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MECHANICAL PROPERTIES OF
THE INLAND EMPIRE DOUGLAS FIR

by

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requirement for the degree of
Master of Science

Montana State University
1938

Approved:

/s/ J. H. Ramskill

Chairman of Board of
Examiners.

/s/ W. G. Bateman

Chairman of Committee
on Graduate Study.

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INTRODUCTION

It is recognized that the Rocky Mountain type of Douglas fir (Psuedotsuga taxifolia) is inferior in strength to the Pacific Coast type. Pacific Coast fir rather than Rocky Mountain material is specified in building contracts due to its superior strength and because better data on these strength properties is available.

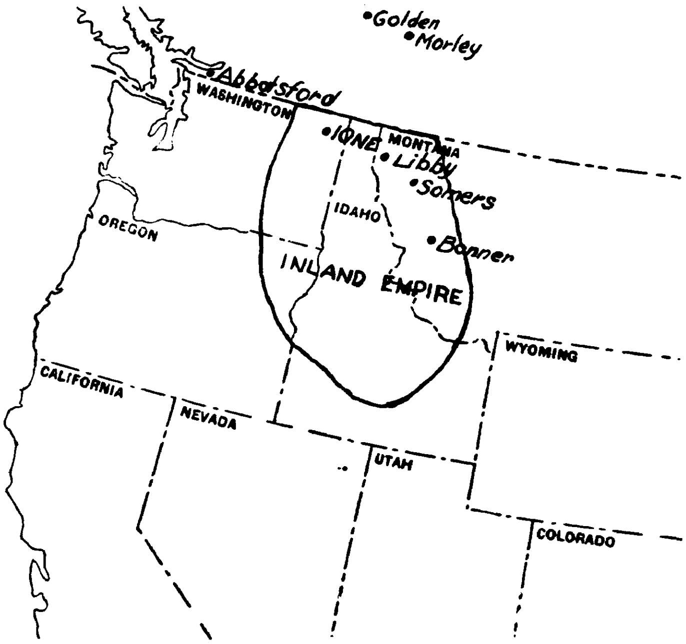


Figure 1.-Map of Inland Empire region.

However, it was believed that Douglas fir from the region known as the Inland Empire was superior to the Rocky Mountain fir, and compared favorably with that from the Pacific Coast. "The 'Inland Empire' region comprises northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon." (18)

See figure 1. On investigation of the mechanical properties of the Inland Empire Douglas fir was undertaken at Montana State University in order to derive a set of strength values, by which Inland Empire fir could be compared with the Rocky Mountain and Pacific Coast types and be given due recognition for its strength properties; and in order to determine the relationship between these strength values and the following related properties, namely, specific gravity, percentage of summer wood, and rings per inch (rate of growth), and if possible to determine the relationship of strength to locality of growth.

Review of Previous Work

A study of the effect of locality of growth upon strength properties of Douglas fir was made by the Forestry Branch of the Canadian Department of Interior. It was found that of three localities, material from Abbotsford on the coast of British Columbia was the strongest and material from Morley, Alberta, on the eastern slope of the Rocky Mountains the weakest, with material from Golden, British Columbia on the western slope having strength properties approximately midway between those for material from the other two localities, (5) p. 26-28.

Tests made by the U. S. Forest Products Laboratory show the same trend, the Douglas fir of greatest strength being the Pacific Coast type, the material of least strength being the Rocky Mountain type, and the Inland Empire material having strength properties higher than the Rocky Mountain fir but lower than the Pacific Coast type of fir.

A Canadian study was made of the relationship of rate of growth and percent of summer wood to specific gravity and maximum crushing strength. This work shows an optimum growth rate for each species above or below which specific gravity and maximum crushing strength decrease, and also shows a general increase in specific gravity and maximum crushing strength for higher percentages of summer wood, (21) p. 10-13.

The relationship between specific gravity and strength for all species both coniferous and hardwood has been worked out in equation form by the U. S. Forest Products Laboratory. It was found that strength varied either directly proportional to or as a power of specific gravity, (23) p. 60.

Methods and Procedure

Selection of Material

The material tested in this investigation was donated by five Inland Empire lumber companies: The J. Neils Lumber Company at Libby, Montana; the Somers Lumber Company, Somers, Montana; The Pan Handle Lumber Company, Ione, Washington; The White Pine Sash Company, Missoula, Montana; and The Anaconda Copper Mining Company, Lumber Department at Bonner, Montana. The material was sawed from logs going through the mill as it was not possible to obtain selected growing material in the woods, due to the expense that would have been incurred. The sources of material and general locality of growth are tabulated in table 1. The test material was sawed in planks 6 feet long, 8½ inches wide, and 2½ inches thick. The planks were shipped in a green condition. Each shipment or lot was identified by a number.

Testing of Material

Tests were made for static bending, compression parallel to grain, and

Table 1.- Source of material used in tests, and number of tests made for each lot

Lot No.	Sawmill		Locality of growth	No. tests made
	Company	Location		
1	Anaconda Copper Mining Co.Lbr.Dept.	Bonner, Montana	Blackfoot Valley, Mont.	2
2	White Pine Sash Co.	Missoula, Mont.	Ravalli County, Mont.	2
3	J. Neils Lbr. Co.	Libby, Montana	Lincoln County, Mont.	17
4	Somers Lbr. Co.	Somers, Montana	Flathead County, Mont.	12
5	J. Neils Lbr. Co.	Libby, Montana	Lincoln County, Mont.	6
6	Anaconda Copper Mining Co.Lbr.Dept.	Bonner, Montana	Blackfoot Valley, Mont.	4
7	Pan Handle Lbr. Co.	Ione, Washington	Pend Oreille Co., Wash.	6
8	J. Neils Lbr. Co.	Libby, Montana	Lincoln County, Mont.	9

shear parallel to grain. An Olsen testing machine of 30,000 pounds capacity, designed for testing wood, was used in this work. The machine was belt driven by a 5 H.P. electric motor with a constant speed of 1,300 R.P.M. The speed of descent of the loading head was regulated by means of a gear box on the testing machine, being .105 inches per minute for static bending tests, .024 inches per minute for tests in compression parallel to grain, and .015 inches per minute for tests in shear parallel to grain. Figure 2 is a view of the laboratory and testing machine.

The test pieces for static bending were cut to a size of 30 inches in length and 2 inches square, with the annual rings parallel to one side of the piece, and with the grain as nearly parallel to the longitudinal edges of the piece as possible, no cross grain with a slope of more than one in twenty being allowed. The cross sectional dimensions of the beam were calipered to within .001 inch before testing. The beam was then placed with the side nearest the pith upward, on roller bearing plates resting on knife edges placed 28 inches apart. The load was applied at the center by a rounded maple block attached to the loading head, until failure occurred.

After the static bending test the undamaged portions of the beam were used for tests in compression parallel to grain and shear parallel to grain. Test pieces used in compression tests were cut 2 inches square and 8 inches in length. In order that failure would occur near the middle of the test block, each was wrapped in paper with only the ends exposed and allowed to dry 12 hours in a warm room. The increased strength at the ends of the

Figure 2 - View of Laboratory.

test piece, due to lowering of the moisture content, caused failure under test to always occur in the middle portion of the block. In order to obtain a uniform distribution of pressure over the ends of the block, the load was transmitted from the machine to the upper end of the test piece through the flat face of a hemispherical bearing block, which may be seen in figure 2 on the work bench to the left of and behind the testing machine. Cross sectional dimensions were measured as for static bending test pieces.

Test blocks for shearing were cut 2½ inches long, two inches square and notched at one end, leaving a shear face 2 inches square projecting 3/4 inch from the main portion of the block. Each shearing block was cut with the annual rings parallel to the shear face. The tests were made in a metal shearing tool with a 1/8 inch offset between the supporting surface and the shearing plane. The actual dimensions of the shear face were measured with calipers before testing.

The load, being applied to a test piece by the machine, was weighed by means of scales provided on the machine. In static bending and compression parallel to grain tests, the load was recorded at 15 second intervals. In shearing tests the scale beam was kept balanced constantly till failure occurred, only the maximum load being recorded.

As the testing machine runs at a constant rate of speed and the load was recorded at regular intervals, the deflections of the sample being tested were computed. Errors due to shear distortion at the points of support and loading in bending tests, or to local distortion at the extreme ends of compression blocks have been eliminated by stress-strain diagrams, which were also used to determine proportional limit, the point at which the load and deflection cease to increase at the same rate. See figure 7.

Calculations

Values computed after testing were for moisture content, specific gravity, percent of summer wood, rings per inch, and proportional limit, in addition to the strength properties which are modulus of elasticity, modulus of rupture, and fiber stress at proportional limit, in static bending; maximum crushing strength, and fiber stress at proportional limit in compression parallel to grain; and shear parallel to grain. Immediately after each test, a block 2 inches square was cut as close to the point of failure as possible. The sample block was then weighed on a torsion balance shown in figure 2, and four measurements for each dimension taken by calipers. The sample was then dried to constant weight at 100^{0} C. Moisture content was computed on the basis of oven dry weight (dry weight ÷ (wet weight - dry weight) x 100 = moisture content in percent).

Specific gravity computations were based on oven dry weight and volume as tested, the oven dry weight of the sample block in grams divided by its volume in cubic centimeters when green being equal to specific gravity.

For determination of percentage of summerwood and rings per inch, a 3/4 inch section was cut near the point of failure, seasoned, and then planed and sandpapered smooth. Percent of summerwood was measured by a comparator manufactured by the Gaertner Scientific Corporation, Chicago, and having a horizontally moving microscope equipped with cross hairs and a scale measuring to .01 millimeter. The width of each successive summerwood band on a radius across the section was measured without setting the instrument back to zero, thus getting the cumulative width of summerwood bands in the section; which divided by the width of the block itself, measured on the same radius, gives the proportion of summerwood.

The number of rings per inch was arrived at by dividing the number of rings counted on the radius by the width of the block measured on the same line.

Proportional limit is that load, up to which the load and deflection increase at the same rate, while being subjected to a slowly applied load, such as that developed by the testing machine. After the proportional limit is exceeded the deflection becomes successively greater for each added unit of load. This is indicated by the constantly increasing departure of the load-deflection curve from a straight line as shown in figure 7. The point at which the curve first begins to depart from a straight line determines the proportional limit. The proportional limit values in both the static bending and compression parallel to grain tests were determined by this method from the load deflection diagrams used to compute the deflections of the test pieces.

The significance of the calculated static bending values known respectively as modulus of elasticity, modulus of rupture, and fiber stress at proportional limit may be better understood if the following relationships of the dimensions of a beam to deflection and breaking strength are kept in mind.

Deflection varies:-

(1) Inversely proportional to the width
(2) Inversely proportional to the cube of the height

(3) Directly proportional to the cube of the length. (12) p. 106.

Breaking strength varies:-

(1) Directly proportional to the width

(2) Directly proportional to the square of the height

(3) Inversely proportional to the length. (12) p. 102.

Modulus of elasticity in static bending was determined by substituting corresponding load and deflection valves taken from below the proportional limit in the formula: $E = \frac{1}{4} \frac{P \times L^3}{b \times h^2 \times D}$
in which:

E = modulus of elasticity

P = load

L = length between supports

b = breadth of beam

h = height of beam

D = deflection at center of beam, produced by the load

P. All valves are expressed in inches or pounds. This modulus is a measure of the stiffness of a beam or its resistance to bending. That is a beam with a high modulus of elasticity will sag less than one with a lower modulus.

Modulus of rupture in static bending, a measure of the maximum breaking strength, is computed by the formula: $R = 3/2 \frac{PL}{bh^2}$
in which:

R = modulus of rupture

P = load causing failure

b = breadth of beam

h = height of beam,
all values being in inches or pounds.

The same formula is used to determine fiber stress at proportional limit by substituting the value of P at the proportional limit, determined from the stress strain diagram. Fiber stress at proportional limit is the computed stress in the uppermost and lowermost fibers of a beam when loaded to the proportional limit. Fiber stress at proportional limit is the streng value used in determining the safe working load for beams. A load higher than that for fiber stress at proportional limit can be sustained for a time but a continuous load causing stresses above the proportional limit will ultimately cause failure. (16) p. 12. Figures given for maximum crushing strength are equal to load causing failure divided by the cross sectional area of the test piece.

For fiber stress at proportional limit in compression parallel to grain, the load at which the stress strain diagram begins to depart from a straight line is divided by the cross sectional area.

Values given for shear parallel to grain are equal to the maximum shearing load divided by the area of the shear face.

Maximum crushing strength, and fiber stress at proportional limit, in compression parallel to grain plus shear parallel to grain are important factors governing the design of joints in timber structures.

Wood increases in strength with loss of moisture. Drying of green wood to 12 percent moisture content will about double the strength in compression parallel to grain. Most of the specimens were green at the time of testing; but to correct the strength values of those that were not, and also to determine the strength values for air dry wood, the figures for all strength properties were adjusted to 12 percent moisture and to 24 percent where necessary. For these adjustments the formula:

$$\text{Log } S_3 = \text{Log } S_2 + (M_2 - M_3)\ \frac{\text{Log } \frac{S12}{Sg}}{(Mp-12)}$$

was used, S_3 being the adjusted strength value for the moisture content M_3, while S_2 and M_2 are corresponding strength and moisture content values as tested. S_{12} and S_g are strength values for wood at 12 percent moisture and green wood respectively, taken from tables of strength values. M_p is an arbitrary figure for the moisture content of green wood and is below the fiber saturation point. It is given in a table as 24 percent for Douglas fir. (23) p. 61-62.

The strength values adjusted for moisture content were plotted as curves with either rings per inch, percent of summerwood, or specific gravity as the independent variable. The curves for strength and rings per inch were drawn free hand. Those curves with percent of summerwood or specific gravity as the independent variable (x axis) were fitted by the least squares method. Standard deviations were computed and values varying from the mean, for each specific gravity or summerwood class, by more than three standard deviations were eliminated. The curves were computed by the formula $y = a + bx$, the x and y values being summed up and substituted in the simultaneous equations:

$$\begin{aligned} \Sigma(y) &= Na + b\Sigma(x) \\ \Sigma(xy) &= a\,(x) + b\Sigma(x^2) \end{aligned}$$

to solve for a and b from which the curves were computed.

Variations of Strength Values from Curves

The standard deviations from the curves of the strength values remaining after rejection of abnormal figures are given, in table 2 for strength and specific gravity in relation to percent of summerwood, and in table 3 for strength in relation to specific gravity. All deviations for strength

Table 2.- Standard deviations from curves of summer wood and strength, and summer wood and specific gravity

(All stresses expressed in pounds per square inch)

Property	Moisture condition	
	Green	Air dry (12 percent moisture content)
Static bending		
Modulus elasticity	99,300	117,700
Modulus rupture	319	1,160
Fiber stress at prop. limit	460	1,150
Compression parallel to grain		
Maximum crushing strength	340	1,090
Fiber stress at prop. limit	695	1,520
Shear parallel to grain	155	226
Specific gravity		
27 - 29 percent summer wood	.0147	
34 - 36 percent summer wood	.0355	

Table 3.- Standard deviations from curves of specific gravity and strength
(All stresses expressed in pounds per square inch)

Property	Moisture Condition	
	Green	Air dry (12 percent moisture content)
Static bending		
Modulus elasticity	76,000	78,500
Modulus rupture	472	788
Fiber stress at prop. limit	600	1,238
Compression parallel to grain		
Maximum crushing strength	475	869
Fiber stress at prop. limit	483	970
Shear parallel to grain	171	228

are in pounds per square inch.

The abnormal values eliminated in fitting curves were all below the curve of best fit. The figures for maximum variation below the curve are given as percentages in tables 4 and 5. For the majority of abnormal values the variation was about half the maximum given in the table. These abnormalities may be due to preexisting compression failures caused by rough treatment in logging or to compression wood, an abnormal type of wide ringed wood, with a high proportion of summerwood, found on the lower side of branches and leaning trunks of coniferous trees. In some of the tests, showing the greatest variation below the curve, are found large amounts of summerwood up to 46.6 percent with the summerwood band eccentric in width, these being characteristics of compression wood. Compression wood is lower in specific gravity than would be expected for its large percentage of summerwood (see tables 2 & 4) and is generally deficient in strength properties. It may be found in any degree of gradation from normal wood to well developed compression wood and is not always easily detected. The very lowest values were for a low moisture content when tested, under which condition compression wood exhibits a greater inferiority to normal wood than when green. (11) p. 22-26.

