AN INVESTIGATION OF THE DEFORMATION OF A 3S-O SHEET SPECIMEN DURING TENSILE FAILURE

Thesis by

T.P. Goebel

In Partial Fulfillment of the Requirements
For the Degree of
Aeronautical Engineer

California Institute of Technology
Pasadena, California
1949

ACKNOWLEDGEMENTS

The author wishes to thank Dr. E.E. Sechler for his encouragement and guidance, Dr. D.E. Hudson and Mr. Pol Duwez for their helpful comments on the manuscript, and Mr. Milton Wood and Mr. Marvin Jessey for their assistance in the investigation.

TABLE OF CONTENTS

I. INTRODUCTION

It is recognized that the "necking down" of a tensile specimen which occurs prior to failure is essentially a plastic flow phenomenon. Careful observation of this flow could conceivably be used to determine the plasticity properties of various metals and also to check the applicability of some of the assumptions in the theory of plasticity.

The present preliminary tests were carried out primarily for the purpose of developing an experimental technique. A motion picture camera was used to photograph a deforming grid in the neck of a sheet tensile specimen while the load was simultaneously recorded on a recording oscillograph. This technique yielded two-dimensional strain data on one surface of the specimen and the total load as functions of time. This is admittedly not all the information desired on the plastic flow, but it does allow a partial correlation of strain rate with rate of loading, and a determination of the extent of elastic and plastic deformation on one surface of the specimen.

II. DESCRIPTION OF THE TEST SPECIMENS AND OF THE TESTING EQUIPMENT

Consideration of resolution limits of the available film made it desirable to photograph an area of only about one square inch. This precluded the possibility of using American Society of Testing Material's standard tensile coupons because failure had to occur at one place on the specimen. Hence the modified sheet specimens shown on figure 1 were used. The test section was 1.00 x 0.081 inches and the radius of the sides of the section was 16 inches. The specimens were milled from 3S-O sheet in the as-received condition.

The grid was prepared at twenty times size and reduced photographically to a circle diameter of one twentieth of an inch. The conventional photogrid technique as described in reference (1) was used in printing the grid directly onto the specimen.

The total load was measured by means of two strain gauges mounted on a dummy specimen which was bolted to one end of the test specimen through a splice plate as shown on figure 1. The total load was recorded on a Heiland recording oscillograph. An electrical impulse geared to the camera shutter was superimposed on top of the load record so that the load at any particular camera frame could be uniquely determined. The general test set-up with the camera in place is shown in figure 2.

A 16 mm. Paillard Bolex camera was used at a speed of 64 frames per second with an exposure time of one one-hundred and twentieth of a second. An undistorted reference grid was photographed alongside the actual deforming grid.

The camera and the recording oscillograph were turned on when the deformation was observed to be increasing rapidly. The grips on the Baldwin Southwark testing machine moved apart at an approximately constant rate which, of course, determined the total time during which plastic flow occurred. The important consideration here, however, is not that if the grips had moved apart faster the strain rate would have been greater, but that the local strain rates were recorded by the camera and the loading by the oscillograph.

III. RESULTS

Tests were conducted on six specimens with longitudinal axes orientated in three different ways, 0 degrees, 45 degrees, and 90 degrees to the direction of rolling. Camera film came out satisfactorily for three tests and these records are shown on figures 3 through 8. They are for one specimen cut at right angles to the direction of rolling and for two specimens cut in the direction of rolling.

The load record for the last second of each test was traced directly off the recording tape and is presented with the strain pictures. It is seen that the load dropped suddenly (in about one one-hundreth of a second) from near full load to about half load, a few hundreths of a second after the first appearance of failure in the center of the specimen. Subsequently the edges continued to carry load for two-tenths to three-tenths of a second longer while undergoing further deformation. It is noted that complete failure did not occur until one to two hundreths of a second after the load had dropped to zero.

The load, replotted on a condensed time scale, is shown on figure 9 for the last three and one half seconds before failure. The maximum load was reached approximately two seconds before final failure occured and the strain pictures indicate that at about this time the sides of the section changed curvature, and the center depression began to develop.

The specimens after failure are shown on figure 10.

IV. CONCLUSIONS

These preliminary tests have shown that the photo-grid method can be adapted successfully to the study of time rates of strain.

"Necking down" commenced at about full load and proceeded during a very gradual load drop-off. The tri-axial stress condition in the center, together with the small restraint in the thickness direction, produced a flow of material from the center. This caused a transverse depression in the center of the specimen which deepened gradually until brittle failure occured on the centerline. Shortly after this failure appeared, a redistribution of stresses around the resulting sharp discontinuity caused the load to drop suddenly by about half. The subsequent complete load release was relatively gradual, and the last little bit of flow occured at no load.

Specimens of ductile metals which have no definite yield point may be expected to fail in a similar manner. No directly comparable results were found in the literature, but it is interesting to make a comparison with Miklowitz's tests on mild steel bars (reference 2). The cross-like depressions that he observed did not appear in the present investigation and may, therefore, be the consequence of the definite yield point of mild steel. The data of references (3) and (4) were for different alloys and could not be used for direct comparison.

No consistent directional properties were noted in these specimens.

A determination of the plastic properties of the metals from these, or similar, tests would require a calculation of the stress distribution during "necking down". This might be possible to do from the observed boundary shape using an approximate method as discussed in reference (5). Qualitatively the present tests corroborated the stress distribution calculated by Bridgman for the plastic flow during "necking down".

It is suggested that for future tests it might be worth while to photograph two sides of the specimen by use of a prism-mirror arrangement, and thereby to obtain accurate thickness data.

V. REFERENCES

1. "The Photogrid Technique", by K. Cornell, American Photography, November, 1942.
2. "Influence of the Dimensional Factors on the Mode of Yielding and Fracture of Medium Carbon Steel", Miklowitz, Jour. Appl. Mech., Sept., 1948.
3. "Plastic Flow Characteristics of Aluminum-Alloy Plate", Klingler and Sachs, Jour. Aero. Sci., Oct., 1948.
4. "The Plastic Flow of Aluminum Alloy Sheet Under Combined Loads", Lankford et al, Metals Technology, Aug., 1947, T.P. 2237.
5. "Stress Distribution in the Neck of a Tensile Specimen", P.W. Bridgman, Amer. Soc. for Metals, Preprint, 1943.

