

Article

# Manufacture of Profiled Amabilis Fir Deckboards with Reduced Susceptibility to Surface Checking

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**Abstract:** Machining grooves and ridges (peaks) into the surface of wooden deckboards reduces undesirable checking that develops when “profiled” boards are exposed to the weather. We aim to develop improved profiles for amabilis fir decking to reduce its susceptibility to checking, and also to examine whether profiling influences distortion (cupping) of deckboards. We systematically varied radii of grooves and peaks, and the heights and widths of peaks in profiled deckboards, exposed them to the weather, and measured checking and cupping of boards. Profiling significantly reduced the numbers and sizes of checks in amabilis fir deckboards, but increased cupping. Profiles with narrow grooves and tall peaks were generally better at restricting checking than profiles with wide grooves and shorter peaks. Our results suggest that one of the profiles we tested would be better at restricting checking than profiles used previously to manufacture profiled decking from amabilis fir. We conclude that the surface checking of profiled amabilis fir decking can be significantly reduced by altering the geometry of surface profiles. In principal, the same approach could be used with other softwood species that have potential to capture a share of the large and important market for wood decking.

**Keywords:** wood; amabilis fir; decking; profiling; checking; cupping; confocal profilometry

## 1. Introduction

The manufacture of decking is an important industry, and in the US alone over 3.6 billion lineal feet (1.1 billion metres) of decking valued at 7.1 billion (US) dollars is manufactured each year [1]. The majority of detached houses in North America have a deck or porch that are invariably surfaced with deckboards [2]. Most deckboards are manufactured from wood, particularly coniferous timber (softwood) that has been pressure-treated with chemicals to improve its resistance to biological deterioration [3]. Pressure-treated wood accounts for seventy-five percent of the market for deckboards [3], but it is facing increasing competition from products manufactured from wood-plastic composites (WPCs), polyvinyl chloride, aluminium, tropical hardwoods and modified woods [1]. These products are more costly than pressure-treated wooden deckboards, but they maintain their appearance better when they are used outdoors, in part because they are less susceptible to surface degradation, particularly cracking, hereafter termed checking [4–6]. Checks are the macroscopic response of deckboards to moisture-induced stresses and anisotropic shrinkage of wood [7]. An additional response is for deckboards to distort (cup). Both forms of degrade occur when wooden deckboards are exposed outdoors to the weather. The checking of wooden decking can be reduced by adding hydrophobes (wax and/or oil) to the chemical preservatives that are used to treat the decking [8,9], or by applying a water-repellent stain to deckboards [10]. An alternative approach to reducing the checking of deckboards that is attracting increasing attention in North America is to machine small ridges (peaks) and grooves into the surface of boards [11–18]. The dimensions of

these ridges and grooves vary considerably in commercially “profiled” boards for no apparent reason other than their effects on the appearance of boards [19]. A profile with narrow grooves, however, was more effective than a profile with wide grooves at reducing the checking of decking manufactured from amabilis fir (*Abies amabilis*, (Dougl.) ex J. Forbe) wood, whereas the opposite was the case with southern pine (*Pinus* spp.) decking [13,15]. These findings suggest that the dimensions of surface profiles influences their ability to reduce the checking of wooden deckboards. To test this hypothesis, we manufactured profiled decking from amabilis fir wood and systematically varied radii of grooves and peaks, and the heights and widths of peaks at the surface of deckboards. We exposed profiled deckboards to the weather and measured checking and cupping of boards. Our results show that profiles with narrow grooves and tall peaks were generally better at restricting checking than profiles with wide grooves and shorter peaks, and suggest that one of the rib profiles we tested would be better at restricting checking than profiles that have been used in the past to manufacture profiled decking from amabilis fir.

## 2. Materials and Methods

### 2.1. Design of New Surface Profiles and Manufacture of Customized Tooling

Eleven different profiles were designed based on preliminary research that quantified the topography of profiles used commercially in Asia, Australia, Europe, New Zealand and North America [19]. There were three comparable designed profiles within each of the three different profile types we defined previously (rib, ribble and ripple) [19]. The ribbed profile had very narrow grooves and hemispherical peaks with groove radius (R1) to peak radius (R2) ratios of 6.67%. Comparable ratios for the ribble and ripple profiles, which had wider grooves, were 50% and 83.3%, respectively. Within each of these three profile types, the height to width (H/W) ratios of profile peaks were varied to create tall (+25%), standard (0%, baseline) and short (−25%) versions of each of the different profile types (Table 1).

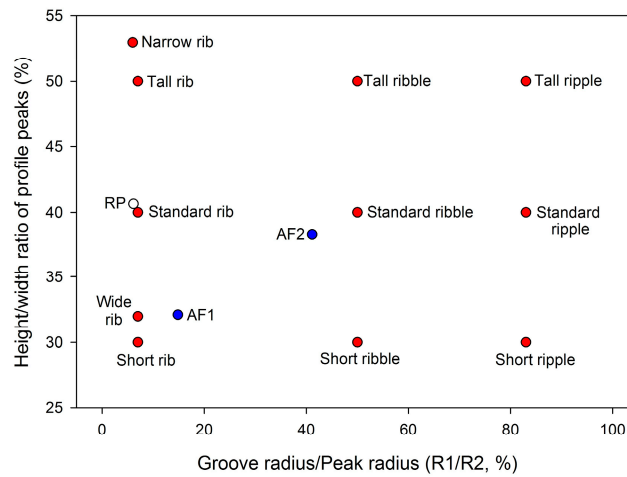
**Table 1.** Dimensions of the designed profiles used to manufacture profiled deckboard samples from amabilis fir.

