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(6) MECHANICAL PROPERTIES, INCLUDING FRACTURE TOUGHNESS AND FATIGUE, AND RESISTANCE TO STRESS-CORROSION CRACKING OF STRESS-RELIEVED STRETCHED ALUMINUM ALLOY EXTRUSIONS.

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ABSTRACT

Samples from about 225 lots of 2014, 2024, 6061, 7075, 7079 and 7178 extrusions in sizes listed in applicable specifications have been ordered from two major producers.

Three samples of 6061-T6510 extruded shapes have just been received. Arrangements have been made to have test specimens machined from these samples.

(a)

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FIRST QUARTERLY REPORT

MECHANICAL PROPERTIES, INCLUDING FRACTURE TOUGHNESS AND FATIGUE, AND RESISTANCE TO STRESS-CORROSION CRACKING OF STRESS-RELIEVED STRETCHED ALUMINUM ALLOY EXTRUSIONS

I. Introduction.

In the tables of design mechanical properties for aluminum alloys in MIL-HDBK-5, the "A" values for ultimate tensile stress, tensile yield stress and elongation in one direction are the minimum values required in material specifications. These values are based on statistical analyses of the results of considerable number of inspection tests of commercial lots as described in Section 1.4.1.2* of MIL-HDBK-5. The values are chosen so that, with 95 per cent confidence, the properties of 99 per cent of the total production lots of the particular alloy, temper, product and size range will meet or exceed those values. Tests for the tensile properties in other directions and for the compressive, shear and bearing properties are seldom, if ever, made during routine inspection and it would be impractical to provide an equally large amount of data for establishing individually the values for these other properties. For this reason, the "A" design values for these properties are "derived" values based on a smaller number of tests, as described in Section 1.4.1.3* of MIL-HDBK-5.

The desirability of stretching heat-treated aluminum alloy products, not only for straightening, but also to reduce residual stresses and warpage during subsequent machining operations, has been recognized in recent years by the establishment of the TX51-type tempers. It is realized, however, that this stretching may have a significant effect on some of the mechanical properties,

* As revised November 1, 1963.

particularly a reduction of the compressive yield strength in the longitudinal direction. While values for some of the properties not covered by specifications are included in MIL-HDBK-5, it is not certain that all of these values would be the same if they had been established on the statistical basis recommended by the Handbook Reliability Subcommittee of the MIL-HDBK-5 Working Group.

The data to be obtained under this contract are intended to form a satisfactory basis for establishing design mechanical properties for use in MIL-HDBK-5, including stress-strain and tangent-modulus curves, for aluminum alloy extrusions in the TX51X tempers. For comparison, limited similar tests will be made of extrusions in "heat-treated-by-user" tempers.

II. Scope.

The scope of this program will include the determination of the following properties of 2014, 2024, 6061, 7075, 7079 and 7178 extruded shapes in the sizes and tempers listed in Table I:

1. The ultimate tensile stress, tensile yield stress, compressive yield stress, ultimate shear stress, and tensile elongation in the longitudinal and long-transverse directions at locations required by specifications, and for shapes thicker than 2 inches, in the short-transverse direction.

2. The same properties at the center of the cross-section for shapes wider and/or thicker than 1.5 in.

3. The ultimate bearing stress and bearing yield stress in the longitudinal and long-transverse directions with (a) flatwise

specimens from the same locations as in the tensile tests and, (b) for shapes equal to or greater than 1.0 in. in thickness, edgewise specimens from the center of the thickness.

4. The moduli of elasticity in tension and in compression in the longitudinal and long-transverse directions, of representative lots.

5. Tensile and compressive stress-strain curves and compressive tangent-modulus curves for the longitudinal and long-transverse directions of the same lots for which moduli are determined. Complete tensile stress-strain curves for representative lots.

6. Plane-strain stress-intensity factor, K_{Ic}, in the longitudinal and long-transverse directions of representative lots.

7. Axial-stress fatigue strengths in the longitudinal and long-transverse directions of representative lots.

8. Resistance to stress-corrosion cracking of representative lots.

From these data, the following information will be developed:

1. Statistically reliable expected-minimum tensile, compressive, shear and bearing properties suitable for inclusion in MIL-HDBK-5.

2. Moduli of elasticity and typical and minimum tensile and compressive stress-strain curves and tangent-modulus curves suitable for inclusion in MIL-HDBK-5.

3. Average (if practical, statistically reliable average) values of plane-strain fracture toughness (K_{Ic}) and fatigue lives, for engineering comparisons.

4. Relative resistance to stress-corrosion cracking.

III Material.

The alloys, tempers and sizes of the samples of extruded shapes to be tested are shown in Table I.

Samples from about 225 lots of extruded shapes have been ordered from Alcoa and another major producer. Quotations for price and delivery of about 1/3 of the total number of lots to be tested were requested from two other major producers. Of the two producers, only one submitted quotations. Therefore, orders for about 1/3 the number of lots of extrusions of the different alloys and thicknesses were sent to the one outside producer that quoted.

Since all samples are to be obtained from regular production orders for customers, and no samples are to be extruded especially for this investigation, it is probable that the desired number of lots will not become available in every combination of alloy, temper, and size that is desired. Therefore, the schedule for this program is based upon the expectation that at least 2/3 of the total number of samples of lots ordered will actually be tested.

In general, the samples of extrusions are to be selected from regular lots produced for aerospace customers. All samples are to be from lots that meet the requirements of applicable Federal, Military and AMS Specifications. No two samples of any alloy and thickness range shall be from the same production run except that those of the 2024-T851X and 7075-T7351X will be taken from the same respective lengths as those of 2024-T351X and 7075-T651X.

Three samples from lots of 6061-T6510 extrusions were received the second week in June. The thicknesses of these extrusions are as indicated in Table I.

IV. Procedure.

The specimens and procedures used will in general be in accordance with ASTM methods, and in essential agreement with Federal Test Method 151.

