TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 78.

IMPACT TESTS FOR WOODS.

By

Bureau of Standards.

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Although it is well known that the strength of wood depends greatly upon the time the load is applied little consideration has been given to this important fact in testing material for airplanes. It is the purpose of this paper to present results obtained in impact tests for woods conducted under the direction of Professor H. L. Whittemore, Bureau of Standards, for the Committee on Materials for Aircraft of the National Advisory Committee for Aeronautics.

Woods having the greatest strength for their weight are used for Airplane wing beams although the static and compression tests upon which the selection is made do not represent even approximately, the actual loading conditions on the airplane structure. In normal flight, the loads are fairly constant if the effect of vibration is neglected. In stunting during which the maximum loads occur, the excessive load is only applied for about five seconds at most. Again in landing, forces are suddenly applied through the landing wheels which may cause the failure of other parts of the structure.

Many tests have shown that the strength of wood loaded for many months is about half that which would produce failure in, say one-half hour.* The resistance to loads applied for a very short time are known to be greater still. For example, the fiber stress at the elastic limit in impact bending in which the stress is applied and relieved in 1/25 second or less, is about twice the value for static bending.** If the effect of time under load was known to be the same for all woods then reliance could be placed on the results of the usual static tests, such as the transverse, to determine the relative value of the material, but on the other hand, impact tests may give information unobtainable from other tests. In this connection Record's opinion may be of interest.***

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* Johnson's "Materials of Construction," 5th edition, 1918, p. 208.

** Bulletin No. 556 - "Mechanical Properties of Wood." p. 27, etc.

*** Samuel J. Record - "Mechanical Properties of Wood," p. 33.

"Impact testing is difficult to conduct satisfactorily and the data obtained are of chief value in a relative sense, that is, for comparing the shock resisting ability of woods of which like specimens have been subjected to exactly identical treatment. Yet this test is one of the most important made on wood, as it brings out properties not evident from other tests. Defects and brittleness are revealed by impact better than by any other kind of test. In common practice nearly all external stresses are of the nature of impact. In fact no two moving bodies can come together without impact stress. Impact is, therefore, the commonest form of applied stress, although the most difficult to measure."

If the impact or suddenly applied loading test can be made cheaply and easily it might replace the transverse and other test for wood, particularly for acceptance of material. For airplane woods, it would have the advantage of testing the material under the conditions under which the maximum loads are applied. It has often been claimed and Record agrees that an impact test is more useful than the static tests for detecting "Brash" or brittle material. The value of this so-called "brittleness" test is shown by the specification for mahogany (Central American) V 7-November 1918 of the British Engineering Standards Association. The impact test is required but, the transverse test is optional with the inspector.

A summary of the requirements of the British Standard Specifications for Aircraft Materials and the Air Board Specifications are given in Table 1. The tests for brittleness are made in an Izod impact machine having a tup weighing 20 lbs., swinging on a radius of 2 ft. When the tup is released from the usual horizontal position the available energy is 40 ft. lb.

Table 1.

Specification	Material	Standard specimen shall absorb not less than
British Engineering Standards Association British Standard Specifications for Aircraft Materials V.4, Nov. 1918	Ash	10
" V.7 "	Mahogany (Central American)	6
" V.6 "	Mahogany (West African)	6
" V.5 "	Walnut	9
Airboard 2 v. 1, July 1918	Silver spruce and approved substitutes	
	Grade A	8
	Grade B	4

Of the impact tests made in this country those reported by the Forest Products Laboratory in their extensive investigation of the Mechanical Properties of Woods, are perhaps, the best known. The impact bending test is made upon a beam 2 by 2 by 30 inches over a length of 28-inch span. A 50-lb. hammer is dropped upon the stick at the center of the span, first from a height of 1 inch, next 2 inches, etc., up to 10 inches, then increasing 2 inches at a time until complete failure occurs. The deflections of the specimens are recorded on a revolving drum by a pointer attached to the hammer. This pointer also records the position the specimen assumes after the shock. Thus data are obtained for determining the various properties of the wood when subjected to shock.*

Although this test is very valuable, the results do not allow a comparison to be made of the energy required to break two different materials. Until the stress in the specimen reaches the elastic limit all of the energy of the blow is returned to the hammer and should not be considered in computing the impact resistance of the material. After the specimen takes a permanent set, only part of the energy is returned, the remainder causing permanent injury of the material. This portion in-

* See Note 2, Page 15.

creases as the height of fall is increased until failure occurs. It is evident, therefore, that the energy of the hammer does not measure the impact resistance of the wood, and that a comparison of two woods cannot be made by comparing the energy absorbed.

In addition, there are a number of ways in which a transverse wood specimen may fail, "classified according to the way in which they develop tension, compression and horizontal shear and according to the appearance of the broken surface as brash or fibrous." This somewhat complicates the direct comparison of two specimens.*

After consideration of the test methods outlined above, the Bureau of Standards undertook a preliminary investigation of impact tests of wood. Testing machines of the pendulum type were used as the energy absorbed by the specimen can be read directly from the height to which the tup rises after striking the specimen. A study of the most suitable form of specimen was made to obtain one which was thoroughly practicable.

No values for woods of different species were obtained and no detailed study was made of the material used for these tests. Whenever possible, comparisons are made of specimens cut from the same stick.

Testing Machines.

