EFFECT OF PRESSURE TREATMENT WITH COAL-TAR GREGOTE
ON THE STRENGTH OF DOUGLAS-FIR STRUCTURAL TIMBERS

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Introduction

Does pressure treatment with coal-tar creosote or other preservatives seriously impair the strength of structural timbers? This question is of importance to engineers designing load-bearing structures of creosoted wood. Unfortunately, a conclusive answer cannot be given. The comprehensive investigation required to provide the necessary information would cost several hundred thousand dollars, and it is unlikely, therefore, that it will be made soon. Various limited studies and tests have provided some useful information but not enough to settle the question. For the most part, these tests were confined to creosoted wood, particularly timbers of structural size.

Thousands of important structures have been built of creosoted wood, and billions of board feet of creosoted wood used during the last 50 years. Service life of 30 to 40 years is common for creosoted-wood bridges, trestles, pole lines, culverts, pile structures, railway tracks, and other load-carrying structures under conditions favorable to decay and insect attack. Thus, the economy of creosoted wood and its practicability for load-bearing structures has been established by long and successful use, despite the inadequacy of information about the specific effect of the preservative treatment on strength of the wood. It is customary in designing such structures to use the same design stresses for treated timber as for untreated timber used under conditions favorable to decay (1).2

The purpose of this report is to discuss information available from strength tests on creosoted timber made by the U. S. Forest Products Laboratory and others. A review of all available reports and publications on the subject was made. Some strength data were found on wood treated under heating and pressure conditions more severe than are permitted under the standard specifications of the American Wood Preservers' Association. These data were omitted

1 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
2 Underlined numbers in parentheses refer to references at end of this report.
from this report because they are not representative of present good practice. All data found on the strength of wood creosoted under conditions permitted by present specifications were included. These data were limited to Douglas-fir. Similar information on hardwoods and other softwood species is not available.

Effect of Preservative

In the application of preservative oils under heat and pressure to protect timbers from attack by decay, insects, or marine borers, the effect of the preservative itself on the wood properties appears to be negligible. For example, the preservative oils that are widely used for this purpose, such as coal-tar creosote, solutions of tar or petroleum in creosote, or solutions of toxic chemicals in petroleum, are not corrosive to wood and should not adversely affect its properties.

In the absence of evidence to the contrary, therefore, it is assumed that it is not the preservative oil, but the treating conditions, which involve the application of heat and pressure, that are mainly responsible for the adverse effect treatment with preservative oils may have on the strength of treated wood.

Effect of Treating Variables

The effect of treating conditions on the strength properties of wood depends to a large degree upon the severity of the heating and pressure conditions used. Heating at high temperatures for long periods of time, followed by the application of excessive pressures, can be expected to cause more damage to the wood than moderate treating conditions. Some of the more important variables that influence the results are: (1) species of wood, (2) dimensions of timbers treated, (3) heating medium used, (4) temperature of the heating medium, (5) length of heating period used in conditioning the wood for treatment and length of time the wood is in the hot preservative, (6) moisture content of the wood at time of treatment, and (7) preservative pressure used.

The effect of treating conditions on the strength properties may depend to a considerable extent on the species, since some woods are more easily injured by heat or pressure than are others. The rate of heating also is affected by the density of the wood. No comparison of species is possible in the present discussion, however, since data were available only for Douglas-fir.

The dimensions of the timber influence the results, since the rate of temperature change and the temperatures attained at any point within the piece will depend to a considerable degree on its size and shape.

Since the surface coefficient of heat transfer varies with the heating medium, the rate at which the temperature increases within a timber exposed to a given exterior temperature will be slower in some heating mediums than
in others. For example, the surface coefficient of heat transfer for con-
densing steam is greater than that for water, hence steam heats wood somewhat
faster than does water at the same temperature. Water, however, heats wood
faster than oil and oil heats faster than air at a low relative humidity.
The rate of heating in air increases as the air humidity is increased.

