EFFECT OF PLACING SECOND STRESS RAISING NOTCHES IN THE FIELD OF INFLUENCE OF EXISTING GROOVE

by

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A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1969

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NOMENCLATURE

h = thickness of model in inches.

w = width of model in inches.

R = radius of groove in inches.

r = radius of notch in inches.

θ = angle of orientation of notch.

x = distance from center line to the fringe.

ℓ = distance from center line to the root of the groove.

P = applied load (dial reading in pounds).

N = fringe order.

M = bending moment in in./lbs.

Z = modulus of section in cubic inches.

$\sigma_{nom.}$ = nominal stress in psi.

$\sigma_{max.}$ = maximum stress in psi.

f_{σ} = material fringe value in psi/in./fringe.

K = stress concentration factor for groove alone.

K_{sup} = stress concentration factor with notches superposed.

INTRODUCTION

The effect of a single discontinuity, such as a fillet, a hole, a notch, ..., etc., in a stressed member is the rise of stress in its region. Strength reduction factors are well known in such cases. Strength of a member can further decrease if two stress raisers are superimposed one on the other. Some investigations have been conducted to study this effect of superposition of stress raisers, however, an exact relation has not been established. In some cases the product of the separate stress concentrations was found to be a good approximation for the net effect, while in other cases the product may be higher or less than the resultant stress concentration factor. All of these tests were based on the existence of the second stress raiser at the location of maximum influence of the first one.

This report is concerned with the study of the effect on adding a second semi-circular notch, and its size, on the stress concentration factor of an existing shallow groove. The difference here is that the location of the second notch is not at the point of maximum stress on the groove surface.

Due to the fact that stress concentration factors are higher in tension than in bending for the same model, tests were carried out here in both types of loading.

Photo-elastic techniques were used to obtain the required information.

PREVIOUS WORK ON SUPERPOSITION OF STRESS CONCENTRATION FACTORS

A. J. Durelli, R. L. Lake, and E. Phillips (1)*, studied the stress concentrations produced by multiple semi-circular notches placed on both edges of a plate under uni-axial state of stress. They used photo-elastic techniques to arrive at the conclusion that the stress concentration factor decreases by adding more notches of the same geometry. Notches were not superposed on each other, but they were close enough to influence each other.

A. Q. Mowbray (2), found that the stress concentration factor of the combined effect of a semi-circular groove on a fillet ranged from 0.79 to 0.89 times the product of theoretical factors for the groove and fillet alone. He obtained these results by using electric resistance strain gages for his measurements.

A. Astumi (3), in 1955, used numerical analysis to find the stress distribution in the case of a strip under tension containing two equal circular holes placed longitudinally. He concluded that the stress concentration factor for two holes is smaller than the case of single holes; and, as the two holes come closer to each other, the value of stress concentration factor decreases. When the distance between holes was large enough such that there was no interaction between them, the stress concentration factor

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*Refers to References

was 3.0. As the holes were placed closer together, the stress concentration factor decreased. At a distance between holes equal to the width of the strip, and for the ratio of the hole radius to this distance of 0.3, the stress concentration factor was 2.1.

In 1954 Astumi (4) studied theoretically the stress concentrations in a strip under tension containing two pairs of semi-circular notches placed symmetrically on the edges. He found that the value of stress concentration factors for the case he treated was less than that for the case of two semi-circular notches of the same radius. His results were in close agreement with the experimental results of Durelli and others.

Frank W. Paul and T. R. Fraucett (5), concluded that the multiplication rule for stress concentration factors of notch and groove is very close to the resultant stress concentration factor when the notch is located on the groove at the point of maximum stress. Their work was with specimen in bending.

Vittorio Vicentini (6), proposed a solution for the plane problem of two circular notches of different radii superposed at the edge of a strip. The proposed equation is based on some assumptions suggested formerly by Mowbray and others that are valid in particular cases of superposition. The solution is based upon Neuber's equations for deep and shallow notches. Theoretical values of stress concentration factors compared favorably with experimental results obtained from strain gages and photoelasticity in a series of tests he carried out. He concluded that the resulting stress concentration factor of superposed notches is lower than the product of the two single stress concentration factors.

This difference increases as the ratio of the notch radii decreases.

H. T. Gencsoy, and H. F. Hamilton (7), made some tests on the overlapping stress fields due to various combinations and orientations of holes and semi-circular grooves. The results of their investigation indicated that the sizes and relative positions of discontinuities had a substantial effect on the resultant stress concentration factor. Cases like the addition of notches on the surface beside the existing notches decreases stress concentration factor while the addition of a notch on the surface of a fillet or at the point of maximum stress of a groove increases stress concentration factor. They found the product of individual stress concentration factors in the case of superposing a notch on a fillet ranged from 16.3 to 10.2 percent higher than the resultant stress concentration factor. This compares favorably with Mowbray's (2) strain gage analysis for similar geometric configurations on steel plates under tension. They agreed with Paul and Faucett (5) to consider the product equal to the resultant stress concentration factor in case of notch superposed on shallow groove. They used this conclusion to extrapolate their experimental results.

EXPERIMENTAL PROCEDURE

Model Preparation

All models were cut from 10 inch x 10 inch x 0.25 inch-thick sheet of Epoxy (PSM-5). This material was chosen because of its high modulus of elasticity, high sensitivity, good machinability and very low creep and time edge effect. To prepare a model of the configuration shown in Figure 1, the holes were drilled first using a templet to locate their relative positions. Second, the specimen was cut to approximate size by sawing. Finally, the exact size was obtained by using another templet for the boundaries of the model with the grooves only. This finishing operation was done by using a very high speed router.

The model obtained was examined in the polariscope under no load and it showed no serious residual or time edge effects. A correction factor was used to take care of these effects when necessary instead of annealing the parts.