Results and Discussion

EFFECT OF RATE OF GROWTH ON STRENGTH

The relation found between rings per inch and strength for green wood is illustrated by figures 8 to 13. For modulus of elasticity in static bending, maximum crushing strength, and fiber stress at proportional limit in compression parallel to grain, there is evident an optimum growth rate,

Table 4.- Maximum variation below curves of percent of summer wood and strength, and percent of summer wood and specific gravity for either green or air dry material

Property	Variation (percent)
Static bending	
Modulus elasticity	39
Modulus rupture	35
Fiber stress at prop. limit	54
Compression parallel to grain	
Maximum crushing strength	69
Fiber stress at prop. limit	69
Shear parallel to grain	40
Specific gravity	
27-- 29 percent summer wood	7
34-- 36 percent summer wood	11

Table 5.- Maximum variation below curves of specific gravity and strength for either green or air dry material

Property	Variation (percent)
Static bending	
Modulus of elasticity	36
Modulus rupture	32
Fiber stress at prop. limit	54
Compression parallel to grain	
Maximum crushing strength	64
Fiber stress at prop. limit	66
Shear parallel to grain	42

above or below which the wood is weaker. For modulus of rupture and shear parallel to grain, an increase in strength with rings per inch is shown, while fiber stress at proportional limit in static bending is little affected.

In comparison, the relationship of maximum crushing strength to rate of growth, as worked out by the Canadian Forest Service is illustrated in figure 3,(21) p. 10. Here the same type of relationship exists between rate of growth and maximum crushing strength as found in this study of Inland Empire fir.

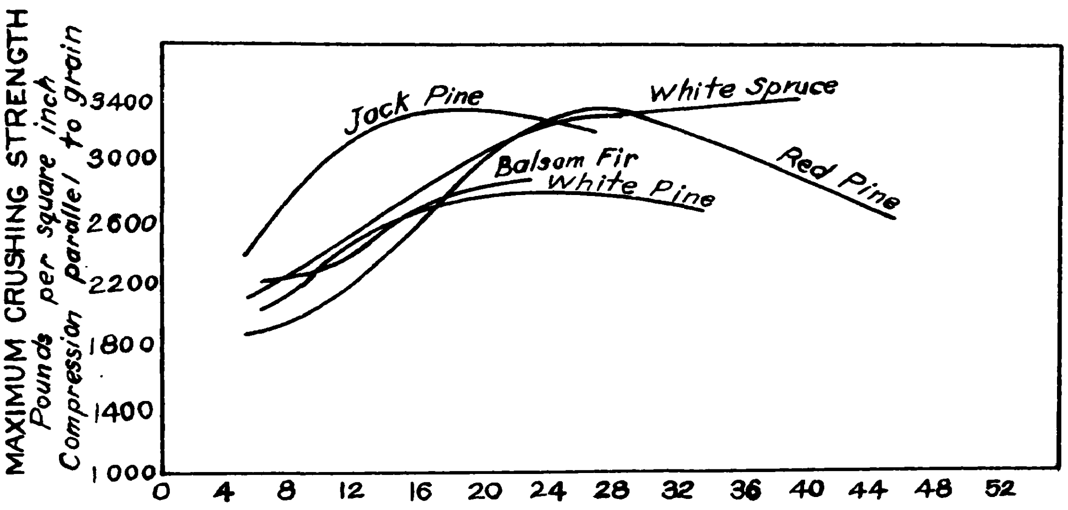
EFFECT OF PERCENTAGE OF SUMMERWOOD on STRENGTH

In figure 14 percent of summerwood is plotted against rings per inch and seems to be increased in slower grown material.

Figures 16 to 21 show a consistent increase in all strength values with percent of summerwood which is the hard, dark portion of the annual ring. The summerwood cells are thick walled with small cavities, or in other words the summerwood contains more wood substance and therefore has a greater density. Note the relationship between percent of summerwood and specific gravity in figure 22. The results of the Canadian study given in figures 5 and 6 show a similar relationship of specific gravity and strength to percentage of summerwood.(21)

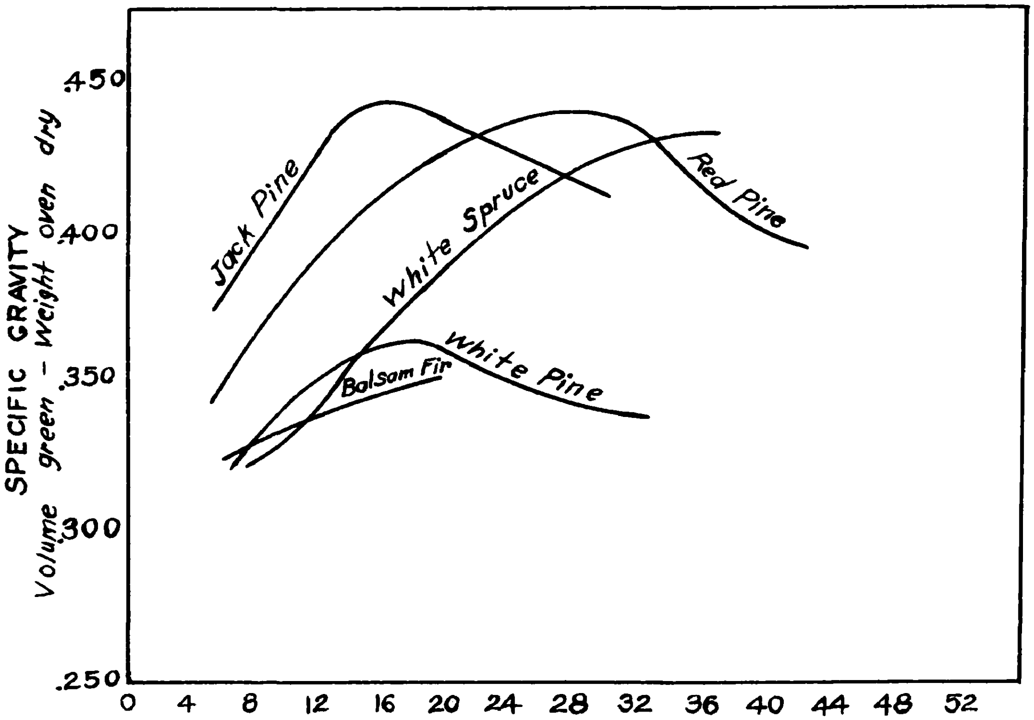
EFFECT OF SPECIFIC GRAVITY ON STRENGTH

Considering the direct relationship between percent of summerwood and specific gravity and between percent of summerwood and strength, there must be a similar relationship of specific gravity and strength. In



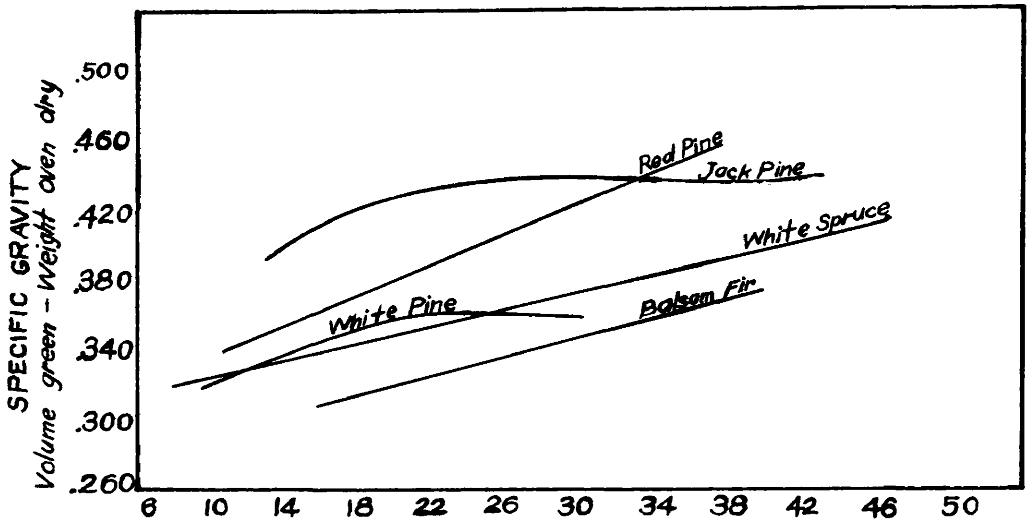
Rate of growth (Rings per inch)

Figure 3.- Relation of maximum crushing strength in compression parallel to grain to rate of growth (rings per inch) for some Canadian conifers.



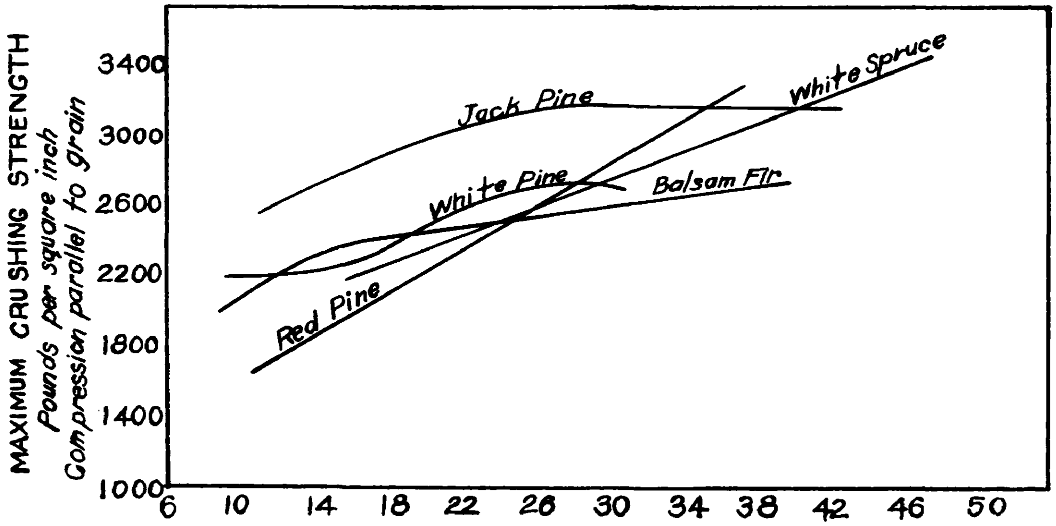
Rate of growth (Rings per inch)

Figure 4.- Relation of specific gravity to rate of growth (rings per inch) for same species as shown in figure 2.



Percentage Summer Wood

Figure 5.- Relation of specific gravity to percentage summer wood for same species as shown in figure 2.



Percentage Summer Wood

Figure 6.- Relation of maximum crushing strength in compression parallel to grain to percentage summer wood for some species as shown in figure 2.

figures 23-28 are curves showing the correlation between specific gravity and strength for the Douglas fir tested in this study. These curves show a consistent relationship of increasing strength with higher specific gravity as with strength and percent of summerwood.

Interrelation of Rate of Growth Percentage of Summer Wood and Specific Gravity and Their Effect on Strength

Increased rate of growth in coniferous trees results in a larger proportion of springwood, and consequently a smaller proportion of summer wood in the annual ring. Also the cells of the springwood are large and thin walled, while those of the summerwood have thicker walls and a smaller cell cavity and hence contain a greater proportion of wood substance. This wood substance has a specific gravity of 1.54 regardless of species (12) p. 32. Therefore wood with a larger percentage of summerwood would have a greater density as illustrated in figure 22. Strength properties show an increase with higher specific gravity which is dependent on an optimum growth rate, resulting in a high percentage of summerwood and consequently a high specific gravity. Therefore the strength of the wood from an individual tree would be determined by the rate at which it had been grown, the strongest wood being produced by trees having a medium rate of growth.

EFFECT OF LOCALITY ON STRENGTH

The average values for strength, rings per inch, percent of summerwood, and specific gravity of each lot of Inland Empire fir tested in this problem are given in table 6. The averages for each of the four localities are represented graphically in figures 29 and 30. It is seen, that among the

of Inland Empire Douglas fir
(All stresses expressed in pounds per square inch)

Lot no.	Locality	Moisture content	Rings per inch	Percent summer wood	Specific gravity	Static bending			Compression parallel grain		Shear parallel to grain
						Modulus elasticity	Modulus rupture	Fiber stress prop. limit	Maximum crushing strength	Fiber stress prop. limit	
3	Lincoln Co.Mont.	24%	24.9	28.9	.4467	1,342,187	9,010	5,010	3,949	3,285	991
		12%				1,589,129	14,971	10,298	8,167	7,402	1,356
4	Flathead Co.Mont.	24%	22.5	33.2	.5182	1,517,800	10,108	5,021	4,627	3,735	1,364
		12%				1,823,587	16,797	10,321	9,569	8,381	1,865
5	Lincoln Co.Mont.	24%	22.5	29.7	.5064	1,332,011	9,442	4,974	4,515	3,709	1,292
		12%				1,600,350	15,690	10,225	9,337	8,323	1,767
6	Blackfoot Valley	24%	44.3	34.0	.5220	1,345,450	10,052	5,191	4,040	3,039	1,357
		12%				1,616,575	16,705	10,670	9,355	6,818	1,856
7	Pend Oreille Co. Wash.	24%	17.9	31.0	.4209	1,375,044	8,872	5,108	4,501	4,071	1,346
		12%				1,652,150	14,744	10,499	9,308	9,134	1,842
8	Lincoln Co.Mont.	24%	9.4	26.8	.4521	1,305,359	8,879	5,167	4,226	3,727	1,220
		12%				1,568,361	14,765	10,620	9,831	8,363	1,670
Ave.		24%	22.1	30.2	.4778	1,357,100	9,267	5,068	4,266	3,587	1,209
		12%				1,630,300	15,402	10,395	8,821	8,057	1,655

four localities, the rate of growth decreases with more easterly location, while percent of summerwood and specific gravity show a slight increase. This is evidently due to slower growth. See figures 14 and 15. However, no consistent relation of strength to location within the Inland Empire can be shown from this data.

Upon examining the strength values in table 6 for the Douglas fir tested in this problem it is seen that the values for modulus of elasticity in static bending agree quite closely with the Forest Service average for the Inland Empire as given in table 7 but other strength values and specific gravity are higher than for coast fir even (23) p. 50-51. The explanation offered is that material used in the Forest Service tests was taken throughout the entire cross section of that portion of the tree, at least from 8 to 16 feet above the ground, while the material used in this study would probably be sawed from near the periphery of the lower part of the butt log, in order to secure clear material. For some strength properties such as maximum crushing strength, shear, tension perpendicular to grain, and hardness, the strongest material is found at the butt of the tree. This portion of the tree also contains the material of highest specific gravity. Strength properties and specific gravity also increase from the pith outward to the periphery of the tree trunk (5) p. 35-59. The specific gravity of the Inland Empire fir tested in this study, see table 6, was found to be practically as high as the average of the coast fir given in table 7 and higher than that from some localities on the Pacific Coast given in table 8 (16) table 21. Consequently, higher strength values would be expected.

