TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Materials and Environmental Technology

EFFECT OF HYDROTHERMAL PRE-TREATMENT ON THE COLOUR OF HARDWOOD VENEERS

HÜDROTERMILISE EELTÖÖTLUSE MÕJU LEHTPUU SPOONI VÄRVUSOMADUSTELE

(MASTER'S THESIS)

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Tallinn 2021

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THESIS TASK

Student: Anthony Chijioke Maduagwu

Study programme: KVEM – Technology of Wood, Plastic and Textiles

Main speciality: Wood Technology

Supervisor(s): Researcher, Anti Rohumaa, PhD

Reseacher, Natalja Savest, PhD

Thesis topic:

(in English) Effect of hydrothermal pre-treatmeant on the colour of hardwood veneers

(in Estonian) Hüdrotermilise eeltöötluse mõju lehtpuu spooni värvusomadustele

Thesis main objectives:

1. To assess the effect of log soaking temperature on the colour of Estonian hardwoods.

2. To determine if log soaking duration affects veneer colour

3. To examine if delayed drying of veneer affects the dry veneer colour

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Preparation and colour measurements of samples from logs soaked for 24 h with different temperatures	06/2020
2.	Preparation and colour measurements of samples from logs soaked for 24 h with different temperatures	01/2021
3.	Collecting and analysing data, thesis writing and submission	05/2021

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Head of study programme: Prof. Jaan Kers........................ 25.05.2021a

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CONTENTS

List of abbreviations and symbols

Abbreviations

T_g **–** Glass transition temperature

LVL – Laminated veneer lumber

CIE - Commission Internationale de l'Eclairage

ASTM – American society for testing materials

mc – Moisture content

ANOVA – Analysis of variance

Symbols

ΔE – Colour change value

L* - White ~ Black in the CIELab colour space

a* - Red ~ Green in the CIELab colour space

b* - Blue ~ Yellow in the CIELab colour space

ΔL* – Change in lightness

Δa* – Change in redness

Δb* – Change in yellowness

INTRODUCTION

The colour of wood will arguably be chief among other non-structural (surface properties) of wood products. It will play a key role in consumers choice of product more because, unlike other surface characteristics, colour appreciation can be assessed by the ordinary visual observation not requiring any particular skill or tool to see.

Generally, wood products, including veneer and plywood, are graded based on their physical and structural properties, under physical properties, colour, texture, and grain patterns, including presence or absence of defects and knot on the surface. Customers seem to care more about these physical properties, especially colour when buying the products because, they can make visual assessments themselves, and over the years, it appears that consumers would instead go for wood products that are darker than the light ones because it tends to suit the decorative purposes for which they are mainly used (Aydin & Colakoglu, 2005). Construction industry workers will undoubtebly care more about the strength properties of wood materials.

However, wood colour could also indicate the treatment process that wood material has gone through. For wood-based products such as veneer and plywood, wood logs are always subjected to series of manufacturing processes often requiring heat up to 180 ^{o}C in the process. First, when logs are soaked before peeling, normally up to 40 ^{o}C in industries and even more during drying with temperatures up to 180 ^{o}C, it would be expected that this will have a direct impart on the overall properties and characteristics of the final product, including colour (Rohumaa, 2016).

In veneer and plywood industry, the wood materials will go through different stages where they are subjected to various thermal treatments, e.g., log pre-heating (commonly soaking or steaming) and veneer drying. The primary purpose of pre-heating of logs before peeling is to soften the log for more effortless workability and increased productivity during peeling. The softening of logs during heating before peeling occurs as a result of the glass transition temperature (T_g) of the wood polymers: cellulose, hemicellulose and lignin being exceeded and varies for different materials.T_g is described as the temperature when 30–50 carbon chains will start to move. At the glass transition temperature, the amorphous regions of -lignin part- of wood fibres experience the transition from a rigid state to a more flexible state, making the wood fibres at the border of the solid-state to be rubbery and softer and easier to cut (Shrivastava, 2018). Broadly, hardwood species are considered better for veneer production because it is relatively bendable (Lutz JF, 1971), when the veneer is peeled, it passes through a rotary lathe and often bends in the process. Hardwood species withstand these bending stresses better than softwood. The reason behind this is not well documented, but some researchers believe this may be because of the comparatively less lignin content of hardwood species.

Also, some complex chemical reactions are activated in the process due to the presence of phenolic extractives majorly responsible for wood colouration that alters the colour properties of the wood materials (Huang et al., 2012). The rate and nature of these alterations in colour will depend mainly on wood species involved, the length of log soaking time used, log soaking temperature. Over the years, hydrothermal treatment of wood materials has been shown to affect the surface quality of veneers. Other factors such as surface roughness, and wettability have already studied to some extent, but colour has received less attention.

The aim of this thesis therefore is to examine how thermal pre-treatment of logs affect the colour properties of veneer on selected Estonian hardwood species.
In this study four different wood species, birch (*Betula pendula* Roth), aspen (*Populus Tremuloides*), grey alder (*Alnus Incana*) and black alder (*Alnus glutinosa*) will be used.

The objective of this study is to answer the following questions:

1. How does the log soaking temperature affect the colour of Estonian hardwoods?
2. How does the soaking duration affect the colour throughout the veneer mat?
3. How will the delay in drying of veneer affect the colour of Estonian hardwoods?

1 LITERATURE REVIEW

1.1 Wood Colour and Measurement

Wood colour generally would refer to the natural colour tone of dried wood without any form of artificial treatment and it would greatly vary depending on the wood species more than any other factor (Jirous-rajkovic & Sedlar, 2014). These natural wood colours are somewhere between white, yellow-brown, and red and often not strictly uniform across the wood surface. Technically, wood colour can be described as the unabsorbed light rays, which are retained after light rays hit on a wood material's surface. The degree of this light retention is dependent on the structural composition of the wood, which will depend on the percentage contents of cellulose, hemicellulose, and lignin which absorbs or reflects a certain amount of light rays. Basically, phenolic extractives present in the wood structure are responsible for their unique colouration, and vary for different species (Huang et al., 2012).

A major consideration for end-users of wood products with veneer as a finishing material such as laminated veneer lumber (LVL) and plywood and, in fact every other wood product is colour (Aydin & Colakoglu, 2005). Colour may be the most significant factor in terms of marketability of all the physical surface properties of veneer and wood products, maybe only second to mechanical properties. It appears that the darker the wood colour, the prettier and more acceptable most wood modifications during processing appear to make it lighter. Colour of wood and its aesthetic value is a significant player in the pricing and valuation of wood (Aydin & Colakoglu, 2005). Colour measurement is a subjective matter that is dependent on the reflectance of light from the surface and appreciated based on individual perception (Bombardier & Schmitt, 2010; Rosu et al., 2010).

Wood users will generally be attracted to beautiful colours and would be more disposed to patronize colourful wood products especially when they are guaranteed the colour will be consistent with the product through its lifetime. There are no documented effects of veneer processing on the colour. However, in the research to study the chemistry of colour modification by (Huang et al., 2012) of heat-treated wood exposed to artificial weathering shows that heat-treated wood is more resistance to photo-degradation and can be attributed to increasing the lignin percentage of test sample species (birch, aspen and Jack pine) due to less influence of heat on hemicellulose, but upon exposure to artificial weathering, the lignin contents reduced again by approximately 2.5% after 3 days leaving no clear substantial different in colours with untreated samples. This occurence means that weathering has more influence on wood colour change/degradation than heat treatment (Huang et al., 2012). Colour perception and measurement is a complex subject. Three things are required to see colour. These are the light source, the object, the observer. A light source must be a natural source of light, such as the sun or any light bulb (Clarke, 2006).

Colour can be measured using a spectrophotometer, an optical colour measurement device used to evaluate colour uniformity of material surfaces. The device uses the L*, a* and b* coordinates named CIELab colour space values. Three parameters describe the CIELab system as defined by the Commission Internationale de l'Eclairage (CIE): L^* axis represents the lightness, a^* and b^* are the chromaticity coordinates; $+a^*$ for red, $-a^*$ for green, $+b^*$ for yellow and $-b^*$ for blue. The L^* value varies from 100 (white) to zero (black) (see Figure 1.1).

