FIELD DURABILITY OF CCA- AND ACA-TREATED PLYWOOD COMPOSED OF HARDWOOD AND SOFTWOOD VENEERS

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ABSTRACT

Current American Plywood Association standards for plywood panel products arc based on structural performance and allow hardwood veneers to be included in southern pine plywood. However, the American Wood Preservers' Association's (AWPA) standard for permanent wood foundations requires that plywood be made only of softwood plies. Hardwoods arc generally more difficult to protect from decay using waterborne preservatives than are softwoods. The objective of the study reported herein was to document field performance of plywood composed of both hardwood and softwood veneers treated with waterborne preservatives and to determine if AWPA requirements are warranted. Results arc given for hardwood- and softwood-treated plywood tests after 10 years of ground exposure in southern Mississippi. With reference to southern pine plywood and the current AWPA standard for preservatively treated wood used in permanent foundations, we conclude that the requirement that plywood be composed only of softwood plies is prudent.

Softwood dimension stock and plywood panels, treated with waterborne preservatives, arc used in building foundations. American Plywood Association (1) specifications for plywood panel products arc based upon structural performance. Those specifications do not restrict species within grades that meet specified structural properties. Veneers of yellow-poplar *(Liriodendrum tulipifera)* and sweetgum *(Liquidamber styraciflua)* arc accepted in southern pine plywood in the United States. This is of particular concern when using treated plywood in wood foundations. Hardwoods arc known to be more difficult to protect from decay with waterborne preservatives than are softwoods, and there is no consistent body of evidence that this reduced protection can be overcome by merely increasing the retention of waterborne preservatives in hardwoods.

Furthermore, heartwood of yellow-poplar and sweetgum is difficult to penetrate with preservatives (14). For these reasons, the American Wood Preservers' Association's (2) C-22 standard for permanent wood foundations requires that plywood be composed only of softwood plies.

The objective of the study reported herein was to document field performance of plywood, composed of both hardwood and softwood veneers treated with waterborne preservatives, and to determine if AWPA C22 restrictions arc warranted. Field tests arc considered important because prior research with *Eucalyptus globulus* (15) demonstrated that in contrast to results from laboratory tests, high retention levels of CCA did not prevent soft-rot attack under field conditions.

The hypotheses that have been proposed to explain the difference in durability between hardwoods and softwoods treated with waterborne preservatives emphasize the differences in wood anatomy, wood chemistry, and the increased requirements for copper (10 to 20% more) in hardwoods.

Anatomical studies by Levy (13) showed that susceptibility of hardwoods to soft-rot decay was correlated with the percentage of wood occupied by fibers and to the number of fibers/cm^2 in a transverse section. When the toxic threshold for CCA is expressed as a percentage of copper to wood on a weight-to-weight (w/w) basis, there is no relationship between toxic threshold and fiber cell wall thickness nor between

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toxic threshold and the number of fibers between vessels. Only the percentage volume of wood occupied by fibers is related to toxic threshold. Levy concluded that poor penetration of fiber cell walls by preservative and a high fiber cell wall to lumen volume ratio resulting in a low retention of preservative in fiber cell walls contribute to a predisposition of hardwoods to soft-rot attack.

With copper-containing preservatives, good microdistribution of copper throughout all wood tissues seems essential to protect hardwoods from soft-rot attack. Poor microdistribution accounted for failure of high loadings of CCA II to protect sapwood of *Eucalyptus globulus* Labill. and *E. saligna* Sm. from soft rot (15). Even at retention levels of 25 kg/m^3, the preservative did not penetrate and fix in fiber cell walls, which is where the soft-rot decay occurred. McNamara et al. concluded that variations in microdistribution of CCA in treated Eucalyptus wood could not be compensated by treating wood to high retention levels (even 25 kg/m^3). They also concluded that groundline maintenance treatment for Eucalyptus poles is necessary to prevent decay in standing pole populations around the world.

In contrast, Leightley and Norton (12) reported that in Australia, individual pole retention levels of CCA from 32 to 34 kg/m^3 delay soft-rot deterioration significantly, perhaps indefinitely. They concluded that retention levels of less than 16 kg/m^3 in the sapwood of individual hardwood poles are unlikely to delay deterioration sufficiently to ensure an economic performance in some instances. Other research in Australia also indicated that long-term protection of at least some hardwoods is possible. For example, hardwood *(Ceratopetalum alum* and *Ackama paniculata)* veneers treated with CCA (Celcure A) remained in almost perfect condition throughout 20 years of ground exposure near Wauchope, N.S.W., Australia (11).