The strength values obtained in this study show that the Inland Empire

FIGURE 7 TYPICAL LOAD DEFLECTION DIAGRAM

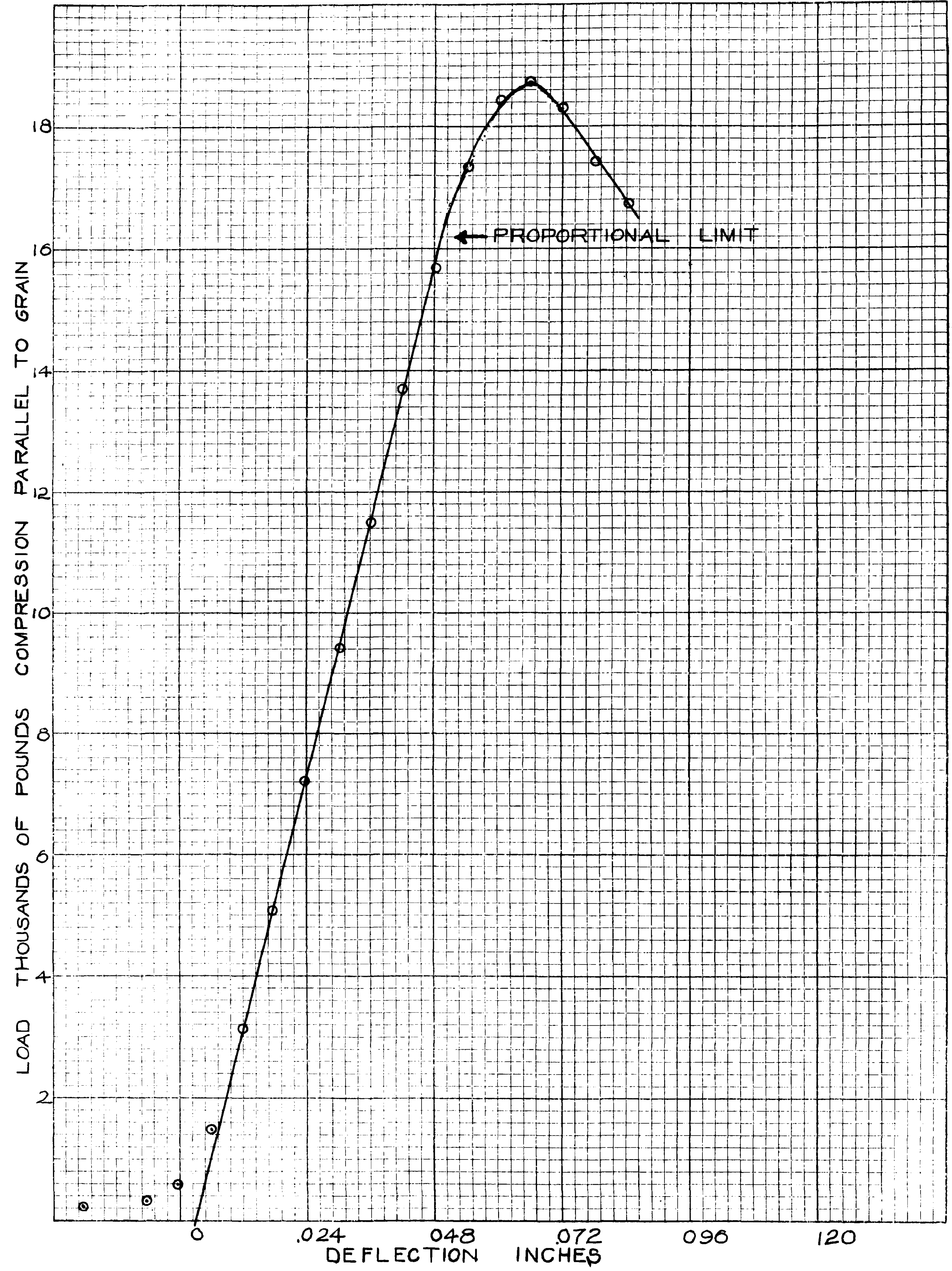
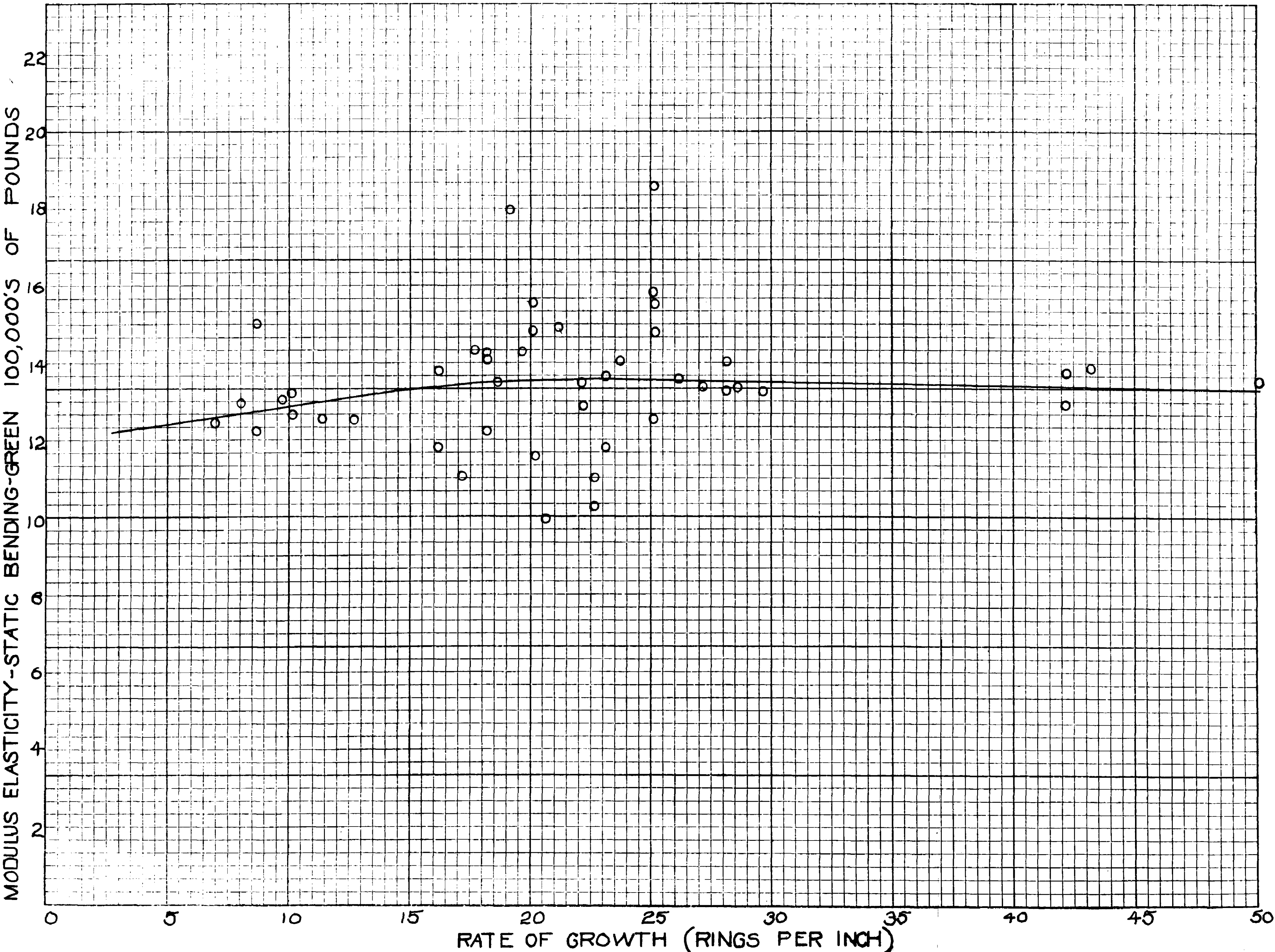


FIGURE 8


MODULUS ELASTICITY-STATIC BENDING-GREEN 100,000'S OF POUNDS
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25
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35
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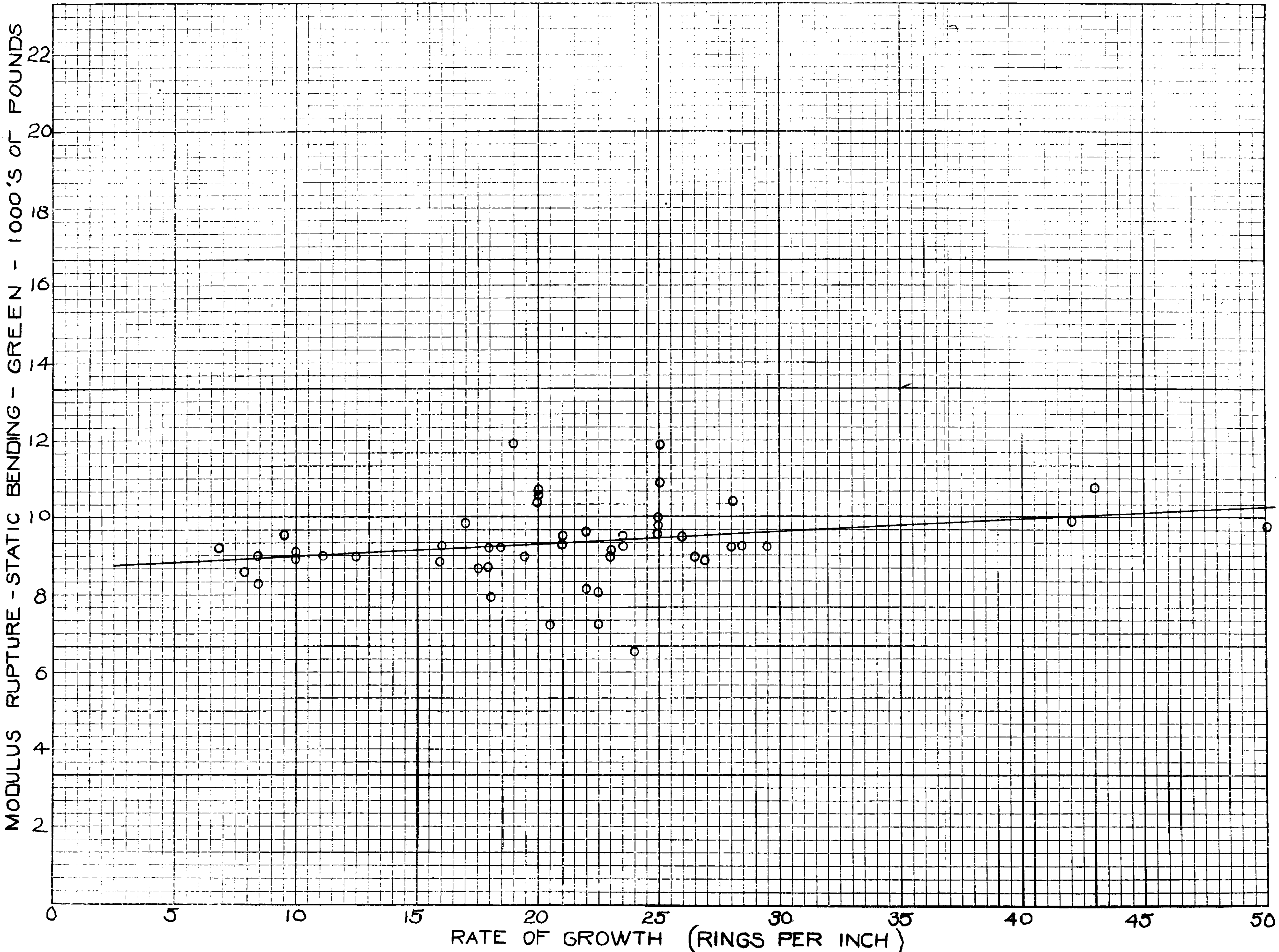
45
50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 9



MODULUS RUPTURE - STATIC BENDING - GREEN - 1000'S OF POUNDS
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20
18
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25
30
35
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45
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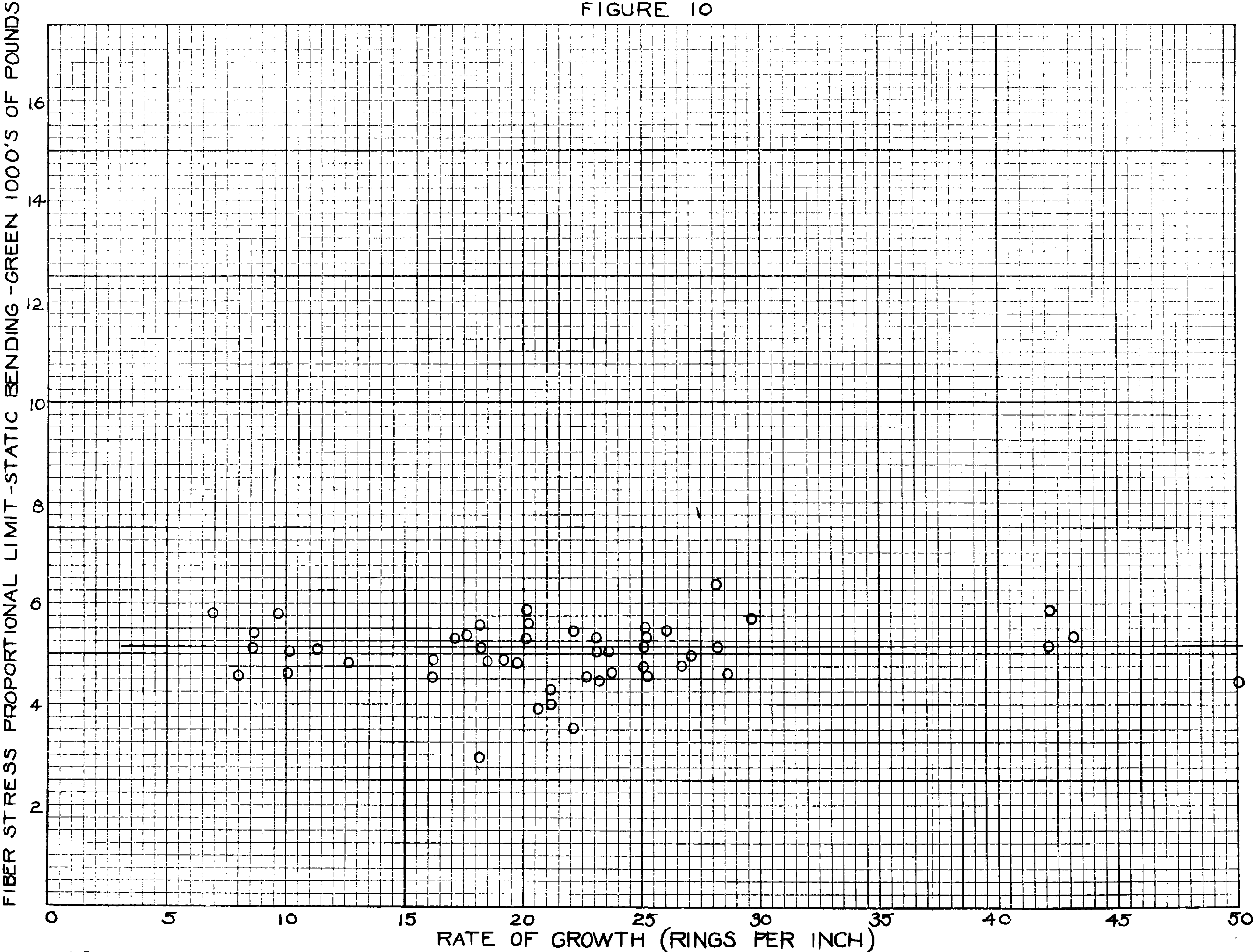
RATE OF GROWTH (RINGS PER INCH)

FIGURE 10


FIBER STRESS PROPORTIONAL LIMIT-STATIC BENDING-GREEN 1000'S OF POUNDS
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25
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35
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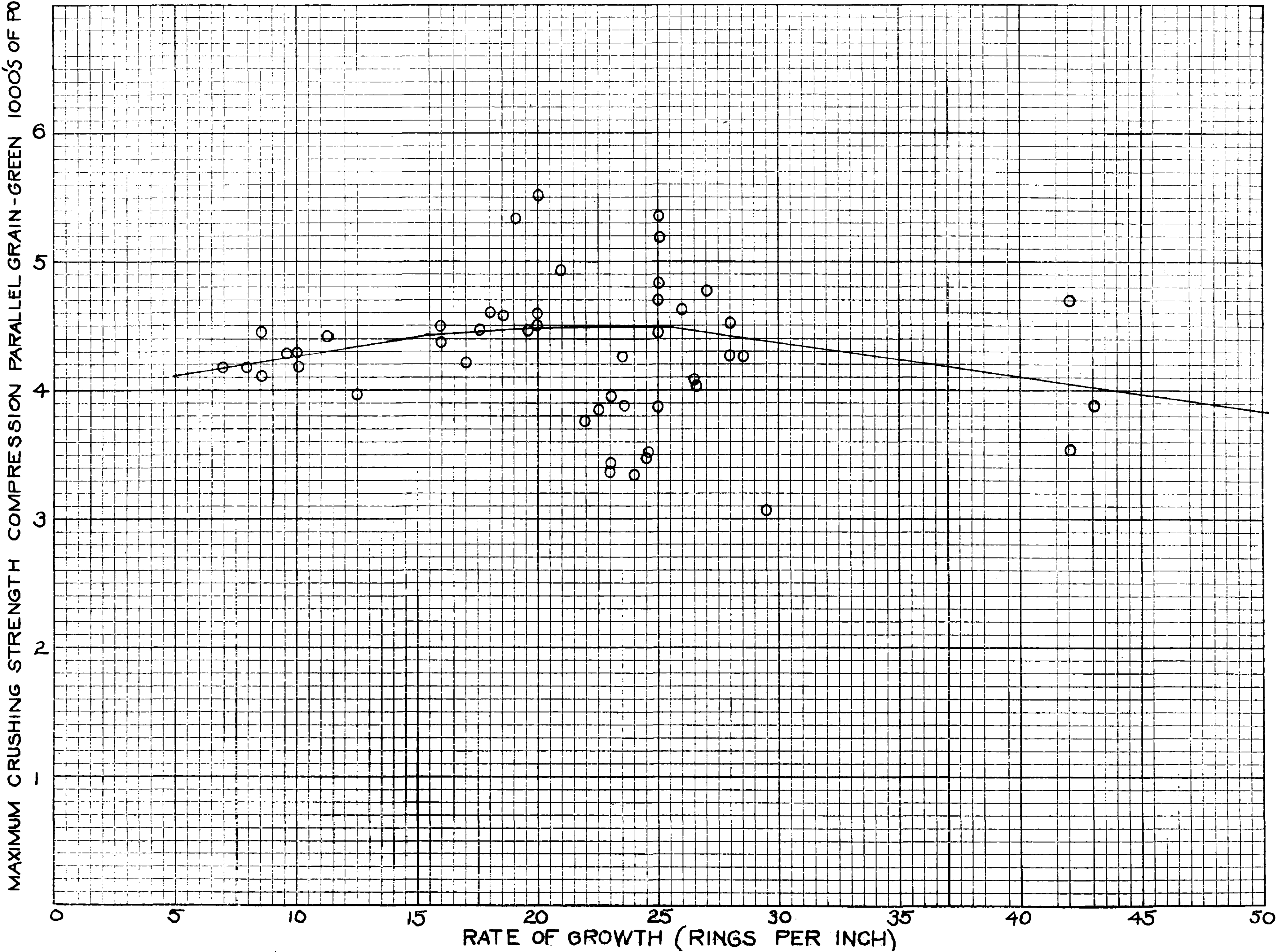
RATE OF GROWTH (RINGS PER INCH)

