Department of Wood Science

UNIVERSITY OF BRITISH COLUMBIA

Finishing of Thermally Modified Wood

Christopher Czapiewski

WOOD 493

A Report Submitted in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Wood Products Processing

In

The Faculty of Forestry

September 6, 2011

Acknowledgements

I would like to thank all of the people who helped me in the making of this paper. First off I would like to thank Lorne Oss and Doug Northgraves from All Natural Wood Decking inc. for taking interest and providing me with the all of the wood samples I needed for this study. Next I would like to thank my primary advisor in this study, Professor Phil Evans, for his assistance from day 1 in helping me actually get stain onto my samples, all the way to the end in helping me refine my final draft. I would like to thank my good friend Tinina Dubé for pushing me through my entire university career to deliver the best work that I could and inspiring me to love the WPP program. Lastly, I would like to give a special thanks to my parents who both supported me in their own ways in making my post secondary experience as comfortable as possible and occasionally kicking me in the ass when necessary.

Abstract

An exterior wood finish can be an effective way to reduce thermally modified wood's sensitivity to ultra violet light. But, which finish is the most resistant at preventing premature graying? How do we know that the finish will perform on thermally modified wood the same way as it does on unmodified wood? This study delves into these questions by examining the colour stability of 3 thermally modified, and unmodified, wood species coated with 6 commercially available deck stains subjected to artificial weathering for 1000 hours. A Spectrophotometer was used to measure the colour change of latewood and earlywood in finished and unfinished thermally modified and unmodified wood. Stain #4 outperformed the other 5 stains in terms of its ability to resist lightening and overall colour change of different wood samples. Douglas-fir had the greatest resistance to discolouration and maintained the most uniform colouration of its growth rings. This study also confirms previous findings that thermally modified wood is more colour stable than unmodified wood. While the modified wood samples became lighter after UV exposure, the unmodified wood became darker. The earlywood in thermally modified wood changed colour to a greater extent than latewood, and always became lighter. The latewood in thermally modified wood turned darker on the unstained samples, but turned lighter on the stained samples, and at a faster rate than the earlywood. Therefore, staining a piece of thermally modified wood creates uniformity between the colours of the latewood and earlywood. This study indicates that not all wood species or exterior finishes perform equally and that some finishes are better at resisting discolouration of thermally modified wood products. For that reason, there is merit in performing further studies to find the combination of finish type and thermally modified wood species that is the best at resisting discolouration during weathering.

Keywords: Thermally Modified Wood, Thermal Modification, ThermoWood® process, Stellac® technology, Accelerated Weathering, Artificial Weathering, Ultra Violet, Spectrophotometer, Colour Stability, Douglas-fir, Hemlock, Southern Yellow Pine, Growth Ring, Earlywood, Latewood, Stain, Finish, Solid Particle Content

Contents

1. Introduction

Thermally modified wood (TMW) is a wood product with altered physical and chemical properties created from subjecting wood to extremely high temperatures. Thermal modification increases wood's water repellency at the cost of decreasing its strength properties (Pena, Breese and Hale 2005). TMW is used outdoors because it is more durable and dimensionally stable than unmodified wood in above ground applications (Welzbacher, et al. 2009; Stingl, et al. 2007). However, TMW is sensitive to the sun's ultra-violet (UV) light. UV light has been recognized as the main contributing factor to the undesirable graying of TMW used outdoors. Welzbacher et al. (2009) classified TMW as "very durable" to "moderately durable," in outdoor applications, but the wood rapidly (6-12 months) discolours when it is exposed outdoors. An outdoor study that came out at the University of Natural Resources and Applied Life Sciences in Vienna concluded that TMW grays homogenously faster than untreated wood (Stingl, et al. 2007). Currently, the suppliers of TMW are concerned that consumers are deterred from purchasing their product because it grays when exposed outdoors. Therefore, it is important to understand how the affects of graying, or more correctly the weathering of, TMW can be delayed or prevented.

The most common means of combating the weathering of wood is through the application of UV resistant or exterior wood finishes. Many finishes can restrict the weathering of modified and unmodified wood (UMW) alike. Pavlic et al. (2007) investigated the performance of finishes on oil-heat-treated (OHT) Norway spruce and concluded that "OHT wood is a suitable substrate for finishing with existing commercial coatings." Pavlic even found that thermal modification improved many of the finishes properties such as adhesion, penetration and water resistance (Pavlic, et al. 2007). A study from the University of Ghent in Belgium also found that finishes applied to TMW were more durable than those applied to untreated wood (Nienhuis, et al. 2003). The increased performance of finishes on TMW can be attributed to the increased moisture resistance and dimensional stability of TMW (Morozovs, Akerfelds and Buksans 2007). Certain finishes claim to offer superior UV protection for wood (Cabot 2011). These claims however are rarely tested. The issue of which type of finish is most successful at preventing the graying of TMW is unresolved. Accelerated weathering tests of TMW, coated with commercially available North American semi-transparent stains, could be used to determine which finish is the best at restricting the weathering of this wood. A stain's solid particle content (SPC) is the measure of the solid material (pigment) present in the mixture. This solid material can block out damaging UV light and restrict the weathering of wood. By examining the colour change of finished samples during accelerated weathering, the effectiveness of a stain at resisting colour change can be related to its different attributes such as SPC and solvent type. Here I hypothesize that the ability of semi-transparent stains to restrict colour changes of TMW exposed to accelerated weathering will be related in part to their solid particle (pigment) contents and possibly the photo stability of the wood substrate (including latewood and earlywood).

This hypothesis was tested using samples of three species (Douglas-fir, Western Hemlock, and Southern yellow pine) both thermally modified and unmodified. The samples were coated with six commercially available semi-transparent stains (described below) and exposed to artificial UV radiation and water spray to reveal differences in surface discolouration. An accelerated weathering device was used to weather samples in a controlled and reproducible environment that yields results in a shorter period of time than outdoor weathering. This study demonstrates the finished wood's capacity to resist fading and colour change while also linking the SPC of the stains to their discolouration. This research also indicates how thermal modification influences the photodiscolouration of the different finished wood species and the influence of tissue type (LW vs. EW) on colour. By improving the colour stability of TMW with the application of UV resistant finishes we can assist the market's acceptance of this wood product as a viable building material for exterior façades.

2. Materials and Methods

2.1 Materials

2.1.1 Wood Samples & Thermal Modification

A local supplier of TMW, All Natural Wood Decking Inc., provided samples of three wood species for this experiment: Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), and Southern yellow pine (SYP) (*Pinus taeda*/*elliottii*/*echinata*). All three samples contained mostly heartwood. To obtain matched samples, boards of each species were cut into two equal pieces, with only one half subjected to thermal modification. The ThermoWood® process was used to modify the samples. This process was carried out in a Stellac® kiln. **Figure 1** shows the phases of the ThermoWood process and the temperatures the wood was subjected to. The samples, originally 2" x 6" nominal size, were planed and divided into segments of 6.35mm x 69.85mm x 158.75mm (¼" x 2 ¾" x 6 ¼"). One face per piece remained unplaned to become the surface to be finished.

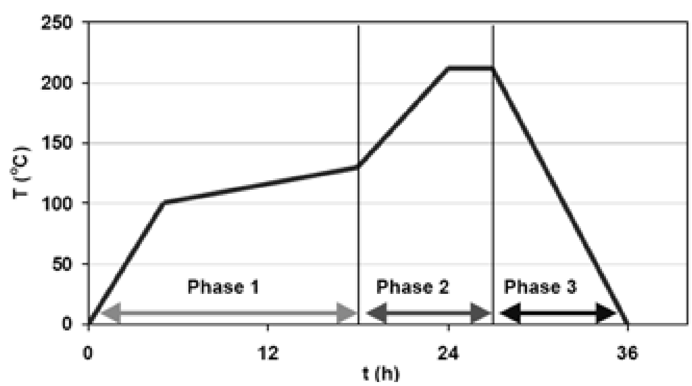


Figure 1. – The ThermoWood® process used to thermally modify wood samples. The graph shows the temperatures and timeframes used to modify wood.

2.1.2 Wood Finishes

The six wood stains used in this experiment were all chosen to be a similar medium brown cedar-like colour. The solid particle content (SPC), by weight of each stain, was measured to obtain an estimate of the amount of pigment within each stain. SPC may influence the performance of a stain because higher levels of pigments block more light from reaching wood surfaces (Holme 2005). To calculate SPC, a sample of each stain was dispensed into a separate aluminum dish and weighed. The dishes were placed into an oven at 100°C for eight hours to allow the solvents from each stain to evaporate. The dishes were then re-weighed and the SPCs of the stains were calculated using **Eqn. 1** (Evans 2010). The properties of each stain are shown in **Table 1**.

$$SPC\ (\%) = (\text{mass of dried stain} / \text{mass of wet stain}) \times 100\% \qquad (1)$$

Table 1. – The six commercial stains used in this experiment, and their properties.