Hulme and Butcher (10) proposed the concept that soft rot could be controlled in hardwoods simply by increasing the retention levels of copper in wood. Butcher (5) later proposed that the relative susceptibility of a given hardwood species to soft rot, described as decay potential of untreated wood and expressed as a product of mean loss of wood substance and wood density, was the major factor governing the requirement for copper (on a percent w/w basis) to prevent soft rot in CCA-treated hardwood. Subsequent laboratory attempts to reference the toxic threshold (percent copper w/w) for CCA to the natural susceptibility of other hardwoods to soft rot (decay potential) has been rather successful (6), with the exception of *Fagus sylvatica* and Eucalyptus (5).

In separate investigations using *Fagus sylvatica* and *Betula verrucosa,* Henningsson et al. (9) observed a good correlation between copper content of the wood and loss in dry mass caused by soft-rot attack for ammoniacal treatments with delayed drying, but not with ammoniacal treatments that received normal drying or with CCA. X-ray microanalysis of variously treated field specimens of *Fagus sylvatica* L., *Betula verrucosa* Ehrh., and *Eucalyptus regnans* F. Muell., exposed 1 to 40 years above ground or in soil in Sweden and the United Kingdom, revealed that penetration and tissue distribution of copper were more homogeneous in the ammoniacal-based treatments than in other treatments that did not have wall-swelling characteristics (8). Fibers in all samples showed markedly lower preservative elemental levels than did either vessels or rays. The microdiffusion of copper into fibers of wood pressure-treated with copper-containing ammoniacal preservatives can also be enhanced, even in beech, by delaying the evaporation of ammonia after treatment (9). Ammoniacal treatments with delayed drying have better soft-rot protection than conventional treatments. These results imply that processes that enhance wall swelling will enhance microdistribution of preservative, thereby enhancing protection.

Nilsson (16) concluded that hardwood species will be only temporarily protected by high retention levels of CCA. Vinden et al. (17) drew similar conclusions from results of soil bed studies using CCA-treated birch stakes. In those studies, toxic effects of CCA in birch were reflected by a linear increase in lag time. However, when decay became established, the rate of decay was similar at all preservative retention levels. The authors inferred from these results that greater preservative loadings provide increased protection, but there is no true toxic threshold, ie., the preservative system will eventually fail.

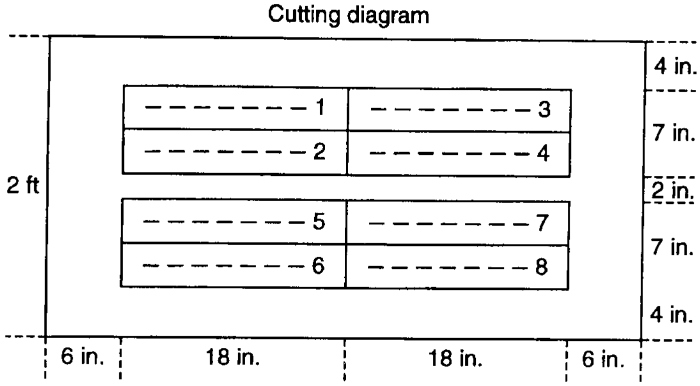
Differences in wood chemistry are thought to contribute separately or jointly to innately greater biological susceptibility of hardwoods to soft rot and decay fungi and to different patterns of preservative fixation in the hardwoods. A high content of pentosan and other hemicelluloses in hardwoods was considered by Levy (13) as contributing to a predisposition of hardwoods to soft rot.

Nilsson (16) hypothesized that the difference between softwoods and hardwoods in susceptibility to soft rot reflects the differences in lignin content and possibly the type of lignin. He proposed that soft rot in low susceptibility wood (softwoods) can be prevented at CCA levels that are too low for preventing growth of soft-rot fungi. Formation of T-branches in hyphae of soft-rot fungi is induced by a chemical factor. The number of sites where this chemical factor occurs is dependent upon the carbohydrate/lignin ratio. Few sites occur in high lignin timbers (softwoods), whereas a high number of sites can be expected in low lignin timbers (hardwoods). CCA treatment masks or modifies the sites so that the penetrating hyphae are unable to detect them. The masking is complete in timbers with a high lignin content, whereby soft-rot attack is prevented. Only partial masking occurs in hardwoods with a low content of lignin, which allows soft rot to occur.

