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FOREWORD

This report was prepared by the National Bureau of Standards under Air Force Order No. AF(33-657)62-362. The contract was initiated under Project No. 7381, "Materials Application", Task No. 738103, "Data Collection and Correlation." The work was administered under the direction of the AF Materials Laboratory Research and Technology Division, with Mr. R. E. Wittman as project officer.

This report covers work conducted from January 1963 to December 1963.

The mechanical testing was performed in the Glass Section under Mr. C. H. Hahner, the Section Chief. The statistical analysis was made by J. M. Cameron of the Statistical Engineering Section.

ABSTRACT

In order to establish realistic design criteria applicable to selected oxide glasses having utility as viewing windows in Air Force vehicles, certain physical properties have been determined throughout the useful temperature range of these glasses.

Temperatures below which no creep was detected for annealed specimens at stresses of 33 per cent of the average modulus of rupture are reported for five of the glasses in the program.

The relationship of the area under stress to the strength for annealed plate specimens was investigated. It was found that: 1) Fracture originates randomly throughout the area of uniform stress. 2) The strength decreases as the area under maximum stress increases. 3) Specimens that fracture at the edge are generally weaker than those that fracture on the surface.

This report has been reviewed and is approved.

W. P. CONRARDY
Chief, Materials Engineering Branch
Applications Division
AF Materials Laboratory

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INTRODUCTION

The high speeds of modern aircraft and the resulting high operating temperatures create problems in finding a material for aircraft enclosures that will withstand high temperatures as well as stresses introduced by thermal gradients and loading. For the proper utilization of glass in these applications, accurate information on properties at elevated temperatures is required.

The program was initiated by the Aeronautical Systems Division with the objectives of: 1) developing test methods for measuring the effect of temperature on the physical properties of glass, and 2) determining the properties of some presently available commercial glasses that appear to be suitable for aircraft glazing. The properties determined were stress-rupture, creep during stress-rupture tests, modulus of rupture, and Young's modulus.

This report contains results, on five of the seven glasses in the program, that show the minimum temperature at which creep occurred at a stress level of 33 per cent of the average modulus of rupture. The results of a study on the effect of area under stress on strength is also presented.

This report is the eighth annual summary report and covers the work completed between 1 January 1963 and 31 December 1963.

Manuscript released by authors December 1963 for publication as a WADC Technical Documentary Report.

CREEP

A study was made to determine, under selected conditions, the temperature at which creep can first be detected, or the temperature below which creep will not occur. Since creep depends on both the amount of applied stress and temperature, many combinations could be conceived to give results under a particular set of conditions. A comprehensive study of the temperature at which creep first occurs under different conditions is beyond the scope of this project, and unless specific problems or applications were considered, may be a relatively meaningless accummulation of data. The work done here is simply a "base" that may be useful to compare other work to, or as a place to start in solving an actual problem.

Five of the seven glasses in the program were used in this study. These glasses were representative of the five different compositional types in the program (soda-lime-silica, borosilicate, aluminosilicate, 96% silica and fused silica). The following conditions were used to determine the temperature at which creep was first observed:

1) Annealed glass only was used.

2) A stress-level of 33% of the average modulus of rupture obtained at 50°C below the strain point was used. This stress-level was chosen since previous work showed no failures occurred at this stress-level when the load was applied for 500 hours.

3) The specimens were tested until they exhibited creep or for 500 hours.

4) Three specimens were tested in each group.

5) Temperature increments of 10°C were used.

6) It is estimated that with the apparatus used creep of the order of 0.00025 inches per hour was detectable.

The results are presented in Table I. This table gives: the glass tested, the applied stress, the strain point temperature, the temperature at which creep was first observed, and the temperature at which no creep was observed.

Table I. Temperatures for Creep and No Creep at 33% Stress

Glass	Applied Stress	Temperature		
		Strain Point	Observed Creep	No Creep in 500 hrs
	psi	°C	°C	°C
CGW 7740	2700	515	340	330
CGW 1723	2595	672	560	550
CGW 7900	2555	820	580	570
CGW 7940	3565	990	720	710
LOF Soda-Lime-Silica	2330	517	370	360

EFFECT OF THE AREA UNDER UNIFORM STRESS ON THE STRENGTH OF FLAT GLASS

Introduction

The ASTM test for determining the strength of flat glass, "Flexure Testing of Glass C 158-43" calls for a specimen 10 inches long by 1½ inches wide and ¼ inch thick. This specimen is supported on knife edges located eight inches apart and loaded with a single knife edge at mid-span.