All tests will be made in testing machines that meet ASTM and Government requirements for accuracy.

All tensile tests will be made in accordance with ASTM Methods of Tension Testing of Metallic Materials (E8-65T). Whenever possible, the specimens from thicknesses 0.499 in. or less will be full-thickness sheet-type specimens (Fig. 7 of E8-65T). The specimens from thicker shapes will be 1/2-in. dia, except where it is necessary to use subsize round specimens (Fig. 9 of E8-65T). Specimens used in determinations of modulus will differ from these in that the gage lengths will be 6 in. Their test sections will be of uniform width or diameter.

All compression tests will be made in accordance with ASTM Methods of Compression Testing of Metallic Materials (E9-61) and will be made using a subpress (Fig. 3 of E9-61). The specimens from shapes thinner than 0.500 in. will be of the full-thickness, 0.625 in. wide, and 2.63 in. long (Table II of E9-61). These specimens will be laterally supported by a Montgomery-Templin fixture (Fig. 4a of E9-61). The specimens from thicker shapes will be cylindrical, 1/2 in. in diameter x 1-7/8-in. long (l/r = 15); except that for most determinations of modulus of elasticity, 3/4 in diameter x 3-1/2-in. long specimens will be used.

Tensile and compressive yield stresses will be determined from load-strain diagrams obtained autographically for each lot in each direction.

On the basis of these tests, two thickness ranges of each alloy and temper will be chosen, and from each of those two ranges, three lots will be selected, preferably those having the high, medium and low properties, for tensile and compressive stress strain tests. Complete tensile stress-strain tests will be made of these lots of each alloy and temper. Longitudinal and long-transverse specimens will be from the locations required by the material specifications. The procedure in the tensile tests will meet the requirements of ASTM Method for Determination of Young's Modulus at Room Temperature (E111-61), and strains will generally be measured over a 6-in. gage length using an Amsler-Martens mirror-type extensometer (ASTM Class A). In most compressive tests, strains will be measured over a 2-in. gage length with a Tuckerman optical strain gage (ASTM Class A), except that a 1 in. gage length will be used in tests of shapes thinner than 3/4 in. For each test, the modulus will be determined as prescribed in the ASTM Method (E111-61). Based on the various tests, typical and minimum stress-strain and tangent-modulus curves will be developed using the method similar to Boeing's method in Attachment 59-25 of minutes of 18th meeting of ANC-5 Panel.

Tests to determine ultimate shear stress will be made with specimens from the same locations as in the tensile tests, except that tests of short-transverse specimens will be made only on shapes 3 in., or more, in thickness. When possible the specimens will be 3/8 in. in diameter; specimens of smaller diameter will have to be used for shapes 3/8 in., or less, in thickness. The tests will be made with an Amsler double-shear tool in which a 1-in length is sheared from a specimen 3 in. long, the end thirds being supported throughout their lengths. In the tests of longitudinal and long-transverse specimens, the loads will be applied in the direction normal to the major surfaces of the shape from which the specimen was taken.

Bearing tests will be made in accordance with ASTM Method E238-64T using longitudinal and, if possible, long-transverse sheet-type specimens, 0.094 in. thick x 1-1/8 in. wide, with a 0.375 in. dia hole and edge distances of 1.5 and 2.0 D. Flatwise and edgewise specimens will be tested from shapes of suitable size. The edgewise specimens from shapes thinner than 1-1/2 in., however, will be only 1 in. wide and have a 0.250 in. dia hole. Before making these tests, the test fixture and specimens will be cleaned ultrasonically in a suitable non-toxic solvent (Toson 3, Giannini Controls Corp.). The yield stress will be determined as the stress at a permanent deformation of 2 per cent of the pin diameter, as indicated on autographic load-deformation diagrams.

Based on the results of the tensile tests, specific lots will be chosen for fracture-toughness, fatigue and stress-corrosion tests. They may or may not be the same lots chosen for the stress-strain tests.

Fracture-toughness tests will be made in accordance with the methods described in ASTM STP 381 on fatigue-cracked single-edge-notched specimens from the longitudinal and long-transverse directions. The geometry of the specimen, shown in Fig. 1, is the same as that used by W. F. Brown et al, and so the fracture parameters will be calculated from relationships developed from their calibration. The specimens will be fatigue cracked by flexural or axial-stress loading at nominal stresses equal to or less than 20 per cent of the tensile yield strength; the crack developed by fatigue loading will be at least 0.1 in. long (total slot length ~1 in.). The plane-strain stress intensity factor, K_{Ic}, and the plane strain-energy release rate, G_{Ic}, will be determined from the load at the initial burst of unstable crack growth (pop-in). Pop-in will be detected from load-deformation curves developed with SR-4 electrical resistance strain gage units, mounted as in Fig. 2, with a deformation magnification of 500 on the recorder. Methods of establishing whether the pop-in is significant in terms of amount of unstable crack growth will be as indicated in the minutes of meetings of the ASTM Fracture Committee, May 10, 11, and 12, 1965.

The axial-stress fatigue strengths will be determined with specimens of the design in Fig. 3 in Krouse fatigue machines operating at 2400 rpm. Three longitudinal and three long-transverse specimens will be taken from each lot selected for fatigue testing.

The resistance to stress-corrosion cracking in 3-1/2% (by weight) NaCl solution (Sterling Granulated Salt) will be determined with longitudinal and long-transverse 0.125-in.-dia tensile specimens of the design in Fig. 4 and, for samples 0.750 in. or more in thickness, with short-transverse C-rings of the type in Fig. 5. The 0.125-in. dia specimens will be stressed in frames as indicated in Fig. 6 and 7, while the C-rings will be stressed by tightening the screw as indicated in Fig. 8; the stresses will be 75 per cent of the tensile yield stress. The alternate-immersion cycle will include total immersion of specimens for 10 minutes per hour and aeration above the solution for the remaining 50 minutes per hour, 24 hours a day for 12 weeks. The equipment, such as shown in Fig. 9, consists of large stationery aluminum alloy tanks containing the salt solution and a mechanism for raising and lowering the specimens to provide the alternate-immersion cycle. All fractures will be examined to determine their nature, and all tensile specimens that do not fracture during exposure will be tested in tension to determine the loss in properties as compared with control specimens exposed to the same environment but without stress. The short-transverse C-rings that do not fail will be examined for incipient stress-corrosion cracking.