Gray and Dickinson (7) presumed that arsenic interferes with copper adsorption. They speculated that adsorbed copper was responsible for blocking Nilsson's (16) T1 sites in the S_2 layer of the fiber cell walls. They observed that the amount of copper required for protection of birch from soft rot was influenced by formulation. They also speculated that treatment of some hardwoods and softwoods with fixed copper, followed by arsenic, would increase resistance to soil rot.

Methods

Treated plywood stakes were prepared and evaluated in field trials following procedures described in AWPA standard E7 (3), with certain variations as detailed herein. Southern pine (SP) plywood 2-by 4-foot panels (0.6-by 1.2-m) and precut 3.5- by 18-inch (88.9-by 457.2-mm) plywood stakes, composed of all SP veneers or combinations of SP veneers and either sweetgum (SG) *(Liquidamber styraciflua)* or yellow-poplar (YP) *(Liriodendrum tulipifera)* veneers, were



Stake	Assignment of edge treatments
4 & 5	Reference
1, 3, 7	No edge treatment
2, 6, 8	Edge treatment with 5% solution of preservative

Figure 1. — Cutting diagram and assignment of edge treatments for stakes cut from a preservative-treated quarter panel of plywood.

treated to a range of target retention levels of chromated copper arsenate, type III (CCA-C), or with ammoniacal copper arsenate (ACA) (4). Following treatment, additional stakes (3.5 by 18 in. (88.9 by 457.2 mm)) were cut from the treated panels. These stakes were installed vertically to a depth of 9 inches (228.6 mm) in a field plot in southern Mississippi and subsequently inspected at intervals for the presence of decay fungi and termites.

Plywood

Mill-run plywood panels were provided by member firms of the American Panel Products Association. [1]All plywood panels were three plies and 15/32 inch (12 mm) thick. The following five lay-ups were used: 1) SP-SP-SP; 2) SP-SP-YP; 3) SP-YP-SP; 4) SP-SP-SG; and 5) SP-SG-SP.

The plywood arrived at the USDA Forest Service, Forest Products Laboratory (FPL), as 4- by 8-foot (1.2- by 2.4-m) panels. These were stored indoors at FPL until cut into quarter panels for treating. Each 4- by 8-foot (1.2- by 2.4-m) panel was cut into two 4-by 4-foot (1.2 by 1.2 m) halves. One half was subsequently cut into two 2- by 4-foot (0.6- by 1.2-m) panels with the grain of the exterior faces parallel to the long dimension of their quarter panel. The identity of each quarter panel was maintained through subsequent treating and drying processes. The moisture content (MC) of the quarter panels was measured with a Delmhorst moisture meter as they were being cut. All quarter panels had less than 11 percent MC prior to treatment.

Treatments

Two preservatives, CCA and ACA, were used. Quarter panels of each type of plywood were pressure-treated with one of five concentrations of CCA or ACA to achieve target retention levels of 0.1,0.2, 0.4, 0.6, and 1.2 pcf (1.6, 3.2, 6.4, 9.6, and 19.2 kg/m^3). Treating solutions were prepared by diluting concentrates of CCA and ACA with tap and distilled water, respectively.

Twenty panels (4 panels of each type of lay-up) were simultaneously treated in each concentration of each preservative. The four panels for each lay-up were derived from a different 4- by 8-foot (1.2- by 2.4-m) source panel (plywood sheet). The quarter panels that were treated with either ACA or CCA were essentially "matched" across four treatment levels of each respective preservative in that those for CCA came from the same original 4- by 8-foot (1.2- by 2.4-m) plywood sheet as did the quarter panels treated with ACA.

For target retention levels of 0.4 and 0.6 pcf (6.4 and 9.6 kg/m^3), 10 replicate, precut stakes of each lay-up were treated along with the quarter panels.

