Checking of Profiled Southern Pine and Pacific Silver Fir Deck Boards

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Abstract

This study tests the hypothesis that the effectiveness of surface profiling at reducing the checking of deck boards exposed to weathering varies with wood species and profile type. Southern pine (*Pinus* sp.) and Pacific silver fir (*Abies amabilis*) deck boards were machined to produce three different types of surface profiles: flat (control), ribbed (V-shaped grooves), and rippled (U-shaped grooves). Boards were exposed to accelerated weathering for 5 days, and the number and sizes of checks that developed in boards were quantified. Surface profiling reduced the total number and total width of checks in both Pacific silver fir and southern pine deck board specimens, but it had a greater effect at reducing checking in Pacific silver fir than in southern pine. The ribbed profile, in particular, was much more effective at reducing checking of Pacific silver fir than it was at reducing the checking of southern pine. Therefore, we conclude that the effectiveness of surface profiling at reducing checking of deck boards depends on wood species and the type of profile machined into wood surfaces. Checks developed in the grooves between the ribs of profiled boards and appeared to be constrained from becoming wider to a greater extent than becoming longer. Therefore, we conclude that the beneficial effect of profiling on the appearance of boards arises because checks are much narrower than those on flat boards and are located in the grooves, where they are difficult to see.

The checking of wooden deck boards has been a source of dissatisfaction to consumers for a long time (Fowlie et al. 1990). This dissatisfaction is being exploited by manufacturers of plastic and plastic-wood decking, who claim that their products do not check or split (Green 2005). These plastic deck boards have captured 15 to 26 percent of the total market for deck boards in North America at the expense of wooden deck boards (Markarian 2005, Koenig 2010). The loss of market share for wooden decking has led to interest in methods of reducing the checking of deck boards exposed to the weather. Checking of deck boards can be reduced by pressure treating boards with preservatives that contain wax or oil (Zahora 1991, Evans et al. 2009) or by regularly applying a water-repellent stain to deck boards when they are in service (Ross et al. 1992). An alternative approach to reducing the checking of deck boards is to machine the surface of boards to create a series of narrow V (ribbed)– or U (rippled)–shaped grooves. Deck boards with ribbed surface profiles are common in Europe, Australia, and New Zealand, but we cannot find any published accounts from these regions on the effectiveness of profiling at reducing checking. Recent studies in Canada have demonstrated the effectiveness of surface profiling at reducing the surface checking of Subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) deck boards exposed to natural weathering (McFarling and Morris 2005, Morris and McFarling 2008, McFarling et al. 2009). Profiling also reduced the total length of checks in blue-stained lodgepole pine (*Pinus contorta* var. *latifolia* Wats.) deck boards exposed to natural weathering, but it did not reduce the depth of checking, and rippled profiling did not reduce the width of checks (Morris and McFarling 2008). These studies suggest that the effectiveness of profiling at reducing the checking of wooden deck boards may vary among different wood species, and it may also depend on the type (shape) of profile used. In this study we test this hypothesis by comparing the checking of profiled southern pine (*Pinus* sp.) and Pacific silver fir deck boards with that of flat (control) boards subjected to accelerated weathering. The decking market is very important for companies manufacturing treated lumber, and in North America alone the residential decking and railing market is valued at US$2.8 billion per annum (Koenig 2010). Southern pine is the most important

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wood used for treated decking in North America, and this is the first published report on the effectiveness of profiling at reducing the checking of this species. Pacific silver fir is harvested together with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) from coastal forests of British Columbia, but the former is the more treatable of the two species (Morris 1995). Therefore, it is better suited for use as treated decking. However, Pacific silver fir develops checks when it is used for decking, and hence it can benefit from check-reducing treatments.

This study forms part of a larger research program that is examining ways of reducing the checking of wood exposed outdoors (Evans et al. 1997, 2000, 2003, 2009; Christy et al. 2005).