Stain	Stain Type	Colour	Solvent Type	Warranty Claim	Approx. Price of 1 Gallon Can
#1	Penetrating / Film forming	Cedartone No. 3-533	Water	3 yr Deck / 5 yr Fence	$35
#2	Penetrating / Film forming	Cedar Naturaltone 716	Mineral Spirits and Linseed Oil	3 yr Deck / 5 yr Fence	$35
#3	Penetrating / Film forming	Cedartone 101	Mineral Spirits	n/a	$30
#4	Penetrating / Film forming	3854 Coco Shell	Water	4 year	$40
#5	Penetrating / Non-film forming	216 Natural Cedar	Heat Bodied Linseed Oil	n/a	$45
#6	Penetrating / Non-film forming	MC-502 Natural cedar	linseed Oils and Alkyds	n/a	$40

2.2 Procedures and Analysis

2.2.1 Sample Preparation

The order in which finishes were applied to the samples was randomized. Jämsä et al. (2000) concluded that thermal modification does not negatively affect the performance of wood coatings and that no changes in the method of application are needed. Each coating was therefore applied according to the manufacturer's directions. The stains #1, #2, #4, and #5 were all applied in a single coating with a bristle brush. Stain #3 required two coatings, and stain #6 required that excess stain be wiped off before drying. Six control samples were also included in the experiment, one for each wood species, both thermally modified and unmodified. A square box was etched onto the surface of each of the 42 samples with a razor blade to provide a reference point for colour measurement. These boxed areas included both earlywood (EW) and latewood (LW). In a few instances where the separation between growth rings was very small, a random reference point was assigned to the sample. Assigning only a single reference point for the colour readings of each sample was deemed acceptable as Stingl (2007) concluded that TMW grays very homogeneously, with a low standard deviation between measuring points.

Figure 2. – The 36 unmodified and thermally modified samples of 3 wood species, just after they were coated with the six different semi-transparent stains

2.2.2 Accelerated Weathering

The samples were weathered using a Q.U.V. accelerated weathering device according to the schedule in Table 2.

Table 2. – Q.U.V. parameters for the weathering cycle used to artificially grey the 42 samples

Temperature (during U.V.)	Irradiance	Intervals		Cycle Time	Number of Cycles
		U.V. Exposure	Water Spray		
60° C	0.68 W/m^2/nm	5 hours	1 hour	200 hours	5

The samples were exposed to a total of 1000 hours of accelerated weathering in the Q.U.V. They were removed for colour measurement every 200 hours.

2.2.3 Colour Measurement

The colour of the samples before weathering, and after each 200 hour period, was measured using a Minolta Spectrophotometer (CM-2600d) and expressed using the CIE-Lab colour space coordinate system L*, a*, and b* (lightness, red-green-axis, and yellow-blue axis) as performed by Stingl (2007). The L*, a*, and b* variables were converted into a ratio of their value after weathering over their initial (unweathered) value to show their percent change over time (L*Ratio, a*Ratio, b*Ratio). The samples' overall colour change (ΔE*) was also calculated from the L*, a*, and b* values for each time interval (**Eqn. 2**). This method of colour measurement and calculation of TMW accords with those used by Stingl's (2007) and Grzeskiwicz' (2009) weathering test of TMW. However, unlike these previous studies, this study took separate colour measurements of EW and LW for each sample to identify colour variation in annual growth rings. In the few cases where the annual rings were too narrow to distinguish EW and LW with the spectrophotometer lens, a single measurement was taken as an average for EW and LW.

$$\Delta E^* = \sqrt{((L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \qquad (2)$$

ΔE*... overall colour change   L ... lightness   a...red-green   b...yellow-blue
1...initial value   2 ... value at current time interval

The samples were also scanned with a high definition computer scanner for qualitative analysis of colour changes. Scanned images are obtained under consistent lighting conditions and with a high level of detail (1.4 Megapixel resolution). The 42 samples were scanned before the weathering process and after 1000 hours exposure in the Q.U.V. device.

3. Results and Discussion

3.1 Stain Comparison

3.1.1 Solid Particle Content

The SPC of the stains ranged in their values. **Figure 3** shows the SPCs of the six selected stains. Stain #1 had the lowest SPC of the stains (17.9%), while #6 resulted in the more than half of its liquid weight being solid particles (54.1%) (**Fig. 3**). The other four stains had similar SPCs to each other (±5%).

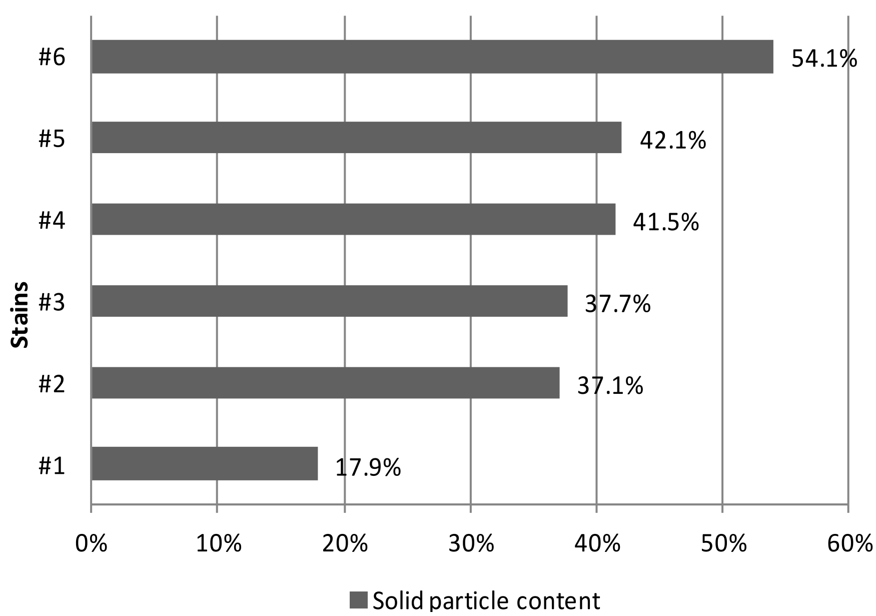
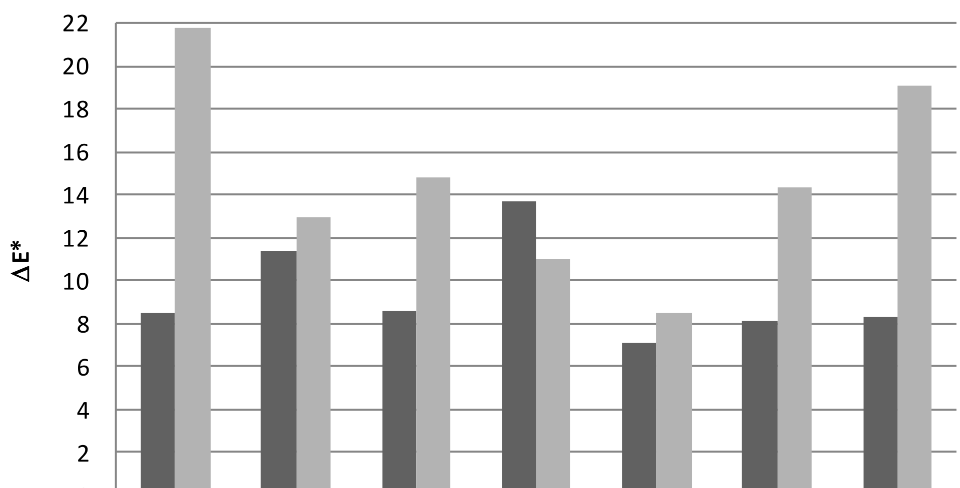


Figure 3. – Solid particle content of the six semi-transparent stains that were selected.

3.1.2 Changes in Colour

The stains varied in their ability to restrict colour change of TMW and UMW samples exposed to accelerated weathering. **Figure 4** shows the overall colour change (ΔE*) for the stained and unstained samples after 1000 hours of weathering. These numbers are the average taken from three sampled species and their LW and EW. Stain #4 showed the smallest colour change for both the TMW and UMW samples (**Fig. 4**). The colour change of stain #4 on TMW (ΔE*= 7.1) was 20% less than unfinished controls. In contrast, colour changes of samples finished with stains #2 (ΔE*= 8.5), #5 (ΔE*= 8.1), and #6 (ΔE*= 8.3), were very close to the control group (ΔE*= 8.5) (**Fig. 4**). The TMW samples coated with stains #1 (ΔE*= 11.3) and #3 (ΔE*= 13.7) showed greater colour changes than the unfinished weathered controls (ΔE*= 8.5) (**Fig. 4**). However, these stains showed smaller colour changes on the UM samples than the unstained controls and samples finished with the other stains, except for #4 (**Fig. 4**).