Transverse Test - These tests were made in a Riehle Universal machine having a capacity of 50,000 lbs. The apparatus for measuring the deflections as well as the method of applying the load was similar to that used by the Forest Products Laboratory** Two Wisler dial micrometers, one on each side of the specimen, were connected to it by fine copper wire which was wound on the pointer axle.

Impact Test - Izod. - A regular Izod machine made by Bultman Company, for metal specimens was modified by substituting a heavy steel block bolted to the frame for the specimen vise and clamping the wood specimens with a strap bolted to this block. This machine is shown in Fig. 1. The maximum energy available is 120 ft. lb. and the energy absorbed by the specimen is read directly from the graduated dial at the top of the machine. The specimen was protected where struck by the tup by a 1/16 in. sheet steel cap.

Impact Test - Charpy type. - To allow specimens to be tested under transverse loading, a pendulum impact machine shown in Fig. 2, was designed and built having a tup formed like that of

* See Note 3, Page 33.
** See Note 2, Page 12.

a Charpy impact machine. This had a broad striking face back of the center of gravity of the tup and with the center of the striking face at the same distance from the axis as the center of percussion. In this way, the conditions which have been found to give good results with the Charpy machine, were at least approximately fulfilled for this impact machine for wood.

The specimen was supported horizontally upon two blocks which moved in a slotted base to obtain any span up to 36 inches. The tup weighed the same as that for the Izod machine and the available energy was the same, 120 ft. lb.

Outline of Tests.

(a) Material. All the wood was clear straight grained, spruce intended for airplane use, which was well seasoned. All the woods were said to be spruce, stick A being Sitka spruce and sticks H and I spruce from North Carolina. The moisture content and specific gravity for each wood are given in Table 2. The annular rings were, in all specimens, parallel to the direct motion of the tup.

Table 2.

Moisture Content and Specific Gravity of Woods.

Wood	Moisture content %	Specific gravity
A	9.145	0.475
B	9.21	.44
C	8.335	.36
D	9.47	.505
E	9.75	.535
G	9.51	.40

(b) Transverse Tests. In order to obtain data for comparison with that from the impact tests, transverse tests were made on several of the sticks. The specimens were 2 by 2 by 31 inches and were tested on a span of 28 inches. Some were notched as described below for the impact tests at the middle of their length. Load deflection diagrams were drawn and the energy required to rupture the specimens computed.

(c) <u>Impact Tests - Izod</u>. Unless varied for the purpose of studying the effect on the results, the following conditions were maintained constant during these tests.

a. The energy of the blow was 120 ft. lb.

b. The distance of the striking edge from the top surface of the clamping block was 2.5 in.

c. The center of the notch, if any, was in line with the top of the clamp block.

d. The upper edge of the strap clamping the specimen was very slightly rounded.

e. A constant torque, approximately 5 lbs. on a lever arm of 8 in. or 40 in. lb. was used for each of the 3/4 in. screws holding the clamp.

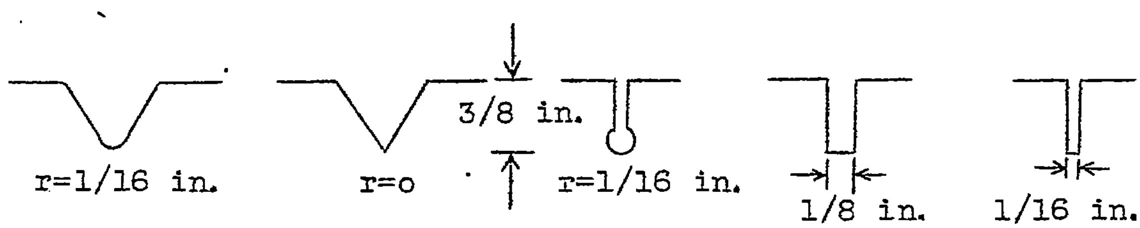
f. The depth of the notch, if any, was 3/8 inch.

g. The length of the clamped portion of the specimen was 4 in.

The following conditions were varied:

A. <u>Cross Sectional Area</u>:- Two sizes of specimens were used, the first 7/8 by 7/8 and the second, 1 by 1-3/8 in. After notching to a depth of 3/8 in. the dimensions were 7/8 by 1/2 and 1 by 1 in. and the sectional areas were about 0.43 and 1.00 sq. in. respectively.

B. <u>Form of Notch</u>:- These forms of notch were used:



I II III IV V

C. <u>With and Without Notch</u>:- Specimens with and without notch were used.

D. Length of Clamped Portion:- Specimens which were clamped for two inches were used as well as those clamped for four inches.

E. Energy of Blow:- Blows delivering an energy of 60 ft. lb. were used as well as those delivering 120 ft. lb.

F. Radius of Strap Edge:- A radius of 1/8 in. was used as well as the sharp edge.

G. Clamping Pressure:- Torques of 16 in. lb. and 80 in. lb. obtained by exerting forces of 2 and 10 lbs. respectively on a wrench 8 in. long were used.

(d) Impact Tests - Charpy Type. Due to the high impact resistance of the wood used for this work, it was found impossible to fracture many of the larger specimens. The limited amount of material available made it impracticable also to make a sufficient number of specimens to determine the value of this method of test.

The energy of the blow was in all cases 120 ft. lb. and the span 28 in. The following conditions were varied during these tests:

A. Cross Sectional Area:- Two sizes of specimens were used, the first 1.50 in. square and the second 2.00 in. square.

B. With and Without Notch:- Some were tested with notch and some without.

Test Results.

