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MEASURING AND MODELLING OF PROCESS INDUCED DISCOLORATION IN TASMANIAN BLACKWOOD (Acacia Melanoxylon)

David Tanton 1[1], Mark Dewsbury[2], Hartwig Kunzel[3]

ABSTRACT: Process induced discoloration of Tasmanian Blackwood (Acacia melanoxylon) has a significant economic impact on the timber industry in Tasmania Australia. This research aims to reduce hardwood timber discolouration caused by Tasmanian Blackwood drying processes as practiced in Tasmania, Australia which affect the amount of solid timber production waste from sawmill operations. Methods used in this research included site and rack surveys which were analysed using statistical and graphical methods and chemical and biotic analyses. To understand if we could replicate the results in a more economical process, two dimensional hygrothermal simulation was also undertaken. The site-based rack surveys and supporting statistical analysis identified a range of factors contributing to process induced discoloration. The two-dimensional hygrothermal analysis showed a strong correlation between the location of types of discoloration and the movement of heat and moisture within the timber over a two-year simulation period.

KEYWORDS: timber, discoloration, hygrothermal simulation, stickermark

1 – INTRODUCTION

Tasmanian blackwood (Acacia melanoxylon) is a slow growing tree species from the south and eastern regions of Australia that produces a dark coloured hardwood which is prized for it's visual appearance. Blackwood is usually yard dried slowly [1], as faster drying processes can induce both deformation and discoloration defects in the timber. Within its natural habitat, Tasmanian Blackwood only grows as occasional arisings, being harvested within naturally regenerated forest coupes [2]. Few plantations of Tasmanian blackwood exist within Tasmania as they represent a long term investment (around 60 years in Tasmania) and as a result, the species has been designated a special interest species by the state government and production is limited to 10,000m3 per year [3]. During drying, discoloration of Blackwood timber has been an ongoing problem for many years, however the market accepted product is either utilised as-is or treated it with stains to the extent that discoloration was not visible. More recently, market perceptions regarding natural grain and colour patterns within timber has changed such that non-natural discoloration of timber is now perceived in a much more negative light [4].

2 - BACKGROUND

Discoloration of timber worldwide is a constant challenge, as different species and drying conditions and practices can produce different discoloration types given separate scenarios. Process induced discoloration can be caused by a wide variety of factors [5]. Usually they are relatively simple to solve matter. where an obvious cause is present. In the case of blackwood however, no obvious cause has been identified, but discolouration is evident in approximately 30% of the final dried product, appearing mostly as regular discoloration lines called stickmarks (sticker-mark), of various appearances and colours. This results in 30% of the final dried product being either downgraded in value, reprocessed or rejection of the affected product, which affects the financial, environmental and social sustainability of the overall product. This paper gives an overview of the research that has been undertaken into process induced discoloration in Blackwood and some of the findings.

[1] Author 1 David Tanton, School of Architecture and Design. University of Tasmania, Launceston, Australia, david.tanton@utas.edu.au, 0000-0001-5145-190X

[2] Author 2 Mark Dewsbury, School of Architecture and Design, University of Tasmania, Launceston, Australia, mark.dewsbury@utas.edu.au, 0000-0002-3607-3637

[3] Author 2 Hartwig Kuenzel, Fraunhofer-IBP, Fraunhofer Str. 10, 83626 Valley, Germany, hartwig.kuenzel@ibp.fraunhofer.de, 0000-0001-8305-0262

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Fig 1 – Racks of timber undergoing yard-drying

Fig 2 - Blackwood timber displaying left to right - dark sticker marks, light sticker marks.

Architects, engineers and other design and construction professionals are increasingly specifying the use of timber in the construction of buildings due to concerns around sustainability and lower carbon emissions[6]. This results in a multitude of different design types with varying uses of timber, from timber buildings with solid timber frames, through to timber-rich buildings that use timber for interior fit-outs and detailing but have a lower structural usage of the material. Current design, stylistic and market trends dictate that most processed materials used for internal fit-outs be of consistent visual quality both in color and visual consistency[4].Timber can be an exception to this rule, as a number of studies identify that variance in surface colour and visual texture aligns closely with consumer preferences [7, 8], and the presence of natural features such as knots are not always a limiting factor in consumer perceptions [9]. Architects and other design professionals are not always educated on the specific properties of timber, resulting in the specification of materials that are not always suitable for purpose [10].