In recent years there has been an increasing trend away from single point loading called for by ASTM and a substitution of two point loading, an arrangement that produces an area of uniform stress between the loading knife edges. The reason for the use of the two loading knife edges is based on the work of Griffith (1) and follows the thought that the strength of glass is dependent on the flaws in its surface, so a test which places more of the surface under uniform stress will give a better representation of the strength of the glass than a test which places only a small portion of the surface under maximum stress.

Previous work on this project (2) has shown that in strength tests made on a number of samples, the specimens that failed from a fracture originating on the edge were as a group significantly weaker than those that failed from fractures originating on the surface of the specimen.

With the above in mind, a test was designed to investigate: 1) The relationship of the area under uniform stress to the strength of glass, and 2) the comparison of the strengths of specimens fracturing at the edge and on the surface.

Experimental

Specimens were obtained from two different glass producers. These specimens were from production runs of soda-lime-silica plate glass in the annealed condition, approximately $\frac{1}{4}$ inch thick. They were cut by the manufacturer and supplied as laths ready for testing.

ASTM Standard Method C 158-43 was followed, except for variations in the specimen size and loading configurations and the testing of 50 specimens in each group. Specimens were stored at 75°F and 50 per cent relative humidity for a minimum of 48 hours before testing and were then tested under these same conditions. Cellophane tape was applied to the compression surface of the specimens immediately before testing. This was done to hold the fragments together after fracture to facilitate locating the fracture origin. After breaking the specimen, the fracture origin was identified as to whether it lay on the surface or edge of the specimen, and its distance to the supporting knife edge was measured to the nearest 1/8 inch.

The areas under uniform stress, specimen dimensions, and test configurations are shown in Tables II and III. Both glasses were tested in the same manner. All statistical comparisons were made by use of the t-test (3) at the 5 per cent level of significance. No comparisons were made between the two glasses.

Results and Discussion

Figures 1 and 2 show the average modulus of rupture and the stress at the fracture origin plotted as a function of area under uniform stress for glasses A and B respectively. Several items of interest are apparent in the results:

1) The strength decreases as the area under uniform stress increases.

2) There is no significant difference between the strength of glass specimens of different dimensions when the same areas (3 square inches and 6 square inches) are under uniform stress.

3) There is up to approximately 1000 psi difference between the modulus of rupture and the stress calculated at the fracture origin for all two point loading configurations. For mid-point loading the difference increases to the range of 1997 psi to 2665 psi.

4) For Glass A, specimens of both widths exhibit the behavior of strength decrease with increase in area under uniform stress and show no significant difference in strengths when groups of equal stress areas are compared. This pattern holds true for Glass B except in the category of the specimens loaded at mid-point. Here, the 0.75 inch wide specimens are significantly stronger than the 1.5 inch wide specimens. There is no readily apparent reason why the 0.75 inch wide specimens from two different companies show such different patterns when the other specimens produce similar patterns.