V. Discussion of Results.

Arrangements have been made to have test specimens machined from three samples of 6061-T6510 extrusions listed in Table I.

VI. Summary.

Samples from about 225 lots of 2014, 2024, 6061, 7075, 7079 and 7178 extrusions in sizes listed in applicable specifications have been ordered from two producers.

Three samples of 6061-T6510 extruded shapes have just been received and arrangements have been made to have test specimens machined from these samples.

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R. E. Davies
R. E. DAVIES

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D. O. SPROWLS

amz

VII. Tables and Figures.

TABLE I

EXTRUSIONS TO BE TESTED IN VARIOUS TEMPERS

Alloy	Thickness Range, in.	Cross Sectional Area, sq. in.	Temper
2014	0.125-0.499	All	-T651X, -T62*
	0.500-0.749	All	
	≥ 0.750	≤ 25	
	≥ 0.750	>25, ≤ 32	
2024	0.050-0.249	All	-T351X
	0.250-0.749	All	
	0.750-1.499	All	-T851X, -T42*
	≥ 1.500	≤ 25	-T62*
	≥ 1.500	>25, ≤ 32	
6061	≤ 0.249	All	-T651X, -T62*
	0.250-0.499	All	
	0.500-1.499	All	
	≥ 1.500	All	
7075	≤ 0.249	All	-T651X
	0.250-0.499	All	
	0.500-1.499	All	-T7351X
	1.500-2.999	All	-T6*, -T73*
	3.000-4.499	≤ 20	
	3.000-4.499	>20, ≤ 32	
	4.500-5.000	32	
7079	≤ 0.249	≤ 20	-T651X, -T6*
	0.250-0.499	≤ 20	
	0.500-0.749	≤ 20	
	0.750-1.499	≤ 20	
7178	≤ 0.249	All	-T651X, -T6*
	0.250-0.499	All	
	0.500-1.499	All	
	1.500-2.999	All	
6061	0.125	Samples Received	-T6510 (ARL No. 317846)
	0.126		-T6510 (ARL No. 317847)
	0.250		-T6510 (ARL No. 317848)

* Contractor to produce these "heat treat by user" tempers from -0 temper.