Materials and Methods

Experimental design and statistical analysis

The experimental design employed here used factorial principles to investigate the effect of two fixed factors (wood species and profile type) on response variables (total check number, total check length, total check width, and average length and width of the 10 largest checks found in specimens). Boards obtained from six different trees for each species (Pacific silver fir and southern pine) provided replication at the higher level. Boards from each species were paired together to create six groups (blocks). The two boards in each block were each cross-cut to produce six specimens (three specimens for each species), and specimens from each species were randomly allocated to the different profiling treatments (ribbed, rippled, and flat). Profiled Pacific silver fir and southern pine specimens and the unprofiled controls from block 1 were grouped together in three pairs; each pair having the same profile. A pair of specimens was randomly allocated to the two sample holders in the weatherometer, and specimens were exposed to accelerated weathering for 5 days. The order in which specimens with the same profile were weathered was randomized. The weatherometer was able to weather two specimens at a time, and therefore it took 3 weeks to test the six specimens in each ‘‘block.’’ Once the three pairs of specimens from the first block were tested, specimens in block 2 were exposed to accelerated weathering and so on until all specimens were tested. The total number of specimens tested was 36 (18 specimens per species), and it took 18 weeks to test all the specimens.

The experimental design accounted for random variation (between boards and specimens) and variation due to the fixed factors (species and profile type). The main effects of, and interactions between, each of the two fixed factors on check numbers and sizes were tested for significance using an appropriate multifactorial analysis of variance (ANOVA). The factorial design of the experiment allowed data to be averaged across nonsignificant results, giving the experiment greater precision. Statistical computation was performed using Genstat 12 (VSN International 2009). Check size data were transformed into natural logarithms to ensure that they met the requirements of analysis of variance, i.e., normality with constant variance. For a similar reason, check numbers were transformed into square roots before ANOVA. Significant results are presented in graphs. Error bars in these graphs representing the minimum difference between means that are statistically significant at the 5 percent level can be used to estimate whether differences between individual means are statistically significant. We also present a table showing the statistical significance of wood species and profile type and the interaction of species and profile type on check numbers and sizes.

Selection of wood and machining of profiles

Six southern pine and a similar number of Pacific silver fir deck boards measuring 2,500 (length) by 140 (width) by 40 (thickness) mm were purchased from a retailer and donated by a lumber company, respectively. We selected plain-sawn boards with different growth ring widths and wood densities to maximize the possibility that each board came from a different tree (Table 1). We also attempted to obtain ‘‘clear’’ boards that were free of knots. Knots were absent from all the southern pine boards, but a few intergrown knots were present in some of the Pacific silver fir boards. The southern pine wood was faster grown and denser than the Pacific silver fir wood, but the average slope of grain (deviation of grain from the long edge of the sawn specimen) of specimens cut from boards for each of the two species were similar (Table 1). All the boards were stacked horizontally and conditioned at 20°C ± 1°C and 65 ± 5 percent relative humidity for 3 months. Each board was cross-cut to produce three specimens of equal length. Specimens were machined using a rotary moulding machine and customized tooling to produce boards with ribbed, rippled, or flat surface profiles. Figure 1 shows cross sections of southern pine and Pacific silver fir specimens with ribbed and rippled profiles. The ribbed profile has eased edges, and the rippled profile does not completely extend to the edges of boards (Fig. 1). Both of these modifications to the profiles are designed to minimize edge damage to the boards caused by foot traffic. Machining reduced the thickness of boards to 23 mm and their widths to 133 mm (Fig. 1). A specimen 5-cm long in the longitudinal direction was sawn from the end of each deck board, and board samples were cross-cut to produce specimens that were 400 mm in length.

Confocal profilometry of machine profiles

Previous reports on the ability of profiling to reduce surface checking of deck boards have not accurately quantified the dimensions of profiles that are machined into boards (McFarling and Morris 2005, Morris and McFarling 2008, McFarling et al. 2009). The lack of such information makes it difficult to understand the precise difference between ribbed and rippled profiles and would prevent researchers from attempting to reproduce previous findings on the effect of surface profiling on checking of deck boards. Therefore, in this study we quantified the dimensions of the profiles machined into Pacific silver fir and southern pine specimens using confocal profilometry. Deck board subsamples measuring 4 by 4 cm were placed on the *x*-*y* stage of a chromatic confocal profilometer (Altisurf 500), and the surface topography of a small area (10 by 10 mm) was measured. The profilometer used a 3-mm probe, scan speed of 100 mm/s, sampling frequency of 300 Hz, and resolutions in the *x*-*y* and *z* directions of 12 by 12 μm and 3,000 μm to 92 nm, respectively. The software Papermap was used to produce two- and three-dimensional images of the profiled subsamples showing the dimensions of the profiles (ribs and grooves). The grooves were 1.05 mm deep

Table 1.—Wood characteristics of southern pine and Pacific silver fir specimens exposed to accelerated weathering.