VI. APPENDIX

A. Preparation of the Specimens

1/16 oz. of ammonium bichromate $(NH_4)_2Cr_2O_7$, ¼ oz. of LePages photoengraver's glue, and 1/64 oz. of a strong ammonia solution were added to 2 oz. of tap water and mixed thoroughly. Later 1 oz. each of tap water and denatured alcohol were added to the solution.

In the preparation of the specimens several cleaning agents were tried including acetone, carbon tetrachloride, and a commercial aluminum cleaner, none of which produced acceptable results. Scouring with a fine pumice (ground soapstone) and tap water was extremely effective and proved completely satisfactory.

The sensitizing coat was applied with a small atomizer under ordinary room lighting, and then the specimens were dried in a dark, heated cabinet. It was discovered that two or three very light coats gave the best results. The grid was contact-printed onto the specimen using a No. 2 photoflood at 30 inches, and an exposure time of 8 minutes. The unexposed coating was then washed off and a solution of black dye applied to the specimen. It was discovered that if the sensitizing coat was too thick, the exposed grid washed off with unexposed coating. The best method found for washing the specimens was to dip them very slowly into a quiet water bath. Otherwise the grid tended to flow slightly during washing. It was found unnecessary to soak the specimens in a heated black dye as suggested in reference (1). A few drops of dye applied to the grid and allowed to soak in for a minute or so produced entirely satisfactory results.

B. Modification and Adjustment of the Camera

The focal length of the 16 mm. Paillard Bolex camera was too short to allow the desired focusing, so a 0.1 inch collar was made to increase the focal length to 1.1 inches. The camera was focused before each run with a focusing eye-piece centered on a target which automatically allowed for parallax. Using Eastman super-X panchromatic film, two No. 2 photofloods at 30 inches with an f-stop of 5.5 and a speed setting of 64 frames per second were found to give satisfactory results.

The prediction of the amount of camera film and oscillograph tape required to complete a run was found to be most difficult. The records of several runs were lost because either the film or the tape ran out before failure occurred.

C. Adaptation of the Recording Oscillograph

The Heiland recording oscillograph was modified by the addition of a remote control micro-switch which was connected to the camera push button in such a manner as to insure that the oscillograph and the camera operated simultaneously. One element of the oscillograph was used to record a make-break contact on the camera which was positively geared to the shutter so as to make contact every eight frames. This allowed correlation between load record and strain pictures and was necessary since it was anticipated that the mechanical drive on the camera would not keep the shutter speed at exactly 64 frames per second. The actual records show that the camera speed did, in fact, vary from 64 frames per second to about 52 frames per second.

The Heiland record was clouded considerably indicating that there must have been a light leak in the box. The oscillograph was placed fairly close to the photofloods, although not in their direct beams, and the intense illumination must have caused the record clouding.

