

The potential for check reduction using surface coatings

R.W. Rice
E.M. Wengert
J.G. Schroeder

Abstract

Surface checking in red oak (*Quercus* spp.) causes considerable loss in lumber that is used in the furniture and flooring industry. In this series of experiments, a surface coating was applied to unseasoned; presurfaced red oak lumber in order to restrict the moisture loss from the surface to test the hypothesis that a reduction in the rate of surface moisture loss would reduce surface checking. Restricting the surface moisture loss prevents the formation of steep moisture gradients and attendant differential stresses that result in surface checking. A variety of coatings were tested using steady-state diffusion methods and small sample drying before choosing a polyvinyl acetate compound for drying tests with full-sized lumber. Three, 500 BF lumber drying tests were performed using varying amounts of coated and uncoated lumber. Two of the tests indicated that a coating is effective in reducing surface checking. The third test, in which many of the surfaces were dry before the coating was applied, produced more checking in the coated than in the uncoated lumber. Although the results are preliminary, the coating technique appears to be a potentially viable method of reducing surface checking if the coating is applied to very green lumber.

The oak species (*Quercus* spp.), which represent about 41 percent of all hardwoods, are collectively the dominant tree species in the eastern deciduous forests, as well as the dominant species used in the furniture and flooring industries.

The wood of oak contains a relatively large volume of thin-walled ray cells when compared to other species (14). Such cells can be readily broken by the transverse stresses that develop during drying. The result is that oaks are prone to surface checking during the initial stages of drying. In a study comparing the air-drying degrade losses for the most common hardwoods,

King (10) discovered that 55 percent of the losses occurred in the oak species. Cuppett (5) found that nearly 15 percent of red oak volume was lost to degrade. Almost 80 percent of the total losses were due to checking and splitting. Gammon (6), in an extensive study, found that 14 percent of the red oak surveyed underwent a grade lowering during drying. The cause of the grade lowering in most cases was attributed to drying degrade. Bean and Spoerke (2), studying drying losses in the state of Pennsylvania, found that on a volume basis nearly 3 percent of 4/4 and 13 percent of 8/4 red oak had some form of seasoning degrade. A recent study by the Virginia Division of Forestry has determined that the average air-drying degrade for oak is 12.2 percent of volume (1). Finally, McMillen estimated the losses due to surface checking were about 5 percent of the value of the lumber (12). The objective of this research was to investigate a method of reducing the surface checking in red oak lumber during drying.

Background and hypothesis

Oak dries in direct response to the temperature, relative humidity (RH), and air velocity of the environment. The relative importance of these factors is contingent on the moisture content (MC) of the lumber (3). The initial drying period, during which the first one-third of the MC is lost, is the critical period for the formation of surface checks (3).

Moisture loss during the initial drying period is controlled primarily by the air velocity and the ambient RH. The air velocity controls the rate at which evaporation

The authors are, respectively, Research Associate and Professor, Dept. of Forest Prod., VPI&SU, Blacksburg, VA 24061; and Project Leader (Retired), Southeastern Forest Expt. Sta., P.O. Box 2570, Asheville, NC 28802. This paper was received for publication in November 1987.

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from the surface occurs and the RH controls the amount of moisture that the air may absorb from the drying wood (8).

In theory, reducing the drying rate by increasing the ambient RH and/or decreasing the air velocity would result in less surface checking. In practice, these procedures result in an increase in nonuniformity of drying within the stack and drying times that are excessive.

A number of technologies have been developed to reduce the amount of surface checking. These may be categorized as methods that increase or maintain lumber strength or methods that slow the drying rate by controlling the lumber surface or boundary conditions.

The strength of wood decreases as the drying temperature increases (3). Therefore, it is common practice to use low temperatures during the initial drying period to maintain wood strength. A second method by which the strength of lumber can be effectively increased is by presurfacing the lumber surfaces prior to drying. Presurfacing reduces the surface roughness, which can lead to areas of stress concentration that promote surface checking (16).

The second approach to controlling surface degrade is to slow the drying rate of the lumber. This is generally accomplished by reducing the surface fiber or boundary layer moisture loss. The most common method of doing this is to maintain high ambient RH conditions. Surface treatments (e.g. salt) that alter the hygroscopicity of the lumber surfaces have also been effective in controlling moisture loss (4,1 1).