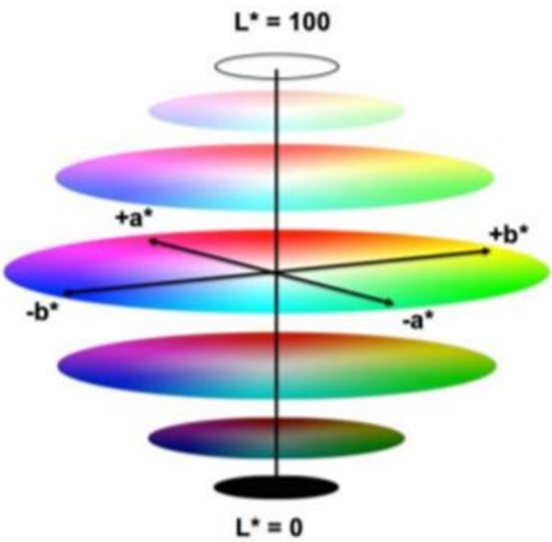

Figure 1.1 The CIELab colour space (Service, 2013)

1.2 Veneer Production Process

Veneer can be either rotary peeled or sliced depending on the end-use. The veneer for decorative purposes is often sliced. This eliminates the incident of lathe checks in rotary peeled veneer and the desired dimensions can be achieved with modern joining and gluing technologies. It can be safely assumed that sliced veneer will have relatively better surface properties mainly due to the absence of lathe checks, unlike rotary peeled veneer. The veneer used for industrial-scale plywood production is mostly rotary peeled, and the process is mostly the same for every company, with slight variations depending on wood species and the company involved.

The typical industrial process is presented in Figure 1.2. In the factory, the logs are measured, sorted, and stored by quality. Before the peeling process, wood must be softened in order to cut into a smooth veneer of even thickness, so the logs are soaked in 40 ºC temperature water bath for one or two days. Moist, warm, and debarked logs are rotary cut into thin veneer layers usually 1.5 mm thick. The drying process as full veneer mats or clipped sheets follows for 4-5 minutes at 170 ºC hot air. After drying, veneer sheets are inspected for defects such as split-ends, knot holes, loose knots, colour defects, etc. and sorted by quality. The veneer sheets are then packaged or mainly sent to next working line – for producing plywood.

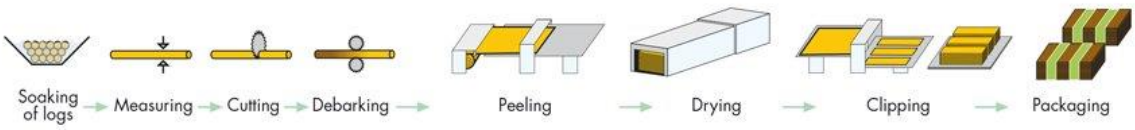

Figure 1.2 Industrial venere processing process (UPM Plywood 2016)

As it was described, wood material will go through several processes where the elevated temperatures are used, e.g. soaking, drying.

The main reason for heating the logs is to soften the wood. When the wood is softened, it increases yield per log upon peeling and has a less negative effect on the cutting knife of the rotary peeler (Chen et al., 2021; Kim et al., 2021). The studies have also shown that elevated soaking temperature can affect the colour of wood and other properties prior use (Rohumaa, 2016). This softening of timber logs before peeling occurs because of the glass transition temperature (T_g) described in the introduction. The studies of the T_g of natural wood polymers (lignin, hemicellulose, and cellulose) show that the T_g of these components when dry is relatively high. When dry, isolated cellulose has a T_g of about 230 – 250 ºC, the T_g of hemicelluloses in the range of 150 – 200 ºC and the T_g of lignin is about 130 – 200 ºC (Goring, 1966).

Peeling is perhaps the most essential aspect of the veneer production process, and as such, most companies and factories pay special attention to this, majorly ensuring adequately trained and qualified staff can operate the peeling machines and oversee the process. Generally, the peeling process have two variable division a) peeling settings and b) cutting speed (Rohumaa et al., 2016). Lathe settings are vital parameters in veneer peeling and the optimum settings are different wood species.

1.3 Factors That Affect Wood Colour

There are many factors that affect the colour of wood. As it has already been stated, the main determinants of the colour of a particular species of wood will generally depend on the structural composition of the wood species, especially on the amount of phenolic extractives. This situation, however, refers to green wood but wood is rarely used green. Therefore, when considering the factors that affect wood colour, it becomes crucial to consider the effects of the processing parameters of wood. These factors include but are not limited to the following: microstructure, moisture content, heat, biological reactions, chemical reactions, oxygen, and presence of light. It has been suggested that the red hue in wood can be attributed to phenolic extractives present in the wood microstructure and that the yellowish colouration in wood due to the photochemistry of lignin and the dark colouration of heartwood mainly due to the oxidation of phenolic compounds in the dead cells of the heartwood (Sandoval-torres et al., 2010)

1.3.1 Moisture Content and Microorganisms

Microorganisms can cause discoloration in wood, especially when it is exposed to dampness. Fungus attacks the sap wood of wood materials due to the presence of some sugars; this affects not only the colour of the wood but also the structural properties. This fungus action hampers the transportation of water and other minerals, causing the wood to be discoulored and, in most cases, die. (Sandoval-torres et al., 2010)

Moisture content affects the colour of wood surfaces just like every other material. When a material is wet, the wetness affects the reflectance of light rays on the surface, thereby making the material appear darker (Budakci, 2012). Wood materials generally will appear darker when they are wet (Antti, 2017). Wood is a hygroscopic material having the ability to adsorb or lose water to the environment when is kept over a period to reach an equilibrium state with the surrounding environment. This phenomenon will indeed have some ability to affect the surface properties of wood significantly if it is not well monitored. Mechanical properties of wood remain constant below fibre saturation point (FSP). It is crucial to measure the strength of wood materials when they have reached the desired 'use state' moisture content, which depends mainly on the service and environment and must be lower than the point generally between 25-30 ^{0}C (Shmulsky & Jones, 2011). Many types of research involving physical surface property measurement of wood materials often deal with minimal moisture content.

1.3.2 Heat

Heat is a preeminent factor that affects veneer colour. The increase in temperature generally leads to colour changes in wood (Babiak et al., 2007). Some studies have shown that hardwood species discolour less slowly than soft woods at lower temperatures. This discoloration is generally attributed to the complexity of chemical reactions of wood polymers, including oxidation and hydrolyses reactions. These reactions lead to photo-degradation of lignin and wood extractives which tends to push these extractives towards the surface of the wood thereby altering the appearance. In most cases, these reactions reverse at a different rate upon cooling and further distort the wood colour (Bonifazi et al., 2015; Rosu et al., 2010) This phenomenon also happens when wood is dried at elevated temperatures. When wood logs are soaked at elevated temperature (commonly not exceeding 70 ^{o}C) before peeling to obtain veneer, it tends to plasticize the lignin (amorphous) parts of wood and this ensures more effortless workability with fewer fractures and stresses on the veneer mat produced (Rosu et al., 2010) It can be expected that these would also influence the colour of wood both initially and when the veneer product is used. Still, the magnitude or extent of colour changes is not known. The studies show that degradation of extractives leads to de-yellowing of wood colour (Jomaa, 2012).

1.3.3 Ageing

Ageing would also lead to changes in wood colour. Over the years, various studies have been carried out to investigate how ageing affects. Ageing can be natural or artificially induced. Every material will naturally be subject to some form of irreversible degradation in both physical and structural properties over the time of usage. These degradations will surely lead to reduction in the material ability to meet its structural requirements and physical deformation, especially in appearance and colour occasioned mostly by a combined action of light, oxygen and temperature and it will also depend on the environment where it is exposed (Huang et al., 2012).

The significant percentage of wood materials are used for decorative and aesthetic purposes. That is why it is essential to ascertain its durability in terms of colour and appearance. Some studies show that the natural ageing process of wood materials in terms of colour changes is similar to changes when the ageing process is accelerated by thermal exposure thereby making it always possible to predict the rate of changes and defects which in itself, will be essential in the conservation of cultural and natural heritage and art restoration (You et al., 2017) as well as aid in the determination of the longevity of the wooden materials.

1.3.4 Weathering

Weathering is another major factor that affects the colour of wood. Just like every other known material, wood materials are always subjected to weathering. The rate at which the materials will discolour as a result of weathering would depend on the amount of exposure to weathering agents, the processing factors and parameters as well as the surface finish of the material. The most noticeable effect of weathering will be seen in the colour of the material. Wood species and structural compositions affect the rate of weathering and discoloration (Bonifazi et al., 2015).

The main factor among agents of weathering on the surface of wood materials will be heat in form of UV radiations and elevated temperature, which triggers complex chemical reactions leading to the photodegradation of the wood polymer.This was known from the research by (Griebeler & Rodriguez, 2014), which was mostly used as an artificial tool to study the effects or rate of weathering. Other factors include rain and ageing. To limit the rate of weathering on the surface of wood materials, most wood products companies will go for the application of clear-coats and varnishes on the surface of the wood material for protection.

1.3.5 Industrial Treatment Process

A wide range of factors affects the colour of wood during and after processing. Tables 1.1 and 1.2 and 1.3 show the summary of some reviews of how wood colour varied based on specific preparations and treatment have being received.

In studying the impact of log pre-heating on birch veneer surface quality, bond formation and plywood performance by (Rohumaa, 2016), colour measurements were performed on 0.8 mm birch sapwood veneer strips using a spectrophotometer. The results showed the differences between the samples soaked and peeled at 70 ^{0}C and those soaked at 70 ^{0}C but allowed to cool down to 20 ^{0}C before peeling. More remarkable colour change was observed from samples soaked and peeled at 20 ^{0}C as shown in Table 1.1.