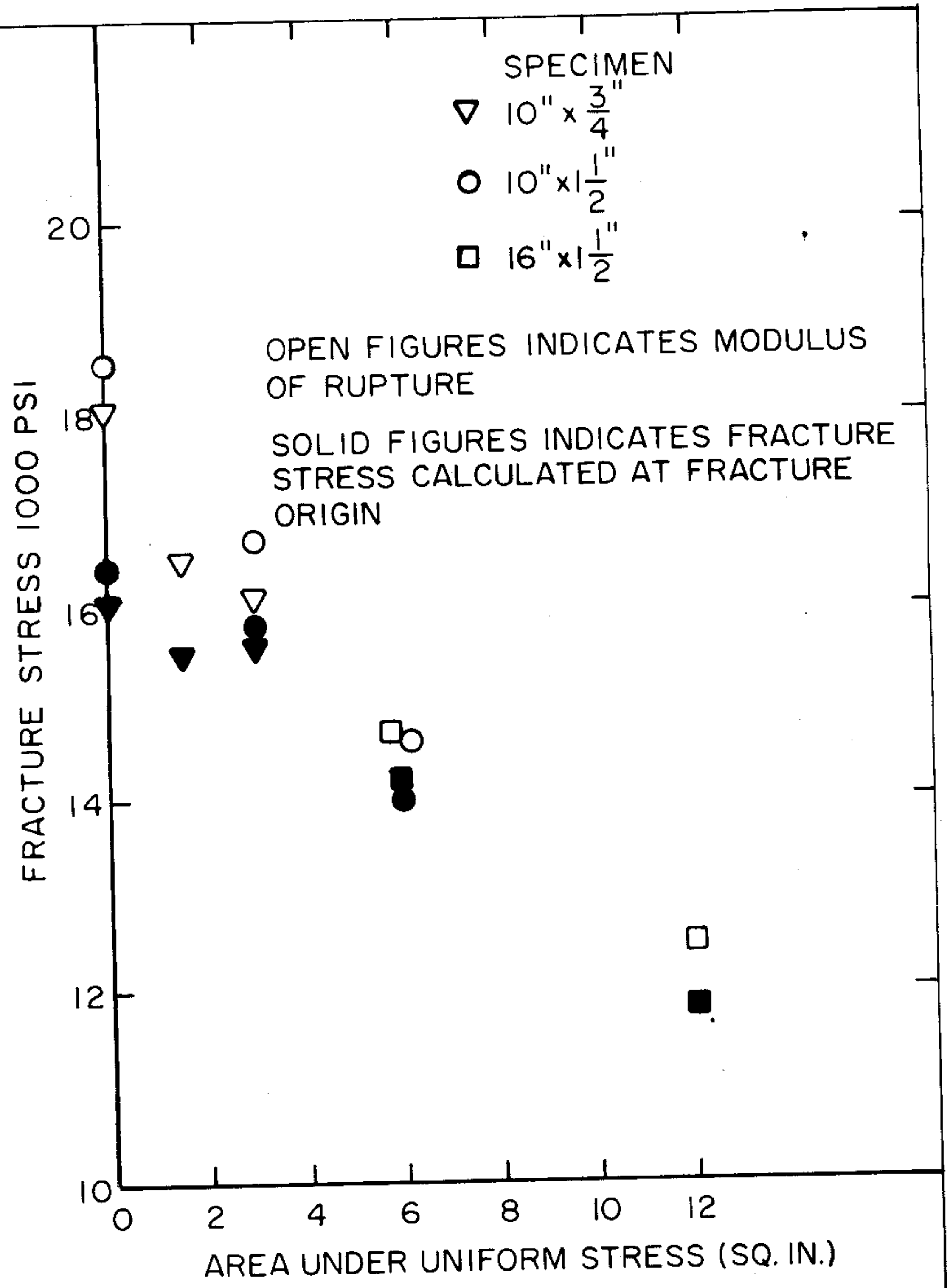


FIGURE 1 THE RELATIONSHIP OF THE AREA UNDER UNIFORM STRESS TO THE FRACTURE STRESS FOR GLASS A.

