Distributed: FKI Technical Division meeting (N.Y.) July 30, 1965

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD

Project 1108-30

Report Two

A Preliminary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

July 12, 1965

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CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD

SUMMARY

This study has for its purpose the development of information regarding the long-term load-carrying ability of corrugated board and boxes. Because of the long time intervals required to obtain data this report summarizes a preliminary analysis of the major data trends and explores methods of analyzing the creep deflection *vs.* time curves.

For the materials evaluated the results to date indicate that

1. The following average box failure lives were obtained from a relationship between applied load ratio and the logarithm of time.

Applied Load Ratio	Box Failure Life, days
0.70	11.5
0.65	32
0.60	92
0.55	260

2. At this stage the effects of flute and board series on the relationship between failure life and the applied load ratio are obscured by test variability.

3. The box failure lives tend to be considerably greater than those reported by Kellicutt and Landt.

4. The variability in box creep failure lives is large though much of the variability is apparently explained by the variability in conventional box

compression tests. Because of the large variability, use of average failure life can be misleading.

5. In the box creep tests, failure seemed to occur as the deflection reached the value obtained in the conventional box test.

6. Column creep failure lives exhibited a similar relationship with applied load as the boxes but gave somewhat shorter lives, in general. The column creep lives were about as variable as the box creep lives.

7. A preliminary analysis of a portion of the box results was carried out to develop mathematical expressions to fit the box creep deflection vs. time curves. If the path of the creep curves can be predicted from conventional short-term tests, it should be possible to

(a) estimate creep failure times from the intersection of the creep deflection time equation with the critical box deflection or

(b) estimate the creep time to reach any specified deflection level which might be associated with damage to the contents.

8. For this preliminary analysis, a power function was employed to describe the creep deflection vs. time curves. Regression equations of the following type were obtained:

$$t = K_1(D-D_o)^{K_2}$$

or

$$\text{Log } t = \text{Log } K_1 + K_2 \text{ Log } D-D_o$$

where

$\underline{t}$ = time
$\underline{D}$ = deflection at time $\underline{t}$

and

$\underline{D}_o$, $\underline{K}_1$ and $\underline{K}_2$ are constants.

9. Equations of the above type fitted the creep curves reasonably well. Estimates of box creep failure life were made which were only in fair agreement with observed values. However, creep test variability is large and would prevent close estimates in any case.

10. To be of greatest utility the constants in the regression equations must be constant for most combined board constructions or must vary in some predictable way with the applied load or other factors. Further analysis is needed to determine if generalized equations can be developed.

INTRODUCTION

Stacking performance involves the interrelated variables of load, deformation, and time. The failure as a function of time of boxes exposed to constant loads during warehousing is a major use hazard for corrugated boxes. It is well known that a corrugated box subjected to warehouse stacking will support for a prolonged period only a relatively small fraction of the box compression strength as determined by a laboratory box compression test. For this reason a study is in process to provide information relative to the warehouse stacking (creep) characteristics of corrugated boards and boxes.

Because of the long time intervals and the variability in failure times of the boxes and board, the accumulation of data is slow. For that reason a preliminary analysis of available data is underway to explore the major data trends and methods of analyzing the data. This should facilitate use of the information and permit changes in emphasis of the experimental program where it appears desirable. This preliminary report discusses

(a) the relationship between applied load and creep failure life for boxes and short combined board columns,

(b) the effect of variability in box compression characteristics on the creep failure life variability of boxes, and

(c) analysis of deflection vs. time curves for boxes.

BACKGROUND CONSIDERATIONS

Paper is classified mechanically as a viscoelastic material. Its prerupture response to an applied load may include several types of deformations.

They include (a) immediate elastic deformation, (b) delayed elastic deformations which are recoverable in reasonable lengths of time after removal of load, and (c) nonrecoverable deformations which are not recoverable in a reasonable length of time after removal of load.

If strain or deformation is plotted against time, a curve having the form shown in Fig. 1 will be obtained for nearly all materials. Thus, the responses of most materials to long-term loads are quite similar though somewhat different mechanisms may be involved for dissimilar materials.

When load is applied the initial deflection OA is obtained. This is usually considered to be instantaneous and is composed of elastic, delayed elastic and plastic deformation.

In the primary stages of the creep curve the rate of deformation continuously decreases. In the second stage the rate of deformation is approximately constant. Although it is often treated as a straight line it may actually be a very flat curve with a point of inflection where the rate of deformation begins to increase again. In the third stage the deformation increases and failure eventually occurs.

The actual creep curve obtained often departs from that shown in Fig. 1. It will depend on such factors as the magnitude of the load applied, moisture content, temperature, etc. For example, if the load applied is large relative to box compression, the secondary stage may be absent entirely and an S-shaped curve will be obtained.

The tensile creep properties of paper have been studied by a number of investigators. For example, Brezinski has carried out a comprehensive study of the

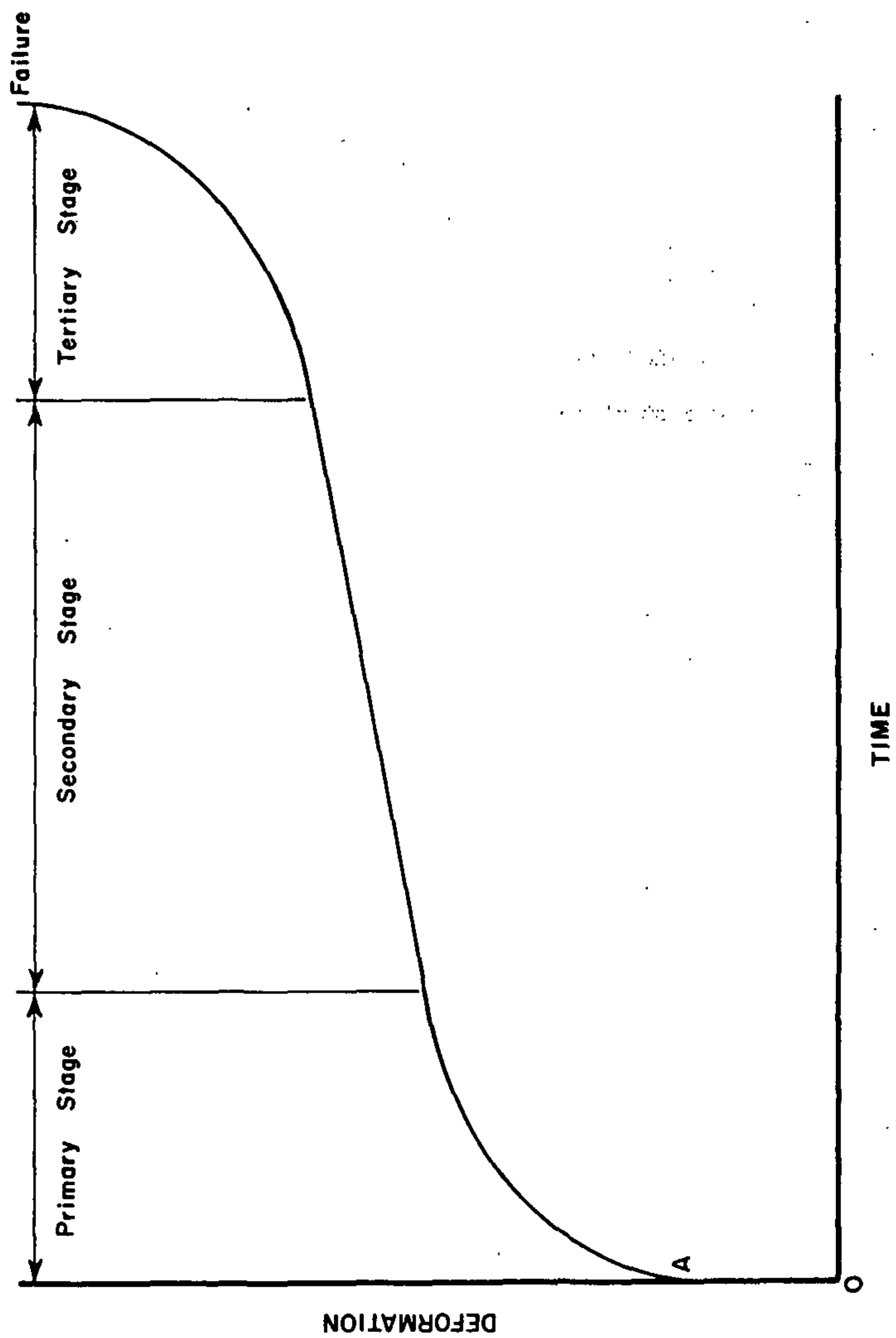

Fig. 1. Constant Load Creep Curve

creep behavior of paper (1). A portion of Brezinski's results are shown in Fig. 2. Brezinski found that at early times or low loads his results could be described in terms of the following equation

$$y/L_o = Bt^a + c \quad (1)$$

where

y = creep deformation, inch (first load)
L_o = initial specimen length, inch
t = time of loading, seconds

and

B, a, and c are constants.

