Non-Destructive Analysis Reveals Effect of Installation Details on Plywood Siding Performance

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Abstract

This study evaluated the influence of a variety of construction techniques on the performance of plywood siding and the applied paint, using both ultrasound and conventional visual inspection techniques. The impact of bottom edge contact, flashing vs. caulking board ends, priming the bottom edge, location (Wisconsin vs. Mississippi) and a gap behind the siding to facilitate drainage were tested. Test fences were constructed to provide outdoor exposure of 2 replicates of each permutation using full factorial design. Yellow poplar (*Liriodendron tulipifera*), a decay prone wood species was used for the plywood to accelerate the results. After four years of outdoor exposure, mushrooms were observed on the surface of some boards and all were removed for lab evaluation. Extensive water staining was seen on the backs of the boards caused by water travelling upward from the bottom edge. Sound velocities were measured to determine the degree of decay. Herein we will present an analysis of the relative merits of ultrasound vs. visual inspection. We also analyze factors impacting performance, including the poor performance obtained when the bottom of a piece of wood is in contact with another surface, and the unusually poor performance of the gap behind siding. The study will conclude with recommendations for construction practices.

Note: the version of this paper in the conference proceedings showed visual evaluations had erroneously high statistical power in Table 1. This version has corrected that error and the accompanying discussion.

Introduction

Paint and wood substrate performance testing has traditionally been evaluated with visual inspection methods. Physical testing of the wood properties has potential advantages because of the inherent problems of bias, training, repeatability, human error, rating standards, etc. associated with visual inspection methods. Automated methods also have the potential for continuous or more frequent monitoring, labor savings, and more. This study, then, evaluated the ability of NDT via ultrasonic wave propagation through the thickness of the wood specimen to detect changes in plywood properties over time, and compared the sensitivity and degree of property change to visual evaluations.

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The construction methods used to install wood siding can have a large influence on the decay rate and overall performance of the siding. In this study several installation methods known to be detrimental to performance, but still widely practiced, were tested to see just how important they are in siding performance, and also to test the NDT methodology.

Experimental

13mm thick, 5 layer rough sawn, T1-11 plywood panels of yellow poplar were manufactured for this study because this species is extremely prone to decay and would accelerate results. Strips 14cm tall x122cm wide, representing the bottom edge of a standard siding panel were coated with Sherwin Williams (Cleveland, OH) A-100 latex primer and A-100 latex paint facing South 90 degrees in outdoor exposure for 48 months (Mississippi) or 62 months (Wisconsin). A full factorial design with 2 replicates was used, with conditions and evaluated variables shown in Table 1.

Mississippi (MS) is subtropical hot and humid, Wisconsin (WI) is temperate ranging from -30 to +30C. The ends of boards were primed and then sealed with a caulk joint to the trim, as shown in Figure 1(common), or flashed (not commonly done), which basically leaves the left and right end of the siding unfinished except for the paint on the board ends. We also tested whether a gap at the bottom of each board was helpful, as it is expected to prevent water from wicking into the wood from the flat surface below. Whether the bottom edge had a coat of primer or not was another variable, with the intention that the primer would slow moisture entry. A gap behind the siding is normally recommended to allow drying of the siding through the back face, so we tested with and without a gap. The top edge of boards was unprimed but flashed to prevent water entry, and backs were unpainted.

A Sylvatest Duo (CBS-CBT, Les Ecorces, France) unit operating at 22 kHz was used to measure ultrasound transmission time and peak energy of compression waves through the thickness of the tested wood and some unexposed controls at the end of the study. The transmitter probe and the receiver probe were positioned at the selected test point, one on each side. A constant pressure of 207 kPa was applied to the probes during each measurement cycle through compressed air control. This probe–wood contact pressure was determined based on a series of repeatability tests with different pressures and proved to enable good coupling between the samples and the probes. Samples were equilibrated to the ambient laboratory environment before testing.