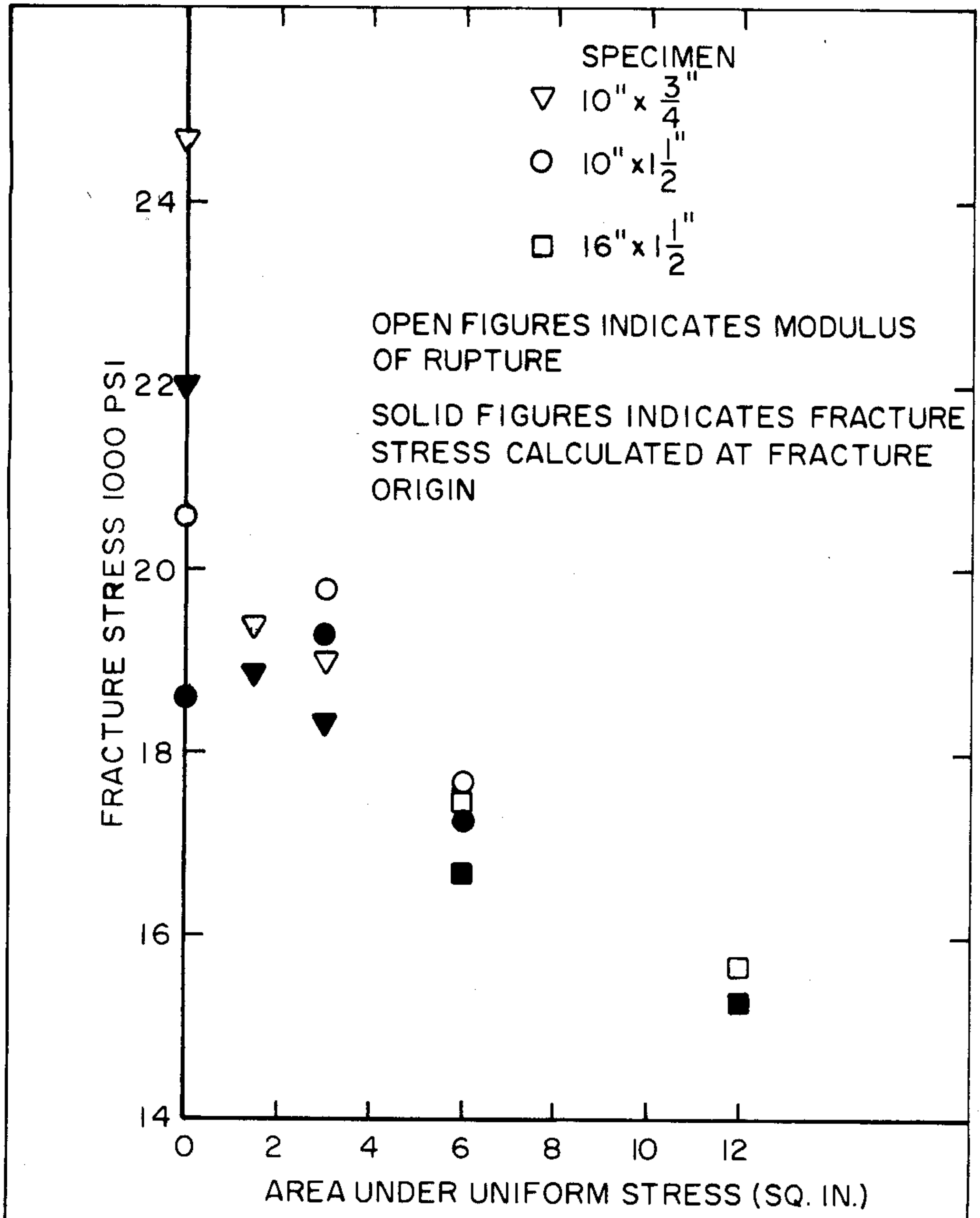


FIGURE 2 THE RELATIONSHIP OF THE AREA UNDER UNIFORM STRESS TO THE FRACTURE STRESS FOR GLASS B.

The average values of the modulus of rupture and stress at fracture are presented in Tables II and III along with their standard deviations and coefficients of variations. These values are presented for all the specimens in each test group as well as for sub-groups containing only the surface fractures and the edge fractures.

Inspection of these tables shows that for every test group, for both modulus of rupture and stress at fracture, the strength is greater when the fractures originate on the surface rather than the edge of the specimen. A statistical analysis shows that the difference is significant for the modulus of rupture in four out of eight cases for Glass A and for all eight cases for Glass B. For stress at fracture the difference is significant in six out of eight cases for Glass A and seven out of eight cases for Glass B.

Figures 3 and 4 show the location of the fracture origins along the length of the specimens. It is readily apparent that the fracture origins tend to fall relatively uniformly throughout the area of uniform stress, and for mid-point loading the fracture origins are compressed around the point of maximum stress.

Table II. Average Modulus of Rupture and Stress at Fracture for Glass A

Area Under Uniform Stress (in)^2	Specimen Dimensions Width (in)	Specimen Dimensions Length (in)	Test Spans Load (in)	Test Spans Support (in)	Specimen Group[1]	Number of Specimens	Modulus of Rupture Mean (psi)	Modulus of Rupture S.D.[2] (psi)	Modulus of Rupture v[3] (%)	Stress at Fracture Mean (psi)	Stress at Fracture S.D. (psi)	Stress at Fracture v (%)
0.0	0.75	10.	0.	8.	All	50	18112	4400	24.29	16115	4465	27.70
					S	33	18784	4551	24.23	17259	4427	25.65
					E	17	16806	3881	23.14	13895	3730	26.85
0.0	1.50	10.	0.	8.	All	50	18591	4137	22.25	16353	4254	26.01
					S	37	19308	3966	20.54	17170	3908	22.76
					E	13	16550	4074	24.62	14026	4489	32.00
1.5	0.75	10.	2.	8.	All	50	16539	3329	20.13	15476	3495	22.58
					S	24	17487	3035	17.36	16338	3297	20.18
					E	26	15664	3404	21.73	14681	3546	24.15
3.0	0.75	10.	4.	8.	All	49	16116	3708	23.01	15595	3783	24.26
					S	32	17440	3392	19.45	16830	3688	21.91
					E	17	13625	2976	21.84	13272	2793	21.04
3.0	1.50	10.	2.	8.	All	50	16736	3470	20.73	15838	3880	24.50
					S	34	17546	2610	14.88	16865	3477	20.62
					E	16	15016	4440	29.57	13654	3887	28.47
6.0	1.50	10.	4.	8.	All	50	14607	3567	24.42	14044	3751	26.71
					S	33	15260	3412	22.36	14976	3473	23.19
					E	17	13341	3618	27.12	12236	3702	30.25
6.0	1.50	16.	4.	14.	All	50	14657	4618	31.51	14212	4916	34.59
					S	35	14820	4710	31.78	14812	4777	32.25
					E	15	14274	4534	31.76	12811	5114	39.92
12.0	1.50	16.	8.	14.	All	50	12483	3117	24.97	11849	3322	28.04
					S	19	13365	3566	26.68	13188	3813	28.91
					E	31	11942	2729	22.85	11028	2732	24.77

[1]/ All signifies all of the specimens in the group; S indicates surface fractures; E indicates edge fractures.

