THE VARIATION OF THE INDEX OF NOTCH SENSITIVITY WITH CHANGING FATIGUE LIMIT

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THE VARIATION OF THE INDEX OF NOTCH SENSITIVITY

WITH CHANGING FATIGUE LIMIT

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ACKNOWLEDGMENTS

This thesis is dedicated to my father,

Bennie Clyde Dareing,

and to my mother,

Hazel Alice Dareing.

PREFACE

In recent years the exact knowledge of the maximum stress and its location in the member has become more important, especially in cases where weight is a critical factor in the design. In some cases the member might be designed to endure a limited number of stress cycles so that the member could be lighter in weight. In this design the stress cycles to failure must be known so that the member can be replaced before failure occurs.

This condition makes the index of notch sensitivity a critical part of the design. The relation of the index of notch sensitivity to the fatigue limit is presented in this thesis. Three variables that affected the change of the index of notch sensitivity are also presented.

The author wishes to recognize his advisor, Professor W. H. Easton, whose assistance and comments throughout the project were indispensable. To the Division of Engineering Research and Experiment Station of Oklahoma State University, whose financial support made this thesis possible, I express my sincere gratitude.

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LIST OF SYMBOLS AND ABBREVIATIONS

psi	pounds per square inch
lb	pound
in.	inches
mt	metric ton
sq in.	square inches
σ_{max}	maximum stress, psi
σ_{min}	minimum stress, psi
σ_{nom}	nominal stress, psi
σ_{mean}	mean stress, psi
σ_{ampl}	stress amplitude, psi
σ', σ''	changing stresses, psi
K_t	theoretical stress concentration factor
K_f	strength reduction factor
q	index of notch sensitivity
ϵ_{max}	nominal strain, in. per in.
ϵ_{nom}	nominal strain, in. per in.

DEFINITION OF TERMS

Nominal stress is the local stress as calculated by elementary strength of materials equations.

Stress-Cycles curve is the curve obtained by plotting the fatigue limits with their corresponding number of stress cycles to failure.

Endurance limit is the maximum stress to which the specimen can be subjected an infinite number of times without failure.

Fatigue limit is the maximum stress to which the specimen can be subjected for failure to occur at a specified number of cycles.

Limit stress is the maximum stress to which a part can be subjected without being damaged.

CHAPTER I

INTRODUCTION

It is a well known fact that the limit stress for a given specimen subjected to dynamic loading is lower than for the same specimen subjected to static loading. Up to the present date there has been no completely adequate theory formulated to explain this phenomenon. It is therefore necessary to test the specimen by subjecting it to dynamic loading conditions and at the same time controlling the environment to simulate the actual working environment. The specimen may be subjected to dynamic loading by complete reversal of the load from tension to compression, by fluctuating the load from a maximum tension to a minimum tension, or by fluctuating the load from a maximum compression to a minimum compression. The type of loading for the test must correspond to the actual working type of loading whether axial, bending, or torsional.

In most cases the limit stress for a specimen subjected to dynamic loading is the maximum stress that will not cause failure regardless of how many times this maximum stress is repeated. In some cases the specimen may be designed to endure a limited number of stress cycles.

It has been proven in the past by methods such as the theory of elasticity and photoelasticity that at abrupt changes in cross-section the localized stress is much higher than the nominal stress as calculated by elementary strength of materials equations. The ratio of this theoretical maximum stress to the nominal stress is called the theoretical stress concentration factor. Curves are available which give the theoretical stress concentration factor for a given geometry and type of loading (1)*. The stress concentration factor provides a quick way to find peak stresses. Thus, the theoretical maximum stress, σ_{max}, is the product of the nominal stress and the theoretical stress concentration factor. In equation form this relation is:

$$\sigma_{max} = K_t \sigma_{nom}$$

At the endurance limit and at different fatigue limits for a dynamically loaded specimen, a special concentration factor is used which will be designated by K_f and called the strength reduction factor. The strength reduction factor is the ratio of the fatigue limit determined from a polished unnotched specimen divided by the fatigue limit determined from a notched specimen.

The deviation of K_f from K_t is described by the term index of notch sensitivity, q, which is that property of the material which determines the extent to which a stress concentration of known theoretical magnitude is effective in reducing the strength (2). The strength reduction factor and the theoretical stress concentration factor are related by the index of notch sensitivity. The relationship of these three variables is expressed by the equation

$$q = \frac{K_f - 1}{K_t - 1}$$

* Numbers in parenthesis refer to the bibliography.

CHAPTER II

STATEMENT OF THE PROBLEM

When a stress-cycles curve has been obtained from experimental data for an unnotched specimen, it follows that different points along this curve give the stress which will cause failure to occur at the corresponding number of stress cycles. This stress will be assumed to be the theoretical maximum stress. The nominal stress on a notched specimen, which would produce failure at any selected number of stress cycles, can be predicted theoretically by dividing the corresponding stress as found from the unnotched specimen's stress-cycles curve by the theoretical stress concentration factor.

It is known that the actual stress-cycles curve for the notched specimen does not follow the predicted curve mentioned above. Thus, K_t is not applicable for use in finding the maximum stress for a dynamically loaded specimen.

This research investigates the index of notch sensitivity at different fatigue limits of the notch specimen shown in Figure 2. The material used for these specimens was C 1041 hot rolled steel and the specimens were subjected to an axial fluctuating tensile load.

Three variables were investigated to explain the changing value q as the fatigue limit changed from a high stress to a low stress.

The effect of local yielding will be investigated. Strain measurements will be taken at the root of the notch when the specimen is under the influence of a high dynamic load.

An investigation of cold working will be made by repeating the stresses at high loads. Two different maximum stresses, well above the elastic limit, will be studied to show their relative effect due to cold working the material through stress cycling. In accordance with the definition of cold working, the grains must be permanently deformed. Cycling near the endurance limit causes a change in strength properties similar to that of cold working, but should not be confused with cold working since no permanent deformation occurs.

Measurements of any possible geometry change of the notch will be taken on three different specimens having different maximum loads. These measurements will be taken by using the optical comparator when the specimen is under no load.

CHAPTER III

PROCEDURE AND EQUIPMENT

To find the stress-cycles curve for a given specimen, a number of test specimens are needed. The first specimen is dynamically loaded at a high stress which causes failure after a few cycles. The second specimen is loaded at a somewhat lower maximum stress than that of the first. The corresponding number of cycles required to cause failure is greater than the number of cycles to failure of the first specimen. Each time failure occurs, a new specimen replaces the fractured specimen. The new specimen is subjected to a lower maximum stress, which results in longer life of the specimen. This procedure is followed until one of the last specimens is dynamically loaded at a certain maximum stress at which failure does not occur. When this point is reached the stress-cycles curve is almost parallel to the abscissa. The number of cycles is plotted along the abscissa. The last specimen does not fracture, but endures for a certain number of cycles after which the test is stopped. The arbitrary number of stress cycles at which the test is stopped is usually in the range of one to ten million cycles (3). This, however, depends upon the material tested.

Note that the test is started by subjecting the first specimen to a high load instead of a low load. This allows a faster control of the test because failure does occur. If the series of tests is begun by testing the first specimen at a stress that is too low, much time may expire before it is discovered that the stress is below the endurance limit. In this type of test, the limit stress should be approached from the higher stresses.

The conditions under which the specimens were tested were ambient atmospheric temperature, a constant speed of 460 cycles per minute, and a fluctuating tensile load. The fatigue machine used in this test was the UHP 20 axial loading fatigue testing machine, made by the Losenhousen Company of Germany. This machine has a dynamic loading capacity of tensile load variations from 22,050 pounds maximum to 300 pounds minimum. The machine cannot alternate the load from tension to compression, but can only fluctuate the load from a maximum load to a minimum load. This type of loading is illustrated in Figure 1. Plate I is a view of the fatigue testing machine used for this test.

The stress-cycles curve was obtained by testing a number of specimens. Each specimen was subjected to a cyclic fluctuating load varying from a minimum load of 300 pounds to a maximum load. A different maximum load was used for each specimen. This procedure was repeated with each specimen until the endurance limit was found.

The Goodman Diagram for SAE 1045 indicates that for this particular type of fluctuating load, the elastic limit of the material is its endurance limit (4). The material C 1041 hot rolled steel, was subjected to a static tensile test to find its stress-strain relationship. The Stress-strain curve thus obtained is shown in Figure 10. It indicates that the elastic limit of the material is 50,000 psi. This was used as a guide in selecting the maximum stresses.