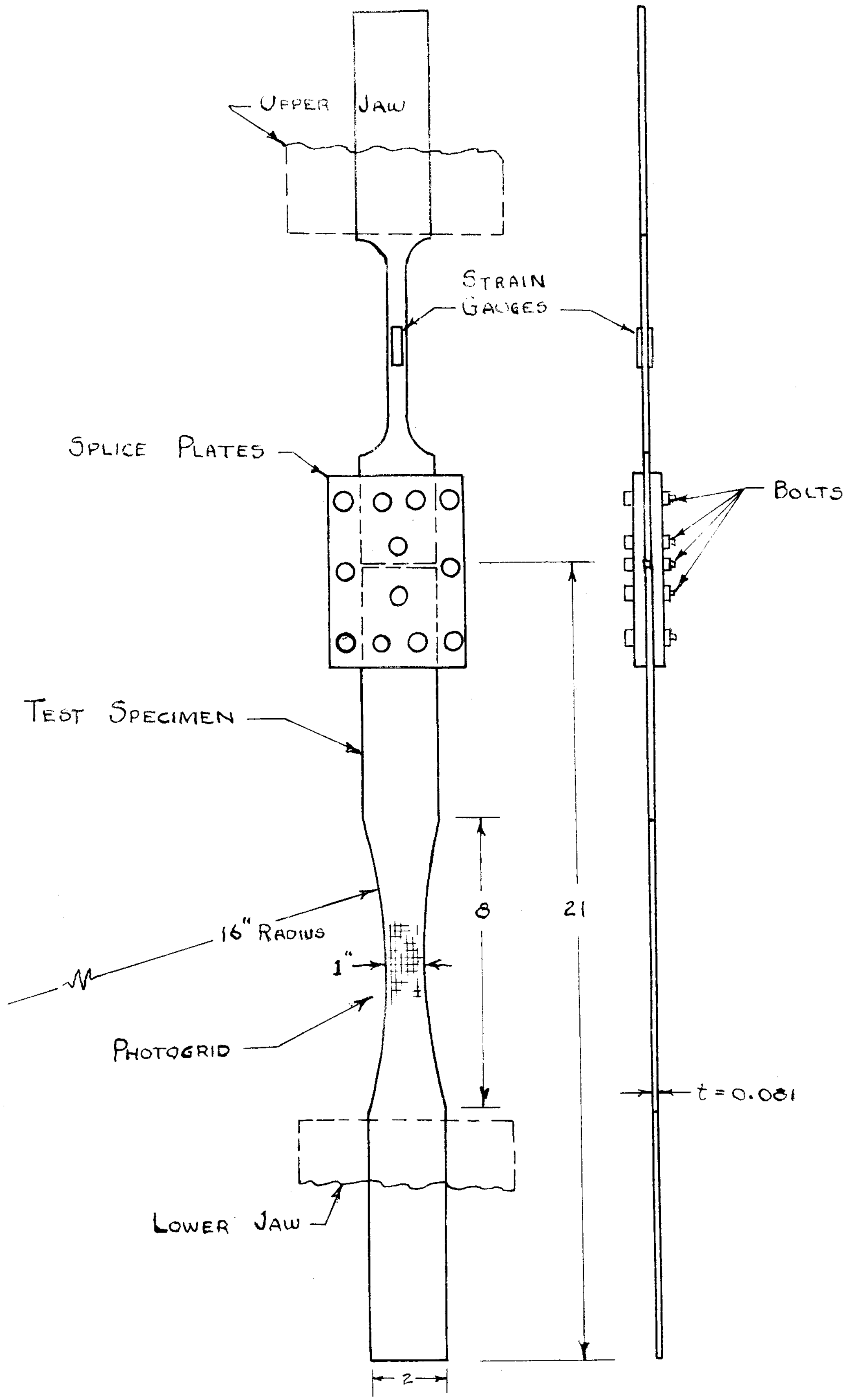


Fig. 1 Test Specimen and Strain Gauge Installation

FIG. 2

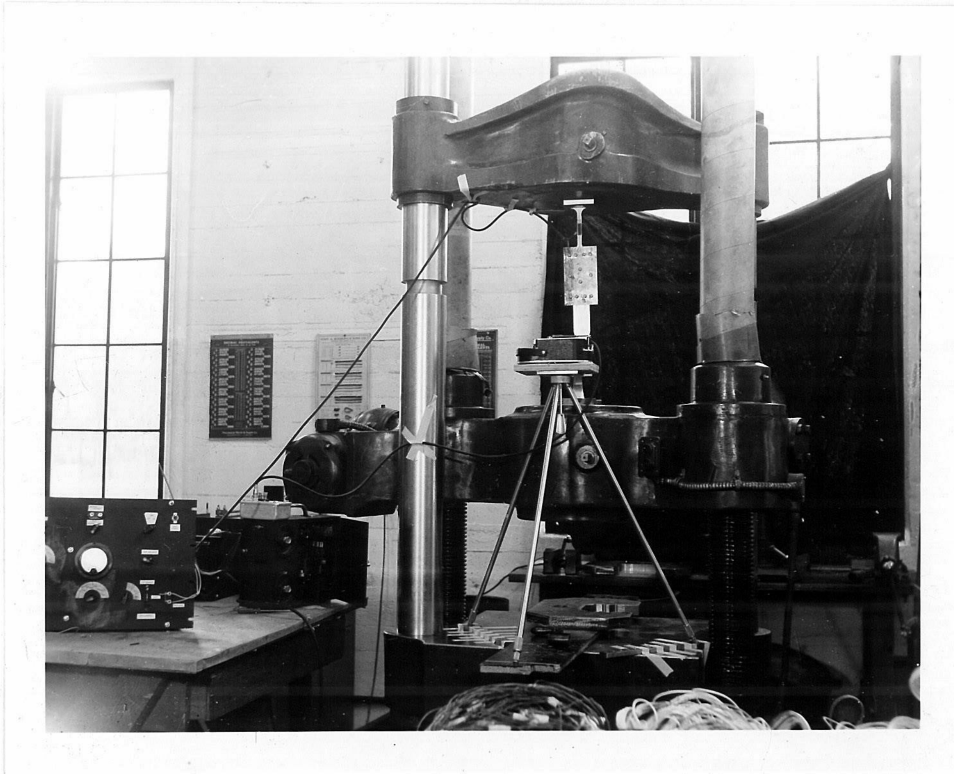


Figure 2 General View of the Test Set-Up