More recently, moisture pallets that consist of two plywood or veneer sheets separated by stickers have been used to restrict surface moisture loss. Each layer of drying wood is sandwiched between two moisture pallets. These pallets have proven effective in reducing surface checking during the drying of thick oak lumber(9). Another approach to restricting moisture loss from lumber, and the method used for this research, is to use a coating applied directly to the surface of the lumber. End coatings have been successfully used for years to slow the moisture loss and prevent the ends of lumber from splitting during drying, and a number of low-cost coatings are commercially available for this purpose.

Based on the background information just outlined, an experimental methodology was developed to specifically test the hypothesis that a moderate reduction in the rate of surface moisture loss, obtained using a coating applied directly to the surface of unseasoned red oak lumber, is an effective method to reduce surface checking in 4/4 oak lumber.

Methods and materials

Prior to testing the hypothesis, it was necessary to choose a suitable coating. A suitable coating is one that is readily available, coats wood surfaces uniformly, and is easily handled when applied to lumber surfaces. A

suitable coating must also restrict the moisture loss from the surface of a drying board sufficiently to prevent surface checking, yet allow the board to dry. Much of the preliminary experimentation centered on assessing coating properties and compositions. The result of the preliminary tests was the selection of a particular coating with which to test the hypothesis. This coating was applied to lumber surfaces that were dried under severe conditions and an evaluation was made to determine if the hypothesis was correct.

The overall experimental approach may be outlined as follows:

1. Choose a variety of coatings for testing.
2. Subject all coatings to a preliminary quantitative and qualitative evaluation, and eliminate coatings that are clearly unsuitable for use as lumber surface coatings.
3. Subject the remaining coatings to further testing in order to choose one coating with which to test the hypothesis that a surface coating is effective in reducing surface checking during drying.
4. Using the coating selected in step 3, coat the surfaces of green oak lumber. Once coated, subject the lumber to drying conditions that would be expected to cause checking of uncoated lumber.
5. Quantitatively assess the results of the tests in step 4 as an evaluation of the hypothesis.

Coating selections and descriptions

Six coating types were chosen for these tests based on commercial availability, estimated cost, or previous research reports (7, 13, 15). The six coating types were as follows:

1. *Urea-aldehyde paste*. This coating was developed by the USDA Forest Service (15) and consists of dimethylol urea, urea, borax, starch, and water. The paste has the consistency of wet concrete, and when dried, becomes a brittle, water-soluble coating.

2. *Lignin di-isocyanate*. This film, developed by Dr. W.G. Glasser of Virginia Tech, consists of a combination of hydroxypropylated lignin, hexamethylene diisocyanate, methyl ethyl ketone, and catalyst. This lignin film was chosen because early testing indicated that the film was an excellent moisture barrier and could be readily applied to the surface of wood due to its low viscosity. The film appears to remain flexible as long as the surface of the wood remains wet, but dries to a brittle film as the surface dries.

3. *Mobil Cer-M*.¹ This is a commercial, proprietary, "microcrystalline" wax solution used as a log or lumber end coating. The major components of the solution consist of what the manufacturer terms a "microcrystalline" wax, water, and a surfactant. This solution was chosen because it is widely available and is claimed to be effective in reducing end splitting in logs and lumber, a condition which is frequently the result of rapid moisture loss. When dry, the solution forms a semiclear coating.

4. *Anchorseal*.¹ Anchorseal is a commercially available, paraffin based, end coating for logs and lumber. This colloidal solution consists of paraffin, water, and a surfactant. This coating was also chosen because it is

¹The use of trade names does not constitute endorsement by the USDA Forest Service.

