Engineering Research Institute

University of Michigan

Ann Arbor

PROGRESS REPORT

to the

AVIATION PANEL

of the

ASME-ASTM JOINT COMMITTEE ON THE EFFECT OF TEMPERATURE

ON THE PROPERTIES OF METALS

FOR THE

STATISTICAL EVALUATION OF CREEP-RUPTURE PROPERTIES

OF HEAT-RESISTANT ALLOYS

(PROJECT AP1)

November 1, 1952

PROGRESS REPORT

ON

STATISTICAL EVALUATION OF THE CREEP-RUPTURE PROPERTIES OF HEAT-RESISTANT SHEET ALLOYS

(PROJECT AP1)

This report summarizes the status as of November 1, 1952, of Project AP1, the Statistical Evaluation of the Creep-Rupture Properties of Heat-Resistant Sheet Alloys. The investigation may be briefly summarized as follows:

1. Ten 0.040-inch thick sheets each of Type 321, Type 347 (Ta), N-155 (Ta) and Inconel-X Alloys are being subjected to creep-rupture tests. The sheets being furnished for the work each represent separate heats from normal commercial production.
2. Each material is to be tested as near as possible to the following conditions:

Alloy	Temp. (°F)	Desired Rupture Time (hours)		
	1200	20	80	300
Type 321	1350	20	80	300
	1500	5	20	80
Type 347 (Ta)	1200	20	80	300
	1350	20	80	300
	1500	5	20	80
N-155 (Ta)	1200	20	80	300
	1350	20	80	300
	1500	20	80	300
Inconel-X	1350	20	80	300
	1500	20	80	300
	1650	5	20	80

All specimens were to be taken across the direction of rolling. Percent deformation versus time data are to be taken. Constant preheat conditons are to be used in testing.

3. Conventional room temperature tensile tests are to be conducted on each sheet for the purpose of determining any unusual variations in the materials.

4. Upon completion of the tests the data are to be analyzed statistically.

Material Received

The sheets received to date and the information supplied concerning the sheets is given in Table I. The total number of each material received were:

Type 321 - - - - - - - - - - - - 14 sheets (2 are duplicate heats)
Type 347 - - - - - - - - - - - - 3 sheets +4 (3)
N-155 - - - - - - - - - - - - - - 5 sheets
Inconel-X - - - - - - - - - - - - 7 sheets +2 (-1)

The N-155 sheet which did not contain Ta is not to be tested pending attempts to complete the ten sheet quota with those made with Cb + Ta. Six sheets of Type 347 which were stabilized with Cb alone have also been withheld.

Correspondence indicates the the following materials will also be submitted:

6 sheets of Type 347 (Ta) by The Crucible Steel Company

3 sheets of Inconel-X by the International Nickel Company

6 sheets of N-155 (Ta) by The Haynes-Stallite Company

The correspondence indicates the Type 347 (Ta) sheets will be received in the near future. Delivery of the Inconel-X was indicated to be three to six months from August 1952. Delivery of the N-155 (Ta) sheet was indicated to be dependent on rolling of a thickness now only rolled infrequently.

PROGRESS ON PROJECT

The Project AP1 committee asked that complete agreement be obtained on testing procedures before the work was undertaken. In view of this the committee was circulated regarding:

1. Sampling Procedure for Sheets

   Due to a misunderstanding regarding rolling direction of the sheets received, approval was received for the sampling scheme shown by figure 1, and a number of samples were prepared. It subsequently developed that the specified rolling direction in soliciting the sheet materials had been in the opposite direction. Attempts were unsuccessfully made to independently verify the rolling direction by metallographic examination at that time. In view of the fact that rolling directions were specified to be the 27-inch direction, it was decided to procede on that basis and the sampling scheme shown by figure 2 was approved. Confirmation of the rolling direction for the N-155 (Ta) sheets was obtained from the manufacturers. This has not been obtained for the other alloys.