The effect of any given heating conditions on the strength of the wood
will depend both on the temperature and on the length of the heating period.
Heating for a long time at a given temperature may have the same effect as
heating for a shorter time at a higher temperature. Laboratory studies on
small pieces of wood (9) indicate that, for any fixed time of heating, the
relation between different temperatures and their effect on the wood will
vary according to some exponential function and not in a direct proportional
relation. For example, the effect obtained by increasing the temperature
from 250° to 300° F, was considerably more than the corresponding effect
obtained when the temperature was raised from 200° to 250° F. That is, equal
temperature changes produced larger and larger losses in strength in going
from the lower to the higher temperature range.

In these experiments (9) it was found that regardless of the heating
medium used, the effect of heat on the physical properties of the wood was
cumulative. In other words, repeated short heating periods damaged the wood
as much as did continuous heating at the same temperature for a period ap-
proximately equal to the sum of the shorter heating intervals.

The moisture content of the wood at the time it is heated will also
affect the results, since hydrolysis and its weakening effects are accelerated
when the moisture content is high.

Other treating variables that may affect the strength are the treating
pressure and the length of time pressure is applied. Marked checking and
collapse may develop if too high pressures are used, especially if applied
for long periods following long heating. Some woods, however, can withstand
considerably higher treating pressures than others. The effect of pressure
also is influenced by the timber dimensions and the temperature of the wood.

The successful treatment of wood requires that the moisture content be
reduced sufficiently to permit satisfactory penetrations and absorptions.
It is also necessary that the temperature of both the preservative oil and
the wood be kept high enough during pressure treatment to allow suitable pene-
tration of the preservative. With wood that has been sufficiently air sea-
soned, the period that the wood is heated in the oil can be relatively short.
When it is necessary to treat green timbers, the charge is generally con-
ditioned by the steaming-and-vacuum method or by the Boulton process, also
known as the boiling-under-vacuum process. A process also has been recently
developed and patented which employs hot oil vapors in reducing the moisture
content and for conditioning certain types of timber. The boiling-under-
vacuum process was used for conditioning the green timbers used in the tests
discussed in this report.

Specifications for preservative treatment usually set limits on the
maximum temperatures and heating periods permitted in the conditioning treat-
ment and during the pressure period, so that the treating conditions will be
as mild as is consistent with satisfactory penetration and absorption. Specifications also usually limit the pressure used in treating various species.

Formerly, excessively high temperatures and long heating periods were employed in the treating operations, and these often seriously impaired the strength of the wood. For example, steam pressures as high as 50 to 100 pounds per square inch (298° to 338° F.) were sometimes used in the past for conditioning both Douglas-fir and southern pine, while steam pressures ranging from 25 to 35 pounds (267° to 281° F.) were very commonly used. Sawed Douglas-fir timbers were sometimes steamed at 60 to 90 pounds of pressure (307° to 331° F.) for 4 to 6 hours. In addition to the use of high steam temperatures, it was common practice to maintain a vacuum after steaming for as long as 5 to 8 hours or more with the steam coils heated. The timbers nearest the surfaces of the heated steam coils and cylinder were usually severely heated by radiation during the vacuum period.

Standard specifications prepared in more recent years by organizations concerned with the treatment of wood, such as the American Wood Preservers' Association, generally limit steam-conditioning temperatures to not over 259° F. for southern yellow pine. Very little steaming is used with Douglas-fir and that is limited by the specifications of the American Wood Preservers' Association to not more than 6 hours at a temperature not higher than 240° F. In the boiling-under-vacuum conditioning treatment for green Douglas-fir, the specifications permit a maximum temperature of 220° F. for round timbers but do not limit the length of the conditioning period. Since moisture is commonly evaporated during the conditioning period, the wood is usually at a lower temperature than that of the heating medium. In the final expansion bath sometimes used following the pressure period in the treatment of Douglas-fir, the specifications permit the temperature of the oil to rise to 220° F. for a period not specifically limited. A final steaming period for cleaning purposes is permitted for not over 3 hours at a maximum temperature of 240° F.

### Strength Tests of Creosoted Douglas-fir Timbers

A resume of all the test data available on the strength of Douglas-fir timbers creosoted under conditions permitted by present American Wood Preservers' Association specifications is given in table 1. The conditioning temperatures used were well below the maximum temperatures permitted. A few of the treating pressures used on seasoned wood exceeded the present permissible maximum of 150 pounds per square inch, but none of the pressures used with green wood exceeded that limit.