In order to find the dynamic strain at the root of the notch, the strain measuring system was calibrated, and the strain was read directly

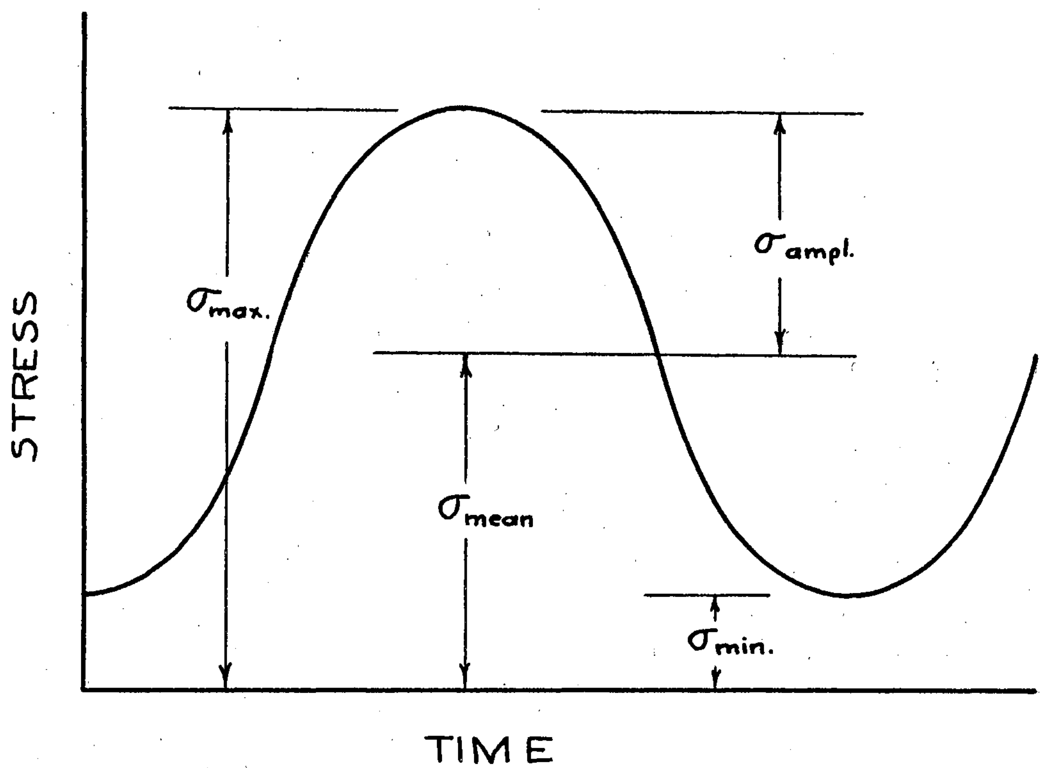
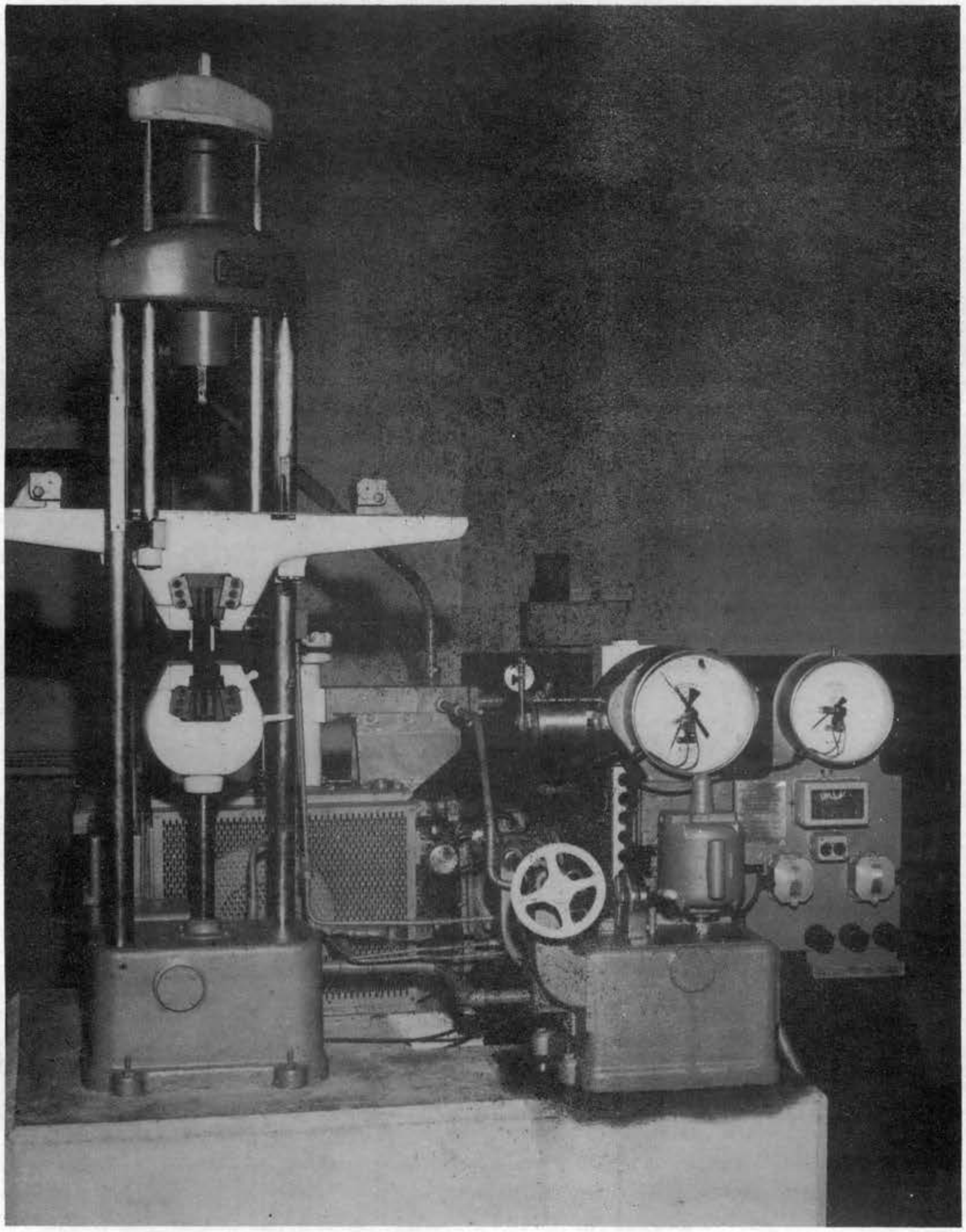


Figure 1. Stress-Time Diagram

PLATE I. FATIGUE TESTING MACHINE



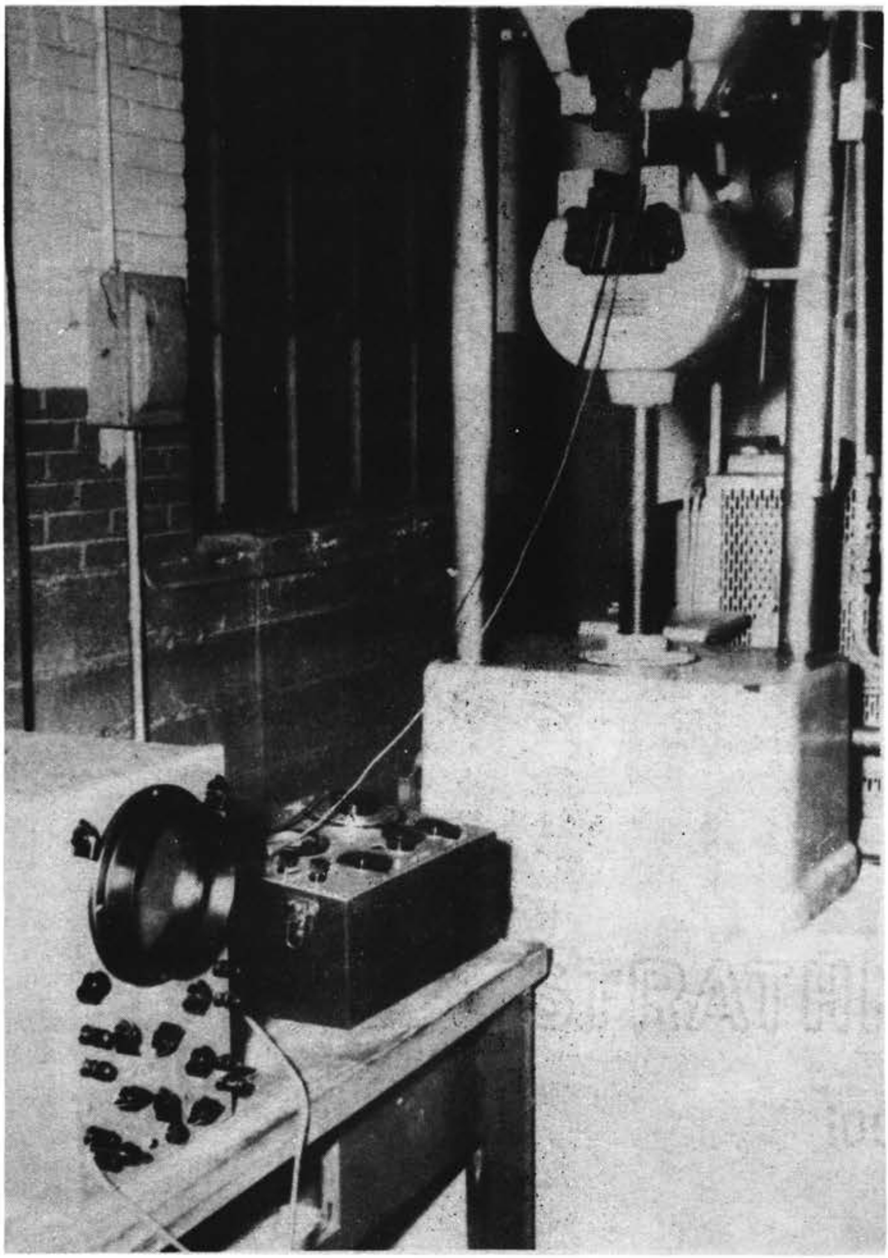
from the oscilloscope screen. This eliminated the difficult and almost impossible method of using the wheatstone bridge alone.