2. Machining of Specimens

   Considerable delay resulted from efforts to obtain agreement on procedures for machining the gage length. The N-155 (Ta) specimens must be machined by grinding. Type 347 (Ta) reportedly is also subject to damaging by cutting tools. In order to avoid excessive cost a compromise was worked out whereby the N-155 (Ta) materials will be milled to not less than 1/32-inch of finish size on each side and then ground to finish size. The same procedure will be used for all specimens. Final grinding is done in the longitudinal direction using a 46 grit, white borlon, medium hard wheel with a vitrified bond (Simond's Wheel WA46-K5-V1).

3. Temperature Adjustment Time

The Committee for Project AP1 approved the following procedure forbringingthe specimens to temperature:

(a) Set up specimens in units and turn heat on at 4:00 P. M. so as to bring temperature within 50°F of test temperature by 5:00 P. M.

(b) Allow specimen to stand overnight, raising the temperature to test temperature between 8:00 and 9:00 A. M. the next day.

(c) Make final temperature adjustments so that the specimens can be loaded at 1:00 P. M.

4. Type Specimens

The specimens being used are shown by the sketch of figure 3. This is the same procedure described by A. S. T. M. Designation E-8 except that the taper is omitted. The holes drilled in the shoulders are for pins used to locate the collars of the extensometer system.

5. Extensometer System

The collars for the attachment of the extensometer are fixed by pins inserted in the holes drilled through the specimen shoulder. Extension rods are attached to the collars and extend out of the furnace. Rollers carrying a mirror are inserted between each pair of extension rods. As the specimen deforms the mirrors are rotated. The rotation is measured by a scale reflected in the mirror to a telescope. The readings on both sides of the specimens are taken and averaged. The sensitivity of the extensometer system is three-millionths of an inch per inch in the 2-inch gage length.

6. Creep Measurement

In view of the type of work involved a complete recheck is being carried out on the problem of expressing the creep in terms of a percentage of 2-inch gage length. The steps involved are:

(a) The specimen and extensometer system have evolved from a number of previous attempts to measure creep of sheet specimens. The collars of the extensometer system are attached to the shoulders of the specimen though a pin inserted in the hole drilled in the specimen. This procedure has been adopted because no suitable way has been found to attach extensometers directly to the gage length for testing conditions of the type prescribed. The rapid and extensive creep allows collars to loosen. Secondly, it is also difficult to keep collars tight at temperatures above 1200°F even when attached to the shoulders of the specimen. The pins have been found to give a permanent location of the collars regardless of the amount of creep or the testing temperature.

(b) Attaching the extensometer to the shoulders of the specimen introduces a gage length uncertainty. Extension occurs in the fillet and shoulder as well as the gage length. Furthermore, the relative amount of deformation varies depending on the stages involved in the test.

(1) On loading the specimen, the specimen length covered by the extensometer deforms elastically in accordance with the stresses existing in the gage length, fillets, and shoulder lengths.

(2) As the load increases past the proportional limit, a steadily increasing amount of the fillet area deforms

plastically. The total elongation measured during this part of the test then becomes a function of the proportional limit, the stress-strain curve past the proportional limit, and the stress pattern existing in the fillet.

(c) Once the load is applied and creep allowed to take place, the extensometer measures the creep in the gage, fillet, and shoulder sections. Assuming that the stress causing creep in the fillet section is in accordance with the load divided by the cross-sectional area (neglecting effect of the complex stress system) the measured deformation outside of the gage length becomes as a first approximation a function of the stress-creep rate characteristics and the length of the fillet-shoulder section.

To translate total extension measurements into percent elongation, an "effective" gage length is established. The effective gage length is the hypothetical gage length which would deform the same amount as the total deformation measured by the extensometers.