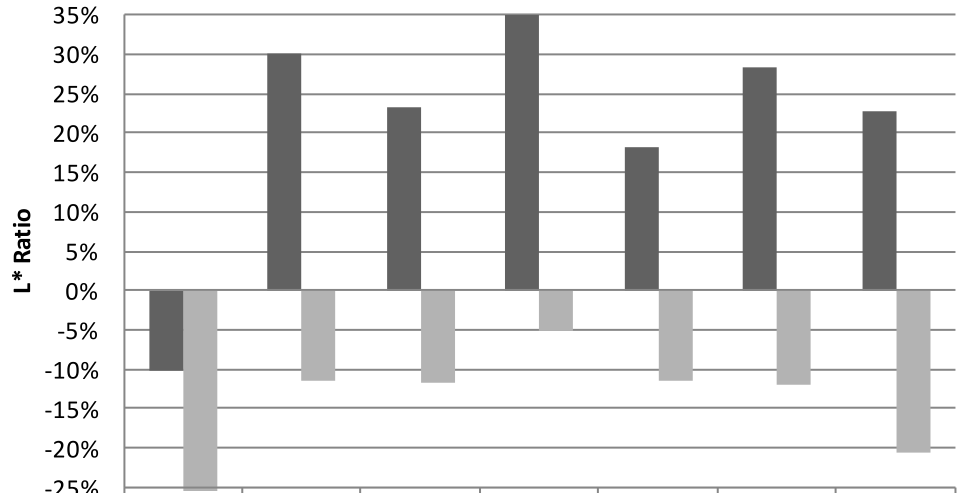


	CONT	#1	#2	#3	#4	#5	#6
TMW	8.5	11.3	8.5	13.7	7.1	8.1	8.3
UMW	21.8	12.9	14.8	11.0	8.5	14.3	19.1

Figure 4. – Overall colour change (ΔE*) of thermally modified wood (TMW) and unmodified Wood (UMW) samples, coated with 6 different wood stains, after 1000 hours of artificial weathering. Values are averaged across the 3 different wood species (Douglas-fir, Hemlock, and Southern Yellow Pine), as well as earlywood (EW) and latewood (LW) tissues. CONT = Control sample without stain.

There was a correlation between a stain's SPC and the extent of colour change of the finished samples. Stains #4, #5, and #6 had the highest SPCs (**Fig. 3**), and also had the lowest colour change on TMW (**Fig. 4**). Conversely, stain #1 had the lowest SPC (17.9%), and TMW samples finished with this stain had the second highest level of colour change (**Fig. 4**). However, the SPC of a stain is not a precise predictor of its ability to restrict colour changes of finished wood samples exposed to accelerated weathering, for example, stain #3 had a relatively high SPC (37.7%), but TMW samples finished with it showed the greatest colour change (**Fig. 4**). This finding suggests that other factors influence the colour change of stained samples exposed to accelerated weathering. The three stains most resistant to colour change each contained different solvents (**Table 1 and Fig. 4**). Furthermore, both the most and second least colour resistant stains, #4 and #1, were water based (**Table 1**). These observations suggest that there is not a good relationship between solvent type and colour stability of stains exposed to accelerated weathering.

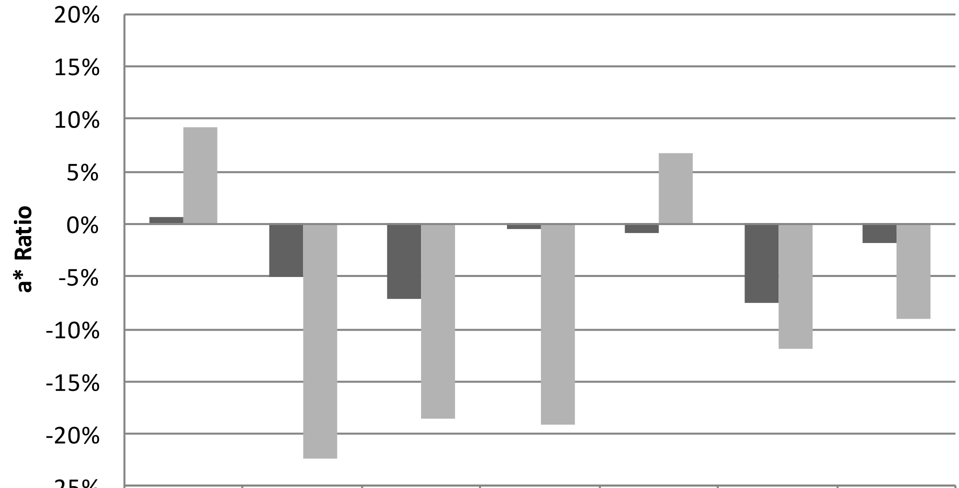
The change in a wood sample's lightness plays a significant part in our perception of colour change and graying. **Figure 5** shows the percent change in lightness (L* Ratio) for the stained and unstained samples after 1000 hours of accelerated weathering. Positive values indicate that samples became lighter, whereas negative values indicate that samples became darker. All of the stained TMW samples became lighter during weathering, while all of the UMW samples became darker (**Fig. 5**). The unfinished TMW controls also became darker during weathering (this observation is explained in the discussion below) (**Fig. 5**). Stain #4 on TMW displayed the least amount of lightening (+18%), while stain #3 displayed the most lightening (+35%) (**Fig. 5**).



	CONT	#1	#2	#3	#4	#5	#6
TMW	-10%	30%	23%	35%	18%	28%	23%
UMW	-26%	-12%	-12%	-5%	-12%	-12%	-20%

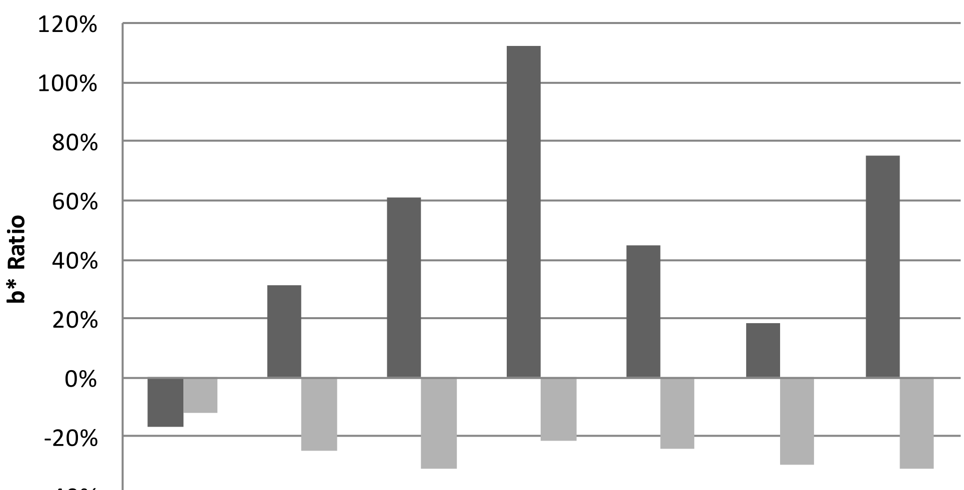
Figure 5. – Percent change of lightness (L*Ratio) of thermally modified wood (TMW) and unmodified wood (UMW) samples, coated with 6 different wood stains, after 1000 hours of artificial weathering. Positive values indicate that samples became lighter. Negative values indicate that samples became darker.

Change in the colour coordinates a* and b* also influence the total colour change of samples exposed to weathering. **Figures 6 and 7** show percent changes in a* and b* coordinates (a*Ratio and b*Ratio) of stained and unstained samples, after 1000 hours of weathering. Positive or negative changes in a*Ratio represent the sample becoming redder or greener, respectively. Positive and negative values for b*Ratio indicate that the samples became yellower and bluer, respectively. Changes in the a* parameter for TMW samples were minimal, with stains #4 (-1%), #6 (-2%), and #3 (~0%) showing the smallest changes (**Fig. 6**). All of the stained TMW samples became yellower (+b*), while all of the stained UMW samples became bluer (-b*). Stain #5 on TMW yellowed the least (+19%), while samples coated with #3 showed the most yellowing (+113%) (**Fig. 7**).



