Supplement to

THE FATIGUE BEHAVIOR OF WOOD AND PLYWOOD SUBJECTED TO REPEATED AND REVERSED BENDING STRESSES

The Fatigue Behavior of Douglas-fir and Sitka spruce Subjected to Reversed Stresses Superimposed on Steady Stresses

Information Reviewed and Reaffirmed

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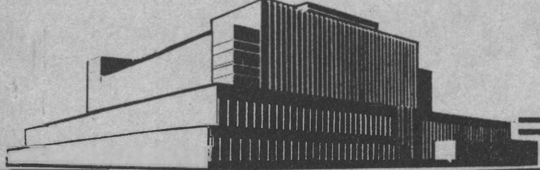

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE FATIGUE BEHAVIOR OF DOUGLAS-FIR AND SITKA SPRUCE SUBJECTED TO REVERSED STRESSES SUPERIMPOSED ON STEADY STRESSES[1]

By

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Summary

This report presents results supplementary to those in Forest Products Laboratory Report No. 1327, "The Fatigue Behavior of Wood and Plywood Subjected to Repeated and Reversed Bending Stresses." In that publication were given the description and usage of the flat-plate type of fatigue machine, the determination of the specimen shape, the background for the use of microswitches as a mechanism for determining initial failure, and the results of the fatigue investigations made in this study prior to July 1943.

This supplement reports the results of fatigue tests in which cantilever bending specimens, instead of being vibrated about the neutral position, or vibrated in only one direction from the neutral position, with an amplitude equal to a deflection corresponding to a predetermined percentage of the modulus of rupture, were vibrated in two other manners:

(1) Through cycles having amplitudes corresponding to predetermined percentages (varying from 15 to 60) of the modulus of rupture, with the midpoint of the cycle in all tests being at a deflection producing a stress of 20 percent of the modulus of rupture. The mean stress was therefore 20 percent, while the maximum varied from 35 to 80 percent of the modulus of rupture.

(2) Through cycles having amplitudes in all tests producing a maximum deflection corresponding to a maximum stress of 60 percent of the modulus of rupture, the midpoint of the cycle being varied to give mean stresses equal to predetermined percentages (from 0 to 30) of the modulus of rupture.

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[1]This report is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available. Original report written by W. J. Kommers dated May 1944.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Tests in the first manner were made on Douglas-fir and Sitka spruce. Those of the second were made on Sitka spruce only. The specified percentages of stress are the percentages of modulus of rupture to which the deflections produced by the testing machine correspond.

The results indicate that with a mean stress of 20 percent the number of cycles to shutoff increases rapidly as the range of stress is decreased. For example, the number of cycles is on the order of 200 when the range is from +80 to -40 percent, and some 20 million when the range is from +40 percent to zero.

It is indicated also that with a certain maximum stress the number of cycles to shutoff increases as the mean stress is increased. For a maximum stress of 60 percent, for example, the number of cycles is about 400 when there is a complete reversal of stress, and about 500,000 when the mean stress is increased to the point such that there is no reversal of stress.

Introduction

A graph (fig. 1)[3] of the frequency distribution of load factors resulting from gust action in nonaccelerated flight shows the characteristic of rapid decrease of frequency each way from a modal value of load factor of unity, with only rare occurrences of very high and very low load factors. To design a machine that would apply loads to produce this kind of a stress pattern would be difficult, and to make such a test manually would be arduous and time consuming. The only other method of attaining the results from a laboratory procedure would be to determine the so-called "damage lines"[4] as have been determined for various metals. From these lines, knowing the numbers of cycles of stress at any stress intensity, it would be possible to estimate the reduction in endurance due to such variations in overstress. Understress values would not materially change the life of wood specimens, inasmuch as work hardening due to moderate stressing, with resulting increase in life, is not a factor in wood as it is in steels.