Profile Type	Peak ht, mm	Peak Width, mm	Groove Radius, mm	Peak Radius, mm <sup>1</sup>
Standard ripple	2.0	5.0	1.0	1.2
Tall ripple	2.5	5.0	1.0	1.2
Short ripple	1.5	5.0	1.0	1.2
Standard ribble	2.0	5.0	0.65	1.3
Tall ribble	2.5	5.0	0.65	1.3
Short ribble	1.5	5.0	0.65	1.3
Standard rib	2.0	5.0	0.16	2.4
Tall rib	2.5	5.0	0.15	2.2
Short rib	1.5	5.0	0.16	2.4
Wide rib	2.0	6.25	0.13	2.0
Narrow rib	2.0	3.75	0.11	1.7

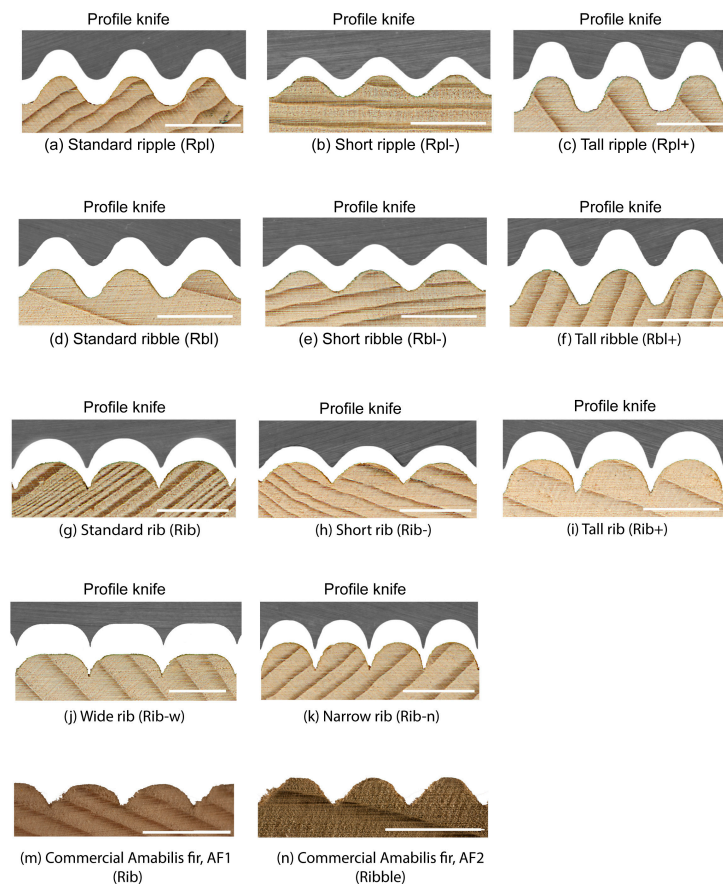
<sup>1</sup> Numbers of peaks per 15 cm (groove frequency) was 30 for all profiles except wide rib and narrow rib profiles, which had 24 and 40 peaks per 15 cm, respectively.

The H/W ratios of profile peaks are comparable between each of the three profile types (Figure 1). In addition, two more rib profiles were designed in which the widths of the peaks were changed by ±25% to create wide and narrow rib profiles (Table 1 and Figure 1). Accurate engineering drawings of each of the different profiles were produced using AutoCAD (Autodesk, San Rafael, CA, USA) and cutter knives capable of machining each profile were manufactured by a specialist tooling company (Great Lakes Custom Tool Mfg. Inc., Peshtigo, WI, USA). Two knives, 150 mm wide, with a body diameter (Ø) of 125 mm and hook angle of 15° were manufactured for each profile. The appearance of the cutter knives and associated ripple, ribble and rib profiles can be compared in Figure 2. The rib

(AF1) and ribble (AF2) profiles used in commercial trials of profiled amabilis fir decking are also depicted in this figure (Figure 2m,n).



**Figure 1.** Geometry of the different profiles machined into the surface of amabilis fir deckboard samples exposed to natural weathering. The geometry of profiles in commercially manufactured amabilis fir deckboards (AF1 and AF2) and a profiled radiata pine deckboard (RP) are also depicted in the graph.



**Figure 2.** Appearance of the different: ripple (a–c); ribble (d–f); and rib (g–k) profiles that were machined into the surface of amabilis fir deckboard samples, and part of the profiling knife that matches each of the different profiles. The two profiles that have been used commercially to produce profiled amabilis fir decking are also shown (m,n). Scale bars = 5 mm.