Calibration

Two calibration models were cut from each plate, one for calibration in bending and the other for tension. Both models were loaded to determine the fringe constant of the material used. Although this constant should be independent of loading conditions, a slight deviation between the two was observed. The loading

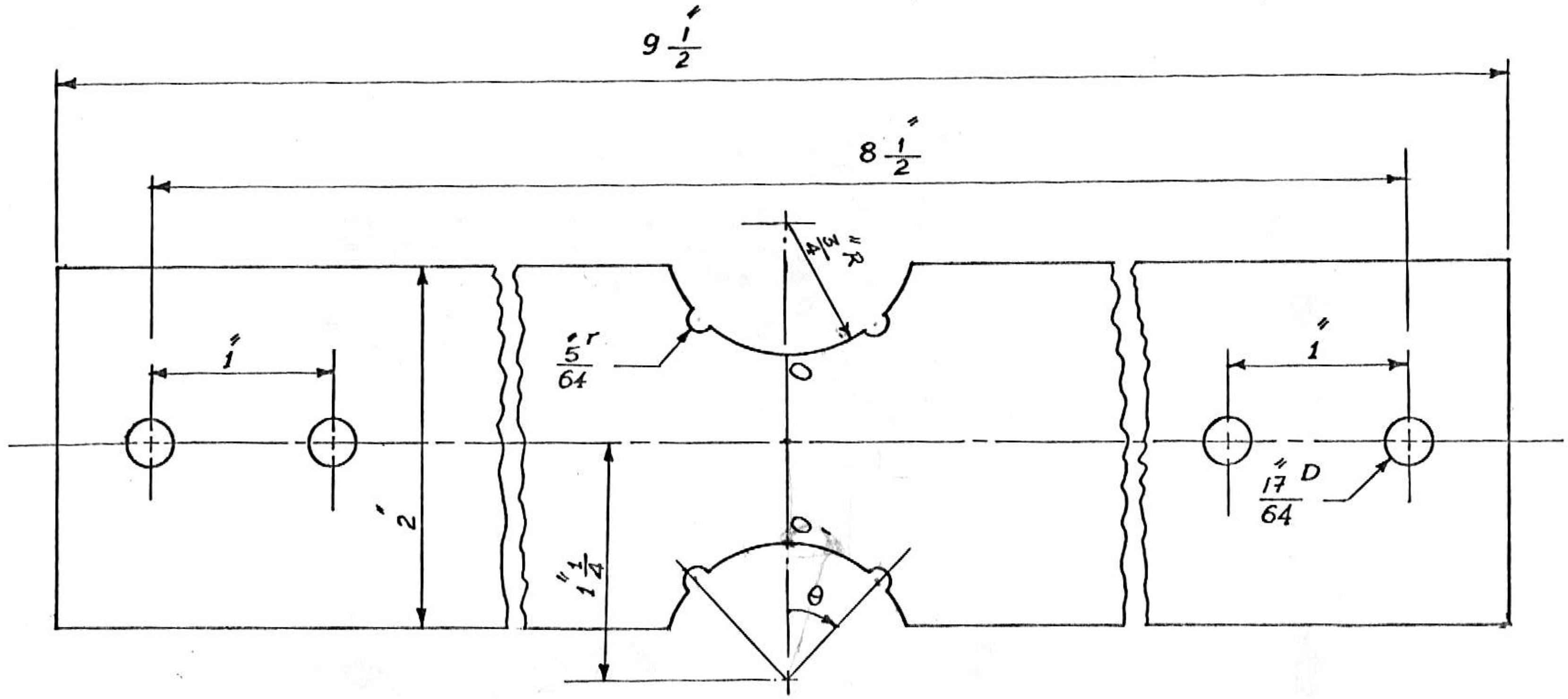


Fig. 1 Testing Model

Scale 1:1

Dimension in inches

conditions were the same for calibration tests and the test specimens, so that the constant obtained in bending was used for bending and the one for tension with tension tests. Appendix I gives the details of both calibration tests. The results obtained for f_σ with mercury green monochromatic light were:

For bending, f_σ = 61.7 psi/in./fringe, and

for tension, f_σ = 58.9 psi/in./fringe.

Testing

A fringe pattern was obtained by mounting the test specimen in the loading frame according to the required case of loading. The specimen was placed in the polariscope field which was oriented to give either a dark or a light field. The polariscope with the loading frame is shown in Figure 2.

Six models were made, one with the large groove only, the other five contain four semi-circular notches symmetrically placed on the surface of the groove. These five models had five sizes of notches (4/64, 5/64, 6/64, 7/64, and 8/64 inch radii). The angle θ was kept the same in the five models.

Bending Tests

The load was gradually applied until a reasonable number of fringes were obtained. A fringe photograph was taken immediately to minimize the effect of creep. Typical photographs are shown on page 9.

To get the maximum stress at points 0 and $\grave{0}$, the fringe order was plotted against the nondimensional distance (x/ℓ) from the

Order No. 9350 (4/22/1969)