The full-cell process was used. The treating cycle consisted of a vacuum at 27 inch Hg for 30 minutes, followed by pressurization at 150 psi (0.105 kg/mm^2) for 2 hours. Plywood quarter panels were stickered to permit uniform flow of liquids between panels during treatment. Immediately after pressure was released, panels were removed from the treating cylinder, wiped free of excess preservative on the surface, and weighed. Preservative uptake was calculated on the basis of weight gain during treatment.

After weight gain was determined, all plywood panels were stacked, draped with polyethylene, and allowed to stand for 2 weeks. After 2 weeks, plywood panels were kiln-dried at a moderate schedule that did not exceed 140°F (60°C) to an MC of 19 percent or less. Eight 3.5- by 18-inch (88.9-by 457-mm) stakes were cut from each panel **(Fig. 1).** All stakes were given four unit numbers to indicate lot, panel, quarter panel, and stake number. Stake numbers were also positioned so that the identification of the type of wood in each ply could be followed throughout the experiment. Stake numbers 2,6, and 8 were given a preservative treatment on their edges. The edges of these stakes were brushed with a 5 percent solution of the preservative with which they had been treated, i.e., either CCA or ACA. Stake numbers 1,3, and 7 were installed without edge treatment.

Field exposure

In November 1985, 10 replicate stakes of each combination of lay-up by treatment were installed in the Harrison Experimental Forest (southrn ississippi). All treated stakes and 10 replicate untreated controls from each type of lay-up were set out in a randomized block design. Each stake was inserted vertically into the soil to a depth of half its length (9 in. (228 mm)).

Stakes were inspected annually for 5 years and biannually thereafter. At each inspection, an attempt was made to rate the amount of decay and termite attack that had occurred in each veneer. Numbered ratings were given according to the

[1]The contributions of plywood from Boise Cascade, Georgia-Pacific, and Weyerhaeuser Co. Inc. are gratefully acknowledged.

criteria shown in **Table 1.** Note that percentages reflect cross-sectional area that was affected by decay or attacked by termites.

Evaluations of the condition of the middle veneer proved to be difficult and were limited to the visible edges of those veneers until serious decomposition had occurred in the outer veneers. For this reason, we report the condition of only the exterior veneers, because the entire surface area of those could be independently examined. Furthermore, these veneers failed primarily as a result of decay, thus we address only ratings for decay in this report.

Comparisons emphasize frequency distribution patterns of performance that were observed after 10 years of exposure. Particular attention was placed on ratings for decay of 7 or less, because that is regarded as sufficient to cause structural weakening in the plywood. A rating of decay or soft rot at less than 3 or 10 percent of the cross-sectional area of individual plies was difficult and somewhat subjective. However, these ratings do show evidence of some softening at the time of inspection. The experimental design with only 10 replicates per variant does not permit rigorous testing of subtle differences among combinations of wood species and preservative retention levels. From a functional viewpoint, the frequency rating of 7 or less for any ply within a group of 10 replicates is probably more important than a comparison of median values. To assess the two preservatives with the different wood species, it is perhaps best to compare the distribution of decay ratings at different retention levels.

TABLE 1. — Ratings used to describe decay and termite attack.[a]

Rating	Severity of decay	Rating	Severity of termite attack
10	No decay	10	No termite feeding, but termites may have nibbled on wood
9	Suspicion or trace of decay < 3%	9	Termite feeding < 3%
8	Decay > 3% but < 10%	8	Termite feeding > 3% but < 10%
7	Decay > 10% but < 30%	7	Termite feeding >10% but < 30%
6	Decay > 30% but < 50%	6	Termite feeding > 30% but < 50%
4	Decay > 50% but < 75%	4	Termite feeding > 50% but < 75%
0	Decay > 75%; may be broken	0	Termite feeding > 75%; may be broken

[a] Percentages reflect cross-sectional area affected.

TABLE 2. — Retention achieved in preservative-treated plywood composed of all southern pine veneers.

Concentration treating solution, oxide basis	Target retention	Actual retention[a]	
		CCA	ACA
(%)	(pcf (kg/m^3))		
0.25	0.10 (1.6)	0.10 (1.6)	0.09 (1.4)
0.50	0.20 (3.2)	0.19 (3.0)	0.20 (3.2)
1.00	0.40 (6.4)	0.41 (6.6)	0.33/0.41[b] (5.3/6.6)
1.50	0.60 (9.6)	0.59 (9.4)	0.52/0.58[b] (8.3/9.3)
3.00	1.20 (19.2)	1.18 (18.9)	1.24 (19.8)

[a] Determined on basis of weight gained during treatment.
[b] With these two treatments, stakes cut prior to treatment had a retention much less than the target level. With all other treatments and with stakes cut from panels given these two treatments, actual retention levels approximated targeted retention levels.