	CONT	#1	#2	#3	#4	#5	#6
TMW	1%	-5%	-7%	0%	-1%	-8%	-2%
UMW	9%	-22%	-19%	-19%	7%	-12%	-9%

Figure 6. – Percent change of the colour coordinate a*(red - green axis) for thermally modified wood (TMW) and unmodified wood (UMW) samples, coated with the six different wood stains, after 1000 hours of artificial weathering. Positive values indicate that the samples became redder. Negative values indicate that samples became greener.



	CONT	#1	#2	#3	#4	#5	#6
TMW	-17%	31%	61%	113%	45%	19%	75%
UMW	-12%	-25%	-31%	-21%	-24%	-29%	-31%

Figure 7. – Percent change of colour coordinate b*(yellow - blue axis) for thermally modified wood (TMW) and unmodified wood (UMW) samples, coated with the six different wood stains, after 1000 hours of artificial weathering. Positive values indicate that the samples became yellower. Negative values indicate that the samples became bluer.

Overall, the colour measurements indicate that stain #4 retained its original colour better than the other finishes. This is supported by scanned images of all the samples after weathering which show that samples finished with stain #4 faded the least **(Fig. 8)**.

Figure 8. – Scanned images of the samples of Douglas-fir, Hemlock, and Southern yellow pine (respectively) finished with stain #4, after 1000 hours of accelerated weathering.

My findings for total colour change of TMW accord with those of Gonzalez-Pena (2009). He stated that ΔE^* of TMW is highly influenced by ΔL^*. However, my findings only partially agree with those of Schnabel, et al. (2009), who observed that the colour of TMW after accelerated weathering shifted to a reddish yellow colour, whereas the samples here shifted to a greenish yellow colour after weathering.

It is worth mentioning that colour changes of samples finished with stain #3 were unexpected. This finish had a relatively high SPC and was the only stain that required 2 coats, but it showed the greatest colour changes during accelerated weathering **(Fig. 9)**.

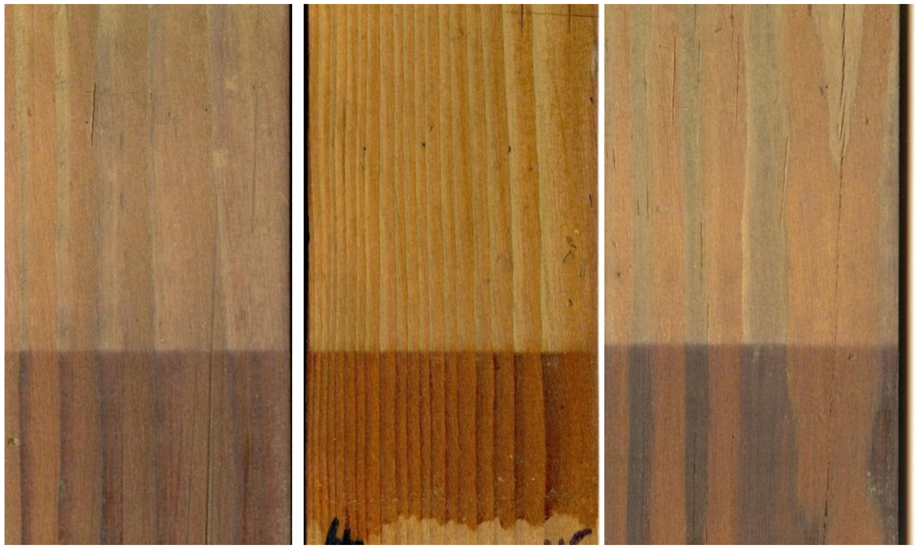


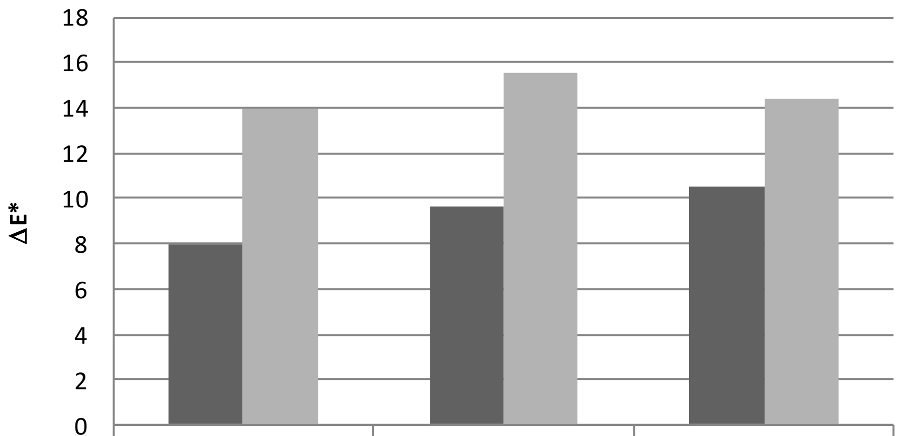
Figure 9. – Scanned images of the samples of Douglas-fir, Hemlock, and Southern yellow pine (respectively) finished with the stain #3, after 1000 hours of accelerated weathering.

This is the first study that has compared the effectiveness of a range of semi-transparent stains on thermally modified North American wood species. My results are of practical significance because it is now possible to recommend a smaller range of finishes that would be suitable for further testing. This study also suggests further lines of research, for example, why stain #4 performs so well and what qualities of this stain relate to its effectiveness at resisting discolouration during weathering?

3.2 Wood Comparison

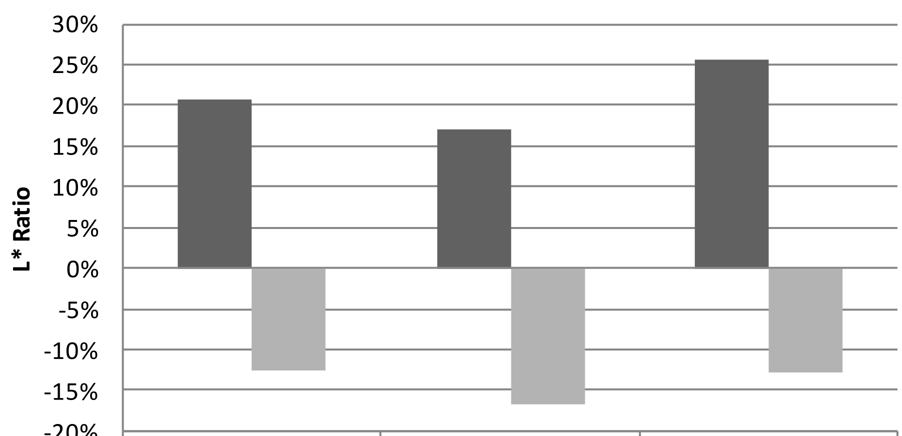
3.2.1 Difference in Species and Modification

This study shows that resistance to artificial weathering can be affected by wood species as well as by thermal treatment. **Figure 10** shows the overall colour change (ΔE^*) of the three different species, both finished and unfinished, after 1000 hours of weathering. The colour change for thermally modified, finished and unfinished, Douglas-fir (ΔE^*= 7.9) was 33% less than that of SYP (ΔE^*= 10.5), and 23% less than that of hemlock (ΔE^*= 9.7) (**Fig. 10**). All three species show that when modified they are substantially more resistant to colour change (**Fig. 10**). **Figure 11** shows the percent change in lightness (L^* Ratio) of the three species after 1000 hours of weathering. Irrespective of species, TMW becomes lighter (+L* Ratio) during weathering while UMW becomes darker (-L* Ratio)(**Fig. 11 and 12)**. SYP displayed the greatest degree of lightening (+26%)(**Fig. 11**). TMW was lighter after 1000 hours of artificial weathering, but the unstained controls changed more quickly and began to darken after 200 hours exposure before becoming lighter (**Appendix III**).



	Douglas-fir	Hemlock	SYP
TMW	7.9	9.7	10.5
UMW	14.0	15.5	14.4

Figure 10. – Overall colour change (ΔE*) of thermally modified wood (TMW) and unmodified wood (UMW) samples after 1000 hours of artificial weathering. Values are averaged between the 6 wood stains and control sample, as well as earlywood (EW) and latewood (LW) tissues.



	Douglas-fir	Hemlock	SYP
TMW	21%	17%	26%
UMW	-13%	-17%	-13%

Figure 11. – Percent change of lightness (L*Ratio) of thermally modified wood (TMW) and unmodified wood (UMW) samples after 1000 hours of artificial weathering. Positive values indicate that samples became lighter. Negative values indicate that samples became darker. Source values are averaged as described in Figure 10.