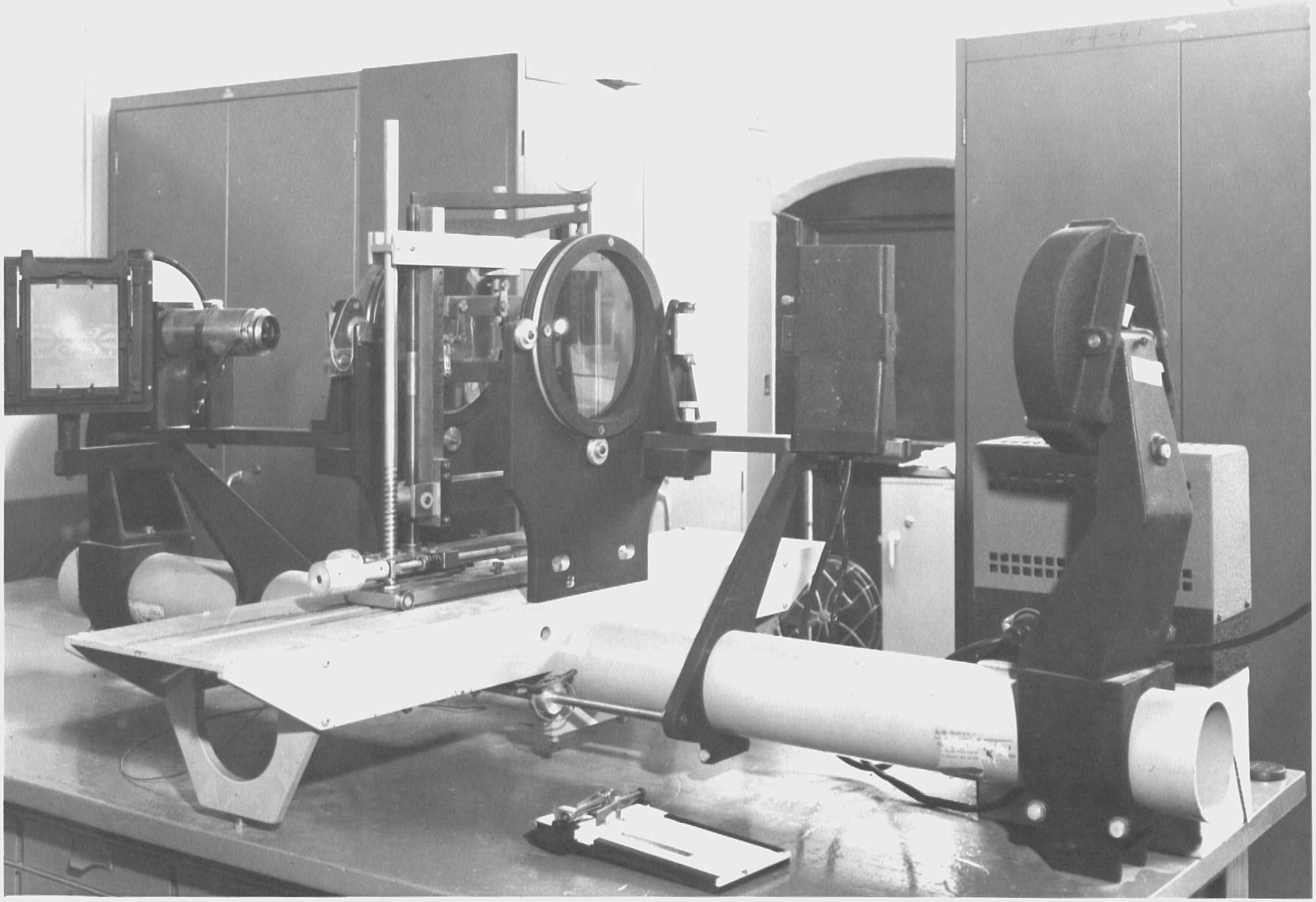
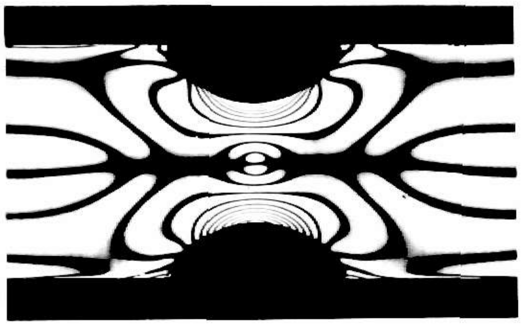
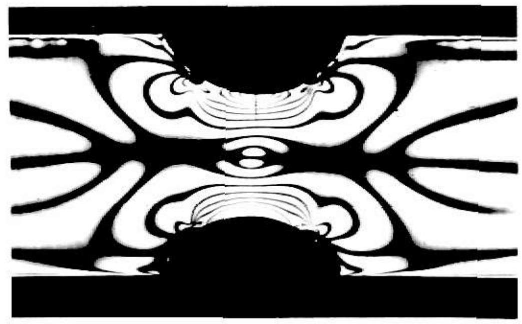


Figure 2. Circular Polariscope with the Test Specimen Loaded in Bending

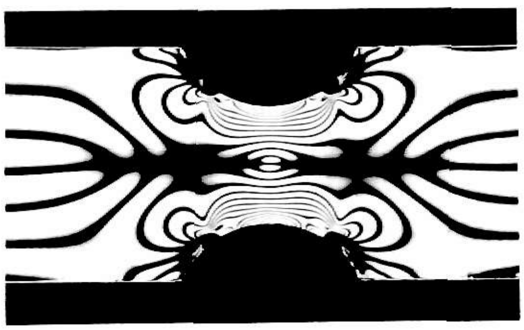
Order No. D-5692



(a) No Notches, Load 15.6 Divisions

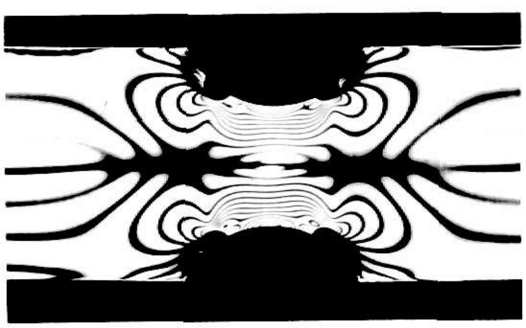


(b) 4/64 inch radius Semi-circular Notches, Load 15 Divisions

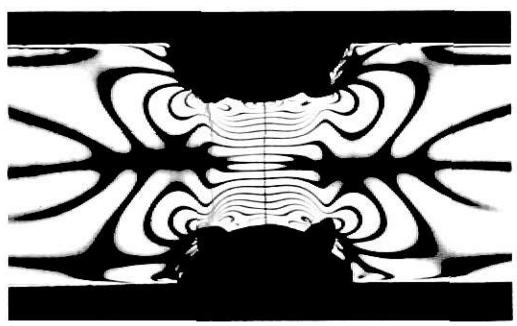


(c) 5/64 inch radius Notches, Load 20 Divisions

(d) 6/64 inch radius Notches, Load 15 Divisions



(e) 7/64 inch radius Notches, Load 21.4 Divisions



(f) 8/64 inch radius Notches, Load 15 Divisions

Figure 3. Fringe Patterns for Specimen Loaded in Bending

centerline of the specimen. Extrapolating the resulting curves to the boundary determined the fringe order at these points. Calculations for a particular case are given in Appendix II.

Tension Tests

The two photographs shown in Figure 4 are just for illustration of the fringe pattern in the case of tension. These photographs cannot be used for quantitative results as in the bending photographs because fringes do not accumulate on line $0\acute{0}$. They move toward the center, then start to form a loop and depart from the central portion. Another technique was used to calculate the stress concentration factor to get more accurate results (see Appendix II).

It was noticed that due to time edge effects the fringes started not from the boundaries at 0 and $\acute{0}$, but they started at points 88 percent of the distance from the centerline to the edge. A correction factor of (1/0.88) was used to get the stress concentration factor at the boundaries. The validity of this correction factor was checked experimentally and will be discussed later.

