What can colour tell us about the quality of thermally modified wood?

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Abstract

Thermally modified wood is an excellent material for wood cladding and decking. It is more stable and durable than untreated wood and it does not contain harmful chemical preservatives. However, not all thermally modified wood is made equal. The 'quality' of this material is determined by the processing temperature and time, and there are certain conditions that improve stability performance and other conditions that improve wood durability. Determining which is the right wood for the right application can be difficult. If something goes wrong with the treatment, either by human error or fraudulent activities, then the wood cladding or decking will fail. This paper explores the possibility of using colour measurements to determine thermally modified wood quality. The idea is simple. Is it possible to measure colour on the surface of thermally modified wood and compare with the colour that the same product would have if it was processed using the correct conditions? If the colour matches, then we know that the product is genuine.

Wood cladding

The focus of this paper is wood cladding because it is such an important component of a building, especially if we want to promote wood as the material of choice. Timber has a long history of use as a cladding material, but most wood cladding has some form of coating to protect from humidity and sunlight. Also, scheduled maintenance is normally needed to avoid premature aging and a decline in aesthetics, a disadvantage compared to other cladding materials.

With the growing trend for multi-storey wooden buildings, regular maintenance cycles could be cost prohibitive for traditional wood cladding. Best practice maintenance cycles vary depending on wood species, coating systems and in-service conditions, but typically these can range from 12-monthly to three or five-yearly. If the user does not adhere to the recommended maintenance cycles, the supplier's guarantee may become void.

The New Zealand Building Code also requires cladding to be manufactured, detailed and installed correctly and periodically maintained to ensure its durability and preserve its weathertightness performance and aesthetic appeal (MBIE, 2016). Continuous increases in modern building design complexity are raising the performance requirements for cladding materials and designers, and builders need to carefully consider how to achieve weathertight and durable cladding solutions.

To meet these challenges, researchers around the world have developed treatments to enhance wood properties such as durability, colour stability, hardness and dimensional stability in all weathering conditions, along with resistance to fire. Some solutions use chemical treatments that are applied through pressure impregnation and permanently modify the wood fibre (Rowell, 2006; Kumar, 2007; Hill, 2006). These treatments work very well, but they can be expensive. For example, the Technical Research Institute of Sweden found that chemically modified wood can be four to 10 times more expensive than the untreated alternative (Forskningsinstitut, 2013).

Thermal modification of wood is another option. Thermal modification is the most commercially successful wood treatment practised today, with worldwide production increasing consistently over the last two decades. The process consists of exposing wood to high temperatures in the absence of oxygen for short periods of time, typically between 160°C and 240°C for 0.5 to 10 hours (Esteves & Pereira, 2008). Under these conditions the wood is modified by a slow pyrolysis process that reduces the material hygroscopicity, increases the dimensional stability, and makes the wood less susceptible to biological degradation (Tjeerdsma et al., 1998). Thermally modified wood has been proven so reliable in performance that some suppliers endorse their products for 30-year in-service life without the need for surface coating (MetsäWood, 2014).

Checking the quality of thermally modified wood

Thermally modified wood is good, but not all thermally modified wood is made equal. The changes that wood experiences during thermal modification are caused by chemical reactions that are activated by temperature and accumulate with time. For one species and treatment technology, there will be an optimum set of process conditions that will result in the best balance between stability and durability for the intended application. This is what we call 'quality', the guarantee that the wood was treated under optimum process conditions.

The optimum processing conditions have been established through comprehensive long-term research that involves testing the durability of treated wood for years under different environments. Once the processing conditions are found, they cannot be changed arbitrarily during production as the possible effects on long-term performance of a product are unknown. The risks of changing processing parameters are huge, as the effect may only become evident after many years of service.

In Finland, producers of thermally modified wood recognised the risk of processors using arbitrary treatment conditions. They understood that inexperienced or unscrupulous producers could damage the reputation of the product in the long run, creating a lose-lose situation both for users and producers of properly treated wood. The solution was to create the ThermoWood® Association to self-regulate producers to comply with process guidelines. All companies that join the Association agree to have their operations inspected by an accredited auditor. In exchange, they are allowed to use the trademark name as guaranty that the wood has been treated correctly.

The Association also publishes a handbook that sets down the process conditions, specifies the raw materials requirements, recommends the most suitable applications for the treated wood, and provides research-based information about chemical and physical changes as a function of the treatment temperature (Mayes & Oksanen, 2002). They found that increasing temperature enhances wood durability but causes some mechanical properties to deteriorate.

