341018	1.05	1.10	1.12	0.58	0.57	0.55	1.29	1.87	1.36	1.59	1.28	1.71	1.36	1.64		
	4X 8	341019	1.02	1.01	1.15	0.58	0.56	0.55	1.30	1.87	1.31	1.59	1.26	1.70	1.31	1.68		
	4X16	341020	1.02	1.10	1.16	0.58	0.57	0.56	1.30	1.74	1.34	1.61	1.29	1.79	1.39	1.66		
	5X 5	341021	1.02	1.02	1.15	0.60	0.59	0.58	1.27	1.83	1.45	1.69	1.30	1.78	1.36	1.63		
	5X10	341022	1.03	1.05	1.14	0.58	0.57	0.56	1.29	1.85	1.43	1.57	1.29	1.74	1.34	1.62		
	5X20	341023	1.05	1.07	1.09	0.62	0.61	0.59	1.33	1.79	1.40	1.67	1.35	1.83	1.44	1.73		
	6X 6	341024	1.03	1.01	1.16	0.60	0.59	0.58	1.30	1.88	1.48	1.69	1.34	1.79	1.43	1.69		
	6X12	341025	1.02	1.06	1.14	0.59	0.57	0.56	1.26	1.74	1.37	1.67	1.27	1.68	1.34	1.59		
	6X24	341026	1.00	0.99	1.08	0.57	0.55	0.53	1.26	1.71	1.37	1.64	1.27	1.61	1.34	1.57		
7075-T7352	2X 8	341027	1.06	1.05	1.12	0.62	0.59	---	1.49	1.96	1.44	1.70	1.48	1.95	1.62	1.63		
	3X12	341028	1.01	1.10	1.14	0.59	0.60	0.60	1.44	1.91	1.50	1.75	1.38	1.89	1.51	1.66		
	4X 8	341029	1.05	1.09	1.14	0.61	0.59	0.59	1.46	2.00	1.59	1.86	1.51	1.95	1.54	1.87		
	4X16	341030	0.96	1.08	1.12	0.60	0.60	0.58	1.41	1.86	1.50	1.73	1.39	1.86	1.50	1.80		
	5X 5	341031	1.05	1.03	1.15	0.62	0.60	0.62	1.55	1.96	1.53	1.79	1.46	1.96	1.51	1.83		
	5X10	341032	1.01	1.05	1.17	0.62	0.60	0.62	1.50	1.95	1.60	1.79	1.53	1.98	1.56	1.89		
	5X20	341033	1.00	1.07	1.11	0.61	0.60	0.59	1.47	1.88	1.51	1.76	1.43	1.88	1.52	1.83		
	6X 6	341034	1.05	1.02	1.11	0.65	0.63	0.61	1.56	2.06	1.58	1.81	1.53	2.01	1.57	1.84		
	6X12	341035																
	6X24	341036																
7079-T652	2X 8	341037	1.03	1.13	1.17	0.64	0.61	---	1.51	2.03	1.53	1.76	1.50	1.96	1.51	1.75		
	3X12	341038	1.04	1.08	1.17	0.61	0.51	0.60	1.49	1.95	1.44	1.72	1.53	1.96	1.49	1.74		
	4X 8	341039	1.05	1.10	1.16	0.63	0.62	0.61	1.44	1.91	1.50	1.73	1.51	1.92	1.54	1.76		
	4X16	341040	1.03	1.06	1.12	0.62	0.61	0.60	1.52	1.96	1.51	1.75	1.44	1.94	1.49	1.80		
	5X 5	341041	1.03	1.06	1.15	0.66	0.63	0.64	1.54	2.06	1.50	1.73	1.44	1.97	1.46	1.71		
	5X10	341042	1.01	1.11	1.18	0.62	0.62	0.60	1.48	1.98	1.48	1.71	1.44	1.91	1.50	1.74		
	5X20	341043	1.02	1.07	1.17	0.63	0.63	0.60	1.63	1.85	1.56	1.73	1.41	1.87	1.45	1.72		
	6X 6	341044	1.08	1.14	1.09	0.67	0.66	0.65	1.55	2.04	1.56	1.72	1.53	2.01	1.58	1.78		
	6X12	341045	1.03	1.07	1.18	0.64	0.63	0.61	1.50	1.91	1.51	1.73	1.43	1.93	1.49	1.69		
	6X24	341046	0.99	1.09	1.16	0.63	0.61	0.61	1.36	1.86	1.48	1.71	1.27	1.78	1.45	1.69		

TABLE VII

SPECIFIED MINIMUM VALUES FOR ALUMINUM ALLOY HAND FORGINGS
(F22615-68-C-1285)

Alloy and Temper	Thickness, in.	Longitudinal		Long-Transverse		Short-Transverse		Federal Specification
		Tensile Strength, psi	Yield Strength, psi	Tensile Strength, psi	Yield Strength, psi	Tensile Strength, psi	Yield Strength, psi	
2024-T352	Up thru 2.000	65 000	56 000	65 000	56 000	---	---	QQ-A-367g
	2.001-3.000	63 000	55 000	64 000	55 000	62 000	52 000	
	3.001-4.000	63 000	55 000	63 000	55 000	61 000	51 000	
	4.001-5.000	62 000	54 000	62 000	54 000	60 000	50 000	
	5.001-6.000	61 000	53 000	61 000	53 000	59 000	50 000	
2024-T352	All	---	---	---	---	---	---	None
7075-T7352	Up thru 2.000	65 000	54 000	64 000	52 000	61 000	50 000	None**
	2.001-3.000	64 000	53 000	63 000	50 000	60 000	48 000	
	3.001-4.000	62 000	51 000	61 000	48 000	58 000	46 000	
	4.001-5.000	61 000	49 000	59 000	46 000	57 000	44 000	
	5.001-6.000	60 000	48 000	58 000	45 000	56 000	43 000	
7075-T652	Up thru 2.000	72 000	63 000	71 000	61 000	---	---	QQ-A-367g
	2.001-3.000	72 000	62 000	70 000	60 000	67 000	55 000	
	3.001-4.000	71 000	61 000	70 000	59 000	66 000	54 000	
	4.001-5.000	70 000	60 000	69 000	58 000	65 000	53 000	
	5.001-6.000	69 000	59 000	68 000	56 000	64 000	52 000	

* Offset equals 0.2 per cent.
 ** The Aluminum Association, "Aluminum Standards and Data", April 1968.