FIGURE 11


MAXIMUM CRUSHING STRENGTH COMPRESSION PARALLEL GRAIN-GREEN 1000'S OF POUNDS
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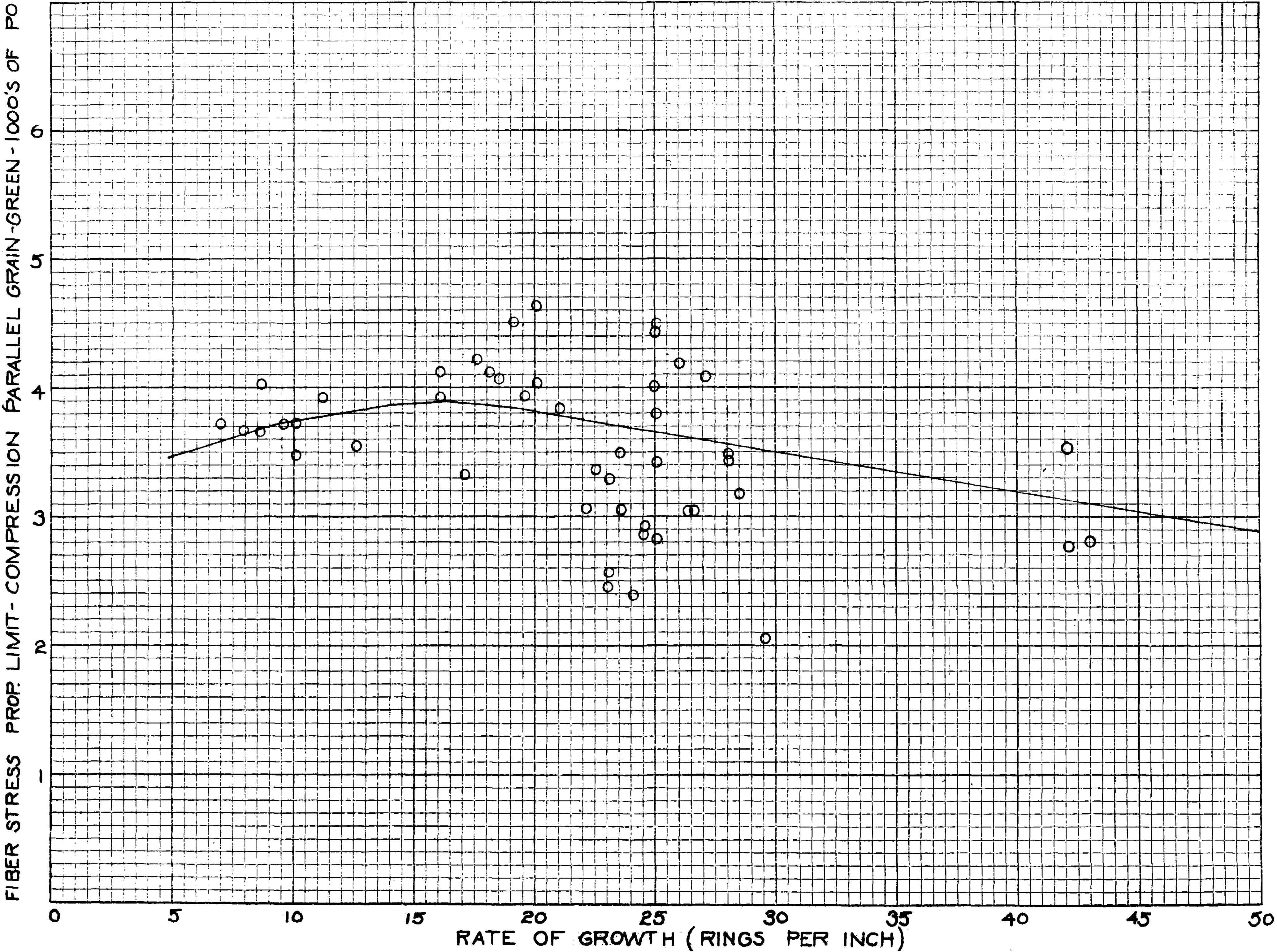
50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 12


FIBER STRESS PROP. LIMIT- COMPRESSION PARALLEL GRAIN-GREEN-1000'S OF POUNDS
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5
10
15
20
25
30
35
40
45
50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 13

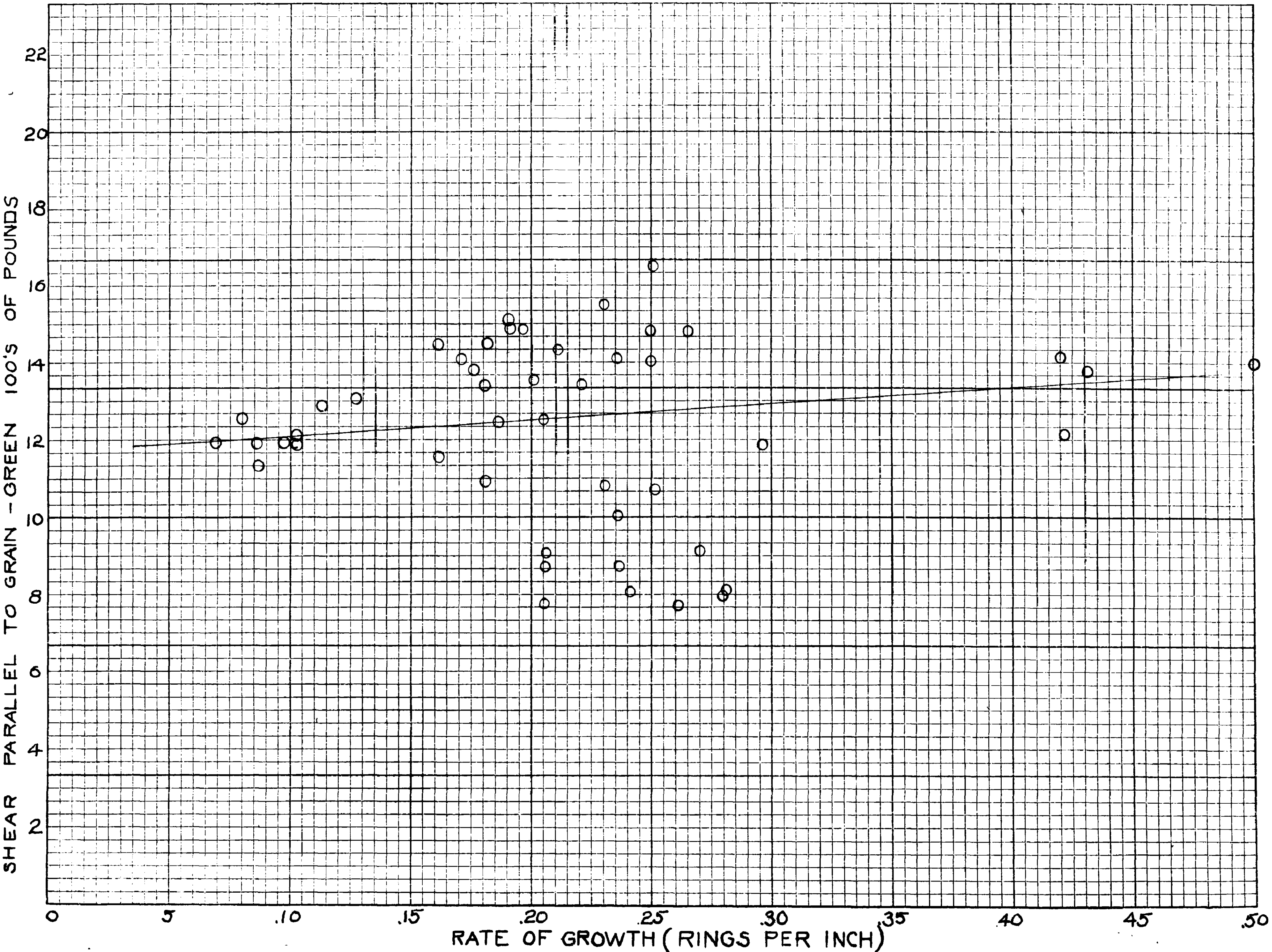
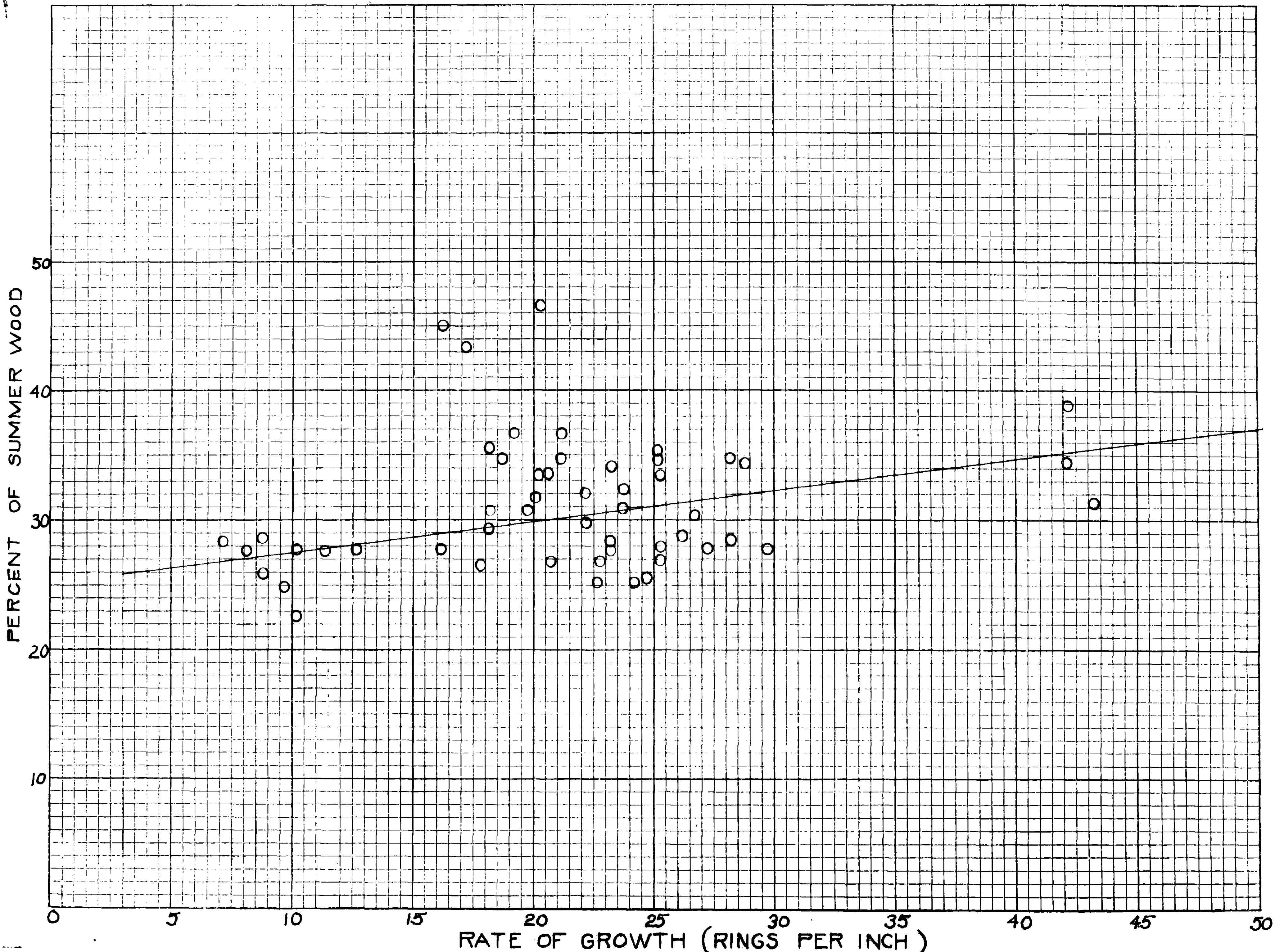

SHEAR PARALLEL TO GRAIN - GREEN 100'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
0
5
.10
.15
.20
.25
.30
.35
.40
.45
.50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 14