Because of the difficulty of designing and building a testing machine to apply the varying intensities of stress encountered in aircraft flight, information concerning the effect of a known reversed stress, having a mean value other than zero, on the fatigue life of the material was obtained from the equipment available (flat-plate-type fatigue machines). This type of stress cycle may be visualized as a reversed stress superimposed on a steady stress (fig. 2). Twenty percent mean stress value of the cycle was chosen, as corresponding to a design factor

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[3] Statistical Analysis of Service Stresses in Aircraft Wings. Hans W. Kaul. NACA Tech. Mimeo. No. 1015, June 1942.

[4] The Effect of Overstressing and Understressing in Fatigue. J. B. Kommers. ASTM Proceedings, Volume 43.

of five in aircraft structures, and simulating the steady-flight load of one g. The reversed stresses would then simulate the vibrational and gust loads that have been recorded[3,5] in aircraft parts during flight. Since the stress cycles, as encountered in aircraft, are not of the completely reversed stress type, such as reported in Report No. 1327, the additional information here presented should be of value to the designer.

Material Tested

The specimens of Sitka spruce and Douglas-fir tested in this series were cut from kiln-dried planks to dimensions of 3/8 by 1-1/4 by 9 inches and were numbered during the cutting to show the position of each specimen in the plank. All the specimens used were of clear, straight-grained material. Fatigue specimens and control specimens were taken from alternate positions in the plank (fig. 3) such that the annual rings were parallel to the width and the grain direction was parallel to the length of the specimen. All were seasoned and tested under controlled conditions of 80° F. and 65 percent relative humidity. The average values of specific gravity and modulus of rupture of the Sitka spruce plank and the Douglas-fir plank were 0.40 and 0.45, and 10,240 and 10,700 pounds per square inch, respectively. The specimens from each plank were divided into two groups, one for control static-strength tests and the other for the fatigue tests. The testing procedures and equipment used were the same as described in Report No. 1327.

Methods of Test

The methods of test were essentially the same as described in Report No. 1327. Microswitches with a clearance of 0.003 inch were placed on each side of the specimen, but, except when the mean stress was zero, the switch actuated to cause shutoff was the one on the side corresponding to the maximum deflection.

In preparing a test, the specimen was clamped on the machine and loaded in succession with weights corresponding to the specified mean and maximum stress respectively. The corresponding deflections were then used as the mean and maximum deflection imposed by the machine.

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[5] Load Factors Obtained on Civil Airplanes in Acrobatic Maneuvers. E. I. Ryder. Journal of Aeronautical Sciences, April 1942.

Explanation of Charts

The 20 percent mean stress test data are plotted on semilogarithmic paper in figures 4 and 5, with the maximum stresses as ordinates and the cycles-to-shutoff as abscissas. The values of reversed-stress intensity were varied from 60 percent of the static modulus of rupture down to approximately 18 percent for Sitka spruce (fig. 4) and down to 14 percent for Douglas-fir (fig. 5). Tests that continued for 50 million cycles without failure were then discontinued. Figure 6 shows the results of tests on specimens that were subjected to stress cycles having the maximum stress intensity at 60 percent of the static modulus of rupture, and with the mean stress of the cycles varied from 0 to 30 percent of the static modulus of rupture. Each point shown on this graph is the numerical average of three tests.

Discussion

As indicated in Report No. 1327, there was, in the previous series, little difference in the fatigue results on Sitka spruce and Douglas-fir, subjected to completely reversed stress cycles, when the life in cycles was plotted against the reversed stress in percent of the modulus of rupture of the material. In the present series there seems to be no significant difference between Sitka spruce and Douglas-fir with respect to the endurance strengths up to 50 million cycles with a mean stress of 20 percent. The slight discrepancy between the endurance strengths at 50 million cycles, of Sitka spruce and Douglas-fir (19 and 17 percent of the static modulus of rupture, respectively) as shown in figures 4 and 5, is assumed to be due to natural variation in the strength of wood specimens rather than to a difference in the two species. The values of 19 and 17 percent were determined as being the highest stresses that can be superimposed upon a steady stress of 20 percent without causing fatigue failure within a life of 50 million stress cycles.