At longer times (e.g., secondary stage) or higher loads the deformation-time relationship became linear on the semilogarithmic plot and could be described by the following equation

$$y/L_o = K_1 \text{ Log } t + K_2 \quad (2)$$

where K_1 and K_2 are constants.

Rance (2,3) has presented creep curves of paper at several constant loads. In general, the deformation increased rapidly with time and the log of the time to rupture decreased linearly with the applied load. Similar results were obtained by Jacobsen (4) and with cellulose films by Cheung (5).

There has been little published work relative to the creep characteristics of paperboard or boxes in compression. Kellicutt and Landt (6) have published results for corrugated boxes showing a semilogarithmic relationship between applied load and time.

Recently Odqvist (7) reviewed existing theories of ductile fracture by various authors and generalized a theory advanced by Kachanov (8). The generalized theory explains the shape of the fracture time – applied stress curve.

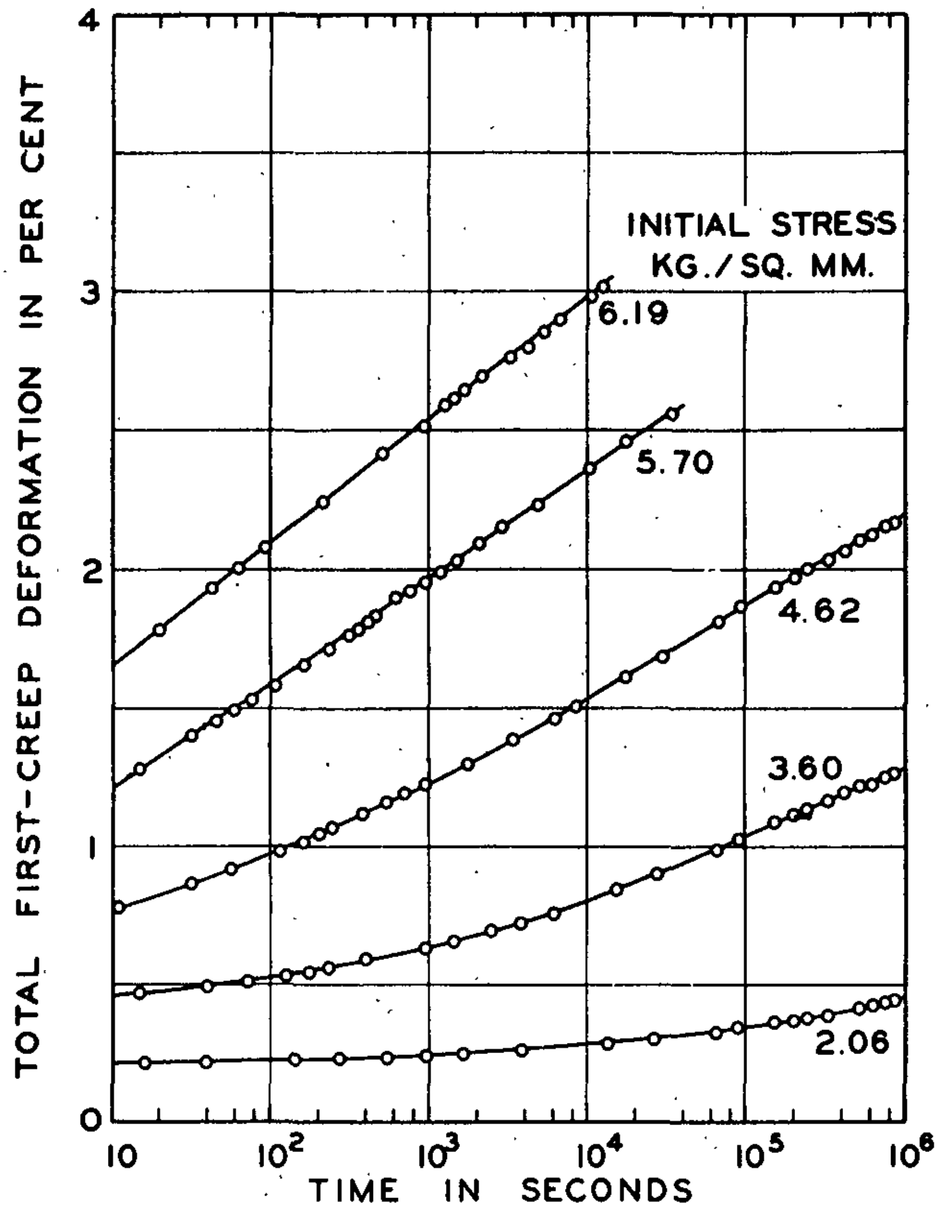

Fig. 2. First-Creep Curves of Handsheet 23
(Brezinski)

In a recent publication, Clouser (9) reviewed the many mathematical expressions used to describe the creep curves of various materials. For the wood beams he used, a power equation similar to Equation (1) was used to describe the creep curve up to the point of inflection. Failure of the wood beams gave a linear relationship between stress level and the logarithm of time to failure.

There is an extensive literature regarding the creep behavior of various materials. These will be reviewed at a later date.

MATERIALS

The box samples in Table I are under test in this program.

DISCUSSION OF RESULTS

BOX FAILURE TIMES AND DEFLECTION VS. APPLIED LOAD

The creep failure times and deflections for the boxes are summarized in Tables II and III and illustrated in Fig. 3. Inspection of the data indicates that the variability in stacking life at a given load ratio is large – often varying by a factor of 5 or 10 for a given sample and load ratio. This variability makes it difficult to determine whether other factors such as box size, flute, or board series significantly affect the relationship between failure time and the applied load rates.

Separate regression lines were computed for the A, B, and C flute data and for the combined data. The equations are given in Table IV.

While somewhat different regression equations and, hence, lines were obtained for the separate flutes, the limited data in B and C flutes suggest that the use of separate regression equations might be dangerous. This is particularly true for C-flute where the extremely long stacking times recorded for the 350-lb. series sample boxes had a major influence on the regression line. Whether the long stacking lives should be attributed to flute, to board series, or to some other factor is, at least, debatable at this time.

As a matter of interest the differences in slope were tested using IBM covariance program 6.0.032. The slope differences were not significant, suggesting that lines of common slope could be fitted to the data for the separate flutes.

