PROPERTIES OF TREATED AND UNTREATED *PINUS RADIATA* PLYWOOD AFTER 12 YEARS' WEATHERING

J. M. McLAUGHLAN

Forest Research Institute, Private Bag 3020,
Rotorua, New Zealand

(Received for publication 22 November 1990; revision 10 September 1991)

ABSTRACT

An exterior exposure trial was established in Rotorua in 1976 to monitor the performance of plywood panels in which the individual veneers were treated with a copper-chrome-arsenate (CCA)-type preservative prior to panel lay-up. Three-ply panels of 9.6-mm-thick *Pinus radiata* D. Don plywood were erected vertically on a test face with a northerly aspect. The trial included three adhesive types, five preservative treatments, and four surface/exposure treatments. Panels were tested prior to exposure and then after 1, 2, 4, and 12 years.

Regression models were used to evaluate the effect of various treatment combinations. It was determined that wood failure, assessed from the failed surface of the tension shear test sample with lathe checks pulled to open, declined significantly over time in plywood with veneers treated to 5 kg CCA/m^3. This decline occurred in fully exposed panels and also in panels stored indoors. The uncoated melamine-urea formaldehyde panels had failed completely after 12 years and delaminations occurred in panels of the other adhesive types with one failure occurring for the panel bonded with phenol formaldehyde and treated to 10 kg CCA/m^3. Uncoated panels with CCA treatment generally fared less well than either the untreated or the copper naphthenate panels. Assessment of serviceability after 12 years was difficult because of the differences in wood failure values obtained from the tension shear test and the chisel test.

Keywords: plywood; adhesives; preservative treatments; all-weather exposure; bond strength; wood failure; *Pinus radiata*.

INTRODUCTION

Plywood in New Zealand is produced by five mills and the total volume in 1989 was 63 655 m^3 with over 95% of this from the exotic pine resource (Ministry of Forestry 1989). A market survey conducted in 1986 indicated that of the 59 000 m^3 then produced, 56% was used domestically for cladding, sarking, and exterior applications (Maughan & Clough 1986). Exterior-grade plywood is produced in a range of thicknesses from 9 to 15 mm with a maximum sheet size of 2440 × 1216 mm. The face veneer is generally of a high grade with a textured rough-sawn finish and often with a vertical groove pattern. Rotary-peeled *Pinus radiata* veneers are bonded with a phenol formaldehyde (PF) resin and the panels are preservative treated. The most common treatment chemical at the present time is *tri*-butyltin oxide in a light organic solvent applied by either a modified Bethell or the Lowry process.

Where plywood panels are exposed to natural weathering, their performance is influenced by the development of face checks and other surface deterioration and by the durability of the glue bond. There is no published information on the performance of *P. radiata* plywood exposed to the weather, although with the recent reform of building controls in New Zealand, this will become an important consideration, not only with plywood, but with all materials used in construction. The building controls are changing from prescription-based standards to those based on performance concepts and, in so doing, are following the trend in other countries including Scandinavia and Britain. The part of the building code that will directly affect the wood-based panel industry relates to the provisions for durability which set out the expected life of products subjected to only minor or routine maintenance. Exterior wall cladding and sheathing are listed in a draft document (Building Industry Commission 1990) as requiring a 15-year life span.

Hutchinson *et al.* (1977) reported on the effect of green veneer treatments on *P. radiata* plywood. Small laboratory samples, treated with a CCA preservative up to 30 kg/m^3 by the diffusion method, still met the requirements for bond quality as measured by the chisel test: for untreated panels and for the 30 kg/m^3 treatment, bond quality was 6.2 on a scale of 0 to 10. The Forest Research Institute in Rotorua maintains a service test appraisal programme on preservative-treated components. The oldest record relating to plywood is for a building in Auckland that was constructed in 1975 and sheathed with painted *P. radiata* plywood treated with Tanalith NCA by diffusion. At the last assessment in 1984 the material was in good condition except for extensive checks and minor buckling on the wall with a northerly aspect (D. Page, FRI, pers. comm.).

Published research work on plywood performance has been on material with no preservative treatment. *Pinus* spp. and *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) plywood bonded with an extended PF resin and coated with a high-quality paint, had a low incidence of glueline delamination after long periods of all-weather exposure (Black *et al.* 1976). If plywood is not surface coated it will lose a significant proportion of its flexural and shear properties: bending strength (modulus of rupture, MOR) decreased by 50% in mahogany (*Khaya* spp.) and beech (*Nothofagus* spp.) plywood exposed to the weather for 10 years (White 1975). In *Pinus* spp. plywood exposed to the weather for 6 years, MOR was reduced by 50–60%, which was more than modulus of elasticity (MOE) but similar to that for solid wood controls (Biblis & Lee 1982). Flexural stiffness (EI—modulus of elasticity × moment of inertia), a measure of the ability to resist deformation under load, was reduced on exposure of the plywood to the weather; however, the reduction was less than for MOE.