[2]/ Standard deviation.

[3]/ Coefficient of variation.

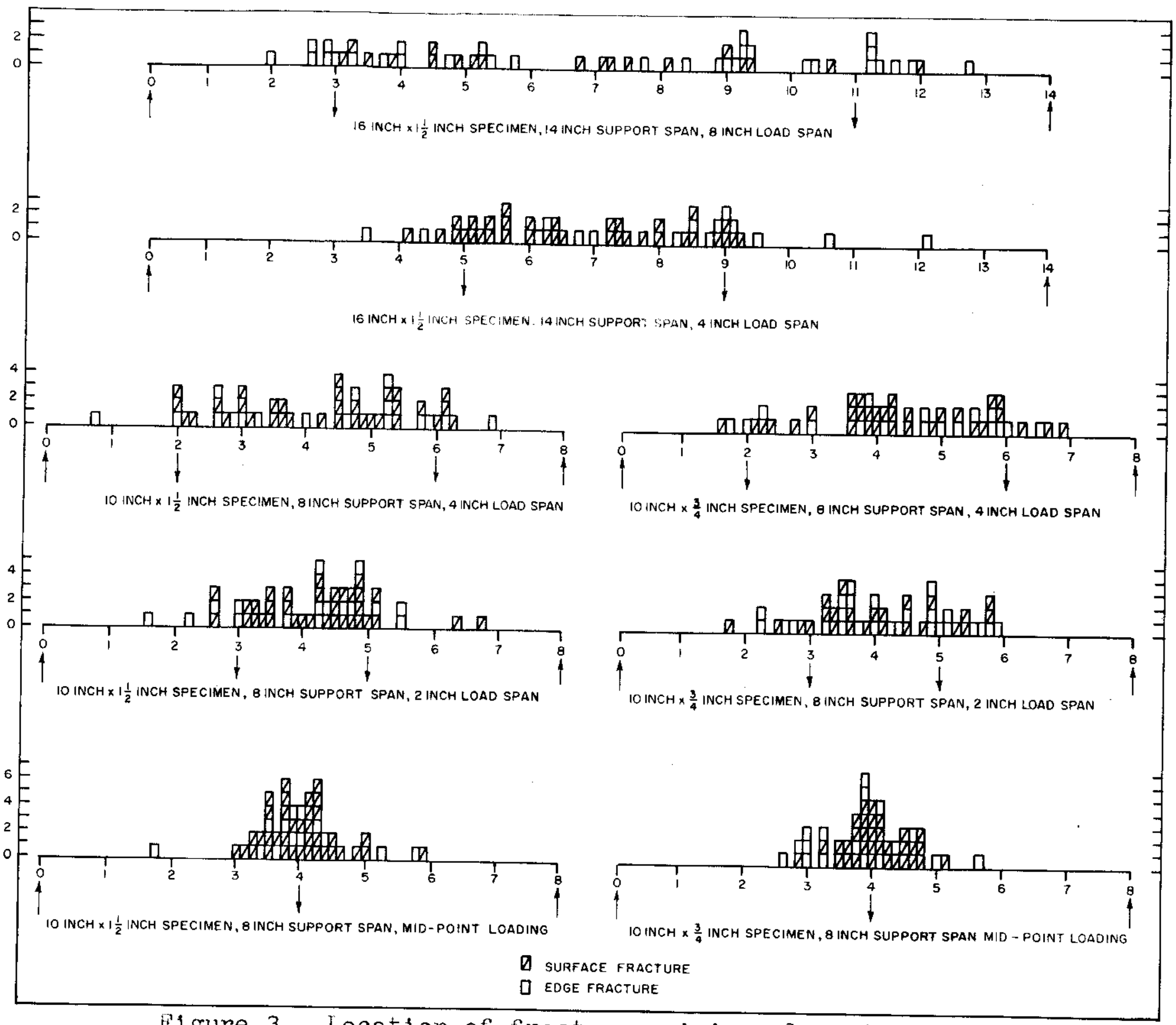
Table III. Average Modulus of Rupture and Stress at Fracture for Glass B