RESULTS AND DISCUSSION

Preservative retention levels in all treated panels approximated the target retention levels **(Table 2).** However, stakes cut prior to treatment and treated with ACA had retention levels somewhat less than the target levels. Observed retention levels in stakes cut prior to treatment and treated with CCA approximated the target retention level.

During the first 10 years of exposure, all untreated control stakes failed, and all but one stake treated to a target retention level of 0.1 pcf (0.2 kg/m^3) of either preservative failed. The opposite was true for stakes treated to retention levels of 1.2 pcf. All stakes at that retention were surviving and showing excellent performance **(Table 3).** The greatest range in conditions occurred at the intervening target retention levels of 0.2 to 0.6 pcf (3.2 kg/m^3 to 9.6 kg/m^3). Therefore, comparisons of performance were made within this range of retention levels.

Treating the edges of plywood stakes with preservative solution after they were sawn from the treated panel did not enhance the performance of those stakes. Stakes with and without edge treatment had similar frequency distribution patterns among the various decay categories **(Table 3).** Functional performance (i.e., ratings greater than 7 versus ratings of 7 or less) was also comparable. Isolated instances of inadequate functional performance (rating of 7 or less) occurred in stakes that contained hardwood veneers and were treated to retention levels of 0.4 or 0.6 pcf (3.2 or 9.6 kg/m^3) with and without edge treatment.

The difference between hardwood and softwood plies in durability was generally more pronounced with CCA-treated stakes than with ACA-treated stakes. With CCA-treated stakes, both hardwood veneers were less durable than the southern pine counterparts. The distribution of ratings for hardwood veneers alone **(Table 3)** was generally broader and of lower median value than that of the southern pine veneers. Even at target retention levels of 0.6 pcf CCA, ratings of 7 occurred in stakes with hardwood veneers **(Table 3).** (A retention of 0.6 pcf is specified for wood in foundations (2).)

With both ACA and CCA, performance of yellow-poplar veneers was less than that of southern pine veneers. There was a greater tendency for failure (rating of zero) even at retention levels of 0.4 pcf (3.2 kg/m^3). The distributions of decay ratings for either the individual yellow-poplar veneers **(Table 3)** or the plywood that contained yellow-poplar plies **(Table 4)** at all three retention levels were generally broader and of lower median value than those of the corresponding softwoods against which they were compared.

The performance of sweetgum veneers in ACA-treated stakes was not demonstrably different from that of southern pine veneers when performance was viewed across all retention levels. At the target retention of 0.4 pcf (3.2 kg/m^3), a tendency for early development of decay in the hardwood veneer was apparent, but this was at the very earliest stages of

Stakes cut from treated panel;
no edge treatment to stakes after cutting
0.1 pcf
(1.6 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP							10							10
	SP							10							10
SG/SP/SP	SG							10							10
	SP							10							10
YP/SP/SP	YP					1		9							10
	SP					1		9							10

Stakes cut from treated panel;
no edge treatment to stakes after cutting
0.2 pcf
(3.2 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP	2	2	4	2					2	1		1		6
	SP		3	5		2				1	1	2			6
SG/SP/SP	SG		1	2	1		2	4					2	1	7
	SP	1	1		5	2		1		1			1		8
YP/SP/SP	YP			1	1	4		4		1		2	1	1	5
	SP	1	2	4	2			1	1	2	3	2	1		1

Stakes cut to size prior to treatment
0.4 pcf
(6.4 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP	6	4						6	4					
	SP	5	4	1					4	5	1				
SG/SP/SP	SG	5	3	1	1				6	4					
	SP	8	2						6	4					
YP/SP/SP	YP	1	5	3				1	3	5		1			1
	SP	7	3						2	7	1				

Stakes cut from treated panel; no edge treatment to
stakes after cutting
0.4 pcf
(6.4 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP	7	2	1					1	7	1	1			
	SP	9	1						1	3	6				
SG/SP/SP	SG	5	3	2						6	4				
	SP	5	5						1	9					
YP/SP/SP	YP	1	4	2	2			1	3	5	1				1
	SP	5	5						3	4	3				