Information on the performance of adhesive-preservative interactions is gaining importance in other composite wood products, including fibreboard and particleboard which are now being used where they require protection from fungi. The only practical option for the application of the water-based preservatives at the present time is to treat the furnish prior to forming and consolidation in the hot press.

In 1976, when this exposure trial was set up, the preservative treatment options were limited to water-based CCA-type treatments. Treatment of the finished panels by this method requires a second drying step which can lead to warping, splitting, and checking of the surface veneers. Options available with CCA treatment that overcome the need to dry twice include the treatment of green veneers by either a dip diffusion or a vacuum pressure process. Difficulty may arise over the bonding of veneers treated by these methods owing to the deposit of preservative salts on the surface and their subsequent interference with adhesive bonding.

The primary objective of this research project was to investigate the performance of *P. radiata* plywood preservative-treated by dip diffusion of the green veneers. The trial also included untreated plywood and plywood brush-coated with copper naphthenate preservative. Painted and unpainted panels were either exposed to the weather or stacked indoors, and over a period of 12 years samples were removed and tested for glueline quality and flexural properties.

METHOD

Laboratory-produced 3-ply panels with a range of preservative and surface treatments were erected on a vertical test fence situated in the outdoor exposure trial area at the Forest Research Institute in Rotorua (38° 07′ S, 176° 19′ E, 288 m a.s.l.). The panels were fully exposed to the weather with the top surface facing north to maximise exposure to the sun. These conditions were intended to represent a severe exposure situation. The design of the experiment included as a control a matching set of panels that were block-stacked in a partially heated building.

Prior to exposure in 1976, and at various times over the next 12 years, panels were removed for testing (Table 1) which included assessment for glueline quality by the tension glueline shear test (ASTM D906-64:1978) and a chisel test (NZS 3611:1970), and flexural properties of MOR and MOE (ASTM D3043:1978). The calculation for these last two properties was based on the moment of inertia of the entire cross-section and the dimensions of the sample prior to testing. Other assessments were also carried out for the number of checks occurring on the surface and for the presence of delamination. Panels that were protected by a brush-applied paint coat were removed and recoated once during the term of the trial.

TABLE 1–Outline of tests

Assessment period (years)	Test type	Property	Panels tested	Replicates per treatment
0,1,2,4,12	ASTM D906 glueline shear*	Shear stress: open, closed Wood failure: open, closed	2	4 open/4 closed†
	ASTM D3043 bending‡	Modulus of rupture (MOR) Modulus of elasticity (MOE)	2	4
2,4,12	NZS 3611§	Bond quality (BQ)	2	4

* Soaked in water at room temperature for 24 hours and tested wet

† Lathe checks pulled open and closed

‡ Exposed face in tension and tested after conditioning at 65% RH, 20°C

§ Soaked in water at room temperature for 24 hours and tested wet

Materials and Treatments

Rotary-peeled veneers, 1.2 × 1.2 m × 3.2 mm, from defect-free *P. radiata* were purchased from a local plywood mill. After the appropriate preservative treatment, the veneers were made up into 3-ply panels.

These panels were subdivided to give four test panels, 500 × 500 mm, which were then assigned to one of four treatments: (1) interior exposure and block stacked; (2) exterior exposure, uncoated; (3) exterior exposure, protected with an alkyd-based primer on all surfaces and on the top surface with an undercoat and full-gloss topcoat of white alkyd paint; (4) as for the paint treatment except pretreated by brush-coating with a silicone-based water repellent. A summary of the preservative treatments, adhesive types, and surface-exposure treatments is presented in Table 2.

TABLE 2–Summary of treatments for plywood

Adhesive	Preservative	Exposure/Coating
1. Phenol-formaldehyde (PF)	1. None	1. Interior / uncoated
2. Melamine-urea formaldehyde (MUF)	2. Plywood brush-coated with copper naphthenate	2. Exterior / uncoated
3. Cross-linked polyvinyl acetate (XPVA)	3. Diffusion of green veneers to 5 kg CCA/m^3	3. Exterior / painted
	4. Pressure treatment of veneers to 6 kg CCA/m^3*	4. Exterior / water-repellent plus paint
	5. Diffusion of green veneers to 10 kg CCA/m^3	

* This preservative treatment was used for PF-bonded plywood only.

Preservative treatments included dip-diffusion of the green veneers in a solution of Tanalith NCA to give salt retention levels of 5 and 10 kg/m^3 using the method outlined by Hutchinson *et al.* (1977). After a period of time in block-stack, the veneer surfaces were washed in water to remove salt deposits and then dried. A third treatment was included in the trial for PF-bonded panels only, in which veneers from another source were pressure treated with Tanalith NCA by a commercial treatment plant to a net salt retention of 6 kg/m^3; the final treatment for the panel was brush-coating with a 2% solution of copper naphthenate.