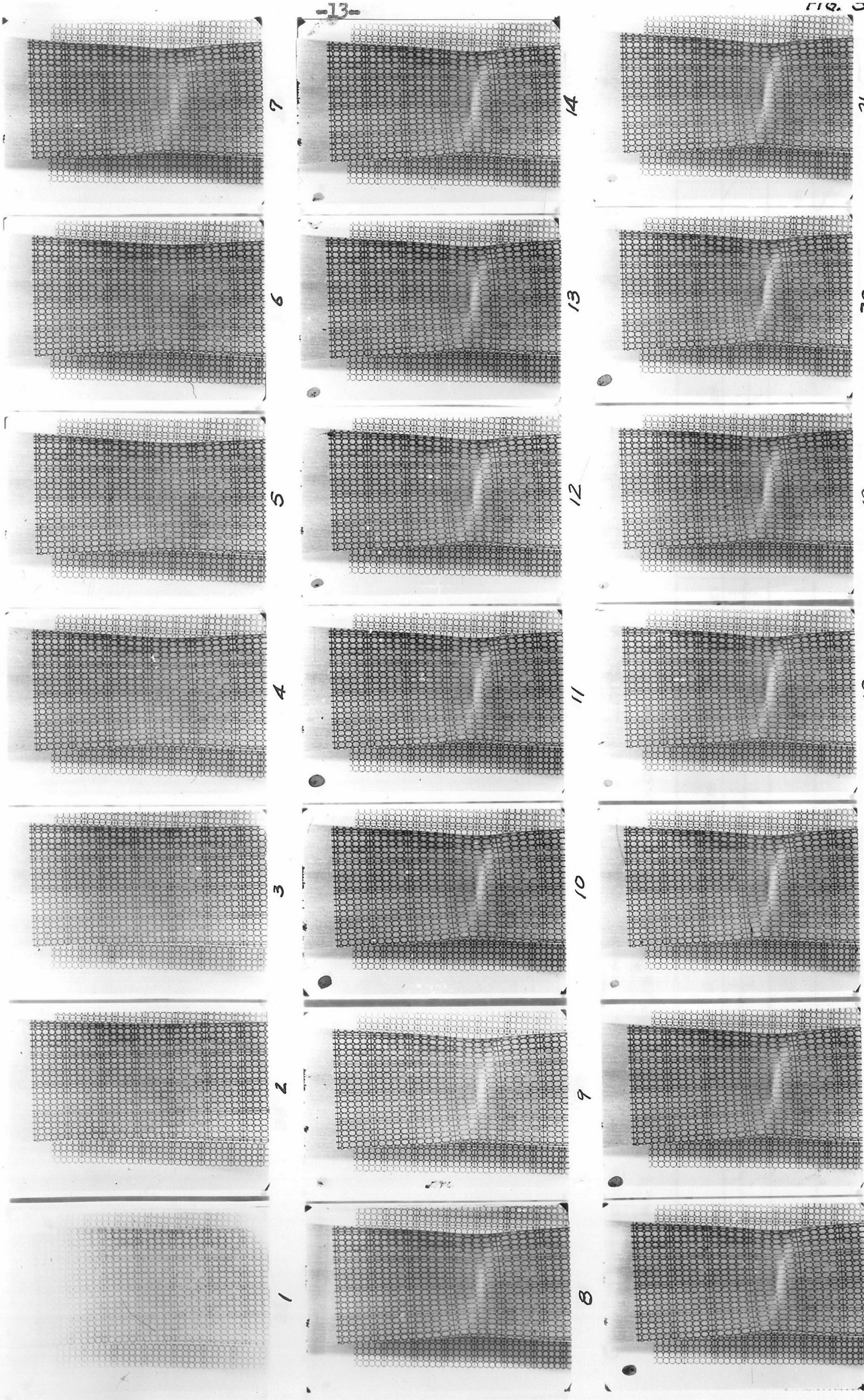
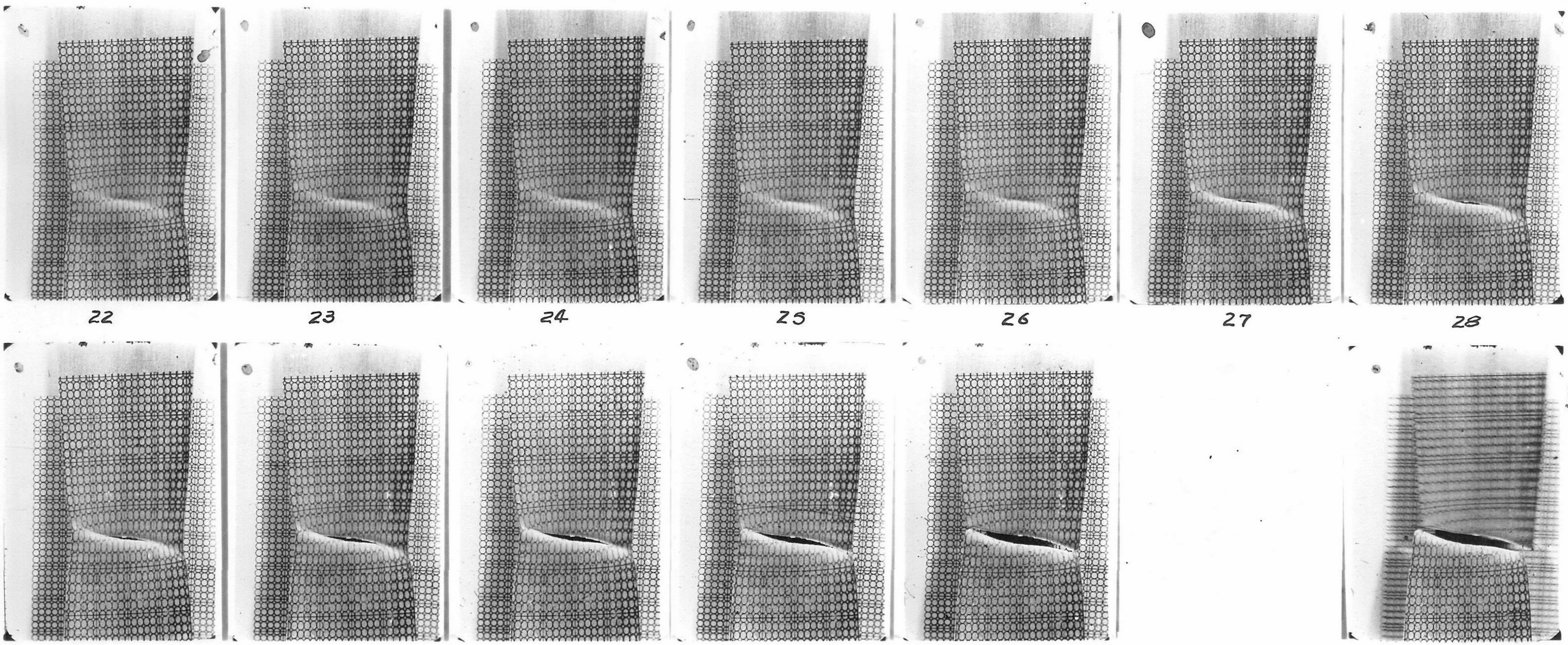


FIG. 3



Grid Distortion at Various Times and Tension Load versus Time - Run 1 $\alpha = 0°$