TABLE VII

Table VIII

TABLE VIII

RESULTS OF LONG-TRANSVERSE AXIAL-STRESS FATIGUE TESTS
OF STRESS-RELIEVED ALUMINUM ALLOY HAND FORGINGS (R=0.0)
(F33615-68-C-1385)

Alloy and Temper	Sample		Cycles to Failure		
	Size, in.	Number			
	Maximum Stress, psi		60 000	40 000	35 000
2014-T652	2x8	341007	34 200	4 358 100	10 264 500*
	4x8	341009	17 700	1 032 800	6 252 200
	5x10	341012	18 900	230 000	10 017 300*
	6x12	341015	7 700	142 200	14 323 200*
	Log-Mean Fatigue Life		17 200	619 400	
2024-T652	2x8	341017	22 600	252 900	10 029 500*
	4x8	341019	12 700	180 700	13 845 700*
	5x10	341022	14 300	90 200	17 189 300*
	6x12	341015	7 200	93 600	14 882 400*
	Log-Mean Fatigue Life		13 700	140 200	
	Maximum Stress, psi		60 000	45 000	38 000
7075-T7352	2x8	341027	28 100	4 084 800	14 882 600*
	4x8	341029	4 700	82 400	1 455 800
	5x10	341032	9 800	51 100	105 800
	6x12	341035			
	Log-Mean Fatigue Life				
7079-T652	2x8	341037	22 200	109 800	720 500
	4x8	341039	22 700	61 400	11 607 400*
	5x10	341042	19 200	75 500	162 700
	6x12	341045	11 400	40 200	146 400
	Log-Mean Fatigue Life		18 100	66 900	

* Specimen did not fail.

TABLE IX

STATUS OF LONGITUDINAL AND LONG-TRANSVERSE STRESS-CORROSION TESTS

TRIPLICATE 0.437" DIAMETER TENSION SPECIMENS STRESSED IN DIRECT TENSION*
 EXPOSURE: 3.5% NaCl Solution by Alternate Immersion.
 † Dash Number and Days to Failure.

Alloy and Temper	Forging Size, in.	Sample Number	Longitudinal Specimens		Long-Transverse Specimens			
			Stressed 75% Y.S.		Stressed 75% Y.S.		Stressed 50% Y.S.	
			No.	Days	No.	Days	No.	Days
2014-T652	2x8	341007	L3		T3	64	T6	
			L4		T4	8	T7	
			L5		T5	59	T8	
2024-T852	2x8	341017	L3		T3			
			L4		T4			
			L5		T5			
7075-T7352	2x8	341027	L3		T3			
			L4		T4			
			L5		T5			
7079-T652	2x8	341037	L3		T3	59	T6	
			L4		T4	64	T7	
			L5		T5	27	T8	

* Duplicate unstressed specimens were also exposed in each instance.

† Specimens were exposed November 24, 1968. When no entry is shown in the "Days" column, specimen has not failed.

Table X

TABLE X
STATUS OF SHORT-TRANSVERSE STRESS-CORROSION TESTS
TRIPPLICATE 0.125" DIAMETER TENSION SPECIMENS STRESSED IN DIRECT TENSION.
EXPOSURE: 3.5% NaCl Solution by Alternate Immersion

Alloy and Temp ^o	Forging Size, in.	Sample Number	Stressed 75% T.S.		Stressed 50% T.S.		Stressed 22.5 ksi		Stressed 15.0 ksi		Stressed 7.5 ksi	
			P/N ^o	Days	P/N ^o	Days	P/N ^o	Days	P/N ^o	Days	P/N ^o	Days
2014-T652	2x8	341007	--	--	--	--	0/3	05-78	0/3	05-78	0/3	05-78
	3x12	341008	--	--	--	--	3/3	6,8,8	0/3	05-78	0/3	05-78
	5x20	341013	--	--	--	--	0/3	05-78	0/3	05-78	0/3	05-78
2024-T652	2x8	341017	1/3	14 (2-05-78)	0/3	05-78	--	--	--	--	--	--
	3x12	341018	0/3	05-78	0/3	05-78	--	--	--	--	--	--
	5x20	341023	0/3	05-78	0/3	05-78	--	--	--	--	--	--
7075-T7352	2x8	341027	0/3	05-78	--	--	--	--	--	--	--	--
	3x12	341028	3/3	6,8,8	--	--	--	--	--	--	--	--
	5x20	341033	0/3	05-78	--	--	--	--	--	--	--	--
7079-T652	2x8	341037	--	--	--	--	0/3	05-78	0/3	05-78	0/3	05-78
	3x12	341038	--	--	--	--	0/3	05-78	0/3	05-78	0/3	05-78
	5x20	341043	--	--	--	--	2/3	15,27(13-05-78)	0/3	05-78	0/3	05-78

• Duplicate unstressed specimens were also exposed in each instance.

• P/N denotes number of specimens failed over number exposed.