## 2.2. Manufacture of Profiled Decking

Six plain-sawn amabilis fir boards with a nominal size of 2'' × 6'' × 16' and an approximate actual size of 1.5'' × 5.5'' × 16' (approximately 40 × 140 × 4877 mm<sup>3</sup>), were donated by a commercial company. We specified that sample boards should be representative of those likely to be selected for conversion into a premium decking product. The boards were largely free knots, but there was large variation in their growth ring widths and densities. Boards were cross-cut using a chop-saw (Omega T55-300, OMGA Industries Inc., South Bend, IN, USA) to produce 12 samples, each 400 mm in length. Each sample was planned to a thickness of 38 mm using a European rotary planer (Martin T44, Otto Martin Maschinenbau, Ottobeuren, 87724, Germany). Samples from the first parent board were assigned at random to the different profile types, including the unprofiled control. The two relevant profile knives for the first selected profile were inserted into a 125 mm diameter, two-wing, cylindrical rotary cutter head (Great-Loc SG Positive Clamping Universal Tool System, Great Lakes Custom Tool Mfg. Inc., Peshtigo, WI, USA) with a hook angle of 15°, and secured in place. The cutter head was placed on the machine spindle of a moulding machine (Weinig Profimat 26 Super, Michael Weinig Inc., Mooresville, NC, USA), aligned and then secured in place. The decking sample was then machined using a feed speed of 13 m/min, and a spindle speed of 6000 rpm to produce the selected profile. This process was then repeated for the second assigned profile and so on until all twelve samples (including the flat control) from the first parent amabilis fir board were profiled. Then, samples from the second parent board were profiled as above, followed by samples from boards 3, 4, 5 and 6 until all 72 samples (6 boards × 12 samples) had been machined. This procedure involved significantly more work than simply machining the six samples for each profile together, however, it ensured that samples from each parent board could be treated as being independent of those machined from other parent boards (as required for statistical analysis of data). The final dimensions of the profiled boards were 400 (length) × 135 (width) × 31.75 mm<sup>3</sup> (thickness). A bench drill (Delta 161/2, Akhurst Machinery Ltd., Delta, BC, Canada) was used to pre-drill four holes (Ø = 3.97 mm) in each of the deckboard samples. Each hole was positioned 40 mm from end-grain, and 23 mm from the edge of the sample. The ends of the samples were sealed with epoxy resin (G2 Epoxy, System Three Epoxy, Auburn, WA 98001, USA) to reduce checks from developing in end-grain. Decking samples were air-dried in a conditioning room at 20 ± 1 °C and 65 ± 5% relative humidity (r.h.) for two months to ensure they were dimensionally stable, which enabled us to accurately measure the cupping of boards before outdoor exposure, and quantify the initial geometry of surface profiles. Samples were not treated with wood preservative as would occur commercially. Treatment of deckboards with aqueous wood preservative (and subsequent drying) causes boards to check [20], but differences in the checking of untreated and treated samples diminish when they are exposed outdoors to natural weathering [21]. However, we acknowledge the need for field trials that evaluate the performance of profiled amabilis fir deckboard samples treated with wood preservatives, and such trials are currently underway.

## 2.3. Characterization of Profiled Decking Boards and Outdoor Weathering

The growth rate and grain angle of each amabilis fir sample were measured using a ruler and protractor, as described previously [15,22]. The densities of separate matched wood samples were measured by water-displacement and oven-drying overnight at 105 ± 5 °C. The average growth rates, densities and grain angles of the amabilis fir samples were: Growth rate = 20 growth rings per cm (Max = 30; Min = 8; STDev = 9.4); Density = 0.38 g/cm<sup>3</sup> (Max = 0.41; Min = 0.33; STDev = 0.028; Grain angle (degrees) = 1.18 (Max = 1.5; Min = 0.3; STDev = 0.56).

Confocal profilometry, using a 3 mm probe at a gauge resolution of 0.333 nm and a spacing of 10 µm, was used to obtain numerical values for the height, width, groove radii, and peak radii of profiles in each sample, and also to create high quality images of samples after weathering [19,23]. Profiled samples and the matching flat controls cut from each of the six parent boards were screwed to separate wooden sub-frames made from pressure-treated "2 × 6" lumber to create six mini-decks. Boards were fastened at each corner to the sub-frames using 63.5 mm long galvanized decking screws

(Robertson 8 mm gauge, Home Depot, Richmond, BC, Canada). A gap of 6.35 mm was left between each of the 12 boards in each rack. Unprofiled amabilis fir boards, measuring  $400 \times 50 \times 31.75 \text{ mm}^3$ , were screwed to each end of the row of 12 boards on each rack to prevent the edges of test samples at the ends of the racks from being exposed to the weather. The weathering racks were exposed outdoors in Vancouver on UBC's Point Grey Campus (49.257,  $-123.244$ ) for six months from 20 February 2012 to 20 August 2012. The weather conditions during the exposure trial are summarized in Table 2.

**Table 2.** Weather conditions in Vancouver, British Columbia, Canada during the six-month exposure trial.

Month	Temperature ( $^{\circ}\text{C}$ )			Total Precipitation (mm)	Total Sunshine (h)
	Mean	Minimum <sup>1</sup>	Maximum <sup>1</sup>		
February	4.8	2.0 (−4.7)	7.7 (12.6)	133.6	75.8
March	5.6	2.3 (−2.8)	8.7 (14.3)	111.6	105.8
April	9.6	6.0 (1.4)	13.1 (16.8)	93.2	142.4
May	12.2	8.3 (4.9)	16.1 (23.5)	42.6	269.2
June	14.3	10.9 (7.6)	17.8 (22.0)	76.8	156.9
July	17.7	13.7 (9.4)	21.7 (26.0)	27.8	290.8
August	19.6	14.4 (11)	23.5 (28.6)	2.9	305.7

<sup>1</sup> Mean minimum and maximum temperatures (with extremes in parentheses). Data are for Vancouver International Airport (49.196,  $-123.182$ ), [http://climate.weather.gc.ca/historical\\_data/search\\_historic\\_data\\_e.html](http://climate.weather.gc.ca/historical_data/search_historic_data_e.html).

#### 2.4. Characterization of Checking and Cupping

Weathered samples were conditioned at  $20 \pm 1 \text{ }^{\circ}\text{C}$  and  $65 \pm 5\%$  r.h. for five days and the length and width of visible checks were measured using a transparent ruler and calibrated optical loupe [15]. The positions of checks within grooves and peaks and whether they crossed peaks were also recorded.

The cupping of deckboard samples, defined as deviation from flatness transversely across the face of each conditioned sample, was measured before and after weathering. Each sample was placed on a flat surface against a steel fence and planer deviations were measured in three places using a dial gauge micrometer attached to a precision-machined steel square. Cupping is expressed in mm from the center of the board to the highest point of distortion.