PERCENT OF SUMMER WOOD
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 15

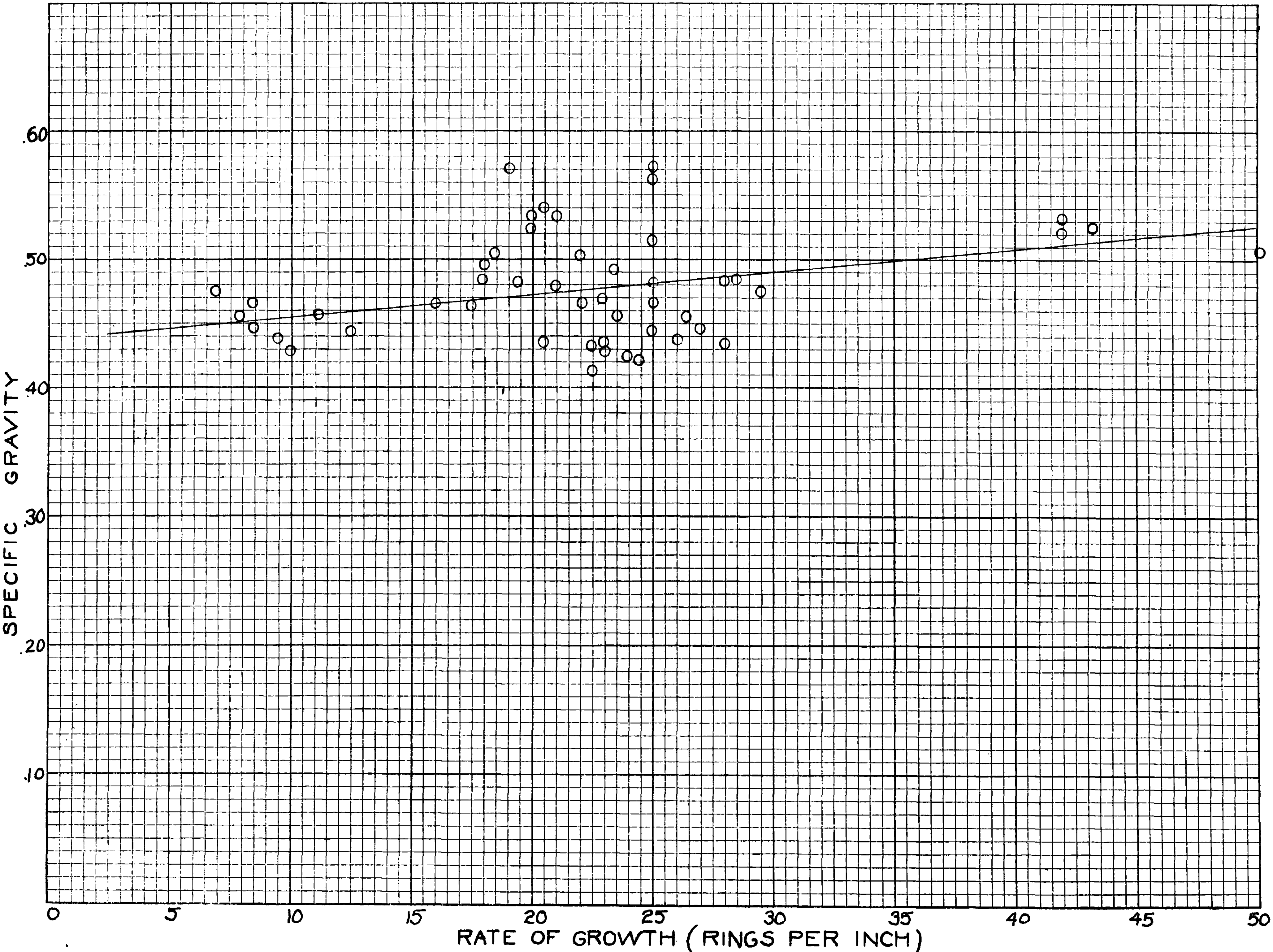
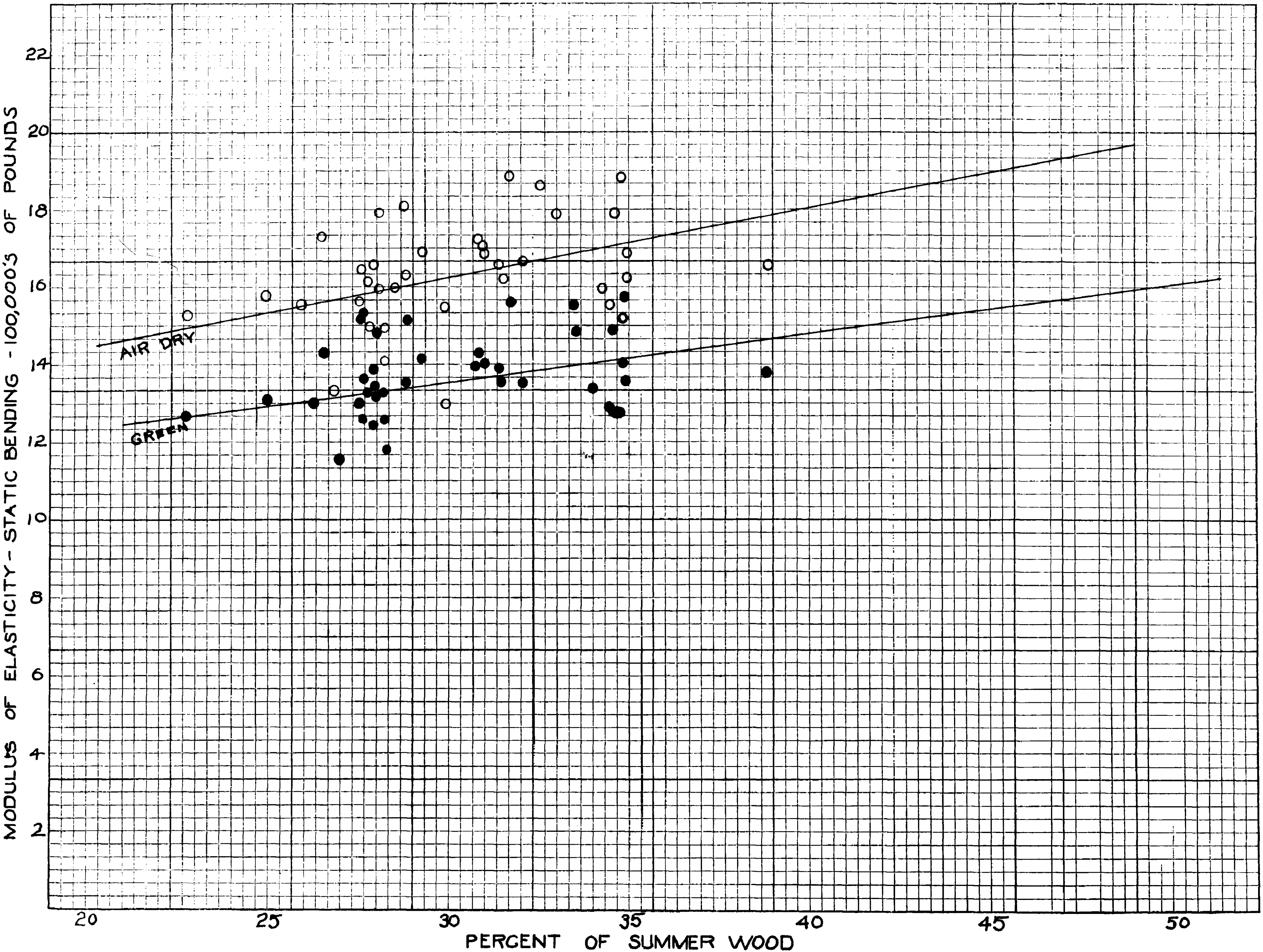

.60
.50
.40
.30
.20
.10
SPECIFIC GRAVITY
0
5
10
15
20
25
30
35
40
45
50
RATE OF GROWTH (RINGS PER INCH)

FIGURE 16



MODULUS OF ELASTICITY - STATIC BENDING - 100,000'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
AIR DRY
GREEN
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 17

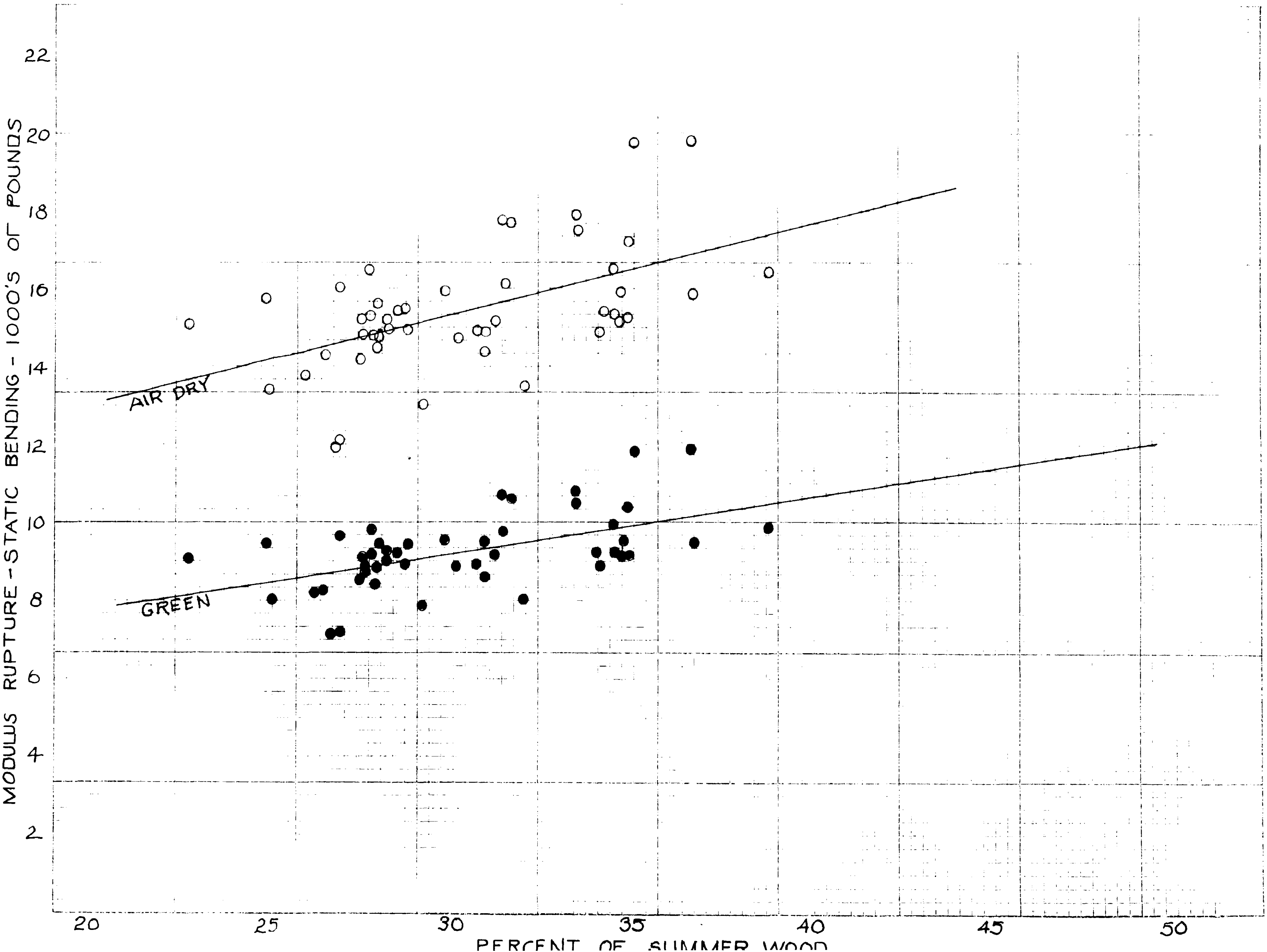

MODULUS RUPTURE - STATIC BENDING - 1000'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
AIR DRY
GREEN
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 18

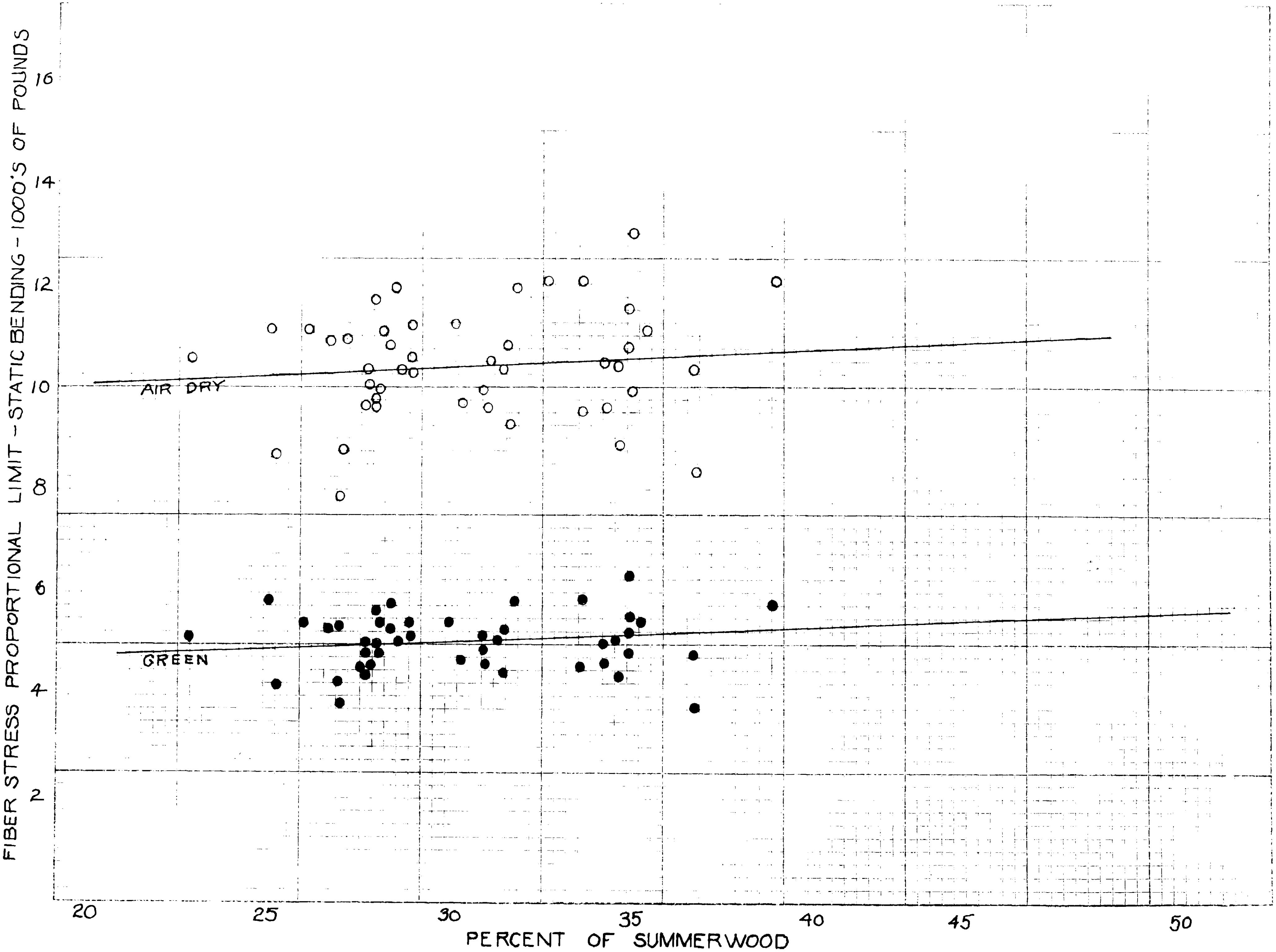
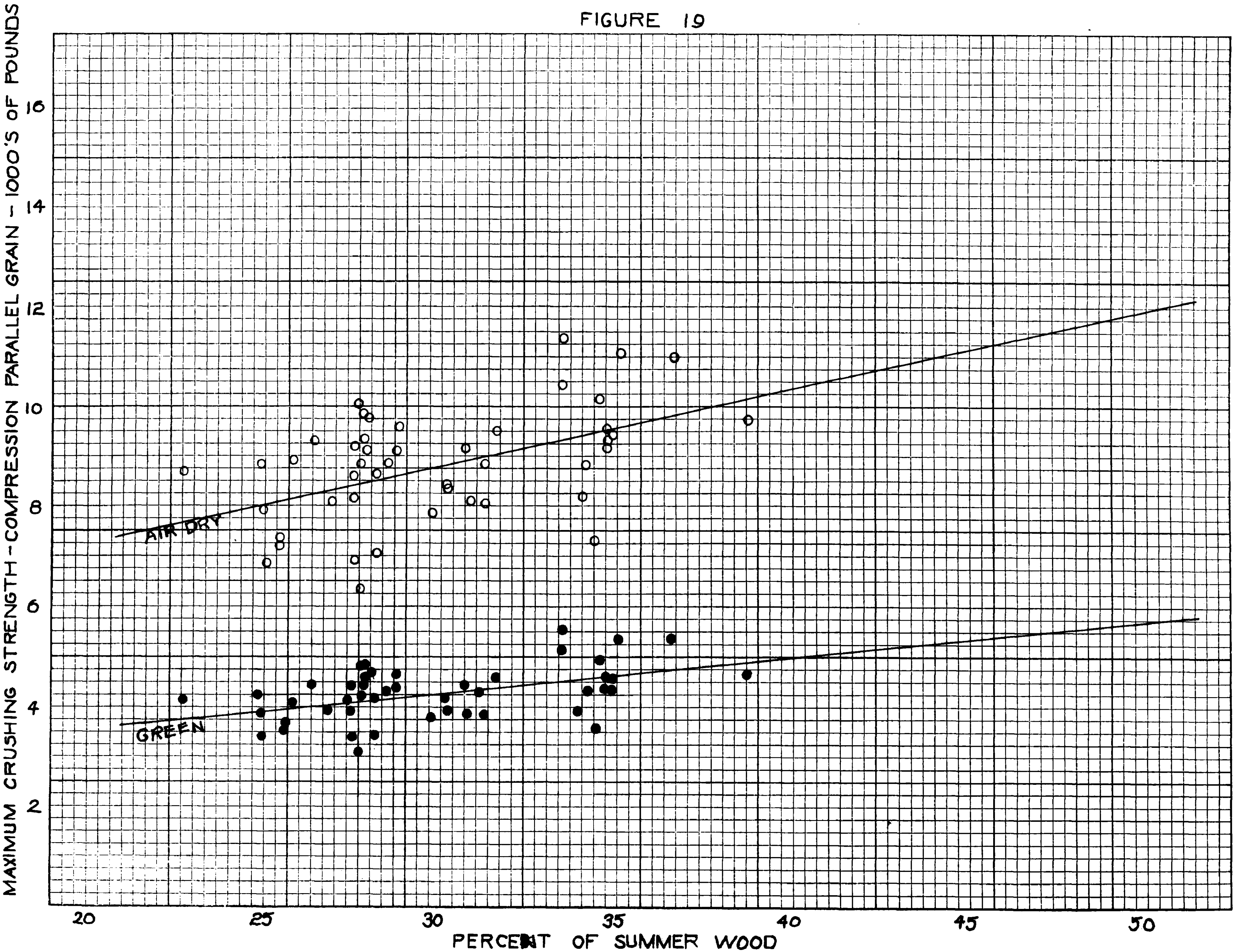