The strain measuring instruments included the oscilloscope, a wheatstone bridge, and a SR-4 strain gage of 1/16 inch gage length which was cemented in the notch root. These instruments are shown in Plate II as they were arranged for the test.

The SR-4 strain gage was one of the resistances in the wheatstone bridge. When the SR-4 strain gage was elongated by the notch strain, the voltage drop across the SR-4 strain gage increased. Thus, a voltage change, which was proportional to the strain, was applied to the oscilloscope and produced a wave whose amplitude varied with the notch strain. This method allowed the dynamic strain to be read from the oscilloscope screen.

The increase in strength by cold working can be detected by an accompanying increase in hardness. This fact was the basis for checking hardness changes as a result of cycling at stresses above the elastic limit. The hardness at two stress levels was measured to determine the amount of cold working in the notch cross-section of the notched specimens. The first specimen was stressed at a maximum of 60,000 psi for 10,000 cycles. The second specimen was stressed at a maximum of 35,000 psi for 100,000 cycles. In this discussion the stresses referred to are nominal stresses and the term maximum stress is the peak cyclic value of the nominal stress as shown in Figure 1. The number of cycles in each case was chosen far enough away from the point of failure so as not to cause fracture of any of the fibers. The specimens were cut in two at the notch and the hardness profiles were found by using a Rockwell Hardness Tester. A sharp cutting tool was used to cut the specimens

PLATE II. STRAIN MEASURING SYSTEM



in two so that any possible additional cold working by the cutting tool would be negligable.

A change of notch radius was anticipated since local yielding was detected by strain measurements at that point. After cycling, the specimen was placed in an optical comparator having a magnification of one hundred to one. Three points were chosen close to the root from which the notch radius was found. The notch was checked after the specimen had been subjected to several different numbers of stress cycles.

In preparing the specimens for the test, care was taken in polishing them to avoid cold working on the surface. The polishing steps are listed below and were applied in the order listed.

1. No. 60 emery cloth
2. No. 100 emery cloth
3. No. 150 emery cloth
4. No. 320 emery cloth
5. Crocus cloth

A light film of oil was put on the polished surface to protect it from corrosion.

The material used in all of the test was C 1041 hot rolled steel. The geometry of the notch and design of the specimen are shown in Figure 2. The radius of the notch was designed so that a one-sixteenth inch SR-4 strain gage could be attached at its root. Although this specimen does not have the exact dimensions of the ones discribed in the <u>ASTM Manual on Fatigue Testing</u>, the specimens listed in this manual were used as a guide.

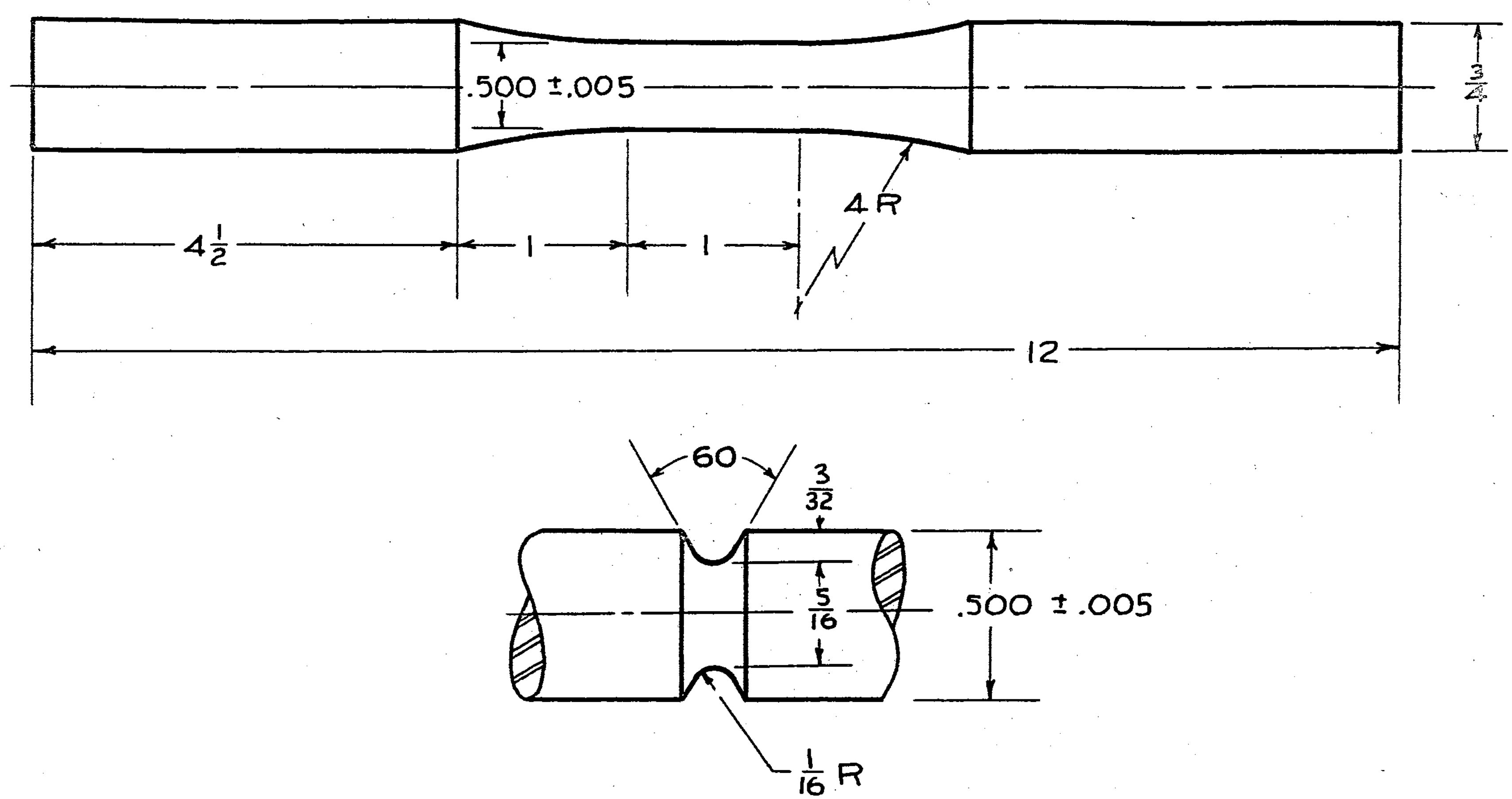


Figure 2. Test Specimens

CHAPTER IV

EXPERIMENTAL TEST DATA

Part A
Stress-Cycles Data

Experimental stress-cycles curves for the unnotched and notched specimens are shown in Figure 3. The experimental data, shown in Tables I and II, were obtained from tests performed in the Oklahoma State University Civil Engineering Testing Laboratory.

TABLE I

STRESS-CYCLES DATA FOR UNNOTCHED SPECIMEN

Material - C 1041 hot rolled steel
Dimensions - see Figure 2

Specimen	max. load mt	max. load lb	diameter in.	area sq in.	stress psi	cycles
1	6.63	14600	0.501	0.197	74200	2.180×10^3
2	6.50	14300	0.504	0.199	72000	3.920×10^4
3	5.92	13020	0.501	0.197	66000	6.020×10^4
4	5.43	11930	0.496	0.193	62000	9.560×10^4
5	5.20	11420	0.500	0.196	58200	1.959×10^5
6	4.92	10820	0.498	0.195	55600	8.283×10^5
7	4.57	10080	0.492	0.190	53000	2.620×10^6
* 8	4.48	9850	0.501	0.197	50000	5.000×10^6

* did not fracture

TABLE II

STRESS-CYCLES DATA FOR NOTCHED SPECIMEN

Material - C 1041 hot rolled steel
Dimensions - see Figure 2

Specimen	max. load mt	max. load lb	diameter in.	area sq in.	stress psi	cycles
9	2.35	5180	0.317	0.079	65600	1.83×10^4
10	2.26	4980	0.325	0.083	60000	4.32×10^4
11	1.88	4140	0.315	0.078	53000	5.68×10^4
12	1.70	3730	0.317	0.079	47200	1.55×10^5
13	1.48	3250	0.325	0.083	39200	7.20×10^5
14	1.29	2840	0.317	0.079	36000	3.27×10^5
15	1.25	2740	0.320	0.0805	34000	2.50×10^6
*16	1.15	2530	0.317	0.079	32000	5.00×10^6