Where timber is used for its visual properties, it is important that the timber is free from significant visual defects such as visible staining, checking/splitting, discolouration and other visual defects that are introduced by means other than natural timber growth processes. Visual defects arising as a result of normal growth processes are seen in a more favourable light by the customer than process induced defects [4]. One major source of visual defects can be from timber production, where individual processes in the timber sawing and drying methods result in specific defects being inadvertently introduced to the timber.

Discolouration of timber is usually not a significant issue as it should be possible to quickly identify sources of that discoloration and correct the process to exclude that discoloration. However, in some cases, it can become a major issue where it involves unknown or seemingly unidentifiable factors. Process induced discoloration can also present as one of several different forms, as shown in Table 1, which can be the result of conditions present in the drying process[5]. The drying process usually involves the application of heat to remove moisture from the freshly sawn high moisture content (MC%) timber. Kiln drying is one of the most commonly used methods worldwide, but in many cases, timber is still dried by racking the timber and drying under outdoor ambient conditions. In these cases, on-site climatic conditions provide the temperature, relative humidity and ventilation conditions to drive the majority of the timber drying process.

Table 1: Significant types of timber discoloration

Chemically induced	Biotic induced	Light induced	Resin exudation
Non-organic chemically induced	Fungal		
Enzymatic	bacterial		
Non-enzymatic			

The types of discoloration shown in Table 1 can be further sub-classified into two major types, those that require moisture to occur and those that do not require moisture to occur. In the cases where moisture is required for discolouration to occur, the drying process itself can drive that discoloration, and it may be the case that the movement of moisture through the timber can both shift chemical concentration gradients and/or accelerate chemical reactions that produce coloured

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compounds as a result. A question this raises then, is it possible to use standard industry available software to simulate the flow of heat and moisture during the drying process to identify the location and dimensions of any potential market limiting discolorations, and thereby simulate the appearance of discolouration patterns with drying timber.

The impetus for this investigation is the ongoing problem of discolouration in Tasmanian Blackwood, Acacia melanoxylon. A species primarily used for its visual properties that can display several different types of discolouration resulting from an unknown source within the drying process. Currently, the scale of the discoloration problem, as advised by several of the largest sawmill businesses that process and dry Blackwood timber, is up to 30% of the timber produced displaying market limiting discolouration. Timber that is discoloured in this way must either be re-graded as a lower value timber, reprocessed, (where possible), to remove as much of the discoloured material as possible, or discarded. Until recently, Blackwood discolouration was not perceived to be a significant problem, as most commercial uses for Blackwood involved the staining of the timber to enhance the natural colours which usually obscured any discoloration that was still visible [11]. Blackwood, like many other Australian species is conventionally dried in racks which are stored in an open-air yard after milling. This is in preference to other drying methods as it has historically been shown to result in fewer drying defects in the final product. The incidence of different types of discolouration in Blackwood timber depends on several factors including the grain orientation, dimensions of the boards, method of drying (kiln drying, yard drying, or shed drying), and other factors.

Production of Tasmanian Blackwood is limited to 10,000m3 per year as it is considered a specialty timber by the Tasmanian state government. The largest sawmills producing blackwood board-stock apply the conventional yard-drying method, as shown in Fig 1. This process is used to dry the green sawn logs from their saturation point to a moisture content of 20%, in either an exposed yard, or under cover. The sawn timber is then further refined and dried in a kiln to a final moisture content of around 12%. These methods and moisture content expectations are specified in Australian Standard 2796.1-1999 Timber – Hardwood – Sawn and milled Products specification–[12]. Kiln drying does not appear to change the incidence of discoloration and was not a variable that was considered as part of this study. All the timber examined as part of this study were processed with exactly the same kiln drying processes.