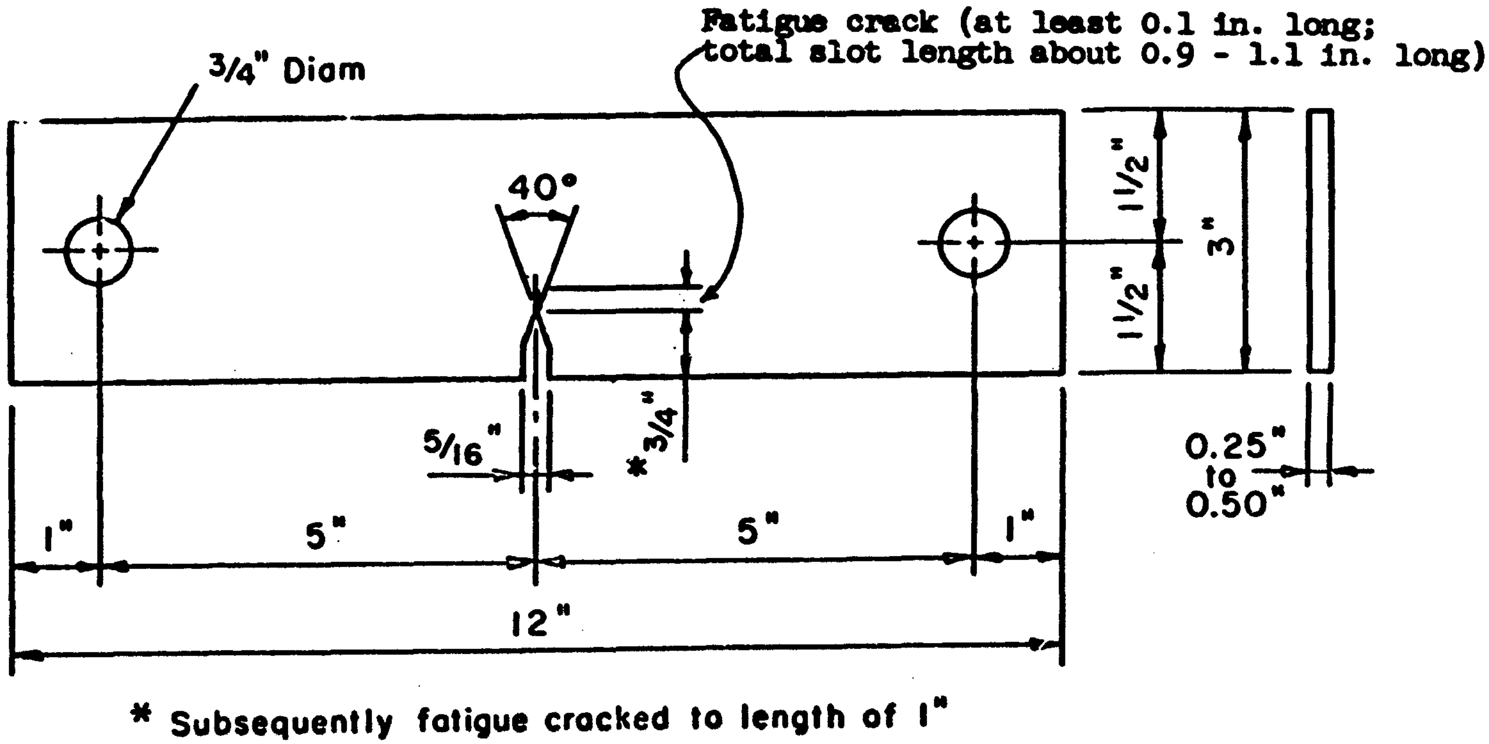


Fig. 1. Single-Edge Notched Fracture-Toughness Specimen

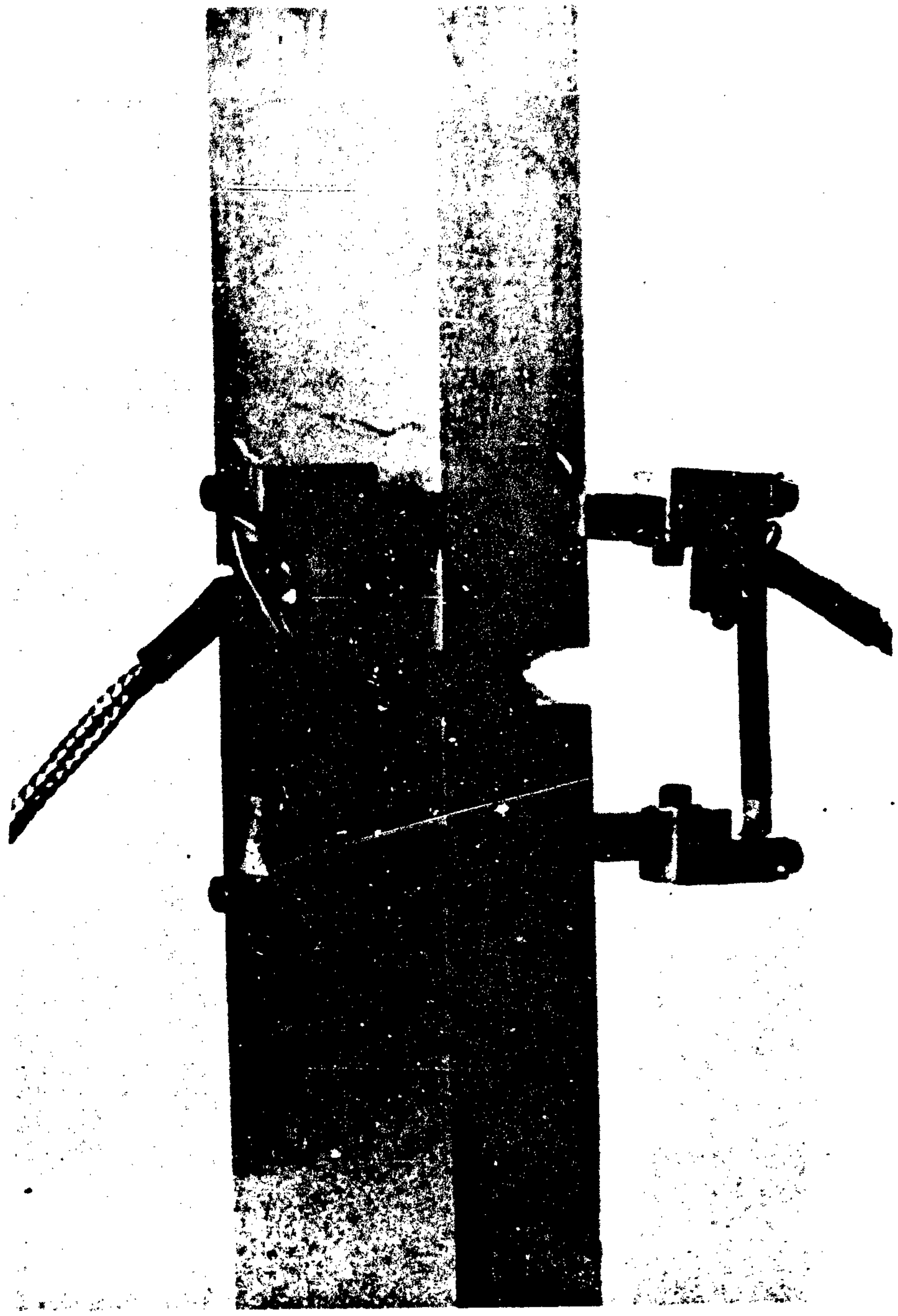


Fig. 2 Single-Edge Notched Fracture Toughness Specimen with SR-4 Strain-Gage Units for Pop-In Detection