Transverse Tests - The results of the transverse tests are given in Table 3, and typical load deflection graphs shown in Figs. 3, 4, 5 and 6. Although the small number of tests made it impossible to obtain all the information desired, it will be noted that the total energy increased with an increase in the modulus of rupture and in a greater ratio. The total energy for the notched specimens is less than for those without the notch, as was to be expected, and the energy per square inch of sectional area is practically the same for the C specimens which are the only ones which can be compared.

Table 3.

Transverse Tests.

Wood	Specimen numbers	Notch	Modulus of rupture lb/sq.in.	Energy absorbed		
				ft/lb.	ft.lb/sq.in.	Variation per cent
E	1-3	Without notch	14,060	191.2	47.8	3.2
C	8-10	"	9,530	88.4	22.0	14.8
C	14-16	I	9,330	66.2	19.4	22.3
G	4, 5, 13	I	10,730	56.1	17.4	31.2
B	6,7,11,12	I	11,200	78.2	24.1	61.2

It is very noticeable that the consistency of the results is much greater for the specimens without the notch. If the energy is to be determined by a static transverse test the same average values will be obtained with the notched as with the plain specimens but the variation of the results will be greater for the former.

Impact Test - Izod - The results of these tests are given in Tables 4, 5, 6, 7, 8, 9 and 10, and fractured specimens shown in Fig. 7. Unless otherwise stated the results are the averages for at least six specimens. It is evident that the energy absorbed is not proportional to the sectional area but the energy per square inch of sectional area is given in these tables as this value is often reported for impact tests.

In order to show the consistency of the readings the average variation is given. This is obtained by computing the average energy absorbed and then the average variation in per cent of the individual results from this value. If a given specimen has a low variation value, reliable results may be obtained from fewer specimens than if a specimen having a higher variation is used.

A. Variable Cross Sectional Area - Table 4. It will be noted that the larger specimens have the higher impact values and also the higher values for the energy per unit area. There is no constant ratio between these values for a given material nor for any form of notch. The larger specimens also have the advantage that the variation in the results is much less than for the smaller specimens.

B. Variable Form of Notch - Table 5. The energy absorbed is independent of the form of the notch but the variation of the results depends somewhat on the notch. Averaging the variations for each notch gives I 10.8, II 16.5, III 16.1, IV 16.3 and V 6.0 per cent. The number of specimens with notch V is too small to consider the low value for this notch reliable. The value for notch I obtained from a large number of specimens shows an apparent advantage for this form. As it has a smooth fillet at the bottom of the notch this was to be expected but apparently notch III should give equally good results. It is remarkable that notches II, III and IV all give 16 per cent, which may be taken as the average variation of the energy from the normal value for notched specimens similar to these.

C. Specimens with and without Notch - Table 6. The results on wood C are the averages from specimens having variable clamped length but the same relation between notched and unnotched specimens is found if the results for each clamped length are compared. There is a noticeably greater energy absorbed by the notched and the variation which is low is about the same for both. There is no advantage in obtaining a high value for the energy of the results are consistent. There is, however, a decided advantage in using the unnotched specimen.

D. Variable clamped Length - Table 7. The energy absorbed by the specimens clamped for 4 in. is considerably greater than for those clamped for 2 in. and averages about 23 per cent. The short clamped length allowed the specimen to crush due to the high bearing stress and so absorb energy.

The variation averages 11.9 per cent for the 2 in. and 9.8 for the 4 in. lengths. As there is no advantage in obtaining a high value for the energy but a low variation is important, it is evident that the clamped length should be 4 in. or more and be a constant for all specimens.

E. Variable energy of Blow - Table 8. As the length of the clamped portion was not the same in both cases, the results are not strictly comparable. If we assume, however, that the effect of variations in the clamped length were the same for wood A as for wood C, (see Table 7) then for the 60 ft. lb. blow the value of the energy absorbed (specimens 16-2 Table 8) should be at least 18.4 ft. lb. for a 2 in. clamped length. This is about 16 per cent more than the value for the 130 ft. lb. blow. Apparently more energy is absorbed if the velocity of the tup is low but the difference is not great and the results are not definite. In impact testing it is usual to release the tup from the same position if the specimens are of similar materials.

F. Variable Radius of Strap Edge - Table 9. The amount the strap edge is rounded within reasonable limits has no influence on the results. It may be expected that with the smaller specimen the energy would increase with an increase in the radius of curvature due to the resulting increased deflection of the specimen.

G. Variable Clamping Pressure - Table 10. The results show that the clamping pressure, within reasonable limits have no effect upon the energy absorbed. The variations are very low. It should be noted that only a few specimens were tested.

Impact tests - Charpy type - Table 11. In a number of cases the specimens failed by splitting instead of by a fibrous transverse fracture.

Although the area of cross section was varied, no comparisons can be made as the wood is not the same for both. There is insufficient data to allow a comparison of these values to be made with Izod tests on the same wood.

The fact that the specimens failed by longitudinal shear and in other ways probably accounts for the high variations which are about twice that found for the Izod test. Comparing the notched and unnotched specimens it is seen that the notched absorbed less energy and probably the variation would be less than for the unnotched due to the character of the fracture.

These tests require a larger specimen than the Izod and the results are not as consistent. The available energy of this machine was much too low for the specimens tested. As the material was limited and the amount required for these specimens was much greater than for Izod specimens, comparatively few of the Charpy types were made.

Conclusions.