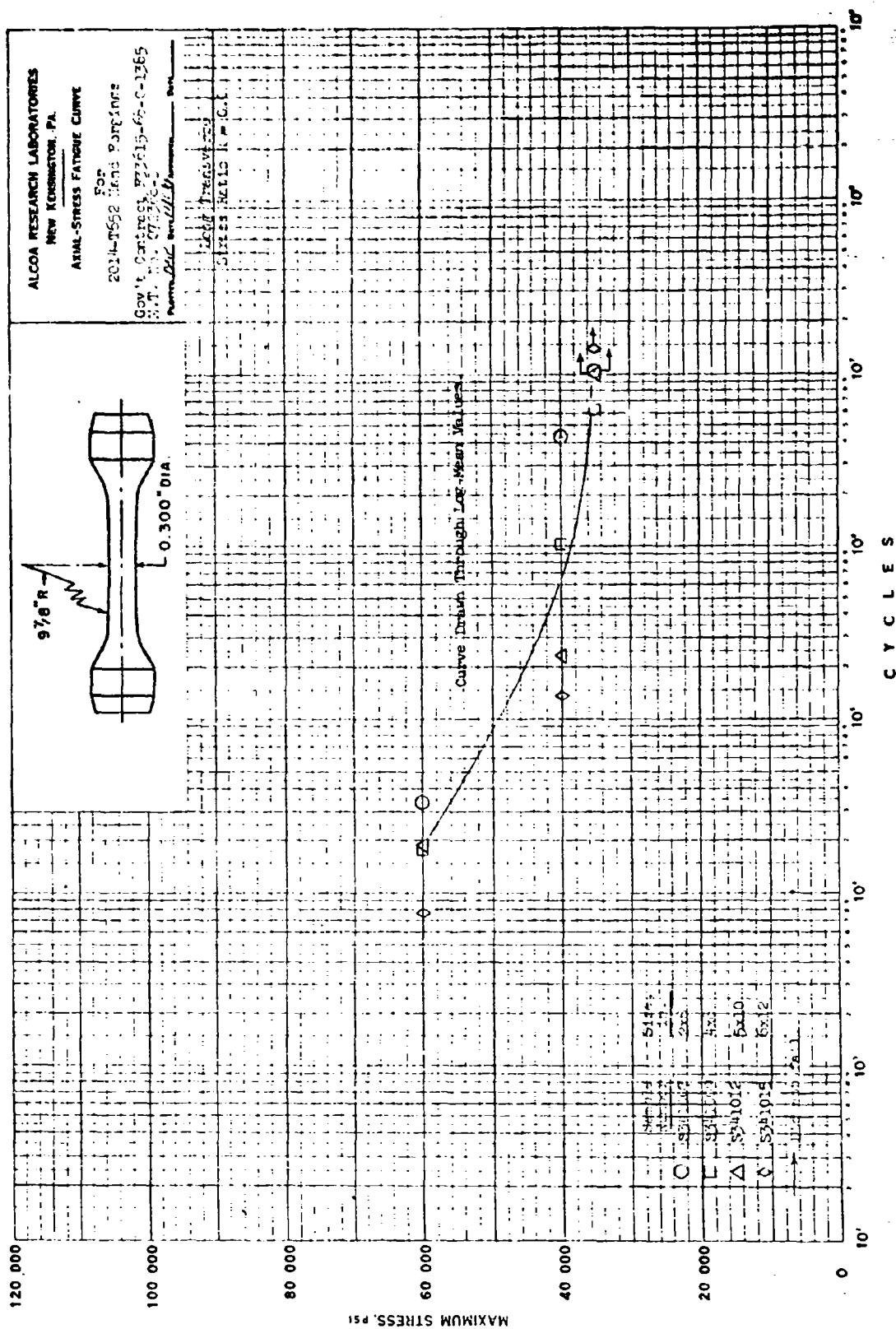


Fig. 1

Fig. 1

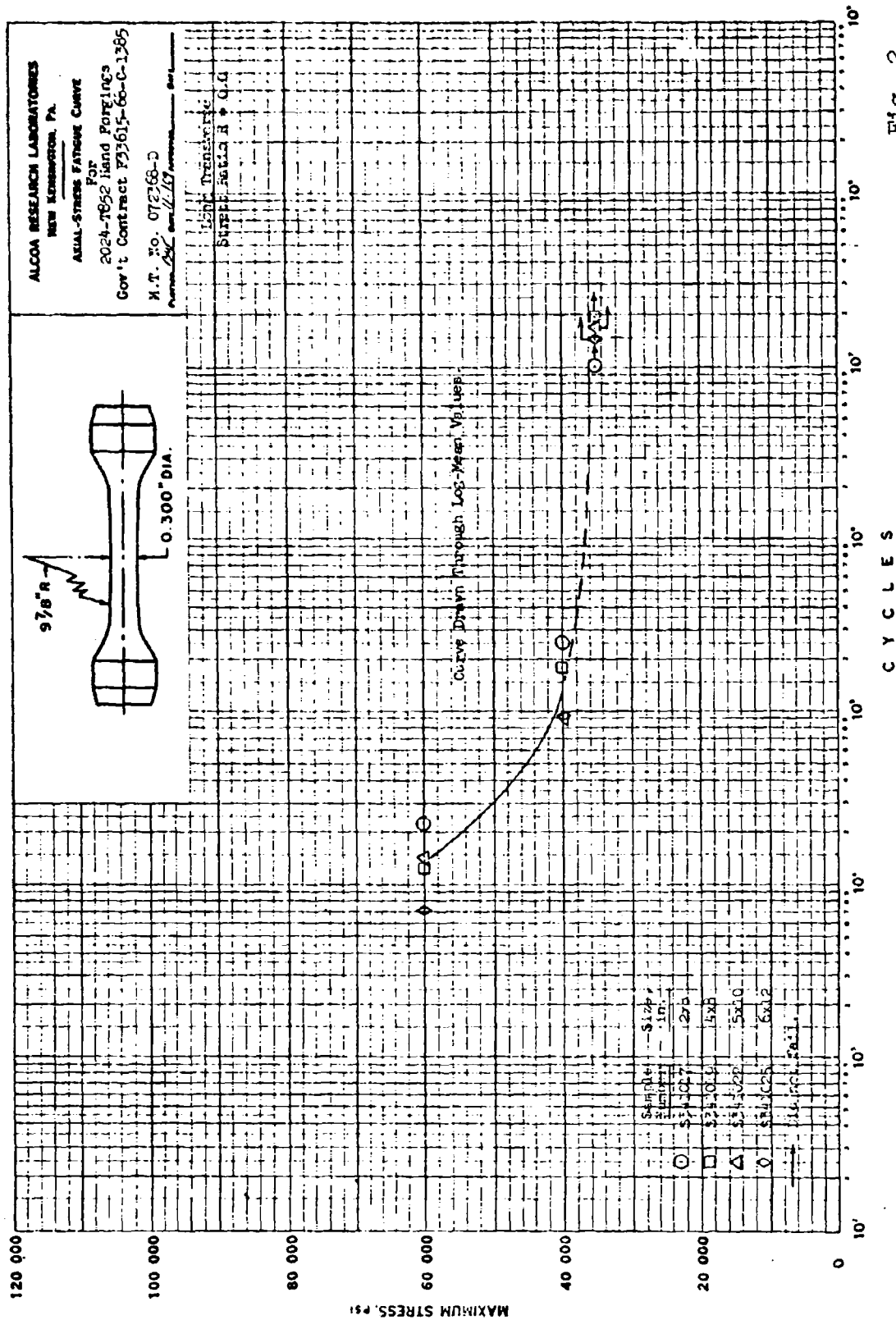


Fig. 2

Fig. 2

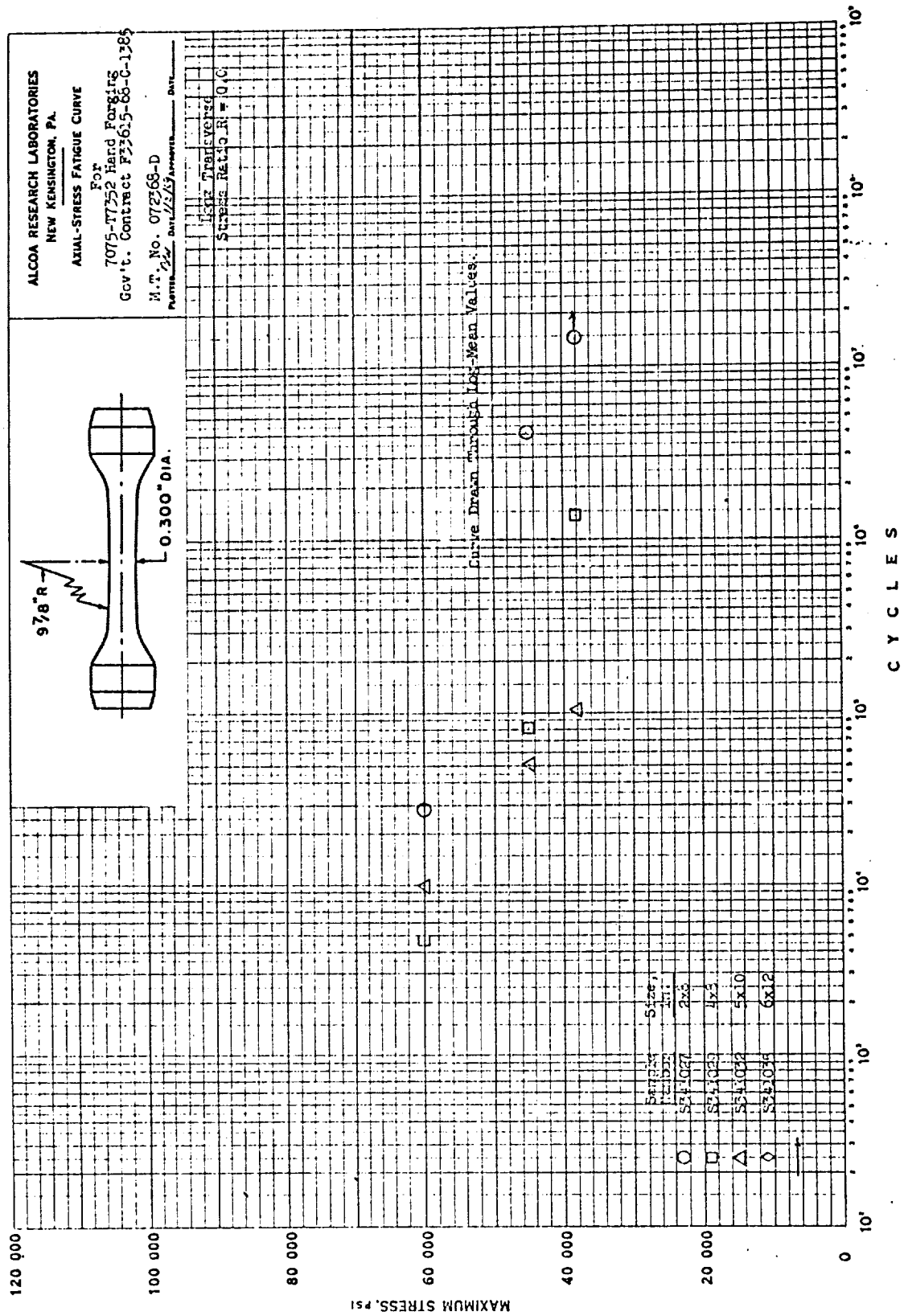


Fig. 3

Fig. 3



S.No. 341007-T4 Etch: Keller's Mag. 100X

Fig. 5. Section Illustrating an Auxiliary Crack in Long-Transverse Specimen from 2-in. Thick 2014-T652 Forging which Failed at a Stress Equal to 75% Y.S.



S.No. 341007-T4 Etch: Keller's Mag. 500X

Fig. 6. Illustrates the Intergranular Character of the Crack Shown Above, Indicating that Failure was Result of Stress-Corrosion Cracking.

Figs. 5 & 6



S.No. 341008-N11 Etch: Keller's Mag. 100X