Area Under Uniform Stress $(in)^2$	Specimen Dimensions		Test Spans		Specimen Group[1]	Number of Specimens	Modulus of Rupture			Stress at Fracture		
	Width	Length	Load	Support			Mean	S.D.[2]	ν[3]	Mean	S.D.	ν
	(in)	(in)	(in)	(in)			(psi)	(psi)	(%)	(psi)	(psi)	(%)
0.0	0.75	10.	0.	8.	All	50	24667	4131	16.75	22002	5142	23.37
					S	33	25492	3756	14.73	22411	5270	23.51
					E	17	23067	4465	19.36	21210	4943	23.30
0.0	1.50	10.	0.	8.	All	50	20580	3207	15.58	18571	3635	19.58
					S	30	21572	2742	12.71	19886	3111	15.64
					E	20	19091	3342	17.51	16599	3534	21.29
1.5	0.75	10.	2.	8.	All	49	19436	3767	19.38	18856	3899	20.68
					S	27	20707	3685	17.80	20487	3548	17.32
					E	22	17877	3317	18.55	16856	3399	20.17
3.0	0.75	10.	4.	8.	All	50	18966	3789	19.98	18320	4406	24.05
					S	29	20567	3164	15.38	20227	3843	18.99
					E	21	16754	3509	20.94	15687	3788	24.15
3.0	1.50	10.	2.	8.	All	50	19788	3088	15.61	19337	3834	19.83
					S	33	20712	2212	10.68	20413	3036	14.87
					E	17	17994	3774	20.97	17248	4424	25.65
6.0	1.50	10.	4.	8.	All	50	17669	4036	22.84	17260	4125	23.90
					S	32	19215	3020	15.72	18891	3067	16.23
					E	18	14919	4219	28.28	14361	4241	29.52
6.0	1.50	16.	4.	14.	All	50	17466	3520	20.15	16720	3902	23.34
					S	25	19641	2259	11.50	19270	2313	12.00
					E	25	15291	3215	21.02	14171	3492	24.64
12.0	1.50	16.	8.	14.	All	49	15722	3403	21.64	15281	3925	25.68
					S	21	16968	3634	21.42	16589	4035	24.32
					E	28	14788	2948	19.93	14300	3605	25.21

[1] All signifies all the specimens in the group; S indicates surface fractures; E indicates edge fractures.

[2] Standard deviation.

[3] Coefficient of variation.


16 INCH x $1\frac{1}{2}$ INCH SPECIMEN, 14 INCH SUPPORT SPAN, 8 INCH LOAD SPAN

16 INCH x $1\frac{1}{2}$ INCH SPECIMEN, 14 INCH SUPPORT SPAN, 4 INCH LOAD SPAN

10 INCH x $1\frac{1}{2}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN, 4 INCH LOAD SPAN

10 INCH x $\frac{3}{4}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN, 4 INCH LOAD SPAN

10 INCH x $1\frac{1}{2}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN, 2 INCH LOAD SPAN

10 INCH x $\frac{3}{4}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN, 2 INCH LOAD SPAN

10 INCH x $1\frac{1}{2}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN, MID-POINT LOADING

10 INCH x $\frac{3}{4}$ INCH SPECIMEN, 8 INCH SUPPORT SPAN MID - POINT LOADING

Figure 3. Location of fracture origins along the length of the specimen for Glass A.