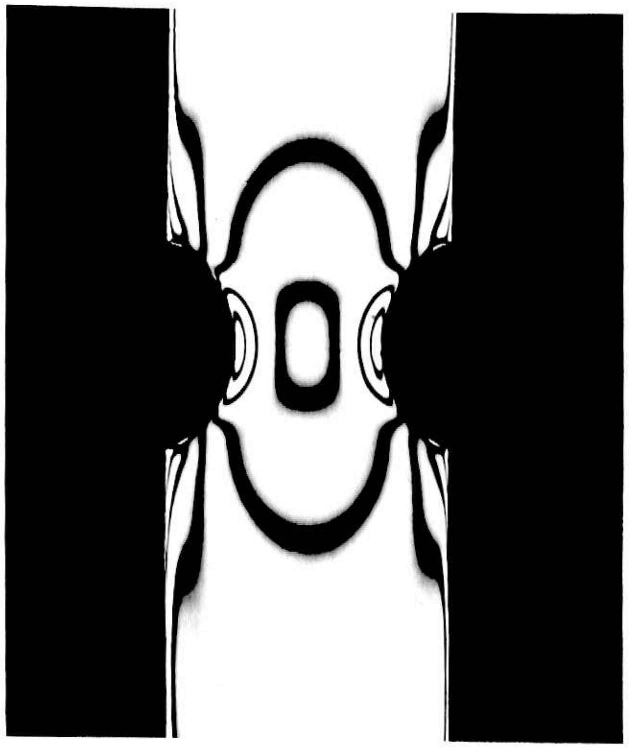
A sample of detailed calculations of one case is given in Appendix II.

Calculation of Stress Concentration Factor

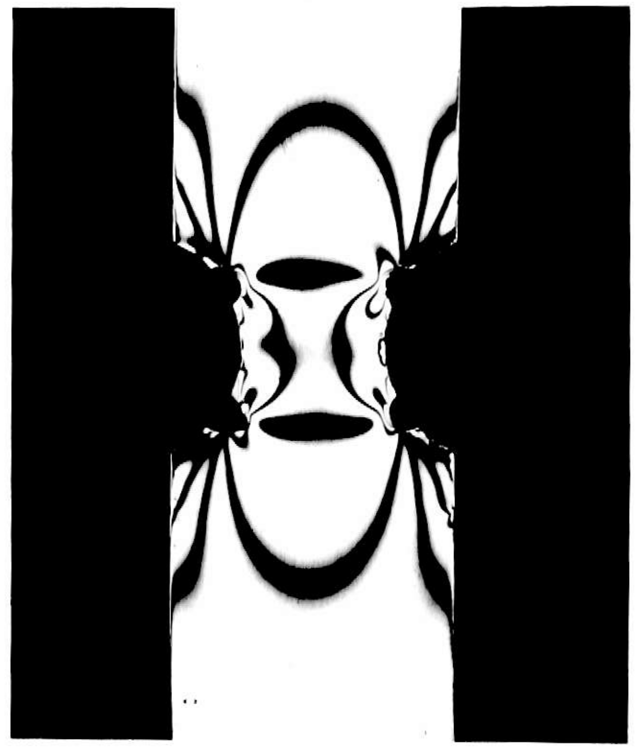
$$K = \frac{\sigma_{max.}}{\sigma_{nom.}}$$

$$\sigma_{max.} = \frac{Nf_{\sigma}}{h}$$

Order No. D-5692



(a) No Notches, Load 22 Divisions, Tension



(b) 8/64 radius Notches, Load 22 Divisions, Tension

Figure 4. Fringe Patterns for Specimen Loaded in Tension

$$\sigma_{nom.} = \frac{P}{wh} \text{ for tension}$$

$$= \frac{M}{Z} \text{ for bending}$$

where w and Z apply to the net section.

EXPERIMENTAL RESULTS

As mentioned before, the photographs of Figure 3 were used to obtain results in bending. Photographs of Figure 4 are fringe patterns in tension.

The following table gives results of both tension and bending tests. These results are plotted in Figure 5.

TABLE 1

Effect of Secondary Notch Size on Stresses at 0 and $\dot{0}$

$\frac{r}{R}$	Stress Concentration Factor		K_{sup}/K	
	Bending	Tension	Bending	Tension
0.0	1.174	1.295	1.0	1.0
0.0833	1.24	1.33	1.055	1.05
0.1042	1.175	1.30	1.001	1.005
0.125	1.125	1.255	0.96	0.97
0.1457	1.09	1.238	0.928	0.954
0.1667	1.073	1.188	0.913	0.916

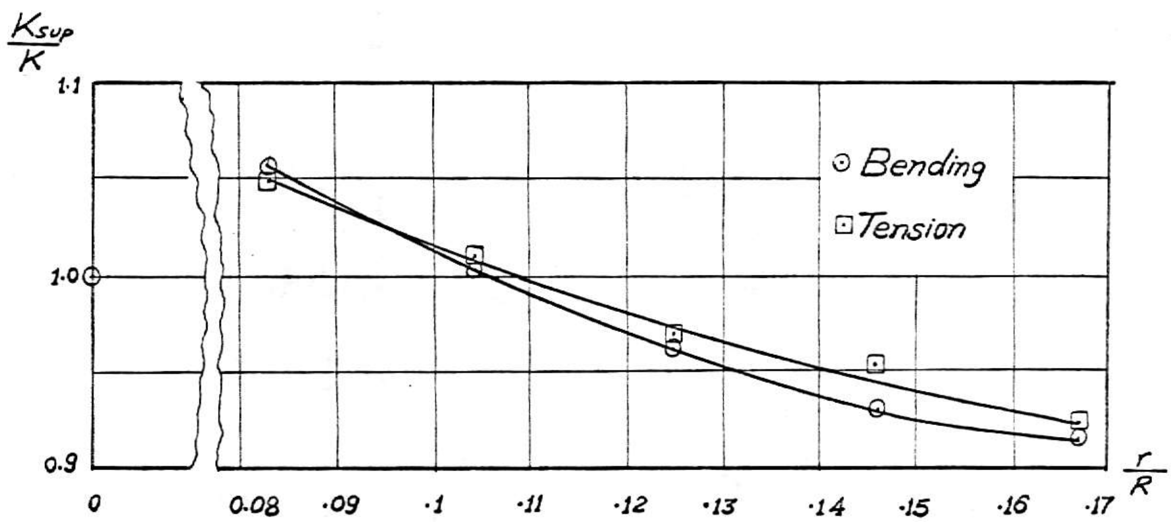


Fig. 5 Effect of Secondary Notch Size on Stress Concentration Factor at O and O′

DISCUSSION OF RESULTS

Values of stress concentration factors for the groove without notches compared favorably with Frocht's studies (8) of similar cases.