* did not fracture

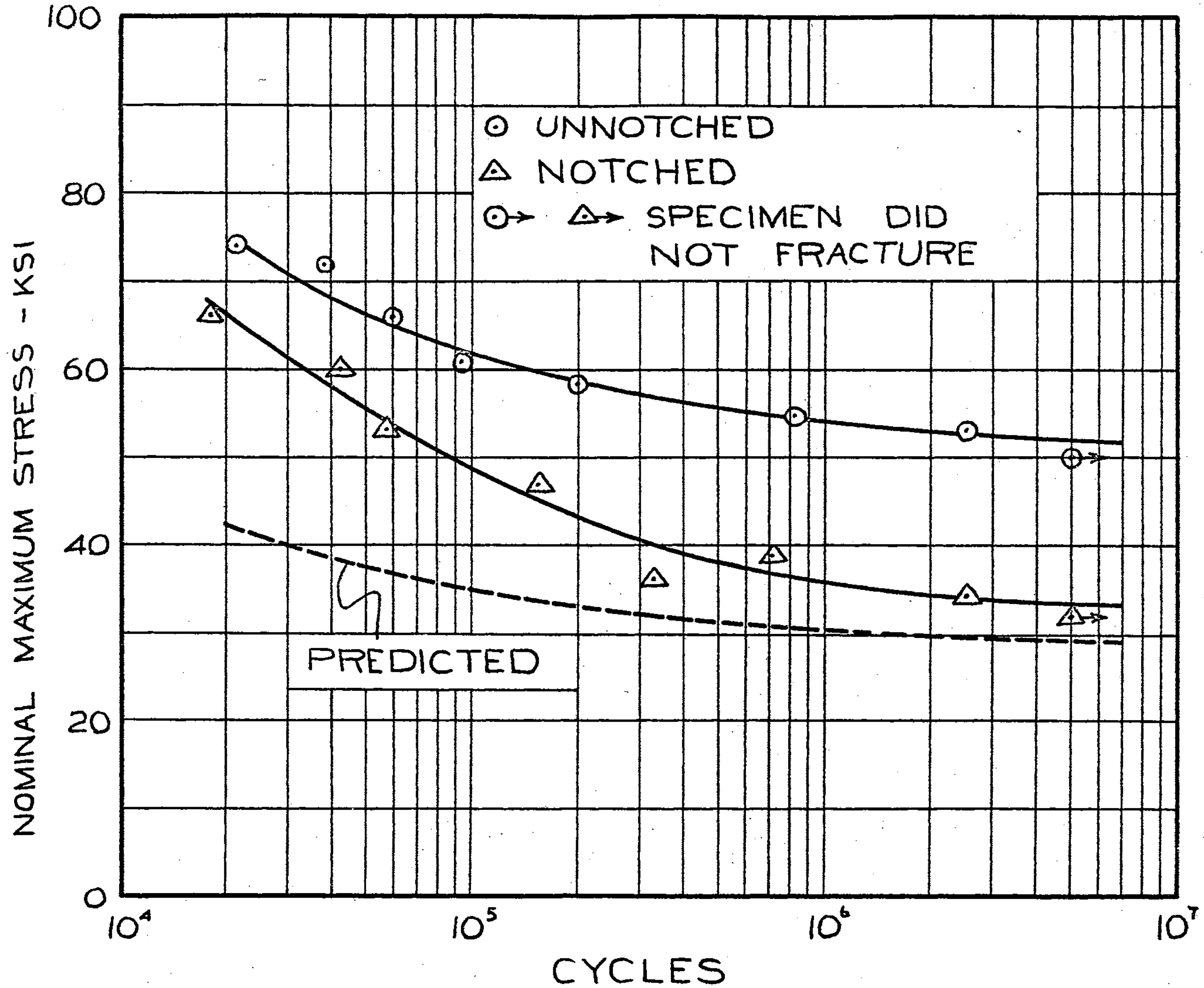


Figure 3. Stress-Cycles Diagram

Part B
Local Yielding

Local yielding was investigated on one of the notched specimens at a nominal stress of 44,800 psi. Since the theoretical stress concentration factor is 1.78*, the theoretical maximum stress was well above the elastic limit of the material.

It was noticed that as the number of stress cycles increased, the local strain at the notch root decreased steadily. Table III gives the data of the test. In Figure 4 a plot of the experimental data is shown. So as not to miss any possible yielding during the first few cycles, the maximum load was applied and released slowly by use of the static loading device. The maximum strain for the first cycle, as given by the strain measuring system, was 0.00209 inches per inch. The second, third, fourth, and fifth cycles were also applied by use of the static loading device. The results of the first five cycles are shown to a reduced scale on the top curve of Figure 4.

Figure 4 indicates that the yielding was more severe in the first few stress cycles. The curve is much steeper at stress cycles below fifty. The elbow of the curve starts at about fifty stress cycles. Past this point the strain decreases only slightly and approaches a constant value as the number of stress cycles is increased.

It is noticed from the stress-strain relation, which is shown in Figure 10, that the elastic limit is 50,000 psi and the strain corresponding to this stress is 0.00166 inches per inch. Locating this

*Figure 11 in the appendix gives a special from of Neuber's nomograph, from which K_t was found.

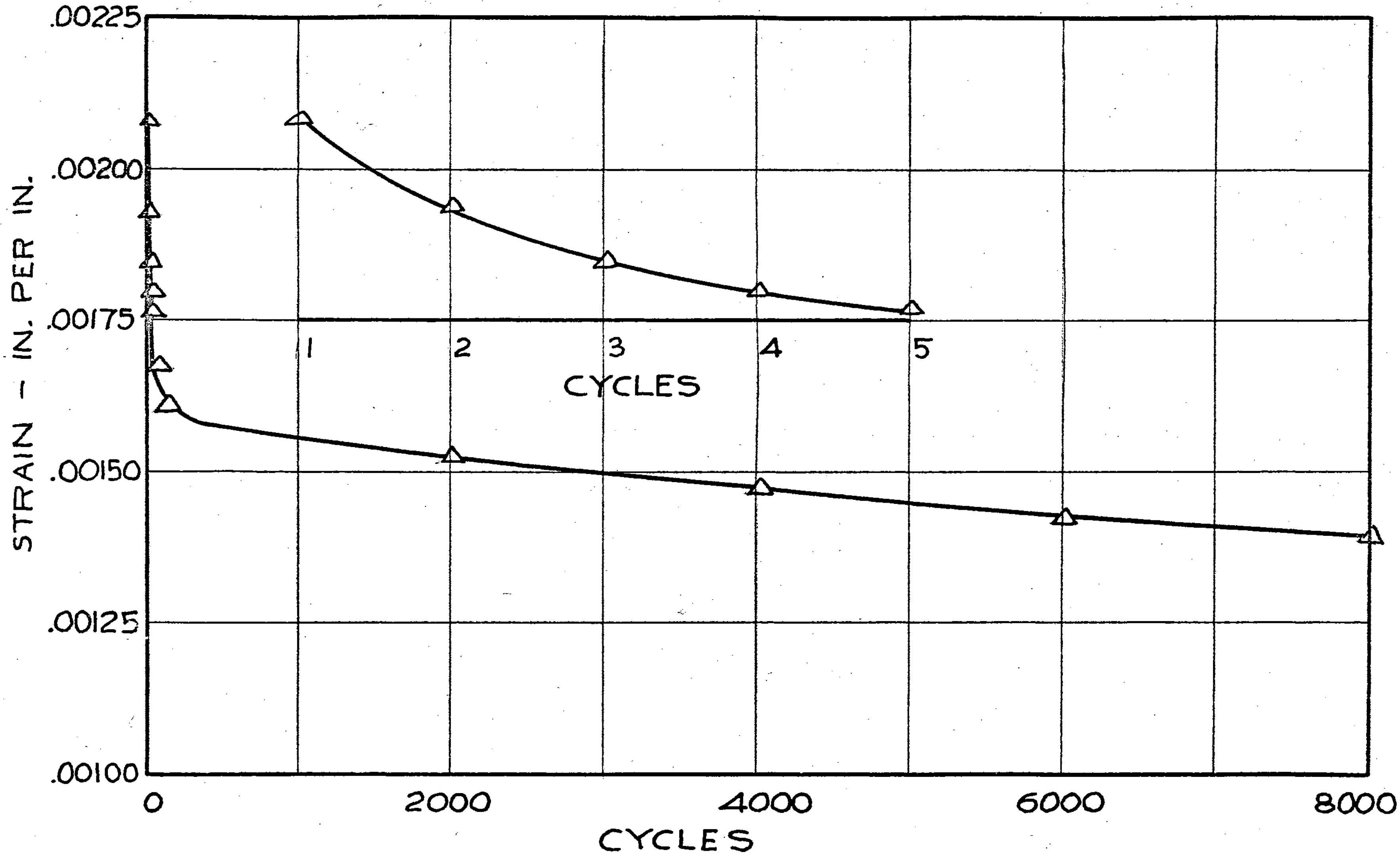


Figure 4. Variation of Strain with Stress Cycles

TABLE III

STRAIN MEASUREMENTS ON A NOTCHED SPECIMEN

amplitude scope divisions	* maximum Strain in./in.	stress cycles
8.4	0.00209	1
7.8	0.00193	2
7.5	0.00185	3
7.3	0.00180	4
7.2	0.00177	5
6.9	0.00169	50
6.6	0.00161	100
6.3	0.00153	2000
6.1	0.00148	4000
5.9	0.00142	6000
5.7	0.00138	8000
5.3	0.00127	10000

* The calibration curve is given in Figure 9 of the appendix. From this curve a calibration equation, equation (a) of the appendix, was derived. This equation was used to calculate the maximum strains listed in Table III.

strain on the curve in Figure 4 it is seen to be at the elbow of the curve. From this it may be said that the amount of yielding depends upon the amount by which the maximum stress exceeds the elastic limit. The strain measuring system indicated there was a small amount of yielding at the root of the notch even after the local stress in the notch root was below the elastic limit. This yielding might be said to be the residual effect of the original plastic deformation.

The nominal strain corresponding to a nominal stress of 44,800 psi is 0.00146 inches per inch. Again looking at Figure 4 it is seen that the curve levels off at a strain slightly below 0.00146 inches per inch. The final strain would not be expected to go lower than the nominal strain. The following is offered as a partial explanation for this slightly lower strain.