The effects of short-term thermo-mechanical densification of veneer on colour of birch and alder were studied by (Bekhta et al., 2014). Dry (5% mc) veneer sheets of 300 x 300 mm were cut and thermo-mechanically densified with temperatures of 100, 150, and 200 ^{0}C and with pressures of 4, 8, and 12 MPa for 4 min.

The non-densified samples were first measured as a base point with a spectrophotometer, followed by measurement of the densified samples, the colour coordinates were close with the samples densified at 4, 8, and 12 MPa at the temperature of 100 and 150 ºC, but changes more significantly with samples from 200 ºC in both of the wood species.

Table 1.1 Colour coordinates of some wood materials treated to different conditions

Research topic	**Wood specie/type**	**Treatment method**	**Description**	**L***	**a***	**b***
Impact of Log pre-heating on birch Veneer surface quality (Rohumaa, 2016)	Birch veneer (sap wood)	Logs were soaked in pre-heated tanks of 20 ºC and 70 ºC, and dried at 160 ºC	Samples soaked and peeled at 70 ºC	74.63± 2.50	3.97 ±0.88	19.06 ±1.07
			Sample soaked for 70 ºC and cooled to 20 ºC before peeling	74.11± 1.63	3.99±0.97	19.13 ±0.99
			Samples soaked and peeled at 20 ºC	72.92± 0,99	3.56 ±0.43	28.53 ±1.01
Colour in short-term thermo-mechanically densified veneer of various wood species (Bekhta et al., 2014)	Alder veneer	Dry (5% mc)veneer sheets 300 x 300 mm were cut and therm-mechanically densified with temperatures of 100, 150, and 200 ºC and with pressures of 4, 8 and 12MPa for 4 min.	Non densified samples	75.58 ±2.55	7.48 ± 2.20	31.08 ± 3.92
			Densified with 100 ºC, 4Mpa	76.98 ± 0.62	6.27 ± 0.56	26.02 ±0.84
			Densified with 100 ºC, 8Mpa	77.24 ± 0.38	6.65 ± 0.19	23.60 ± 0.39
			Densified with 100 ºC, 12Mpa	76.37 ± 0.88	6.97 ± 0.40	26.46 ± 0.42
			Densified with 150 ºC, 4Mpa	74.06 ± 0.19	7.27 ± 0.12	26.84 ± 0.36
			Densified with 150 ºC, 8Mpa	77.43 ± 0.40	5.51 ± 0.16	21.62 ± 0.45
			Densified with 150 ºC, 12Mpa	71.68 ± 1.13	8.1 ± 0.35	25.10 ± 0.36
			Densified with 200 ºC, 4Mpa	62.78 ± 2.09	6.13 ± 0.37	19.27 ± 0.23
			Densified with 200 ºC, 8Mpa	47.18± 2.21	7.58 ± 0.27	17.23 ± 1.10
			Densified with 200 ºC, 12Mpa	54.27 ±1.66	6.27 ± 0.35	17.17 ± 0.37
Colour in short-term thermo-mechanically densified veneer of various wood species (Bekhta et al., 2014)	Birch Veneer	Dry (5% mc)veneer sheets 300 x 300 mm were cut and therm-mechanically densified with temperatures of 100, 150, and 200 ºC and with pressures of 4, 8 and 12MPa for 4 min.	Non densified samples	82.38 ± 0.12	2.96 ± 0.46	24.88 ± 0.25
			Densified with 100 ºC, 4Mpa	82.55 ± 0.28	3.26 ± 0.44	23.82 ± 0.24
			Densified with 100 ºC, 8Mpa	82.08 ± 0.16	6.34 ± 0.55	25.63 ± 0.12
			Densified with 100 ºC, 12Mpa	80.50 ± 0.32	7.17 ± 0.16	27.79 ± 0.50
			Densified with 150 ºC, 4Mpa	80.36 ± 0.62	3.79 ± 1.00	25.35 ± 1.03
			Densified with 150 ºC, 8Mpa	79.22± 0.47	7.90 ± 0.37	23.32 ± 0.43
			Densified with 150 ºC, 12Mpa	79.54 ± 0.18	7.65 ± 0.08	27.20 ± 0.32
			Densified with 200 ºC, 4Mpa	62.07 ± 1.66	10.14 ± 0.06	22.51 ± 0.39
			Densified with 200 ºC, 8Mpa	53.10 ± 2.03	10.44 ± 0.06	21.27 ± 0.66
			Densified with 200 ºC, 12Mpa	56.19 ± 0.84	9.50 ± 0.40	21.55 ± 0.33

Table 1.1 Colour coordinates of some wood materials treated to different conditions (Cont'd)

Effects of heat treatment on colour changes of black alder and Beech (Hikaru et al., 2016)	Black alder	dry(7.5% mc) veneer samples 70 mm x 70 mm conditioned in a 60% RH, 20 ºC room subjected to heat treatment in an oven 190 ºC for 5, 10, 20, 40 min.	Control samples	70.81 ± 1.65	8.42 ± 0.6	25.78 ± 0.28
			Samples treated to 190 ºC for 5 min	68.72 ± 1.67	[illegible] ± 0.56	25.37 ± 0.58
			Samples treated to 190 ºC for 10 min	66.38 ± 1.72	[illegible] ± 0.50	25.04 ± 0.80
			Samples treatd to 190 ºC for 20 min	60.69 ± 1.29	[illegible] ± 0.27	25.38 ± 0.58
			Samples treated to 190 ºC for 40 min	57.05 ± 1.16	[illegible] ± 0.23	23.38 ± 1.04
Effects of heat treatment on colour changes of black alder and Beech (Hikaru et al., 2016)	Beech		Control samples	70.47 ± 0.28	7.61 ±	21.51 ± 0.26
			Samples treated to 190 ºC for 5 min	69.27 ± 0.27	7.86 ±0.18	22.28 ± 0.42
			Samples treated to 190 ºC for 10 min	67.55 ± 0.18	8.51 ±	22.21 ± 0.45
			Samples treated to 190 ºC for 20 min	64.62 ± 0.38	9.48 ±0.20	24.43 ± 0.58
			Samplestreated to 190 ºC for 40 min	60.07 ± 1.58	10.45 ± 0.39	22.86 ± 0.58
Wood Colour of central European wood Specices (Meints, 2017)	Alder	technically dried board 100 x 200 x 12mm conditioned in a room of 20 ºC & 65% RH and 10 - 13% mc (sanded before colour measurement	Dried boards, 13% MC	76.5 ± 4.8	10.5 ± 14	26.2 ± 2.6

(Hikaru et al., 2016) studied the effects of heat treatment on colour changes of black alder and beech.The dry (7.5% mc) veneer samples of 70 mm x 70 mm conditioned in 60% RH, 20 ºC room were subjected to heat treatment in an oven at 190 ºC for 5, 10, 20, 40 min.

The colour coordinates gotten from the treated samples were compared to those of the control samples and colour change ΔE was recorded. The results have shown significant differences between samples treated at 20 ºC and those ones treated at 40 ºC, mostly on the lightness L* colour axis.

1.3.6 Origin of Wood and Seasonal Variation

The season of harvest of the logs used to process the material has been shown to affect the colour. In addition to harvesting season, other related factors that may have some effect on the properties of the wood material include length and season of storage of the harvested logs, climatic conditions of storage and processing according to the study by (Luostarinen, 2009) done with birch wood in Finland. The same study suggested that materials processed from logs harvested in birch plantations which were more fertile and rapid in growth appeared lighter in colour than those from less fertile natural forests.

Table 1.2 Colour coordinates of birch logs harvested in different seasons and different planting conditions (Luostarinen, 2009)

Material Origin	Growing site type	Felling season	Colour Coordinates (wet)			Colour Coordinates (dry)			
			L^*_w	a^*_w	b^*_w	L*	a*	b*	ΔE*
Natural	VT	Autumn	86.8	1.7	18	79.2	4.8	18.6	8.23
		Winter	87.3	1.7	17.5	80.5	4.6	18.6	7.47
		Summer	87.3	1.7	17.9	78.1	5.2	19.8	10.02
Natural	MT	Autumn	87.5	1.3	17.2	79.7	4.5	18.7	8.56
		Winter	87.7	1.3	17.1	81.2	3.9	19.1	7.28
		Summer	88.1	1.3	17.1	79.6	4.5	19.3	9.35
Planted	OMT	Autumn	87.1	1	16.3	81.5	3.6	18.3	6.49
		Winter	87.5	1.2	16.7	81	4	18.5	7.3
		Summer	88	1.1	16.5	80	3.9	19.6	9.02
Planted	Open Field	Autumn	87.1	1	16.4	81.8	3.5	18.3	6.16
		Winter	88	0.9	16.6	80.4	4.2	18.9	8.75
		Summer	88.4	1	16.2	81	3.7	19.1	8.39

VT (Vaccinium-type) is regenerated low fertile field, MT (Myrtillus-type) is medium fertility field and OMT (Oxalis-Myrtillus-type) is high fertility field.