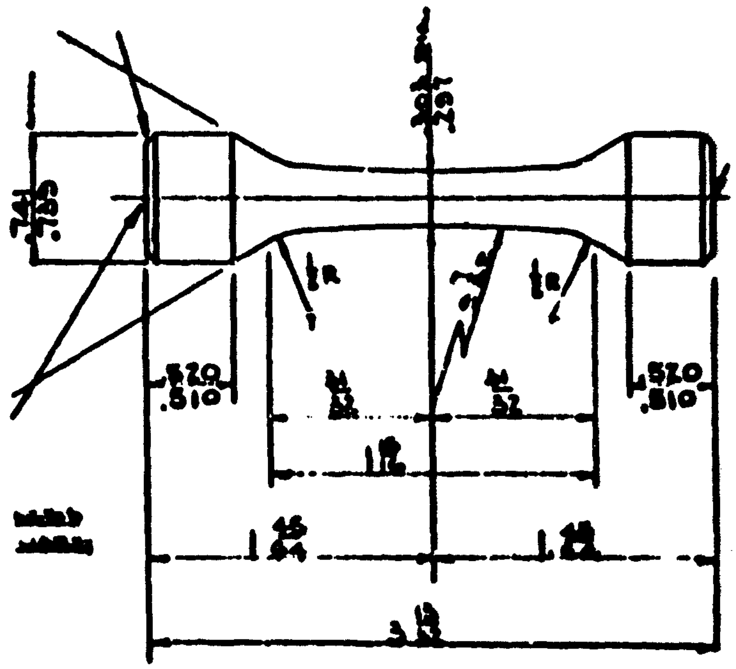
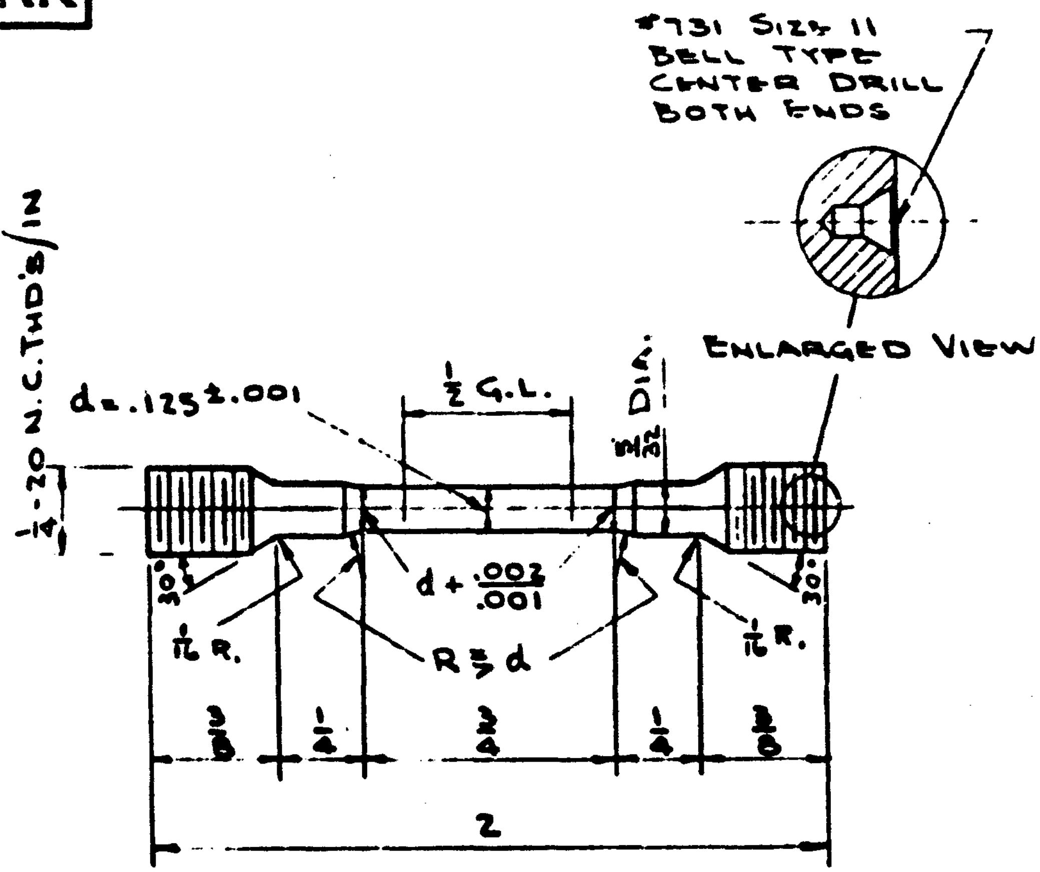