Figure 6 shows the results of the tests of Sitka spruce specimens subjected to stress cycles having a maximum stress of 60 percent of the static modulus of rupture with various values of mean stress. When the mean stress is zero, the stress cycle is completely reversed; when the mean stress is 30 percent of the static modulus of rupture, the stress cycle is of the repeated type from zero to a maximum. This graph indicates an endurance life on the order of 500,000 cycles for a maximum stress of 60 percent when the mean stress is 30 percent (no reversal). Figure 13 of Report No. 1327 indicates for Sitka spruce, with a completely reversed stress of 60 percent of the modulus of rupture, an endurance life of approximately 400. This value has been used as a guide in positioning the lower part of the curve of figure 6.

All of the fatigue tests have been made with the deflection cycle, produced at the beginning, remaining the same throughout the test. This, however, does not mean that the stresses remain constant. It has been shown[6,7] that a stress cycle with a mean stress other than zero is affected by plastic flow in materials such as wood, plywood, and plastics. Relaxation of the mean stress follows as a function of time, probably in the form of a parabolic curve with the plastic phase of the deformation increasing at a decreasing rate. This may be similar to the plastic flow in shear,[8] but as yet little information is available on the relaxation of stress in bending. Since the flat-plate fatigue machine is of the fixed-deflection type, rather than the constant-stress type, the relaxation in the specimens may be appreciable, but the test data presented is in terms of the stresses produced at the start of the test and does not show any correction factor for relaxation.

All the fatigue tests made to date have been on wood and plywood specimeans seasoned under conditions of 65 percent relative humidity and temperatures of 75° to 80° F. The effect of higher and lower temperature and moisture content on the fatigue properties may be appreciable, but this information is not yet available. The effect of the rate of the application of the stress cycles also needs investigation. The 1,790 cycles per minute now used is well below the natural frequency of vibration of the material. The use of this speed was necessary to prevent harmonics that occur when operating the machine at speeds near the natural cantilever vibration frequency, and to prevent change in the elastic curve of the specimen which would actuate the microswitch mechanism used for stopping the machine. The rate of stressing may affect the endurance strength of a specimen and also may affect the amount and rate of plastic flow that takes place.

Investigation concerning fatigue of wood and plywood should be expanded to include the effects of temperature, moisture content, rate of vibration, and varying intensities and kinds of stress on the life of a specimen or wood structure.

Conclusions

The endurance strength at 50 million cycles of stress for solid Sitka spruce and Douglas-fir is a reversed stress of approximately 18 percent of the static modulus of rupture when the mean stress of the cycle is 20 percent of the same static modulus of rupture. In addition, for any particular maximum stress value of a stress cycle, the life of wood specimens is increased by an increase in the value of the mean stress toward the maximum

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[6] A Study of the Fatigue Properties of Macerated Phenolic Molding Material. Senior Thesis, University of Illinois, 1943.

[7] Forest Products Laboratory Report No. 1327.

[8] Forest Products Laboratory Report No. 1324.

These tests were made using flat-plate-type fatigue machines operating at 1,790 revolutions per minute on specimens conditioned at 65 percent relative humidity and at temperatures of 75° to 80° F. Additional test work should be made at various specimen temperatures and values of moisture content, and at various rates of vibration and intensities of stress to determine the effects of these factors on the fatigue life of wood and plywood.