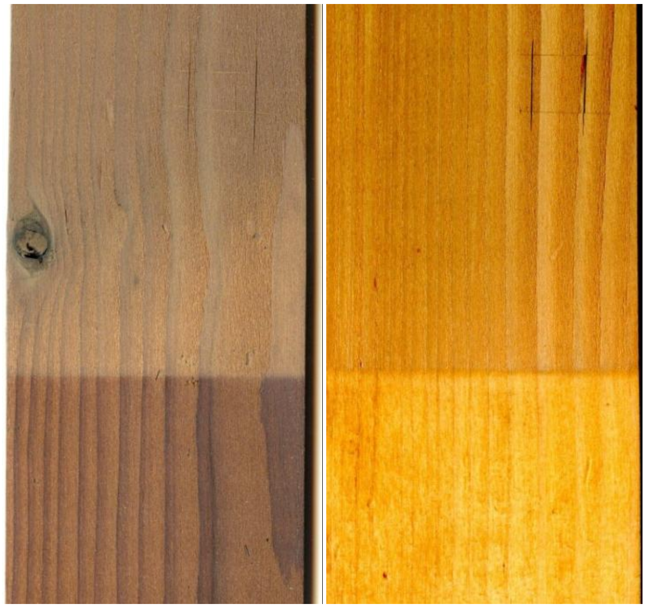


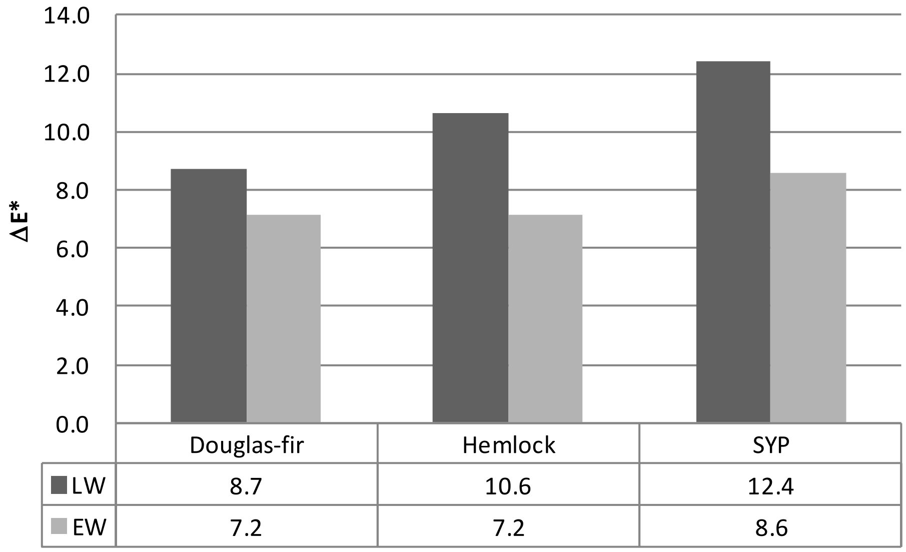
Figure 12. – Scanned images of the samples of hemlock finished with stain #2, after 1000 hours of accelerated weathering. These images represent the lightening of thermally modified wood (TMW), and the darkening of unmodified wood (UMW), after weathering.

In the introduction I suggested that the colour stability of finished samples may be influenced by the photostability of the different wood species. Douglas-fir was the most resistant species to colour change. However, all of the three species were more resistant to colour change when they were thermally modified. This finding is in agreement with previous studies that state that the colour stability of TMW exposed to artificial UV radiation is greater than UMW (Ayadi et al. 2003, Grzeskiewicz and Maminski 2009). The initial darkening of the unfinished TMW control samples is also supported by Schnabel et al. (2009), who reported that L* values for thermally modified beech decreased during the first 83 hours of artificial weathering and then steadily increased. Initial darkening of stained samples may have gone unnoticed here because there were quite long (200 hours) time intervals between colour measurements, unlike Schnabel's study. TMW is reported to be more colour stable than UMW when exposed to light indoors (Ayadi et al. 2003, Grzeskiewicz and Maminski 2009). However, TMW often performs poorly in outdoor weathering trials (Jämsä et al. 2000, Alfredsen and Westin 2009). Therefore, further research is needed to examine if the performance of TMW during artificial weathering is a good indicator of its real world performance.

3.2.2 Difference in Growth Rings

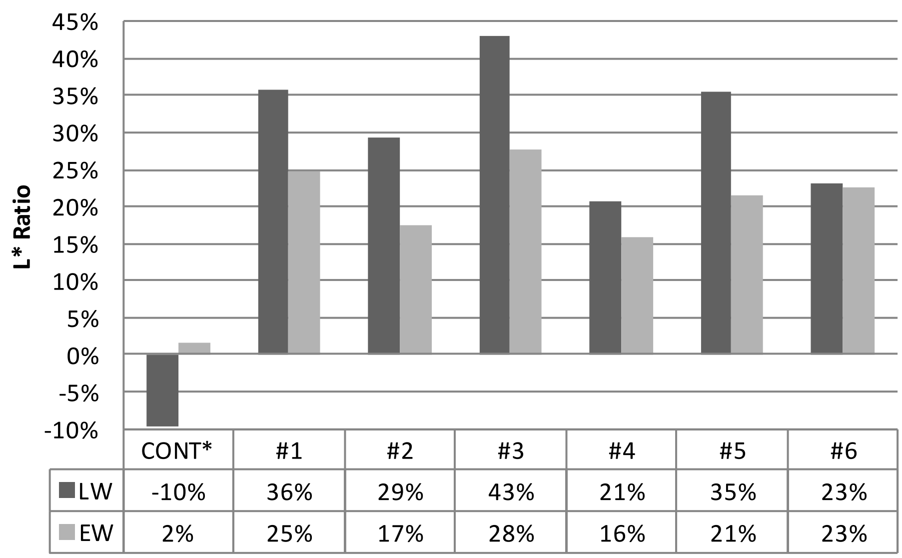
Earlywood and latewood tissues in annual growth rings of TMW weather at different rates. **Figure 13** shows the colour change (ΔE*) of the LW and EW for the TMW samples (both finished and unfinished) for each species. In all three species, the LW changed colour more than EW (**Fig. 13**). The EW in Douglas-fir and hemlock had the lowest colour change (ΔE*= 7.2). Overall, however, Douglas-fir's LW showed the lowest colour change (ΔE*= 8.7) (**Fig. 13**). The greatest colour changes in both LW (ΔE*= 12.4) and EW (ΔE*= 8.6), were observed in SYP. This species also showed the greatest difference between the colour of EW and LW (**Fig. 13**). The images in **Appendix I** and graphs in **Appendix III**, both show that SYP had the greatest contrast in the colour of LW and EW after weathering. The contrast in colour of LW and EW in Douglas-fir and hemlock was not as pronounced as that observed in SYP. **Figure 14** shows the change in lightness (L*Ratio) in LW and EW of the TMW samples for the unfinished control group and the six stained samples. For all of the stained samples, the LW and EW both became lighter. On the other hand, LW darkens while the EW lightens in the unfinished exposed control (**Fig. 14**).

This enhancement of the colour contrast of LW and EW in unstained wood explains why the control samples in **Figure** 5 are the only ones where the TMW samples have a negative L*Ratio, showing overall darkening. The values for L*Ratio in **Figure 5** are averages for the two tissue types. However, in these samples there was a greater proportion of EW, which explains why their surfaces appeared grayer after weathering (**Appendix I**).



	Douglas-fir	Hemlock	SYP
LW	8.7	10.6	12.4
EW	7.2	7.2	8.6

Figure 13. – Overall colour change (ΔE*) of latewood (LW) and earlywood (EW) in thermally modified wood (TMW) samples after 1000 hours of artificial weathering. Values are averaged across the stained wood samples and control sample. *Average between the 6 wood stains only; The LW and EW on the control sample were too close to differentiate.



	CONT*	#1	#2	#3	#4	#5	#6
LW	-10%	36%	29%	43%	21%	35%	23%
EW	2%	25%	17%	28%	16%	21%	23%

Figure 14. – Percent change of lightness (L*Ratio) of the thermally modified wood (TMW) samples after 1000 hours of artificial weathering. Values are separated into latewood (LW) and earlywood (EW) and are averaged across the 3 different wood species. *Average between Douglas-fir and SYP only; The LW and EW in Hemlock were too close to differentiate.

It is interesting to understand how growth rings in TMW influence the colour of different wood species after finishing and weathering. Douglas-fir is the species that displays the smallest colour change between growth rings, while SYP displays the most change. This is significant to manufacturers of TMW because consumers may prefer either more uniform or distinctive looking grain patterns. The LW in TMW naturally darkens; however, when a stain is applied the LW fades faster than the EW and allows the colour of the piece to become more uniform over time. Hence, when a stain is applied to TMW colour differences due to weathering are reduced in comparison to unmodified wood **(Figure 12)**. This is a novel finding and opens up further research on the influence of wood tissue types on the colour changes of finished TMW during weathering.