The ultrasound instrument outputs the mean of five consecutive measures. An average ultrasound transmission time (UTT) and peak energy of the ultrasound signals were recorded three different times in each of three regions of a panel: top, bottom, and end near caulking or flashing. Ultrasonic velocity was calculated by the thickness of the sample measured at the time of ultrasonic measurement divided by UTT. The peak energy represents the attenuation or propagation efficiency of the ultrasound waves through the sample.

Visual evaluations of the substrate integrity and paint cracking were done annually, where a rating of 10 represents pristine condition, 5 means repainting is needed, and 1 is complete failure (ASTM 1993).

Statistical analysis was conducted with JMP Pro 11 software (SAS Institute, Chicago, IL, USA). In table 1, "P" = probability that the treatment had no impact using student's t test. "Effect" is the difference between the means of the two possible values. "Sonic measurement location" data is expressed as the difference between each location and the mean of all locations. In the first 5 rows of table 1, only the first NDT measurement was used (end of panel), so that the same number of observations would be used in comparing NDT vs. visual evaluation sensitivity.

Observations and Discussion

Visual vs NDT Evaluation

Figure 1 shows how ultrasonic measurements were obtained. Table 1 shows the results of statistical analysis. Yellow boxes indicate a probability under 0.5% of randomly obtaining the observed difference, and orange boxes under 5%. The most sensitive analysis technique is the ultrasound speed, based on the largest observed effects and most factors found to be statistically significant. Speed of sound is linearly correlated with stiffness, and stiffness is lost when wood rots. Therefore we interpret our measurements to indicate rot. Because the only thing typically preventing untreated wood from decaying is a lack of available water, we expect low sonic velocity to correlate with high typical moisture content of the wood in service and high decay rate. Peak energy was a very poor analysis technique, by comparison.

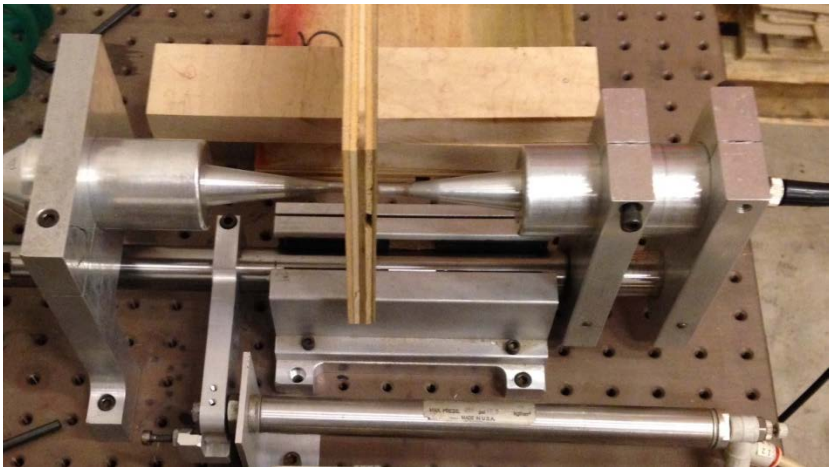

Figure 1: Apparatus for ultrasonic measurement with plywood sample in place.

Visual evaluation for paint cracking and substrate degradation identified smaller changes, with less statistical power, than ultrasonic velocity (Table1). Though visual evaluations are faster, they clearly suffer from sensitivity, as well as the problems of human bias, variability, and difficulties in clearly defining the various levels of the rating system.

The NDT measurements appeared to have more statistical power than visual measurements and identified moresignificant variables. The power of NDT evaluation could be further improved by using all the data points from a given specimen, as is done in the bottom 3 rows of table 1. The NDT data could have been further improved because ~4.5% of the observed speeds were suspiciously fast, between 3500 and 4800m/s, even on the bottom edge of exposed boards showing signs of decay. We were not able to identify the source of these clearly erroneous measurements, and they were retained within the statistical analysis. Clearly the power and effect of the ultrasonic measurement would be dramatically improved if the sources of these outliers were eliminated. We believe that measuring speed of ultrasound through the thickness of the panel, 12mm, reduced the reliability of the measurements. This is because the resolution of the timing electronics was only 8x faster than the average time and because this short sound wave travel distance resulted in very small volumes of wood being tested. Forcing the sound wave to travel a longer distance, as well as using shear waves of lower frequency, would probably improve the data. Shear waves travelling a longer distance could be sent and detected on the same side of the panel, and so allow monitoring of the samples on site over time. Finally, the compression force on the transducers may have closed delamination gaps in the plywood, affecting the results.