FIBER STRESS PROPORTIONAL LIMIT - STATIC BENDING - 1000'S OF POUNDS
16
14
12
10
8
6
4
2
AIR DRY
GREEN
20
25
30
35
40
45
50
PERCENT OF SUMMERWOOD

FIGURE 19



MAXIMUM CRUSHING STRENGTH - COMPRESSION PARALLEL GRAIN - 1000'S OF POUNDS
16
14
12
10
8
6
4
2
AIR DRY
GREEN
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 20

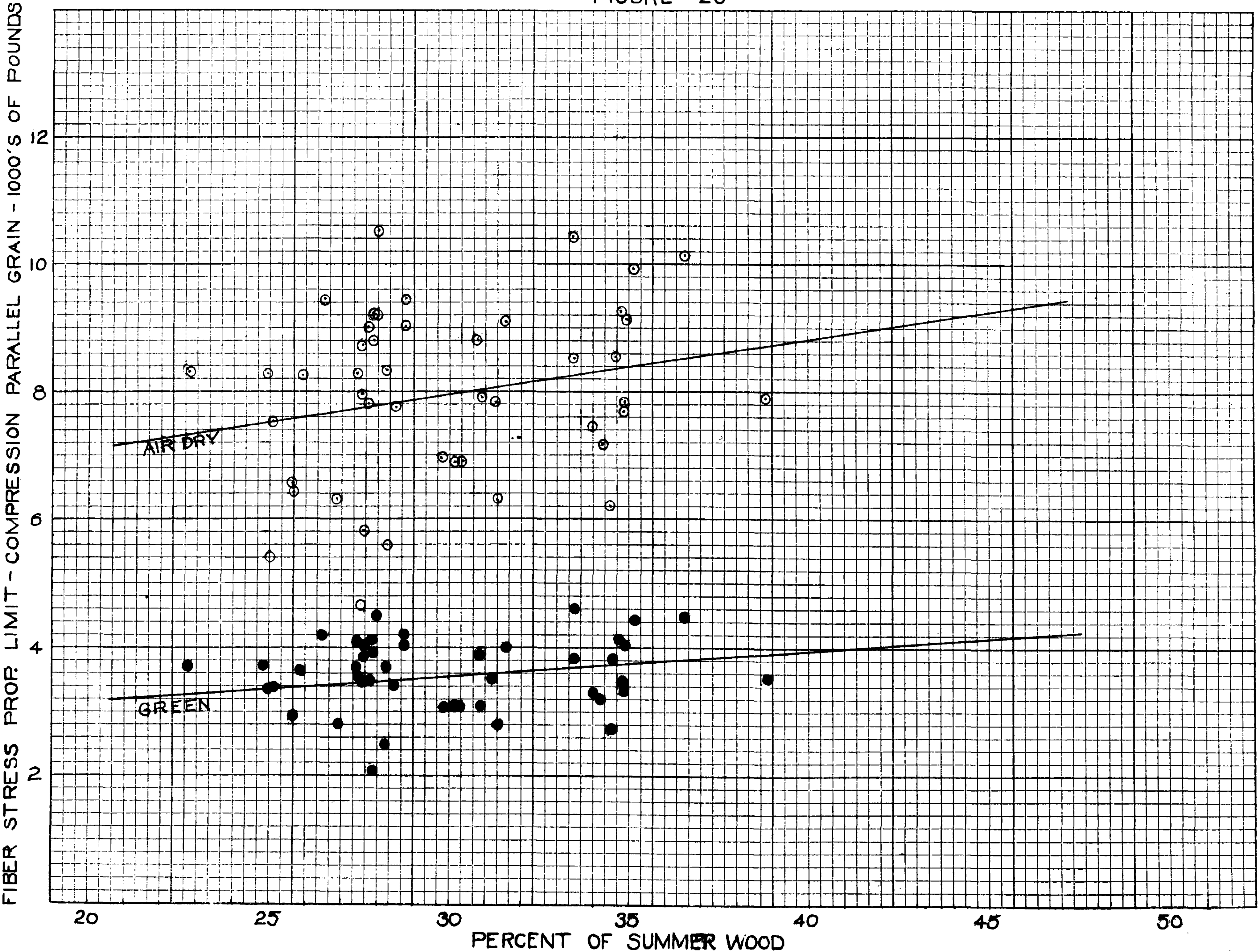
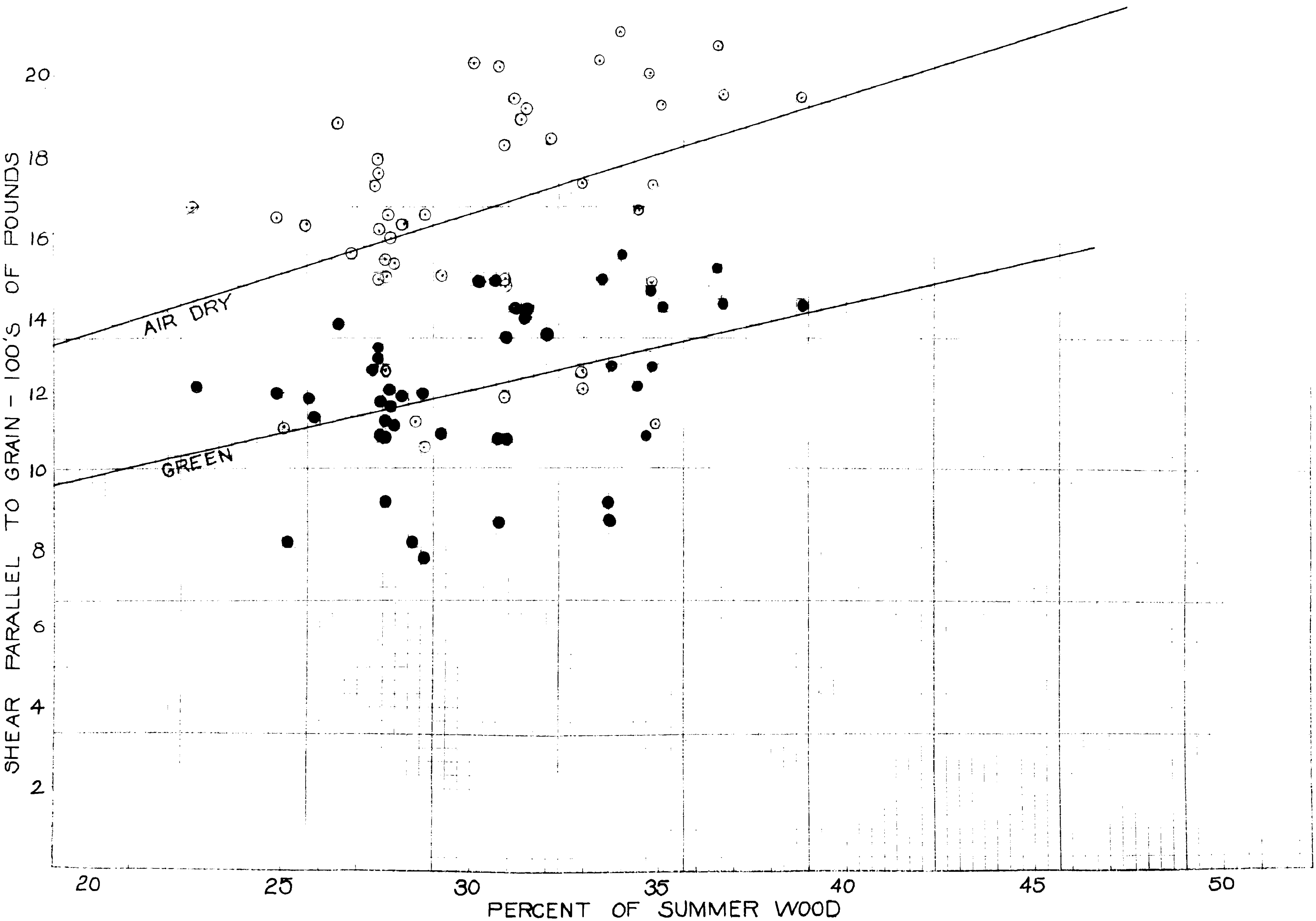
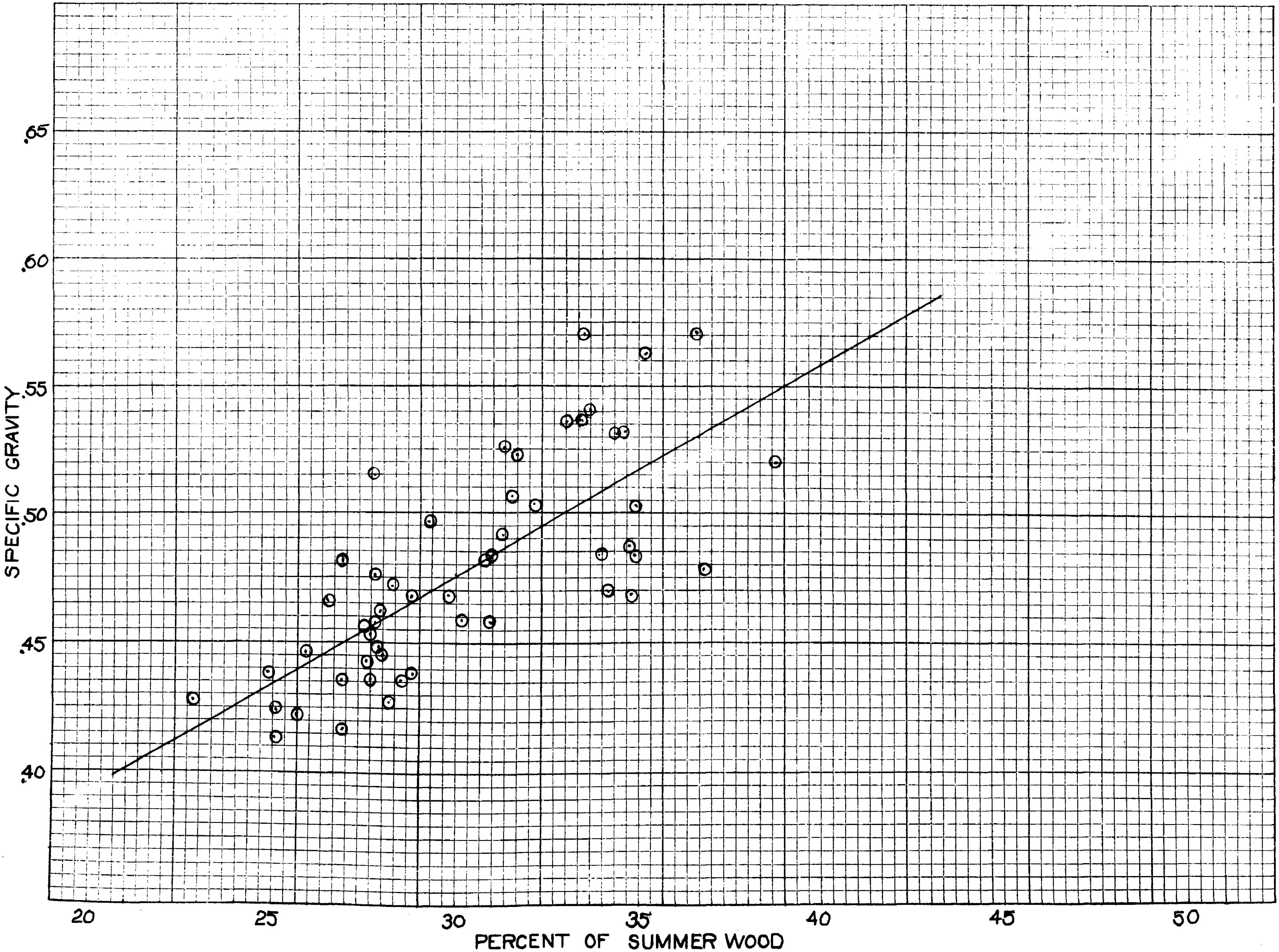

FIBER STRESS PROP. LIMIT - COMPRESSION PARALLEL GRAIN - 1000'S OF POUNDS
12
10
8
6
4
2
AIR DRY
GREEN
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 21



AIR DRY
GREEN
SHEAR PARALLEL TO GRAIN - 100'S OF POUNDS
2
4
6
8
10
12
14
16
18
20
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 22



.65
.60
.55
.50
.45
.40
SPECIFIC GRAVITY
20
25
30
35
40
45
50
PERCENT OF SUMMER WOOD

FIGURE 23

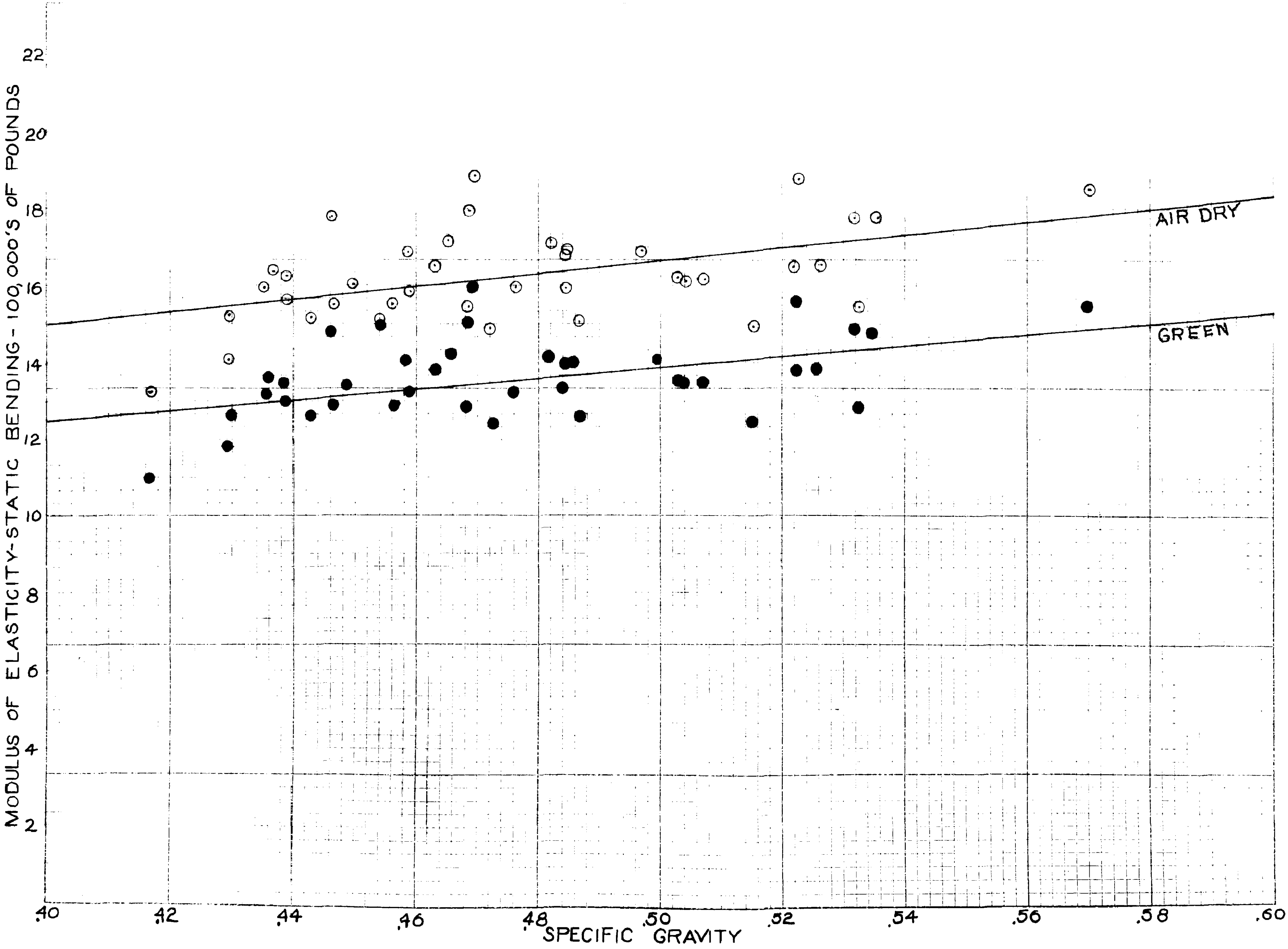

MODULUS OF ELASTICITY-STATIC BENDING-100,000'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 24