To obtain an independent check on the procedure for calculating the gage length elongations, it seemed necessary to carry out emperical check tests. In view of the unknown deformation characteristics of the alloys involved and the uncertainties introduced by the complex stresses in the fillets, any attempts to estimate mathematically proper factors seemed unjustified. For this reason the following experiments have been carried out:

(1) Three of the specimens inadvertently taken parallel to the direction of rolling were set up for room temperature tensile tests using both SR4 strain gages and the mechanical

extensometer. Using the modulus indicated by the SR4 gages, "effective gage lengths" of 3.68-inches were obtained for the elastic portions of the tests. The continued use of this factor past the elastic limit resulted in less indicated deformation than that shown by the SR4 gages. (See figure 4).

(2) Two specimens were prepared with gage marks every inch. The distance between gage marks was carefully measured to 0.0001-inch in the Gage Laboratory of the Production of the Engineering Department. The two specimens were then subjected to creep testing at 1200°F under stresses selected to give high and low creep rates. The tests were discontinued before fracture and the distance between gage lengths again measured. The data obtained is summarized in Table III.

TABLE III

Results of Creep Tests to Check Effective Gage Lengths

	Specimen 1	Specimen 2
Total extension by gage marks	0.020	0.150
Total extension by extensometers	0.0208	0.150
Extension of 2-inch lengths of gage section from gage marks	0.0114	0.1067
Effective gage lengths	2.81	2.78
Average creep rate, % per hour	0.00082	0.174

The agreement between the total extension by extensometers (calculated by geometrical considerations) and by gage marks is considered good and checks our usual experience. The main problem is to establish effective gage lengths for the specimens used. It appears that additional check tests ought to be made for all four alloys and at the extremes of testing temperatures. It is planned to further check the determination of effective gage lengths by testing 1-inch gage length specimens to provide data in which the fillet and shoulder deformation can be subtracted from the total deformation of the standard specimen. These additional checks will be made even though the error introduced by assuming that the effective gage lengths now established to hold over the materials and temperature involved has been found in past work to be considerably less than the reproducability between specimens.

(3) A good solution to the problem of estimating the correct deformation past the proportional limit has not been found. Use of the effective gage lengths established from creep tests leads to first more deviation from the SR4 curves for the room temperature tensile tests, and finally less. (Incidentally, this problem is considerably more troublesome in strip than in round specimens because the cross-sectional area only increases directly with the increased width of the fillet section while in round specimens it increases as the square of the increase in diameter.) At present it is planned to use the same factor as that indicated by the elastic portion of the curves for tests in which the plastic deformation on loading is less than 0.2%. If it should turn out that many of the creep-rupture tests exceed this deformation on loading, attempts will be made to establish better emperical relationships for effective gage lengths during yielding.

Room-Temperature Tensile Tests

The contract required that duplicate tensile tests be conducted on all sheets tested. The object was to establish if there were any unusual physical properties associated with the high temperature properties. The decision was further made by the Engineering Research Institute to delay creep-rupture testing of the N-155 alloy in particular and all other alloys until at least a few tests had been made as a further check on the machining procedures. Improper machining reportedly induces low ductility in the tensile tests.

The room temperature tensile data obtained to date are given in Table IV:

TABLE IV

Room Temperature Tensile Properties of N-155 Alloy Sheets

Heat No.	Ultimate Strength (psi)	Offset Yield Strengths (psi) (0.1%)	Offset Yield Strengths (psi) (0.2%)	Proportional Limit (psi)	Elongation in 2 inches (%)
M624	117,700	50,400	55,400	20,000	56.0
	117,200	51,500	56,800	29,000	55.5
M206	117,700	48,000	56,600	18,000	52.0
	118,300	47,900	56,600	19,000	52.5
M207	118,200	53,500	57,750	28,000	53.6
	119,400	54,750	61,500	26,000	53.6
M208	120,200	58,000	64,500	26,000	52.5
	119,700	52,000	59,500	22,000	53.5

The results of these tests seem quite normal for the alloy. The results may be compared with those reported by the supplier by reference to Table II. The agreement seems to be reasonably good. The elongations obtained were slightly higher than those reported for the material which seems to verify the machining procedure.