Adhesive was applied to the two sides of the dry core veneers (moisture content 8–12%) using a powered-roller glue spreader. The three adhesives used in the trial were: phenol formaldehyde (PF) (Sylvic P99), melamine-urea formaldehyde (MUF) (Sylvic MU3), and a cross-linked polyvinyl acetate (XPVA) (Duralock 150). Panels were pressed in a Barker laboratory hotpress with the same press cycle for all the adhesive types: temperature 142°C, pressure 1.3 MPa, cycle time 8 min. Lay-up of the veneers to form a panel was done so that the surface veneer had the tight side outermost and the core veneer had the tight side towards the top veneer.

One of the problems with an exposure trial which spans a relatively long period of time, is that the formulation of the chemicals and the methods of treatment change with improvements in technology. The adhesive formulation MU7 has replaced MU3, and P96 is now used in place of P99. The preservative Tanalith NCA has been replaced with Tanalith

C and the treatment process is now done only on the consolidated panel. Except for specific items such as decks for membrane-type roofing, most of the treatment is now carried out using an organic solvent preservative solution.

The adhesive types used in the trial represent those classified as weather- and boil-proof or boil-resistant. The cross-linked polyvinyl acetate has similar durability to PF-type resins but is non-gap-filling and is not recommended for permanently stressed joints because of its creep characteristics.

RESULTS

Observations

Surface changes

Face checking of the uncoated plywood panels was observed at an early stage in the exposure, and after an initial 3-month summer period an average of 3.5 checks per 100 mm of panel width was recorded on the top surface. Painting was highly effective in delaying the onset of checking and also its severity: the first checks appeared after 2 years, and after 12 years an average of 5 checks per 100 mm of panel width was recorded. The average number of face checks for uncoated material was 18 per 100 mm at the final assessment. There was no apparent difference in the frequency of checking for the different preservative treatments.

Delamination

Gluelines were inspected for delamination at each test period and after 1 year separation was first observed in MUF (uncoated, 5 and 10 kg CCA/m^3) and XPVA (uncoated, copper naphthenate) panels. At the end of year 2, delamination was noted in uncoated panels of all the adhesives, with the maximum of 18% recorded for MUF treated to 5 kg CCA/m^3. By year 4, MUF-bonded preservative-treated panels were failing completely—two panels of 5 and 10 kg CCA/m^3 and one copper naphthenate. In year 12, no uncoated MUF-bonded panels were available for testing. For the PF resin, one uncoated 10 kg CCA/m^3 panel failed at 4 years and one was severely delaminated after 12 years. No complete board failures occurred for XPVA but all of the uncoated preservative-treated panels were delaminated to varying degrees at the final assessment.

Destructive Tests

Initial values from the tension shear test and the flexural test are presented in Table 3. Preservative treatment of the veneers at the 10 kg CCA/m^3 level had a significant effect on wood failure for the PF and XPVA panels only. The average wood failure values for PF panels with preservative treatments at 6 and 10 kg CCA/m^3 and for XPVA panels with treatments at 5 and 10 kg CCA/m^3 were below the requirement of the US Product Standard PS1-83 of 85%, a value that is expected for an exterior softwood plywood.

In order to investigate the effects of exposure time and the relative importance of the main treatment effects and their interactions, a regression model was fitted to the data. The approach taken was similar to that used by Gillespie & River (1975)—to average the total response to weathering by fitting a regression line.

TABLE 3–Initial properties of plywood

Adhesive	Preservative	Shear stress (MPa)*						Wood failure (%)*				Bending†			
		Closed‡		Open		Ratio %		Closed		Open		MOR (MPa)		MOE (GPa)	
		$\bar{x}$	CV§	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV
PF	Untreated	a 2.54	12	a 2.03	30	a 0.80	33	a 95	11	a 99	3	ab 83.2	16	ab 10.67	19
	Copper naphthenate	a 2.60	20	a 1.77	27	a 0.68	19	a 98	5	a 92	24	a 85.2	7	ab 11.46	12
	5 kg CCA/m^3	a 2.36	19	a 1.76	26	a 0.76	26	a 96	7	a 91	10	a 87.4	13	a 12.78	18
	6 kg CCA/m^3	a 2.20	16	a 1.68	20	a 0.76	10	a 83	28	ab 82	29	b 73.7	15	b 10.77	13
	10 kg CCA/m^3	a 2.50	17	a 1.78	21	a 0.72	21	a 51	74	b 62	52				
XPVA	Untreated	ab 2.09	12	b 1.42	19	a 0.68	14	a 86	30	a 93	10	a 79.7	13	ab 11.75	17
	Copper naphthenate	b 1.87	16	b 1.28	24	a 0.69	20	a 90	16	a 91	26	ab 77.2	13	b 10.77	15
	5 kg CCA/m^3	a 2.47	14	a 1.97	16	a 0.80	13	a 83	29	a 82	30	a 79.1	14	a 12.83	17
	10 kg CCA/m^3	ab 2.10	32	b 1.56	42	a 0.72	21	b 47	68	b 59	66	b 67.8	19	b 10.83	21
MUF	Untreated	a 2.70	13	a 1.96	21	a 0.72	16	a 100	13	a 98	6	a 79.2	10	a 11.10	13
	Copper naphthenate	a 2.61	20	a 1.89	24	a 0.73	23	ab 97	8	a 96	8	a 81.6	14	a 11.46	20
	5 kg CCA/m^3	b 2.16	10	a 1.67	25	a 0.78	26	b 89	13	b 81	19	a 81.9	18	a 11.36	22
	10 kg CCA/m^3	ab 2.30	13	a 1.78	22	a 0.78	22	ab 93	10	a 94	16	a 75.5	14	a 10.95	19