	Southern pine			Pacific silver fir		
Board	No. of growth rings/cm	Density (kg/m^3)	Slope of grain (°)	No. of growth rings/cm	Density (kg/cm^3)	Slope of grain (°)
1	7.3	430	2.0	8.0	375	2.0
2	7.0	523	2.2	12.3	313	0.7
3	7.3	451	0.9	5.3	336	1.0
4	6.7	539	1.3	25.0	332	1.2
5	5.3	523	1.3	37.7	425	4.0
6	6.7	457	1.2	13.3	360	1.5
Avg.	6.7	487	1.5	16.9	357	1.7

in subsamples with a ribbed profile and 2 mm deep in subsamples with a rippled profile. In between the ridges the grooves tapered down to flat areas, which were 0.3 and 0.8 mm wide in the ribbed and rippled subsamples, respectively. Figure 2 shows the surface topography of ribbed and rippled profiles in Pacific silver fir.

Accelerated weathering and quantification of checking

Specimens were placed in a weatherometer designed to accelerate the surface checking of deck boards (Ratu and Evans 2008). Two specimens were placed in separate sample holders and screwed at each corner to a wooden subframe using epoxy-coated self-cutting decking screws (KWIKI, 3.46 by 62.6 mm in size). Specimens were then subjected to a wetting and drying cycle for 6 hours. During this period each specimen was sprayed with 18 mL of water every 30 minutes and continually exposed to heat (73°C) generated by two infrared lamps. After 6 hours, specimens were removed from the weatherometer and passed through an ultraviolet (UV) curing machine (Ultraviolet Systems, UV Technology Ltd.). The UV radiation that each specimen was exposed to in this machine was measured using a UV Power Puck II (EIT Instruments), and results were as follows: UVA = 1,015 mJ/cm^2, UVB = 854 mJ/cm^2, and UVC = 28 mJ/cm^2. Specimens were then returned to the weatherometer and exposed to a long wet and dry cycle. This cycle involved spraying specimens with 18 mL of water every 10 minutes in the absence of heat for a total of 90 minutes. Then the specimens were left in the device under restraint to dry overnight. Specimens were exposed to these cycles for 5 days, except that on the fifth day the long wet and dry cycle was omitted. Five days of exposure to this weathering cycle produces the same level of checking of southern pine specimens as 20 weeks of outdoor exposure in the spring and summer in Vancouver, British Columbia, Canada (Ratu 2009). At the end of each 5-day weathering cycle, pairs of specimens were removed from the weathering device, and visible checks on the surface of specimens were counted. The length and width of these checks were measured using a transparent Plexiglas ruler and an optical magnifying glass containing a calibrated graticule, respectively. Checking is expressed as the total number, length, and width of checks in each specimen. Total check area was also calculated, but results for total check area were similar to those of total check width, and therefore they are not presented or discussed here. The average length and width of the 10 largest checks in each specimen were also quantified. After the weathering test, a 5 by 5-cm cube was cut from each specimen. The basic wood density of these cubes was calculated using their ovendry weight (obtained by ovendrying them at 105°C overnight) and water-saturated volume (by Archimedean displacement). The slope of grain of each board was measured on one of its unprofiled faces using a scribe and protractor.