Fig. 3. Axial-Stress Fatigue Specimens

L-7034-RK



SPECIMEN —— ☐ REQ'D

MACHINING SETUP	D-6996-RK
TOOL BIT	D-7647-RK
CENTER & FACE TOOL	D-7444-RK
TEMPLATE	D-6989-RK
DRIVER	D-6981-RK

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Fig. 1

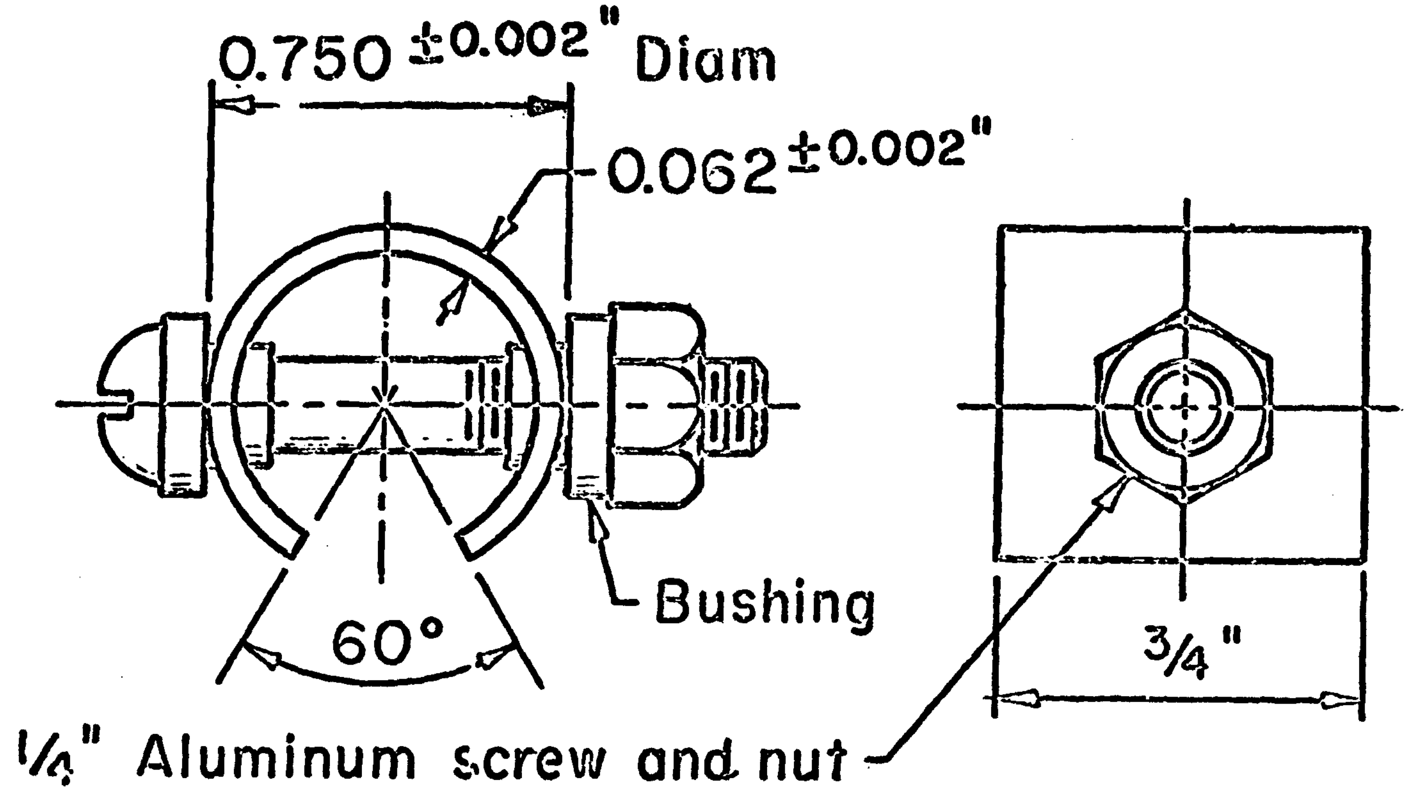
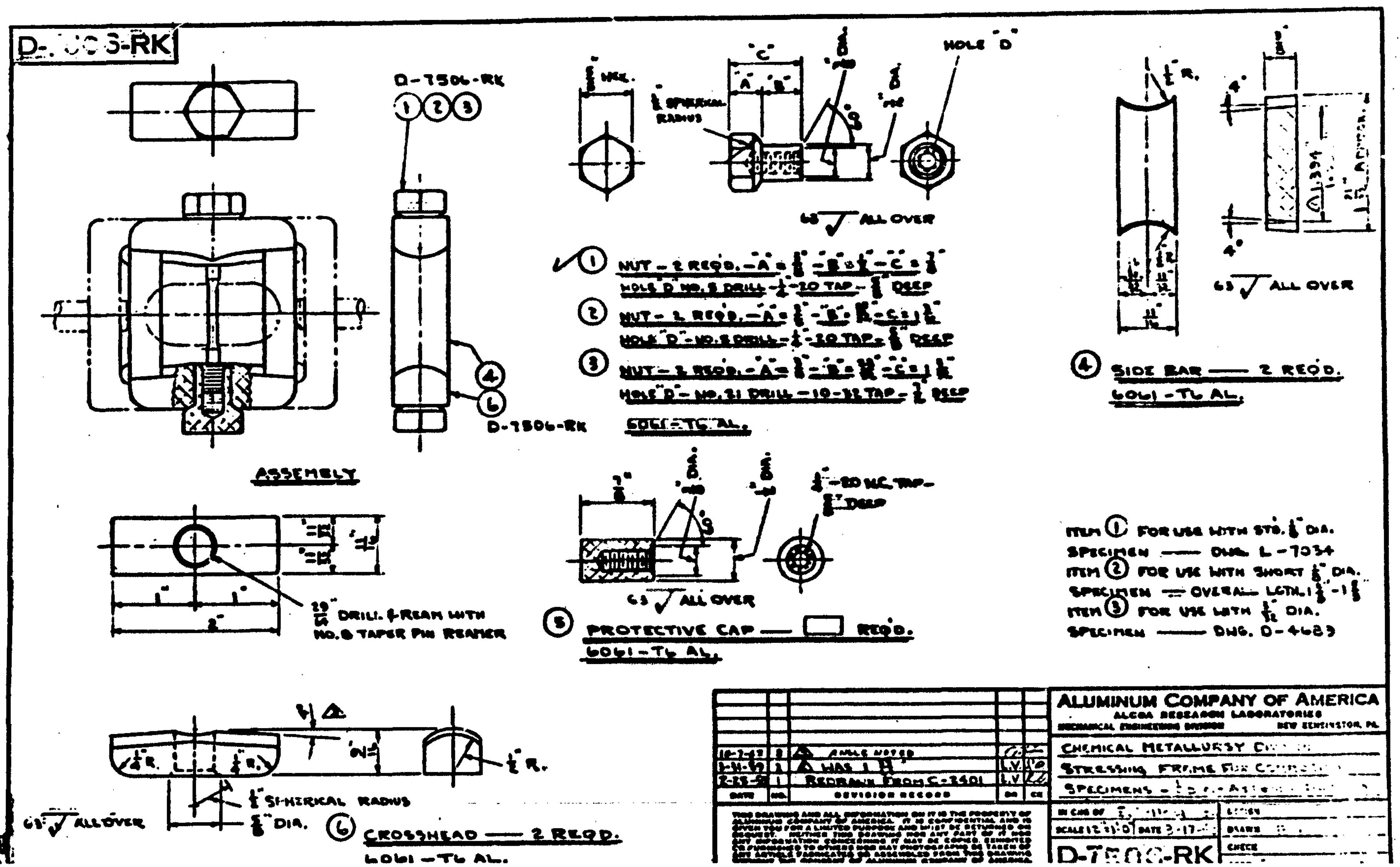