Means with a different letter are statistically different at 95% level

* mean of 16 values

† mean of 16 to 20 values and calculated for gross cross-section properties

‡ lathe checks in core veneer were pulled either to open or close

§ CV coefficient of variation as a percentage

For shear strength and flexural properties the regression model was of the linear form:

$$y = a + bx_1 + cx_2$$

where y is the log-transformed predicted value at some nominated time and x_n the log-transformed value of each treatment variable and their interaction, "a" is the property value at zero time.

For wood failure (WF) and bond quality (BQ) the actual values were fitted to a curvilinear model of the following binomial expression:

$$y = \frac{\exp^{(a + bx_1 + cx_2)}}{1 - \exp^{(a + bx_1 + cx_2)}}$$

The resulting analysis of variance from the regression was used to investigate the differences among the various preservative and surface treatments. The ANOVA table was presented in one of two forms; a common intercept or an independent intercept, depending on whether the regression line was forced through the same y intercept at year 0 or through different intercepts. Where there was a significant difference in the initial panel properties, the appropriate model was one with either an independent intercept or a common intercept with the offending treatments left out of the analysis altogether. The common intercept ANOVA model was appropriate for shear stress (checks open or closed) and bending properties (MOR, MOE) with the main treatment effects presented as Year × Adhesive, Year × Surface, and Year × Preservative (Table 4). Melamine-urea formaldehyde was not included because it was obviously inferior in performance. The analyses for the two adhesives and for each individually show that almost all the main factors were significant but

TABLE 4—Analysis of variance tables for phenol formaldehyde and cross-linked polyvinyl acetate

Source	Four preservative treatments					10 kg CCA/m³ treatment omitted		
	Shear stress		Ratio	MOR	MOE	Wood failure		Bond
	Closed	Open	open: closed			Closed	Open	quality
Year	**	**	**	**	**	**	**	NS
Adhesive								
Year × Adhesive	**	**	NS	**	**	**	NS	**
Surface								
Year × Surface	**	**	NS	**	**	**	**	**
Year × Adhesive × Surface	NS	NS	**	NS	**	*	NS	*
Preservative								
Year × Preservative	**	**	**	*	**	**	**	**
Year × Surface × Preservative	**	*	*	NS	NS	NS	NS	NS
Year × Adhesive × Preservative	**	NS	**	NS	NS	NS	NS	NS
Year × Adhesive × Surface × Preservative	*	**	*	NS	NS	NS	NS	NS

* significant at 95% probability level
** significant at 99% level or greater
NS not significant at the 95% probability level

also that there were significant interactions occurring of both second and third order. Any main effect that has significant interaction cannot be taken at face value. The two-adhesive comparison was free of interaction only for MOR and wood failure with checks open. For the individual adhesives the preservative effect and interaction were not significant for the XPVA-bonded panels. Comments on this analysis for each property are presented below.

Shear stress

The analysis of variance for shear stress for each of the three adhesives gave similar main factor responses for both shear stress with lathe checks pulled to open (SHOp) and shear stress with lathe checks closed (SHCl). The SHCl was confounded by a third-order interaction term (Year × Surface × Preservative) in two of the adhesives, whereas for SHOp only PF panels were affected. The cause of the interaction for SHOp in PF panels is illustrated in Fig. 1A by the non-typical response of preservative treatments at 5 and 6 kg CCA/m^3 and surface/exposures 1 and 2 (uncoated interior and exterior, respectively).

The effect of preservative and surface treatments on SHOp is presented in Table 5 for the three adhesive types. Phenol formaldehyde panels were less affected by weather exposure; after 12 years SHOp was reduced on average to 79% of initial values whereas for XPVA it was reduced to 68% and for MUF to 49%.

TABLE 5–Shear stress for lathe checks pulled to open—predicted and actual values for years 0 and 12 for the three adhesive types

Adhesive	Year	Predicted shear stress open (MPa)								Predicted mean	Actual mean	JSD
		Preservative*				Surface/Exposure†						
		1	2	3	4	1	2	3	4			
PF	0									1.82	1.84	
	12	1.62	1.76	1.06	1.05	0.83	0.67	1.88	1.64	1.19	1.45	NT
XPVA	0									1.45	1.56	
	12	1.07	1.07	0.94	0.86	1.32	0.37	1.13	1.28	0.98	1.06	0.22
MUF	0									1.69	1.82	
	12	0.87	0.88	0.36	0.61	1.60	0	0.66	1.16	0.66	0.89	0.44

* Preservative: 1: untreated; 2: copper naphthenate; 3: 5 kg CCA/m^3; 4: 10 kg CCA/m^3
† Surface/exposure: 1: Interior; 2: Exterior/uncoated; 3: Exterior/ painted; 4: Exterior/painted plus water repellent
JSD: just significant difference 95% level
NT: not tested because of significant interaction

The interior panels with XPVA and MUF were relatively unchanged after 12 years in a block stack whereas the uncoated exterior exposed samples were severely affected. Painting with a water repellent pretreatment resulted in a significantly improved result for the MUF panels. Preservative treatment did not affect panels bonded with XPVA adhesive but it did for MUF where the 5 kg CCA/m^3 panels were less than the 10 kg CCA/m^3. Panels treated with CCA were always lower in strength than the copper naphthenate-treated and the untreated panels.