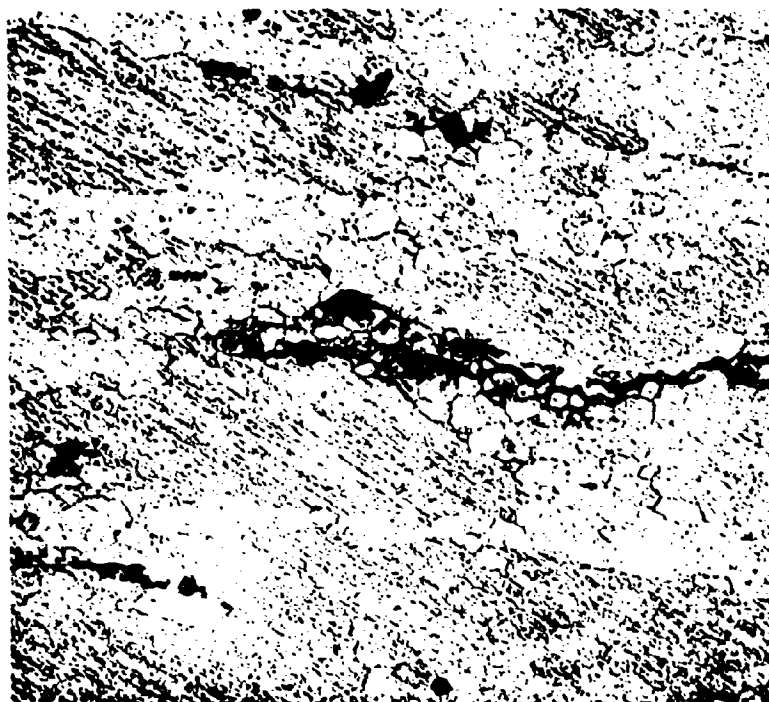
Fig. 7. Section Through Specimen from 3-in. Thick 2014-T652 Forging which Failed at a Stress of 22.5 ksi (35% Y.S.). The Intergranular Character of This Auxiliary Crack is Indicative of Stress-Corrosion Cracking.

Fig. 7



S.No. 341017-N4 Etch: Keller's Mag. 100X

Fig. 8. Section Illustrating Fine Auxiliary Crack in Specimen from 2-in. Thick 2024-T852 Forging Which Failed at a Stress Equal to 75% Y.S.



S. No. 341017-N4 Etch: Keller's Mag. 500X

Fig. 9. Illustrates the Intergranular Character of the Crack Shown Above, Indicating that Failure Was the Result of Stress-Corrosion Cracking.