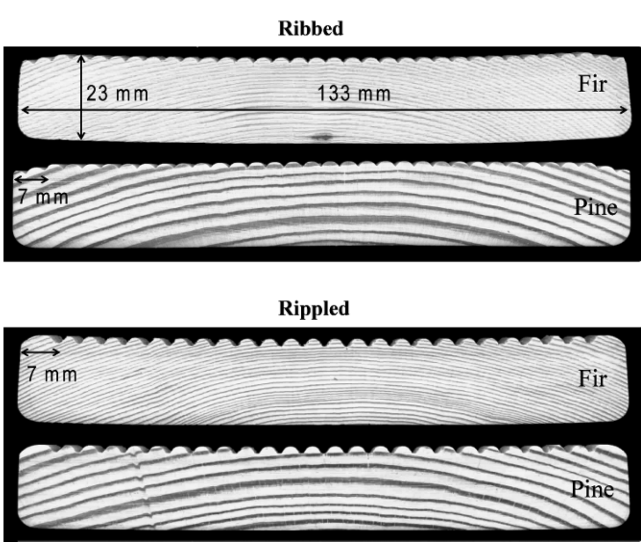

Figure 1.—Cross-sectional dimensions of profiled southern pine and Pacific silver fir specimens.

Results and Discussion

Statistical analysis of data revealed significant effects of profile type on all measures of checking (Table 2). Figure 3a shows the effect of profiling on the number of checks that developed in deck board specimens. The results are averaged across observations of checking in southern pine and Pacific silver fir because there was no significant interaction of species and profile type (S × P) on check numbers (Table 2). Clearly profiling was very effective at reducing the number of checks that developed in deck board specimens during weathering (Fig. 3a). There was no significant difference in the number of checks that developed in specimens with the ribbed and rippled profiles (Fig. 3a). The effects of profiling on total check length and width are shown in Figures 3b and 3c, respectively. These figures plot the results for Pacific silver fir and southern pine separately because there were significant interactions of species and profile type on total check length (P = 0.042) and total check width (P = 0.023), respectively (Table 2). The significant interaction of species and profile type on total check length occurred because the ribbed profile was

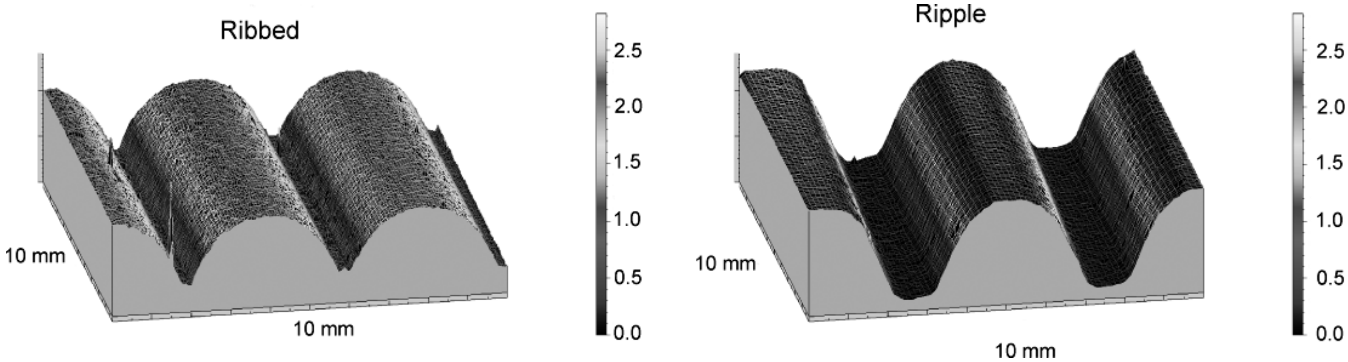

Figure 2.—Surface topography of ribbed and rippled profiles in Pacific silver fir.

very effective at reducing total check length in Pacific silver fir, whereas it was ineffective at reducing total check length in southern pine (Fig. 3b). The rippled profile was ineffective at reducing total check length in both Pacific silver fir and southern pine (Fig. 3b). The significant interaction of species and profile type on total check width occurred because the ribbed profile was much more effective at reducing total check width in Pacific silver fir than it was at reducing total check width in southern pine (Fig. 3c). The total widths of the checks in the ribbed and rippled Pacific silver fir and southern pine specimens, however, were all significantly smaller than those in the unprofiled controls, in contrast to the results for total check length.