Specimens measuring  $25 \times 135 \times 31.75 \text{ mm}^3$  were sawn from each weathered and conditioned deckboard sample. Specimens were re-conditioned at  $20 \pm 1 \text{ }^{\circ}\text{C}$  and  $65 \pm 5\%$  r.h. for three days. The cross-cut, transverse, face of each specimen was sanded using an edge sander (Akhurst PMC-150, Akhurst Machinery Ltd., Delta, BC, Canada) and a 150 grit abrasive belt. A brown gel stain (Varathane 601 Golden Oak, Rust-Oleum Corp., Vernon Hills, IL, USA) was applied to the transverse face of each cross-cut specimen using a spatula and then wiped off with cotton cloth after 300 s. The stain penetrated small checks at the bottom of grooves, and made it easier to see them using a magnifying glass. The presence or absence of checks in the grooves of profiled specimens was noted. Photographs of the transverse faces of samples were taken at  $4\times$  magnification using a Canon EOS 7D camera equipped with a Canon MP-E 65 mm, 1 to  $5\times$  macro-lens (Canon Inc., Tokyo, Japan). Samples were located 150 mm away from the camera and illuminated with a 4.5 Watt external LED light source (Litepanels Micro™, Chatsworth, CA, USA). The camera was attached to a 454 micrometric positioning sliding plate (Lino Manfrotto Co., Cassola, Italy) on a ball joint holder (Sirui K-20X, Sirui Europe, Köln, Germany) to obtain sharply focused images of checks within the grooves of samples.

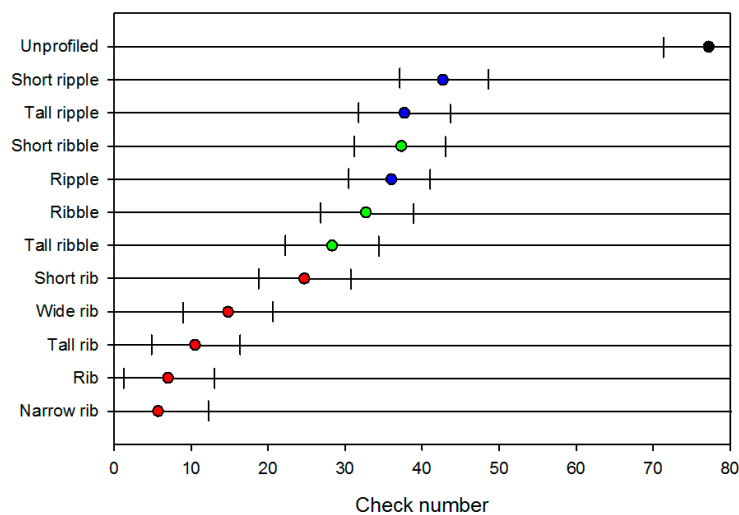
#### 2.5. Statistical Analyses

Our experiment was a randomized block design. Each of the six weathering racks contained 12 deckboard samples (profiled samples and the flat control) and represents a block. The factor of interest (profile type) was fully replicated in each block. Statistical analyses of the effect of profile type on checking and cupping used analysis of variance (ANOVA) for a randomized block design. The flat control sample was unprofiled, and therefore a sub-routine (convstrt) within the program

Genstat was used to produce contrasts between the checking and cupping of this control and all 11 profiled samples, and also between all the profiled samples. The effects of profile type on the following numerical indicators of checking and cupping were analyzed: numbers of visible checks, and average length and width of the ten largest checks in each sample; average area of the largest checks in each specimen (as for 1) that crossed a groove and a peak; cupping measured before (i) and after weathering (ii), and the difference in cupping (ii – i). Multiple linear regression was used to explore the relationships between checking and the following profile parameters: groove radius, peak radius, peak width, peak height and number of peaks/15 cm. All statistical computation including model checking was performed using Genstat (v. 17). Results are presented in graphs and error bars on each graph ( $\pm$  standard error of difference,  $p < 0.05$ , or least significant difference, LSD,  $p < 0.05$ ) can be used to estimate whether differences between individual means are statistically significant [24].

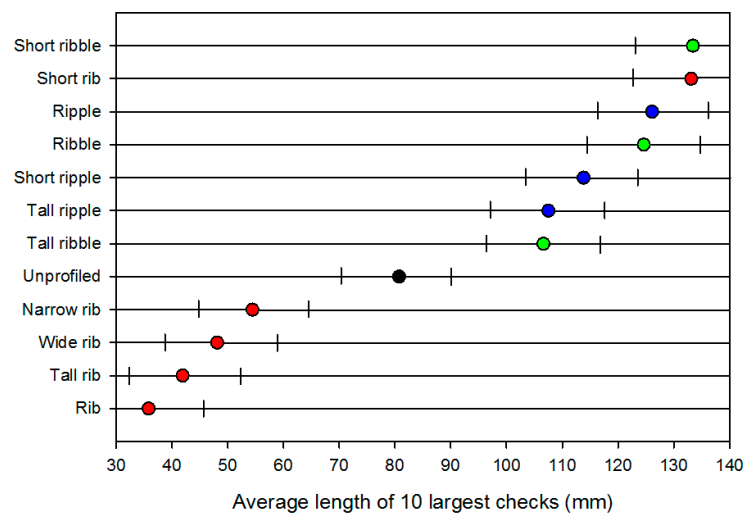
### 3. Results

Significantly fewer visible checks developed in profiled amabilis fir boards compared to the unprofiled control (Figure 3), but there were significant differences in the number of checks that developed in the different profiled boards (rib, ribble and ripple, Figure 3). All of the profiles with narrow grooves (rib profiles, with the exception of the short rib profile) were significantly ( $p < 0.05$ ) better at preventing the formation of visible checks than the profiles with wider grooves (ribble and ripple profiles) (Figure 3).