TABLE I

LIST OF MATERIALS

No.	Flute	Series	Dimensions	Mfg. Joint	Top Load Compression: Load, no. Av.	Top Load Compression: Load, no. Standard Deviation	Top Load Compression: Deflection, in. Av.	Top Load Compression: Deflection, in. Standard Deviation
2406	A	200	16 x 12-1/4 x 9-1/2	Taped	940	47	0.59	0.0527
2407	A	200	21 x 17-1/2 x 19	Taped	975	41	0.64	0.0251
2408	A	200	23-1/2 x 23-1/2 x 19	Taped	1180	85	0.67	0.0327
2430	A	200	23-1/2 x 14 x 12	Taped	1060	75	0.61	0.0611
2456	A	175	13-1/4 x 6-5/8 x 12-1/2	Taped	555	37	0.44	0.0271
2457	C	350	12-1/4 x 12-1/4 x 19-13/16	Glued	1235	98	0.93	0.1657
2510	C	275	16 x 12 x 18-1/2	Stitched	960	49	0.45	0.0268
2497	B	200	15-3/8 x 10-1/4 x 11-3/4	Glued	665	37	0.38	0.0071
2498	B	275	17-7/8 x 16 x 11-3/8	Stitched	970	48	0.45	0.0288
2511	B	175	15-1/2 x 10-1/4 x 14-3/8	Glued	525	43	0.35	0.0233

TABLE II

SUMMARY OF BOX CREEP RESULTS

Applied Load Ratio	Specimen No.	Failure Time, days Sample 2406 A-200	Sample 2407 A-200	Sample 2408 A-200	Sample 2430 A-200	Sample 2456 A-175	Sample 2457 C-350	Sample 2497 B-200	Sample 2498 B-275	Sample 2510 C-275	Sample 2498 B-175
0.75	1	0.22	0.44	1.15		6.46	17.74		0.89	4.88	1.49
	2	0.47	32.08	1.21		4.16	9.36		2.46	13.89	3.27
	3	0.50	15.49	1.07		0.03	26.10		3.11	50.60	4.78
	4	0.32	0.70	1.39		0.24	153.20		6.22	10.39	0.16
	Av.	0.38	12.13	1.20		2.72	51.60		3.14	19.94	2.42
0.70	1	over 250	33.4			33.1	62.6	8.9	127.0		10.9
	2	19.6	40.6			132.7	over 214	53.8	15.9		3.6
	3	20.0	41.7			over 68		9.5	35.7		10.3
	4	4.5	15.2					4.0	35.2		18.6
	Av.		32.7			82.9		19.0	53.4		10.8
0.675	1	30.5	87.9								
	2	62.1	76.4								
	3	38.4									
	4	20.4									
	Av.	37.8									
0.625	1	33.8	15.8	16.5	29.8	115.4	72.6	19.9	263.0	over 2	over 30
	2	4.8	13.6	79.6	62.9	167.4	over 373	7.7	160.4		over 2
	3	155.7	95.9	13.1	90.1	over 373	200.6[a]	140.6	214.3		
	4	115.4	93.8	2.6	over 372	over 374	405.8[a]	101.5	over 213		
	Av.	77.4	54.8	28.0	60.9	141.4	226.3	67.4			
0.575	1	over 93	over 93			over 274	over 274	over 283	over 284		
	2					over 147					
	3					over 93					
0.55	1	113.3	366.6	129.3		over 371					
	2	114.5	over 371	20.6		over 374					
	3	174.4	over 371	199.2							
	4	243.6		over 83							
	Av.	161.4									
0.50	1		344.0								
	2		578.0[a]								
	3		728.9								
	Av.		550.3								

[a] Received two hours exposure to humidities as high as 80% R.H.

TABLE III

COMPARISON OF BOX CREEP DEFLECTIONS PRECEDING FAILURE WITH MAXIMUM DEFLECTION IN THE BOX COMPRESSION TEST

	Deflection, inch									
	Sample 2406	Sample 2407	Sample 2408	Sample 2430	Sample 2456	Sample 2457	Sample 2497	Sample 2498	Sample 2510	Sample 2511
Max. deflection (box compression test), inch	0.59	0.64	0.67	0.61	0.44	0.93	0.38	0.45	0.44	0.31
Creep failure defl., inch[a]										
0.75 load ratio										
1	0.64	0.62	0.73		0.44	0.84		0.42	0.45	0.38
2	0.65	0.71	0.78		0.39	1.02		0.49	0.48	0.35
3	0.56	0.61	0.76		0.39	1.06		0.45	0.62	0.33
4	0.59	0.54	0.73		0.37	1.13		0.54	0.44	0.37
Av.	0.61	0.62	0.75		0.40	1.01		0.48	0.50	0.38
0.70 load ratio										
1		0.67			0.51	1.06	0.41	0.51		0.35
2	0.66	0.69			0.46		0.41	0.54		0.37
3	0.67	0.67					0.40	0.50		0.35
4	0.58	0.69					0.40	0.50		0.39
Av.		0.68					0.40	0.51		0.36
0.675 load ratio										
1	0.69	0.77								
2	0.66	0.70								
3	0.61									
4	0.54									
Av.	0.62									
0.625 load ratio										
1	0.63	0.67	0.62	0.61	0.44	0.99	0.38	0.52		
2	0.63	0.56	0.77	0.68	0.49	--	0.38	0.48		
3	0.70	0.68	0.74	0.61		0.95	0.43	0.52		
4	0.66	0.64	0.76			1.05	0.42			
Av.	0.66	0.64	0.72				0.40			
0.55 load ratio										
1	0.60	0.63	0.78							
2	0.58		0.74							
3	0.54		0.76							
4	0.64									
Av.	0.59									
0.50 load ratio										
1		0.66								
2		0.74								
3		0.75								
Av.		0.72								

[a] [illegible] failure [illegible] the last recorded value [illegible] deflection [illegible]