4. Conclusions

This study has provided new insights into the types of stains that restrict the discolouration of TMW exposed to artificial accelerated weathering. Of the six commercially available stains tested in this study, stain #4 outperformed the other stains in terms of its ability to resist lightening and overall colour change on TMW. The SPC of a stain is only a moderate indicator of its resistance to fading during weathering. The colour stability of TMW is greater than UMW during weathering. Wood species and tissue type (latewood vs. earlywood) also influenced the discolouration of finished TMW during weathering. Douglas-fir had the greatest resistance to discolouration and maintained the most uniform colouration within growth rings. EW changes colour to a greater extent than LW, and always becomes lighter. Conversely, LW changes colour less than EW, and becomes darker, unless coated with a stain in which case it becomes lighter. Further research needs to be done to discover why the LW in TMW responds in this way, and to discover better UV resistant stains and other suitable wood species for modification. The results of this study suggest that the best combination of stain and wood species for TMW is stain #4 coated on Douglas-fir. Furthering our understanding of TMW and its weatherability will encourage the development of a better quality product and increase its competitiveness as an exterior façade material.

5. References

Alfredsen, G. and M. Westin. "Durability of Modified Wood - Laboratory vs Field Performance." *The Fourth European Conference on Wood Modification.* Stockholm, Sweden, 2009. 515-522.

Ayadi, N., F. Lejeune, F. Charrier, B. Charrier, and A. Merlin. "Colour stability of heat-treated wood during artificial weathering." *Holz als Roh-und Werkstoff* 61, no. 3 (2003): 221-226.

Cabot. *Staining Products, SPF Deck and Fence.* 2011. http://www.cabotstain.com/products/product/SPF-Deck-and-Fence.html (accessed September 22, 2011).

Evans, P. D. "Solid Particle Content." *Finishing Test Instructions.* Vancouver, 2010.

Gonzalez-Pena, M. M., and M. Hale. "Color Change in Thermally-modified Wood and its Relationship with Property Changes." *The Fourth European Conference on Wood Modification.* Stockholm, Sweden, 2009. 181-185.

Grzeskiewicz, M. and M. Maminski. "Thermally Modified Wood Protection Against UV Radiation and Water." *The Fourth European Conference on Wood Modification.* Stockholm, Sweden, 2009. 461-464.

Holme, I. "Advances in the science and technology of paints, inks and related coatings: 2005." *SURFACE COATINGS INTERNATIONAL PART B-COATINGS TRANSACTIONS*, December 2005: 285-299.

Jämsä, S., Ahola P., and P. Viitaniemi. "Long-term natural weathering of coated ThermoWood." *Pigment & Resin Tech.* 29 (2000): 68-74.

Morozovs, A., Akerfelds I., and Edgars Buksans. "Influence of Wood Modification on Fire Resistance and Hydrophobic Properties." *The Third European Conference on Wood Modification.* Cardiff: BC Bangor, UK, 2007. 153-156.

Nienhuis, JG, Van De Velde B., Cobben WNH, and EPJ Beckers. "Exterior Durability of Coatings on Modified Wood." *The First European Conference On Wood Modification.* Ghent: Ghent University, 2003. 203-206.

Pavlic, M., Rapp A. O., and M. Petric. "Performance of Coated Oil-heat-treated Wood Systems before and after Artificially Accelerated Weathering." *The Third European Conference on Wood Modification.* Cardiff: BC Bangor, UK, 2007. 201-204.

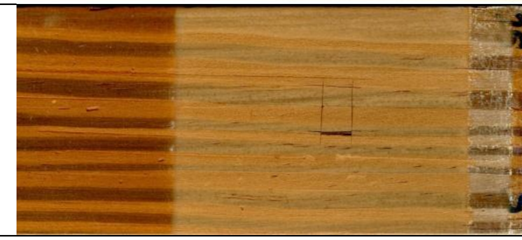
Pena, M. G., Breese M. C., and M. Hale. *Changes in Selected Properties of Heat-Treated Wood: A Study of the Mechanisms.* Bangor: University of Wales Bangor, UK, 2005.

Schnabel, T., Zimmer B., Bachle H., and A. Petutschnigg. "On the Modelling of Colour Changes of Thermally Treated Hardwoods during Artificial Weathering." *The Fourth European Conference on Wood Modification.* Stockholm, Sweden, 2009. 191-194.

Stingl, R., Smutny R., Treberspurg M., and A. Teischinger. "Sustainable Use of Heat Treated Wood as a Facade Material - Preliminary Results of Weathering Tests." *The Third European Conference on Wood Modification.* Cardiff: BC Bangor, UK, 2007. 195-199.

Welzbacher, C.R., Brischke C., Rapp A. O., Koch S., and S. Hofer. "Performance of thermally modified timber (TMT) in outdoor application - durability, abrasion and optical appearance." *Drvna Industrija* 60, no. 2 (2009): 75-82.

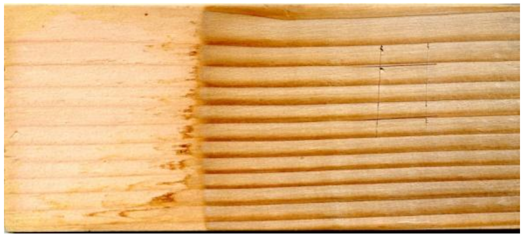
Appendix I – Scans of Thermally Modified Samples after Weathering

Stain	Douglas-fir	Hemlock	Southern Yellow Pine
Controls			
#1			
#2			
#3			

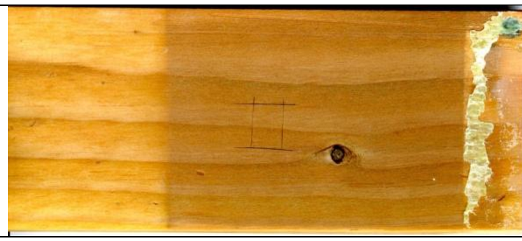
Appendix I – Continued

	Douglas-fir	Hemlock	Southern Yellow Pine
#4			
#5			
#6			

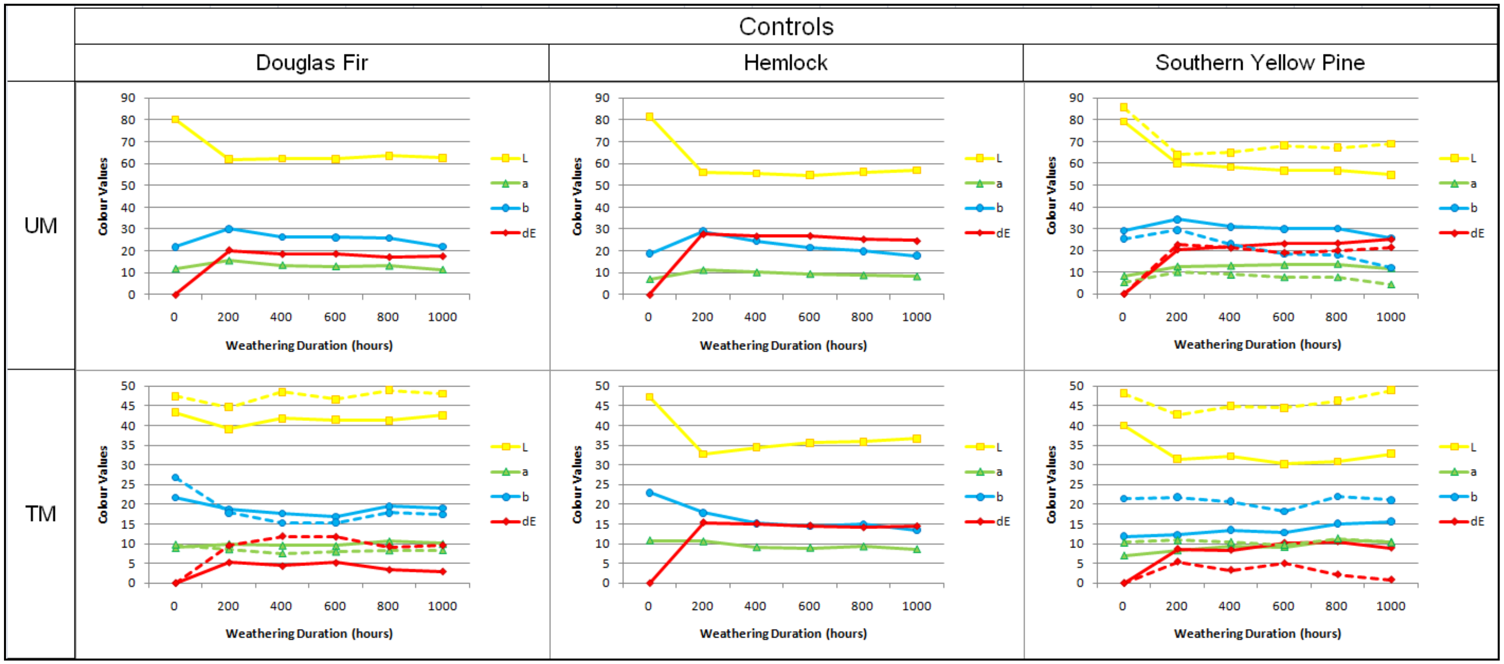
Appendix II – Scans of Unmodified Samples after Weathering