Checks were shorter and narrower in Pacific silver fir than in southern pine, particularly in ribbed specimens (as noted above), and this is reflected in the significant overall effect of wood species on check length ($P = 0.039$) and width ($P = 0.004$; Table 2). There was no significant difference ($P = 0.422$), however, in the number of checks that developed in Pacific silver fir and southern pine specimens (Table 2).

We also examined the effect of surface profiling on the average length and width of the 10 largest checks in deck boards because larger checks influence the appearance and consumer perception of (flat) deck boards to a greater extent than smaller checks. Statistical analysis of data revealed significant effects of profile type on both the average length and width of the 10 largest checks in deck board specimens (Table 2). Figure 4 shows the effect of profiling on the average sizes of the 10 largest checks that developed in deck board specimens during weathering. The results are averaged across observations of checking in southern pine and Pacific silver fir because there were no significant interactions of species and profile type on average check size parameters (Table 2). Surface profile had a significant effect ($P = 0.003$) on the average width of the 10 largest checks that developed in board specimens (Table 2) because checks in profiled specimens were much narrower than those in the flat boards (Fig. 4b). The effect of surface profile on the average length of the 10 largest checks was also statistically significant ($P = 0.017$), but in contrast to the results for total check length (above), and unexpectedly, the average lengths of the 10 longest checks in the profiled specimens were *greater* than those that developed in specimens with a flat profile (Fig. 4a). The average length and width of the 10 largest checks that developed in Pacific silver fir specimens were 48.1 and 0.119 mm, respectively, whereas comparable figures for southern pine specimens were 71.5 and 0.197 mm, respectively. These differences account for the significant effect of species on average length ($P = 0.04$) and width ($P = 0.01$) of the 10 largest checks in specimens (Table 2).

Table 2.—Statistical significance of wood species (S), profile type (P), and the interactions of species and profile type on the checking of southern pine and Pacific silver fir deck board specimens exposed to accelerated weathering.

Check parameter	Statistical significance (P values)		
	S	P	S × P
Total check number (square root n)	0.422	<0.001	0.277
Total check length (ln mm)	0.039	0.033	0.042
Total check width (ln mm)	0.004	<0.001	0.023
Avg. length of 10 largest checks (ln mm)	0.040	0.017	0.185
Avg. width of 10 largest checks (ln mm)	0.010	0.003	0.324

These results for the checking of deck board specimens are augmented by visual observations of the appearance of specimens. The very narrow checks in the ribbed Pacific silver fir boards formed at the base of the V-shaped grooves and could only be seen when viewed close-up. Hence, they did not affect the appearance of the deck board specimens. However, visible checks developed in the knots that were present in some of the ribbed Pacific silver fir boards (Fig. 5a). In one ribbed Pacific silver fir specimen from board 5, a large visually distinct diagonal check developed that crossed two ribs (Fig. 5b). The same type of visually distinct diagonal check developed in the matching rippled and unprofiled flat Pacific silver fir specimens and appeared to be due to the presence of higher slope of grain in these specimens (4.0° vs. a mean slope of grain of 1.28° for the other five specimens; Table 1). A visually distinct check also developed at the top of one of the ridges in a rippled Pacific silver fir specimen from board 6 (Fig. 5c). No such checks developed on the ridges of the rippled southern pine specimens, and the checks that developed in these specimens were always formed at the base of the grooves (Fig. 5d). Checks also mainly formed at the base of the grooves in the ribbed southern pine specimens, but some of these checks were large and visually distinct (Fig. 5e). In addition, ribbed southern pine specimens from boards 1 and 2 each developed a check that crossed a rib. The slopes of grain of these specimens were 2.0° and 2.2°, respectively,