The time edge effect was clear in tension tests and the validity of the correction factor which depends on assuming a linear relation between fringe location and load was checked experimentally. This was checked by recording the load at a certain location of a fringe. When the load is increased gradually, the fringes start to move from the sides to the center. This distance traveled was proportional to the change of load confirming the linear relation.

The addition of a small notch on the groove increased the stress at the point of maximum influence of the large groove – 0 . In this study, the maximum stress observed was for the smallest notch used. The stress decreased as the notch size was increased becoming less than for the groove without notch. Referring to Figure 5, the effect of secondary notches on the stress concentration factor at 0 is less in tension than in bending up to r/R about 0.095, then this is reversed. Up to r/R equals to 0.105 in bending and 0.109 in tension, stress concentration factor at 0 was higher than for the case of the groove alone. Beyond these ratios, the stress concentration factor at 0 decreased below that for the groove alone.

It appears that if smaller notches were checked, the stress would increase up to some limit. Beyond this point it would decrease at some size and not influence the stress at point 0.

The above conclusion can be interpreted by drawing a pattern of force lines which is analogous to stream lines in hydraulic flow. The existence of the groove causes distortion of these lines and they become more crowded at the root of the groove; this is an indication of higher stresses at this location giving rise to a higher stress concentration factor more than unity. The addition of small notches adds more distortion to these lines in the area of the root of the groove giving rise to higher stress concentration factors. As notches become larger, flow lines start to distort away from the area of discontinuity and become more uniformly distributed at the area of study, resulting in a lower stress concentration factor.

For further work in this area, it is recommended to study:

(1) Complete the study of the effect of notch size on stress concentration factor at 0 for smaller notches (with r/R less than 0.0833).

(2) The effect of orientation of the notch (angle θ) on the stress concentration factor at 0.

(3) The effect of a number of these secondary notches on stress concentration factor at 0.

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(4) ______________, "Stress Concentrations in a Strip Under Tension and Containing Two Pairs of Semi-circular Notches Placed on the Edges Symmetrically," Trans. ASME, 1957, Vol. 79, pp. 565-573.

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(10) Lipson and Juvinal, Handbook of Stress and Strength, 1st printing, Macmillan Company, 1963, Chapter 6.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. John C. Lindholm, major professor, for his advice, valuable suggestions and helpful criticisms.

Thanks are due to Professor Frank J. McCormick for his cooperation and help during the experimental work.

APPENDIX I

Calibration Tests

Two calibration tests were carried out to determine the material fringe value of PSM-5 photo-elastic material used.

Bending Calibration Test

The specimen dimensions and load application are shown in Figure 6. The fringe pattern was a series of straight lines parallel to the neutral axis. A photograph was taken at a certain load and the fringe order was plotted against (x/ℓ). The resulting line in Figure 7 was extrapolated to get the fringe order at the boundary. From the fringe order obtained and existing load, f_σ was determined.

The following table shows the variation of fringe order N with the dimensionless distance (x/ℓ) from the neutral axis on both sides.

TABLE 2

Fringe Order Values, Calibration Model in Bending

N	x/ℓ Tension Side	x/ℓ Compression Side
1	.168	.178
2	.342	.355
3	.532	.538
4	.716	.726
5	.925	.913

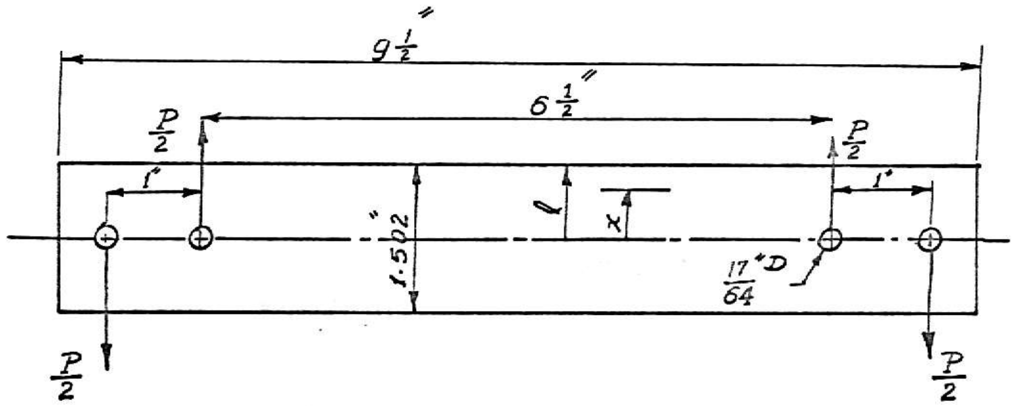

Fig. 6 Bending Calibration Model

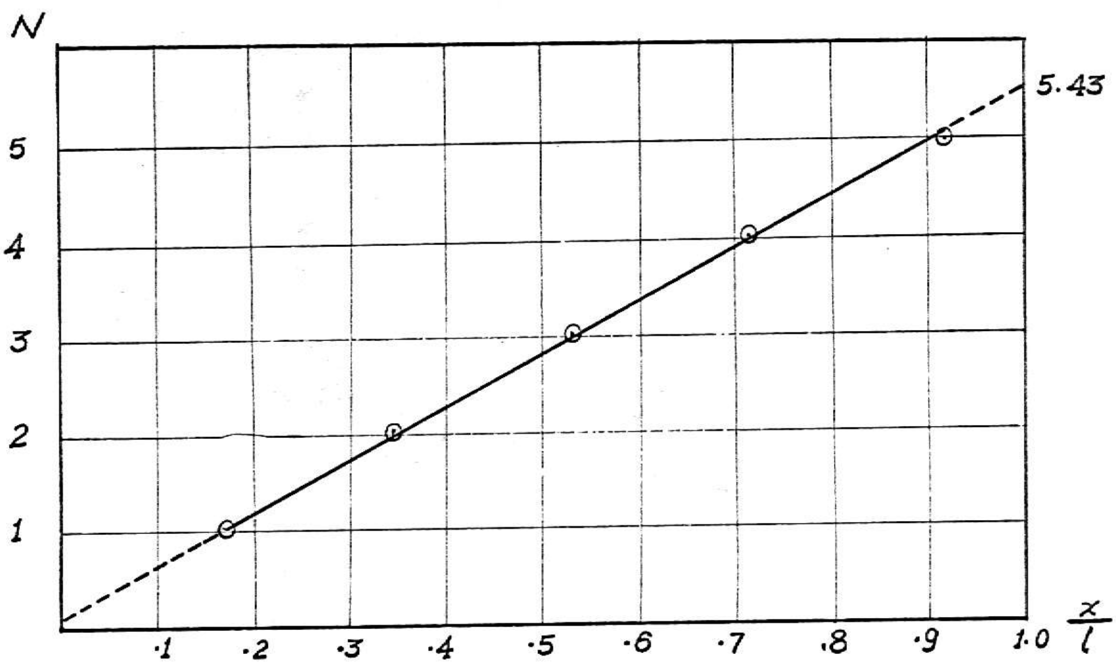

Fig. 7 Variation of Fringe Order with the Distance from the Centerline of the Calibration Model

N was plotted against the average value x/ℓ as shown in Figure 7 and extrapolated to the boundary.