Stakes cut to size prior to treatment
0.6 pcf
(9.6 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP	10							8	2					
	SP	10							9	1					
SG/SP/SP	SG	5	1	3	1				5	5					
	SP	8	2						4	6					
YP/SP/SP	YP	5	3	1	1				5	5					
	SP	10							5	5					

Stakes cut from treated panel;
no edge treatment to stakes after cutting
0.6 pcf
(9.6 kg/m³)

		10	9	8	7	6	4	0	10	9	8	7	6	4	0
SP/SP/SP	SP	7	3						6	4					
	SP	7	3						4	5	1				
SG/SP/SP	SG	4	5	1					2	5	3				
	SP	7	3						4	5	1				
YP/SP/SP	YP	6	4						5	4		1			
	SP	10							5	3	2				

Continued on next page

TABLE — 3. Continued from previous page.

Target retention	Lay-up of plywood[a]	Outer ply	Number of plies in each decay rating category: CCA							ACA						
Stakes cut from treated panel; no edge treatment to stakes after cutting																
1.2 pcf (19.2 kg/m³)			10	9	8	7	6	4	0	10	9	8	7	6	4	0
	SP/SP/SP	SP	9	1						8	2					
		SP	8	2						8	2					
	SG/SP/SP	SG	10							8	2					
		SP	10							9	1					
	YP/SP/SP	YP	8	2						10						
		SP	9	1						10						

[a] SP = southern pine; SG = sweetgum; Y = yellow-poplar.

TABLE 4. — Effect of brush-on treatment to edges of plywood stakes that were cut from preservative-treated plywood panels and exposed in the ground for 10 years.

Target retention	Lay-up of plywood[a]	Edge treatment[b]	Number of stakes in each decay rating category[c]: CCA							ACA						
0.2 pcf (3.2 kg/m³)			10	9	8	7	6	4	0	10	9	8	7	6	4	0
	SP/SP/SP	+	1	5		2	1		1		4	3	2			1
		–		2	5	1	2				1	1	1	1		6
	SG/SP/SP	+			5	3	1	1				3	1	3	1	2
		–			1	3		2	4					1	1	8
	YP/SP/SP	+		1	2	1	1	1	4			3	2	1		4
		–			1	1	4		4		1		2	1	1	5
0.4 pcf (6.4 kg/m³)			10	9	8	7	6	4	0	10	9	8	7	6	4	0
	SP/SP/SP	+	7	3						4	3	3				
		–	6	3	1					1	2	6	1			
	SG/SP/SP	+	4	2	2	2					5	4	1			
		–	4	4	2						6	4				
	YP/SP/SP	+	1	5	1	2		1		2	2	3	2	1		
		–		5	2	2			1	2	3	4				1
0.6 pcf (9.6 kg/m³)			10	9	8	7	6	4	0	10	9	8	7	6	4	0
	SP/SP/SP	+	7	3						5	4	1				
		–	7	3						4	5	1				
	SG/SP/SP	+	5	5						2	7			1		
		–	4	5	1					1	5	4				
	YP/SP/SP	+	6	3	1					6	2	1	1			
		–	6	4						4	3	2	1			

[a] Ten replicate stakes for each plywood lay-up.
[b] + = After stakes were cut from the treated panel, edges of stakes were liberally brushed with a 5% solution of the same preservative (CCA or ACA) from which the source panel was treated; – = no treatment to edges of stakes.
[c] A stake was assigned to a category based on the rating for the worst exterior ply.

degradation. One low rating occurred in a stake with a sweetgum ply and treated with ACA to a target retention of 0.6 pcf (9.6 kg/m³) **(Table 4).**

Conclusions

With reference to southern pine plywood, the AWPA C-22 standard requirement for permanent wood foundations that plywood be composed only of softwood plies seems prudent. Excluding plywood that contains yellow-poplar veneers treated with either CCA or ACA and plywood containing sweetgum veneers treated with CCA is warranted. A demonstrable difference between southern pine and sweetgum veneers treated with ACA was not shown in this field study, but a slight tendency for reduced resistance of the sweetgum veneers to decay was detected.

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