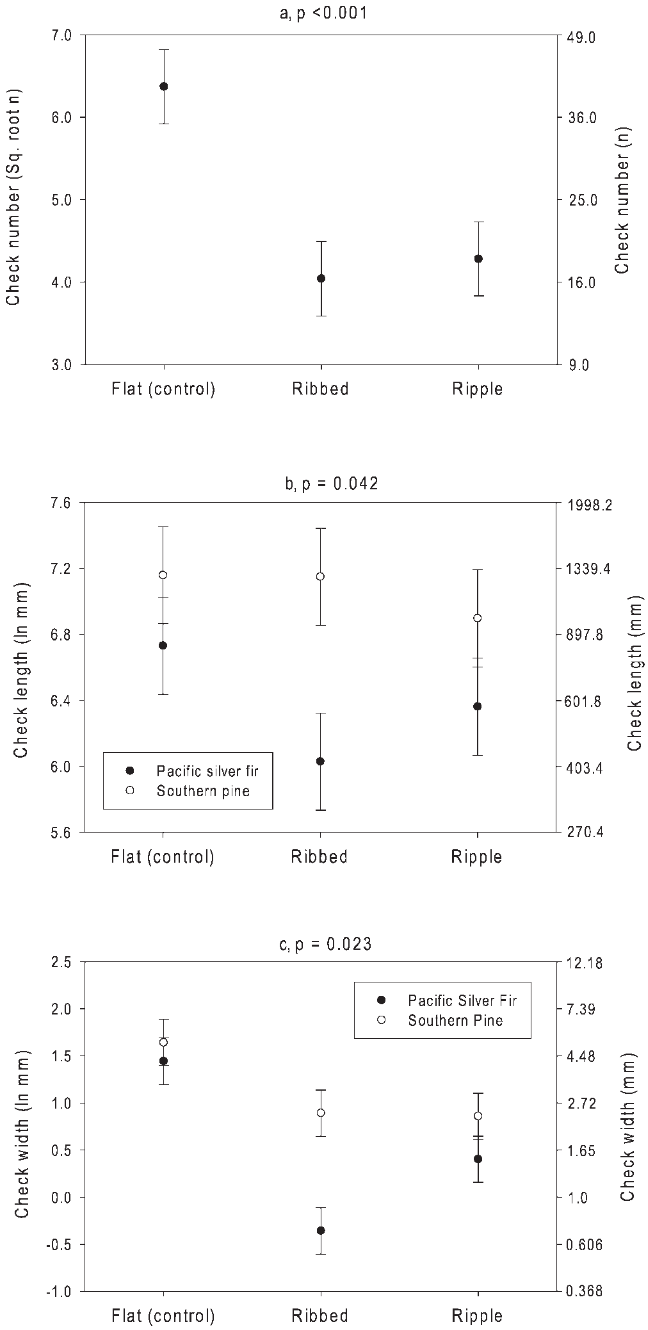

Figure 3.—Total number and sizes of checks in southern pine and Pacific silver fir board specimens with different profiles after accelerated weathering for 5 days. (a) Total number of checks in specimens averaged across southern pine and Pacific silver fir specimens. (b) Total length of checks in specimens. (c) Total width of checks in specimens. The y1 axes use transformed scales, either square roots of check numbers or natural logarithms of check lengths and widths. The y2 axes use the natural scales.

compared with a mean slope of grain of 1.17° for specimens from boards 3 to 6 (Table 1). Figure 5f shows a diagonal check crossing a rib of a southern pine specimen from board 1. The presence of higher slope of grain in this specimen can be observed by comparing the alignment of the ribs with marks created by resin canals, which run diagonally across the ribs (arrow in Fig. 5f). The rippled southern pine boards