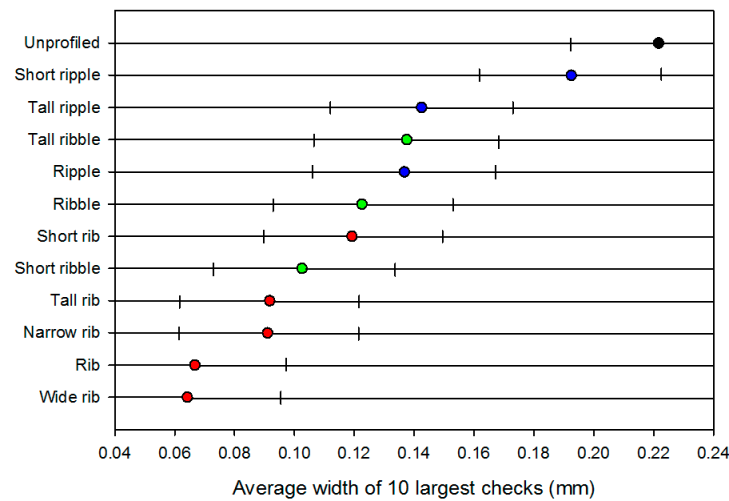
**Figure 3.** Numbers of visible checks that developed in profiled and flat (unprofiled) amabilis fir deckboard samples exposed to natural weathering. Red, green and blue symbols represent boards with rib, ribble and ripple profiles, respectively. Black symbol represents flat, unprofiled, boards.

However, profiling was not as effective at restricting checks from becoming longer (Figure 4). For example, all of the boards with wider grooves (ribble and ripple profiles) had significantly longer checks than the unprofiled control, and only boards with the rib, tall rib, wide rib and narrow rib profiles had significantly shorter checks than the unprofiled control (Figure 4).



**Figure 4.** Average length of ten largest checks that developed in profiled and flat (unprofiled) amabilis fir deckboard samples exposed to natural weathering. Red, green and blue symbols represent boards with rib, ribble and ripple profiles, respectively. Black symbol represents flat, unprofiled, boards.

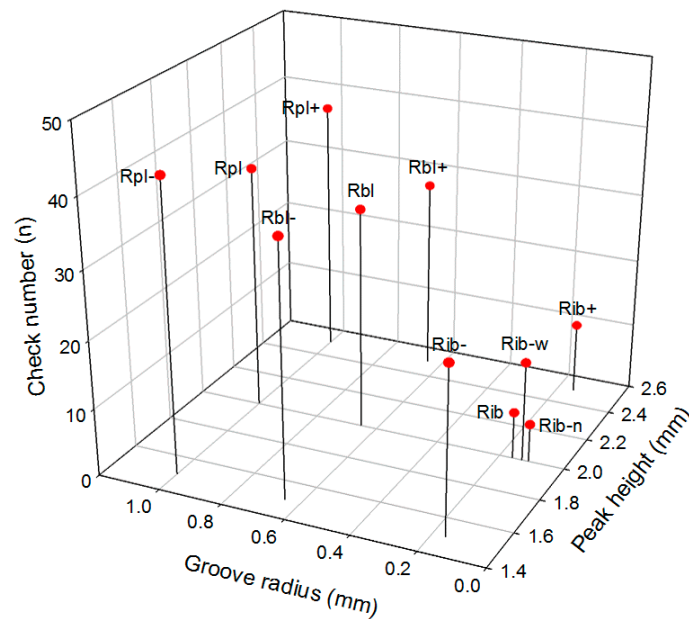
Profiling was more effective at restricting checks from becoming wider, and all of the profiled boards, with the exception of boards with a short ripple profile, had significantly narrower checks than the unprofiled control (Figure 5). The rib profiles were the most effective at restricting checks from becoming wider, and within this profile category, the rib and wide rib profiles were significantly more effective at restricting check width than the ripple profiles (Figure 5).



**Figure 5.** Average width of ten largest checks that developed in profiled and flat (unprofiled) amabilis fir deckboard samples exposed to natural weathering. Red, green and blue symbols represent boards with rib, ribble and ripple profiles, respectively. Black symbol represents flat, unprofiled, boards.

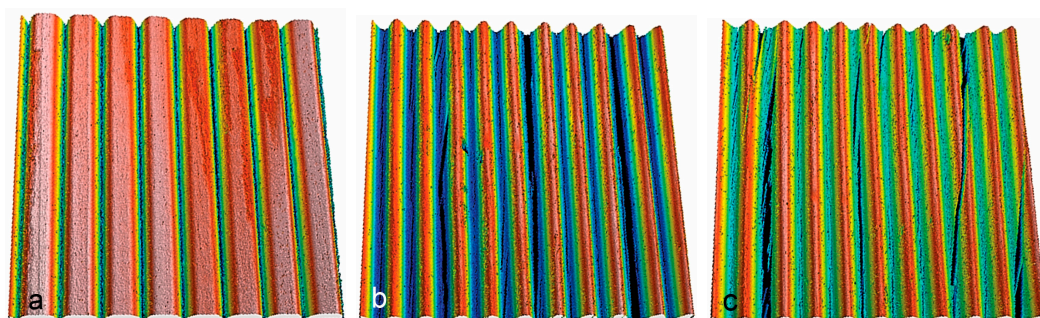
Multiple linear regression was used to test if the profile parameters, groove radius, peak radius, peak height, peak width and number of peaks/15 cm predicted the checking of profiled decking exposed to the weather. Using these parameters, a significant regression equation was found that predicted the number of checks in profiled boards ( $(F_{5,60}) = 18.79, p < 0.001$ ), with an adjusted  $R^2$  of 57.8). A regression model that only included groove radius and peak height also had significant predictive power ( $(F_{2,63}), 43.41, R^2 = 56.6$ ). The effect of groove radius and peak height on check numbers can be more easily visualized in Figure 6, which plots check number against groove radius