Any deviation between the measured strain and the actual strain can be explained partly by Figure 5. The maximum stress is located at point m. The elongation of the SR-4 strain gage is not uniform throughout its length, but the unit elongation is a maximum at point m. This means that the voltage drop across the SR-4 strain gage is not as large as it would be if the entire gage length had been elongated uniformly. The result is the strain indicated by the strain measuring system is smaller than the true strain.

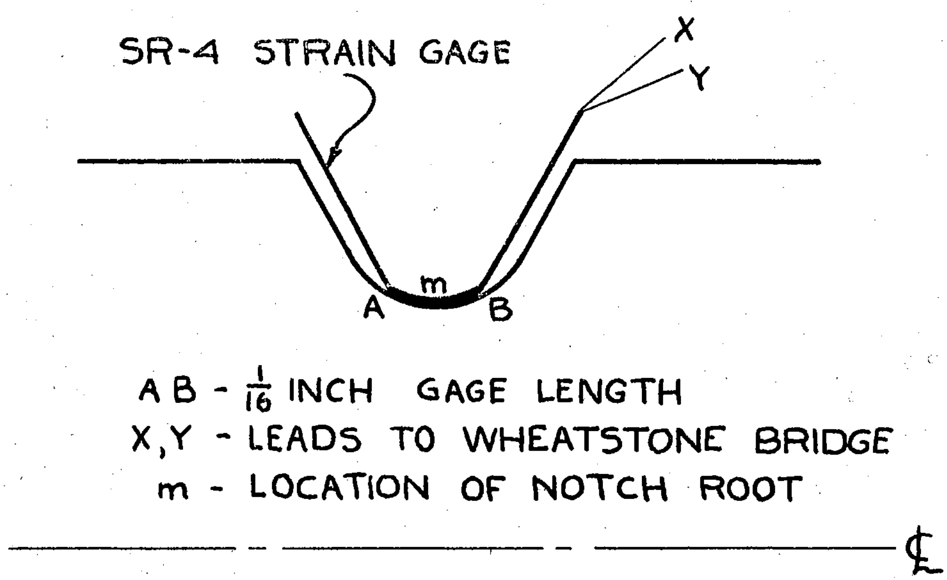


Figure 5.

SR-4 Strain Gage Installation

Part C
Work Hardening

Hardness measurements were taken at different points in the cross-section of the notch to detect any cold working due to the stress-cycling. The result of this hardness check is shown in Figure 6. It is recognized that consistant hardness measurements are rather difficult to obtain even when the material has been annealed. The hardness was checked at different points at the same radius of the cross-section. The values at the same radius were within one half of a Rockwell B number. It is believed that this is a close representation of the hardness profile for the given notched specimen which had been previously subjected to 10,000 stress cycles fluctuating between the maximum stress of 60,000 psi and a minimum stress of 3,680 psi.

Before the specimen was subjected to the stress cycles, a small slice was taken off the end of the twelve inch specimen. The hardness of this slice was assumed to be the original hardness in the notch before stress cycling. For an annealed specimen this assumption would be more nearly correct. The two specimens used in this particular part of the test were annealed. The original hardness in the notch cross-section was Rockwell 80 B.

Since the largest plastic deformation occurs at the root of the notch, the hardness at that point would be expected to be higher than the hardness in the center of the cross-section. The test data does not show this.

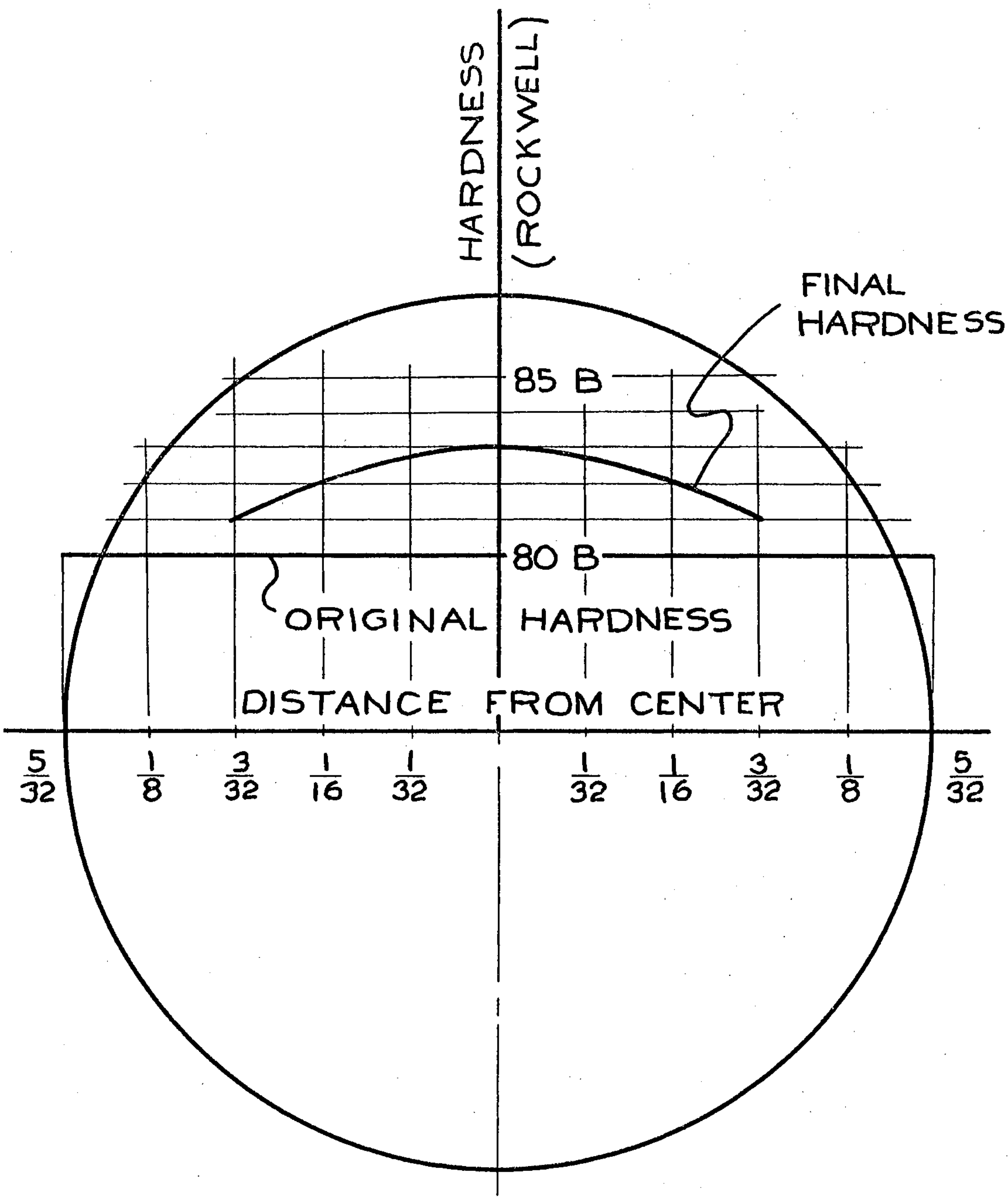


Figure 6.

Effect of Dynamic Loading on
Hardness of Specimen

Part D
Notch Geometry Change

The radius of the notch was checked in the optical comparator at different cycle intervals, the load fluctuations being the same for each cycle. This procedure was repeated for fluctuating loads of three different maximum magnitudes. The first maximum load produced a nominal stress of 60,000 psi which was well in the plastic range. The other two maximum nominal stresses were 45,000 psi and 30,000 psi respectively.

It was expected that any change in geometry of the notch would take place in the first few cycles, since the local yielding was more severe in the first few cycles. The load was applied slowly for the first five cycles, and the notch was checked in the optical comparator after each cycle for a permanent change in geometry.

No change in the radius was noticed in any part of the test. It should be noted, however, that the notch tested had a 1/16 inch radius. If the notch had been one with a smaller radius, a change might have been detected.

Since local yielding was detected by strain measurements, it indicated that there was a change in notch geometry. Thus, although the test did not show a change in notch radius, it seems probable that there was a minute change which could not be detected.

CHAPTER V

DISCUSSION

It is desirable to note some of the possible values that the index of notch sensitivity can have. First, the stress-cycles curve for the unnotched specimen was obtained. From this curve a predicted stress-cycles curve for the notched specimen was obtained by dividing fatigue limits of the unnotched specimen by the theorectical stress concentration factor.

The stress-cycles curve for the notched specimen might be expected to follow this predicted curve, since the maximum stress is the governing stress for fatigue failure. However, the actual stress-cycles curve did not follow the predicted curve, but had a greater slope at the higher stresses.

Since by definition

$$q = \frac{K_f - 1}{K_t - 1}$$

and

$$K_f = \frac{\sigma_{nom} \text{ (unnotched specimen)}}{\sigma_{nom} \text{ (notched specimen)}}$$

as the number of cycles to failure decreases q also decreases. If the stress-cycles curve for the notched specimen intersects the stress-cycles curve for the unnotched specimen, q will be zero at the point of intersection.