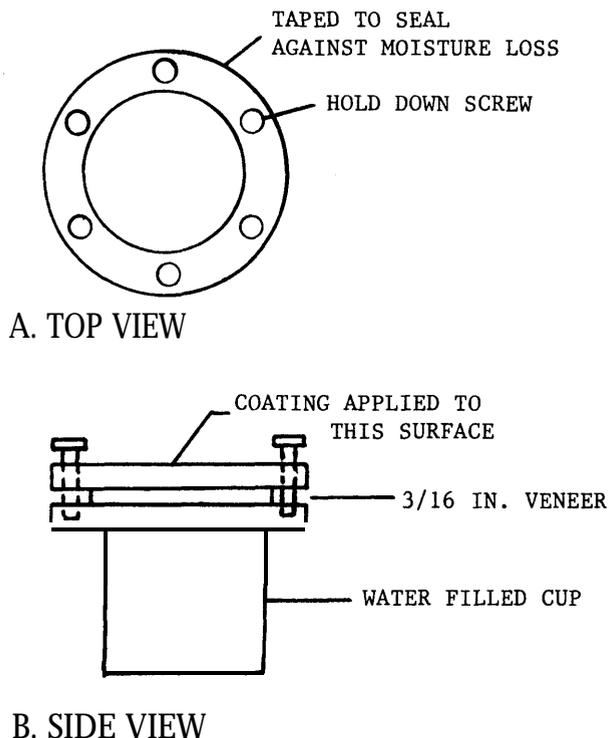


Figure 1. — Apparatus used to conduct the coating transport tests. The cup was inverted after the films were partially dried.

readily available and is claimed to be an effective method to reduce end splitting in logs and lumber. Anchor-seal dries within several hours to form a soft coating.

5. *Sodium alginate*. This sodium compound, a derivative of seaweed, is widely used as a thickener. Preparation involves mixing the granules with water to form a colloidal suspension that dries within several hours to form a very thin and somewhat brittle film. This compound was chosen because Australian researchers have reported the coating to be effective in reducing the surface checking of lumber (7). A 1.5 percent (weight) sample was used for these experiments.

6. *Polyvinyl acetate (PVA)*. A polyvinyl acetate compound prepared and marketed by the Peter Cooper Corporation of New York was the final compound tested. The solution consists of approximately 40 percent acetate polymer; water, a plasticizer, and a surfactant comprise the remaining ingredients. This compound was chosen because it is easily applied, low in cost, and readily available. The solution was diluted by adding approximately 10 percent (weight) water before use to decrease its viscosity. The film made by this compound does not dry thoroughly until the surface of the substrate is dry, but it forms an elastic "skin" on the surface that is dry to the touch.

Preliminary coating evaluations

In order to test the hypothesis, it was necessary to have a specific criterion against which the effectiveness of a coating could be evaluated. To develop this criterion, it is useful to review some background information

and equations that are used to describe moisture movement in wood during drying.

As wood begins to dry, moisture is first lost from the lumber surfaces. The cells that form these surfaces attempt to shrink, but are restrained from doing so by the cells in the interior of the lumber, which has not yet undergone moisture loss or shrinkage. If moisture loss occurs slowly, such as when wood dries under high RH or low air velocity or temperature conditions, drying stresses tend to remain small and checking is not likely. If the moisture loss occurs quickly, large stresses may be generated between the outer drying surfaces and the inner green wood. This condition often results in checking at the surface of the lumber.

If the surfaces of an unseasoned piece of wood are coated with a substance that sufficiently restricts moisture loss, then the moisture movement through the coating will be slowed, regardless of the MC of the lumber or the ambient conditions. If a coating is properly chosen, the moisture loss restriction will prevent the rapid moisture loss that results in surface checking. If a poor coating is chosen, the wood will dry rapidly or will not dry at all.

Under steady-state conditions, the moisture flux resulting from diffusion may be mathematically modeled using Fick's first law, which is written as follows:

$$F_{ss} = D_{ss} \frac{dC}{dX} \quad [1]$$

where:

- F_{ss} = moisture flux [gm/(cm² - sec.)]
- c = moisture concentration (grams of water/cm³ of wood)
- x = thickness of the wood (cm)
- D_{ss} = a proportionality constant termed the diffusion coefficient or transport coefficient (cm²/sec.)

The moisture concentration difference represented by dC in Equation [1] is between the interior of the wood (at a depth X) and the surface of the wood.