Lathe check orientation has been shown by others to affect the wet tension shear strength of plywood joints. *Pinus* spp. plywood gives a higher shear strength and wood failure value

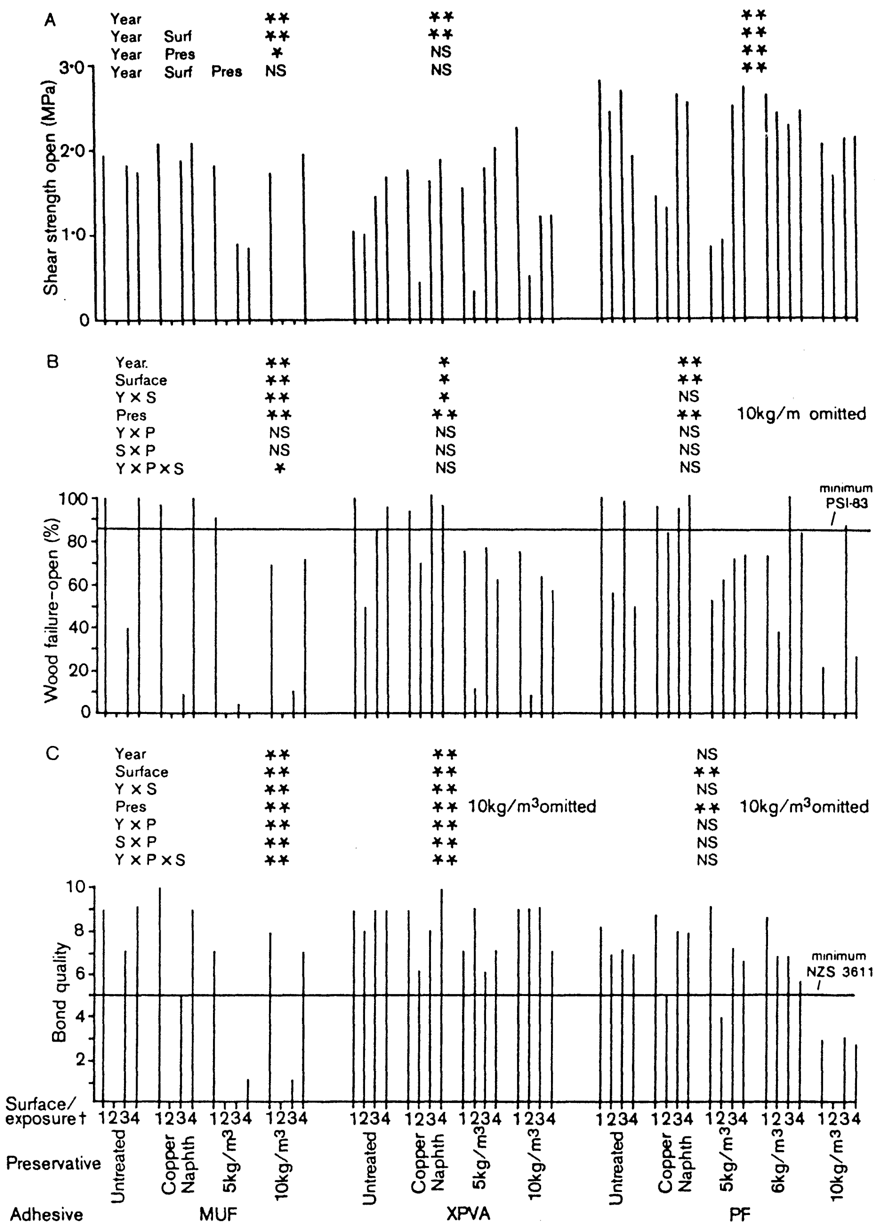

FIG. 1–Analysis of variance and treatment interaction for individual adhesives.
A—Predicted average shear stress with lathe checks pulled to open, after 12 years' exposure;
B—Predicted average wood failure with lathe checks pulled to open, after 12 years' exposure;
C—Predicted average bond quality after 12 years' exposure.
NS not significant
* significant at 95% level
** significant at 99% level
† Surface/exposure: 1=interior; 2=exterior, uncoated; 3=exterior, painted; 4=exterior, water repellent plus paint

when lathe checks are pulled open but plywood from *Picea* spp. (spruce), *Liriodendron tulipifera* L. (yellow poplar), and *Liquidambar styraciflua* L. (sweetgum) will give an opposite effect (McSween & Sellers 1985). *Pinus radiata* plywood produces higher shear strength values for lathe check pulled closed: the initial difference between the two directions was 25% but after exposure to weather this reduced to an average of 8% for the three adhesives.