Thus, when

$$\sigma_{nom} \text{ (unnotched specimen)} = \sigma_{nom} \text{ (notched specimen)}$$

$$K_f = 1$$

and
$$q = \frac{1 - 1}{K_t - 1}$$

$$q = 0$$

Likewise, the value of q will be unity when the stress-cycles curve for the notched specimen intersects the predicted stress-cycles curve for the notched specimen.

Thus, when

$$\sigma_{nom} \text{ (notched specimen)} = \sigma \text{ (predicted)}$$

$$K_f = K_t$$

and
$$q = \frac{K_t - 1}{K_t - 1}$$

$$q = 1$$

The index of notch sensitivity varies from zero to unity between these two points.

Figure 3 shows that at high loads the fatigue limit of the notched specimen approaches the fatigue limit of the unnotched specimen. This means that the strength reduction factor becomes smaller as the fatigue limit increases. The changing value of the strength reduction factor also corresponds to a changing value of the index of notch sensitivity. As the strength reduction factor increases with decreasing fatigue limit, the index of notch sensitivity increases. Figure 7 shows the values of q as a function of the number of stress cycles. Indirectly q is a function of local yielding, cold working, and the change of notch geometry.

In chapter four it was shown by means of the strain gage readings that there does exist local yielding. As the maximum stress in a specific notched specimen decreased, the potential life of the specimen operating under given loading conditions was increased. This follows since the fatigue life of the material depends upon its maximum stress. In Figure 3 it is shown that for a nominal stress of 40,000 psi on a notched specimen, its life was increased 300,000 cycles partly as a result of local yielding.

In Figure 8 it will be noticed that the stress σ'_{max} at the root of the notch was greater than the elastic limit and plastic deformation occured. Upon unloading, a residual compressive stress, σ'_{min}, is left in the outer fibers while the core is pre-stressed in tension. During the next cycle, the maximum stress, σ''_{max}, does not reach as high a peak as did the first maximum stress. Each stress cycle reduces the maximum root stress by this localized yielding. This localized yielding is one of the factors associated with the change which occurs in the root of the notch as the number of stress cycles is increased. At low loads local yielding is not as pronounced, since plastic deformation is not as severe.

From this discussion it follows that when local yielding occurs, the theoretical stress concentration factor has less effect as a stress raiser. Since local yielding is more pronounced at the higher loads, the value of K_f is smaller at the higher loads. Since the index of notch sensitivity is a function of K_f and K_t, it follows that q also is smaller at high loads than at low loads.

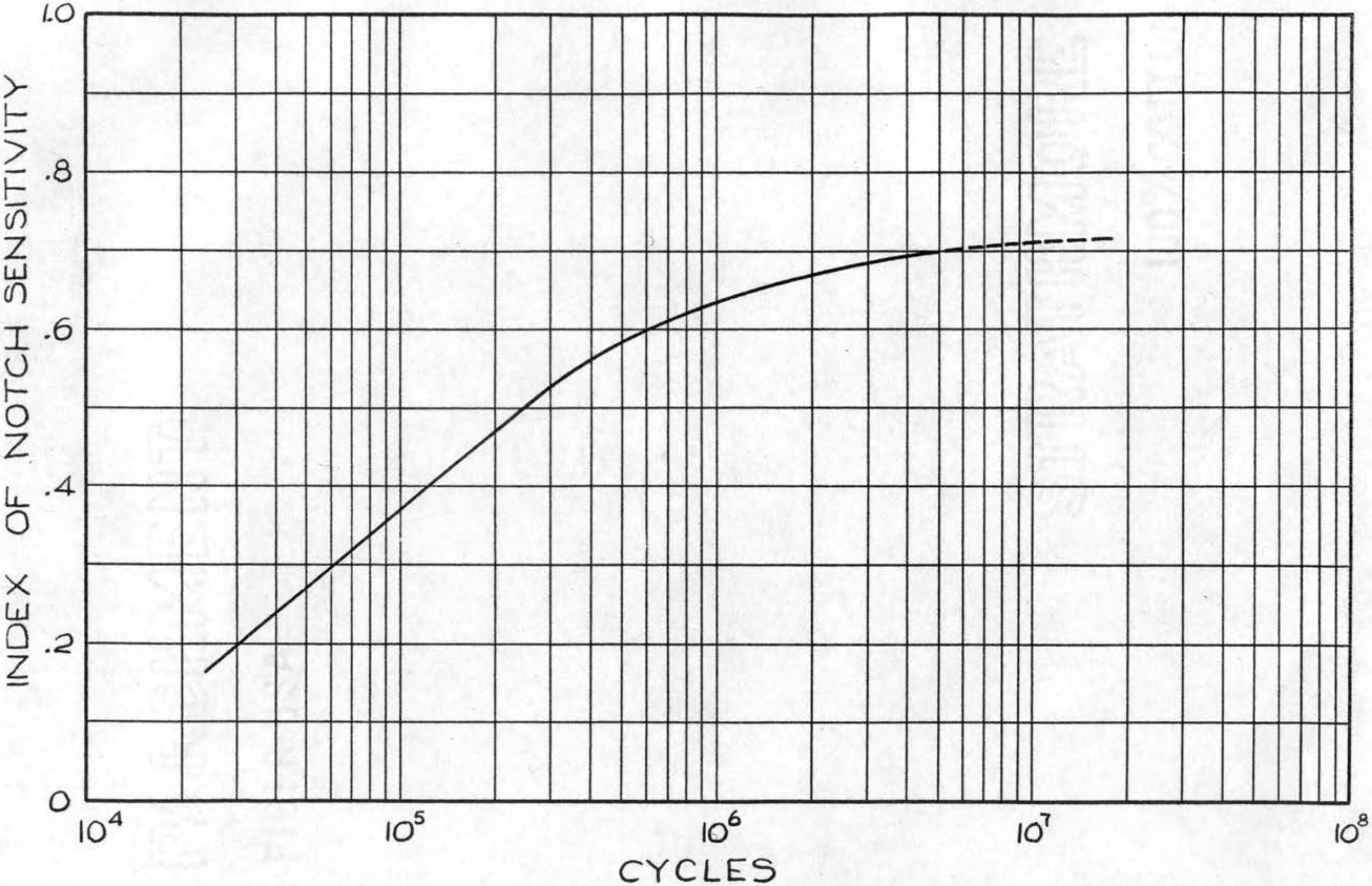


Figure 7. Variation of the Index of Notch Sensitivity with Fatigue Limit

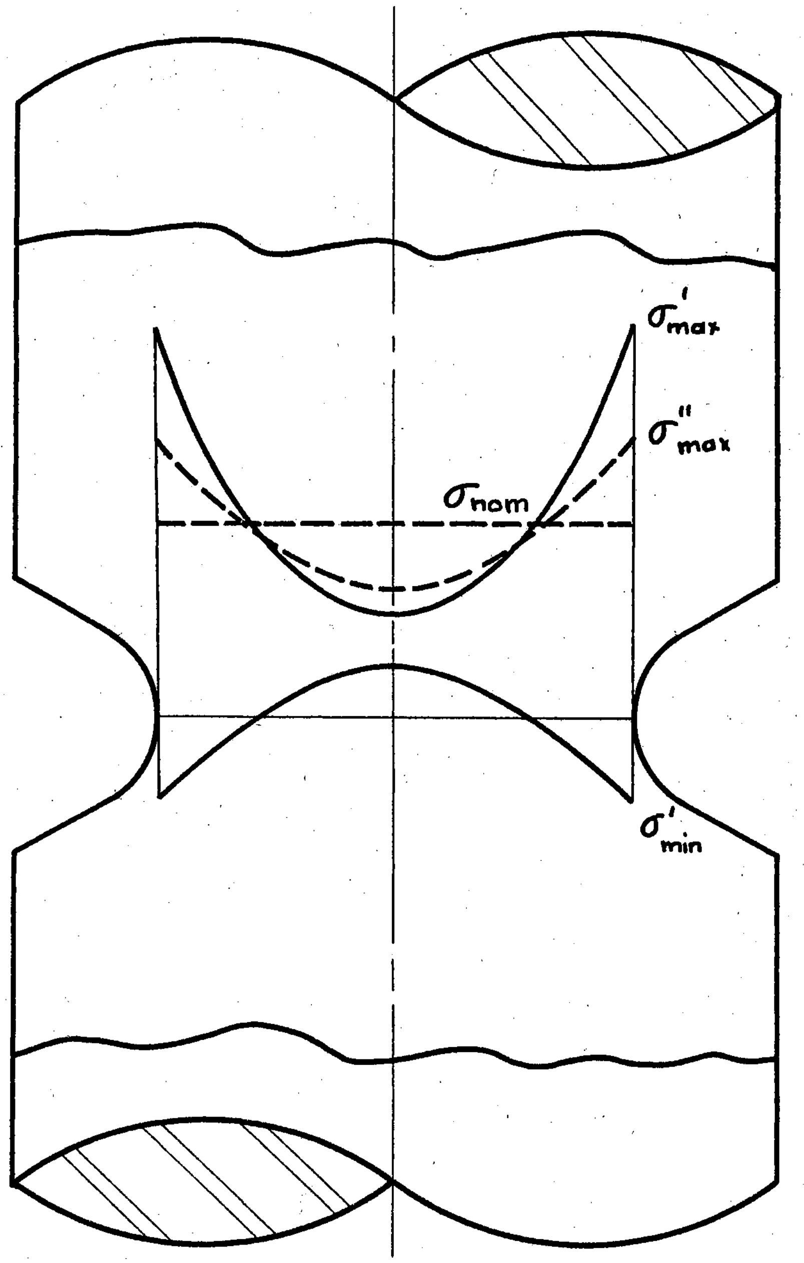


Figure 8.