Applied load = 20 divisions

= 20 div. x 12.62 lbs./div.

= 252.4 lbs.

$$M = \frac{252.4 \text{ lbs.}}{2} \times 1 \text{ in.}$$

$$= 126.2 \text{ in.lb.}$$

$$Z = \frac{hw^2}{6}$$

$$= \frac{0.248 \text{ in. } (1.502 \text{ in.})^2}{6}$$

$$= 0.0933 \text{ in.}^3$$

$$\sigma = \frac{M}{Z}$$

$$= \frac{126.2 \text{ lbs.in.}}{0.0933 \text{ in.}^3}$$

$$= 1354 \text{ psi.}$$

From Figure 7

$$N = 5.43$$

$$\sigma_{max.} - \sigma_{min.} = \frac{Nf_\sigma}{h}$$

$\sigma_{min.} = 0$ at boundaries, and $\sigma_{max.} = \sigma$

$$1354 \text{ psi} = \frac{5.43 \text{ fringes } f_\sigma}{0.248 \text{ in.}}$$

From which,

$$f_\sigma = 61.7 \text{ psi./in./fringe}$$

Tension Calibration Test

The model shape is shown in Figure 8. The load and fringe order was recorded at instant of the start of the fringe at the boundary. The following table is a record of P/w against N. Plotting this relation, the slope of the resulting line represents f_σ.

TABLE 3

Load-Fringe Order, Calibration Model in Tension

N	Dial Reading	$\frac{P}{w} = \frac{\text{Dial Reading x 12.62}}{0.274}$
0.5	0.45	20.8
1.0	0.90	41.5
1.5	1.7	83
2.0	2.3	106
2.5	3	138.5
3.0	3.6	166
3.5	4.3	198
4.0	5	231
4.5	5.6	258
5.0	6.2	286
5.5	6.8	314
6.0	7.5	346