The term dC/dX is the moisture gradient and is a measure of the severity of the drying conditions. The concentration difference in Equation [1] is very difficult to measure because of the associated units and a conversion to readily measurable quantities is required. Using the RH as the driving force for diffusion, Fick's first law may be expressed as follows:

$$F_h = k_h \frac{dH}{dX} \quad [2]$$

where:

- F_h = flux [gm/(cm² - sec.)]
- H = percent RH
- x = thickness of the wood (cm)
- k_h = moisture conductivity [gm/(cm³ - %RH)]

Equation [2] may be readily adapted to moisture movement through a coating applied to the surface of wood. Under these conditions, the thickness (X) represents the thickness of the coating applied to the surface of the drying wood. The relative humidity difference (dH) is between the wood/coating interface and the

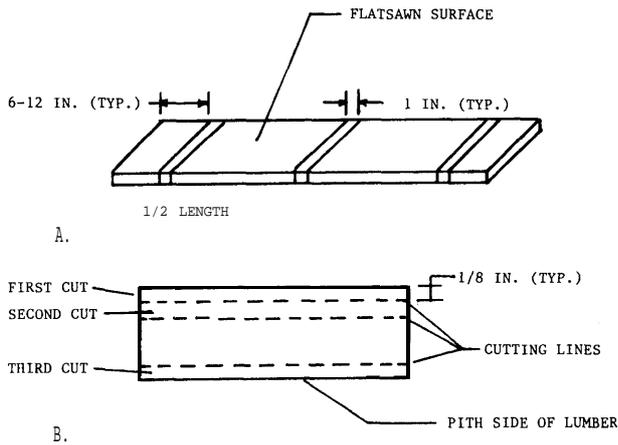


Figure 2. — Cutting diagrams for samples. A. Three 1-inch-wide samples were removed from each board. B. Slices 1/8-inch-thick were cut from the flatsawn faces using a bandsaw.

external environment. During the initial period of drying a green coated board, dH maybe easily determined if it is assumed that the RH at the wood/coating interface is near 100 percent. This assumption is reasonable for a green board if the applied coating prevents rapid surface moisture loss. The RH of the ambient conditions may be measured with a psychrometer.

Tests performed

Equation [2] predicts that the steady-state flow or flux of moisture through a coating that has been applied to a piece of wood is inversely proportional to the thickness of the coating and directly proportional to the RH difference between the wood/coating interface and the ambient conditions. The conductivity coefficient (k_c) is assumed to be a constant for a given coating type.

Equation [2] allows a quantitative evaluation as well as a relative comparison of coatings to be made using a simple diffusion cup test. Diffusion cups (Fig. 1) were fitted with a 3/16-inch-thick, water-saturated, yellow-poplar sapwood (*Liriodendron tulipifera*) substrate, to which a coating was applied. The yellow-poplar substrate was chosen because the species has a relatively uniform cell structure, which results in a uniform moisture flux. A typical coating test consisted of applying a coating to the water-saturated yellow-poplar substrate, allowing the coating to become dry on the surface, and then inverting the water-filled cup. Under these circumstances, all moisture loss from the cup occurs through the coating. The cup was then placed in an environmental chamber at 100°F and 54 percent RH and daily weight loss was monitored for 2 to 4 weeks. The RH difference (dH) in Equation [21] is approximately 46 percent under these conditions and represents a severe drying environment.

Three tests were done with each coating type with a different thickness of coating for each test. The initial thickness was chosen to approximate the thickness that would be obtained if a board were immersed in the coating, removed, and allowed to drain. The immersion

method was subsequently used for coating full-sized lumber, which was the reason for using this thickness as a starting point. The other thicknesses were obtained by doubling and tripling the initial coating weight.

The actual coating thickness was determined in two different ways. Thick coatings, such as the paraffin and wax, were measured after drying using a vernier caliper and averaging a number of thickness values. Thin coating values, such as the sodium alginate and lignin, were determined by casting a film of the same weight and area as the film under test on an inert substrate. After drying, the thin film was removed from the substrate and measured with a micrometer.

The coating area through which diffusion occurred, as well as the time between weighings of the diffusion cups, was known for each test. Using these values, the flux (F_v) in Equation [2] could be easily calculated. Once the flux, RH difference, and coating thicknesses were known, Equation [2] was applied to determine the conductivity coefficient (k_c). Since the value of k_c was constant for each type of coating, the value of k_c became a measure of the effectiveness of the coating in reducing the moisture loss rate from the wood; this will be discussed further in the Results section.

The urea-aldehyde, lignin di-isocyanate, and Mobil Cer-M coatings were eliminated based on these preliminary tests and other factors which became apparent during the tests.