A. Izod Impact Test.

1. The energy absorbed is not proportional to the area of cross section.

2. Specimens 1 in. square give more uniform results than smaller specimens.

3. The difference in energy absorbed due to the quality of the material is greater for smaller specimens than for larger ones.

4. The shape of the notch has no influence upon the amount of energy absorbed with the exception of notches IV and V which perhaps give higher results.

5. Specimens with short clamped length give higher values of impact than the long length.

6. The length of the clamped portion should not be less than 4.0 in.

7. The energy of the blow has probably no influence upon the amount of energy absorbed by the specimen.

8. The radius of curvature of the edge of the strap within certain limits has no appreciable influence upon the results.

9. Unless the specimen is seriously injured the clamping pressure has no effect on the results if the specimen is held firmly.

10. Plain specimens absorb less energy than notched specimens having the same sectional area.

11. Plain specimens give, probably, as uniform results as notched ones.

12. The absorbed energy is, probably, independent of the type of machine.

13. The uniformity of results is satisfactory.

B. Charpy Type Impact Test.

1. Large specimens, with or without notch, do not always fail by fibrous transverse fracture. Failure often occurs by splitting and, therefore, the results cannot be compared with those obtained from small Izod specimens.

C. Transverse Tests.

1. The remark made in regard to the large impact specimens of the Charpy type, holds true for transverse test also.

2. The pendulum impact test of wood is a quick and inexpensive method of determining its resistance to suddenly applied loads and also the quality of the material in general.

3. The specimen for the Izod machine always fractures in the same way and, therefore, the results on different materials may be compared.

4. This preliminary investigation shows that the impact test can be readily standardized and that further work in this direction is desirable.

Table 4.
Izod Test.
A. Variable Cross Sectional Area.

Magnitude of variable	Notch	Net Sectional area sq.in.	Length of clamped portion in.	Wood	Specimen number	Energy absorbed ft.lb.	ft.lb. sq.in.	variation per cent
0.401	I	0.401	2.0	A	23-28	16.28	40.83	14.2
0.968	"	0.968	2.0	A	50-56	62.46	64.69	7.3
0.414	III	0.414	2.0	A	30-35	15.53	36.05	24.9
0.968	"	0.968	2.0	A	57-62	63.95	65.97	12.8
0.412	I	0.412	2.0	C	22-28	6.12	14.79	10.3
0.964	"	0.964	2.0	C	50-56	44.56	46.19	8.1
0.414	III	0.414	2.0	C	29-35	5.34	12.96	20.8
0.979	"	0.979	2.0	C	57-63	46.16	49.90	6.0
0.437	I	0.437	4.0	H	22-28	8.13	18.6	9.8
0.980	"	0.980	4.0	H	50-56	28.9	29.5	15.2
0.457	II	0.457	4.0	H	16-21	8.22	18.0	6.7
1.010	"	1.010	4.0	H	43-48	29.8	29.5	26.2
0.473	IV	0.473	4.0	H	9-15	8.92	18.9	18.8
1.040	"	1.040	4.0	H	29-34	35.6	34.2	13.7

Table 5.
Izod Test.
B. Variable Form of Notch.

Magnitude of variable	Notch	Net Sectional area sq.in.	Length of clamped portion in.	Wood	Specimen number	Energy absorbed ft.lb.	Energy absorbed ft.lb./sq.in.	Energy absorbed variation per cent
1/8 in. wide	IV	1.040	4.0	H	29-34	35.6	34.2	13.7
1/32 in. wide	V	1.000	4.0	H	36-42	38.5	38.5	6.0
Radius at the bottom of notch = 0	II	1.010	4.0	H	43-48	29.8	29.5	26.2
" = 1/16 in.	I	0.980	4.0	H	50-56	28.9	29.5	15.2
1/8 in. wide	IV	0.473	4.0	H	9-15	8.92	18.9	18.8
Radius at the bottom of notch = 0	II	0.457	4.0	H	16-21	8.22	18.0	6.7
" = 1/16 in.	I	0.437	4.0	H	22-28	8.13	18.6	9.5
V notch with r = 1/16 in.	I	0.401	2.0	A	23-28	16.28	40.83	14.2
Charpy notch with r = 1/16 in.	III	0.414	2.0	A	30-35	15.53	36.05	24.9
V notch with r = 1/16 in.	I	0.968	2.0	A	50-56	62.46	64.69	7.3
Charpy notch with r = 1/16 in.	III	0.968	2.0	A	57-62	63.95	65.97	12.8
V notch with r = 1/16 in.	I	0.412	2.0	C	22-28	6.12	14.79	10.3
Charpy notch with r = 1/16 in.	III	0.414	2.0	C	29-35	5.34	12.96	20.8
V notch with r = 1/16 in.	I	0.964	2.0	C	50-56	44.56	46.19	8.1
Charpy notch with r = 1/16 in.	III	0.979	2.0	C	57-63	46.16	49.90	6.0

Table 6.
Izod Test.

C. Specimen with and without Notch.

Magnitude of variable	Notch	Net cross-sectional area sq.in.	Length of clamped portion in.	Wood	Specimen number	Energy absorbed ft.lb.	Energy absorbed ft.lb./sq.in.	Energy absorbed variation per cent
The depth of notch = 0	Without notch	1.055	4.0	I	25-36	27.7	26.2	6.2
The depth of the notch = 3/8 in.	III	1.015	4.0	I	13-24	33.2	32.8	9.5
The depth of notch = 0	Without notch	0.955	2.0 and 4.0	C	2-7	30.8	29.2	8.5
The depth of the notch = 3/8 in.	III	0.965	2.0 and 4.0	C	36-41 50-63	43.8	45.3	5.5

Table 7.
Izod Test.
D. Variable Clamped Length.