Figure 5. C-Ring Assembly For Short-Transverse Stress-Corrosion Tests


ASSEMBLY
D-7506-RK
SIDE BAR —— 2 REQD.
6061-T6 AL.
63 ALL OVER
PROTECTIVE CAP —— REQD.
6061-T6 AL.
CROSSHEAD —— 2 REQD.
6061-T6 AL.
NO. 8 TAPER PIN REAMER
ITEM 1 FOR USE WITH STD. DIA. SPECIMEN —— DWG. L-7034
ITEM 3 FOR USE WITH DIA. SPECIMEN —— DWG. D-4683
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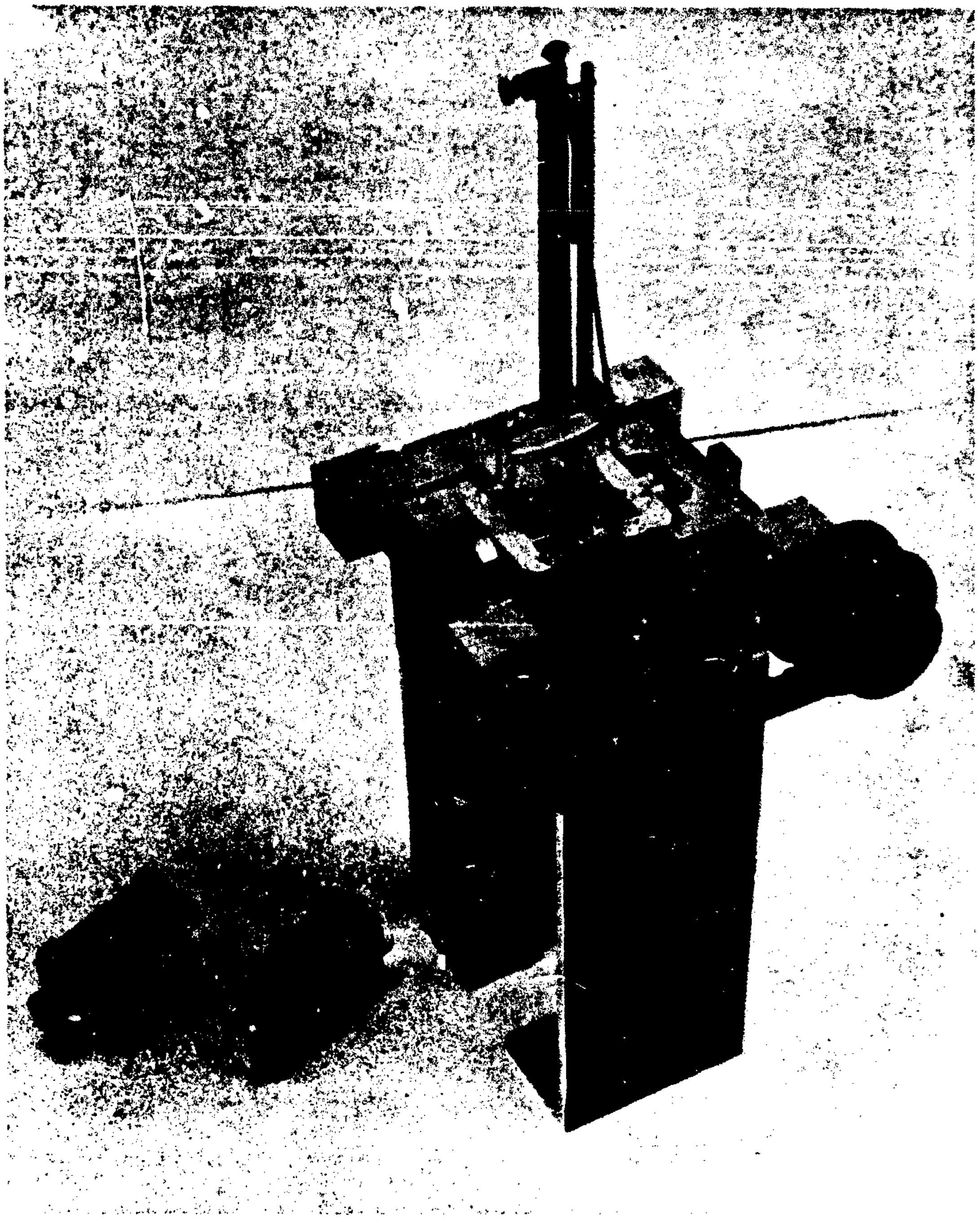
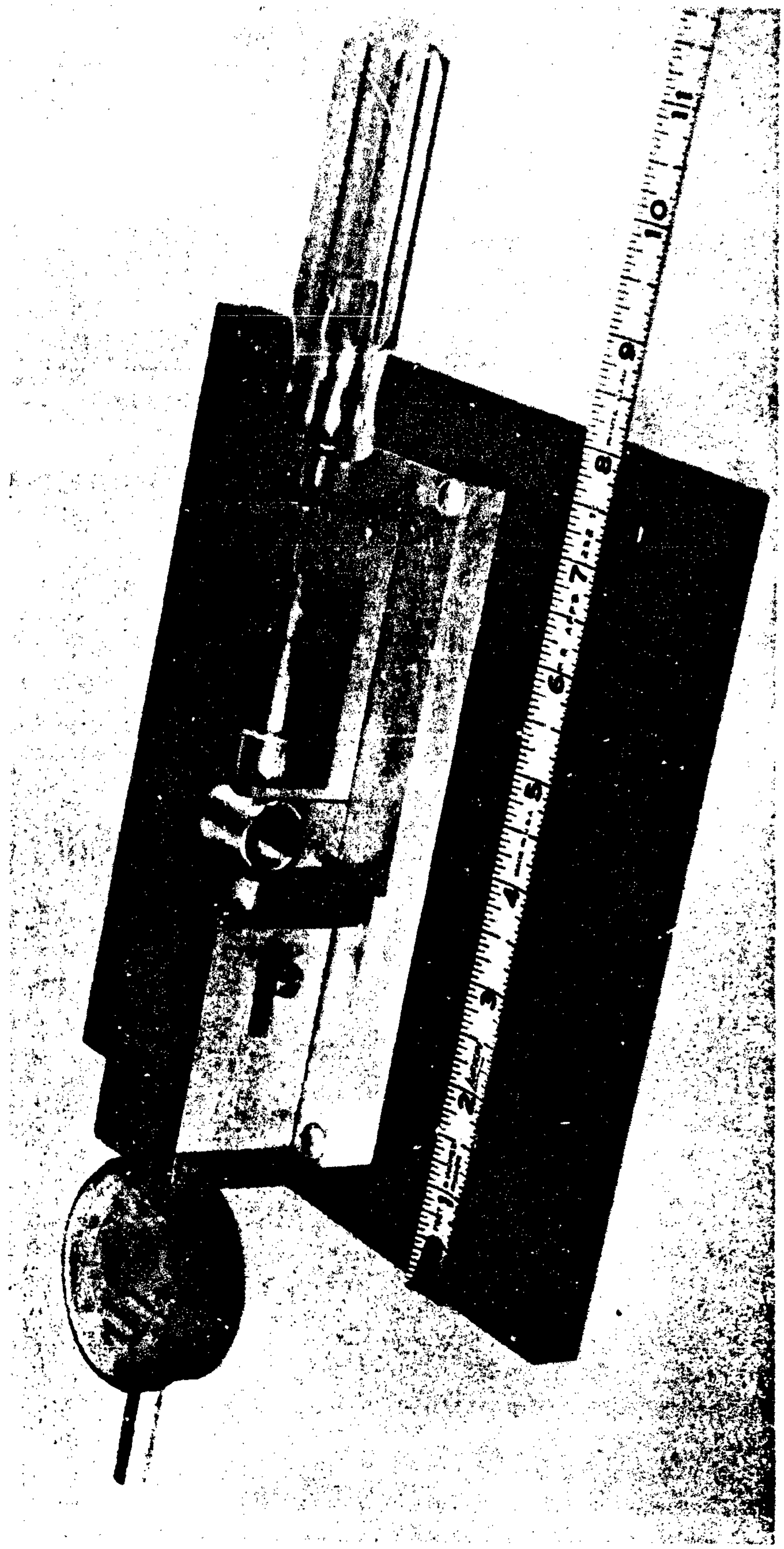