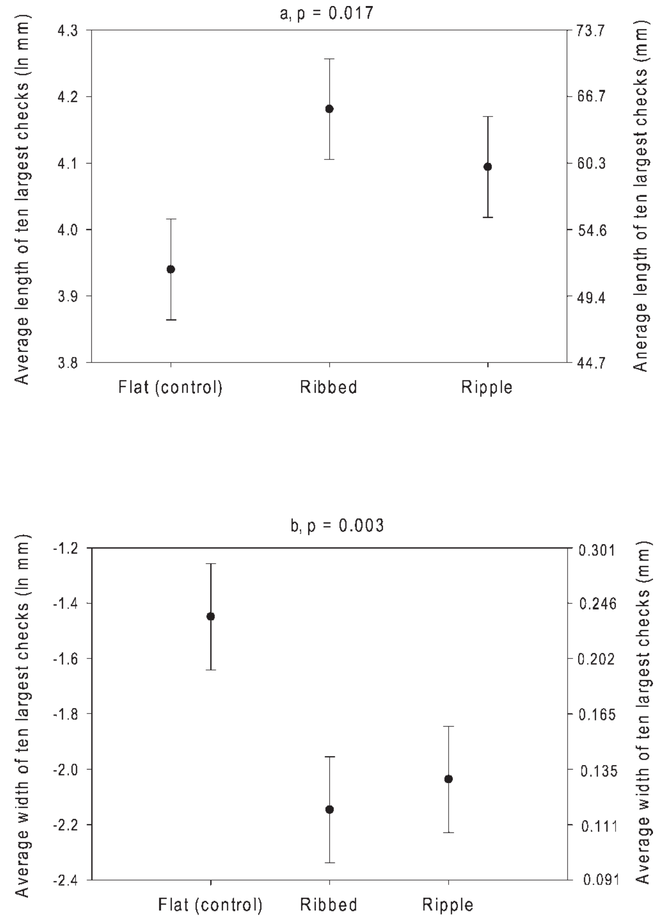

Figure 4.—The average sizes of the 10 largest checks in southern pine and Pacific silver fir board specimens with different profiles after accelerated weathering for 5 days. (a) Average length of the 10 largest checks in specimens. (b) Average width of 10 largest checks in specimens. The y1 axes use natural logarithms of check lengths and widths. The y2 axes use the natural scales.

developed smaller checks, and their visual appearance was better than those of the ribbed southern pine boards, which as mentioned above, sometimes developed quite large checks or separations between ribs (Fig. 5e). Smaller checks, however, were easier to see between the ridges of rippled southern pine boards than between the ridges of ribbed southern pine boards.

In the introduction to this article we hypothesized that the effectiveness of profiling at reducing the checking of wooden deck boards might vary between wood species/profile type. Some of our results supported this hypothesis because profiling, particularly the ribbed profile, was more effective at reducing total check length and width in Pacific silver fir than it was at reducing total check length and width in southern pine. This study was not designed to obtain information on how profiling reduces checking, but some of our findings provide insights into the mechanisms responsible for the reductions in checking of profiled specimens. Checks develop in restrained unprofiled deck boards exposed to wetting and drying because differential shrinkage between surface and subsurface layers leads to the development of surface tensile stresses (Schniewind 1963). Such stresses will be concentrated at surface discontinuities