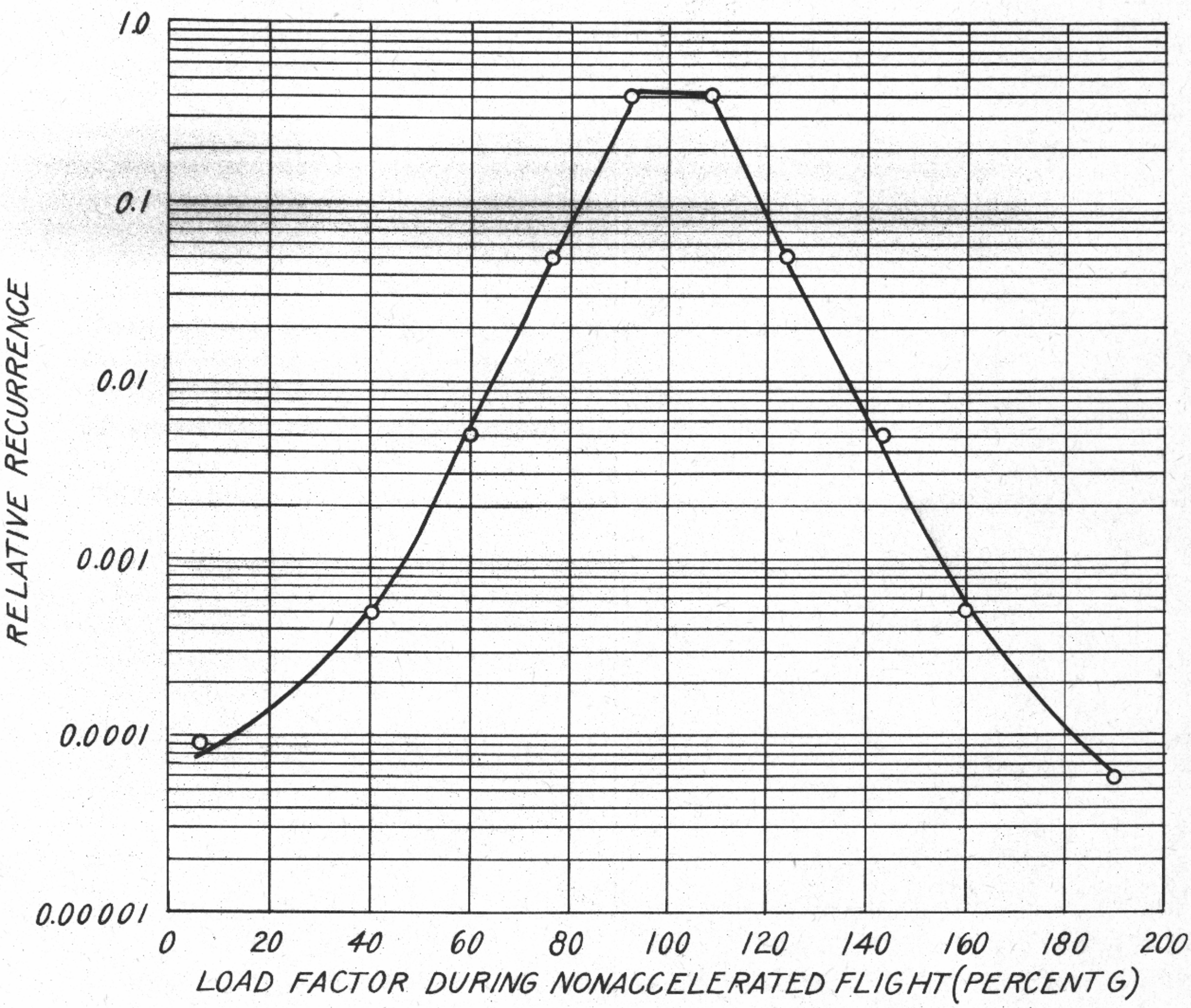

Figure 1.--Frequency distribution of load factors resulting from gust action during nonaccelerated flight. This graph is from "Statistical Analysis of Service Stresses in Aircraft Wings" by Hans W. Kaul, NACA Tech. Mimeo. No. 1015, June 1942.