Tasmanian Blackwood (Acacia melanoxylon) is a timber that has a large range of natural colours even within single trees [13], making it difficult to establish the natural colour of the timber. Further to this, sectioning and colorimetric analysis of the timber boards observed after the drying process was completed, revealed patterns of discoloration through the dried timber boards (Fig 2). As timber colour also changes naturally during the drying process, it is impossible to say exactly what the natural colour of the timber should be after drying.

Further to this, under certain conditions, phenolic compounds can undergo oxidation through several mechanisms which can induce polymerisation producing more complex photochromic compounds (compounds containing more light-reactive chemical bonds showing up as colour). When present in sufficient quantities, these reactions can occur at ambient conditions [14], which may lead to darkening of materials with high initial phenolic compounds.

3 – EXPERIMENTAL SETUP

The research involved three primary methods: a rack survey which was investigated using graphical and statistical methods, chemical analysis, and two-dimensional hygrothermal analysis.

3.1 – Rack survey method

A year-long survey timber production for one Tasmanian based timber company has provided a baseline dataset for analysis of the significant discolouration issue. The two sites use open-air yard drying combined with kiln drying and surface finishing to produce high visual grade timber.

Rack surveys were conducted by marking the end of every board in every rack. An alphanumeric designation was used to record where each board was in located within each rack, Each individual board was assessed for the presence of discoloration after surfacing.. The resulting database was then evaluated to determine where the discoloration occurs within each rack and each yard.

The rack surveys encompassed timber that was sourced from more than one sawmill and dried at four different locations. Every rack in the survey was processed in a single processing plant including the kiln drying process. There is potential for discoloration to be generated by varying factors at each drying yard, so this paper will focus on timber that was dried at one particular drying yard.

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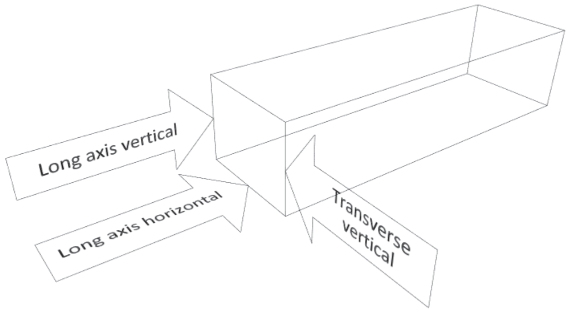

Fig 3 – Possible simulation sections

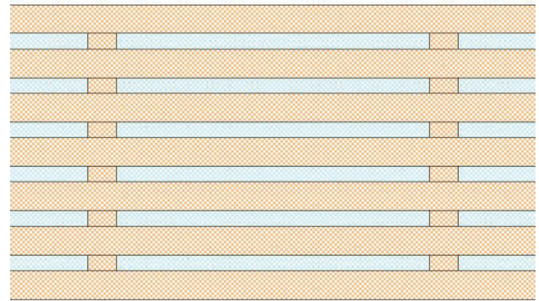

Fig 4 – 2D sectional model used for hygrothermal simulation.

Board level data was recorded on the mill floor, but additional data was recorded against every rack of timber, including the amount of time that each rack had been drying for, the amount of time logs had been in storage for prior to being milled, rack location within the drying yard, and height of the rack off the ground during drying.

After inputting the data into a database, Python programming language was used to display and analyse the survey data for patterns.

4.2. – Chemical analysis

In a parallel research activity, chemical analysis was conducted on discoloured Blackwood samples identified in the site-based research mentioned above. This analysis was undertaken to determine whether there were significant chemical differences between the darkened and non-darkened timber. Several different methods were used to analyse the chemical compositions of both the discoloured and non-discoloured timber, finding a variety of different compounds (including unknown compounds), with the main conclusions being that: *"The production of degradation products of flavonoids (*colour altering compounds detected in the analysis*) is driven by the combination of absorption of UV-vis light, moisture content, temperature and interaction with oxygen. The above results clearly suggest the observed chemical differences are a result of differential rates of chemical oxidation of the wood over time. By using stickers, the protection of the wood in localized regions from UV exposure, oxygen access and differential exposure to moisture is highly likely to slow the local rate of chemical oxidation, which would result in visible differences in coloration from different concentrations of coloured oxidation products*." [15]