Wood failure

Wood failure was assessed from the failed samples of the tension shear test (either WFCl or WFOp) and also from the chisel test (BQ) using a much larger sample size. The two test methods measure essentially the same property; however, differences occurred in both the value and the trend over time for each adhesive type (Table 6). The chisel test (BQ) increased in value for XPVA-bonded panels at year 12 whereas the tension shear test (WF) showed a slight decrease. Phenol formaldehyde panels recorded a large decrease (75%) on weathering according to WF but a smaller change (86%) by the chisel test.

TABLE 6–Actual average wood failure values from two test methods at Years 2 and 12 (each value is mean of 16 treatments)

Test method	PF		MUF		XPVA	
	Year 2	Year 12	Year 2	Year 12	Year 2	Year 12
Tension shear (%) (WF)	89	67	89	46	74	67
Chisel test (scale 1–10) (BQ)	6.8	5.9	7.2	4.6	7.6	8.2

Wood failure values from the tension shear test are used by the softwood plywood industry in North America as a standard by which to judge panel durability. The background for this acceptance has been reviewed by Raymond (1977) and is based on tests with Douglas fir and *Pinus* spp. plywood bonded with a PF adhesive. Wood failure was found to be the best measure of durability in terms of reliability and speed, ahead of alternatives like shear strength, cyclic delamination, and cleavage. However, wood failure was not a good predictor with other adhesive types, including catalysed PVAs and acid-catalysed phenolics. For MUF-bonded plywood samples, a boil test was a better predictor than a cold soak test. As stated earlier, the US Product Standard (PS1-83) requires a minimum average wood failure of 85% in a tension shear sample; this is the expectation for a fully-exposed, exterior-type, softwood plywood. The New Zealand and Australian requirement for such plywood is for a bond quality of an average of not less than 5 after a cold water soak pretreatment. From Fig. 1B and C it is immediately apparent that the test method has an important impact on deciding when a panel has reached the end of its life: the chisel test resulted in a significantly lower failure rate.

The analysis of variance test for both WF and BQ was, like shear stress, confounded by the significant interaction. The Surface × Preservative interaction for each of the three adhesives at year 12 is illustrated in Fig. 1B and C. Gluelines of the uncoated, fully exposed panels were, with few exceptions, consistently lower in quality than the other treatments. There was corroboration between WFOp and BQ values for the MUF panels only.

Several attempts were made to find a regression model for multiple adhesive comparisons that did not give a significant interaction term for the three wood failure measures of WFOp, WFCl, and BQ. This was found only for WFOp using a common intercept model for the XPVA and PF panels with the preservative treatment at 10 kg CCA/m^3 omitted. The ANOVA summary is presented in Table 7. There was no difference in WFOp between the two adhesives, but there was a significant difference due to exposure time, preservative, and surface treatment. The ANOVA table indicates that year and preservative had a similar impact on wood failure values and surface a much lesser effect. The effects of various treatments on wood failure values are illustrated in Fig. 2 where predicted values are plotted from 0 to 15 years. Of the uncoated exterior-exposed panels, the gluelines of the 5 kg CCA/m^3 veneer treatment were degraded most, followed by untreated panels and copper naphthenate-treated panels. An important effect of the CCA preservative is shown by the constant decline in wood failure of the 5 kg CCA/m^3 interior panels. This preservative/exposure combination declined more in glueline quality than the exposed, uncoated, copper naphthenate panels. There was no difference in WFOp between the painted panels and panels coated with paint and water repellent. Of the three preservative treatments, copper naphthenate produced the highest wood failure at 91%, followed by untreated panels at 80%, and finally the 5 kg CCA/m^3 treatment at 58%.

TABLE 7–Analysis of variance for wood failure (lathe checks open) of PF- and XPVA-bonded panels: binomial function with common intercept, three preservative treatments, and four surface/exposure treatments

Source	df	Mean deviation	Ratio	Significance
Year	1	190.98	13.42	**
Year × Adhesive	1	3.90	0.27	NS
Year × Surface	3	90.10	6.33	**
Year × Adhesive × Surface	3	13.57	0.95	NS
Year × Preservative	2	179.33	12.60	**
Year × Adhesive × Preservative	2	24.50	1.72	NS
Year × Surface × Preservative	6	16.23	1.14	NS
Year × Adhesive × Surface × Preservative	6	20.17	1.42	NS
Residual	95	14.23		

** significant at 99% level
NS not significant

Bending properties

The effect of surface and preservative treatments on MOR and MOE and bending stiffness (EI) is illustrated in Table 8 for the three adhesive types.