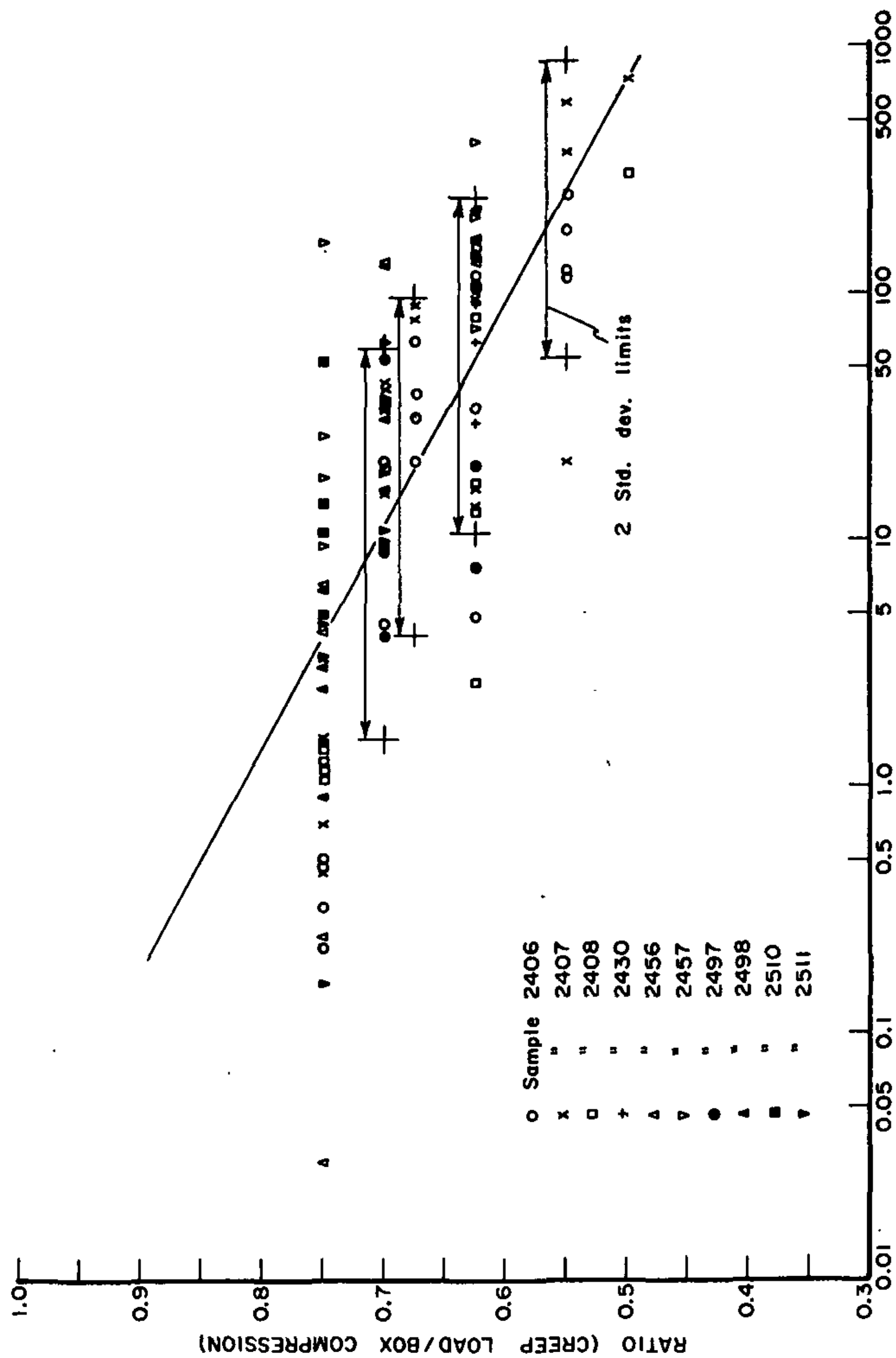

Fig. 3. Relationship Between Failure Life and Applied Load

TABLE IV

BOX FAILURE LIFE REGRESSION EQUATIONS

Flute	N	Regression Equation[a]	Corr. Coefficient
A	59	Log t = 7.81655-9.936R	-0.77
C	12	Log t = 7.10417-7.733R	-0.73
B	27	Log t = 9.96173-12.726R	-0.77
Composite	98	Log t = 7.38290-9.054R	-0.71

[a] t=time to failure, days and R=applied load ratio

In terms of averages, the composite regression line gives stacking times which are considerably greater than those reported by Kellicutt and Landt (6). This comparison is shown in Table V. It is understood by the Institute that Kellicutt more recently has obtained longer stacking times with A-flute materials than originally reported. This would probably reduce the differences shown in Table V. In any event, it is evident that survival time for the empty box decreases drastically as the applied load approaches 65 to 75% of the conventional box compression load.

The use of averages such as the above can be misleading since warehouse stacking complaints may occur because of the poor performance of a few boxes in the lot. Therefore, box variability may require consideration.

The effects of "normal" box variability on survival time was estimated as follows.

1. Two standard deviation limits were computed for each box compression average using the data in Table I. Normally, 95% of the individual box tests should be found within this range.

2. The applied load at each load ratio was divided by the upper and lower two standard deviation load value to give upper and lower limits on the applied load ratio.

3. Survival times at the upper and lower load ratios were read from the curve in Fig. 3.

TABLE V

BOX FAILURE LIFE

Load Ratio	Box Failure Life, days: Fig. 3	Box Failure Life, days: Kellicutt and Landt[a]
0.75	4.0	0.6
0.70	11.5	2.0
0.675	18.5	3.6
0.65	32	7
0.625	54	14
0.600	92	25
0.55	260	86

[a]From Fig. 6, Reference (6).

The stacking survival limits for empty boxes based on compression variability as computed above are shown in Table VI and the average limits are shown in Fig. 3. This procedure appears to account for much of the variability in the individual box stacking results.

It must be emphasized that the above estimates of variability are only concerned with variability of individual boxes from a given sample lot. To determine if two lots of boxes gave different stacking times, the number of boxes

TABLE VI

BOX SURVIVAL TIME LIMITS BASED ON BOX COMPRESSION VARIABILITY

Variation in Failure Time in Days Due to Box Variability at the 2 Standard Deviation Level

No.	Flute	Series	0.70 Ratio High	0.70 Ratio Av.	0.70 Ratio Low	0.675 Ratio High	0.675 Ratio Av.	0.675 Ratio Low	0.625 Ratio High	0.625 Ratio Av.	0.625 Ratio Low	0.55 Ratio High	0.55 Ratio Av.	0.55 Ratio Low
2406	A	200	43	11.5	2.3	68	18.5	4.0	180	54	12.5	720	260	70
2407	A	200	36	11.5	3.1	55	18.5	5.4	105	54	11.0	620	260	92
2408	A	200	70	11.5	0.99	112	18.5	1.8	280	54	6.0	>1000	260	37
2430	A	200	70	11.5	1.08	108	18.5	1.9	280	54	14.8	>1000	260	38
2456	A	175	62	11.5	2.25	100	18.5	2.2	250	54	7.2	1000	260	45
2457	C	350	73	11.5	0.72	130	18.5	1.4	330	54	4.8	>1000	260	30
2510	C	275	44	11.5	2.2	70	18.5	3.8	190	54	13.0	720	260	70
2497	B	200	46	11.5	1.8	79	18.5	3.3	200	64	10.5	800	260	60
2498	B	275	43	11.5	2.3	69	18.5	5.0	180	54	13.4	690	260	72
2511	B	175	88	11.5	0.65	148	18.5	1.25	340	54	14.4	>1000	260	27
		Av.	58	11.5	1.53	94	18.5	4.08	234	54	10.8	855	260	54

evaluated for each sample would have to be taken into account in calculating a standard error of the difference so that a "t" test could be made.

DEFLECTION AT FAILURE VS. APPLIED LOAD

The box deflections near failure in the creep tests are summarized in Table III. In general, the creep failure deflections were approximately equal to the deflections at maximum load in the box compression test. This means that if suitable mathematical functions can be found to describe the relationship between deflection and time, the failure time may be estimated without carrying out lengthy creep tests. This will be discussed in a later section.

COLUMN FAILURE TIMES AND DEFLECTION VS. APPLIED LOAD

To provide information relative to the creep behavior of corrugated board in compression, creep tests are in process on short columns of the type used in evaluating the edgewise compression strength of corrugated board. The test is one of the basic factors governing conventional box compression tests.

The creep failure lives and deflections are shown in Tables VII and VIII and Fig. 4. In general, the creep failure lives of the short columns increased as the applied load decreased in much the same manner as the boxes. The variability of the columns creep failure lives is qualitatively about as great as found for the boxes.

The column creep lives show some correlation with the box creep lives as shown in Fig. 5. However, the relationship is not very precise due to the test variability. Refinements in test methodology and analysis will probably be required to use column creep tests in box creep life prediction. Column creep

TABLE VII

PRELIMINARY DATA ON COLUMN CREEP BEHAVIOR OF COMBINED BOARD

Applied Load Ratio	Speci-men No.	Failure Time, days: Sample 2406 A-200	Sample 2407 A-200	Sample 2408 A-200	Sample 2430 A-200	Sample 2456 A-175	Sample 2457 C-350	Sample 2497 B-200
Maximum load, lb./in.		51.1	42.2	45.7	51.9	34.3	74.4	45.9
0.75	1	1.41	0.17	0.16		1.06	0.79	5.18
	2	0.31	0.05	0.52		3.55	0.95	0.05
	3	1.51	0.16	7.01		0.08	0.33	0.04
	4	0.07	5.57			0.07		
	5	1.01				0.36		
	Av.	0.86	1.49	2.56		1.02	0.69	2.03
0.70	1	14.61	3.42[b]	21.17[b]		8.19	1.03	0.30
	2	2.00[a]	3.63[b]	1.37[b]		4.00	9.44	6.90
	3					25.92		
	Av.	14.61	3.52	11.27		12.70		3.60
0.686	1		0.56[b]					
	2		2.26					
	Av.		1.41					
0.625	1	20.38[b]	12.30	26.64[b]	38.40[b]	30.75	45.97	99.08[e]
	2	85.56[b]	46.70	40.97[d]	23.14	98.99	56.63[b]	15.59[b]
	3	22.08[c]	6.83[b]	219.49	21.11	27.64[b]	28.97	8.42[b]
	4	4.39[b]	6.05	10.64	2.00[a]	46.10[e]	150.00[a]	
	5	11.07	14.44[b]			92.03[d]	13.66[b]	
	6		23.37[b]			120.56[b]		
	7		7.79					
	8		14.44					
	Av.	28.70	16.49	74.44	27.55	69.34	36.31	41.03

[a] Specimen has not reached failure and is still under test; these values are not included in any of the averages.
[b] Failure time is ± 0.31 days.
[c] Failure time is ∓ 0.23 days.
[d] Failure time is ∓ 0.90 days.
[e] Failure time is ∓ 1.31 days.