Table 1.2 shows that the most significant colour change values ΔE, between the wet samples and the dry ones appeared on the logs harvested on the summer especially on the samples from VT, MT and OMT. Also, the results show that the fertility of the growing field affects the lightness of the material positively.

1.3.7 Summary of the Review

Table 1.1 and 1.2 show that the natural colour of wood reacts differently to different treatments. Heat remains one of the major causes of colour alterations in wood. Most of the unique treatments of the wood materials receive are designed to enhance some other properties of the wood and, the colour alterations are just fallouts. The densification treatment shown in Table 1.1 would undoubtebly improve the strength properties of the materials but as it can be seen, had as a result altered the colour of the wood very significantly when done with a high temperature of 200 ^{0}C and pressure of 12 MPa. The implication of this colour alterations will depend significantly on the use of the material being treated, if it is for aesthetic purposes, then a lot of care would be taken and the right treatment types used so that colour alterations would be minimized.

The colour changes observed in each of the different categories stated above maybe due to alteration of the chemistry of the wood material surface when the concentration of phenolic compounds with lower molar mass is influenced as a result of the season of harvest (Rohumaa et al., 2014). The felling season can also cause some variations in the density and bonding strength.

2 MATERIALS AND METHOD

This chapter details the method employed in the study, starting from veneer production, storage, sampling and finally colour measurement in accordance with (ASTM E1164-12, 2017). The wood species used are birch, aspen, black alder, and grey alder.

2.1 Samples Categorization

To achieve the objectives of the study, three categories of samples were collocated, each for every one of the proposed studies.

Table 2.1 Summary of samples collection and Colour measurement

Item	Soaking duration, h	Veneer thickness, mm	No. of species	Soaking temp, ºC	No. of logs for each	wet colour (w_o)	wet colour (w_1)	dry colour (d_o)	dry colour (d_7)	dry colour (d_{28})	dry colour (d_{120})
1	48	1.5	4	20	2	×		×	×	×	×
				40		×		×	×	×	×
				70		×		×	×	×	×
2	24	1.5	4	20	2			×			
				40				×			
				70				×			
3	48	1	4	20	1	×	×	×	×		
				70		×	×	×	×		

Where w_o is wet samples, w_1 is wet samples after 24 h, d_0 is dry samples on the day of drying, d_7 is dry samples after 1 week of drying, d_{28} is dry samples after 1 month of drying and d_{120} is dry samples after 4 months

The first set of samples collected (research question 1) were 1.5 mm thick veneers produced with 48 h log soaking duration and at soaking temperatures of 20 ºC, 40 ºC, and 70 ºC. With this set of samples the effects of log soaking duration on the colour and colour changes after drying were studied. The second set of samples (research question 2) was soaked for 24 h and this was used for evaluation of the effects of soaking temperature on veneer colour. The 1 mm veneer thickness samples (research question 3) were used to determine colour changes based on delayed drying time.

2.1.1 Log Selection and Log Soaking

The veneer peeling and sampling methods were the same for all the categories of samples. The logs were randomly selected from the log yard; there were no particular selection criteria besides the visual examination based on the roundness and straightness of the logs without obvious cracks or defects. The logs were supplied in lengths between 2,800 mm – 3,300 mm, and as such, each of these supplied logs provided two log samples for soaking.

Table 2.1 The overview of log samples used for this research

Sample Specie	**Soaking temp, ºC**	**Veneer thickness, mm**	**Soaking Duration, h**	**Log diameter, mm (log 1)**	**Log diameter, mm (log 2)**	**Average diameter, mm**
Birch	20	1.5	48	214	260	237
Birch	40	1.5	48	270	243	256.5
Birch	70	1.5	48	235	222	228.5
Birch	20	1.5	24	236	218	227
Birch	40	1.5	24	262	248	255
Birch	70	1.5	24	222	243	232.5
Aspen	20	1.5	48	415	315	365
Aspen	40	1.5	48	375	275	325
Aspen	70	1.5	48	390	460	425
Aspen	20	1.5	24	408	329	368.5
Aspen	40	1.5	24	345	298	321.5
Aspen	70	1.5	24	373	401	387
Black Alder	20	1.5	48	286	260	273
Black Alder	40	1.5	48	259	234	246.5
Black Alder	70	1.5	48	250	300	275
Black Alder	20	1.5	24	274	256	265
Black Alder	40	1.5	24	249	312	280.5
Black Alder	70	1.5	24	297	283	290
Grey Alder	20	1.5	48	260	250	255
Grey Alder	40	1.5	48	229	209	219
Grey Alder	70	1.5	48	240	212	226
Grey Alder	20	1.5	24	235	273	254
Grey Alder	40	1.5	24	266	243	254.5
Grey Alder	70	1.5	24	255	238	246.5
Birch	20	1	48	280	-	280
Birch	70	1	48	278	-	278
Aspen	20	1	48	270	-	270
Aspen	70	1	48	215	-	215
Black Alder	20	1	48	285	-	285
Black Alder	70	1	48	270	-	270
Grey Alder	20	1	48	-	-	-
Grey Alder	70	1	48	195	-	195

The attempt was made to determine the annual ring width of selected log samples on their cross-sectional surface after the logs were brought out off the soaking bath with visual observation and it was found to be in the range of 1.5 mm – 2.3 mm.

Log soaking temperatures were 20 ^{o}C, 40 ^{o}C, and 70 ^{o}C for each of the soaking times of 24 h and 48 h.

Debarking of the sample logs was done manually using a draw knife while the log was adequately secured in the horse bench.

Averagely, aspen logs with a diameter range of 275 mm – 460 mm, were bigger than the other wood species, and they produced more veneer sheet samples than the logs of birch, black alder and grey alder.

There are no documented effects of the log diameter on the colour of veneer produced, as well as other physical surface properties, but it is reasonable to assume that the bigger the logs the more difficult it will be to penetrate the core of the wood towards the pith for the soaking heat.

Figure 2.1 Debarked logs fed into the rotary veneer peeling lathe

Figure 2.1 shows how the log is feed into the rotary veneer peeling lathe. Before the peeling, a metal detector was used to ascertain if there were no metals trapped in the logs, which could damage the peeling blade if not detected. The moisture content of the logs was measured on three different equally spaced points along the same axis on the log to fix the moisture content of the logs after debarking.

2.1.2 Veneer Peeling and Cutting

The logs were peeled into veneer mats using the rotary veneer peeling lathe with a constant setting for all the logs, as shown in Figure 2.2

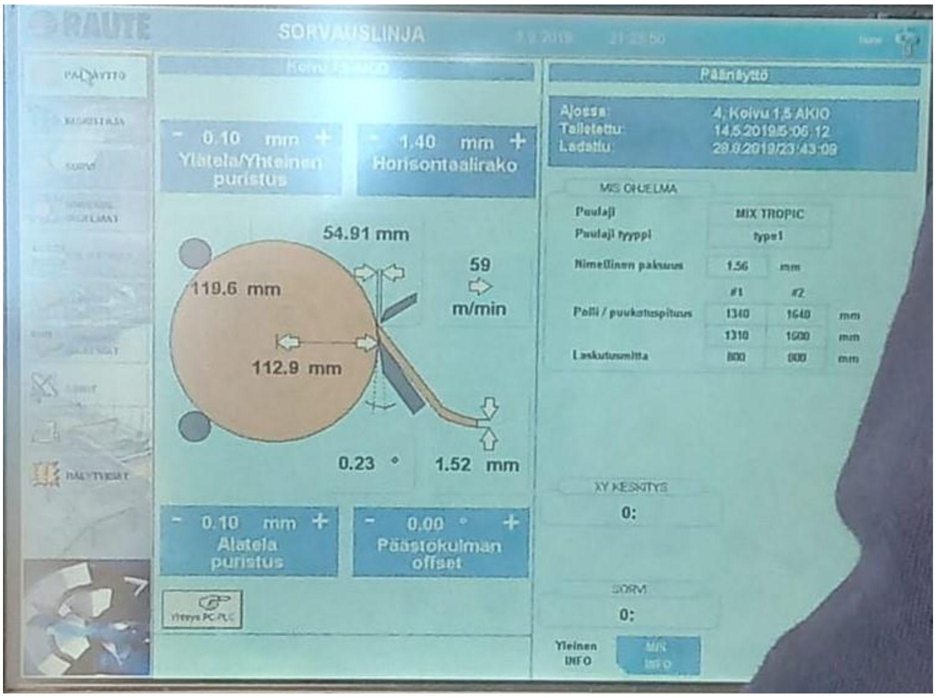

Figure 2.2 Machinery setting for peeling 1.5mm thick veneer mat

Figure 2.2 shows the peeling setting used for veneer peeling for a 1.5 mm thick veneer mat. The veneer peeling speed was set at 59 min/m and the veneer thickness set at 1.52 mm. During the peeling, the efforts were made to manually stretch out and cut the peeled veneer mat so that they do not twist or bend. This was important because the veneer must maintain a smooth surface not only because of colour measurement but also for further research of lathe check inspection and surface roughness that would be determined from the same veneer sheets.