Stain	Douglas-fir	Hemlock	Southern Yellow Pine
Controls			
#1			
#2			
#3			

Appendix II – Continued

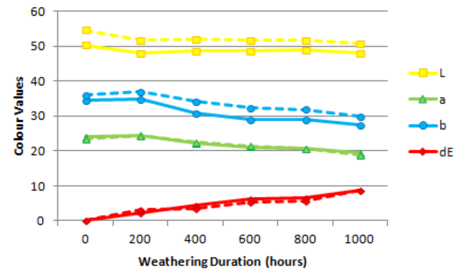
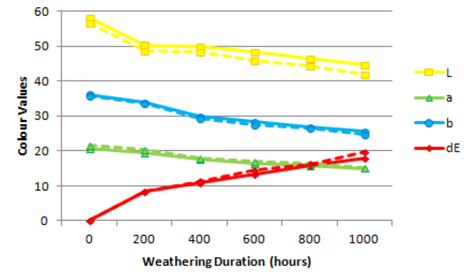
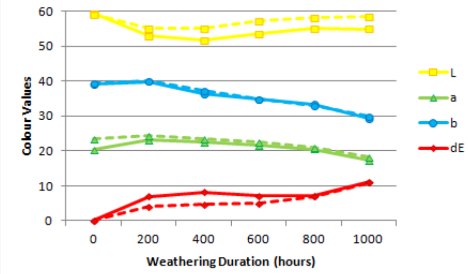
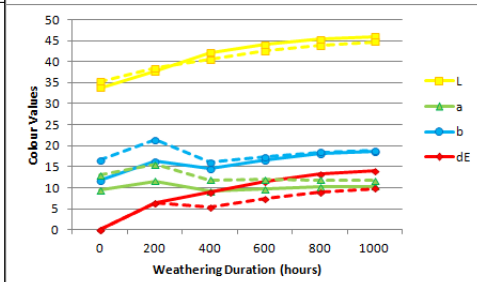
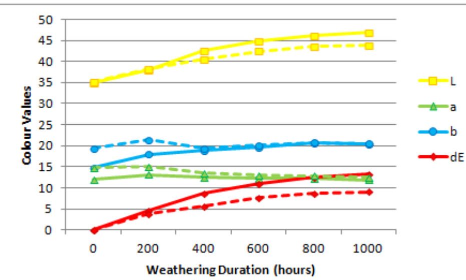
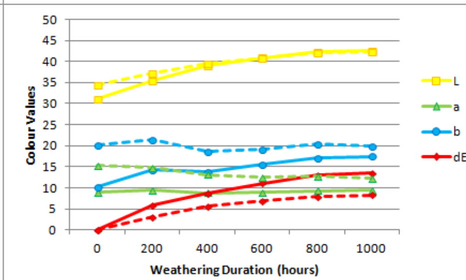
	Douglas-fir	Hemlock	Southern Yellow Pine
#4			
#5			
#6			

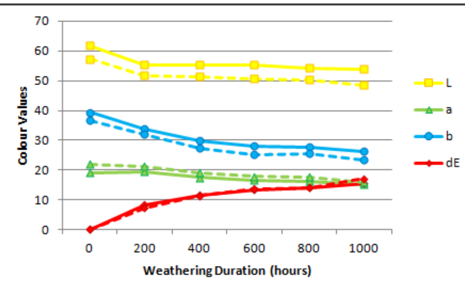
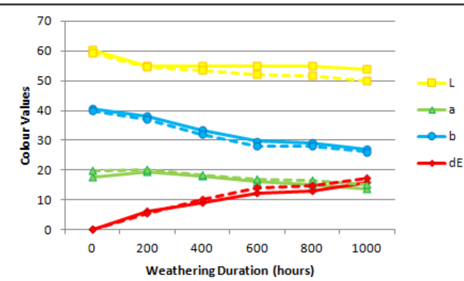
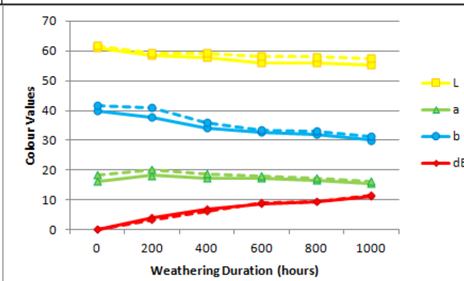
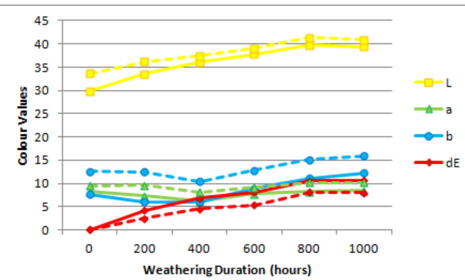
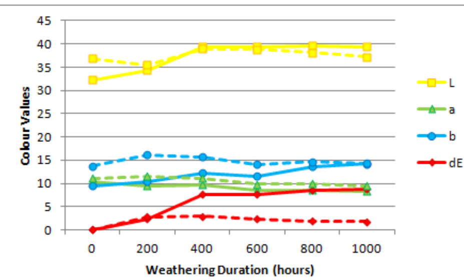
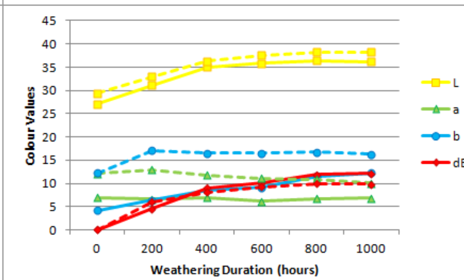
Appendix III – Graphical Representation of Colour Change over 1000 hrs of Artificial Weathering



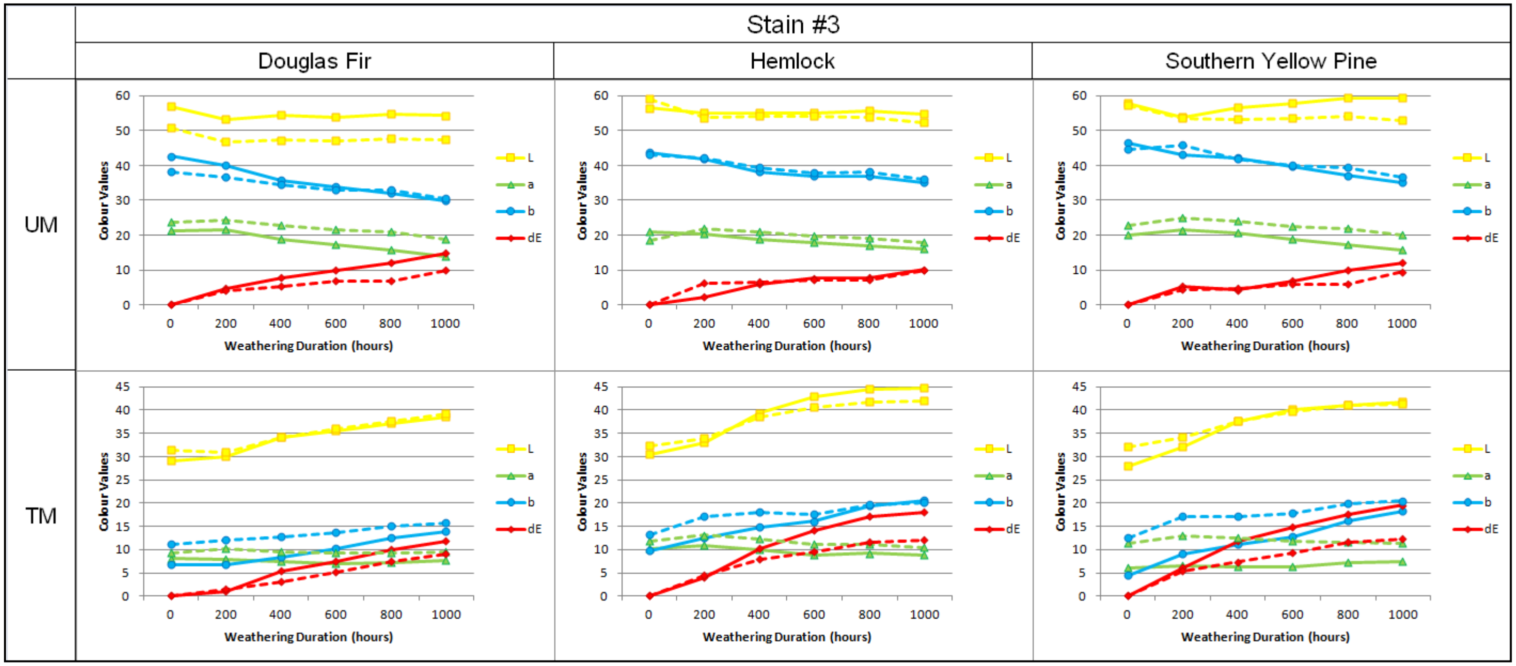
* The colours and symbols associated with each line represent the three CIE Lab parameters, along with the ΔE (dE) calculation of overall colour change. Solid lines represent Latewood readings, and dashed lines represent Earlywood readings.