TABLE VIII

COLUMN CREEP DEFLECTIONS PRECEDING FAILURE

Applied Load Ratio	Specimen No.	Deflection, inch[a]						
		Sample 2406	Sample 2407	Sample 2408	Sample 2430	Sample 2456	Sample 2457	Sample 2497
0.75	1			0.031			0.025	
	2	0.028		0.035			0.023	0.028
	3	0.013	0.034	0.037		0.025	0.062	0.023
	4	0.056	0.030			0.030		
	5	0.046				0.015		
	Av.	0.036	0.032	0.034		0.023	0.037	0.026
0.70	1	0.047	0.031	0.034		0.024	0.028	0.010
	2		0.032	0.040		0.028	0.040	0.021
	3		0.010			0.041		
	4							
	Av.		0.024	0.037		0.031	0.034	0.016
0.625	1			0.027				0.023
	2	0.032			0.033	0.042	0.032	0.029
	3	0.031		0.035	0.023	0.033	0.039	0.022
	4	0.034	0.026	0.030		0.032		
	5	0.039	0.032			0.027		
	6		0.030			0.031		
	7		0.036					
	8		0.041					
	Av.	0.034	0.033	0.032	0.028	0.033	0.036	0.025

[a]The creep failure deflection is the last recorded deflection preceding the collapse of the column.

tests can be useful for studying the creep response of materials and the effect of various fabrication effects such as glue skips, finger lines, etc.

RELATIONSHIP BETWEEN BOX DEFLECTION AND TIME UNDER LOAD

During the box creep test, the deflection gradually increases. Failure occurs as the deflection nears the deflection attained in the box compression test. An idealized representation is shown in Fig. 6. When Load $\underline{R}_1$ is applied