A temperature of 190°C for two to three hours is recommended for stability applications, while a temperature of 212°C for two to three hours is recommended for durability applications. These standards are called Thermo-S and Thermo-D for, respectively, stability and durability applications. There is potential for New Zealand to develop its own standard based on radiata pine, as this is not covered by the ThermoWood® Association.

What does this have to do with colour? Colour can tell us whether the wood has been treated at 190°C or 212°C, or any other temperature, as the wood darkens as the treatment temperature is increased (see Figure 1). Here, we show that for one industrial site, colour measurements can be an effective tool to verify if the wood has been treated correctly according to the standards, and possibly form the basis of a process control tool.

Wood colour study

The material tested was treated according to the standard audited by the International ThermoWood® Association (ThermoWood®, 2019). This standard was used and, as far as we know, it is the only standard for thermally modified wood in the market. Producers outside the ThermoWood® Association are not compelled to use any particular set of conditions so it is not possible to compare results.

The colour measurements are based on the L*a*b* colour space (CIELAB) (Johnson & Fairchild, 2003), where L* is a measure of brightness and the coordinates a* and b* are measures of chromaticity or colour quality. In other words, +a* = red, -a* = green, +b* = yellow, -b* = blue. This study used industrial data generated and published by Torniainen et al. (2015). Petteri Torniainen is a certified auditor for ThermoWood® and regularly measures colour data for wood that has been treated industrially in compliance with the trademark process.

The experimental procedure can be found in Torniainen et al. (2015). In brief, the study measured wood colour in five boards from 33 batches treated with Thermo-S and 82 batches treated with Thermo-D (a total of 575 boards). All batches were treated at the same industrial site but in two different chambers. Thermo-S was only used to treat Norway spruce (*Picea abies*), while Thermo-D was used to treat 26% Norway spruce and 74% Scots pine (*Pinus sylvestris*). The board thicknesses and widths ranged, respectively, between 22 and 50 mm and between 77 and 225 mm.

Figure 1: From left to right, the colour of untreated and heat-treated *Eucalyptus nitens* at low and high temperatures. Source: Scion

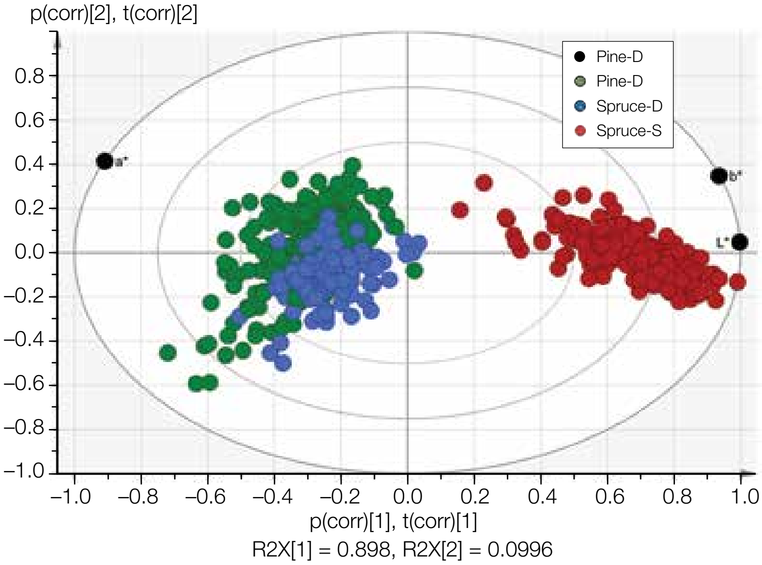

Figure 2: PCA colour separation for thermally modified spruce and pine

Data analysis was carried out using the commercial software SIMCA 15.0. – Trial version (Umetrics, 2013). Now we used a SIMCA with licence paid by Scion. This software is based on the theory of multivariate analysis (Bishop et al., 1975). Relationships between colour parameters were explored by applying Principal Component Analysis (PCA) to identify groups of samples that are intrinsically different from other groups, and Partial Least Square (PLS) to find linear relationships among different sets of parameters.

A linear relationship between colour parameters

The results of the PCA analysis are shown in Figure 2. Each colour represents a thermally modified board (green and blue circles are respectively pine and spruce Thermo-D, and red circles are spruce Thermo-S). The black circles represent the colour parameters L*, a* and b*.