Figure 2.3 Peeled veneer mat from rotary veneer peeling lathe

Figure 2.3 shows the freshly peeled veneer mat spread-out to be cut into size with the help of the guillotine. The peeled veneer sheets were cut into 450 mm x 450 mm and marked accordingly on top of veneer surface before drying.

2.1.3 Veneer Drying, Moisture Content Determination and Storage Conditions

The drying of veneer was performed at constant temperature of 170 ^{0}C. The drying process was started when the steam veneer dryer heated up to 170 ^{0}C. Then the veneer sheets were stacked into the dryer.

Figure 2.4 Veneer sheets stacked up in the steam veneer dryer for drying

Figure 2.4 shows the veneer sheets cut and stacked up in the steam veneer dryer for drying. The oven dry method of determination of moisture content was used. The required moisture content (mc) for measurement samples was 4.5 ± 1.5%. To ensure that the samples attained this mc, the following steps were taken.

1. The smaller (Memmert oven) dryer was used to determine the moisture content of the veneer sheets that were further used to measure the colour
2. The first sheet of wet veneer was dried at temperature of 170 ^oC for 2 minutes. 4 samples of 20 mm x 20 mm pieces were cut, weighed and recorded. The weights were termed as m_1
3. The cut samples were then put in the oven dryer. The standard drying method to measure moisture content was used at 103 ^oC. The pieces were dried at a constant interval of 5 minutes and reweighed. The drying process was performed until there were no further significant changes in the 20 mm x 20 mm veneers pieces weights. The final weights were termed m_2.
4. To determine the moisture content, the following formula was used:

$$mc = (m_1 - m_2)/m_2 \times 100 \qquad \text{Equation 1}$$

where mc – the moisture content, m_1 – initial weight of the dried veneer, and m_2 is the final

5. In the situation where the mc was within the range of 3% - 6%, the drying time of 2 minutes was maintained for the rest of the veneer sheets from the same log sample.
6. In the situation where the mc was more than 6%, the drying time was increased, and the same process repeated until the desired mc was achieved.

After measuring, the average moisture content for all the categories of samples was 4.64%, with drying times ranging from 2 – 3 minutes.
The veneer samples were then kept in a conditioned room with certain climatic conditions with slight variations as shown in Figure 2.5.

Figure 2.5 Veneer storage room climatic setting for veneer samples

Figure 2.5 shows the dry veneer storage room with average temperature of 26 ⁰C and humidity of 10%

2.2 Specimen Sampling

The scheme in Figure 2.6 shows the sample choosing and collecting plan for the colour measurements. To ensure test specimens were spread equally all the depth of the peeled log, samples were taken from every 5th sheet of the cut veneer.

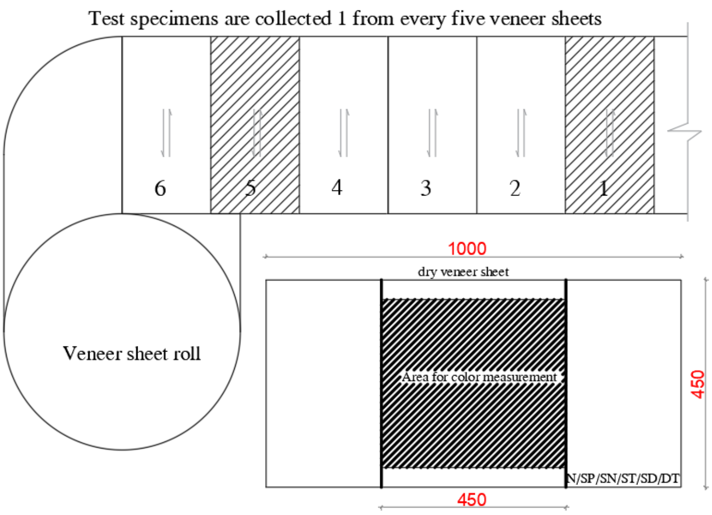

Figure 2.6 Specimen sampling plan for colour measurement. The number of veneer sheet samples and colour measurements taken varies across the log samples.

N – log number, SP – wood specie, SN – sheet number, ST – log soaking temprature, SD – log soaking duration and DT – drying time

Depending on the number of 450 mm x 450 mm sheets produced, the spaces are increased or decreased, and in situations where the next fifth sheet has some spots, defects, or any form of deformation, the next or previous sheet was chosen.

Figure 2.7 Birch veneer sheet with 6 measurement points

Figure 2.7 shows a veneer sheet with colour measurement marks. The marks are numbered and are of the diameter with the colour measurement device; this ensures that the same spots are measured every time.

Table 2.3 The details of veneer sampling for colour measurement

Sample species	Veneer thickness, mm	No. of logs	Soaking temperature, (°C)	Soaking duration, h	No. of veneer sheets	No. of colour measurements taken
Birch	1.5	2	20	48	20	65
Birch	1.5	2	40	48	19	60
Birch	1.5	2	70	48	11	60
Aspen	1.5	2	20	48	20	60
Aspen	1.5	2	40	48	19	60
Aspen	1.5	2	70	48	20	60
Grey Alder	1.5	2	20	48	14	62
Grey Alder	1.5	2	40	48	10	60
Grey Alder	1.5	2	70	48	11	60
Black Alder	1.5	2	20	48	15	62
Black Alder	1.5	2	40	48	20	63
Black Alder	1.5	2	70	48	14	62
Total		**24**	**-**	**-**	**193**	**704**
Birch	1.5	2	20	24	10	30
Birch	1.5	2	40	24	10	30
Birch	1.5	2	70	24	10	30
Aspen	1.5	2	20	24	10	30
Aspen	1.5	2	40	24	10	30
Aspen	1.5	2	70	24	10	30
Grey Alder	1.5	2	20	24	10	30
Grey Alder	1.5	2	40	24	10	30
Grey Alder	1.5	2	70	24	10	30
Black Alder	1.5	2	20	24	10	30
Black Alder	1.5	2	40	24	10	30
Black Alder	1.5	2	70	24	10	30
Total		**24**	**-**	**-**	**120**	**360**
Birch	1	1	20	48	20	60
Birch	1	1	70	48	20	60
Aspen	1	1	20	48	30	60
Aspen	1	1	70	48	28	60
Grey Alder	1	1	20	48	32	64
Grey Alder	1	1	70	48	20	60
Black Alder	1	1	20	48	13	39
Black Alder	1	1	70	48	14	70
Total		**24**	**-**	**-**	**177**	**473**

Table 2.3 shows the details of the samples collected for the three categories and the number of colour measurements performed.

2.3 Veneer Colour Measurement

2.3.1 Device for Colour Measurement

For the colour measurement Colour Quality Controller System CQCS3 was used. The software for the equipment was developed by Shenzhen 3nh Technology Co., Ltd. The software is a high-tech software integrating colourimetry, modern optoelectronics, and computer science. It provides professional normalization, standardization, and data colour management solution for modern enterprises.

The equipment can measure colours directly and the values can be read on its screen. In the case of the great amount of measurement samples in this study, the installed software was used to collect the measure data.

2.3.2 Colour Measurement Plan

The colour of the prepared and marked veneer samples was measured using the spectrophotometer described in section 2.3.1. In the device L*, a* and b* coordinates named by CIELab colour space values was used. L represents the lightness (whiteness) or darkness (blackness) of the sample. The value 100 means that the material is pure white while the value 0 means that the material is pure black. a* and b* represent other unique colours of human vision. a* means green to red while b* means blue to yellow.

Measurement was taken from 8 mm diameter lense of the equiment with 10º observer angle.

For the samples from the logs peeled with soaking duration of 48 h, several measurements were taken at different stages as shown in Table 2.4

Table 2.4 Colour measurement plan for 1.5 mm veneer samples peeled with 48 h log soaking duration

Description	**L***	**a***	**b***
Wet veneer samples	L_w	a_w	b_w
Dry veneer samples (on the day of drying)	L_{d0}	a_{d0}	b_{d0}
Dry veneer samples (1 week after drying)	L_{d7}	a_{d7}	b_{d7}
Dry veneer samples (1 month after drying)	L_{d28}	a_{d28}	b_{d28}
Dry veneer samples (4 months after drying)	L_{d120}	a_{d120}	b_{d120}

Table 2.4 shows the details of colour measurements on the 1.5 mm thick veneer sheet samples peeled with the log soaking duration of 48 h and soaking temperature of 20 ^{0}C, 40 ^{0}C, and 70 ^{0}C. L_w, a_w, and b_w represents the colour coordinates measured on the wet veneer sheets after peeling before drying.

Table 2.5 shows the details of colour measurements on the 1.5 mm thick veneer sheets peeled with the log soaking duration of 24 h and soaking temperature of 20 ^{0}C, 40 ^{0}C, and 70 ^{0}C.