4.3. - Hygrothermal analysis

As the results of the colorimetric and chemical analyses were indicative of the action of both heat and moisture, it was decided to use transient hygrothermal (moisture and heat) calculation methods to analyse the drying of the timber racks. It was considered that the hygrothermal simulation method may provide greater insights than previous use of the typical fluid mechanics calculation methods. Transient hygrothermal simulation tools have been used to examine heat, moisture and mould risks within building envelopes for the last three decades [16-23]. An initial analysis of hygrothermal software tools highlighted that one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) computer simulation tools were available[24]. It was quickly identified that 1D tools were not appropriate as simulation method would need to explore the flow of heat and moisture in at least two dimensions. 3D tools may provide a more comprehensive simulation method, but their relative cost made these tools unsuitable at this early stage of the research. Since 2017, the Architectural Science Laboratory at the University of Tasmania has collaborated with the Hygrothermal team from the Fraunhofer Institute of Building Physics. Due to this collaborative arrangement, WUFI 2D was selected for this stage of the research.

WUFI 2D was developed in the 1990's and has undergone significant calibration studies [25, 26]. However, as this research is the first of its kind, all parties agreed that further calibration may be required.

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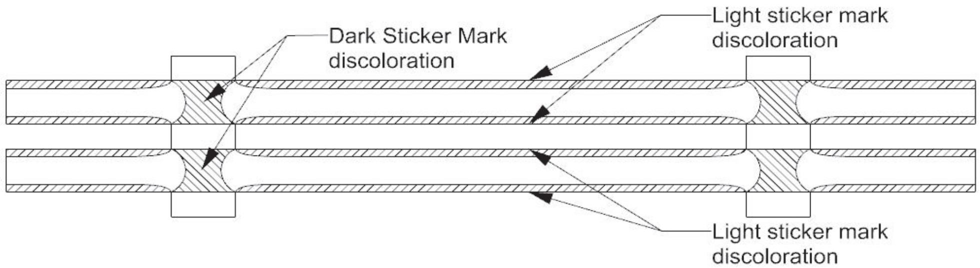

Fig 5 – Sectional location of two types of sticker mark in Blackwood (Acacia melanoxylon)

The WUFI 2D software allows for the use of site measured environmental conditions (hourly air temperature, relative humidity, barometric pressure, wind speed, wind direction and precipitation) as the input climatic data, which would allow the analysis to account for not just seasonality but real-world weather events [27]. This level of inputs and hygrothermal simulation results may provide further insights that might identify irregularities in the site-based data analysis that could be further accounted for.

Furthermore, if the 2D hygrothermal simulation method could predict discolouration locations that matched the site observed data, an exploration of timber stacking methods and sticker types could be undertaken in an effort to reduce the occurrence of sticker mark and reduce processing losses.

Typically, transient two-dimension hygrothermal simulation when used for building envelope design or analysis requires the careful consideration of inputs for the site climate data, the properties if the materials and the interior conditions. In this task, the interior conditions of the timber rack would be created by the flow of air, moisture, and heat through the simulation model. The subsections below discuss each of the input parameters explored.

The two-dimensional simulation software requires the input parameters to consider which axes to create in the model. Determining which axis to evaluate in a sectional hygrothermal simulation was an initial challenge, as sufficient material and rack information was required for the simulation to obtain meaningful results. A vertical section through the rack, perpendicular to the long axis of the rack could be taken with two different variations – (i) one through the position of the stickers and (ii) one without the stickers. The option through the position of the stickers would not account for the long axis of the boards and may not show the area of the discoloration.

The option without stickers would show the drying action in a more detailed manner but would not show the effect of the stickers. A horizontal section through the rack could either show the stickers or the boards, but neither in conjunction with each other. A vertical section through the long axis of the rack was therefore selected as the most appropriate, as it would cut through all of the relevant components of the rack. An example of the timber rack cross-sections that were explored is shown in Fig 3. Fig 4. shows the final version of the long-axis vertical cross-section that was created for this research. Then orange shading represents the timber and stickers, and the light blue shading representing the air between each board.