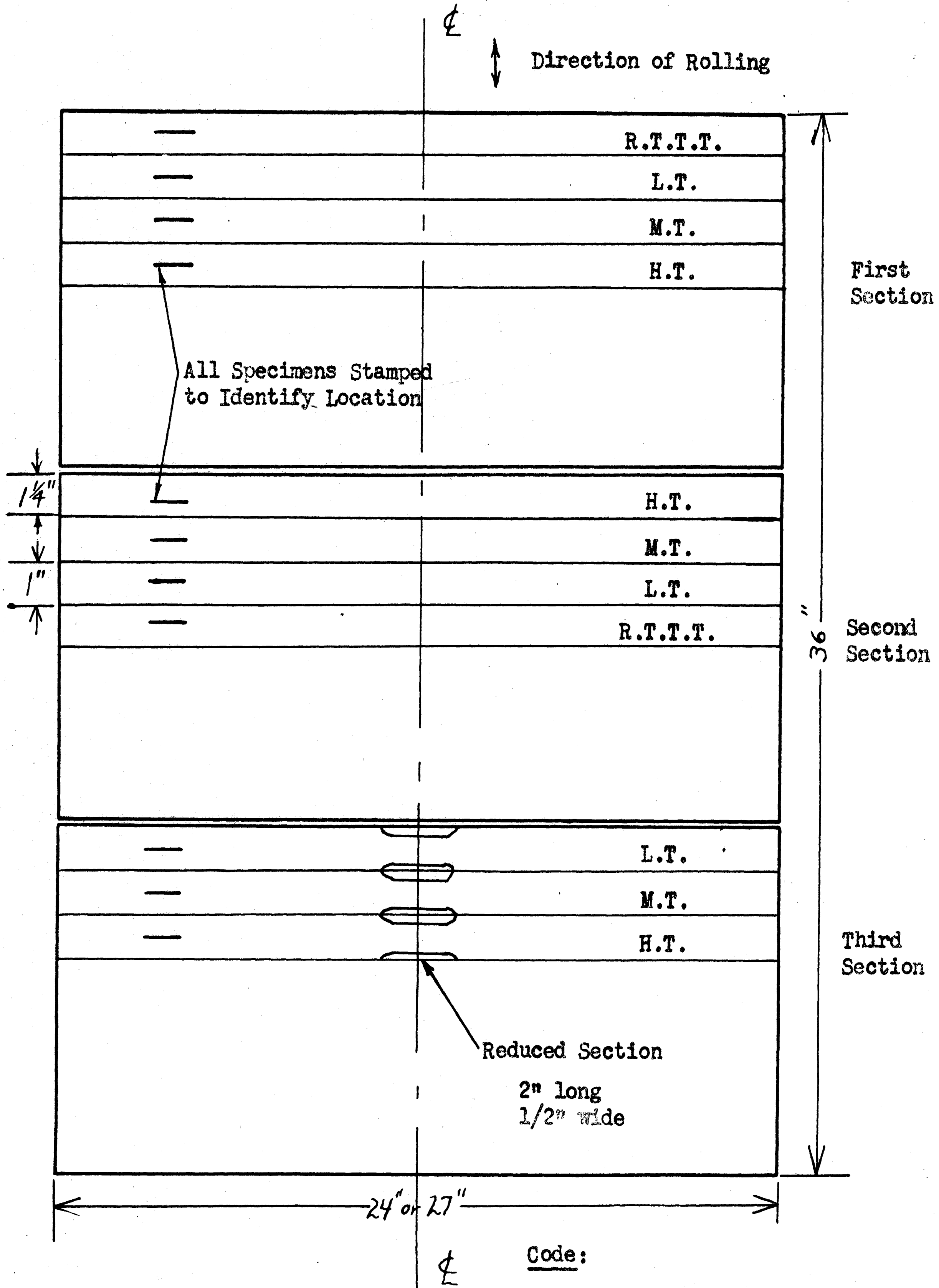
FUTURE WORK

The creep-rupture testing program should be operating with eight units by December 1, 1952. All of the necessary parts for the extensometer systems have been prepared for 10 units. The program requires about 48,000 hours of testing time. This would take about 8.5 months with eight units. Additional units will be available about January 1953 so that it is expected that the work can be finished before July 1, 1953.