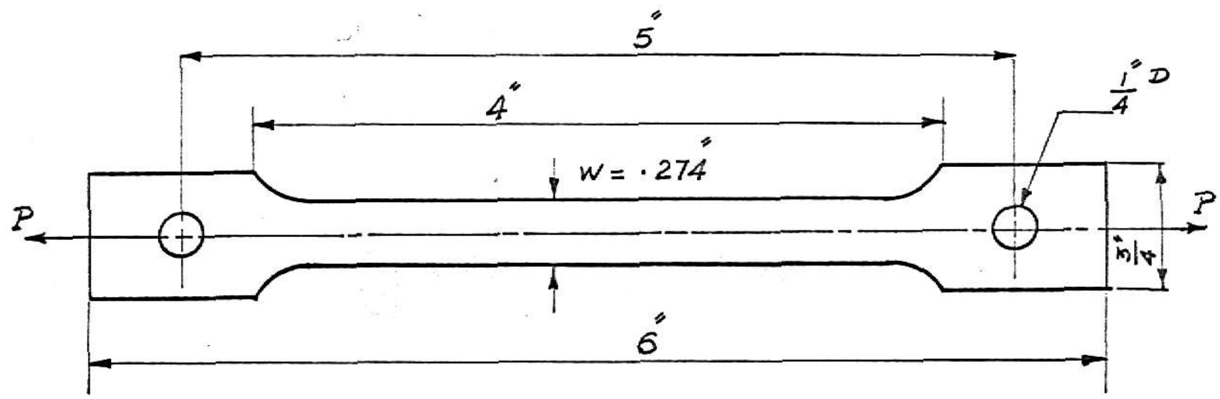

Fig.8 Tension Calibration Model

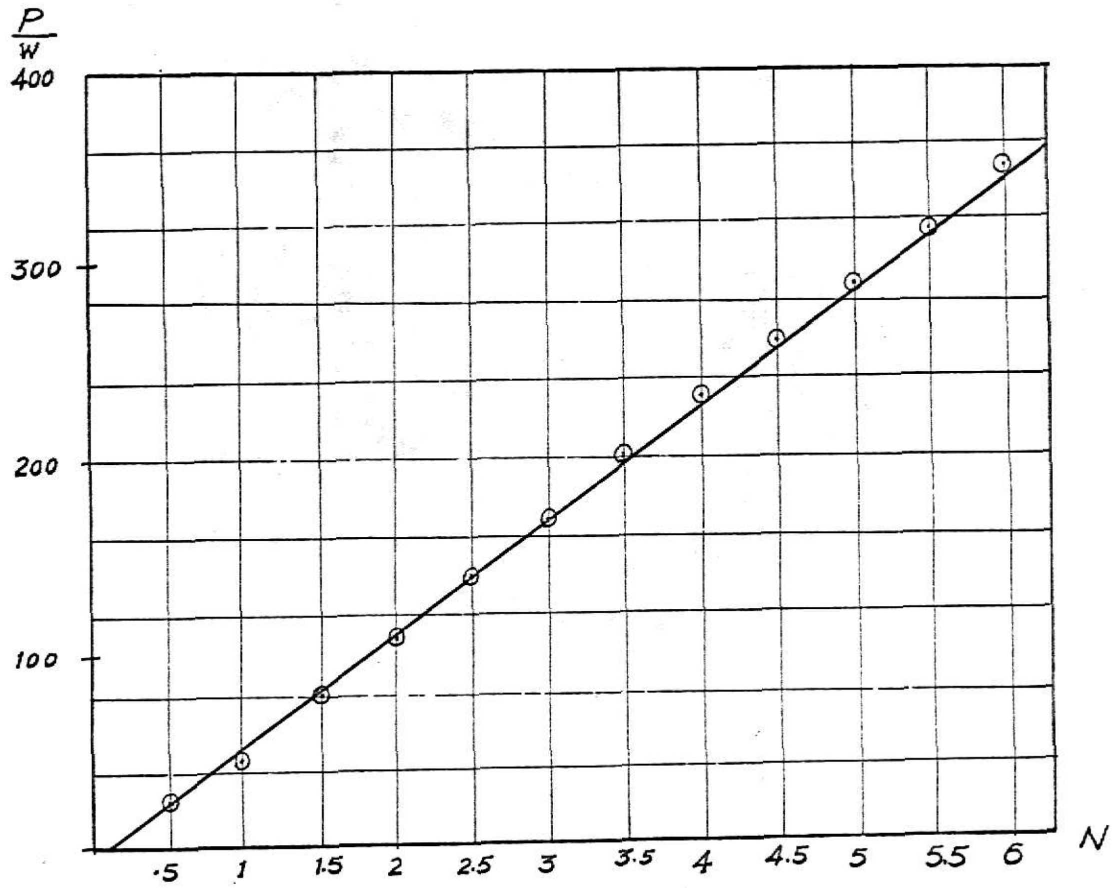

Fig. 9 Calibration Curve in Tension

$$\sigma = \frac{P}{A} = \frac{P}{wh}$$

$$\sigma_1 - \sigma_2 = \frac{Nf_\sigma}{h}$$

But $\sigma_1 = \sigma$, $\sigma_2 = 0$

$$\therefore \frac{P}{wh} = \frac{Nf_\sigma}{h}$$

Or $f_\sigma = \frac{(P/w)}{N}$ = slope of the straight line in Figure 9

= 58.9 psi./in./fringe.

APPENDIX II

Sample Calculations

The following are examples of how to determine the value of the stress concentration factor in bending and tension. The results are for a secondary notch of radius 7/64 inch.

Bending

The following table shows fringe order at different distances from the neutral axis obtained from Figure 3 (e). In Figure 10 this data is plotted and extrapolated to the boundary to get the maximum fringe order.

TABLE 4

Fringe Order Values, Bending Test

N	x/ℓ	
	Tension Side	Compression Side
0	.019	--
1	.145	.106
2	.241	.217
3	.342	.328
4	.443	.434
5	.53	.53
6	.612	.617
7	.68	.685
8	.738	.752
9	.79	.8
10	.838	.848
11	.867	.886
12	.905	.925
13	.93	.963

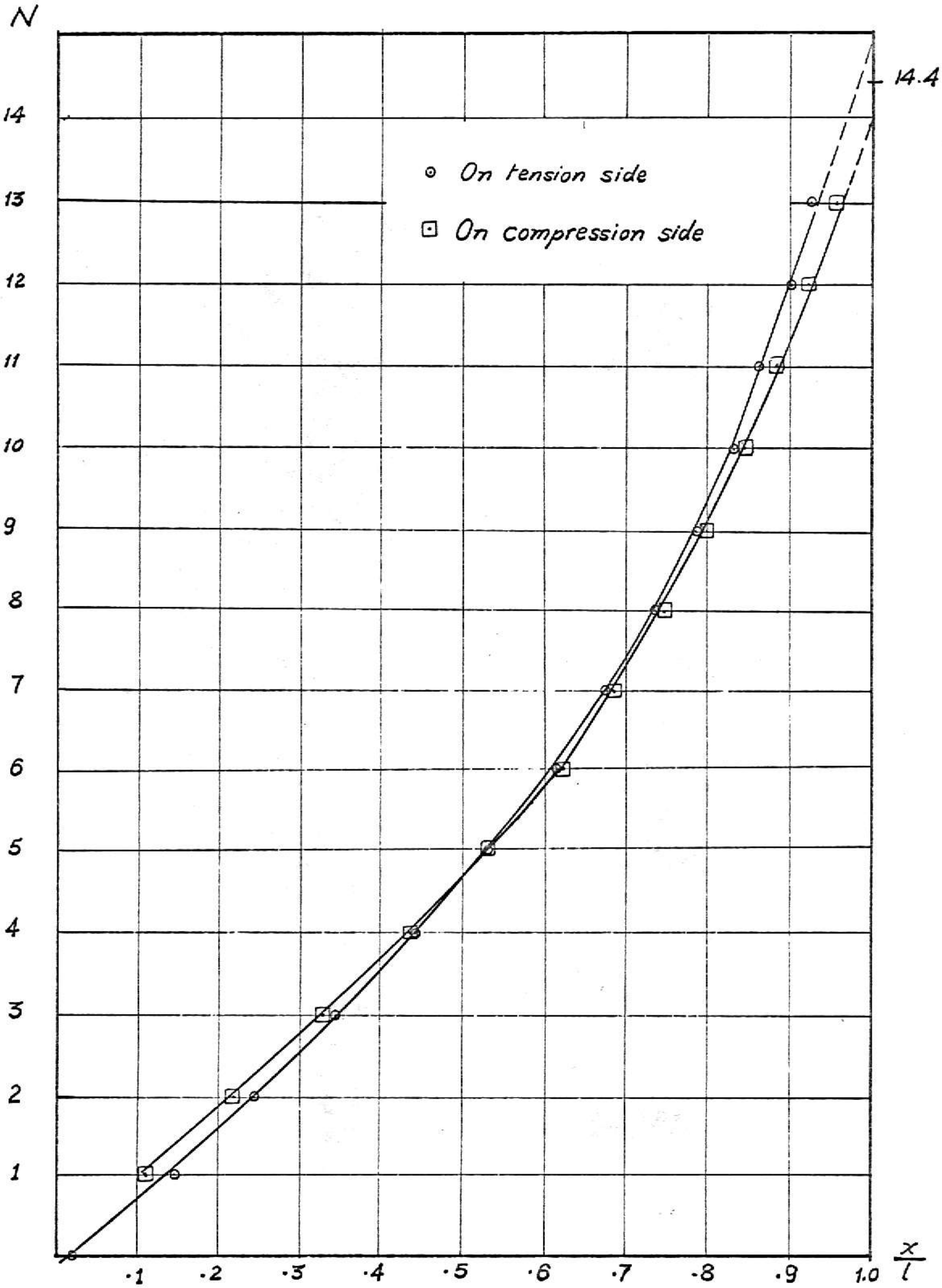

Fig. 10 Variation of N with x/l in Bending test

From Figure 10, the average value of N at the boundary equals to 14.4 fringe.