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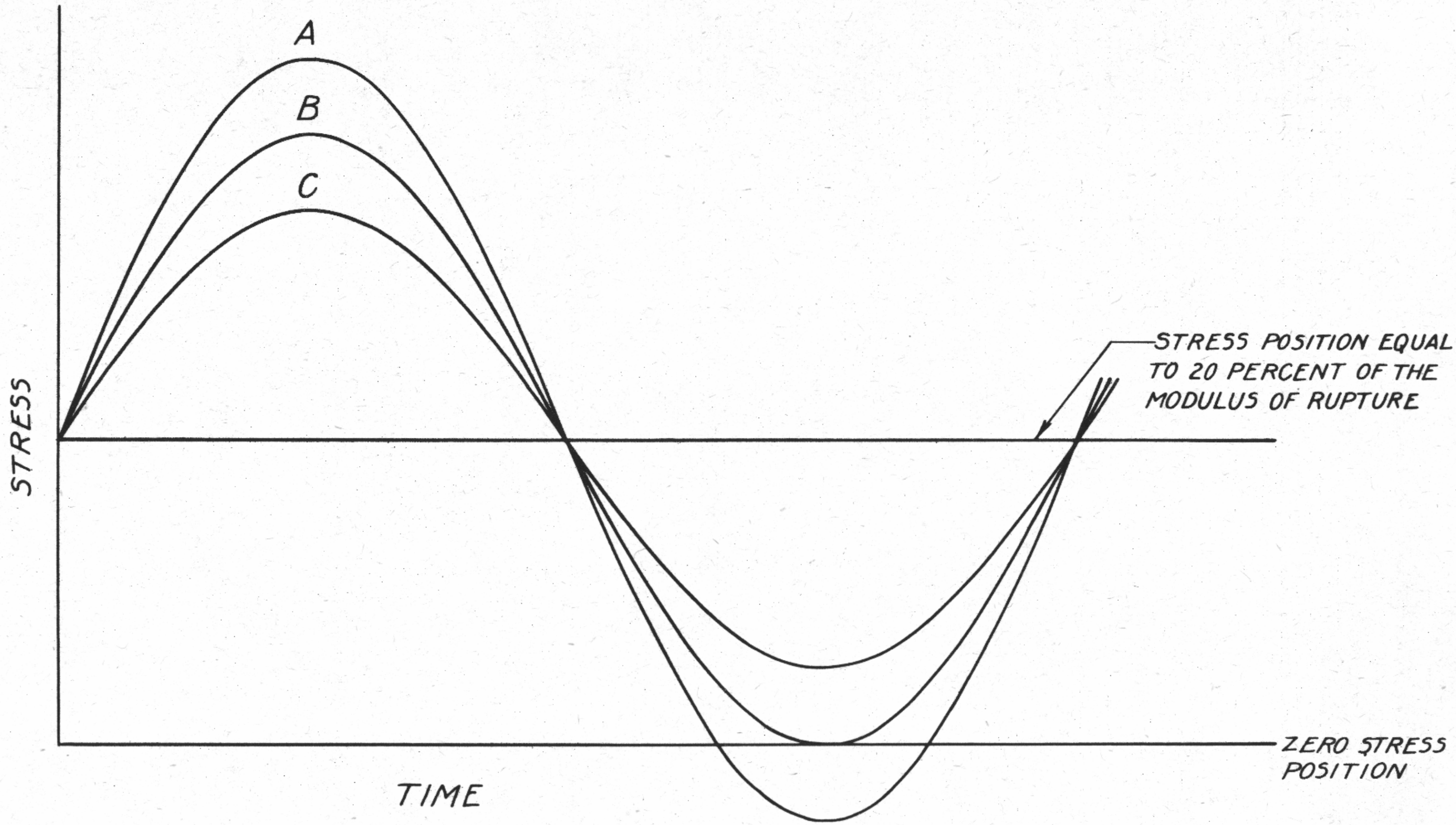

Figure 2.--Types of stress cycles applied to cantilever wood specimens by flat-plate-type fatigue machines. Mean stress for each curve is 20 percent of the modulus of rupture. A, a cycle with slight amount of reversal of stress; B, a repeated-stress cycle ranging from zero stress to its maximum; C, a cycle with the stress always in the same direction.