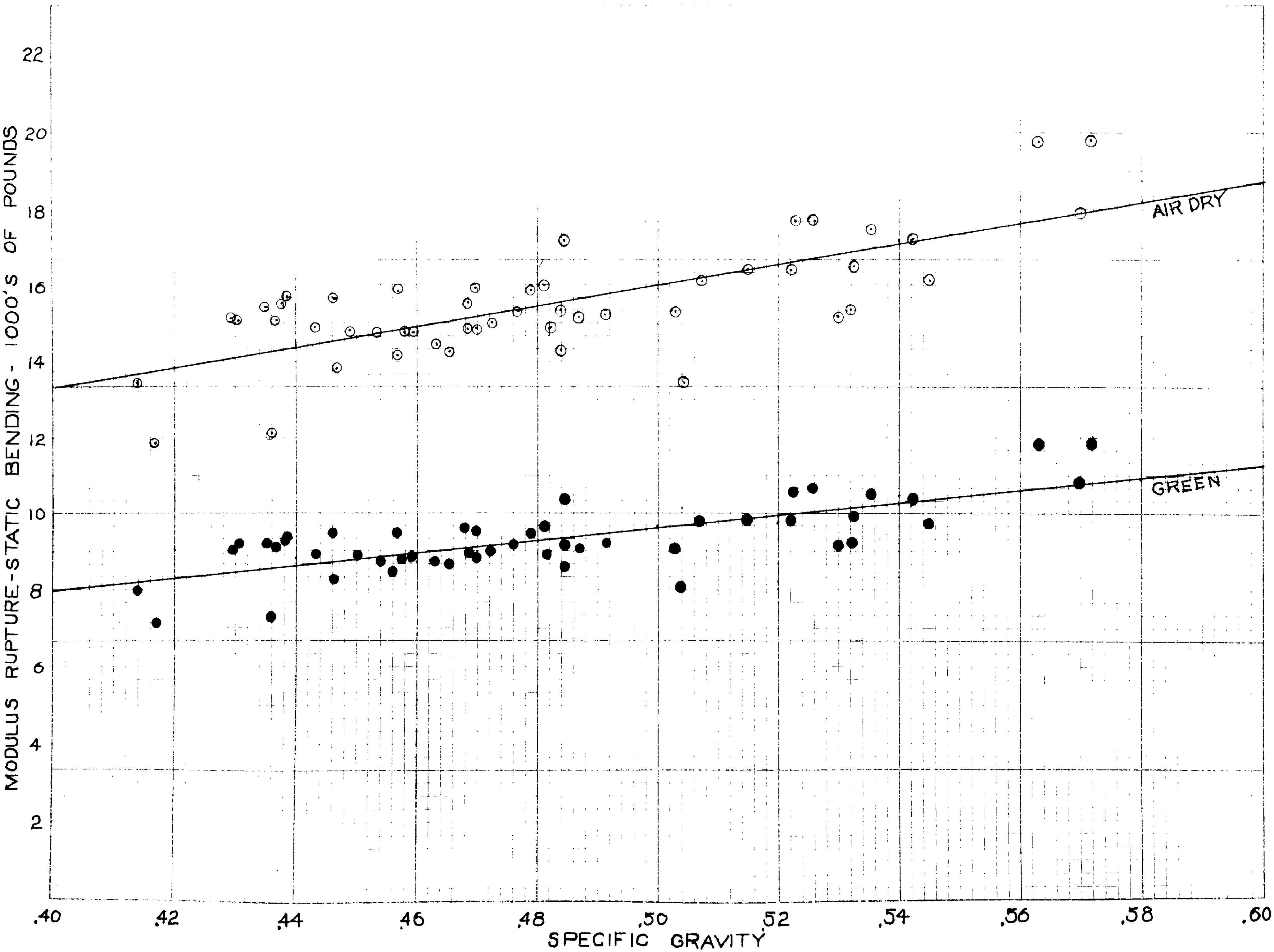

MODULUS RUPTURE-STATIC BENDING - 1000'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 25

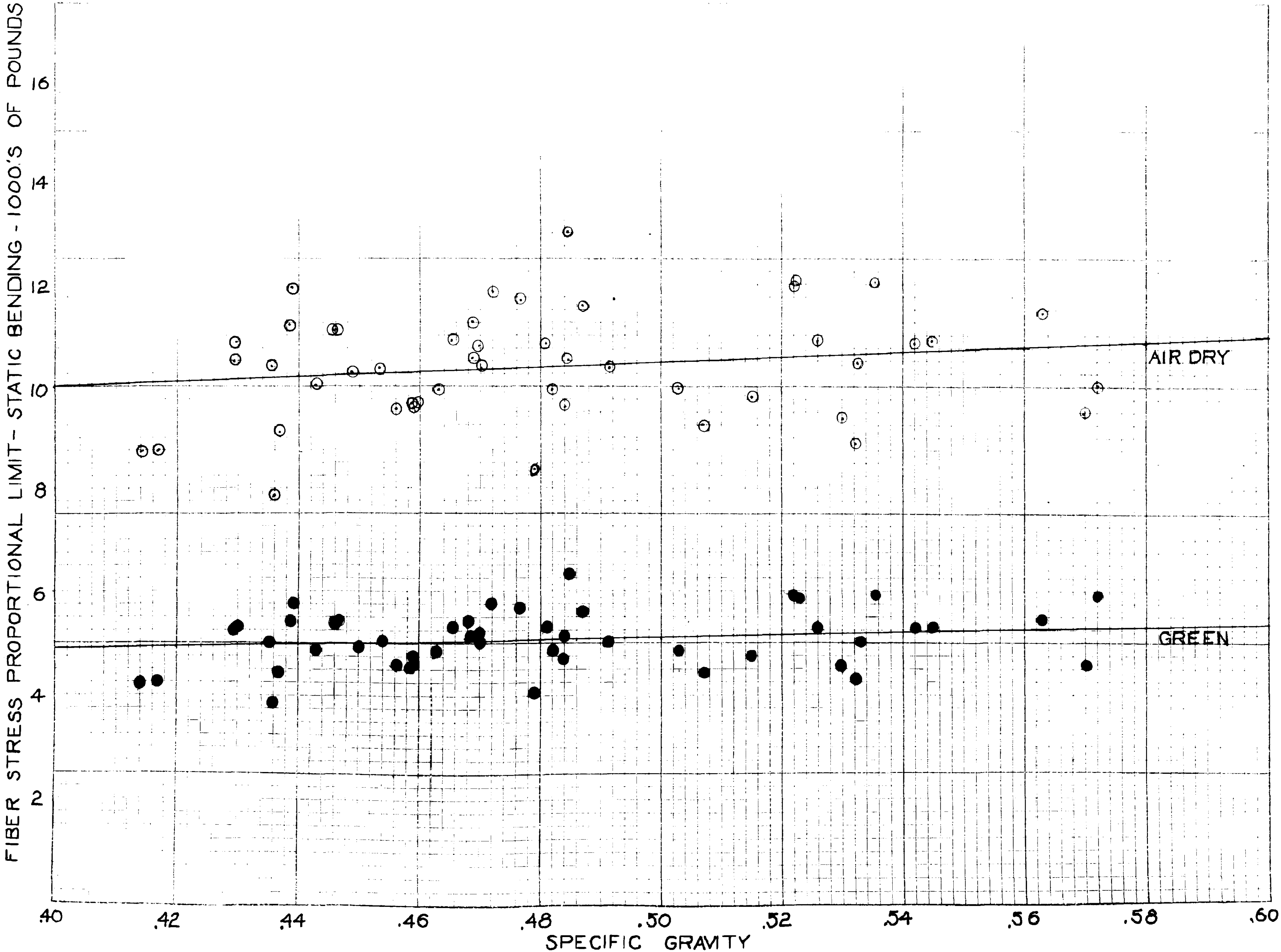
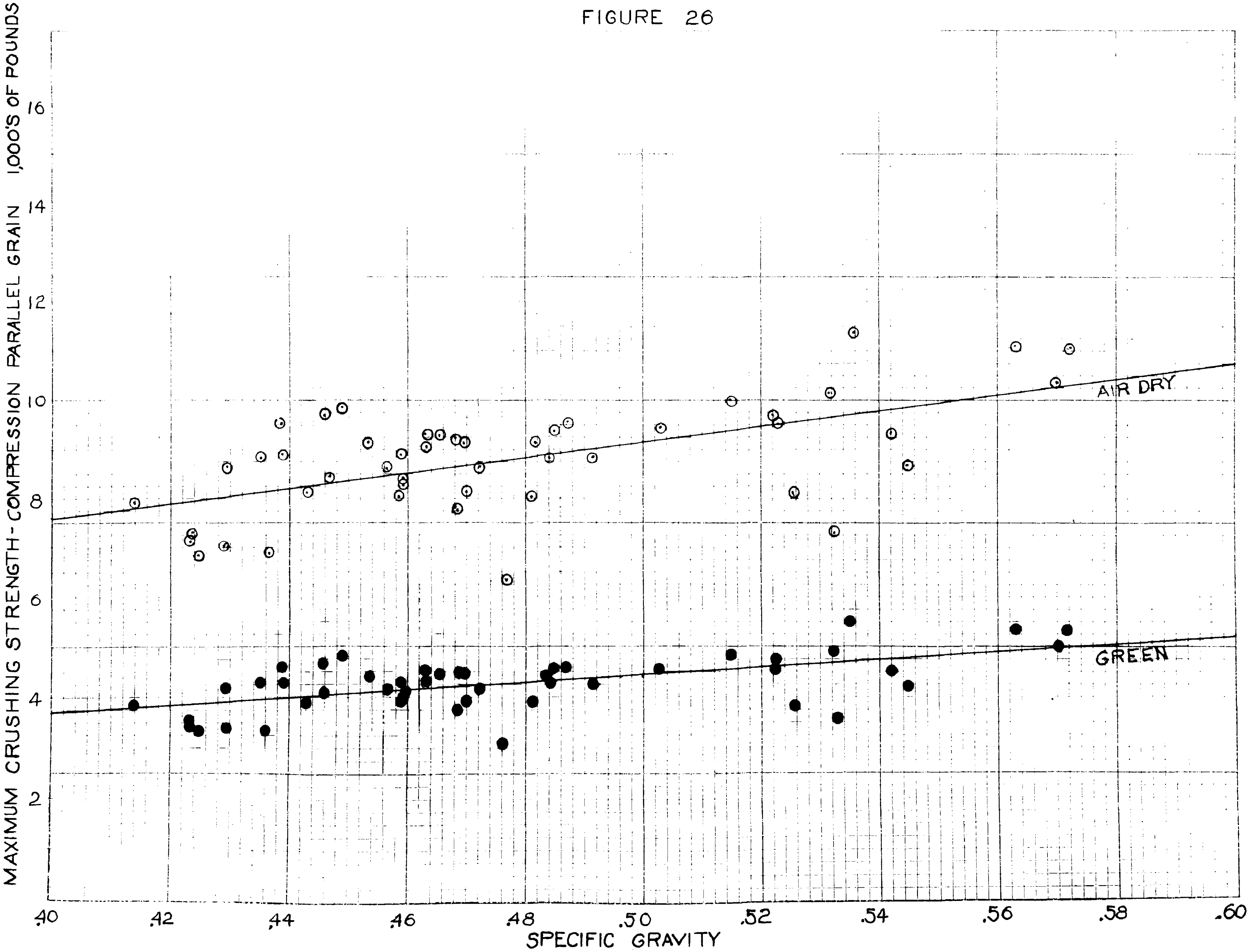

FIBER STRESS PROPORTIONAL LIMIT - STATIC BENDING - 1000'S OF POUNDS
16
14
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 26



MAXIMUM CRUSHING STRENGTH - COMPRESSION PARALLEL GRAIN 1,000'S OF POUNDS
16
14
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 27

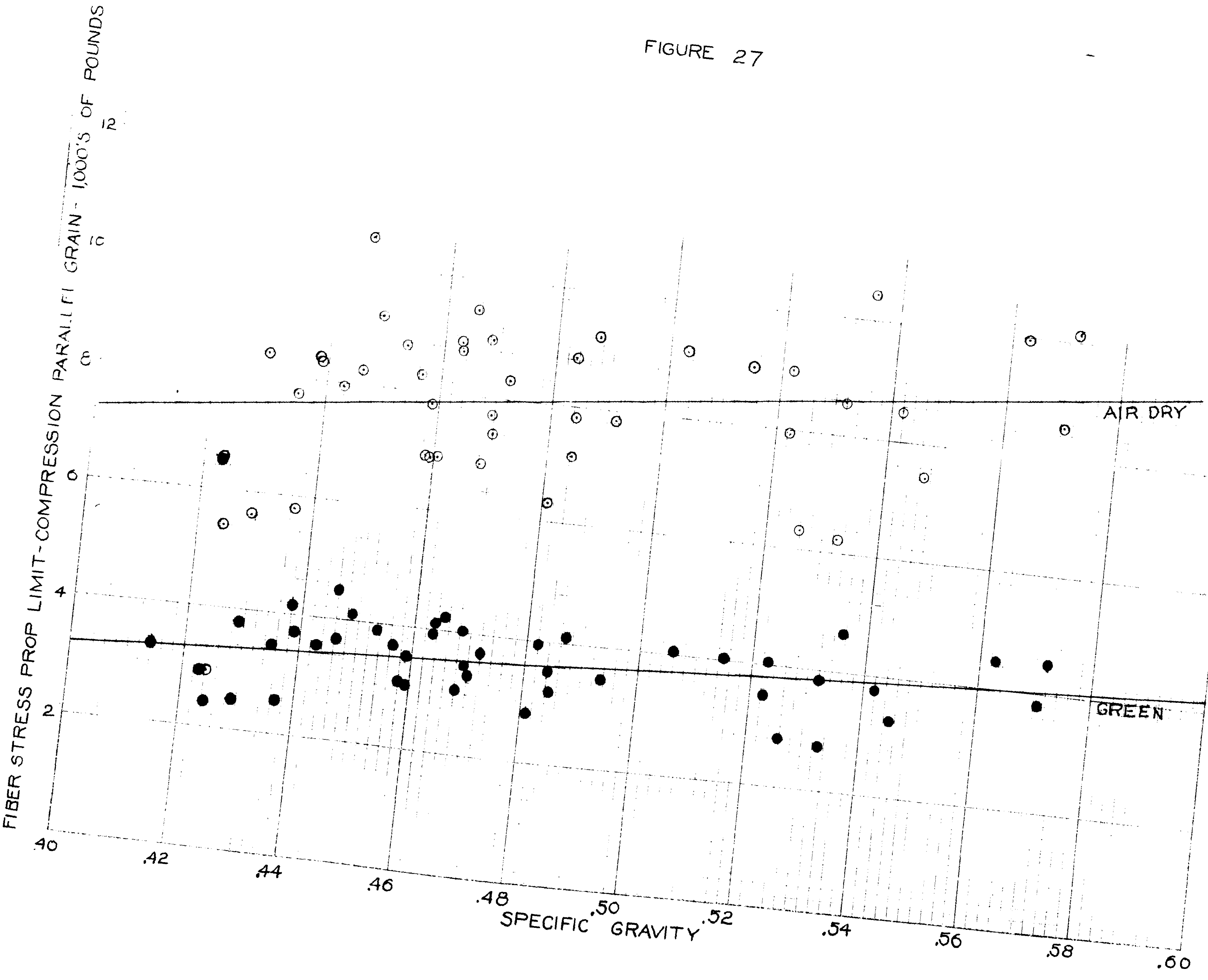
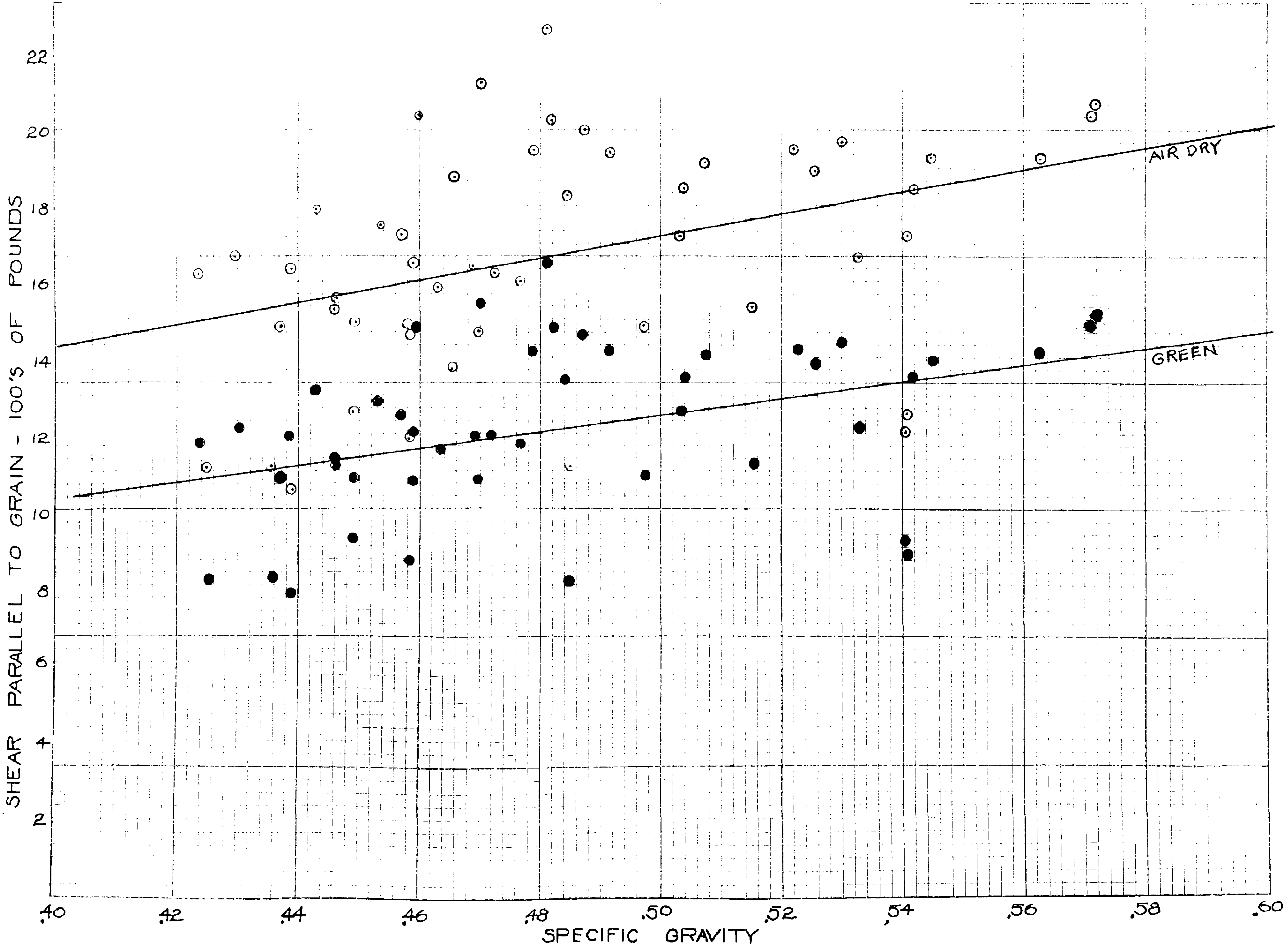