Material: 3S-O ; R=16"; w=1.0"; t=0.081

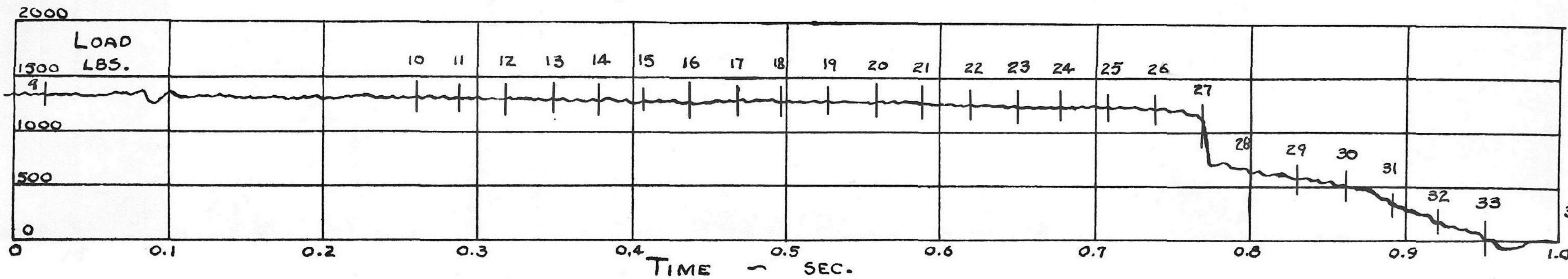
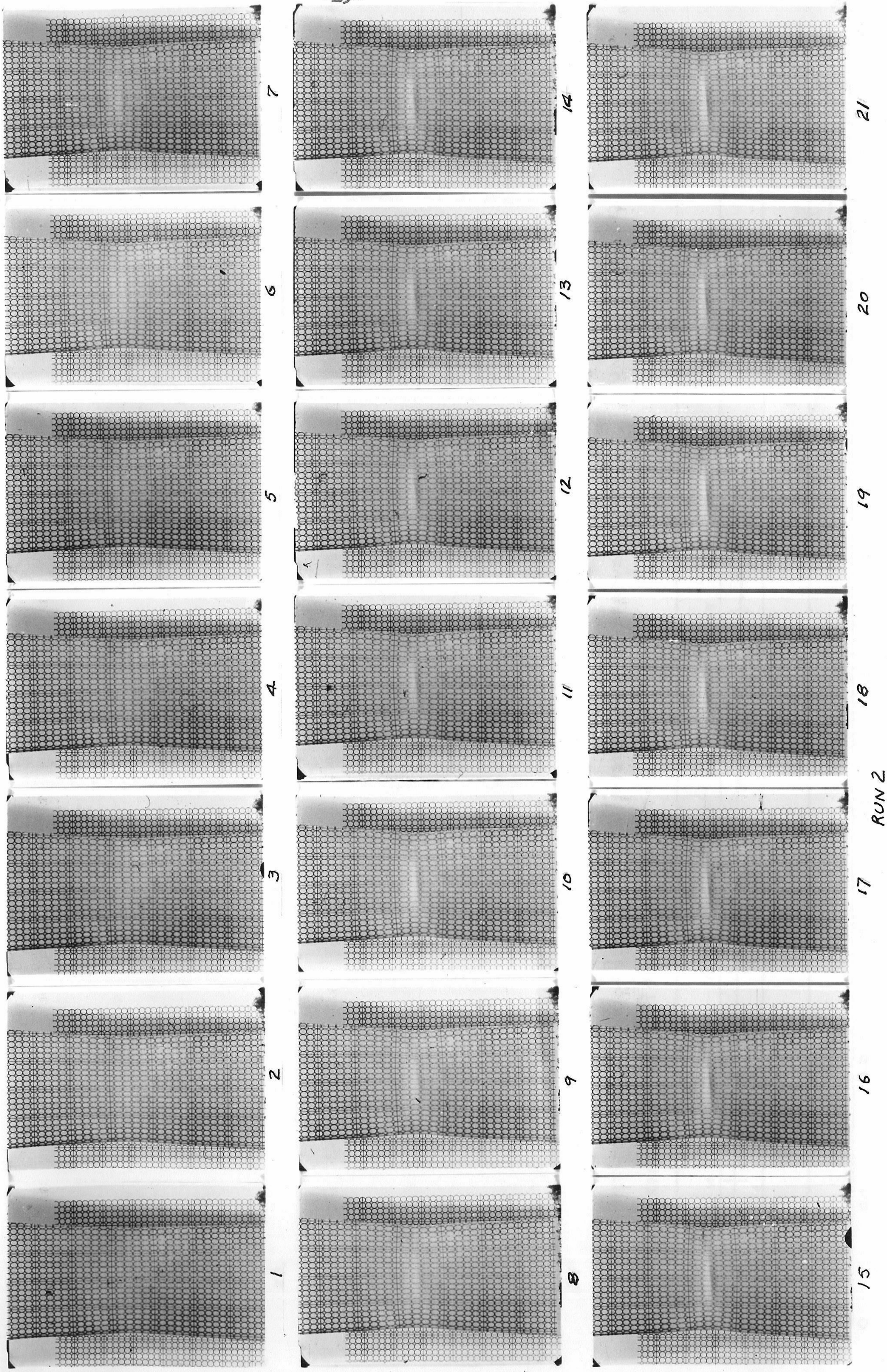
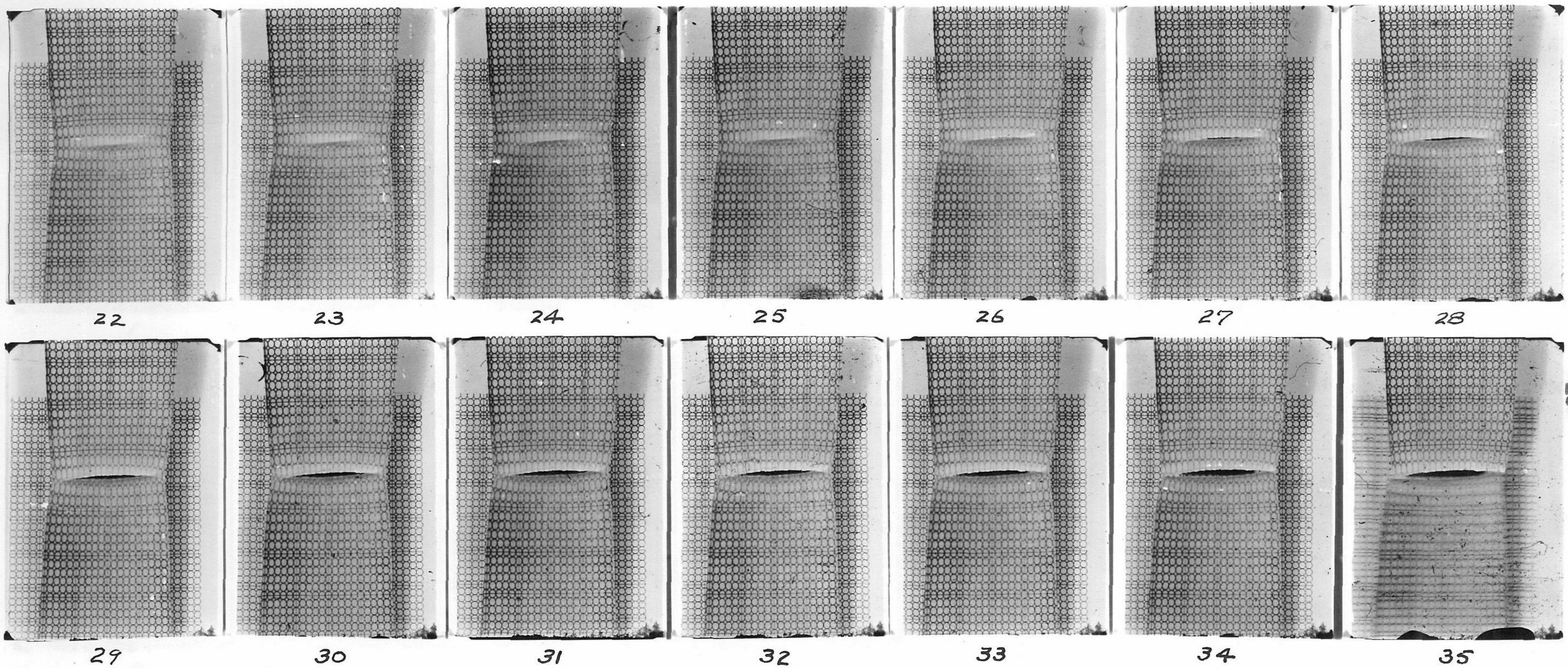