The three coatings that were not eliminated after the preliminary diffusion cup tests (Anchorseal, PVA, and sodium alginate) were used for small sample drying tests in which two flatsawn samples of red oak measuring 3 inches wide by 10 inches long by 1 inch thick were coated with each type of coating by immersion. The samples were then dried at 80°F and a 10 percent ambient RH condition for 1 week. These drying conditions are quite severe and represent a moisture concentration difference (dH) of about 90 percent in Equation (2). After drying, the samples were examined for surface checking.

Based on the consistency of moisture loss reduction and the absence of surface checking during the small sample tests, the PVA coating was chosen for the tests with full-sized lumber to verify the hypothesis that a coating could reduce surface checking.

The final aspect of the experimental design was to apply the selected coating to full-sized lumber. The tests using full-sized lumber consisted of drying three, presurfaced, 500 BF charges of 4/4, coated, red oak lumber under moderate to severe conditions. Two of the three charges also contained uncoated lumber. The mixing of coated and uncoated lumber in a single kiln charge did not affect the drying and allowed a direct comparison of the coating effectiveness.

The three tests differed in several respects. By varying the RH of the ambient, the lumber was subjected to increasingly severe drying conditions for each subsequent test. Each test also contained different amounts of coated and uncoated lumber. In the first test, the method of data analysis was done differently, as will be explained later. In all of the tests using full-sized lum-

ber, the wood was presurfaced on two faces and edged immediately after sawing. The intent of the presurfacing was twofold.

First, the peaks and crevices on the surface resulting from sawing might cause unevenness in the coating deposited on the surface. Presurfacing resulted in a more uniform coating thickness and eliminated the necessity of considering the peak and crevice effect as an additional variable.

Second, surface roughness from sawing could lead to areas of stress concentration and increase the probability of surface checking. Thus, a rough surface might obscure the effects of a coating.

The presence of surface checks in the full-sized lumber was determined by taking 1-inch-long samples from each board as shown in Figure 2. Smaller samples were then sliced from the bark side surfaces as shown in the figure and then flexed slightly to determine if surface checking existed. If the first wafer did not show evidence of surface checking, the sample was considered to be check-free and no further slicing was done. If the first sample showed evidence of checking, a second sample from the same surface was taken. If the second sample showed evidence of checking, a sample was cut from the opposite (pith) side of the board and examined.

The first test with full-sized lumber consisted of 94 boards (about 500 BF of lumber). All of the lumber for the first test was coated on the surfaces by immersion. The kiln-drying period for this test was 8 days. The ambient temperature was maintained at 112°F and the RH was about 62 percent. These conditions represent an RH difference of about 38 percent. Three samples were taken from each board (Fig. 2). If a sample showed evidence of checking, it was considered defective. The percentage defective was calculated by dividing the number of defective by the total number of samples and multiplying by 100.

Test 2 consisted of 33 coated and 33 uncoated boards. The kiln-drying period for test 2 was 6 days. The RH difference for this test was approximately 47 percent. Three samples were taken from each board (Fig. 2). If one of the samples from a given board was defective, the entire board was considered to be defective. The percentage defective was calculated by dividing the number of defective boards by the total number of coated or uncoated boards and multiplying by 100.

Test 3 consisted of 34 uncoated and 26 coated boards. The kiln-drying period for this test was 12 days. The ambient temperature was maintained at 120°F and the RH difference was approximately 70 percent. The percentage of defective material was determined in the same manner as in test 2.

In all of the tests with full-sized lumber, material that seemed to exhibit bacterial infection (based on odor), or had end splitting or checking prior to drying, was eliminated from the final tally. These defects were termed "explained" checks and the boards that contained them were marked before drying.

Results and discussion

Diffusion cup tests

During the preliminary diffusion cup tests, three

TABLE 1. — Comparison of the moisture conductivity and flux for the sodium alginate, PVA, and Anchorseal compounds. Flux values were calculated using Equation [2] and were based on a coating thickness of .09 cm and a dC of 77 percent.

Compound	Measured moisture conductivity (k_w) ($\times 10^5$)	Moisture flux (F_w) ($\times 10^5$)
Sodium alginate	1.0	.86
PVA	1.5	1.28
Anchorseal paraffin	0.49	.42

coatings were eliminated from further consideration.

The urea-aldehyde paste was eliminated due to its volatility in water. A consistently uniform coating thickness on green wood could not be achieved with this coating.