Magnitude of variable in.	Notch	Net Sectional area sq.in.	Wood	Specimen number	Energy Absorbed ft.lb.	Energy Absorbed ft.lb. sq.in.	Energy Absorbed Variation per cent	Energy Absorbed Ratio of Energy*
2	Without notch	0.955	C	5-7 (3 only)	33.1	34.6	8.0	1.25
4	"	0.955	C	2-4 (3 only)	26.5	27.6	9.0	
2	III	0.414	C	29-35	5.34	12.96	20.8	1.20
4	III	0.415	C	16-21	4.50	10.84	16.6	
2	I	0.965	C	50-63	46.36	48.05	7.0	1.23
4	I	0.955	C	36-41	37.32	39.05	3.9	

* Ratio given in last column reports ratio of energy absorbed by the short and long specimens.

Table 8.
Izod Test.
E. Variable Energy of Blow.

Magnitude of variable ft.lb.	Notch	Net sectional area sq.in.	Length of clamped portion in.	Wood	Specimen number	Energy absorbed		
						ft.lb.	ft.lb. / sq.in.	Variation per cent
60	III	0.435	4.0	A	16-21	14.9	34.4	28.6
120	III	0.414	2.0	A	30-35	15.82	38.44	24.9

Table 9.
Izod Test.
F. Variable Radius of Strap Edge.

Magnitude of variable	Notch	Net sectional area sq.in.	Length of clamped portion in.	Wood	Specimen number	Energy Absorbed		
						ft.lb.	ft.lb. / sq.in.	Variation per cent
Radius = 0	III	1.015	4.0	I	1-6 and 13-18	34.5	34.1	10.9
Radius = 1/8 in.	III	1.002	4.0	I	7-12 and 19-24	34.4	34.3	11.7
Radius = 0	Without notch	1.060	4.0	I	32-36	27.5	25.9	5.7
Radius = 1/8 in.	Without notch	1.050	4.0	I	25-30	27.8	26.5	6.8

Table 10.
Izod Test.
G. Variable Clamping Pressure.

Magnitude of variable ft.lb.	Notch	Net sectional area sq.in.	Length of clamped in.	Wood	Specimen number	Energy Absorbed ft.lb.	ft.lb. sq.in.	Variation per cent
16	I	0.985	4.0	C	46-49 (4 only)	48.6	49.3	4.2
80	I	0.953	4.0	C	43-45 (3 only)	50.6	53.0	4.1
16	I	0.420	4.0	C	11-14 (4 only)	6.1	14.5	10.2
80	I	0.428	4.0	C	8-10 (3 only)	5.7	13.3	7.0

Table 11.
Impact Tests in Charpy Type Machine.

Wood	Specimen numbers	Width	Specimens depth	Notch	Net sectional area sq.in.	Energy Absorbed ft.lb.	ft.lb. sq.in.	Variation per cent.
A	27-32	1.50	1.52	Without notch	2.280	88.3	38.8	27.0
D	33-36	1.46	1.51	Without notch	2.200	119.4	54.3	30.7
G	17-19	1.98	1.99	I	3.190	82.4	25.8	6.5
B	20	1.99	1.99	Without notch	3.960	151.0	38.1	-
B	22-23	1.99	1.99	I	3.083	51.2	16.6	1.97

Fig.1.

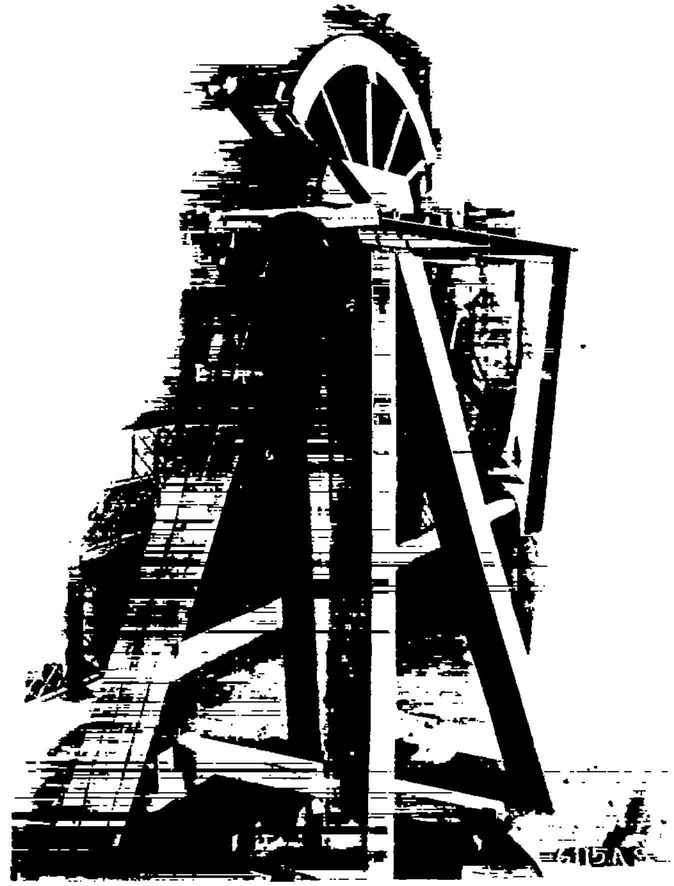


Fig.2.