and peak height. This figure shows that check numbers were correlated with groove radius and negatively correlated with peak height. A significant regression equation was found using profile parameters that predicted the length of large checks in profiled boards ((F5,60) = 11.43,  $p < 0.001$ , with an adjusted  $R^2$  of 44.5). Groove radius and peak height also predicted the length of the ten largest checks formed in profiled boards ((F5,60) = 18.81,  $p < 0.001$ , with an adjusted  $R^2$  of 35.4). Groove radius was a significant ( $p = 0.047$ ) predictor of check width, but it only explained a small percentage of variance (adjusted  $R^2$  of 4.6).



**Figure 6.** Three-dimensional plot showing the effect of groove radius and peak height on the numbers of visible checks that developed in profiled amabilis fir deckboard samples exposed to natural weathering.

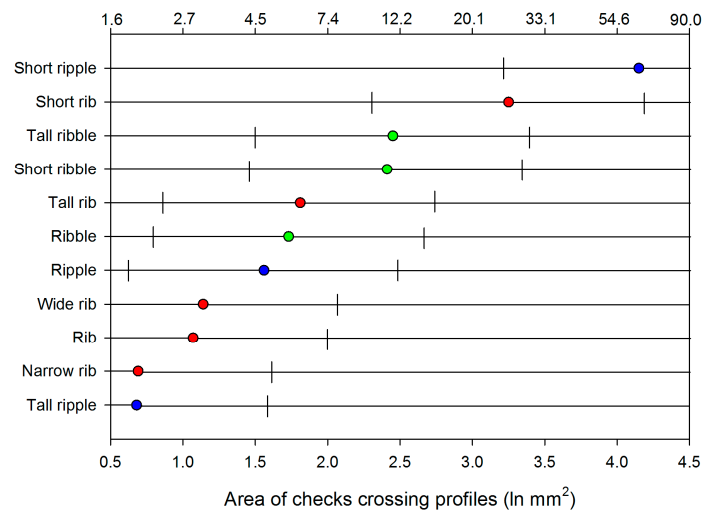
The visible checks that formed in profiled boards were mainly located within profile grooves (Figure 7a,b), but some large checks crossed over profile peaks and these cross-checks were very noticeable (Figure 7c).



**Figure 7.** Confocal profilometry images of the surface topography of profiled deckboard samples exposed to natural weathering for six months: (a) wide rib sample showing checks within grooves; (b) standard ripple profiles showing large and small checks within grooves; and (c) short ribble sample showing large and small checks within grooves and two checks that cross profile peaks (far right).

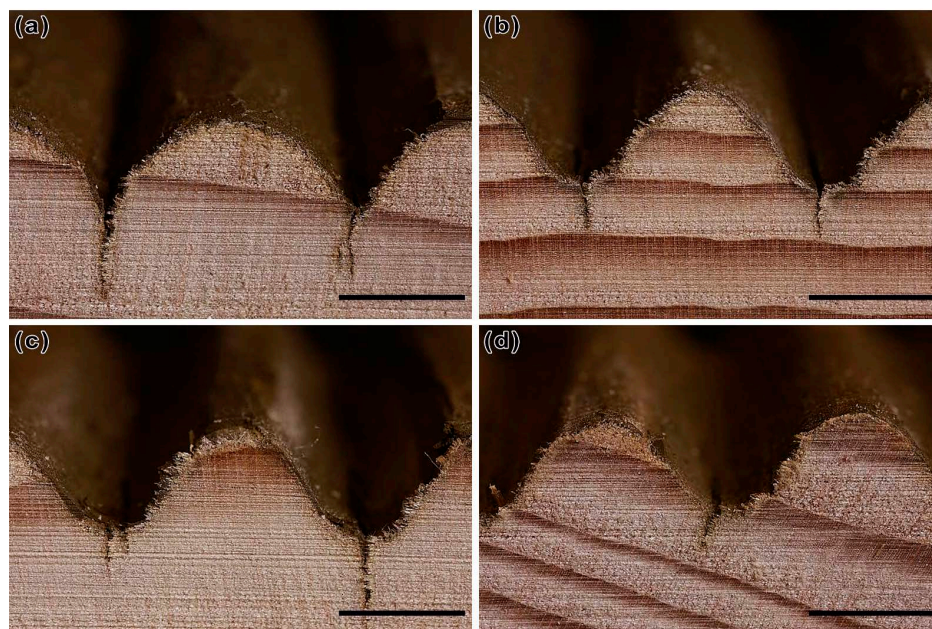
The total area of cross-checks varied between the different profiled boards (Figure 8). For example, the area of large cross-checks in boards with a short rib profile was significantly greater than that of boards with rib, wide rib and narrow rib profiles (Figure 8).