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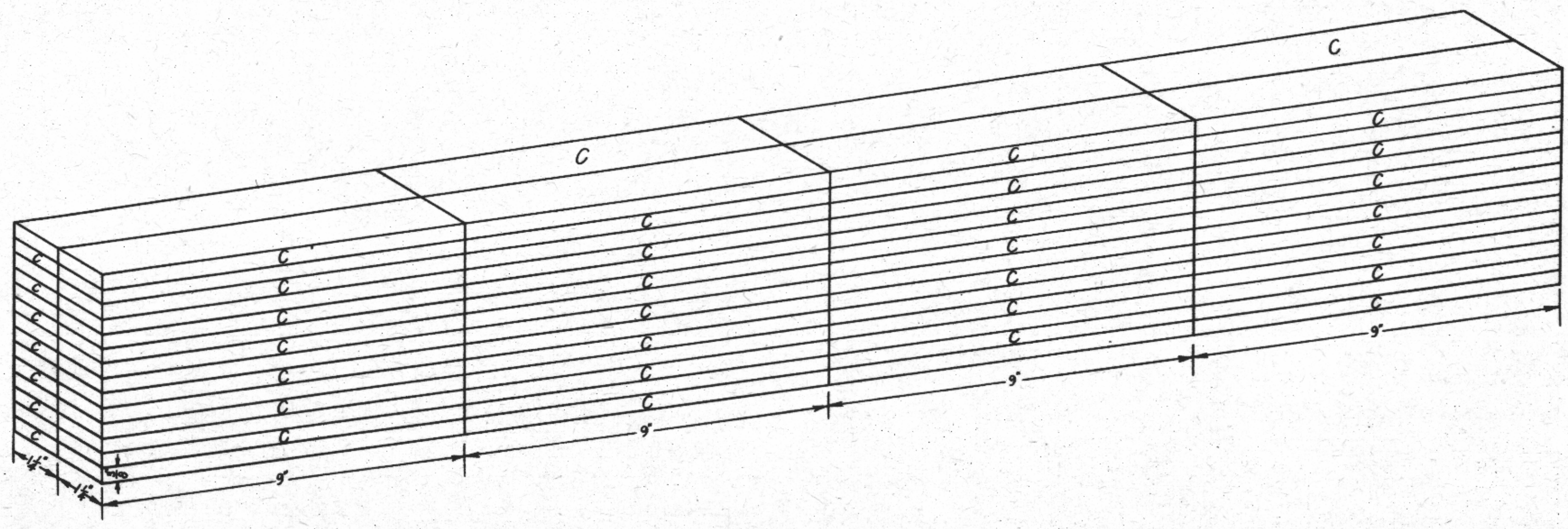

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Figure 3.--Cutting diagram for Sitka spruce and Douglas-fir planks showing how control specimens (c) alternate with fatigue specimens (unlabeled) throughout the plank.