Table 2.5 Colour measurement plan for 1.5 mm veneer samples peeled with 24 h log soaking duration

Description	**L***	**a***	**b***
Dry veneer samples peeled with 20 ^{0}C log soaking temperature	L_{20}	a_{20}	b_{20}
Dry veneer samples peeled with 40 ^{0}C log soaking temperature	L_{40}	a_{40}	b_{40}
Dry veneer samples peeled with 70 ^{0}C log soaking temperature	L_{70}	a_{70}	b_{70}

Tables 2.6 shows the last set of veneer samples made up of 1 mm thick veneer. Two sets of samples were chosen. In the first set samples, every fifth sheet starting from first sheet was collected and in the second set of sample, every fifth sheet starting second sheet was collected from the veneer mat. The colour coodinates of the first set (L_{w0}, a_{w0} and b_{w0}) were measured and dried the same day. The colour coordinates of the dried sample were also measured as (L_{d0}, a_{d0} and b_0) for the second set, the colour coordinates were measured (L_{w0}, a_{w0} and b_{w0}). The samples were left wet for 24 h and

subsequently on the next day re-measured as (L_{w1}, a_{w1} and b_{w1}). The samples were then dried and the colour coordnates of the dry samples were then measured as (L_{d0}, a_{d0} and b_0). After 1 week, the colour coordinates of the 2 set of samples were measured again (L_{d7}, a_{d7} and b_7).

Table 2.6 Colour measurement plan for 1 mm veneer samples peeled with 48 h log soaking duration

Description (1st set)	**L***	**a***	**b***
Wet veneer samples (immediately after peeling)	L_{w0}	a_{w0}	b_{w0}
Dry veneer samples (dried after 24 of peeling)	L_{d0}	a_{d0}	b_{d0}
Dry veneer samples (dried after week of drying)	L_{d7}	a_{d7}	b_d
Description (2nd set)			
Wet veneer samples (immediately after peeling)	L_{w0}	a_{w0}	b_{w0}
Wet veneer samples (24 h after peeling)	L_{w1}	a_{w1}	b_{w1}
Dry veneer samples (dried after 24 of peeling)	L_{d0}	a_{d0}	b_{d0}
Dry veneer samples (dried after week of drying)	L_{d7}	a_{d7}	b_{d7}

2.3.3 Data Analyses

The colour test results and colour differences obtained from the different parameters used in this work were evaluated for significance by means of analysis of variance (ANOVA) which measures differences between means of different results, which were then compared and segregated by Tukey's test ($P < 0.05$).

3 RESULTS AND DISCUSSION

3.1 Visual Observation

Visual assessment of the colour of any material is a very subjective way to view colour. However, efforts were still made to observe the samples during preparation and colour measurements. It appears that aspen had the most homogeneous colour through the whole veneer mat as well as across all the veneer preparation parameters of different log soaking temperatures and soaking durations. The samples were visibly lighter than the samples from other wood species. Grey and Black alder had the most un-uniform colour across the veneer mats and all the parameters considered.

3.2 Colour Measurement Result

Colour measurements were carried out on all the categories of veneer samples collected as shown in Table 2.3 based on the colour measurement and veneer sampling plans shown in Figures 2.4, 2.5, and 2.6. The details of the measurements performed are as shown.

3.2.1 Effects of Soaking Temperature on Veneer Colour

Figure 3.1 shows the different lightness values for birch, aspen, black and grey alder soaked at 20 ºC, 40 ºC and 70 ºC for 24 h.

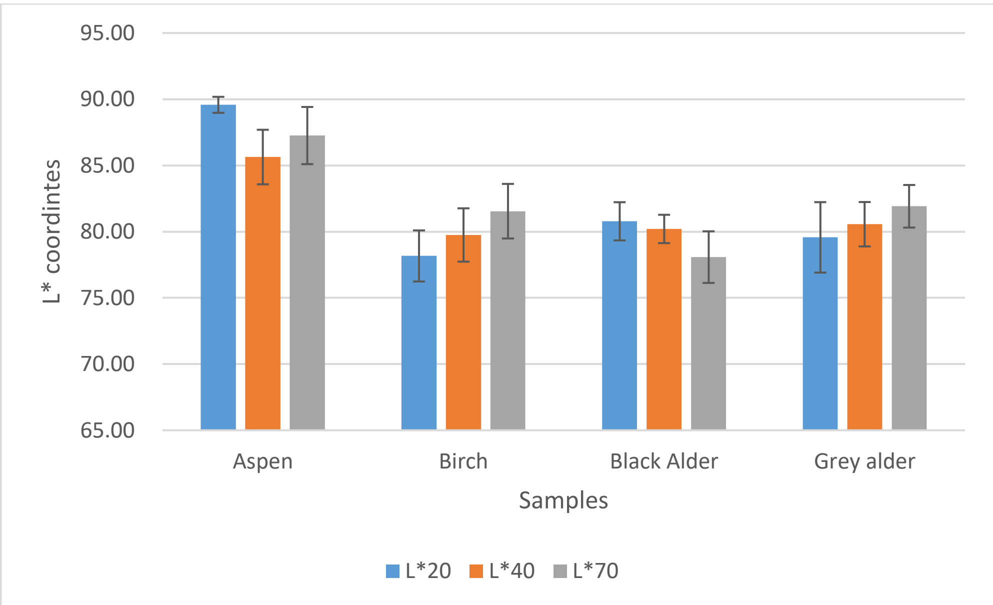

Figure 3.1 L* (lightness) coordinates of aspen, birch, black and grey alder for 24 h at different soaking temperature

Veneer samples from birch logs increased in L* (lightness) with increasing soaking temperature. With 20 ºC soaking birch samples had 81.55 but dropped to 78.17 with 70 ºC. The same applies to grey alder veneer samples, 81.92 with 70 ºC but 79.57 with 20 ºC. Black alder in other hand, decreased in lightness with increasing soaking temperature. The difference in lightness for black alder veneers was more noticeable between 20 ºC and 40 ºC and less so between 40 ºC and 70 ºC. This means that at 70 ºC soaking temperature, birch and grey alder veneer has lighter appearance but black alder appears darker.

Aspen veneer samples showed no consistent pattern with the three log soaking temperatures but were lighter at 20 ºC and darker at 40 ºC.

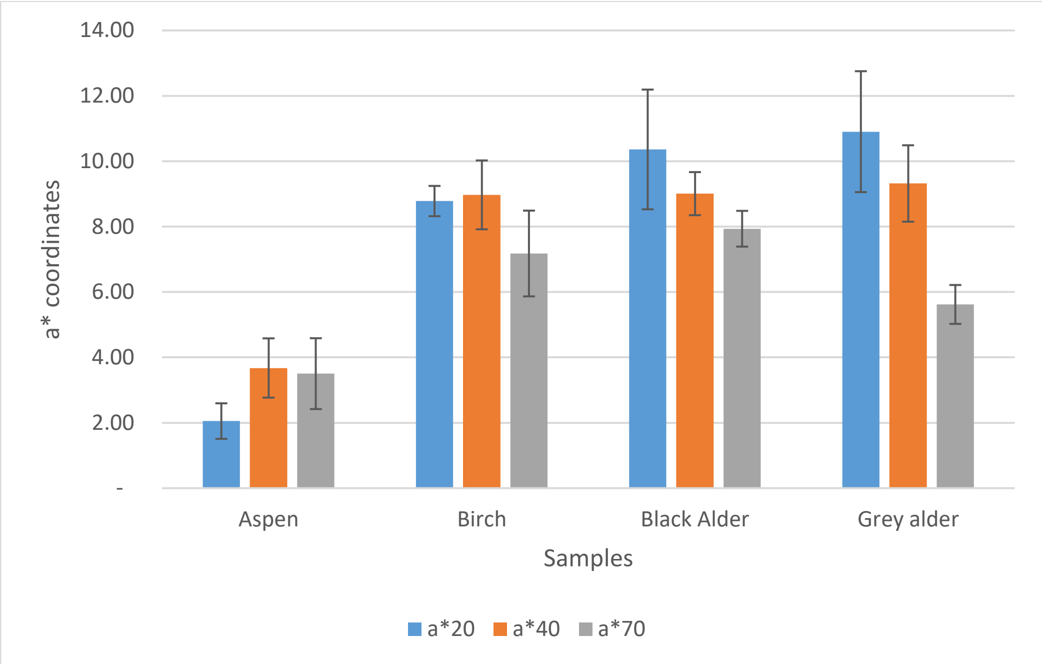

Figure 3.2 a* (red) coordinates of aspen, birch, black and grey alder for 24 h at different soaking temperature

Black and grey alder samples soaked at 20 ºC had significantly different a* (redness) value than those of 40 ºC and 70 ºC. There, the redness reduced with increase of soaking temperature. Birch samples of 20 ºC were more reddish than those ones of 40 ºC and 70 ºC which had no difference between them. The samples from aspen soaked at 40 ºC, and 70 ºC had no signifant change in redness value but differed from those soaked at 20 ºC which had lower value as it can be seen in Figure 3.2. This implies that birch, black and grey alder veneer samples are yellower at low soaking temperatures.