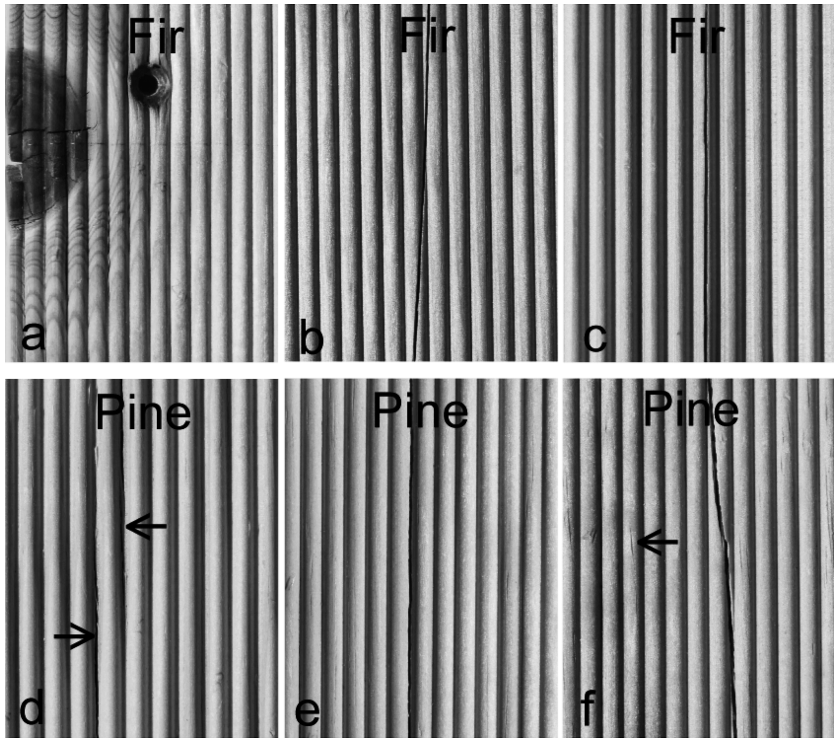

Figure 5.—Appearance of profiled southern pine and Pacific silver fir specimens after accelerated weathering for 5 days. (a) Ribbed Pacific silver fir specimen with a visually distinct check in a knot; note that checks in the grooves below the knot are difficult to see. (b) Ribbed Pacific silver fir specimen with a visible diagonal check crossing the ribs; note that the same type of check was found in the matching boards with flat (control) and rippled (not shown) profiles. (c) Rippled Pacific silver fir specimen with a visually distinct check on top of one of the ridges. (d) Rippled southern pine specimen showing small checks within grooves (arrows). (e) Ribbed southern pine specimen showing a visually distinct check (separation) between ribs. (f) Ribbed southern pine specimen showing a visually distinct diagonal check crossing a rib; note that the resin canals, which are an indicator of grain angle, are aligned at an angle to the ribs (arrow).

such as rays and resin canals, and if these local stresses exceed the tensile strength of the wood, then checks will occur. Localized stress concentrations and checking of materials subjected to tensile stresses can be reduced by machining grooves into their surface (Bhandari 2001). Surface profiling may have had a similar effect in the boards tested here. In addition, the grooves and ridges in profiled boards would reduce surface moisture gradients in boards because they allow water to more easily penetrate surface layers and provide a larger surface area for drying. Hence, the overall surface stresses that cause checking in deck boards are probably lower in profiled deck boards compared with unprofiled deck boards, which may also explain why checking of profiled boards was lower than that of flat unprofiled boards. Nevertheless, stresses would still develop in profiled boards. It has been observed that materials that contain stress relief grooves and are subjected to repeated stresses (as was the case here) develop cracks at the base of the grooves (Ghosh and Srivastava 2006). The same tendency was observed here, and the checks that developed at the base of the grooves tended to follow the slope of the grain. The checks propagated in length rather than becoming wider because profiling had a greater effect at reducing check width than check length. Furthermore, the largest checks in profiled boards were longer than those that developed in flat unprofiled boards. However, even these long checks were difficult to see because they were very narrow, occurred at the base of grooves, and were aligned with the orientation of the grooves. Observations in support of this explanation are the increased visibility of the wide checks that developed in some ribbed southern pine specimens and the fact that checks became very noticeable when they crossed the ridges of profiled specimens. These noticeable diagonal checks only developed in specimens whose profiles were aligned at an angle that was 2° or greater to the grain. Grain angles are higher in the juvenile wood of conifers than in mature wood (Zobel and Sprague 1998). Hence, it is possible that profiling will be less effective at reducing the checking of juvenile wood than mature wood. Further research, however, is needed to test this hypothesis and also to examine in more detail (using greater number of specimens) the effect of slope of grain and profile shape on the mechanism of checking of profiled deck boards exposed to weathering.

Conclusions

Surface profiling reduced checking in both Pacific silver fir and southern pine deck board specimens exposed to accelerated weathering, but it had a greater effect at reducing checking in Pacific silver fir than in southern pine. The ribbed profile was much more effective at reducing checking (total check length and width) of Pacific silver fir than it was at reducing the checking of southern pine. In contrast, the ripple profile was ineffective at reducing check length in both species. Therefore, we conclude that the effectiveness of surface profiling at reducing checking of deck boards depends, in part, on wood species and the type of profile machined into wood surfaces. Checks developed at the base of grooves and appeared to be constrained from becoming wider to a greater extent than becoming longer because profiling had a greater effect at reducing check width than check length. The largest checks in profiled boards were longer than those that developed in flat boards. Therefore, we conclude that the beneficial effect of profiling on the appearance of boards arises because checks are much narrower than those on flat unprofiled deck boards and are located at the base of the grooves where they are difficult to see. Checks that ran across ribs in profiled board specimens, however, were very easy to see. Such checks were observed in some of the profiled specimens whose grooves were aligned at an angle to the grain. Therefore, we suggest that the presence of spiral grain in wood may reduce the effectiveness of surface profiling at restricting the checking of deck boards exposed to weathering.

Acknowledgments

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