The average values after weathering were always higher for the PF-bonded panels. The lower values for the XPVA panels are a reflection of the lower creep resistance of this type of adhesive. Exposure of the uncoated panels reduced MOR to 42% and 35% of the initial values for the PF and XPVA panels; MOE was reduced to 81% and 54%, EI to 64% and 46% for the two adhesives. The interior exposed panels were unchanged in flexural properties after 12 years. Painting of the PF and XPVA exterior exposed panels was effective in

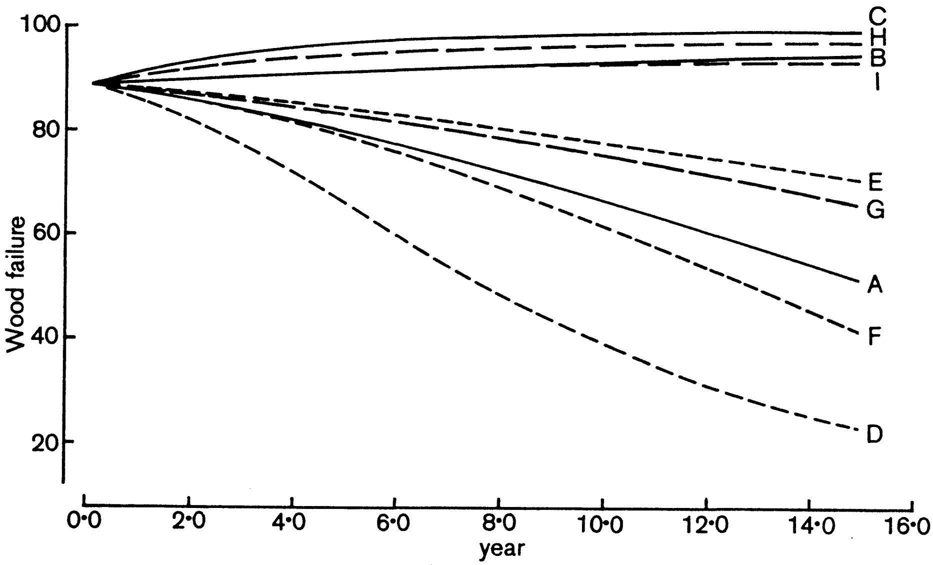

FIG. 2–Curvilinear regression lines for wood failure from the tension shear samples with lathe checks pulled to open—Predicted values for the mean of two adhesives

KEY:			
A	interior,		5 kg CCA/m^3
B			copper naphthenate
C			untreated
D	exterior,	uncoated,	5 kg CCA/m^3
E			copper naphthenate
F			untreated
G		painted,	5 kg CCA/m^3
H			copper naphthenate
I			untreated

TABLE 8–Bending properties of plywood: actual numbers for the three adhesive types after 0 and 12 years

Adhesive	Property	Year 0	Year 12 (percentage of Year 0) Interior	Exterior uncoated	Exterior painted
PF	MOR (MPa)	84.0	78.1 (93)	34.9 (42)	68.1 (81)
	MOE (GPa)	11.4	11.2 (98)	9.2 (81)	11.7 (103)
	EI (N*10^5/mm^2)	360	305 (85)	232 (64)	359 (100)
XPVA	MOR (MPa)	72.8	75.3 (103)	25.2 (35)	55.9 (77)
	MOE (GPa)	11.5	11.7 (102)	6.2 (54)	10.3 (90)
	EI (N*10^5/mm^2)	367	343 (94)	170 (46)	331 (90)
MUF	MOR (MPa)	79.5	81.7 (103)	–	41.6 (52)
	MOE (GPa)	11.2	12.7 (113)	–	7.4 (66)
	EI (N*10^5/mm^2)	381	394 (94)	–	244 (64)

reducing change; MOR was affected the most but was still approximately 80% of the initial values.

In the ANOVA test for the two-adhesive comparison, MOR was the only property free from interactions. All the main treatment factors were significant (Table 5)—preservative at the 95% level and year, adhesive, and surface at the 99% level. Bending strength of PF and XPVA panels under the various treatments is shown in Fig. 3. The CCA preservative treatment resulted in a loss in bending strength for the uncoated panels which was greater than that for the panels without any preservative treatment.