Effect of Residual Stresses on the Stress Gradient in the Notched Specimen

By definition, cold working of steel is the mechanical deformation of steel at temperatures below the transformation temperature. When the steel is plastically deformed at these low temperatures, the pearlite and ferrite grains are elongated in the direction in which work is applied (5). This mechanical distortion results in an increase of hardness and brittleness.

The test did indicate cold working occured during the stress cycling. The first hardness test was made on a notched specimen which had previously been subjected to a maximum fluctuating stress of 60,000 psi for 10,000 stress cycles. The result showed only a slight increase in hardness. The second notched specimen, which had been subjected to a maximum fluctuating stress of 35,000 psi, did not show a differential in hardness. Therefore, as the maximum fluctuating stress is decreased and approaches the elastic limit, the cold working becomes negligable.

The effect of cold working is, in general, to increase the index of notch sensitivity of a given metal, simultaneously with the increase in tensile strength. However, Cornelius and Bollenrath found that a 0.38 per cent carbon steel had a lower index of notch sensitivity in the cold worked condition (6).

The material used in this test contained 0.41 per cent carbon. Therefore, it seems logical in this case that the index of notch sensitivity decreases with a decrease in ductility. Previous literature shows the endurance limit is higher for cold worked material than for the same material not cold worked. The limit stress of the notched specimen is increased due to the cold working done by stress cycling above the elastic limit. This change in strength properties of the material decreases the strength reduction factor. Therefore, the index of notch sensitivity is made smaller at high fatigue limits due to this cold working.

It should be noted that the unnotched specimen was also cold worked due to the stress cycling, but the cold working in the notched specimen was greater because of stress concentration. The differential in cold working of the two is the important factor, since the unnotched stress cycles curve was used as a basis for the calculation of the index of notch sensitivity of the notched specimen.

The calculation of K_t was made on the basis of the original notch radius. It was of interest to investigate the change of notch radius under a given load to see if local yielding had any effect on the geometry of the notch.

When the radius of the notch changes, the fatigue life of the specimen is affected. As the notch radius increases, the theoretical stress concentration factor decreases. As a result, the life of the specimen will be increased. Most of the change of the theoretical stress concentration factor, resulting from a change of radius, occurs during the first few stress cycles and as the stress cycles increases the theoretical stress concentration factor approaches a constant value.

The magnitude of the radius change would depend on the original radius of the notch and the maximum stress produced in the notch. The test indicated that the change in the radius of the notch was very small, and in this case the effect of the radius change on the life of the specimen was negligable.

CHAPTER VI

CONCLUSIONS

Three contributing factors which cause the index of notch sensitivity to change as the fatigue limit changes are local yielding, cold working, and change in geometry of the notch.

Local yielding has a greater effect on this change than cold working or geometry change. The amount of yielding depends upon the amount by which the maximum stress exceeds the elastic limit. This indicates the reason for a low index of notch sensitivity at high fatigue limits. As the fatigue limit is decreased local yielding becomes less severe; therefore, the index of notch sensitivity is larger at lower fatigue limits.

Another factor contributing to the low index of notch sensitivity at high fatigue limits is cold working. This cold working is a result of stress cycling in the plastic region. This cycling increased the hardness of the material which lowered the index of notch sensitivity.

The change in notch radius could not be detected after the specimen was subjected to a maximum nominal fluctuating stress of 60,000 psi. It is believed, however, there was a minute change in radius. The contribution this change in geometry makes toward varying the index of notch sensitivity is negligable.

These factors should be considered by the designer of mechanisms which are to endure through a given number of stress cycles. Material cost and weight can be reduced by checking closely the index of notch sensitivity of the member at different fatigue limits.

It should be recognized that only a limited number of tests were made and that additional tests of this material are needed. The values of q obtained from these tests are applicable only for the material, notch geometry, and type of loading used in these tests.

SELECTED BIBLIOGRAPHY

1. Neuber, Heinz, Theory of Notch Stresses, Edwards, 1946.

2. Greenwood, J. N., The Failure of Metals by Fatigue, Melbourne University Press, 1946.

3. Committee E9, ASTM Manual on Fatigue Testing, American Society for Testing Materials, 1949.

4. Maleev, V. L. and Hartman, J. B., Machine Design, International Textbook Company, 1954.

5. Sissco, F. T., Modern Metallurgy for Engineers, Pitman, 1948.

6. Cornelius, H. and Bollenrath, F., Archiv. f. das Eisenhuttenwesen, 1940.

APPENDIX

CALIBRATION

To calibrate the strain measuring system, a plain two inch gage length tensile specimen was used on which was attached a dial strain instrument and a SR-4 strain gage identical to one cemented in the notch of the notched specimen. The wheatstone bridge was balanced before the static load was applied. As the specimen was statically stressed, the dial strain instrument was read along with the peak to peak deflection of the oscilloscope curve. The calibration curve obtained from this operation is shown in Figure 9.

The relation between the amplitude of the oscilloscope curve and the strain was linear within the range that the oscilloscope was used. After a few points were established on the calibration curve, the general equation of a straight line was applied to obtain the relation between the amplitude and strain. The equation of the calibration curve shown in Figure 9 is derived below.

$$\epsilon - \epsilon_1 = m(d - d_1)$$

$$(\epsilon - 0.0025) = (0.0025/9.5)\ (d - 10)$$

$$\epsilon = (0.0025/9.5)\ d - (0.0025/9.5)\ 10 + 0.0025$$

$$\epsilon = (0.000263)\ d - 0.00263 + 0.0025$$

(a) $$\epsilon = (0.000263)\ d - 0.00013$$

where

ϵ = strain

ϵ_1 = strain at point one

m = slope of strain-deflection curve

d = deflection

d_1 = deflection at point one

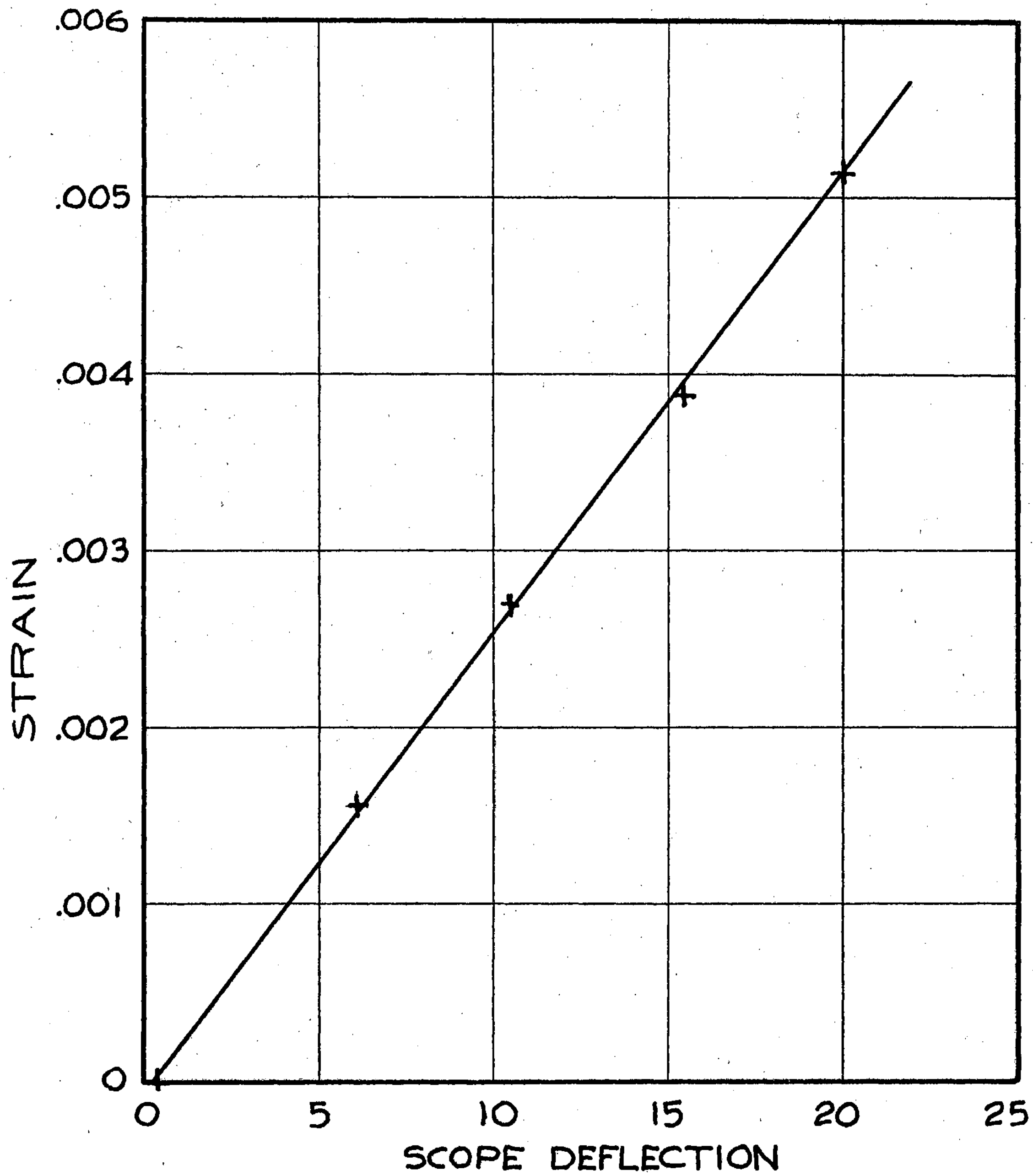


Figure 9.