Figs. 8 & 9



S.No. 341028-N3 Etch: Keller's Mag. 100X

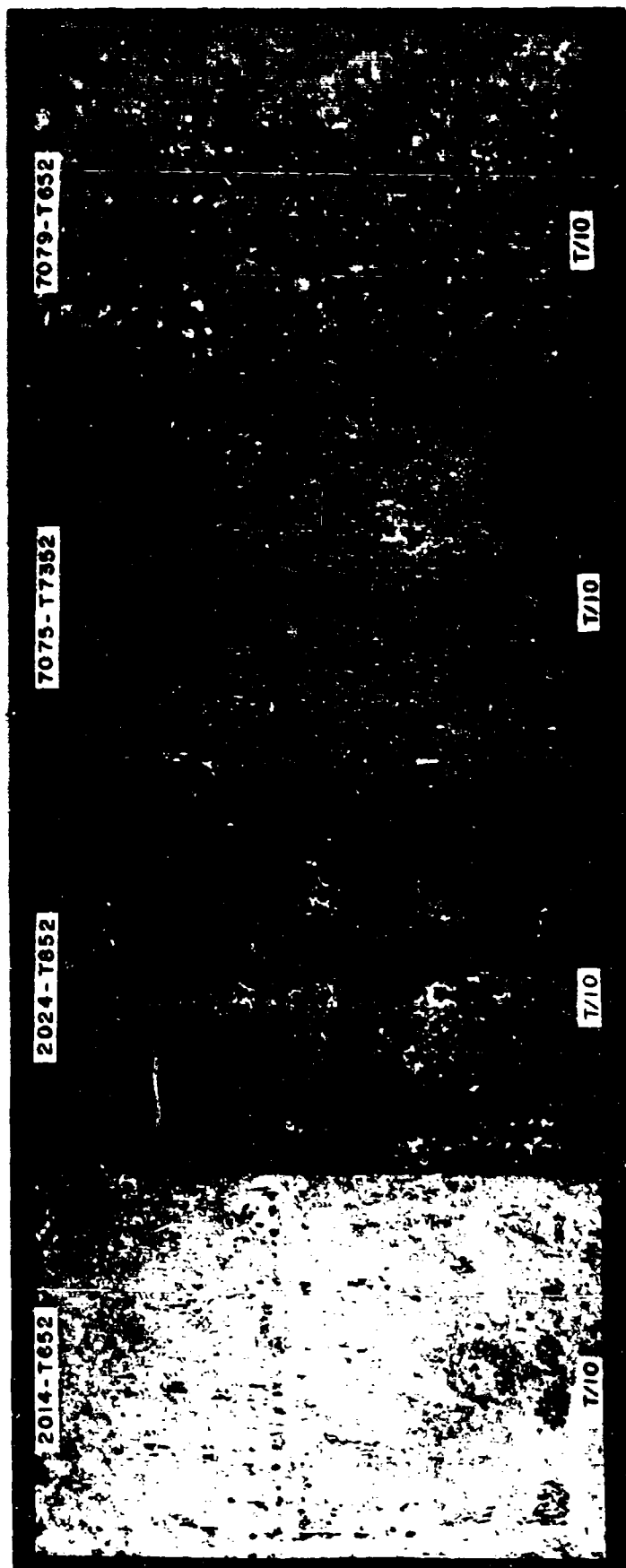
Fig. 10. Section Illustrating Fine Auxiliary Crack in Specimen from 3-in. Thick 7075-T7352 Forging Which Failed at a Stress Equal to 75% Y.S.



S.No. 341028-N3 Etch: Keller's Mag. 500X

Fig. 11. Illustrate the Intergranular Character of the Crack Shown Above, Indicating That Failure Was the Result of Stress-Corrosion Cracking.

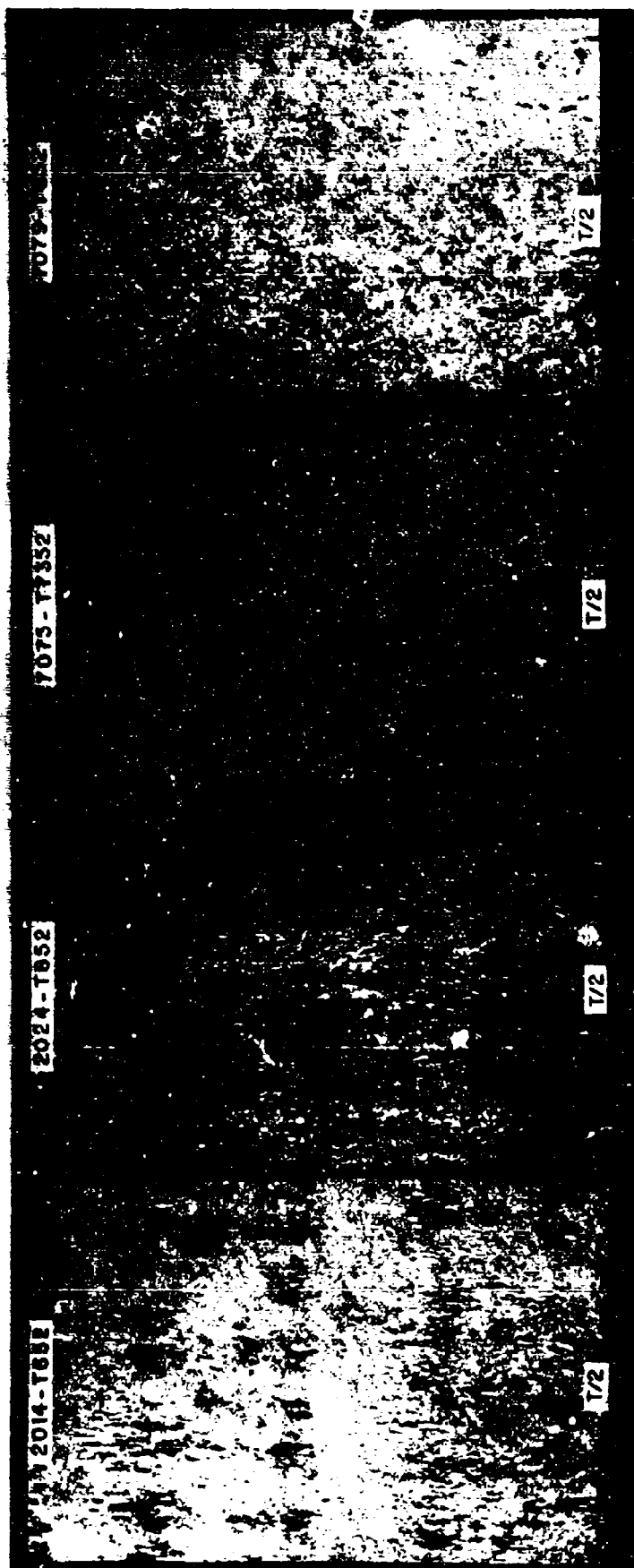
Figs. 10 & 11



Mag. 0.6X

Fig. 12. Illustrates Appearance of Specimens from the 2-in. Thick Forgings After Two Weeks Exposure to the Laboratory Rapid Bifoliation Test. Specimen Surface Corresponds to Plane $1/10$ of Way Through the Forging Thickness.

Fig. 12



Mag. 0.6X

Fig. 13. Illustrates Appearance of Specimens from the 2-in. Thick Forgings After Two Weeks Exposure to the Laboratory Rapid Exfoliation Test. Specimen Surface Corresponds to Plane at Center of Forging Thickness.