Table 1: Impact of exposure conditions on various properties. Positive effects indicate better performance under the first condition (ex. 9mm Bottom Gap is better than 0mm gap because effects are positive)

Effect of construction details on performance

		Sound Speed		Sound Energy		Substrate		Paint Crack	
		P	Effect	P	Effect	P	Effect	P	Effect
Mississippi vs Wisconsin		0.01	9%	0.34	-3%	0.00	-24%	0.00	-10%
Flashed vs. Caulked Ends		0.00	19%	0.08	5%	0.18	5%	0.02	-7%
Bottom Gap (9mm vs 0)		0.00	30%	0.00	13%	0.13	6%	0.08	5%
Primed Bottom (Yes vs No)		0.01	-8%	0.52	-2%	0.58	2%	0.48	-2%
Gap Behind (0 or 5cm)		0.12	5%	0.10	4%	0.30	-4%	0.48	-2%
Sonic Measurement Location	Bottom	0.00	-11%	0.23	-2%				
	End	0.00	-14%	0.00	6%				
	Top	0.00	25%	0.02	-4%				

Leaving a gap between the bottom of a board and the surface below it was the most important factor in good construction. The gap resulted in much lower decay rate (higher speed of sound, higher peak energy), as well as better visual substrate ratings and paint crack ratings. Leaving the gap allows boards to dry out faster after rain stops and potentially reduces the amount of water absorbed by the siding. This observation is consistent with many previous studies (Williams and Winandy, 2008).

Caulking the ends of boards is extremely widespread, though most installations apply caulk between board ends and trim as a fillet joint with caulk pressed into the corner between siding and trim, though manufacturer literature specifically discourage this practice (Dow Corning, 2011) because they are highly prone to sealant failure. After failure the caulk serves to trap moisture inside the structure rather than keep it out. In this study, we applied caulk and flashing properly (Figure 2). Still, the data shows that leaving a gap between the ends of the boards and vertical trim strip, with flashing, results in less decay and better substrate performance. Paint cracking is more severe, likely because moisture is able to enter the end grain of the wood and quickly swell the wood during rain events, putting stress on the paint film. Better sealing of the end grain of wood would likely improve cracking performance. The best overall practice is to cover the ends of the siding with a piece of vertical trim.