Fig. 4

FIG. 5



RUN 2



GRID DISTORTION AT VARIOUS TIMES AND TENSION LOAD VERSUS TIME - RUN 2 $\alpha = 90°$

MATERIAL: 3S-O R=16"; w=1.0"; t=0.081

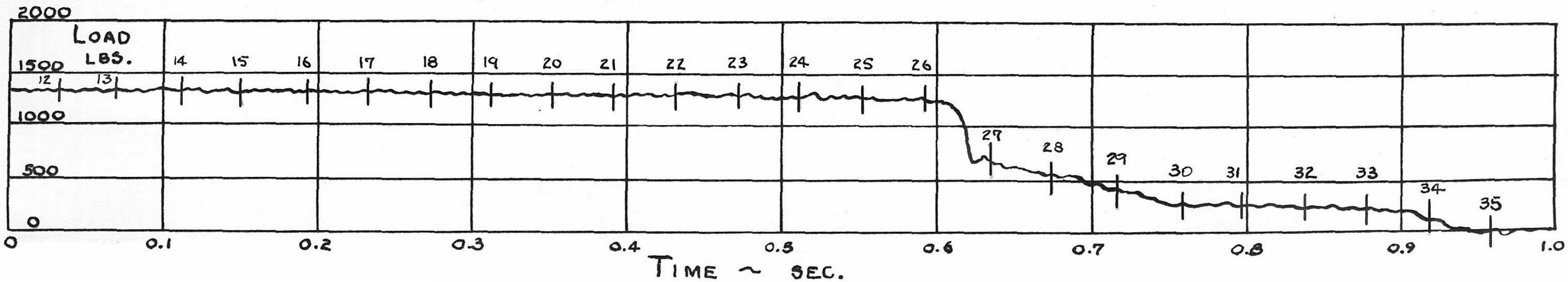
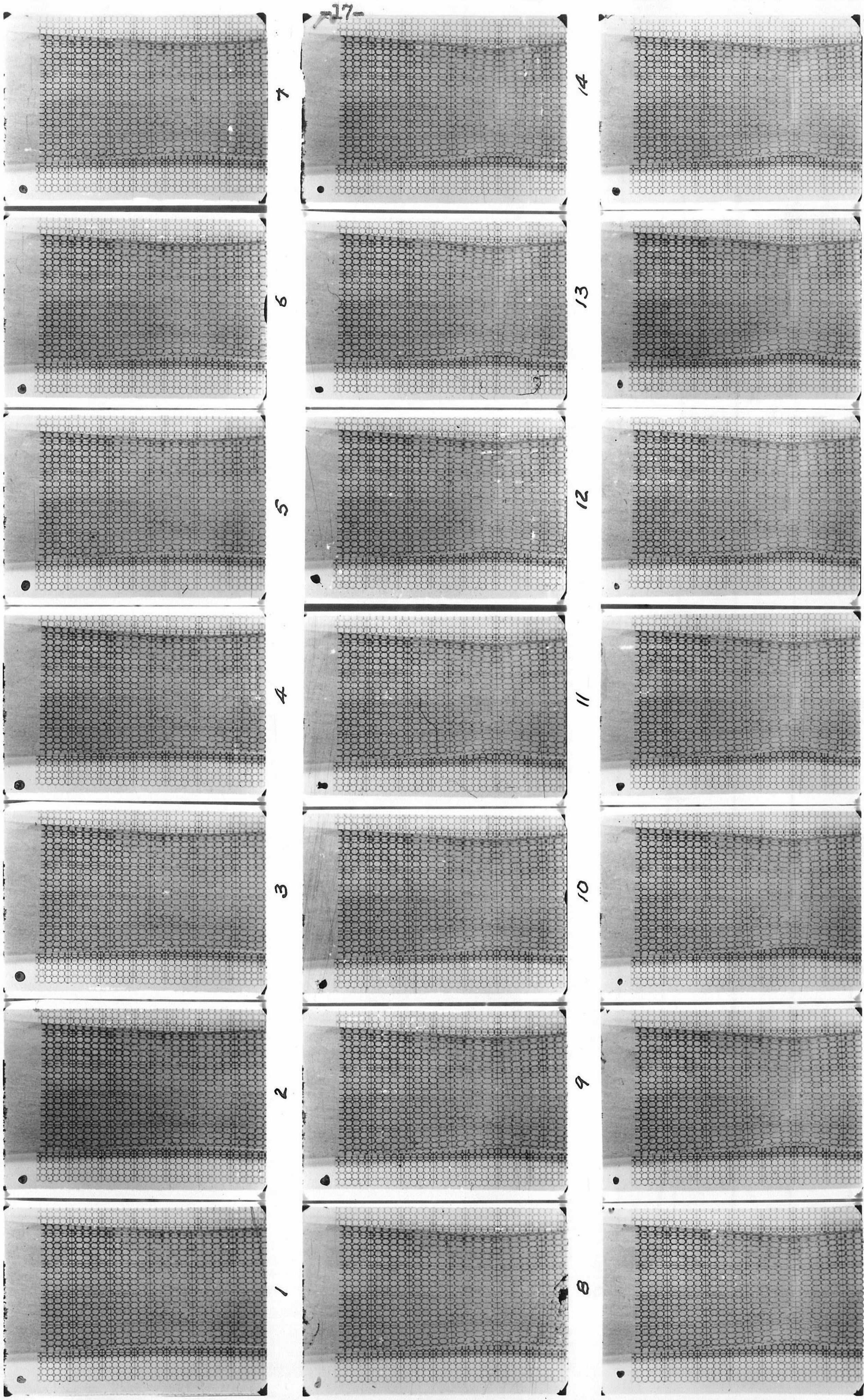
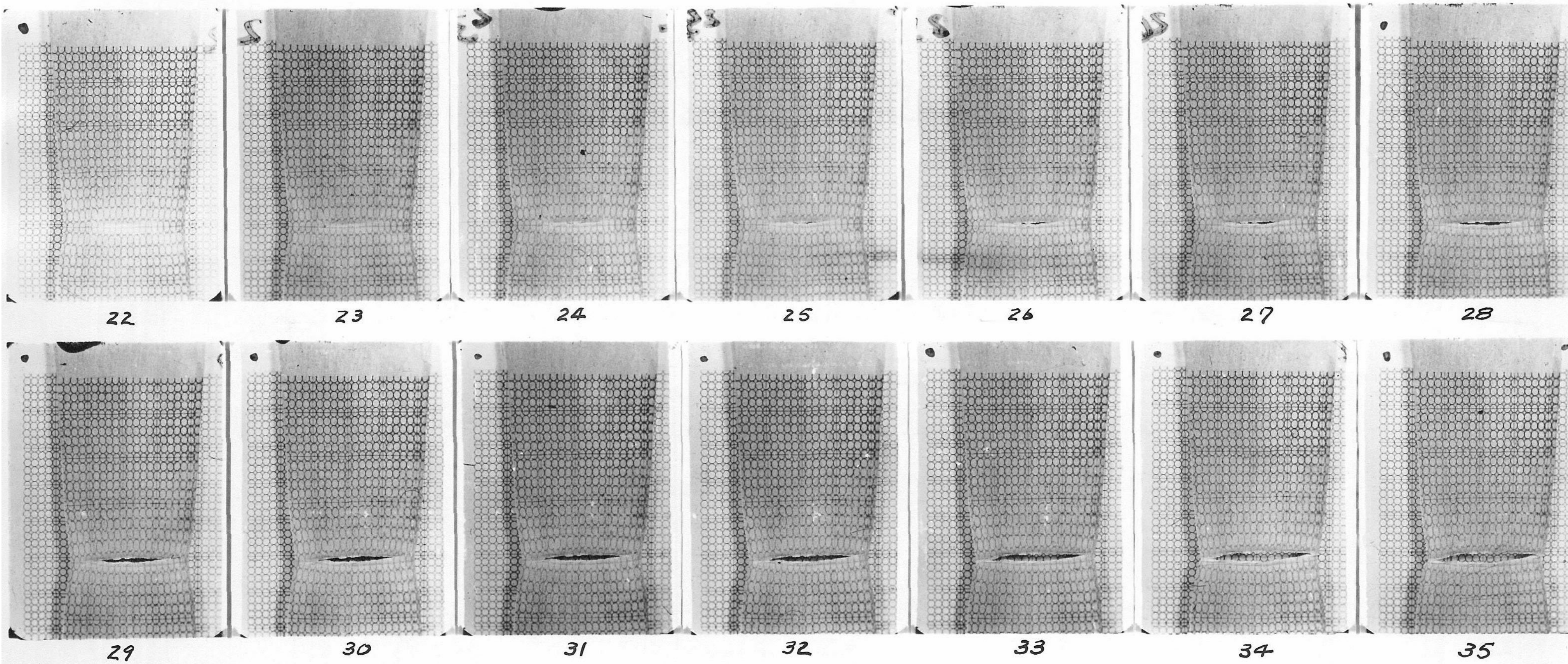