The second coating eliminated was the lignin diisocyanate. This remarkable film, which is nearly impermeable to moisture loss at .012 cm thickness, was considered hazardous due to the volatility of the isocyanate derivatives during preparation. Due to this hazard, any large-scale use of the coating for lumber is probably not feasible.

The Mobil Cer-M coating, although effective in reducing moisture loss, was eliminated because the coating remained somewhat gum-like and difficult to handle even when dry. Although this is not a problem when the coating is used for log or lumber ends, it is a serious disadvantage when handling coated lumber.

Results of the diffusion cup tests for the Anchorseal, PVA, and sodium alginate coatings are shown in Table 1. The flux and conductivity values indicate that all three coatings are effective moisture barriers with the Anchorseal being the most effective.

Small sample tests

There was some concern regarding the thin and somewhat brittle nature of the sodium alginate coating and anticipated handling difficulties with the Anchorseal paraffin-based compound if it were applied to full-sized lumber, but for comparative purposes it was decided to subject all three compounds to the small sample tests described previously.

The small samples coated with sodium alginate and two uncoated samples used as controls checked severely during drying. In the case of the alginate compound, it is likely that the thin coating cracked as the wood began to dry and shrink. The cracked film probably allowed moisture to be rapidly lost from the surfaces of the wood.

The paraffin-coated samples (Anchorseal) lost very little moisture during the 7 days of drying and remained at essentially the same MC throughout the test.

The PVA-coated small samples showed no evidence of surface degrade. The surfaces of the samples appeared to be dry to a depth of approximately 1/8 inch based on a visual examination. Surface cuttings (Fig. 2) showed no evidence of surface checking.

Based on these results plus the ease of handling when dry and the low cost of the solution, the PVA compound was chosen for the full-sized lumber tests.

Full-sized lumber tests

All the boards used for the first test with full-sized lumber were coated. The test results are shown in Table 2. A total of 282 samples were cut from the 94 boards used in the test. Thirty-six of the samples had checks that were "explained" and 14 samples were checked or split during drying. Deleting the explained checks left a total of 246 samples, 14 of which were checked. The overall percentage of defective was 5.7 percent. Under the moderately severe conditions of this test, the percentage of surface checking seems low.

In order to make an accurate comparison between coated and uncoated wood, test 2 consisted of approximately equal numbers of coated and uncoated boards. The drying rate for this test was quite severe for oak, averaging about 7 percent MC loss per day compared with a "normal" value of about 3 percent. During the first 3 days of the test, the average was 10 percent MC loss per day.

The results of test 2 are shown in Table 2. Four of the 33 coated boards (12%) and 7 of the 33 uncoated boards (21%) were surface checked. The coated lumber had a much lower percentage of surface checks and/or splits than the uncoated material, which seems to indicate that the coating is somewhat effective in reducing surface checking.

The results of test 3 are also shown in Table 2. As in test 2, test 3 consisted of both coated and uncoated lumber. The severe drying schedule that was used resulted in a high percentage of surface checking in both the coated and uncoated lumber, with the coated lumber having a higher percentage of defective material. Eight of the 26 coated boards (30.8%) and 8 of the 34 uncoated boards (23.5%) exhibited surface checking.

Test 3 was conducted about 3 weeks after sawing and surfacing. The lumber was covered with plastic and placed outside during the month of January. However, due to unseasonably warm weather, some drying apparently occurred because the lumber used for test 3 had an initial MC about 4 percent less than the lumber used in the other experiments. In addition, the surfaces of many of the boards appeared to be dry before the coating was applied. When the PVA coating was applied to the dry surfaces they became wet and redried as the coating dried. This rapid redrying may have caused the formation of surface checks and resulted in the coated lumber having a higher percentage of defective than the uncoated lumber.

Summary and conclusions

Six coatings were tested for potential use as surface coatings using steady-state diffusion tests, small samples tests, and qualitative criteria. As a result of these tests, a PVA coating was chosen for use in three full-sized lumber tests. The tests with full-sized lumber were all conducted using presurfaced and edged material.

The three tests conducted with full-sized lumber cannot be considered definitive of the effectiveness of surface coatings in reducing drying degrade. However, based on the results of lumber tests 1 and 2, a coating that reduces surface moisture loss appears to be a potentially effective method of reducing surface checking under somewhat severe drying conditions.