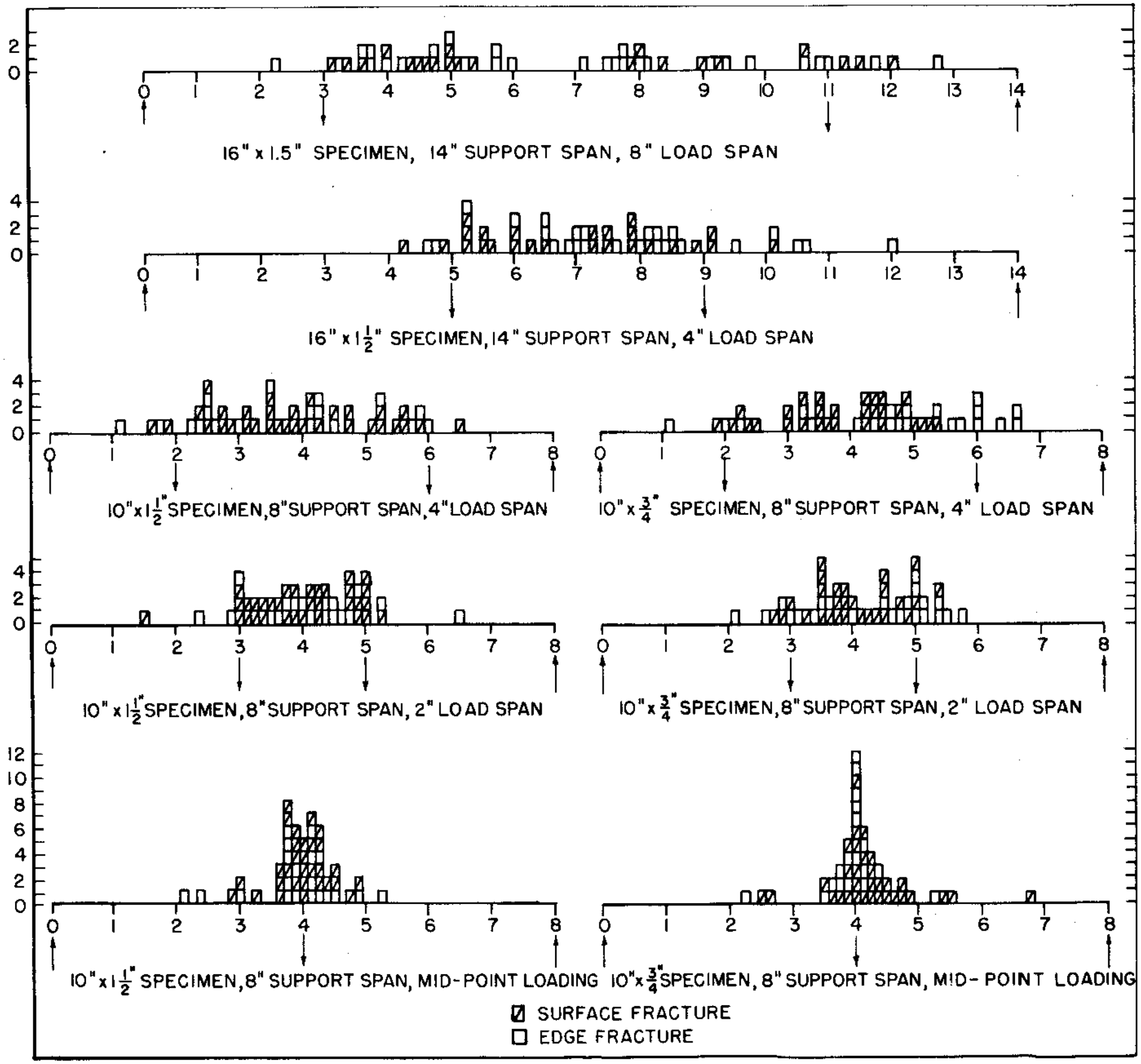


Figure 4. Location of the fracture origins along the length of the specimen for Glass B.

Figure 5 is a histogram of the test groups for Glass A and are drawn for both modulus of rupture and stress at fracture for all of the specimens in a particular group as well as for the sub-groups of specimens that failed from the edge and at the surface. The histogram for Glass B was similar. This histogram shows the shift in strength as the area under uniform stress is increased and also show that the edge failures are generally lower in strength than the surface failures but that they are well distributed into the surface failure values. This shows that some surface flaws are more severe than the edge flaws but in general the edge flaws are the more severe.

The specimens that failed from the edge would have failed at a higher surface strength had they not possessed severe edge flaws, and would have increased the average strength of the group. The edge failures in effect tend to skew the distribution toward the lower end. This implies that a value approaching a true measure of the strength of the surface of glass cannot easily be obtained with this type of test.