Timber size appears to have an important bearing upon the effect of creosote treatment on strength. Tests made several years ago at the U. S. Forest Products Laboratory (10, 13) are of interest in this connection. The material treated for these tests consisted of two pieces, 8 by 16 inches by 7-1/2 feet, and of 18 pieces, 2 by 2 inches by 7-1/2 feet, which were cut from a similar 8- by 16-inch piece. These 20 pieces were subjected (all at the same
time and in the same charge) to heating in creosote without vacuum at 215° F., for 27 hours, followed by pressure of 150 pounds per square inch for 4 hours, with the creosote at 200° F. After treatment, 18 pieces, 2 by 2 by 30 inches in size, were cut from the central 4 feet of each of the treated 8 by 16's, and one piece, 2 by 2 by 30 inches in size, from the central 4 feet of each of the 2 by 2's. These fifty-four 2- by 2- by 30-inch specimens were tested in static bending along with matched, untreated control pieces. Some were tested soon after treatment and some after drying to practically constant weight. The results indicate that the pieces cut from the treated 8 by 16's were reduced in strength more than the pieces treated as 2 by 2's. Also, the pieces from the center of the cross section of the 8 by 16's were found to be reduced in strength as much as or more than those adjacent to the surface.

In the boiling-under-vacuum conditioning process for the tests in table 1, about 1 to 2 hours were usually taken to reach the maximum preservative temperature. In most cases, the vacuum was not applied until the wood had been heated at this preservative temperature for 4 to 5 hours. During the conditioning treatment the amount of moisture driven off varies, depending on other variables such as the amount of sapwood, initial moisture content, and timber dimensions. The boiling-under-vacuum process is usually quite effective as a means of removing moisture from sapwood, but the high resistance of the heartwood of most species makes the process much less effective for reducing the moisture content of heartwood material. Since a reduction in moisture tends to increase the strength when the moisture content of the wood is below the fiber-saturation point (approximately 24 percent for Douglas-fir), there is some question as to the propriety of making direct comparisons between green untreated material and green material immediately after treatment. In the static bending tests, an offsetting factor was the checking that occurred during treatment, which reduced the resistance to horizontal shear.

Formulas are available for moisture-strength adjustments of small, uniformly seasoned specimens, but these formulas are not applicable to timbers that are partially and consequently nonuniformly seasoned. No means are now available for adjusting the strength values of treated and untreated timbers for differences in moisture content.

Discussion of Data

Incising and Treatment

Series of tests by Luxford (5, 6), Rawson (11), and Harkom (3, 4) included data on incising. Test No. 3 (table 1) showed a reduction of 9 percent in modulus of rupture due to incising green material and then seasoning, which is about the same as the reduction in moment of inertia caused by the incising. Fiber stress at proportional limit was less affected, and modulus of elasticity also was affected only slightly. When green material which was incised (test 7) was compared to green material without incising, the reduction in modulus of rupture caused by incising appeared somewhat greater than in test 8. Similarly, fiber stress at proportional limit was reduced somewhat more for green material than for material seasoned after

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incising. Possibly, incised timbers are less subject to severe checking in seasoning than are nonincised timbers. Rawson (test 13) and Harkom (test 16) found less reduction in strength of green timbers caused by incising than is indicated by test 7. This can be at least partly accounted for because they used larger timbers and hence incising would have a smaller effect upon the moment of inertia.

When incised material that was treated while green and tested immediately was compared to green untreated and unincised material, the apparent reduction in strength from incising and treatment (test 11) was less than that from incising alone. The incised treated timbers, however, had a relatively low average moisture content of 15 percent, with the outside inch having only 8.5 percent. This undoubtedly accounted for the high ratios of strength of treated material to that of untreated material, some being well over 100 percent. When material that was incised in a green condition and seasoned before treatment was compared to seasoned unincised matched material, the reduction in modulus of rupture (test 12) was 17 percent, or about 8 percent greater than indicated for incising alone. The reductions for incising and treating were not necessarily additive, however, as indicated by test 10, wherein the reduction in modulus of rupture for treatment alone was about 25 percent.