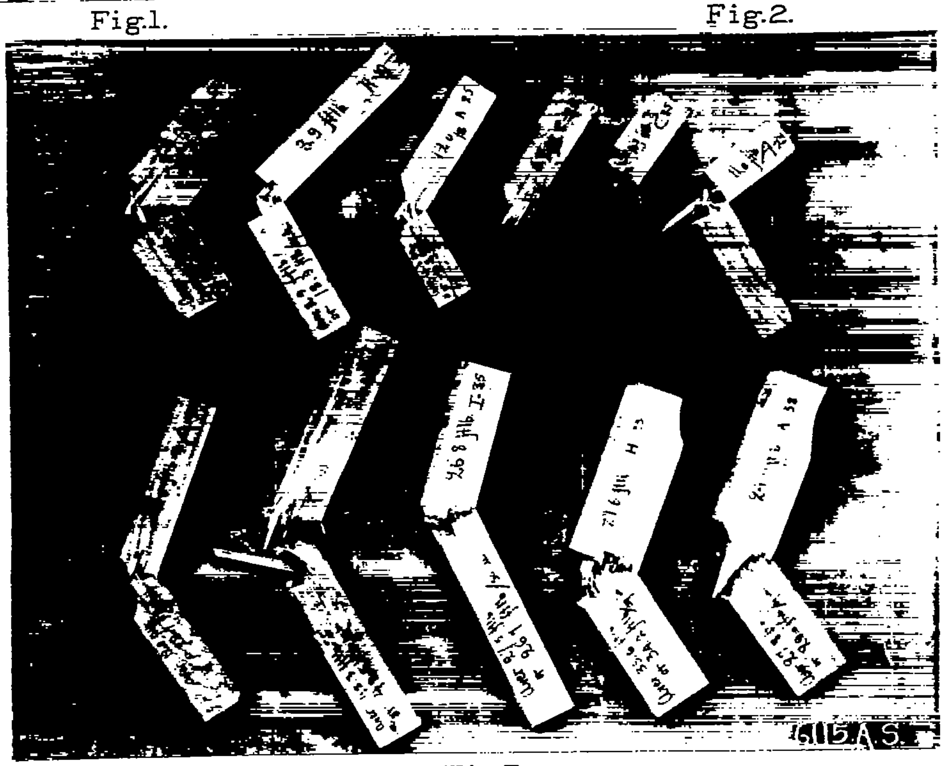


Fig.7.