A likely interpretation of the results of test 3 is that if a coating with an aqueous base is used, in order for it to be effective in reducing surface checking it must be applied to surfaces that have not dried appreciably.

The PVA coating was easily applied and dried quickly on the coating surface. Handling of the coating was not difficult once the coating set.

The PVA coating method outlined could probably be used effectively to reduce degrade of valuable wood subjected to moderately severe drying conditions.

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TABLE 2. - Results of the full-sized lumber tests 1, 2, and 3.

Test no.	Surface	No. of boards in test	No. of samples	No. of defective samples	No. of defective boards	Percentage defective ^a
1	Coated	94	246	14	..	5.7
	Uncoated				..	
2 ^b	Coated	33	99	6	4	12.1
	Uncoated	33	99	10	7	21.2
3 ^c	Coated	26	78	16	8	30.8
	Uncoated	34	102	14	8	23.5

^aIn test 1, the percentage defective was calculated by dividing the number of defective samples by the total number of samples and multiplying by 100; in tests 2 and 3, it was calculated by dividing the number of defective boards by the total number of coated or uncoated boards and multiplying by 100.

^bAverage moisture loss approximately 7 percent per day.

^cAverage moisture loss approximately 5 percent per day.

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Decline in research funds alarms Giese

We've lost the American chestnut. American elms have been devastated. Now facing a series of even more ominous problems, forest science itself may be threatened.

"We face difficult problems, including possible long-term destructive effects from air pollution, acid deposition, the greenhouse phenomenon, tropical deforestation, and international economic competition," says Ronald Giese, who chairs the Univ. of Wisconsin-Madison Dept. of Forestry.

"These issues need a sustained research effort if we are to understand them and prescribe solutions. But the scientific community, which has traditionally been available to deal with such issues, apparently is being dismantled," Giese says.

In the June 1988 issue of the *Journal of Forestry*, Giese documented the decline in the pool of potential and practicing forest scientists in universities and the USDA Forest Service, in federal research funding, and in research investment and action within the forest industry.

"This simultaneous decline in research across broad areas of forestry during the past 10 years is unprecedented in my memory," Giese says. "I doubt that it has happened this century. It may portend a collapse of the forestry research system and our ability to conserve this important resource."

The most troublesome trends, according to Giese, include the following:

1. Fewer young people are entering forestry. The total enrollment at the bachelor's, master's, and doctoral degree levels declined 48 percent between 1980 and 1986, while degrees granted dropped by 46 percent.

2. The forest research community is aging. Almost 25 percent of the forestry faculty in academia are over 55 years old. By 1990, almost half the scientists in the USDA Forest Service will have retired or be eligible for retirement.

3. Universities and the Federal Government have cut forest research positions. The total number of forest scientists in universities and the Forest Service in 1986 was down 16 percent from 1977, and down 21 percent from the peak in 1980.

4. Research funds have eroded. Although state funding for forestry research has increased, funding originating from all other sources has decreased. This produced an overall reduction of 22 percent over the 10-year period. Industrial funding dropped by 39 percent and U.S. Forest Service funding diminished by 19 percent.

"The drastic loss of experienced personnel during the next decade plus the lack of funding for replacements raises serious questions as to how effectively we can resolve major research problems in the future," said Arthur Kelman, a Univ. of Wisconsin-Madison plant pathologist.

"Forest research is suffering from an erosive decline in support," Kelman says. As an example, he points to the drop in research on forest diseases in his own department. "In the past, the UW-Madison was one of the major training centers for forest pathologists. We had as many as 10 graduate students and 4 professors working in this area. But it's become extremely difficult to get money to support forest pathology. We now have no graduate students and we will soon have only one professor in this important field."

Kelman is worried that efforts to reverse declining support will face an uphill battle because of pressures to limit federal spending as a way to reduce the national debt.

Kelman became so concerned about the future of forest research, that he brought Giese's information to the attention of the National Research Council (NRC) of the National Academy of Sciences. The NRC decided the nation's commitment to research on forest biology needed review and is in the process of establishing a study committee that will examine the situation and report back to the academy next year.

Giese hopes the academy report will spur the changes in commitments he thinks are warranted. "In the long run, the vitality of forests and associated environmental values are at stake. The long-term need for understanding forests and their associated economics will not diminish. It will increase as new and unanticipated problems continue to surface," he said.