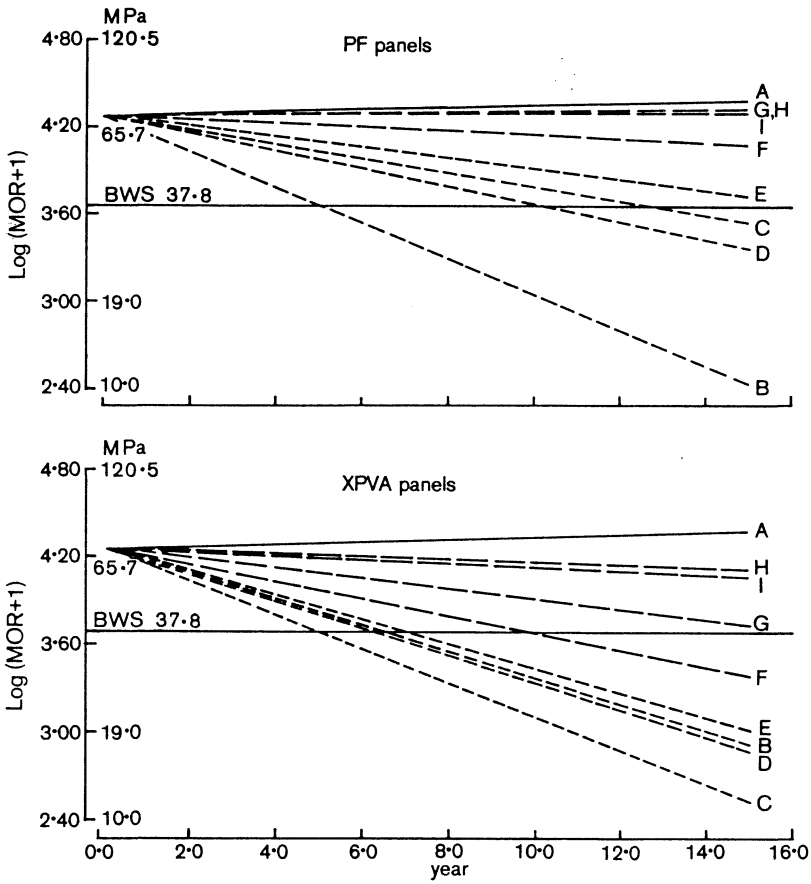

FIG. 3–Linear regression lines for modulus of rupture–Predicted values over a 15-year exposure period for PF- and XPVA-bonded panels (BWS=basic working stress)

KEY:			
A	interior,		untreated
B	exterior,	uncoated,	10 kg CCA/m^3
C			5 kg CCA/m^3
D			copper naphthenate
E			untreated
F		painted,	10 kg CCA/m^3
G			5 kg CCA/m^3
H			copper naphthenate
I			untreated

The basic working stress for clear *P. radiata* parallel to the face grain would be considered a minimum performance level for this material. This was calculated from the NZ Standard 3615:1981 as 37.8 MPa for MOR and 11.5 GPa for MOE by allowing for moisture content and adjusting for load duration and a safety factor. Using this as a guideline, the exterior uncoated panels had technically failed after 12 years (Table 8). The MOE for the painted XPVA and MUF were also below this guideline.

DISCUSSION AND CONCLUSIONS

The treatment of veneers with a CCA-type preservative prior to assembly into a panel affected the quality of the gluelines. The wood failure for panels immediately after fabrication, as determined by the tension shear test, was less for the PF- and XPVA-bonded panels treated with 10 kg CCA/m^3. Also, the gluelines from the 5 kg CCA/m^3 XPVA and the 6 kg CCA/m^3 PF panels did not comply with the North American standard requirement of 85% for an exterior plywood.

On exposure to the weather, the uncoated panels of the CCA-treated veneers exhibited a larger reduction in property values than the untreated panels and those treated with copper naphthenate. This result must take into account the atmospheric conditions that prevail in this thermally active region which from time to time give high localised levels of hydrogen sulphide gas. This reacts with the CCA salts on the surface of uncoated wood products to give a distinctive dark coloration. The dark colour leads to higher temperatures on the surface and a greater dimensional stress than in panels of other treatment types. The behaviour of the interior panels over the term of this trial indicates, however, that even without this effect the preservative treatment will reduce the quality of the glueline.

A paint coating on the exposed surfaces of panels was effective in reducing the decline in properties with weathering. Wood failure of coated untreated exterior panels was similar to that of untreated interior controls. Painting reduced the decline in bending properties and prevented the total destruction of the MUF-bonded panels that would otherwise have occurred. The use of a water repellent prior to painting did not give a uniform response over all the adhesive types and is therefore not recommended.

A comparison of the XPVA and PF panels showed that PF panels retained higher shear strength and flexural properties. Wood failure was the same but bond quality was 40% higher for XPVA. The MUF panels were inferior to the other adhesive types on exposure although initially all panels gave a wood failure greater than 85%. The effect of exterior exposure on the MUF panels indicates that this adhesive type is not suitable for exterior applications.

Glueline quality assessed from the amount of wood failure on the failed surface was dependent on the test method. Values from the two tests used in this trial did not always agree and a judgment as to which treatment/adhesive was serviceable at the end of 12 years' weathering depended on which test was used. The reject rate was higher for wood failure assessed by the tensile shear test.

Much of the information gathered during the term of this trial could not be fully utilised because of the significant interactions that occurred among the treatments. In future, long-term trials should be kept as simple as possible so that the considerable investment in time and effort is able to be realised.

ACKNOWLEDGMENTS

Thanks are due to Mr C. I. Hutchinson who originally set up this exposure trial in 1976, to Ross Anderson and Phillip Crede for undertaking the arduous task of testing the panels, and to Mark Kimberley for assistance with the statistical analysis. Mick Hedley, Hank Bier, and Ian Hutchinson provided valuable comment on an earlier draft of this report.

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