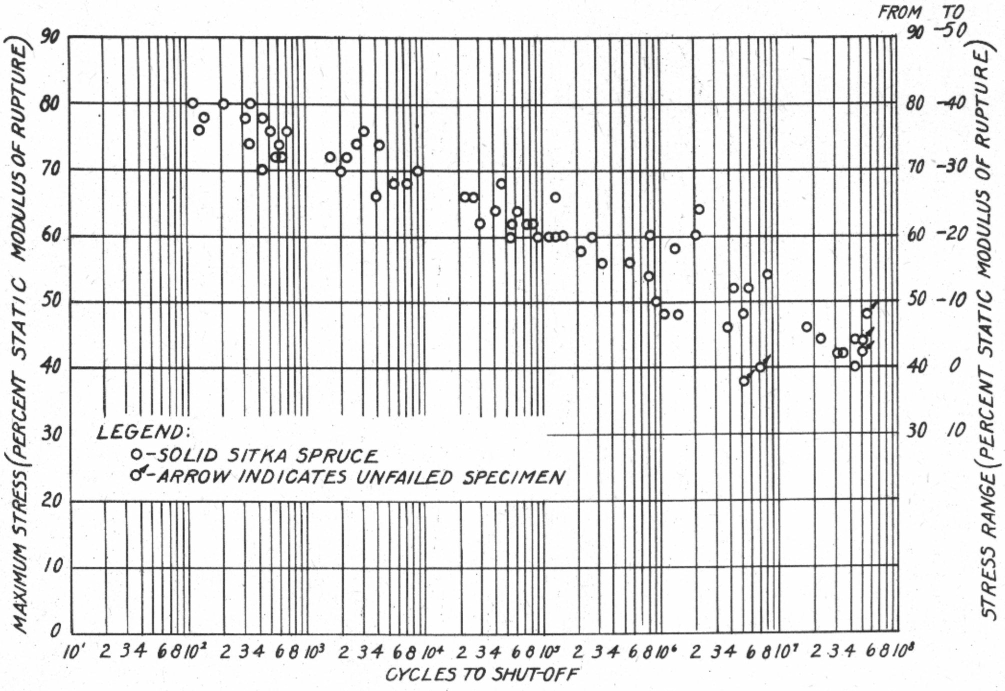

Figure 4.--Tests on Sitka spruce with the mean stress held at 20 percent of the modulus of rupture and the maximum stress varied from 80 percent down to 38 percent of the modulus of rupture.

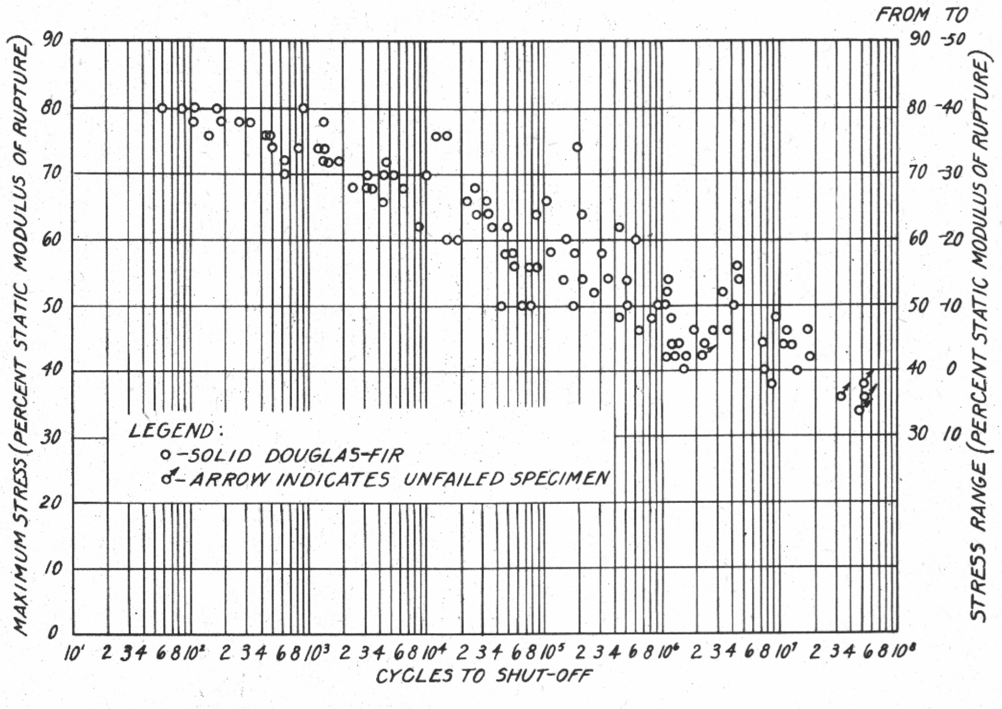

Figure 5.--Tests on Douglas-fir with the mean stress held at 20 percent of the modulus of rupture and the maximum stress varied from 80 percent down to 34 percent of the modulus of rupture.