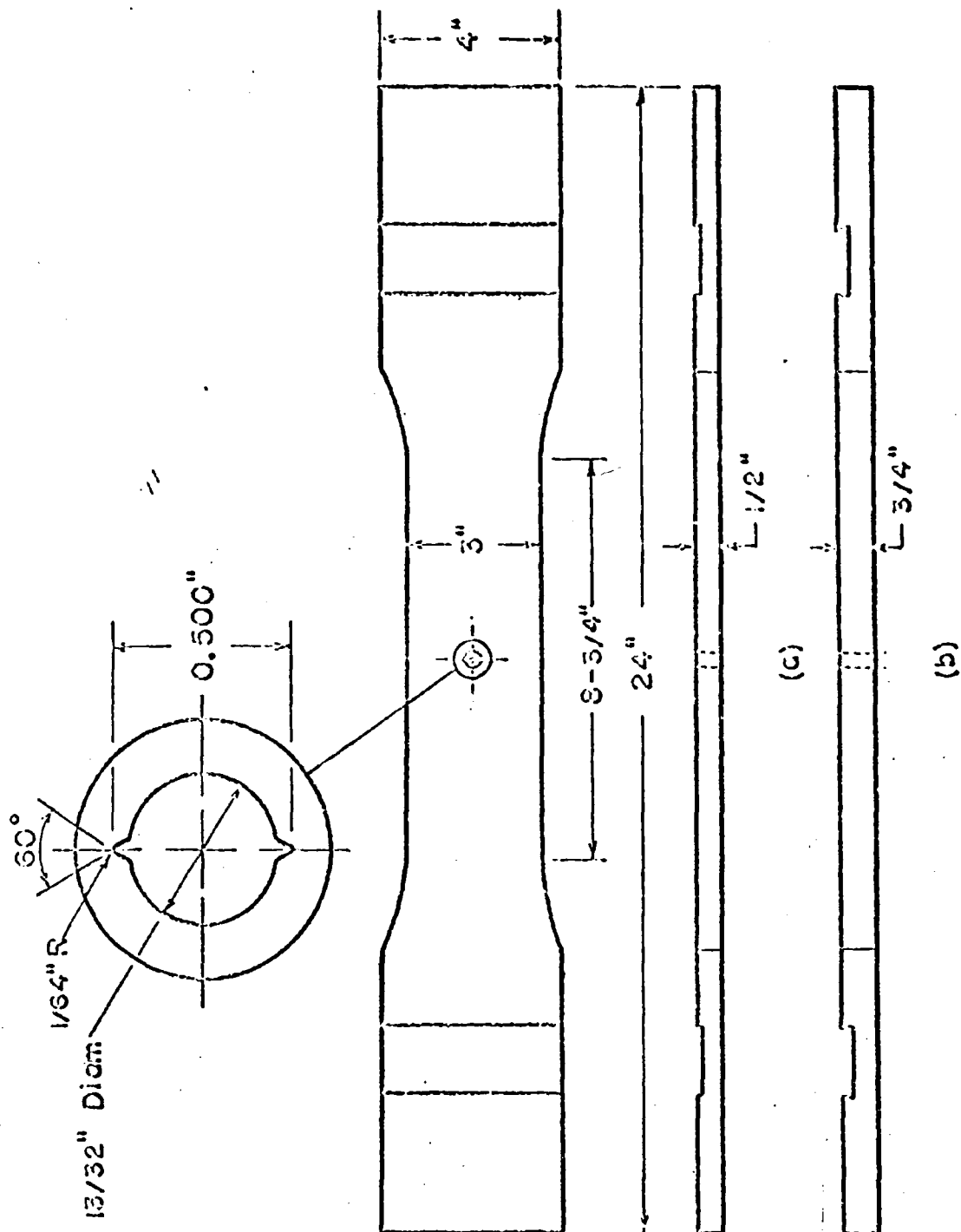


Fig. 14 Center-Notched Fatigue Specimen