One of the main advantages of using the WUFI 2D hygrothermal simulation software for this research, was the capacity to incorporate the hourly measured site environmental data for the simulation climate file. In this initial exploration of using this particular form of software to assess timber drying processes, simulations were completed for two-year cycles, incorporating hourly air temperature, precipitation and relative humidity. As the rack to be simulated was protected from overhead solar radiation, the solar radiation data was not included at this stage. The simulated orientation of the racks was East-West, to replicate the conditions in the drying yards investigated in the rack survey.

The WUFI materials database includes material properties for conduction, mass, thermal capacitance, water vapour diffusion resistivity, moisture storage function, liquid transport coefficient, suction/redistribution, porosity, and others.

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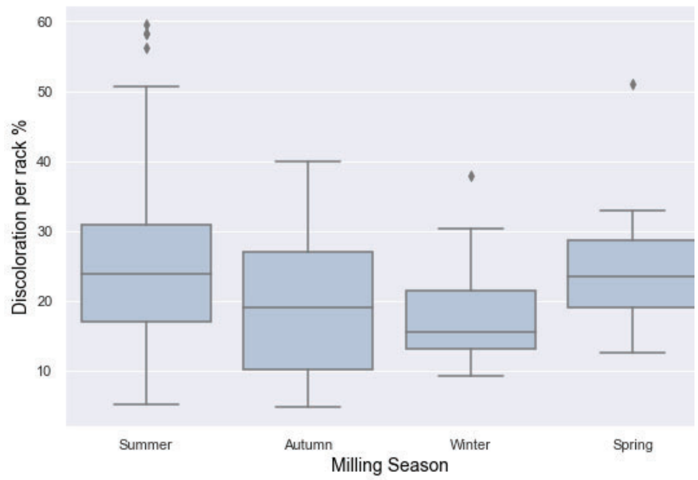

Fig 6 – seasonal differences in discoloration rates

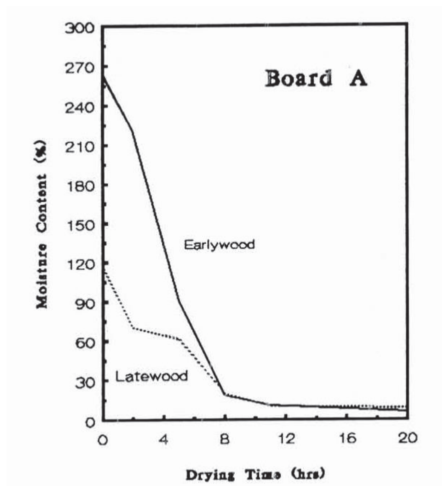

Fig 7 – drying curve for drying timber [28]

As not all the properties for mass of the blackwood timber was known, timber materials within the WUFI 2D materials database were examined for listed materials with expected similar values. Oak-longditudinal and Oak-Radial were selected as being closest match and the properties for bulk density, porosity and built in moisture were modified.

5 – RESULTS

5.1 - Rack survey results

One of the first observations which was apparent at the start of the rack survey was the presence of more than one different type of discoloration. This had been anecdotally reported, but initial reports did not adequately identify all the different types of discoloration that was observed during the rack survey

During the statistical analysis, it became apparent that there were three dominant types of discoloration displayed as Light stickmark, namely; Light stickmark, Dark stickmark and Red stickmark. The stickmarks were found to conform to the location of the sticks (also known as "stickers") used to separate the layers of timber in the rack. Other types of discoloration were also found during the rack survey but were not shown to be significant in subsequent analysis. Sectioning of the timber showed the location of the discoloration as shown in Fig 5

In the initial analysis of the rack survey data along with several other site factors, and seasonal/weather dependent effects were identified as contributing in the occurrence of discolouration, Fig 6. The figure shows the greatest incidence of discolouration occurred during the summer drying period, whilst the winter drying period showed the least presence of discolouration. Identifying the possible impact of the seasonal factors early on confirmed the need to explore the flow of heat and moisture through the solid wood products during the drying process.