Fig. 7. Device for Stressing 1/8-in. diam Specimens for Stress-Corrosion Tests.



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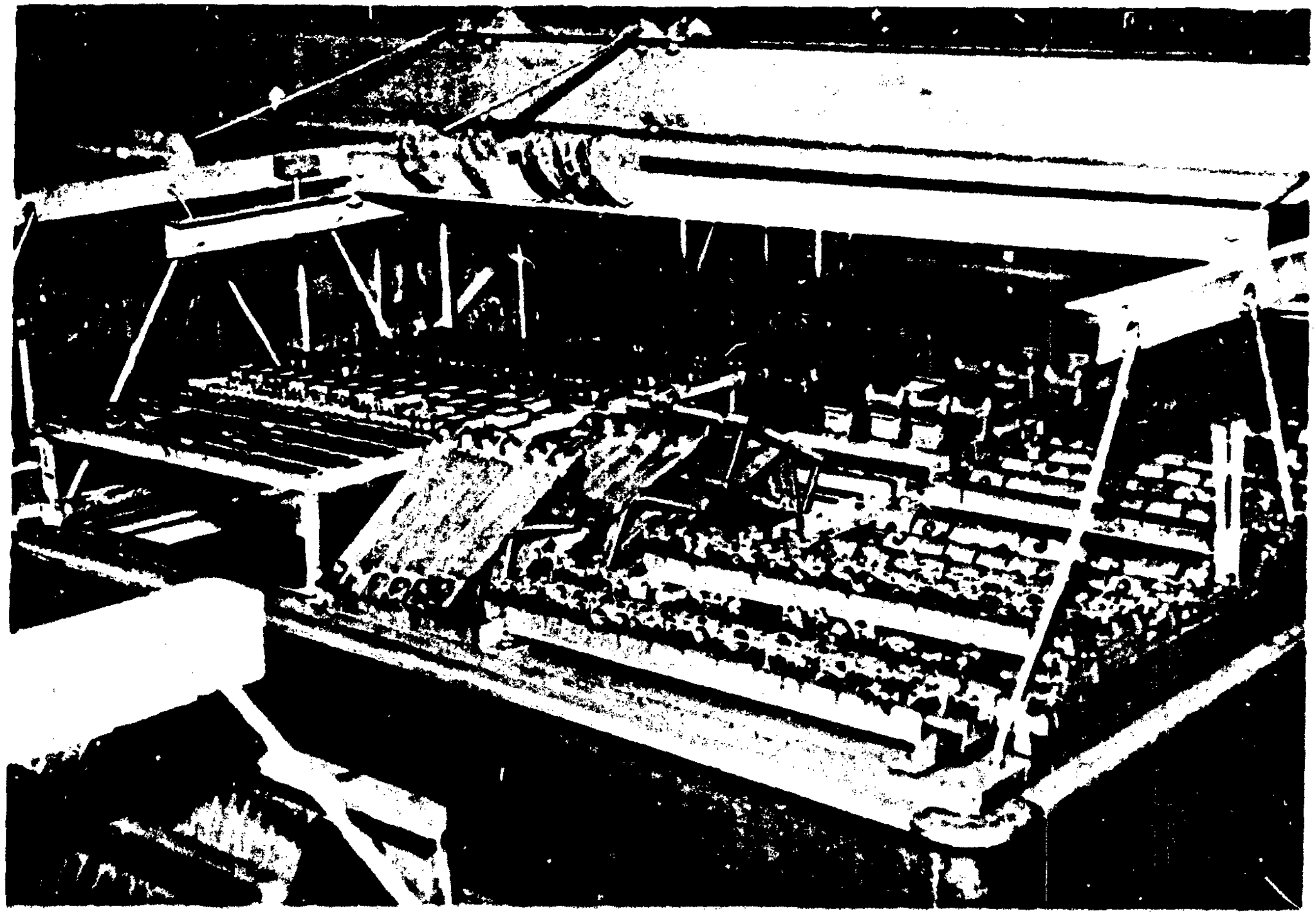

Fig. 9. Equipment for Alternate Immersion Corrosion Tests