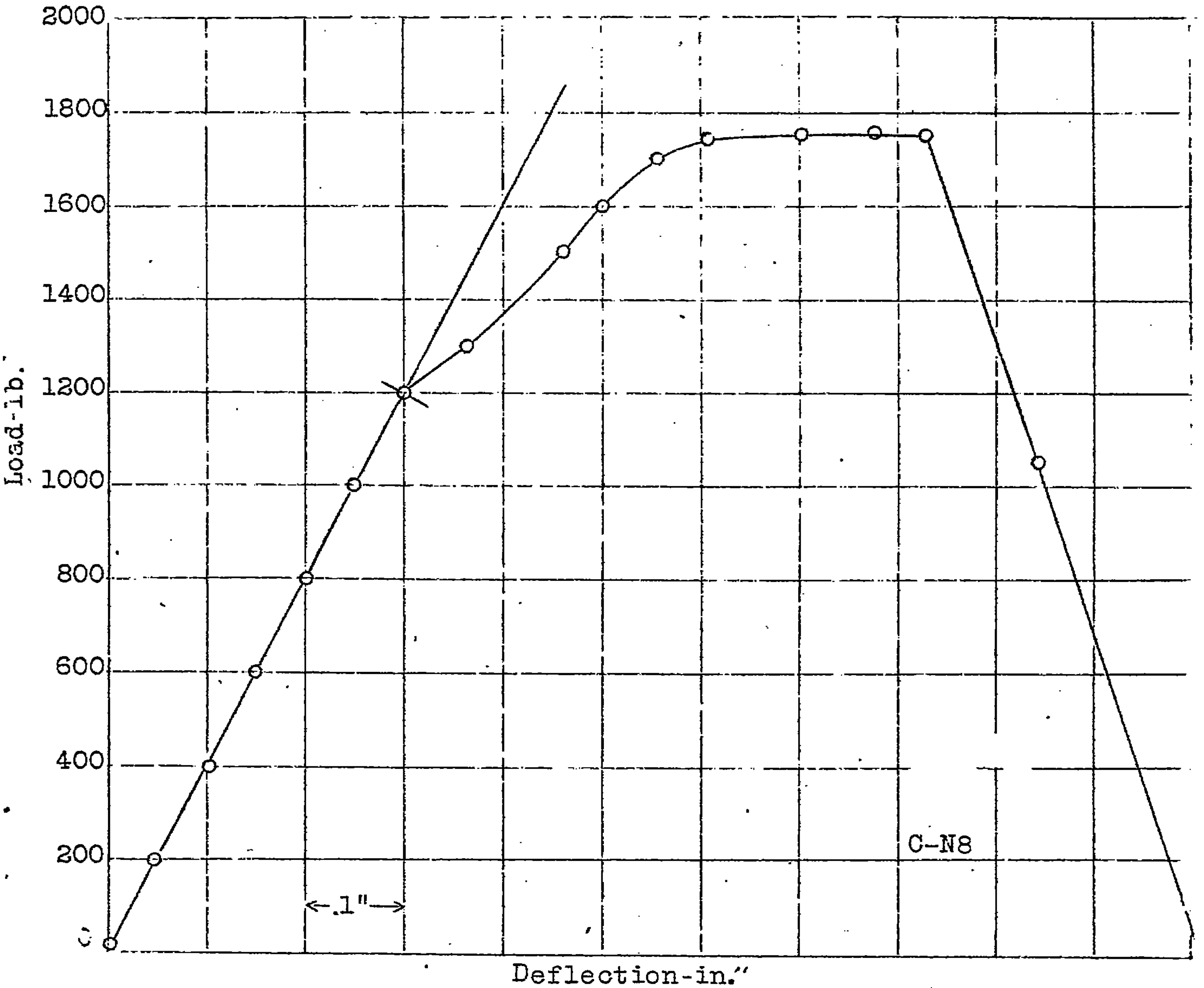


Fig. 3 - Transverse test of spruce without notch.

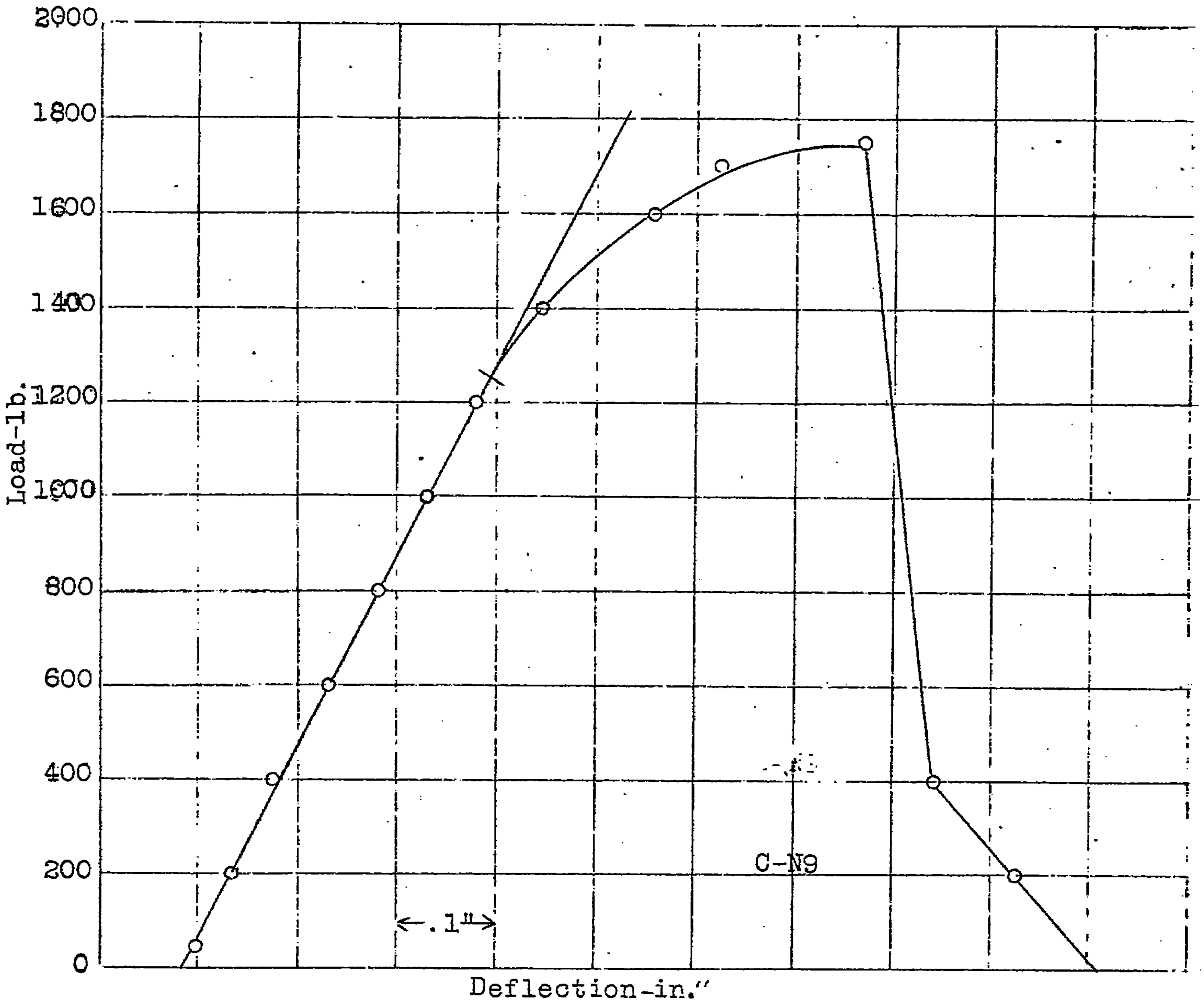


Fig. 4 - Transverse test of spruce without notch.