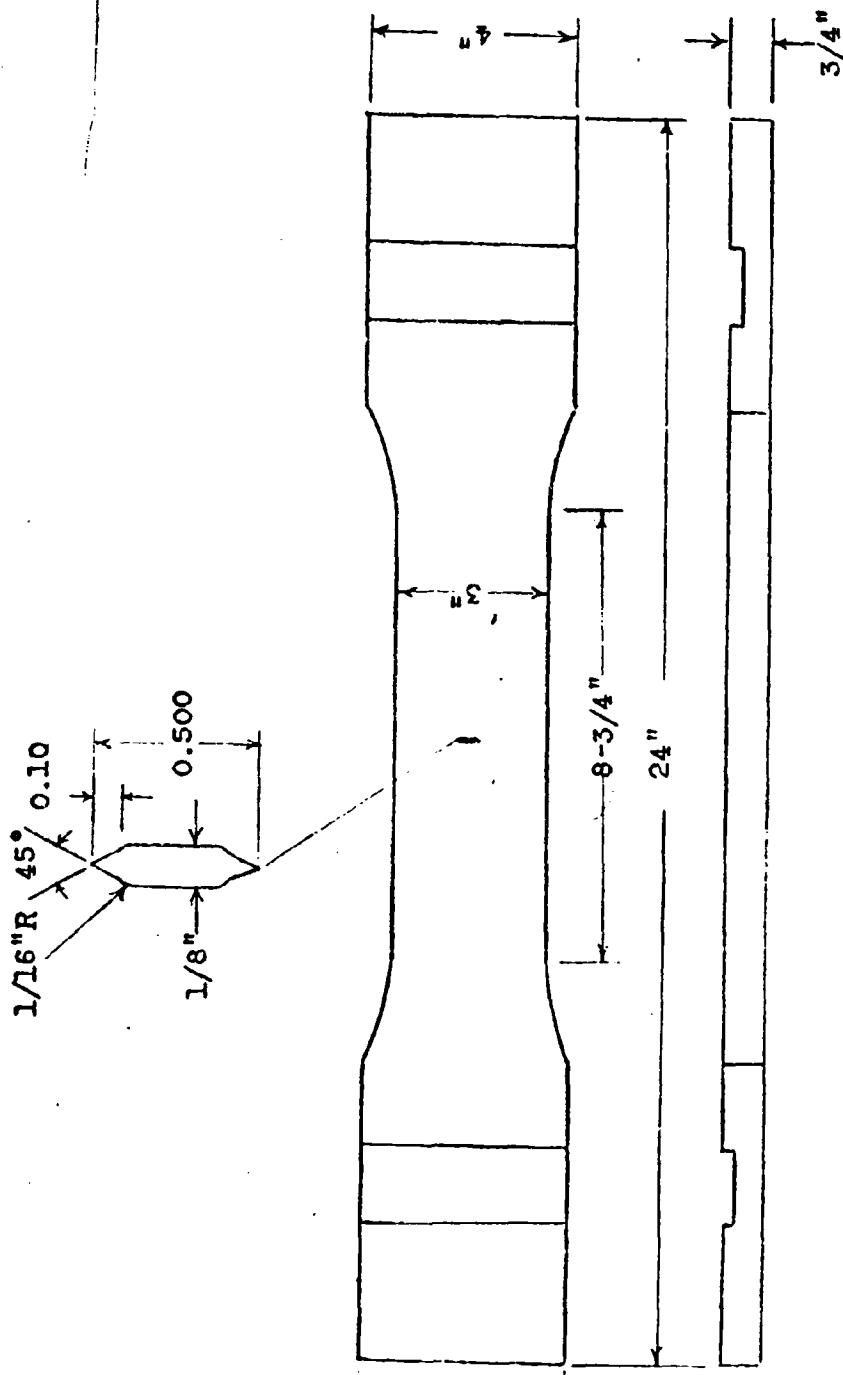
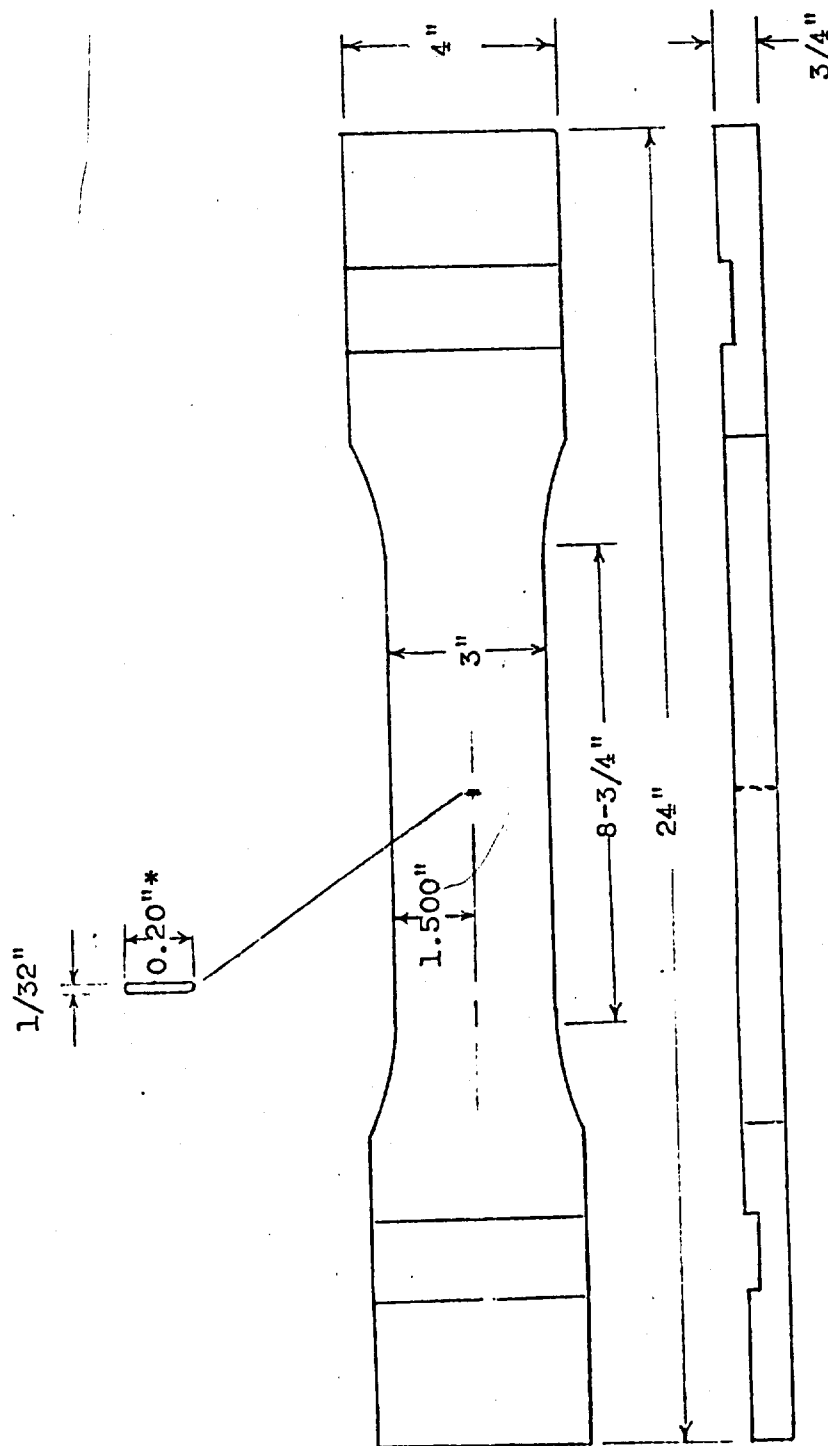
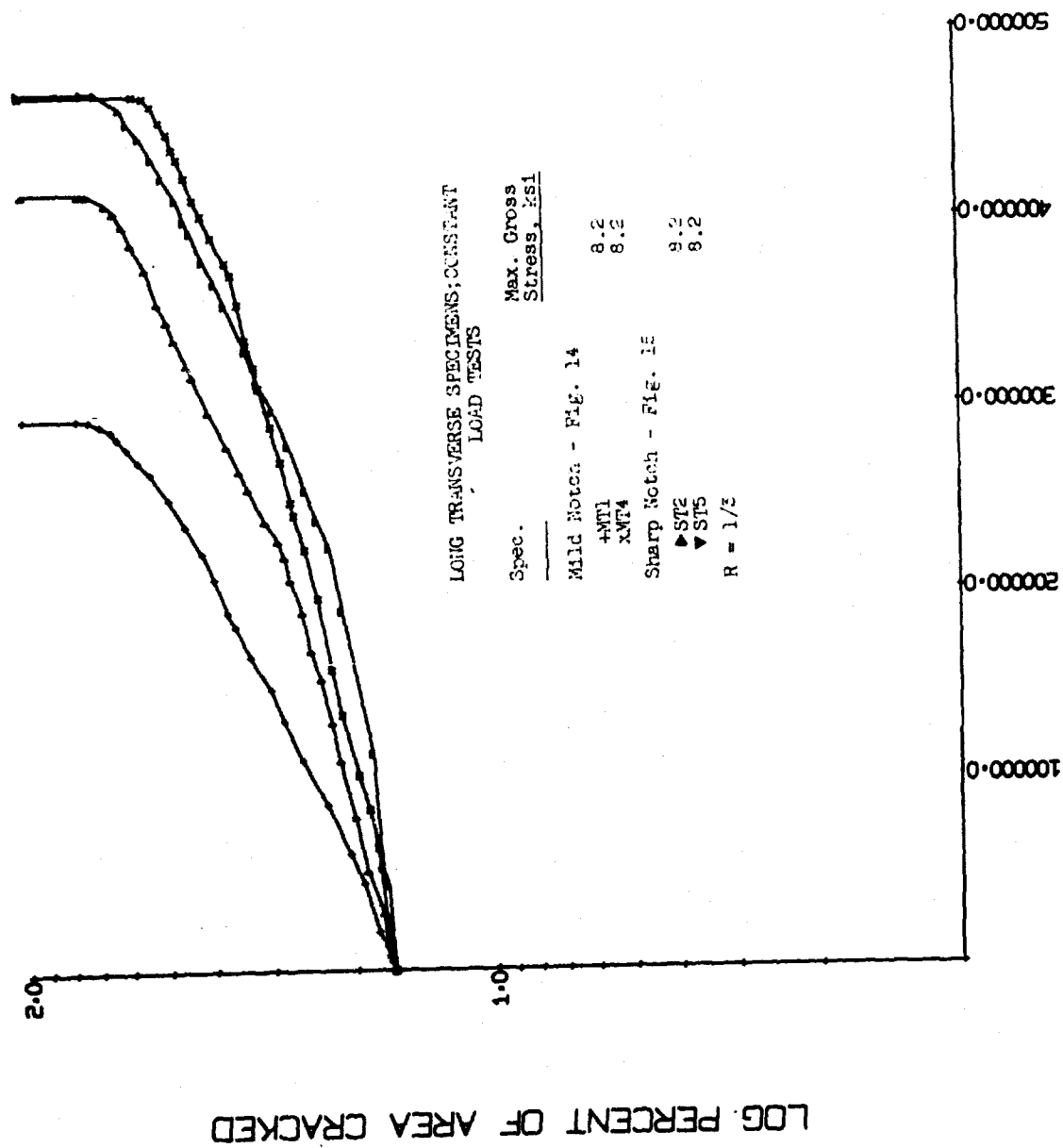