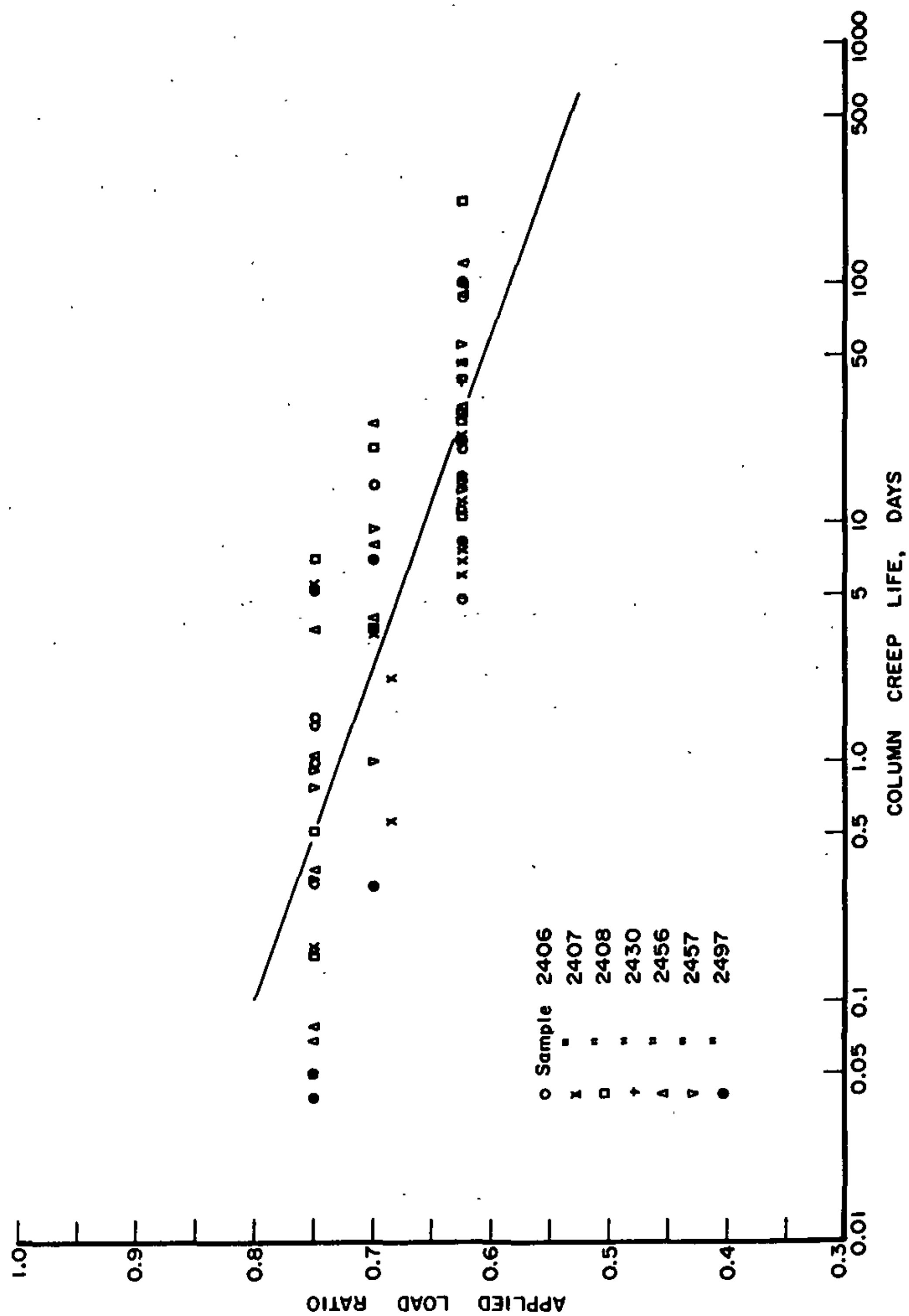

Fig. 4. Relationship Between Applied Load and Column Creep Life

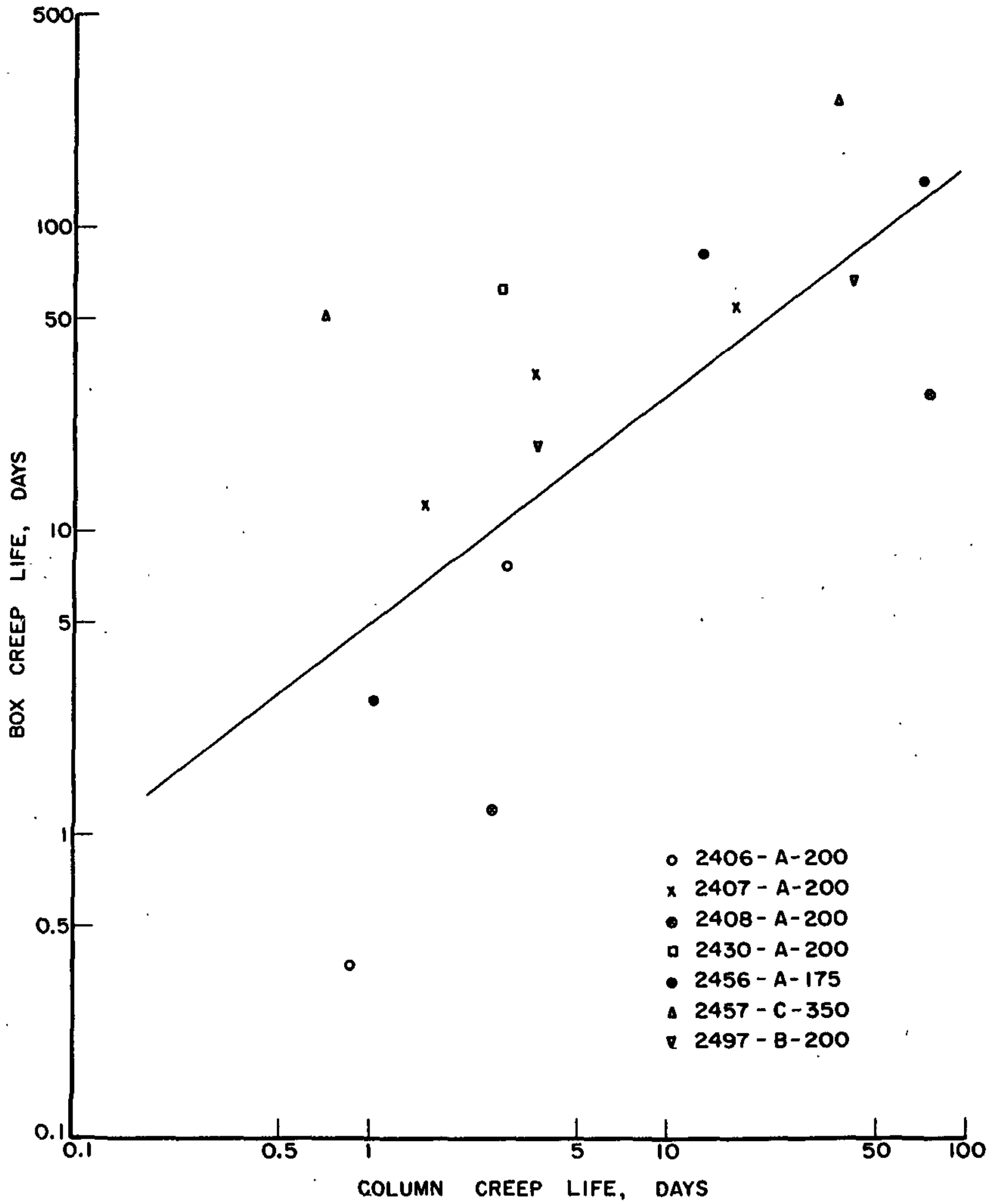

Fig. 5. Relationship Between Short Column and Box Creep Failure Life

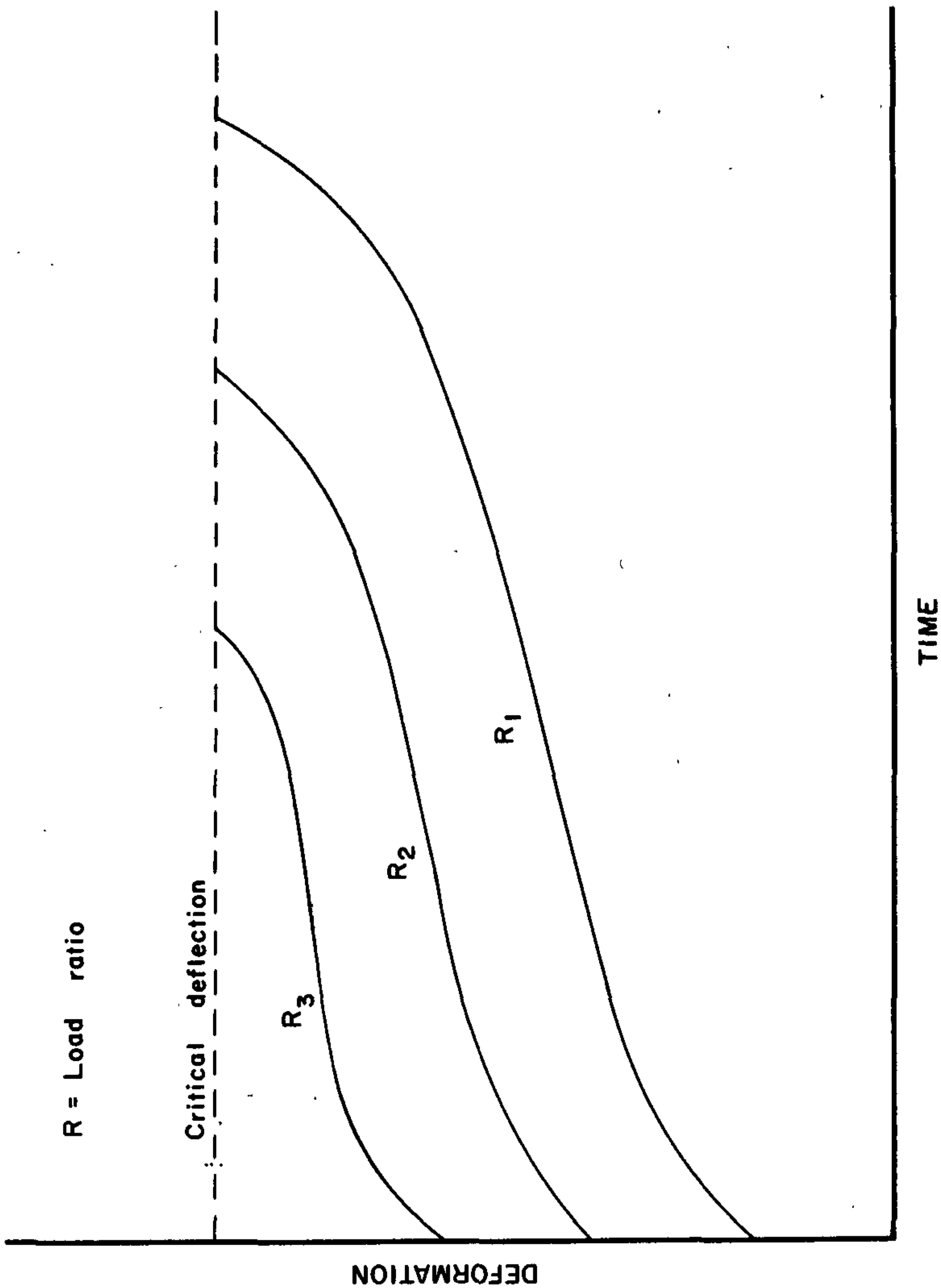

Fig. 6. Idealized Box Deflection *vs.* Time Curves

the time to failure is long although failure occurs as the critical deflection is reached. When a larger Load, R_2 or R_3, is applied failure occurs in a shorter time at about the same deflection level.

If it were possible to predict the path of a curve from data determined in short term tests, failure time estimates could be made. In addition, if it were known that a given product would be damaged at some deflection less than the critical deflection, the time required to reach such deflections could also be estimated. Therefore, an analysis of the data from this viewpoint should have merit.

Box deflection *vs*. time curves depart considerably from the ideal. For individual boxes the shape of the curves, the amount of deflection at a given time and load, and the deflections reached before failure can be quite variable. This variability complicates the selection of suitable functions to describe the deflection *vs*. time curve and can give rise to poor predictions of creep failure life.

A series of deflection *vs*. time curves for Sample 2406 are illustrated in Fig. 7. The box data graphed were selected to have stacking lives near the average for the particular ratio. Preliminary trials indicated that curves of the type shown in Fig. 7 could be described by an expression of the following type

$$\text{Log } t = \text{Log } K_1 + K_2 \text{ Log}(D-D_o) \tag{3}$$

where

t = time
D = deflection

and

K_1, K_2 and D_o are constants.