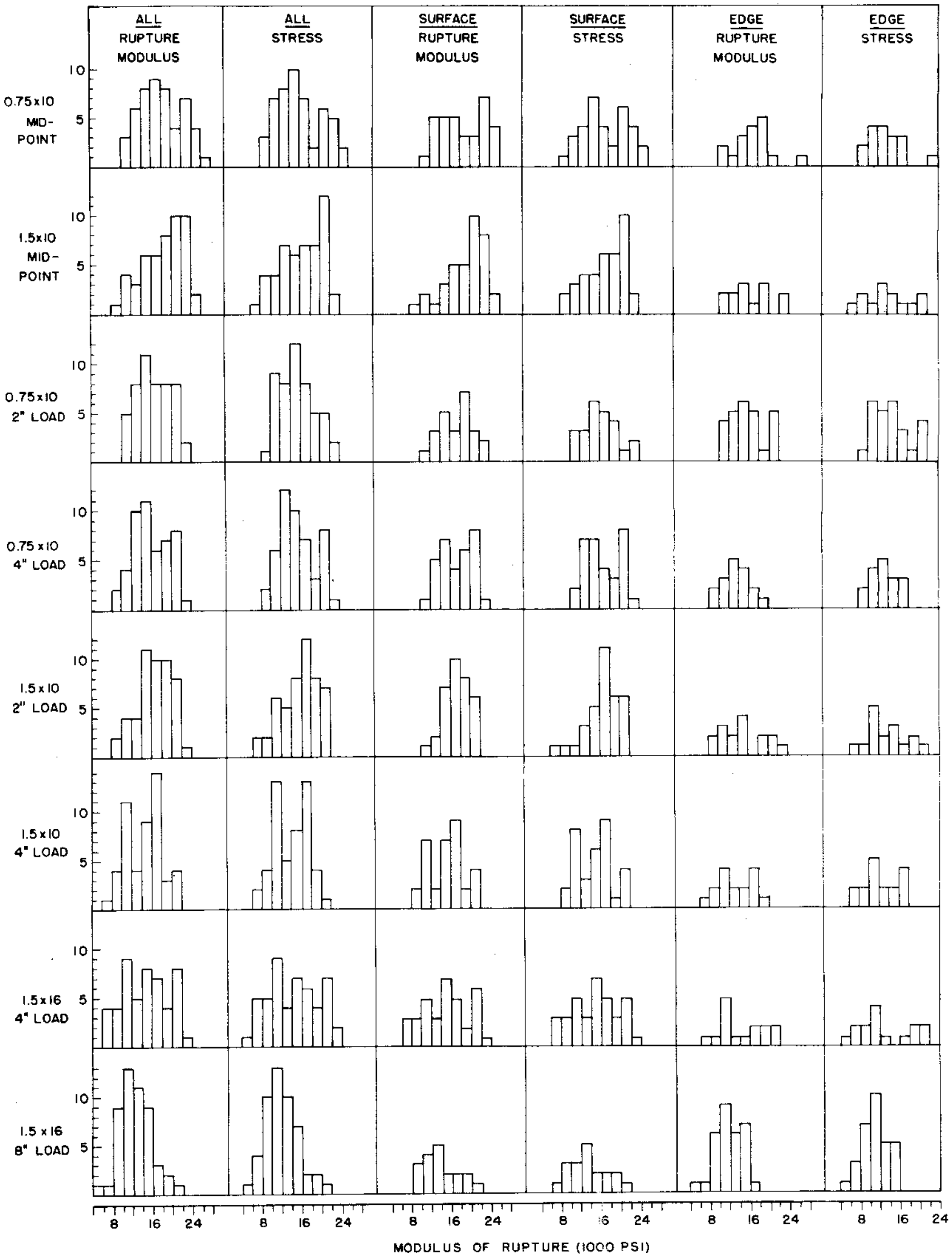


Figure 5. Histograms of test groups for Glass A.

Summary and Conclusions

Flexure tests were made on laths of annealed plate glass from two different glass producers, and tested with both single and two point loading. In these tests it was found that:

1) The larger the area stressed the lower the strength.

2) For specimens of a different size but having the same area under uniform stress there was no significant difference between their strengths.

3) There was up to approximately 1000 psi difference between the modulus of rupture and stress at rupture for all two point loading tests; for single point loading the difference was approximately 2000 psi.

4) Fracture origins for mid-point loading tended to cluster about the point of maximum load while fracture origins in the two point loading tests were distributed throughout the area of uniform stress with some few occurring outside this area.

5) Specimens that failed at the surface tended to be stronger than those that failed from the edge.

The present findings agree well with the "weakest link" concept in flaw theories, the greater the number of the links the higher the probability of finding a weak link and so lower the strength of the whole. On this basis it seems a two-point loading flexure test should be adopted, possibly one in which the loading knife edges are separated by as much as four inches. With the standard ASTM specimen and an eight inch support span this would give a large area under uniform stress with no undue complications from too short a moment arm. Since the flaws on the cut edge are generally more severe than those on the surface of the glass, these two types of failures should be separated and note made of the number and strengths of each.

BIBLIOGRAPHY

1. Griffith, A.A., "The Phenomena of Rupture and Flow in Solids", Phil. Trans. 221A, p 163-198, 1920.

2. Kerper, M.J. and Scuderi, T.G., "Mechanical Properties of Glass at Elevated Temperatures", Bull. Am. Ceram. Soc. 42, p 735-740, 1963.

3. Dixon, W.J. and Massey, F.J., Jr., "Introduction to Statistical Analysis", McGraw-Hill Book, Inc., New York. p 97, 1951.