5.2 – Hygrothermal simulation

The results of the 2D transient hygrothermmal simulation showed drying of the timber layers through the simulated rack of timber. The simulated moisture content showed a high rate of drying down to fiber saturation point (FSP) at around 25% moisture content and a slow loss of moisture content after that until the end of simulation, eventually leveling at around 8% FSP.

This pattern is consistent with drying curves usually seen in drying timber as seen in Fig 7.

The final results of the simulation can be demonstrated in multiple different ways. One of the most informative of which is a three dimensional graph which can be played as a video showing the progressive movement of moisture during the two year simulation period. Fig 8 and Fig 9 show two points during a simulation period, with accumulation of moisture being very visible in Fig 9. In the worst cases, a 30% moisture content difference between under the stickers and the point between the stickers was seen at the point where the simulation reached FSP.

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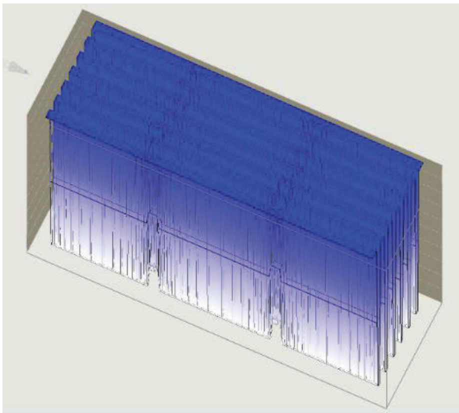

Fig 6 - 3D representation of rack moisture content at start of simulation

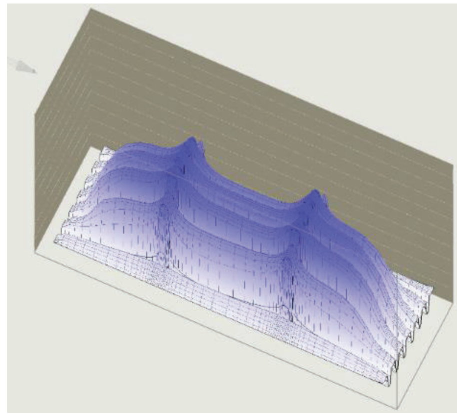

Fig 7 - 3D representation of rack moisture content after 6 months of simulated drying

Figure 8. Images.

6 – CONCLUSION

The primary finding of the statistical data visualization and analysis of the site-based rack surveys was that the discoloration occurred primarily in the outer layers of the racks of drying timber, but the secondary types of discoloration were found throughout the entire rack in greater amounts.

The data visualization and statistical analysis has also indicated that timber thickness is a factor, the impact of thermal mass is significant. As the timber market will always demand certain thicknesses of timber and milling a board for full efficiency requires milling lower thickness boards to make full use of the timber available, changing board thickness is not a viable proposition.

The time of year when the log is milled has been shown to play a significant role in the development of the primary type of discoloration. However, controlling the elements in yard-drying is a difficult proposition, and managing the flow of forest resources to fit a seasonal pattern is also a difficult proposition.

Potential ways forward for the timber industry in this regard will require further experimentation and could be assisted by the use of hygrothermal simulation software, as noted below.

The two dimensional hygrothermal simulation has been shown to demonstrate significant correlations between the observed discoloration shape and location and simulated heat and moisture profiles, indicating that there is significant potential for this method to further developed to inform the most appropriate methods and systems to dry wood such that discoloration could be minimised. To better calibrate the simulation inputs, the physical material properties for blackwood needs to be sought before performing more conclusive simulations.

This research has highlighted that the economical use of two dimensional hygrothermal simulation has the potential to adequately simulate timber drying processes. The ability to easily simulate what the potential loss rate due to discoloration using readily available software that is less technical than other computational fluid dynamics (CFD) methods makes it a potentially viable tool for the timber processing industry.

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