Load - 21.4 division of dial

$$P = 21.4 \text{ div.} \times 12.62 \text{ lb./div.}$$

$$= 270 \text{ lbs.}$$

$$M = \frac{270 \text{ lb.}}{2} \times 1 \text{ in.}$$

$$= 135 \text{ in. lb.}$$

$$Z = \frac{(0.248 \text{ in.}) \times 1 \text{ in.}^2.}{6}$$

$$= 0.0413 \text{ in.}^3$$

$$\sigma_{nom.} = \frac{M}{Z}$$

$$= \frac{135 \text{ lb.in.}}{0.0413 \text{ in.}^3}$$

$$= 3280 \text{ psi}$$

$$\sigma_{max.} = \frac{Nf_\sigma}{h}$$

$$= \frac{14.4 \text{ fringe} \times 61.7 \text{ psi./in./fringe}}{0.248 \text{ in.}}$$

$$= 3590 \text{ psi}$$

$$K_{sup} = \frac{\sigma_{max.}}{\sigma_{nom.}}$$

$$= \frac{3590}{3280}$$

$$= 1.09$$

Tension

The technique used in bending cannot be used in tension tests because the fringes do not accumulate on the line 0-0́.

Therefore, it is necessary to establish a relation between the fringe order and the corresponding load. This relation is as follows:

$$\sigma_{nom.} = \frac{P}{wh}$$

$$= \frac{\text{Dial reading x 12.62 lbs./div}}{\text{1 in x h in.}}$$

$$\sigma_{max.} = \frac{Nf_{\sigma} \text{ psi}}{h}$$

$$= \frac{\text{N x 58.9 psi}}{h}$$

$$K_{sup.} = \frac{\sigma_{max.}}{\sigma_{nom.}}$$

$$= \frac{N}{\text{Dial reading}} \frac{58.9}{12.62}$$

$$= 4.67 \frac{N}{\text{Dial reading}}$$

From this relation, if any value of fringe order and the corresponding dial reading at its start from the boundaries is known, K_{sup} can be obtained by direct substitution in the last equation. For more accurate value of K_{sup}, record the dial reading at the start of each fringe on both sides of the specimen. Plotting N versus the dial reading, a straight line relation is obtained. Substituting the slope of this line for (N/dial reading) in the last equation, a better value for K_{sup} should be obtained. This value corresponds to the point at which the fringe starts. As mentioned before, a correction factor of (1/0.88) will give K_{sup} at point 0.

The following table gives the dial readings at the start of each fringe on both sides of the specimen and the average value.

TABLE 5

Fringe Order-Load, Tension Test

N	Dial Readings		
	On One Side	Opposite Side	Average
1.0	2.5	2.2	2.35
1.5	4.6	4.3	4.45
2.0	6.9	6.4	6.65
2.5	9.1	8.4	8.7
3.0	11.4	10.6	11.0
3.5	13.5	12.4	12.95
4.0	15.6	14.6	15.1
4.5	17.9	16.7	17.3
5.0	20.1	18.8	19.4
5.5	22.1	20.7	21.4
6.0	24.4	22.8	23.6

From Figure 11,

slope = 0.233

$$\therefore K_{sup} = \frac{4.67}{0.88}(0.233)$$

$$= 1.238$$

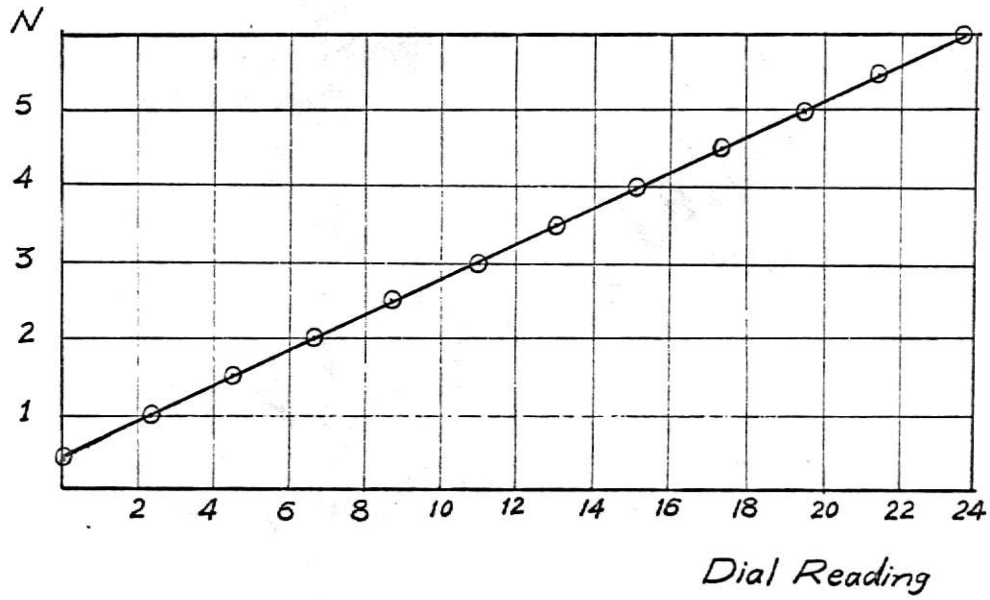

Fig. 11 Variation of N with Dial Reading in Tension Test

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

Kansas State University
Manhattan, Kansas

1969

Standard photo-elastic techniques were used to study the effect of superimposing small semi-circular notches on a shallow groove at a certain location other than the point of maximum stress on the groove surface. Observations were made at the root of the groove for different sizes of notches.

This report is concerned with testing experimentally the effect of changing the ratio of notch radius to the radius of the groove. In each run four equal notches were symmetrically superimposed on the groove surface and tests were carried out in tension and bending. Epoxy material (PSM-5) was used for preparing models because of its good photo-elastic properties. Results of tension and bending showed close agreement.

As concluded from this investigation, the addition of small notches adds more stresses at the root of the large groove up to ratios of radii (notch radius to groove radius) of 0.105 in bending and 0.109 in tension. Notches of radii larger than these ratios cause a better uniformity in stress distribution in the considered sections which means less stress concentration factor than in their absence.

A description of the testing technique and the experimental set up used is given. A sample of how to obtain the existing results are also shown.