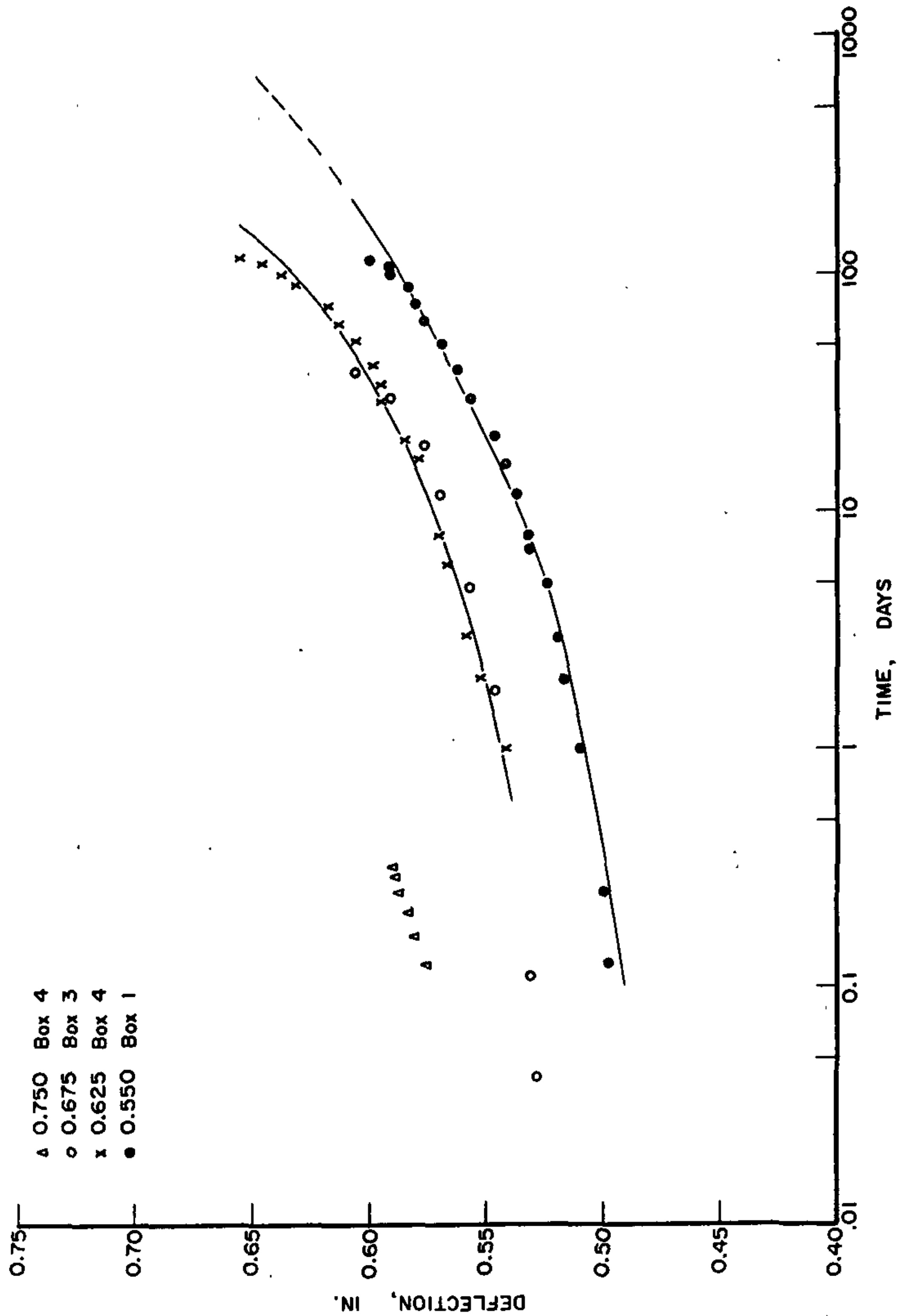

Fig. 7. Creep Deflection vs. Time Curves for Sample 2406

Equation (3) is another form of Equation (1) and has been extensively used in creep curve analyses for other materials. The curves shown in Fig. 7 are for the 0.55 and 0.625 boxes and have the form of Equation (3).

Since three constants are involved, a standard least squares solution cannot be directly obtained. For this preliminary analysis, after a few trials the constant D_o was set equal to the average deflection at 60 min. (D_6) for the given ratio. The difference (D-D_6) was then correlated with time to determine the constants K_1 and K_2.

At this stage the choice of D_6 was somewhat arbitrary. A more thorough analysis would determine whether other values of D_o might be more generally applicable. Other functional choices should also be investigated.

An analysis of the type described above was carried out for 9 boxes from Samples 2406 and 2407. A graph of (D-D_6) vs. time is shown in Fig. 8 and 9 for Samples No. 2406 and 2407, respectively. As may be noted, Equation (3) gives a reasonable fit to the data to nearly the failure point. The regression equations are summarized in Table IX. High correlation coefficients were exhibited by all the regression equations.

Estimates of box failure life were made by substituting the average value of box deflection from the conventional compression test for D. Estimates were also made at the average deflection plus or minus one standard deviation to allow for variability. These results are shown in Table X. As an example, based on the data for Box 1, Sample 2407, load ratio 0.50, a failure life of 310 days was estimated using the average deflection to failure in the box compression test (0.6400). The box actually failed at 344 days. The difference of 34 days is probably acceptable at this time. Allowing for variation in the average box

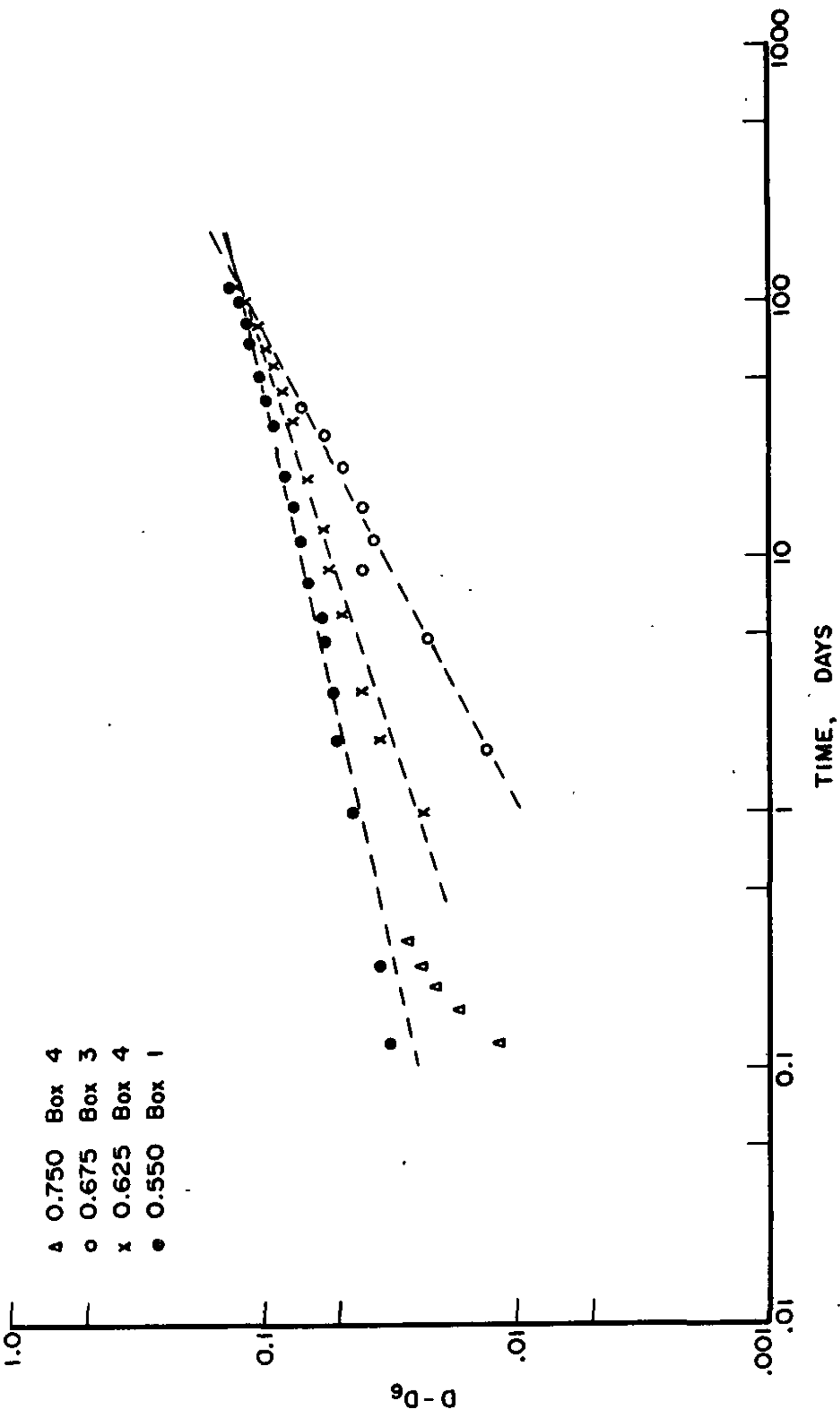

Fig. 8. Relationship Between Box Creep Deflection Difference and Time for Sample 2406