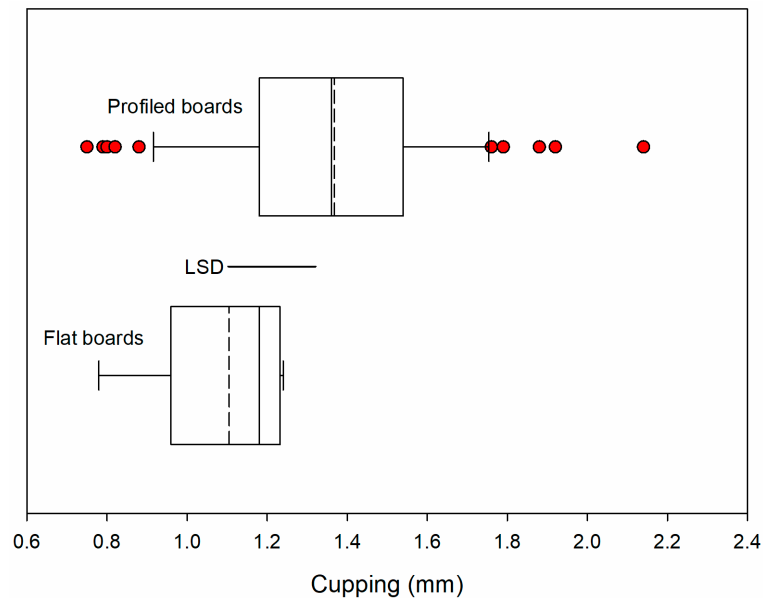
**Figure 8.** Areas of large checks in weathered profiled samples that crossed a peak. X-axis is on a logarithmic scale (natural logarithms, ln), while values on the natural scale ( $e^x$ ) are shown on the X2 axis. Red, green and blue symbols represent boards with rib, ribble and ripple profiles, respectively.

In addition to the large checks that formed in profiled boards, we also observed numerous microscopic checks (micro-checks) in the grooves of the profiled boards. These micro-checks propagated radially from the base of the grooves into the body of profiled boards, and occurred with high frequency in all of the different profiled boards (Figure 9). For example, the percentage of grooves that contained micro-checks varied from a maximum of 98.6% for boards with the rib profile to a minimum of 93.0% for boards with a tall rib profile. Differences in the percentages of grooves in the different profiled boards that contained micro-checks were not statistically significant ( $p = 0.408$ ).



**Figure 9.** Close-up of peaks and grooves in profiled samples after six months of weathering. Note the development of micro-checks at the base of grooves in each of the profiled deckboard samples: (a) standard rib; (b) standard ribble; (c) standard ripple; and (d) standard ribble. Scale bars = 1 mm.

Profiling significantly ( $p = 0.02$ ) increased the cupping of boards exposed outdoors when results are averaged across all profiled boards and compared with the cupping of flat unprofiled boards (Figure 10), but there was no significant ( $p = 0.265$ ) effect of individual profiles on cupping. Hence, the box plot in Figure 10 compares the cupping of flat unprofiled boards, with the cupping of all of the different profiled boards.



**Figure 10.** Difference in cupping of amabilis fir deckboard samples before and after they were exposed to natural weathering for six months. The error bars depict the 10th (left) and 90th percentiles (right). The solid and dotted lines within the boxes represent the median and mean, respectively. The red symbols are outliers representing profiled boards that showed low (left) or large cupping (right).

The mean cupping of boards is indicated by the dotted line within the boxes in the box plot in Figure 10, and the difference in mean cupping of profiled and flat (unprofiled) boards is statistically significant ( $p < 0.05$ ). Furthermore, cupping of some profiled boards (outliers, represented by the red symbols in Figure 10) was much higher than the mean for all profiled boards.

#### 4. Discussion

One of the main aims of this study was to develop profiles for amabilis fir decking that are better at restricting surface checking than the ones used in the past to manufacture commercial quantities of profiled amabilis fir decking [25]. Our results provide some pointers on how this desirable outcome can be achieved. Firstly, rib profiles with narrow grooves should be used in preference to ribble or ripple profiles that have wider grooves. This suggestion is also supported by the results of two previous studies [13,15]. Secondly, the peaks in rib profiles should be tall (2 mm) rather than short (1.5 mm) to more effectively restrict checks from enlarging and crossing profile peaks. The rib profile that was most effective at restricting checking was our standard rib profile (Figures 1 and 2). This profile is very similar to two profiles that are used commercially in Australia and Europe to manufacture decking from radiata pine (*Pinus radiata* D. Don) (Figure 1) and European larch (*Larix decidua* Mill.), respectively [19]. Therefore, manufacture of profiled decking using our standard rib profile would accord with commercial practice in Australia and Europe. The rib profile that was used in the past to manufacture commercial quantities of profiled amabilis fir decking is similar to our short rib profile (Figures 1 and 2). Our results showed that the short rib profile was less effective than the standard rib profile at restricting the checking of amabilis fir decking. Hence, it is likely that the standard rib profile

we tested here would be better at restricting checking than the (short) rib as well as ribble profiles used in the past to manufacture profiled decking from amabilis fir.

We have demonstrated that the effectiveness of profiling at reducing surface checking of amabilis fir decking can be improved by altering the geometry of surface profiles. Profiling is one way that manufacturers of wood decking can better meet the needs of consumers for products with better aesthetics. The need to do this has become more urgent with the emergence of wood-plastic composite (WPC) decking that is taking significant market share from wood decking, in part because it checks less than solid wood decking [4]. Despite this trend, profiling has only been tested on a handful of North American species including southern pine, blue-stained lodgepole pine (*Pinus contorta* Dougl.), subalpine fir (*Abies lasiocarpa* (Hooker) Nuttall), and white spruce (*Picea glauca* (Moench) Voss) [12–18]. Furthermore, the testing that has been carried out has used a limited number of profiles. The approach used here to identify a better profile for amabilis fir could be used to optimize profiles for the aforementioned species as well as others that have potential to be used for decking. The profiles that worked best with amabilis fir, however, may not be the ones that would be the most effective at restricting the checking of other wood species because of the interaction of profile type and wood species on checking that we observed previously with amabilis fir and southern pine [15]. Hence, further research is needed to optimize profiling for other North American species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and subalpine fir whose susceptibility to checking limits their suitability for use as decking [14,26].