Additional tests will be undertaken, as previously discussed, to further check the computations of effective gage lengths.

The room temperatures tensile data are now being accumulated on the Type 347 (Ta) specimens. Assuming that the machining procedure remains satisfactory, the creep-rupture testing program will not be delayed until verification of room temperature properties in future work.

Consideration is being given to utilizing correlations of rupture data by the General Electric parameter method and by modifications said to improve the preciseness of that type of procedure for reducing testing. Two approaches are being used. It is expected that at least a comparison can be made between predicted and actual results. Secondly, if the predictions from fewer tests seems to be accurate for the first few sheets tested consideration will be given to reducing the testing program.

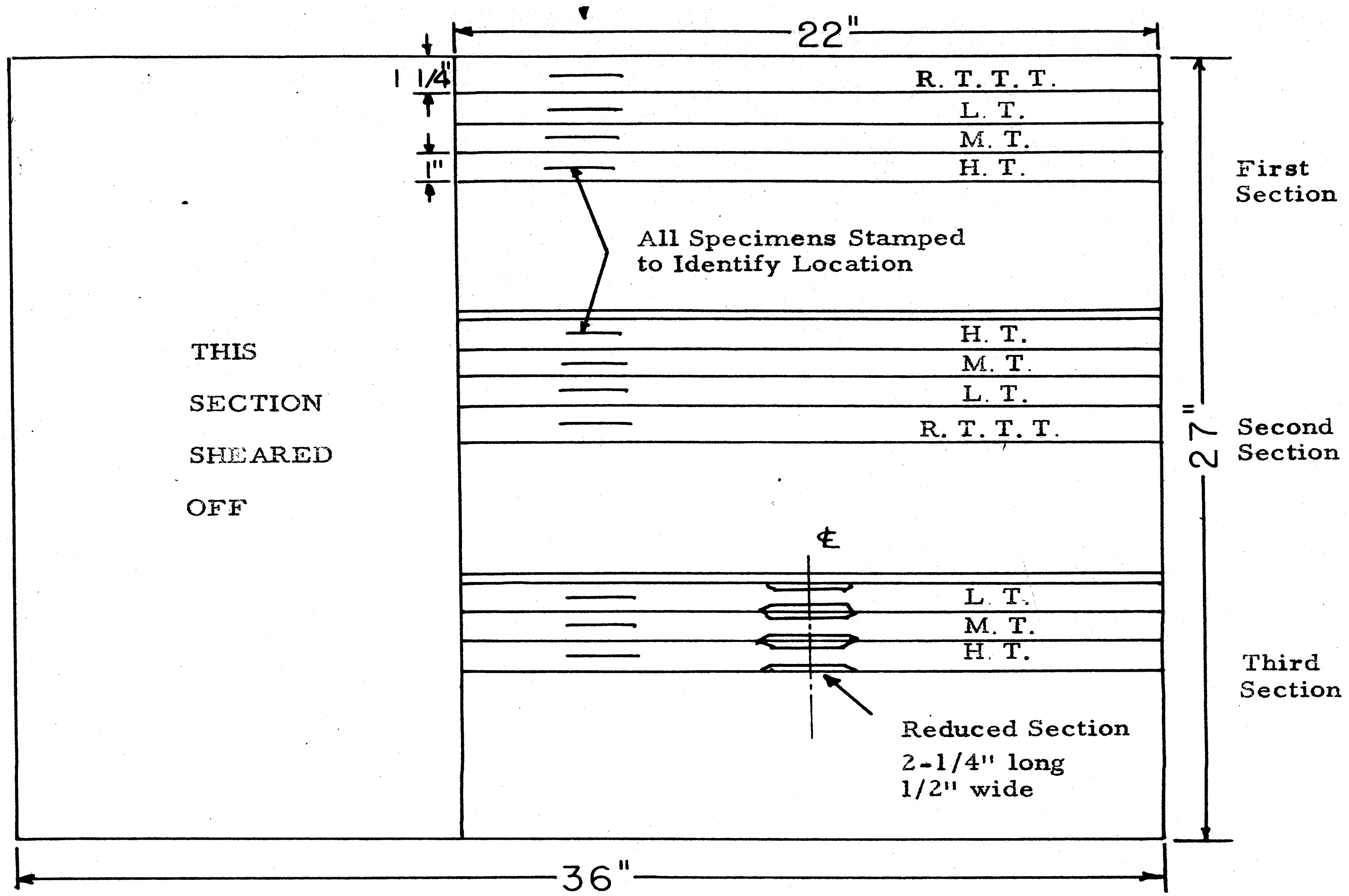


Code:

L.T. = Lowest Temperature
M.T. = Middle Temperature
H.T. = Highest Temperature
R.T.T.T. = Room Temperature Tensile Test

Figure 1.

SKETCH INDICATING PROPOSED SAMPLING PROCEDURE OF SHEET MATERIALS WITH THE 36-INCH DIMENSION PARALLEL TO DIRECTION OF ROLLING.



Code:

L. T.	= Lowest Temperature
M. T.	= Middle Temperature
H. T.	= Highest Temperature
R. T. T. T.	= Room Temperature Tensile Test

Figure 2.

SKETCH INDICATING PROPOSED SAMPLING PROCEDURE OF SHEET MATERIALS WITH 27" DIMENSION PARALLEL TO ROLLING DIRECTION

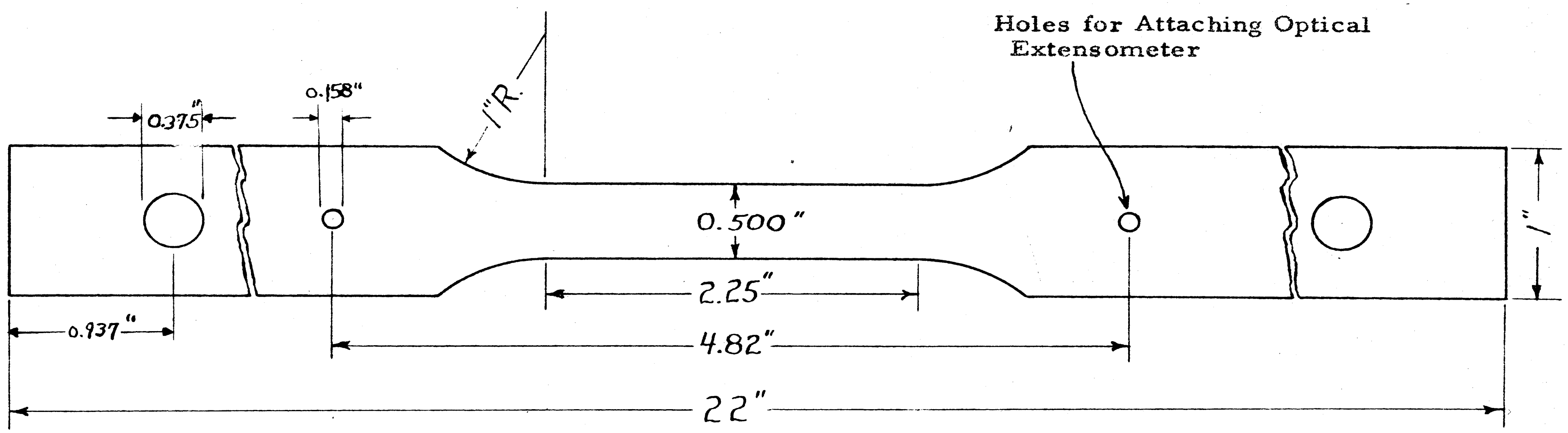


Figure 3. DIMENSIONS OF CREEP-RUPTURE SHEET SPECIMEN.