Calibration Curve of the Strain Measuring System

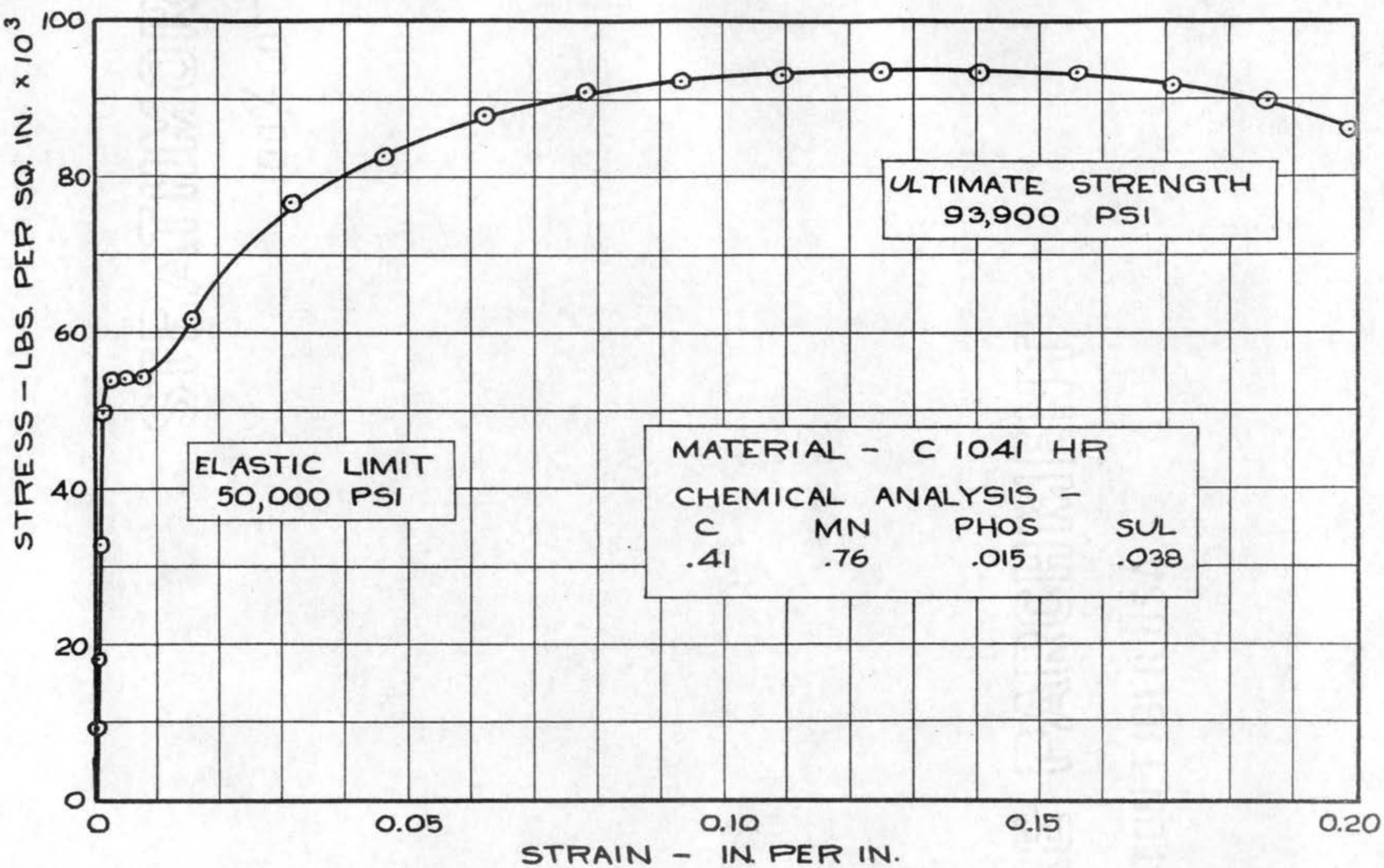


Figure 10. Stress-Strain Diagram of C 1041 Hot Rolled Steel

METHOD OF OBTAINING THE THEORETICAL STRESS CONCENTRATION FACTOR

For the notch shown in Figure 2, Neuber in his nomograph gives a theoretical stress concentration factor, K_t, of 1.78. The following calculations were used and applied to the special form of Neuber's nomograph as reproduced and shown in Figure 11 to obtain the theoretical stress concentration factor.

$$t = 3/32 \text{ inch}$$

$$a = 5/32 \text{ inch}$$

$$r = 1/16 \text{ inch}$$

substituting $\sqrt{t/r} = \sqrt{(3)(32)/(32)(2)} = \sqrt{1.5}$

$$\sqrt{t/r} = 1.224$$

also $\sqrt{a/r} = \sqrt{(5)(32)/(32)(2)} = \sqrt{2.5}$

$$\sqrt{a/r} = 1.58$$

where * t = depth of notch

a = one half the diameter of the specimen at the root of the notch

r = radius of notch

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* see Figure 11

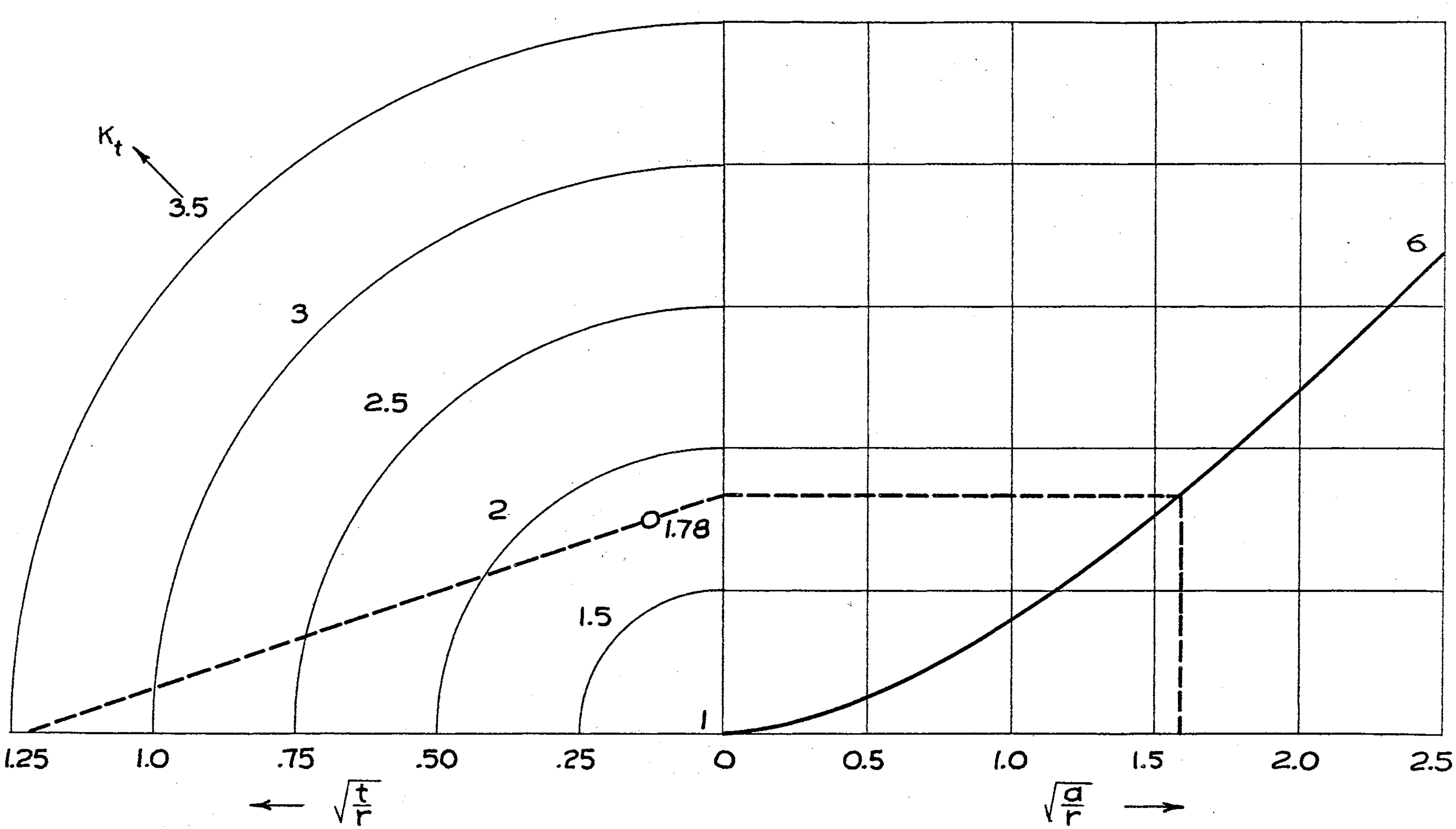

Figure 11. Nomograph for the Determination of the Theoretical Stress Concentration Factor

VITA

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