FIG. 6

FIG. 7



RUN 5



Grid Distortion at Various Times and Tension Load versus Time - Run 5 $\alpha = 0°$

Material: 3S-O ; R=16" ; w=1.0" ; t=0.081

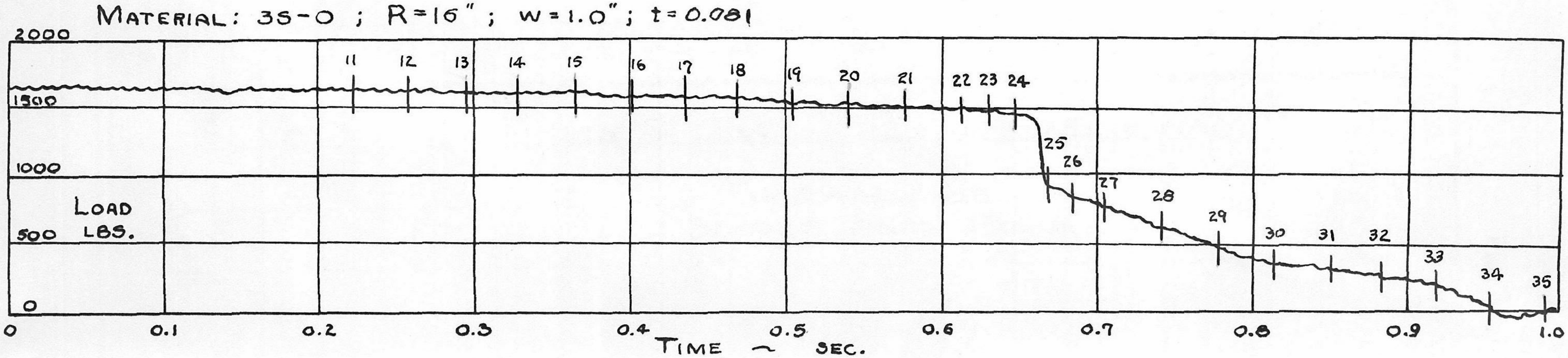
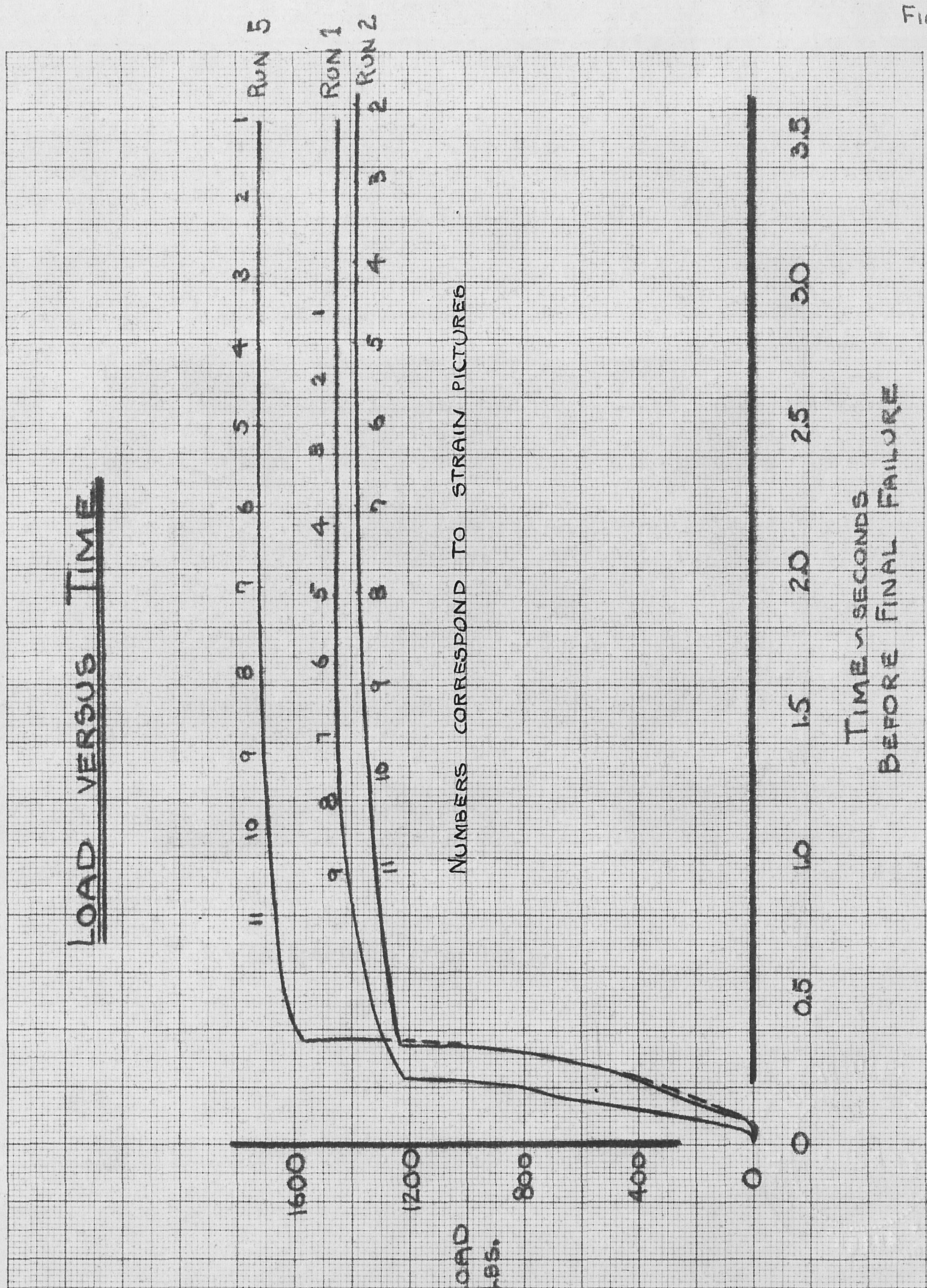


Fig. 8

Fig. 9


LOAD VERSUS TIME
RUN 5
RUN 1
RUN 2
NUMBERS CORRESPOND TO STRAIN PICTURES
LOAD LBS.
1600
1200
800
400
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
TIME ~ SECONDS BEFORE FINAL FAILURE

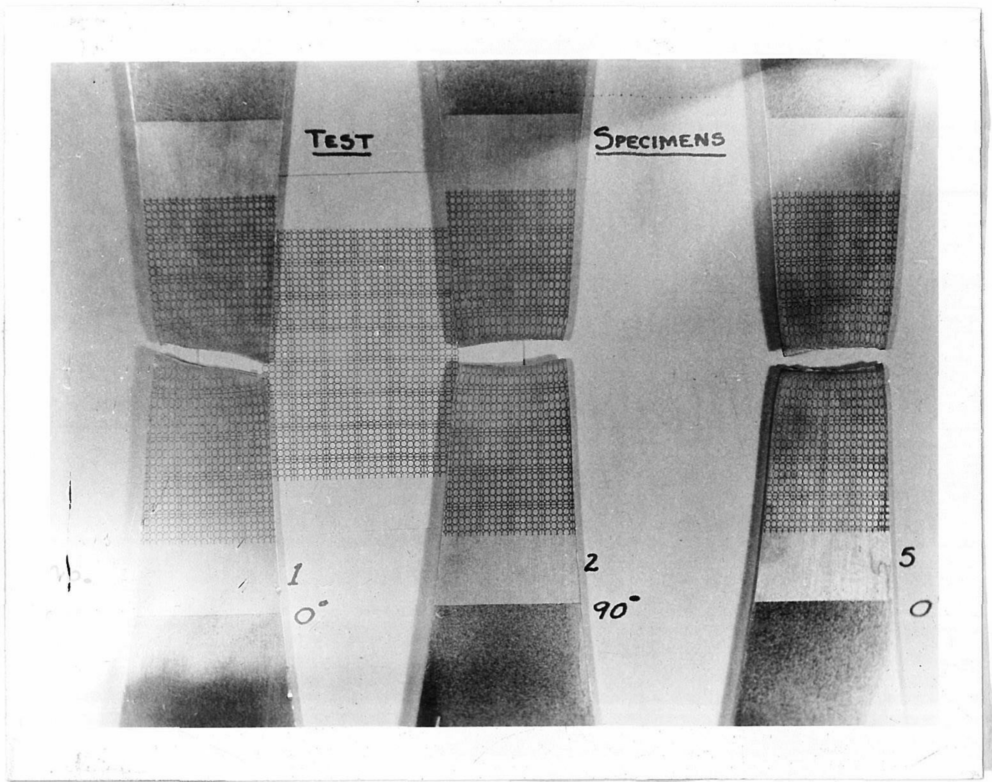


Figure 10 Specimens after Failure