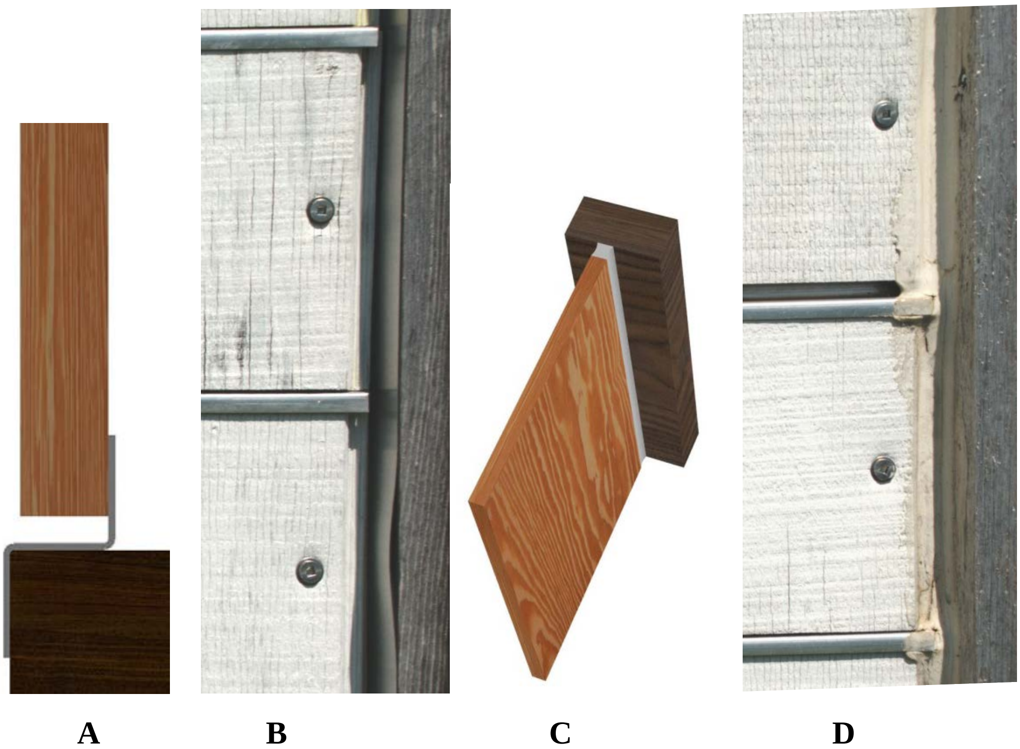

Figure 2: End and bottom finishing details. A, schematic view from top of flashing between panel and trim. B, photo of flashing at end of panel. C, schematic of caulk joint. D, photo of caulked joint on end of test panel. D also shows a gap below the board (upper) and no gap (lower).

Exposure in warm and moist MS (30ºN Lat) resulted in a 9% faster average speed of ultrasound through the wood (less decay) than exposure in WI (43ºN Lat), which we attribute primarily to the shorter exposure time. By contrast, visual evaluations found Mississippi harder on the substrate and paint, in line with our previous experience.

Putting a coat of primer on the bottom edge has been shown in many previous studies to be beneficial to siding performance (Hunt 2009, Carll 2009), but not in this study. Usually primer is useful in preventing liquid water from entering the wood but allows vapor to escape wood. We do not know why in this study the primer was detrimental to performance, although it is known that some early alkyd emulsions (oil based paint dispersed in water) had problems with water barrier properties because of the specific surfactants used (Ekstedt 2003). Because these problems have been identified, we expect modern alkyd emulsions to perform much better, though using simply an oil based primer, rather than an emulsion, seems a safer bet for water repellency.

A secondary drainage plane or gap is made by adding furring strips between the vapor barrier and siding. This is typically referred to as a “rain screen”, or if vented at the top, “ventilated siding”, and is generally recommended. In this study, the bottom of the siding was open and no foundation was present, allowing the wind to pass under the wall. There was no significant effect of the gap but Figure 3 shows that siding on the side with a gap (right) had more water stain, further up the backside of the board, than the side with no gap (left). This is clearly not the intent nor the typical performance of a rain screen. We believe the open space below the siding created a Venturi effect and a low pressure zone behind the siding, which would drive water up behind the siding. This highlights the need for careful attention to installation details. We refer the reader to Rousseau for a description of proper rain screen construction (Rousseau 1990).

Fig 3: Back side of 2 panels after exposure, with caulked edges and no bottom gap showing water staining, more severe with the Venturi effect and gap behind boards (right) while end decay is more pronounced without gap behind boards (left).

Conclusions

In this experiment, ultrasonic velocity measurements were better than visual evaluations at detecting performance differences. Several suggestions are made to improve ultrasonic NDT measurements which should improve the data quality significantly, suggesting that NDT evaluations for wood siding performance have the potential to be much more sensitive and reliable than visual evaluations.

When using wood siding, contact between the bottom of the board and the flashing below is significantly detrimental for every property we observed. Using caulk between ends of boards and vertical trim resulted in slower ultrasonic propagation and lower substrate ratings than flashing the ends, even though the caulking was applied properly. If the ends are to be flashed, however, special attention needs to be given to preventing water intrusion into the siding where it meets the vertical trim. Proper attention to several design details result in significant differences in siding decay rate and paint performance.

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