Generally, it can be stated that for birch, black, and grey alder veneer samples, the redness value decreased with increased soaking temperature and for aspen samples, the a* value increased with increased soaking temperature.

Figure 3.3 shows the effects of soaking temperature on the yellowing of the four wood species soaked at different log soaking temperature. The veneer samples from the peeled aspen logs pre-soaked at 40 ºC and 70 ºC showed similar yellowing effect but differed significantly from those produced at 20 ºC of soaking temperature.

40 ºC soaking temperature had the most significant yellowing effect on birch samples followed by those of 20 ºC and had the least b* values with samples from 70 ºC.

Black and grey alder had similar yellowing effect with samples from 20 ºC having higher b* values than those from 40 ºC and least on 70 ºC samples. Lower soaking temperatures more yellowish than from 70 ºC.

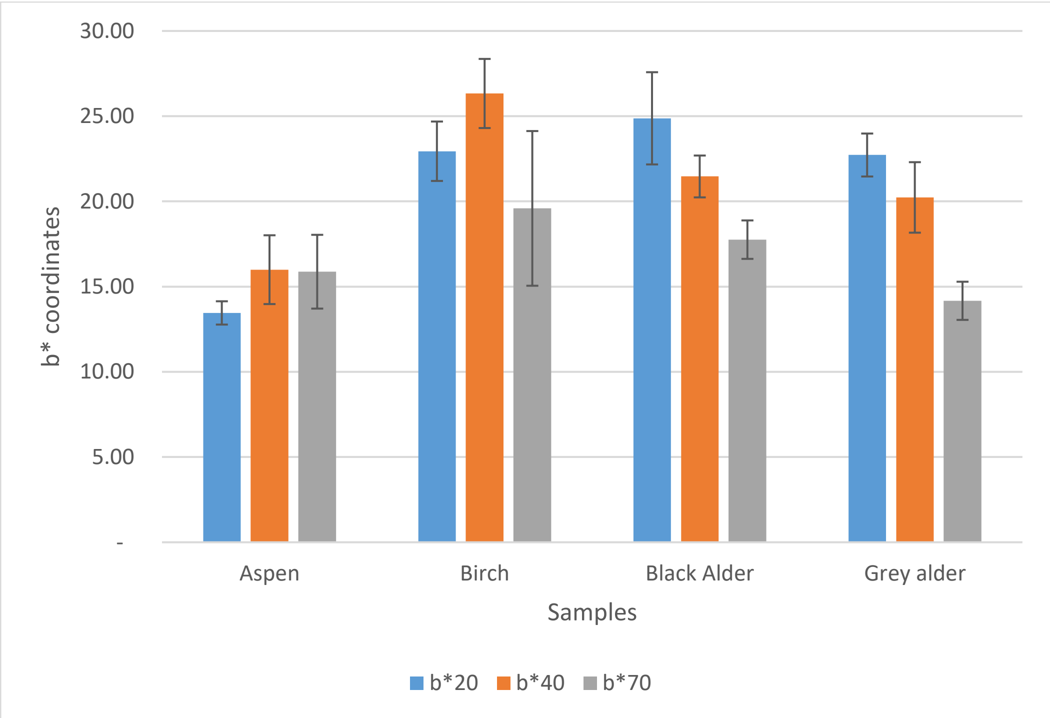

Figure 3.3 b* (yellow) coordinates of aspen, birch, black and grey alder for 24 h at different soaking temperature

Figure 3.4 shows the significant yellowing effect of 40 ^{0}C soaking temperature on the birch samples.

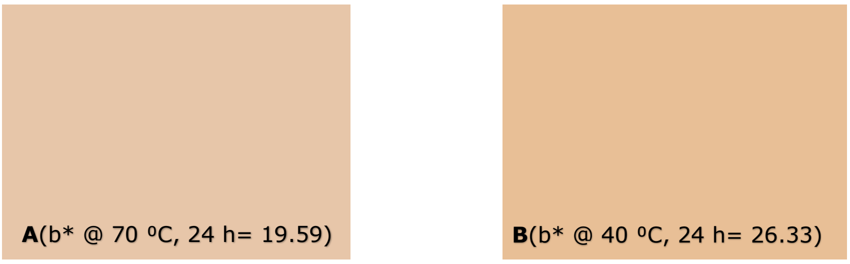

Figure 3.4 The colour tone of veneer soaked at 40 ^{0}C and 70 ^{0}C for 24h

Figure 3.4 shows The b* coordinates (19.59) of the birch veneer soaked at 40 ^{0}C had significantly lower value than those from samples soaked at 70 ^{0}C (26.33). The phenomenon also applies to the alder samples but not obvious with the aspen samples.

Generally, the results have show that elevated soaking temperature leads to decrease in the b* values of birch, grey, and black alder veneer samples. Figure 3.4 also proves that b* coodinates have a greater influence on the wood colour than that of L* and a*.

The results obtained have shown that different wood species react differently to heat in terms of colour changes as suggested by (Babiak et al., 2007). These colour alterations depend largely on the wood specie since they vary in structure and chemical composition. As discussed earlier in Section 1.3.2, the alteration of wood colour when the wood materials are exposed to heat due to complex chemical reactions of the wood polymers which leads to photodegration of lignin part and extractives as opined by both (Bonifazi et al., 2015; Rosu et al., 2010). This therefore suggests that colour alteration depends on the lignin content of the wood specie and the quantity of the heat the wood is exposed to. There are also no documented directions on what way these alterations would take, if they will alter the wood colour by improving the L*, a* and b* values or reducing it.

Figure 3.5 shows the differences in L* coordinates for birch, black and grey alder veneers. There was no remarkable difference at the different log soaking temperatures for the aspen samples suggesting that there might not have been any structural modifictions leading to colour change upon the thermal exposure.

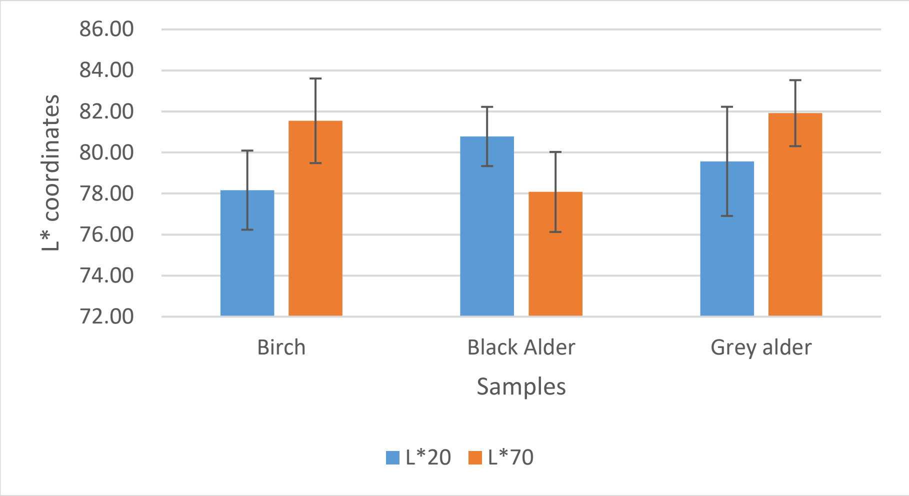

Figure 3.5. Differences in L* (lightness) coordinates of birch veneer prepared at 20 ºC and 70 ºC soaking temperature and at 48 h soaking duration

It can be deduced from these results that soaking of the birch and grey alder logs at 70 ºC increased the L* (lightness) values significantly while the reverse is in the case of the black alder samples. The lightening of birch with 70 ºC soaking temperature agrees with (Rohumaa, 2016). But it seems perhaps that the component of wood colour affected mostly by the change in temperature was the b* (yellow). The log soaking temperature of 70 ºC caused significant de-yellowing on the birch and alders samples while there was no much difference between 20 ºC and 40 ºC. This had an overall impact on the samples making them look pale and this is even obvious to the physical eyes as it can be seen in Figure 3.4.

Again, 70 ºC soaking temperature for 24 h lowered the redness values of all the wood species tested but showed no differences between 20 ºC and 40 ºC just like in the L* and b* colour components discussed above suggesting that increasing soaking temperature from 20 C to 40 may not have been able to significantly alter the structural chemistry of the wood.

Table 3.1 The effects of soaking temperature on a* and b* colour values of test wood species.