Treatment Only

Most of the tests listed in table 1 were made to determine the effect of preservative treatment on the strength of Douglas-fir without previous incision. The average reductions found in modulus of rupture ranged from 26 percent (Luxford, test 10) to less than 1 percent (Goss, test 2, (2)). Timbers in test 10 were seasoned and required no conditioning treatment. No moisture content values are available for test 2, but from other tests it seems likely that the moisture content of the treated timbers was considerably lower than for matched green timber. It is probable that a similar situation existed as in the tests by Luxford (test 9) in which the average moisture content of the treated timbers was only 20.6 percent, while the green matched timbers had 33.2 percent moisture content. Further, the outer inch of the treated material had only 17.5 percent of moisture. The low strength loss shown in test 2, therefore, is probably due to comparing treated timber of low moisture content with untreated timber of higher moisture content.

Other series of tests showed reduction in modulus of rupture from 5 to 18 percent. MacFarland (test 1) showed a reduction of 18 percent in modulus of rupture for Douglas-fir which was treated while green and tested without subsequent seasoning (7). Zimmerman (tests 3, 4, 5, and 6) showed reductions of 7 to 12 percent in modulus of rupture in green Douglas-fir treated but not seasoned or seasoned after treatment compared to similarly seasoned untreated material. Rawson (test 14) showed that green Douglas-fir treated and then soaked for 60 days after treatment was reduced in modulus of rupture only 5 percent as a result of treatment; however, his results showed a reduction of 11 percent in fiber stress at proportional limit. Harkom (test 17) showed that green Douglas-fir treated and then soaked for 5 months was reduced in fiber stress at proportional limit about 11 percent and
in modulus of rupture about 13 percent. Soaking tends to eliminate differences in the strength of treated material and untreated green material caused by differences in moisture content. This is probably a realistic condition in which to compare material, since treated material is necessary only where decay hazard is high because of high moisture content.

In general, fiber stress at proportional limit was affected about the same as modulus of rupture, while modulus of elasticity was generally affected much less by creosote treatment. Compression perpendicular to the grain usually was materially affected by treatment, table 1 showing that the average reductions reported by various investigators for members similar in moisture content ranged from 7 to 25 percent for Douglas-fir timbers conditioned by the boiling-under-vacuum process.

Working Stresses for Timber Used Under Conditions Favorable for Decay

Table 1 shows reductions of strength in bending and in compression perpendicular to grain up to 25 percent, while stiffness (modulus of elasticity) was not greatly affected.

This table representing Douglas-fir treated, or incised and treated within the limits of American Wood-Preservers' Association Specification T2-49, suggests that working stresses may be reduced according to the following tabulation to provide for loss of strength from preservative treatment.

<table>
<thead>
<tr>
<th>Working stress</th>
<th>Approximate range of reduction (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress in extreme fiber in bending</td>
<td>15-25</td>
</tr>
<tr>
<td>Stress in compression perpendicular to grain</td>
<td>15-25</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>0-10</td>
</tr>
</tbody>
</table>

It is important to exercise care in all treating operations so that any harmful effects upon strength do not exceed the amounts indicated in the tabulation. Temperatures, heating periods, and pressures should be restricted as much as is consistent with proper absorption and penetration of the preservative, and in no case should they exceed American Wood-Preservers' Association specifications.

It has been rather common practice to make some reduction of working stress where the heartwood of a naturally decay-resistant species of wood is used without preservative treatment in situations favorable to decay (1). Since the extent of decay and its effect on the strength of a piece in service are very difficult to appraise and may be quite serious, no definite working stress value can be assigned to decayed material. Nevertheless, it
appears that the working stress reductions in the preceding tabulation should be employed to take care of possible loss of strength during the time before decay is detected and weakened timbers can be replaced. When placed in service, untreated wood may be stronger than treated wood, but the more rapid loss in strength from decay, even of the heartwood of naturally decay-resistant woods, will in time cancel this difference. All timbers exposed to the hazard of decay should be inspected at frequent intervals so they can be removed when their further retention seems unsafe.

Effects upon strength, whether from decay organisms or from preservative treatment, are not readily appraised. It is therefore emphasized that the reductions in working stress suggested in this report are only approximate. Specific amounts of reduction must be determined by the designer on the basis of the severity of treatment and the decay hazard involved.

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