Profiling increased the tendency of amabilis fir boards to cup when they were exposed outdoors. Cupping of profiled amabilis fir deckboards exposed to natural weathering was also measured by Morris and McFarling [13]. They stated that only a few of their profiled specimens cupped. Nevertheless, their data indicate that cupping of profiled deckboards (cupping = 0.36 mm) was greater than that of the flat control (cupping = 0.2 mm), in accord with our findings. Cupping of profiled amabilis fir deckboards is a problem because the raised edges of more severely cupped boards can protrude from the surface of decks, creating a tripping hazard. However, cupping of profiled deckboards made from some other species is not such a problem. For example, Akhtari and Nicholas found that profiling reduced the cupping of treated southern pine deckboards exposed to artificial accelerated weathering [17]. Profiling has been applied to western red cedar (*Thuja plicata* Donn ex D. Don) shakes [27] and flat plywood cladding [28], in addition to its more recent use with decking. Profiling reduced the negative effects of checking on the appearance of profiled plywood siding exposed outdoors, but it increased cupping, both in accord with findings here for profiled amabilis fir decking. The problem of cupping of profiled (striated) plywood was solved by increasing the thickness of the striated veneer to create a balanced panel, which equalized stresses in opposing veneers [29]. The same approach is clearly not suitable for amabilis fir decking, but it is possible that stress relief grooves or saw kerfs that are machined into the undersides of some types of deckboards might reduce the tendency of profiled boards to cup when they are exposed outdoors [30,31]. The increased tendency of profiled boards to cup and the formation of micro-checks in almost all of the grooves of profiled boards suggest that profiling fundamentally alters the moisture-induced strains that are responsible for the checking of wooden decking exposed outdoors to weathering. We have confirmed that this is the case using digital image correlation of profiled radiata pine boards exposed to artificial weathering [32]. Our findings on this topic will be the subject of another paper that is being prepared for publication.

Grooves at the surface of materials retain water [33,34], and the trapping of moisture and dirt in the grooves of profiled wooden deckboards concerned Morris and Ingram [20] who mentioned its potential to affect the durability of boards. Morris and Ingram tested this hypothesis by assigning decay ratings to unprofiled and profiled subalpine fir decking that had been exposed to the weather in Vancouver for 10 years [20]. They found that the decay ratings of untreated profiled boards were slightly lower than those of flat unprofiled boards, but they did not regard the difference as significant [20]. They found no difference in the decay rating of profiled and unprofiled subalpine fir boards treated with wood

preservatives [20]. Hence, there have been no concerns about the effect of profiling on the durability of profiled amabilis fir, which is one of the more easily treated Canadian wood species [35].

In addition to the potential effect of profiling on water trapping and durability, another concern with profiled decking is the influence of wood quality on the ability of profiling to reduce the negative effect of checking on the appearance of boards. For example, we recently came across a commercial treated deck in the hot, dry, climate of Canberra, Australia, where many of the deckboards contained numerous, large, cross-checks. This deck was made from fast-grown pine (*Pinus* spp.), and the severe cross-checking we observed may have been due to the presence of spiral grain, which encourages cross-checking [15], and is common in fast-grown, juvenile, pine wood [36]. In another deck made from fast-grown pine and exposed to the weather in the sub-tropical climate of the southern USA, we observed that profile ridges machined into low-density earlywood had separated from the underlying latewood. This defect was only present in the fastest-grown, plain-sawn, boards where the earlywood-latewood interface was close to the exposed upper profiled surface. The amabilis fir wood tested here was far slower-grown, and, although there was variability in its density, ring width and grain angle as noted above, the severe defects we have seen in pine decks were absent from our deckboards. Nevertheless, our previous study showed that grain angles greater than two degrees encouraged the formation of visible cross-checks in profiled amabilis fir decking [15]. This finding, and our anecdotal observations of defective profiled decking made from juvenile pine (*Pinus* spp.) wood (above), suggest that attention should be paid to the quality of wood used to make profiled decking, especially if the decking is to be marketed as a premium product intended to compete with deckboards made from materials such as WPCs that are less susceptible to checking than wood.

## 5. Conclusions

Our results confirm that machined profiles with narrow grooves (rib profiles) are more effective than profiles with wider grooves (ribble and ripple profiles) at restricting checking of amabilis fir deckboards exposed to natural weathering. In addition, we found that rib profiles with 2 mm high peaks were better at restricting checking than a rib profile with a shorter peak (1.5 mm high). We conclude that the geometry of machined profiles at the surface of profiled amabilis fir deckboards significantly affects the checking that develops when boards are exposed outdoors to natural weathering. Our results showed that one of the profiles we tested (standard rib profile) is significantly better at restricting checking than a profile (short rib profile) that resembled one used commercially to manufacture profiled decking from amabilis fir. Our standard rib profile is similar to ones that are used commercially in Australia and Europe. Hence, its use would accord with commercial practice, and may allow industry to develop profiles for amabilis fir deckboards that are better than those used in the past. However, profiling increased the undesirable cupping of deckboards exposed outdoors, and research is needed to solve this problem before the profiles developed here can be used commercially. The approach we used to optimize profiling for amabilis fir could be used to do the same for other North American species such as western hemlock and subalpine fir whose susceptibility to checking limits their suitability for use as decking.

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