FIBER STRESS PROP LIMIT-COMPRESSION PARALLEL GRAIN - 1,000'S OF POUNDS
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 28



SHEAR PARALLEL TO GRAIN - 100'S OF POUNDS
22
20
18
16
14
12
10
8
6
4
2
AIR DRY
GREEN
.40
.42
.44
.46
.48
.50
.52
.54
.56
.58
.60
SPECIFIC GRAVITY

FIGURE 29.- WOOD PROPERTIES BY LOCALITIES

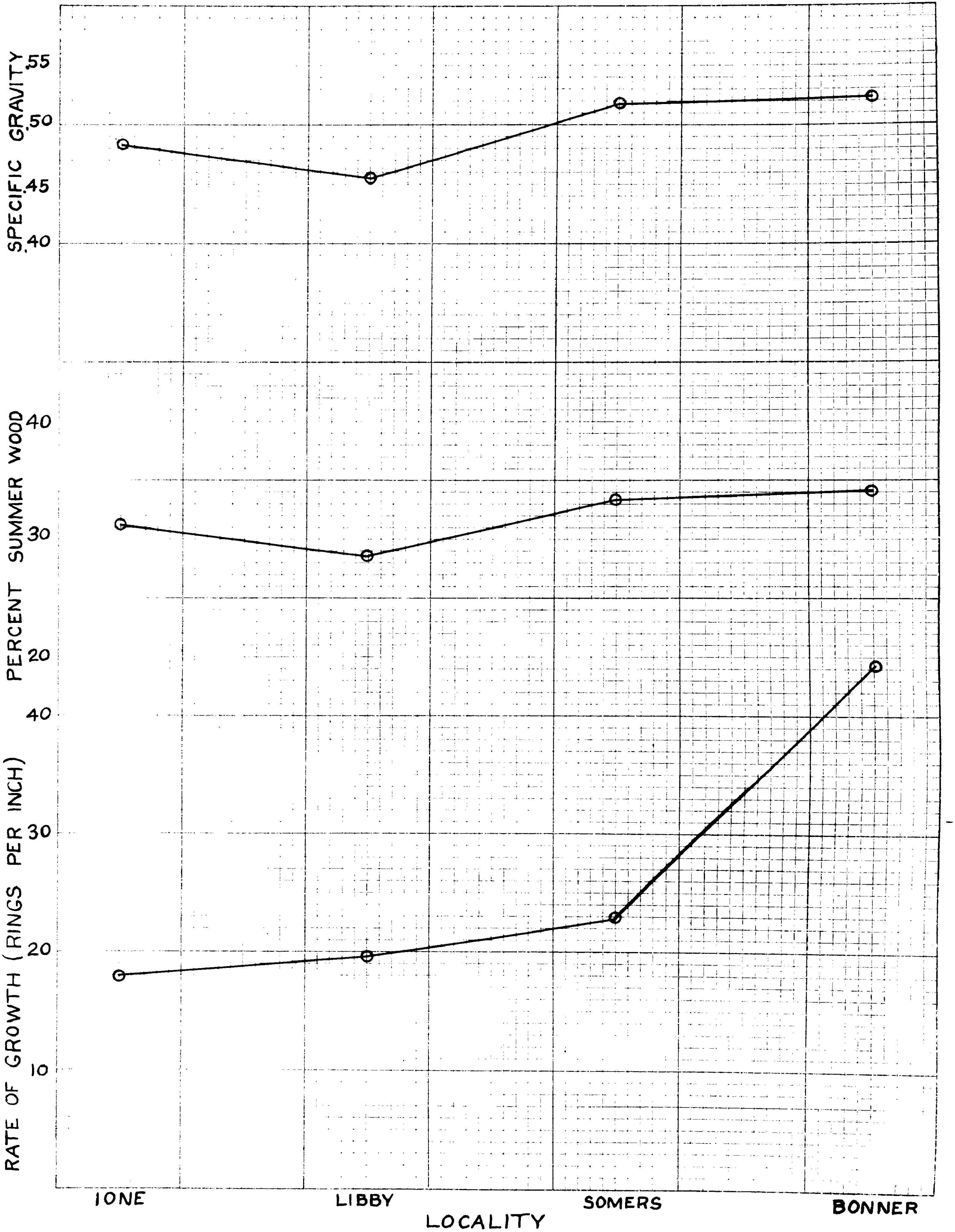


FIGURE 30. — STRENGTH PROPERTIES BY LOCALITIES

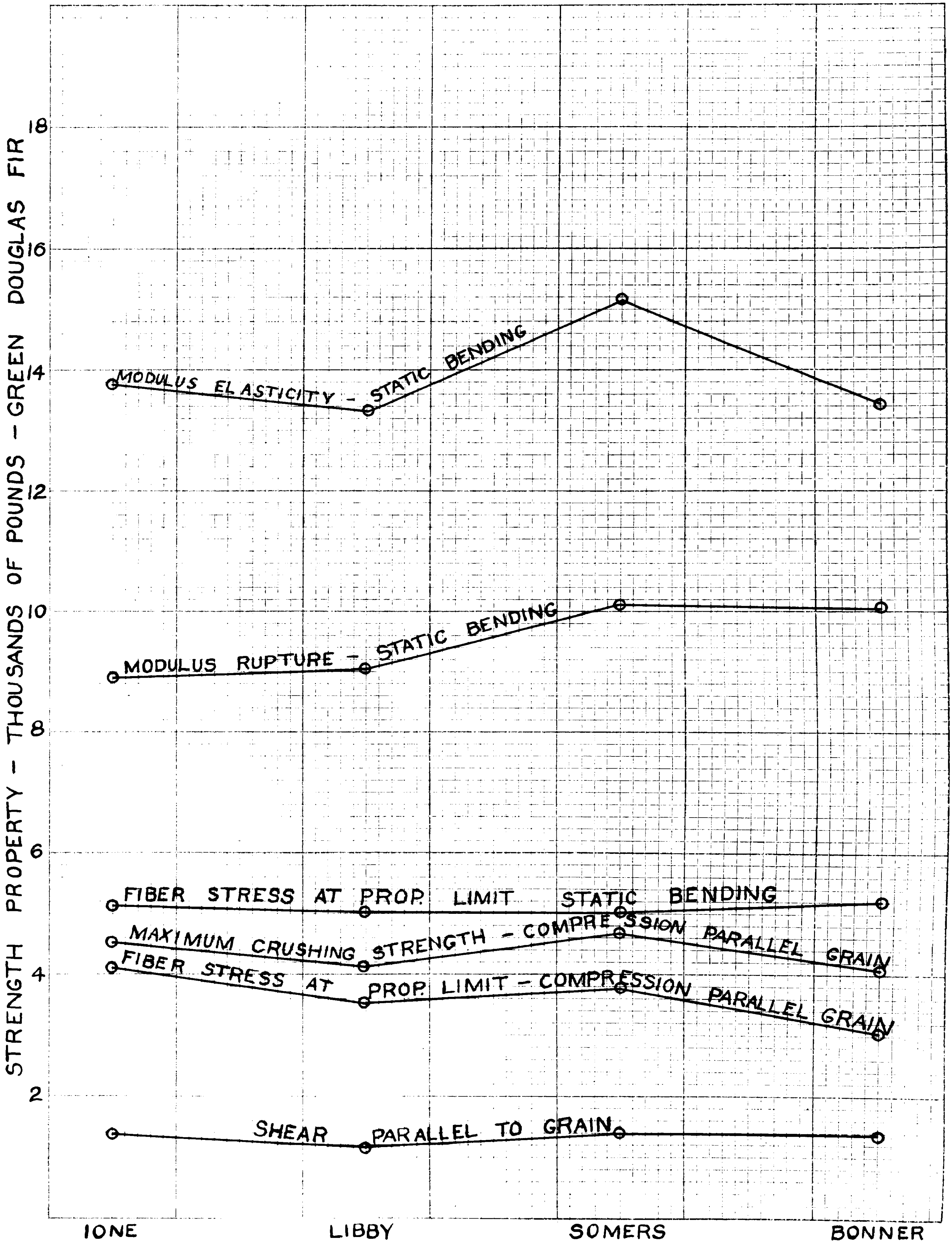


Table 7.- Strength properties and specific gravity of Douglas fir by regions (all stresses expressed in pounds per square inch)

Region	Moisture content	Specific gravity	Static bending			Compression parallel grain		Shear parallel to grain
			Modulus elasticity	Modulus rupture	Fiber stress prop. limit	Maximum crushing strength	Fiber stress prop. limit.	
Coast	36%	.45	1,550,000	7,600	4,800	3,890	3,410	930
	12%	.48	1,920,000	11,700	8,100	7,420	6,450	1,140
Inland Empire	42%	.41	1,340,000	6,800	3,600	3,240	2,460	870
	12%	.44	1,610,000	11,300	7,400	6,700	5,520	1,190
Rocky Mtn.	33%	.40	1,180,000	6,400	3,000	3,600	2,540	880
	12%	.43	1,400,000	9,600	6,060	6,300	4,660	1,070

(From Wood Handbook, U. S. Forest Products Laboratory, page 51, table 8.)

Table 8.- Strength properties and specific gravity by localities of green Douglas fir wood
(All stresses expressed in pounds per square inch)

Locality where Grown	Specific gravity based on volume at test	Rings per inch	Percent Summer Wood	Static Bending			Compression parallel grain		Shear parallel to grain
				Modulus elasticity	Modulus rupture	Fiber stress prop. limit	Maximum crushing strength	Fiber stress prop. limit	
Lewis Co. Wash.	.474	12.3	32	1,627,000	8,040	5,320	4,130	3,780	906
Lane Co. Ore.	.461	19.8	36	1,679,000	7,860	4,860	4,080	3,440	882
Chehalis Co.Wash.	.414	8.8	39	1,407,000	7,010	4,280	3,410	2,780	940
Humboldt Co.Calif.	.444	10.1	36	1,508,000	7,500	4,580	3,830	3,520	961
Clatsop Co.Ore.	.429	17.2	47	1,452,000	7,400	4,640	3,770	3,200	858
Wash.Co. Ore.	.460	15.2	28	1,704,000	7,720	4,840	4,260	.....	1,144
Clark Co. Wash.	.429	15.1	37	1,411,000	6,890	4,540	3,470	.....	849
Lincoln Co.Mont.	.430	19.3	..	1,437,000	7,110	3,890	3,450	2,610	888
Shoshone Co.Idaho	.390	10.6	..	1,239,000	6.390	3,290	3,040	2,310	859
Missoula Co.Mont.	.392	26.2	32	1,124,000	6,410	3,730	3,090	2,660	897
Johnson Co.Wyo.	.418	17.3	22	1,242,000	6,340	3,570	2,920	2,410	856

(From U.S.D.A. Tech. Bull. No. 479, Strength and Related Properties of Woods Grown in the United States, by L.J. Markwardt and T.R.C. Wilson)

Douglas fir is lower in modulus of elasticity (stiffness) than the Pacific Coast type, but higher in modulus of rupture (maximum breaking strength), and higher in fiber stress at proportional limit (the maximum load that may be sustained without permanent deformation of the beam). Fiber stress at proportional limit governs the safe working load for the beam, as any load causing stresses exceeding the proportional limit will ultimately result in failure, while modulus of rupture indicates the ability of the beam to withstand a sudden and unexpected overload, for which allowance has not been made in designing. Also the Inland Empire fir was found to be higher than the Coast fir in shear parallel to grain and higher in maximum crushing strength and fiber stress at proportional limit for compression parallel to grain. These three values bear an important relationship to the strength of joints in timber framing as they determine the bearing area that must be allowed for the ends of truss members and the amount of wood necessary to resist shearing stresses.

According to table 8 the Inland Empire fir of greatest strength is found in Lincoln County, Montana; the material of least strength in Missoula County, Montana; and that having intermediate strength properties in Shoshone County, Idaho. For modulus of elasticity in static bending and for maximum crushing strength, material from Missoula County is weaker than that from Johnson County, Wyoming, which would be of the Rocky Mountain type. On the other hand, material from Lincoln County is stronger than that from Chehalis and Clark Counties in Washington (16) table 21.

Summary and Conclusions

From the results of this study it was found that the strongest wood is produced by trees of a medium rate of growth; that there is a direct relationship between percent of summerwood and specific gravity; and that there is an increase in strength for larger percentages of summerwood or higher specific gravities, resulting from an average rate of growth. However, there are large variations from the general trend, especially in the case of abnormal wood such as compression wood.

The Douglas fir of the Inland Empire may be found in all grades of strength. Inland Empire Douglas fir may be no stronger than the Rocky Mountain type of fir, but on the other hand, the better quality Inland Empire material will be equal in strength to the Pacific Coast type of fir.

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