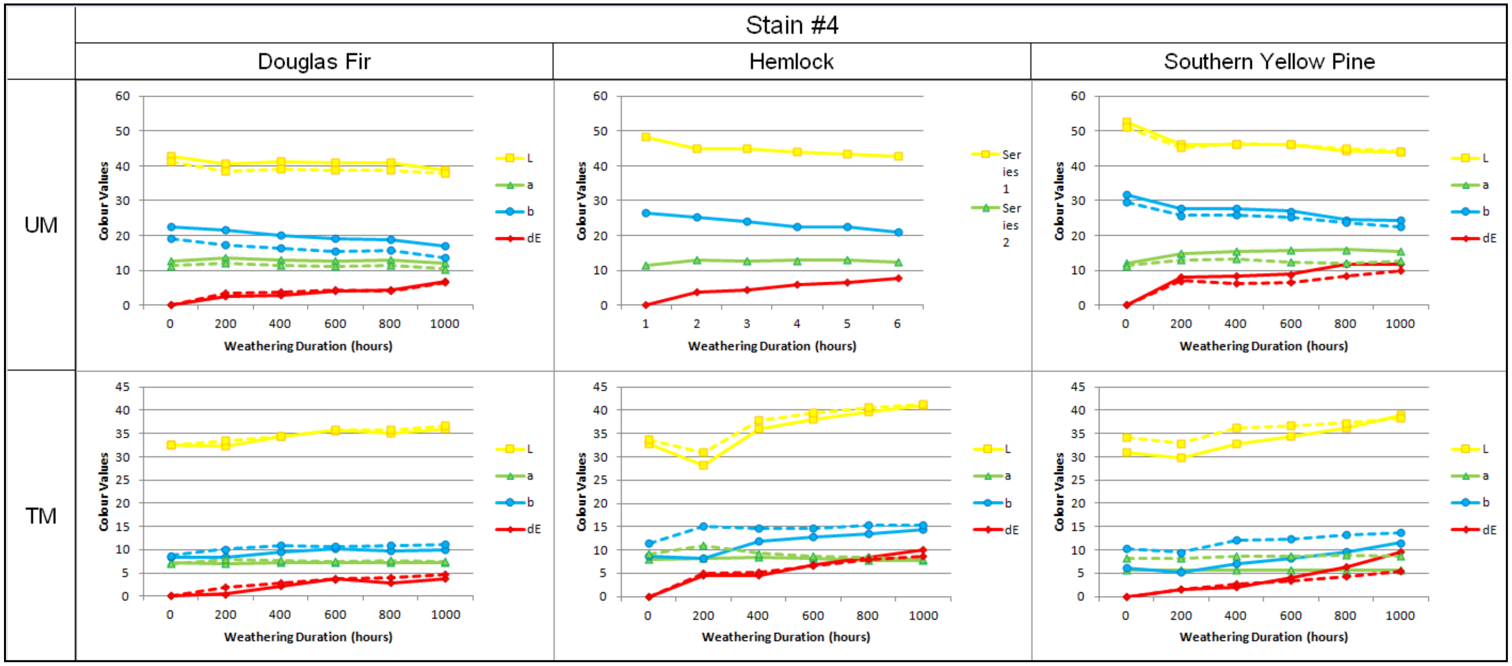
Appendix III – Continued

	Stain #1		
	Douglas Fir	Hemlock	Southern Yellow Pine
UM			
TM			

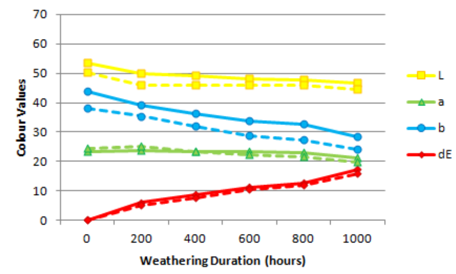
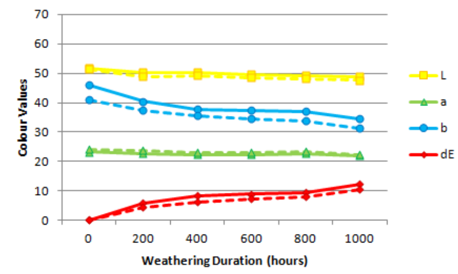
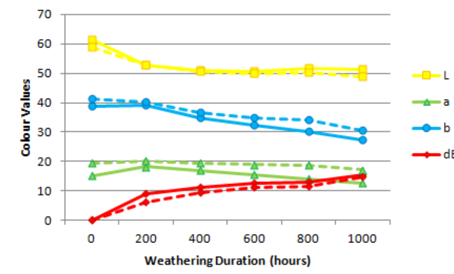
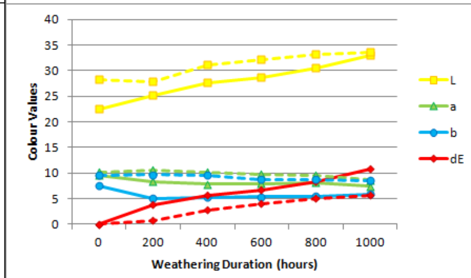
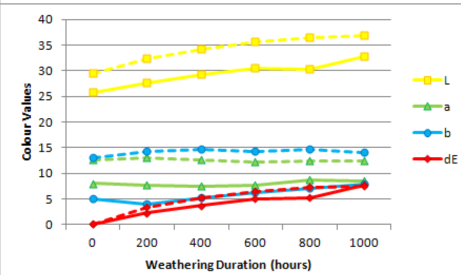
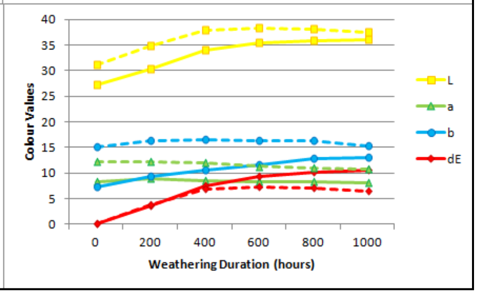
	Stain #2		
	Douglas Fir	Hemlock	Southern Yellow Pine
UM			
TM			

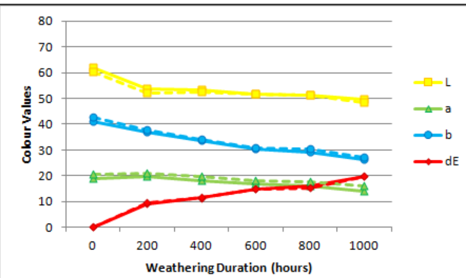
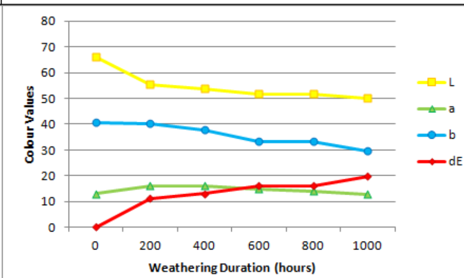
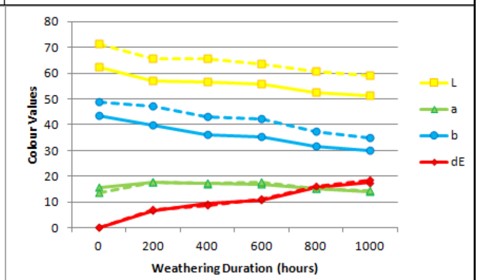
Appendix III – Continued





Appendix III – Continued

	Stain #5		
	Douglas Fir	Hemlock	Southern Yellow Pine
UM			
TM			

	Stain #6		
	Douglas Fir	Hemlock	Southern Yellow Pine
UM			
TM