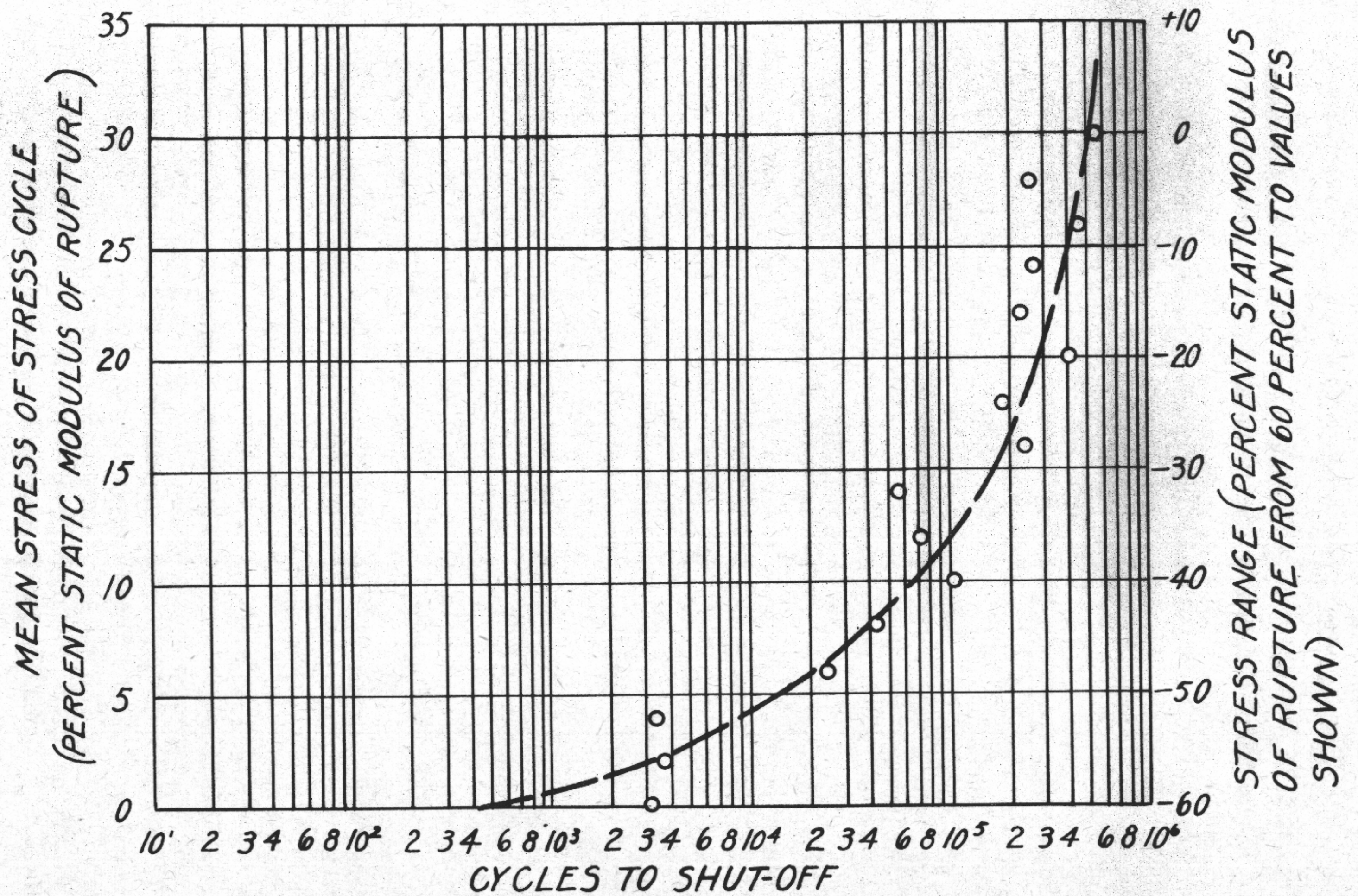

Figure 6.--Tests of Sitka spruce specimens subjected to stress cycles having the same maximum stress, 60 percent of the modulus of rupture, but with varying mean stresses.

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