To establish the colour of a board, we locate that board's point with respect to the centre of the diagram, and then compare with the relative position of the L*, a* and b* black circles. For example, Spruce-S tends to be lighter (+L*) and yellowish (+b*), while Pine-D and Spruce-D tend to be darker (-L*) and reddish (+a*). The PCA analysis does not show any clear colour difference between spruce and pine for the Thermo-D treatment. As a side note, the PCA analysis confirms previous findings published for the same data (Torniainen et al., 2015), and found that for Thermo-D there was an inversely proportional relationship between L* and a*, and for Thermo-S there was a directly proportional relationship between L* and b*.

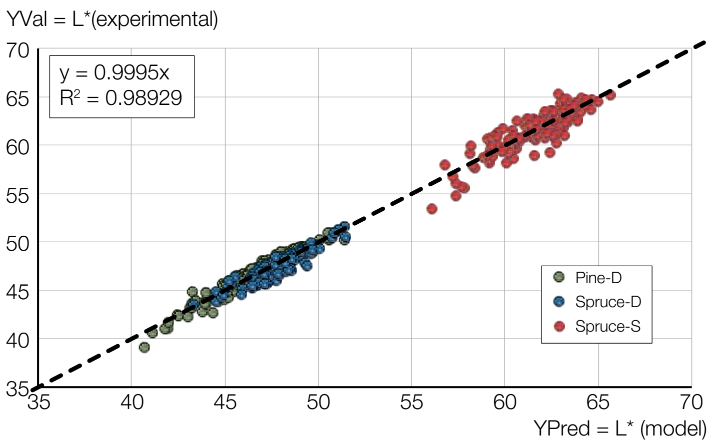

Figure 3: PLC model for colour of thermally modified spruce and pine

The results of the PLC analysis are shown in Figure 3. The PLC analysis finds a linear relationship between the colour parameters, and then shows how close this linear relationship is with the experimental data. The YVal axis shows the real L* value of the boards, while the YPred axis shows the L* value calculated with the following linear relationship:

$$L^* = A + B\,T + C\,a^* + D\,b^* \qquad \text{Eq. 1}$$

where T represents the treatment temperature (Thermo-S = 190°C and Thermo-D = 212°C), and the resulting model coefficients from the PLS analysis are A = 66.0, B = -0.117, C = -3.07 and D = 1.67.

Figure 3 shows that YPred and YVal are very highly correlated with an R2 = 0.99, proving that Equation 1 from the PLC analysis accurately predicts the general relationship between colour parameters. The high R2 coefficient of determination, which is a measure of how close the cycles cluster around the dotted line, assures that the model is able to predict the colour relationship for individual boards. For example, we used Equation 1 to re-calculate the 575 measured L* values. We found that the error between measured and predicted L* had a standard deviation of 1.3%, where the error percentage was calculated with respect to the predicted L*. Of all the samples, 99.7% of the measured L* values were within ±3.9% of the predicted value, which was remarkably close for an industrial operation.

Conclusions

We have shown that there is a highly linear correlation between the lightness and chromaticity coordinates of thermally modified wood. This is based on 115 kiln charges treated in one industrial site compliant with ThermoWood® specifications. The maximum error between the measured wood lightness and the value predicted from colour was around ±4% of the predicted value. This is quite remarkable considering that the correlation included two different kilns, two different species (spruce and pine), two different treatment temperatures (190°C and 212°C), and a range of board thicknesses and widths between, respectively, 22 and 50 mm, and 77 and 225 mm.

We believe that such correlation could be used as an in-line quality control method as colour measurements are fast and non-invasive, giving the producers of thermally modified wood continuous feedback about the quality of their operations. Also, we believe that this method can be used to verify the quality of thermally modified wood before installation. Our study, however, is not able to indicate if the colour of thermally modified wood will remain stable throughout the entire thickness of the wood. We know that the colour of the surface will fade with time, but if colour is stable in zones that are not exposed to sunlight (such as the core of the wood), then our method could also be used as a quality control during secondary remanufacturing, and possibly to determine why a commercial thermally modified wood product does not perform as specified.

The next step for Torniainen would be replicating this study for different industrial sites located in different countries. He has already developed extensive colour databases from certified industrial sites, but such a correlation will need a larger number of parameters than the ones used in this study to explain all sources of variability. The Wood Modification team at Scion is taking a different approach. The focus will be on understanding chemical changes that occur during thermal modification and how they affect the durability of heartwood and sapwood differently. This understanding will provide a larger range of parameters to assess the quality of thermally modified wood than the mere measure of colour, and will be the basis for a species-independent quality assurance method initially optimised for New Zealand species.

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