Fig. 15 Center-Notched Fatigue Specimen



*Specimen precracked to 0.50 in.

Fig. 16 Floc Notched Crack Propagation Specimen



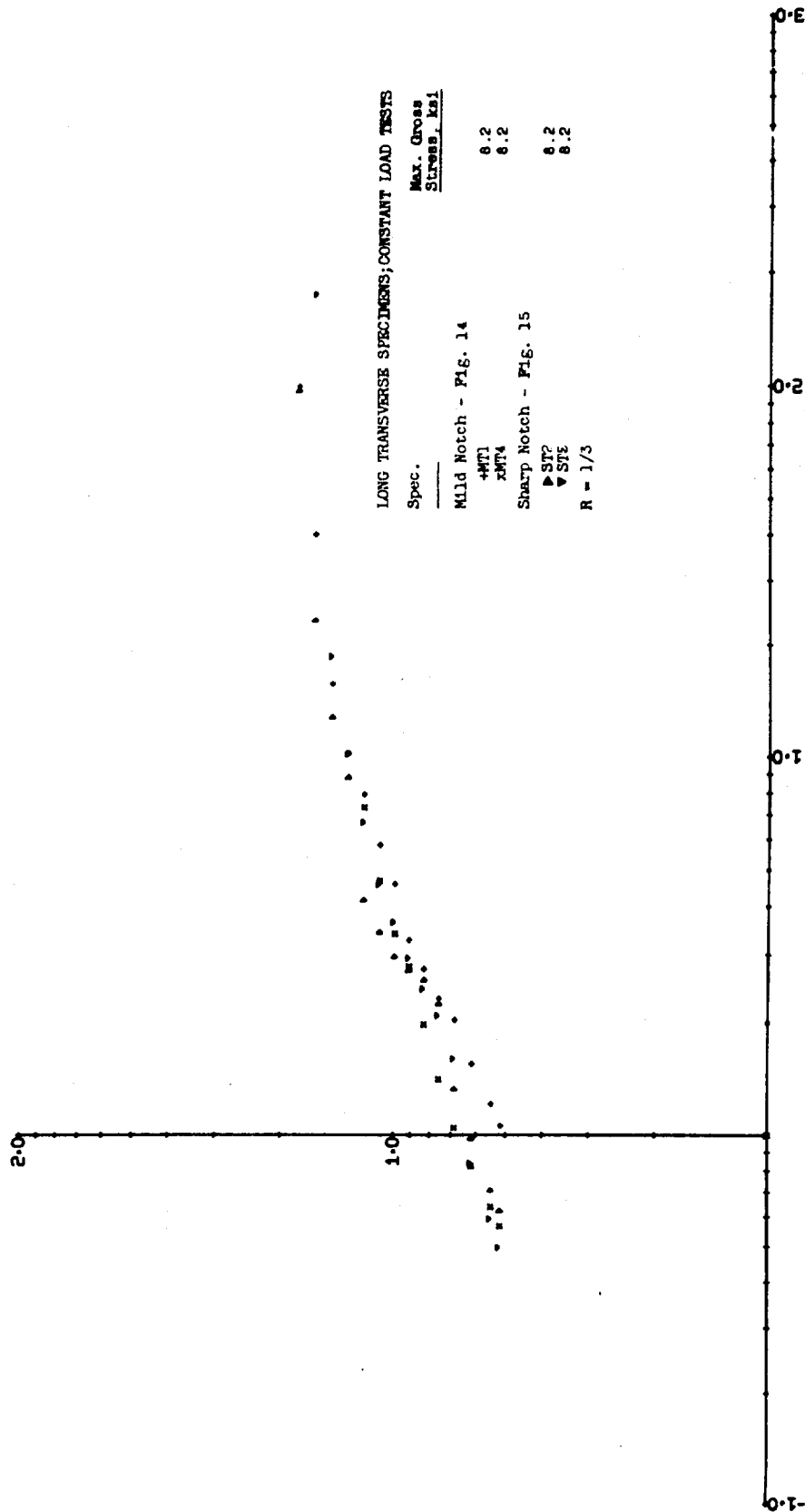
PATIENCE CRACK PROPAGATION OF 2014-T3E2 FORGING - S. No. 24002

Fig. 17

Fig. 17

LOG AK, RANGE OF STRESS INTENSITY FACTOR, KSI. (IN.

Fig. 18



LOG DA/DN, FATIGUE CRACK GROWTH RATE, MICRO IN./CYCLE

FATIGUE CRACK PROPAGATION RATES FOR 2014-T652 FORGING - S. No. 341016

Fig. 18