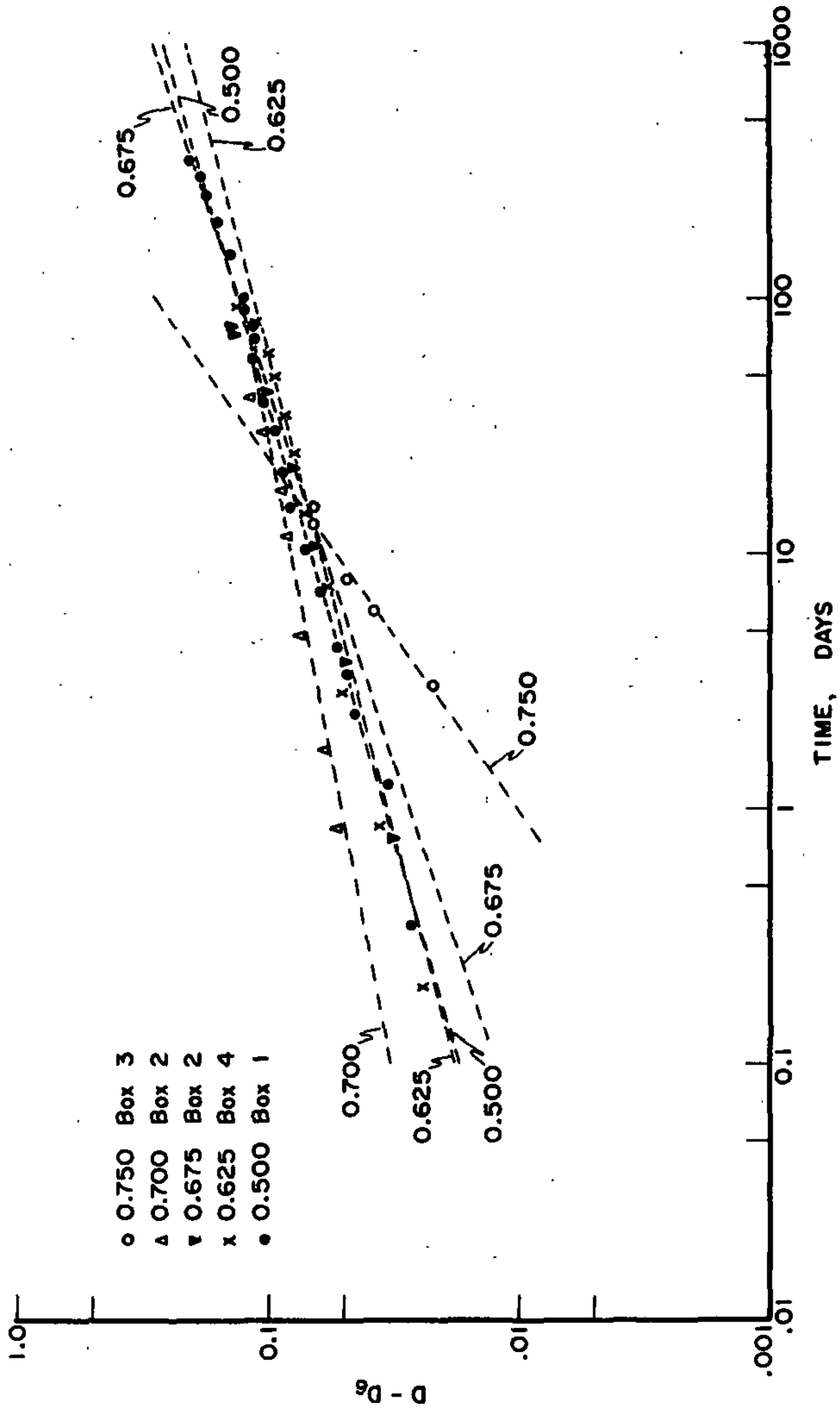

Fig. 9. Relationship Between Box Creep Deflection Difference and Time for Sample 2407

TABLE IX

DEFLECTION VS. TIME REGRESSION EQUATIONS

No.	Load Ratio	Specimen No.	N	N_1[a]	D_6	Regression Equation	Corr. Coeff.
2406	0.75	4	13	6	0.5634	$\log t = 1.2371 + 1.120 \log (D-D_6)$	0.97
	0.675	3	17	12	0.5336	$\log t = 3.7188 + 1.845 \log (D-D_6)$	0.98
	0.625	4	40	35	0.5185	$\log t = 4.8188 + 3.013 \log (D-D_6)$	0.99
	0.55	1	52	46	0.4656	$\log t = 6.0822 + 4.441 \log (D-D_6)$	0.99
2407	0.75	3	10	5	0.5415	$\log t = 2.7551 + 1.382 \log (D-D_6)$	0.99
	0.70	2	22	18	0.5698	$\log t = 6.3859 + 4.962 \log (D-D_6)$	0.98
	0.675	2	28	23	0.5665	$\log t = 4.6538 + 3.066 \log (D-D_6)$	0.99
	0.625	4	34	30	0.5097	$\log t = 5.6329 + 3.891 \log (D-D_6)$	0.99
	0.50	1	83	76	0.4534	$\log t = 5.0558 + 3.475 \log (D-D_6)$	0.99

[a] The number of data points after discarding negative values of $D-D_6$ and time values less than 0.1 day.

TABLE X

ESTIMATES OF BOX FAILURE LIFE

No.	Load Ratio	D[b]	D-D6	Box Creep Life, days: Estimated	Observed: Selected Box	Observed: Av.[a]	Observed: Max.[a]	Observed: Min.[a]
2406	0.75	0.5900	0.0266	0.24	0.32	0.38	0.50	0.22
		0.6427	0.0793	0.98				
		0.5373	--	--				
	0.675	0.5900	0.0564	19	38.4	37.8	62.1	20.4
		0.6427	0.1091	85				
		0.5373	0.0037	--				
	0.625	0.5900	0.0715	25	115.4	77.4	155.7	4.8
		0.6427	0.1242	115				
		0.5373	0.0188	0.45				
	0.55	0.5900	0.1244	120	113.3	161.4	243.6	113.3
		0.6427	0.1771	420				
		0.5373	0.0717	11				
2407	0.75	0.6400	0.0985	23	15.5	12	32.1	0.44
		0.6651	0.1236	32				
		0.6149	0.0734	12				
	0.70	0.6400	0.0702	4.5	40.6	32.7	41.7	20.4
		0.6651	0.0953	22				
		0.6149	0.0451	0.52				
	0.675	0.6400	0.0735	18	76.4			
		0.6651	0.0986	41				
		0.6149	0.0384	2.7				
	0.625	0.6400	0.1303	160	93.8	54.8	95.9	13.6
		0.6651	0.1554	300				
		0.6149	0.1052	72				
	0.50	0.6400	0.1866	310	344	550.3	728.9	344.0
		0.6651	0.2117	520				
		0.6149	0.1615	200				

[a]Average, maximum and minimum of the four test results at each load ratio.
[b]Failure lives read at the average box deflection and the average ± 1 standard deviation.

compression deflection of ± one standard deviation gave estimates of 200 and 520 days. This implies that the odds should be about 1 in 3 that the life is less than 200 or more than 520 days. Even wider limits would be obtained by using 2 or 3 standard deviation limits.

In Table X the agreement with observed values is not good in all cases although a more extensive analysis may improve predictions. Extremely accurate estimates cannot be expected, however, because of the variability in box creep test as shown in Table II.

To be of utility, however, the constants in the regression equations must be constant for most combined board constructions or must vary in some predictable manner with the applied load ratio and short-term tests. In this connection it seems likely that D_6 can be related to the applied load ratio, and the maximum deflection in the conventional compression test.

In Table IX the regression equation slope is smallest for the 0.75 ratio. However, the high ratios are not of great practical interest because they result in short box lives. At the lower load ratios, it is possible the slope coefficient might be either constant (Sample 2407) or related to the load ratio (2406). Additional work is needed to clarify whether either hypothesis is workable. The same remarks hold true for the intercept coefficients in Table X.

It should be emphasized that other mathematical expressions might be suitable for this type of analysis. The investigation of alternative solutions should certainly be carried out in future work.

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