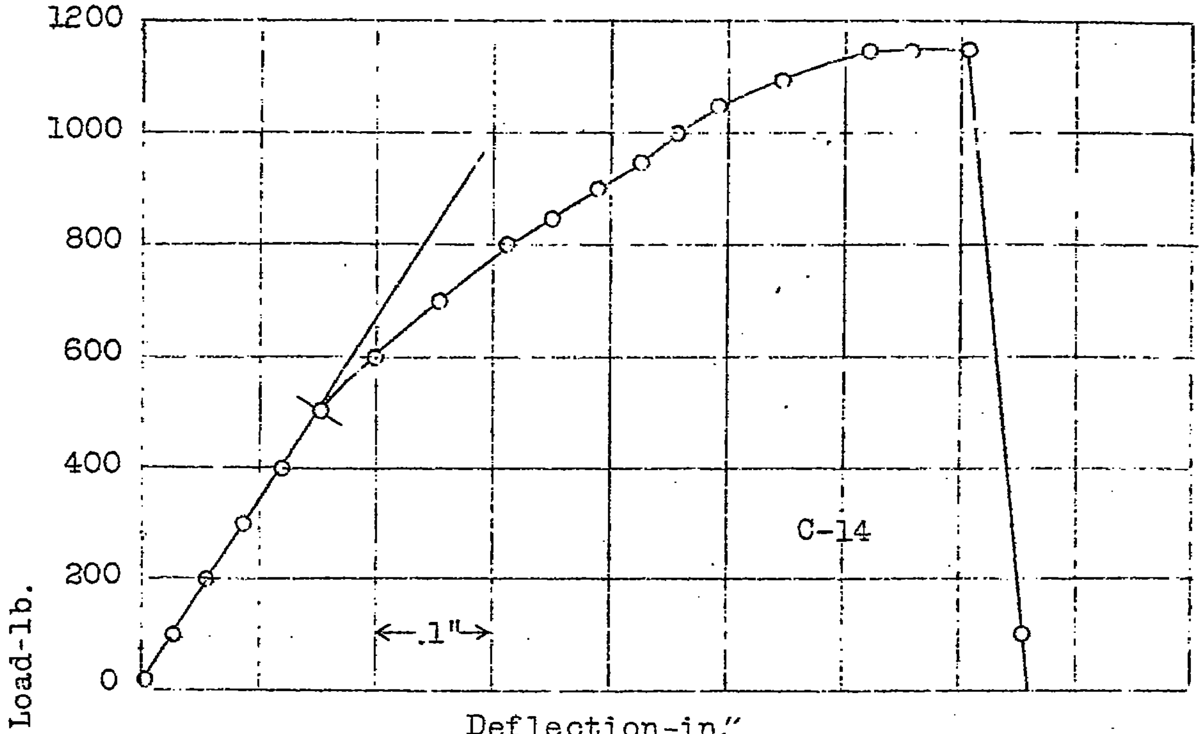


Fig. 5 - Transverse test of spruce with notch.

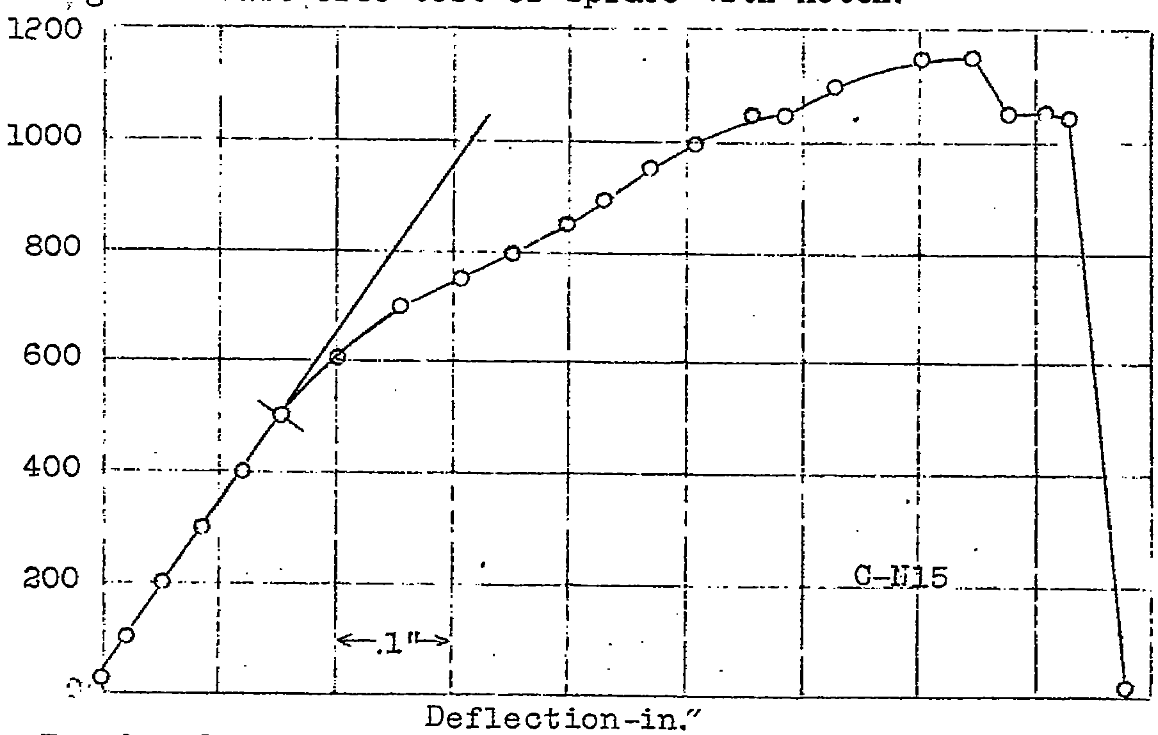


Fig. 6 - Transverse test of spruce with notch.