Sample specie	**a^*_{20}**	**a^*_{40}**	**a^*_{70}**	**b^*_{20}**	**b^*_{40}**	**b^*_{70}**
Aspen	2.05	3.68	3.50	13.46	15.99	15.87
Birch	8.78	8.97	7.18	22.94	26.33	19.59
Black Alder	10.36	9.01	7.93	24.88	21.46	17.76
Grey alder	10.90	9.32	5.62	22.72	20.23	14.17

70 ⁰C soaking temperature improved both the a* and b* values of aspen wood but had direct opposite effects on the saples from birch, black alder and grey alder wood.
It was also checked to see how colour changes across the veneer produced from one log soaked for 24 h at 20 ⁰C, 40 ⁰C, and 70 ⁰C. But no statistically significant differences were observed among the wood species considered.

3.2.2 Effect of Soaking Duration on Veneer Colour

Table 3.2 shows the comparison between the lightness values of veneer samples of the test wood species peeled with 48 h log soaking duration and different soaking temperature. The results show that there was significant drop in lightness for the birch samples soaked at 70 ⁰C and 40 ⁰C, compared to those soaked at 20 ⁰C. For the aspen samples, 70 ⁰C soaking temperature reduced the L* values from 86.96 for 20 ⁰C, 48 h to 85.53 which was close for 40 ⁰C, 48 h.
The grey and black alder samples peeled with 70 ⁰C soaking temperature improved in the lightness values but recorded no noticeable change between 20 ⁰C and 40 ⁰C.

Tabel 3.2 L* (lightness) values for dry veneer samples soaked for 48 h at different log soaking temperatures of 20 ⁰C, 40 ⁰C, and 70 ⁰C

Samples	**L^*_{20}**	**L^*_{40}**	**L^*_{70}**
Birch	83.01 ± 1.33	81.27 ± 2.05	81.42 ± 1.17
Aspen	86.96 ± 1.62	86.95 ± 2.65	85.53 ± 2.02
Black Alder	76.82 ± 2.42	77.15 ± 4.04	79.68 ± 1.19
Grey Alder	76.14 ±3.15	75.41 ± 3.15	81.81 ± 1.13

Figure 3.6 shows the b* coordinates measurement results of the test sample of species. The b* values were the most affected colour coordinate in the samples from 48 h log soaking duration. The black and grey alder samples had consistently reduced b* values with increase in soaking temperature. The drop in yellow colour was more obvious in the 70 ⁰C samples than the samples of 40 ⁰C in both cases. The aspen samples have shown no significant differences in the samples from the soaking temperatures.

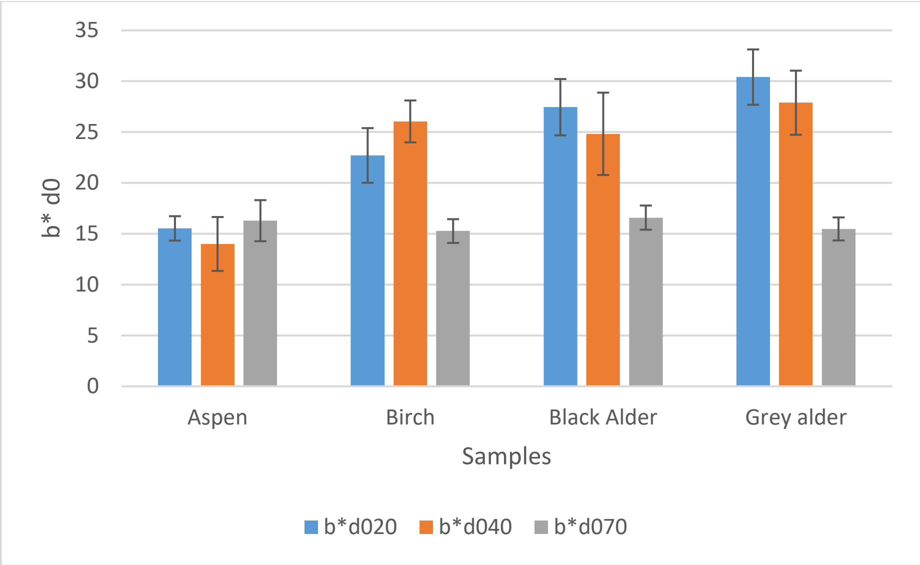

Figure 3.6 b* (yellow) coordinates of aspen, birch, black and grey alder for 24 h at different soaking temperature. Where b*d020, b*d040, and b*d0 is freshly dried veneer samples peeled at 20, 40, and 70 ºC, respectively

The a* values had similar trend as b* values decribed above across all the wood species and soaking temperature. The higher the soaking temperature, the less yellowish the veneer samples were.

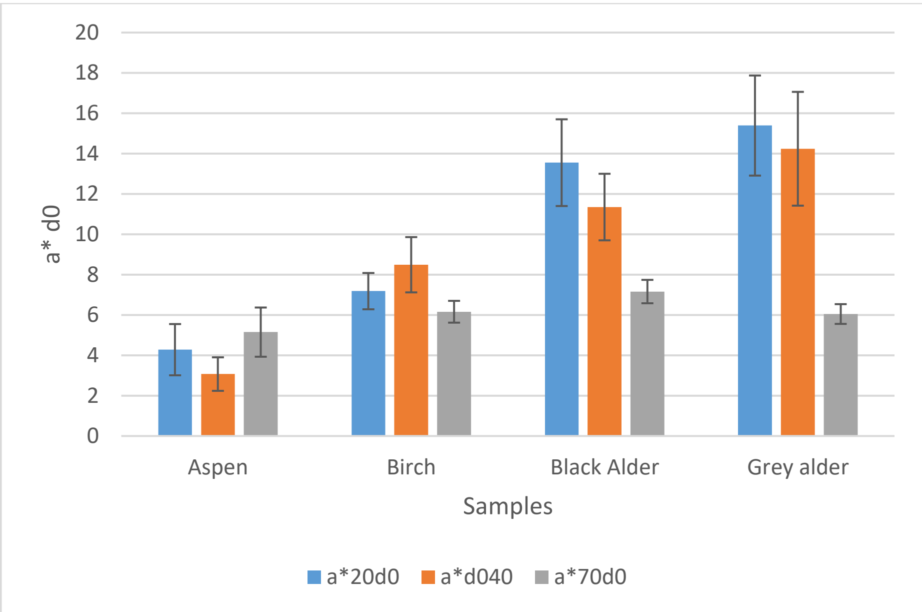

Figure 3.7 a* (red) coordinates of aspen, birch, black and grey alder for 24 h at different soaking temperature, where a*d020, a*d040, and a*d0 is freshly dried veneer samples peeled at 20, 40, and 70 ºC, respectively

Figure 3.7 shows the effect of the different log soaking temperatures on the a* (red) coordinates of the four wood species and they were similar to the trend seen in the samples soaked for 24 h.

The veneer samples soaked for 48 h and peeled with log soaking temperatures of 20 ºC, 40 ºC, and 70 ºC were measured for colour when freshly dried and stored in a conditioned room. The subsequent measurements were taken after some time intervals as indicated to see the influence of time on the dried veneer.

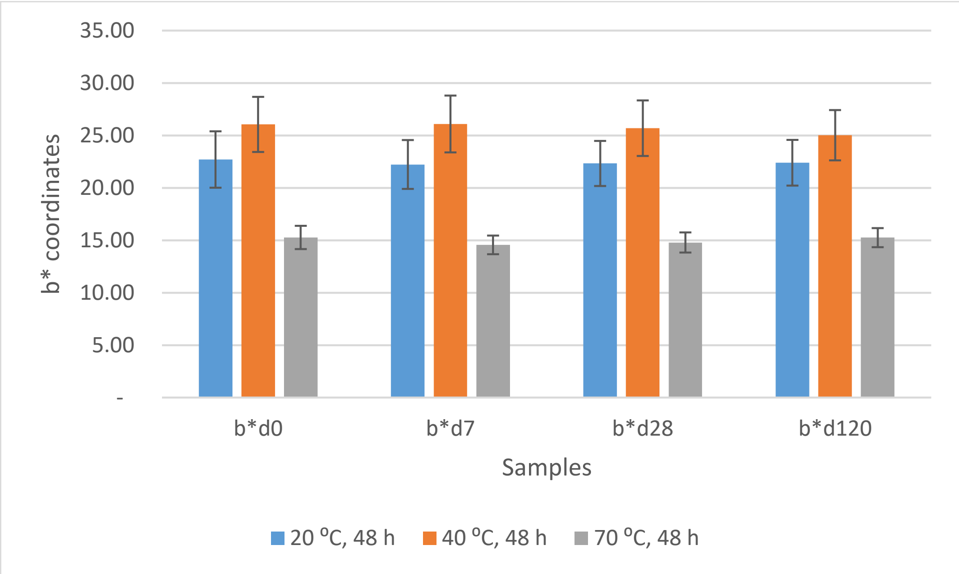

Figure 3.8 b* (yellow) coordinates dried birch veneer samples from logs soaked for 20 C, 40 C, and 70 C at different intervals (0, 7, 28, and 120) days after drying.

Figure 3.8 shows that no changes occurred on the b* (blue to yellow) colour coordinates of the dried veneer samples in 120 days after drying.

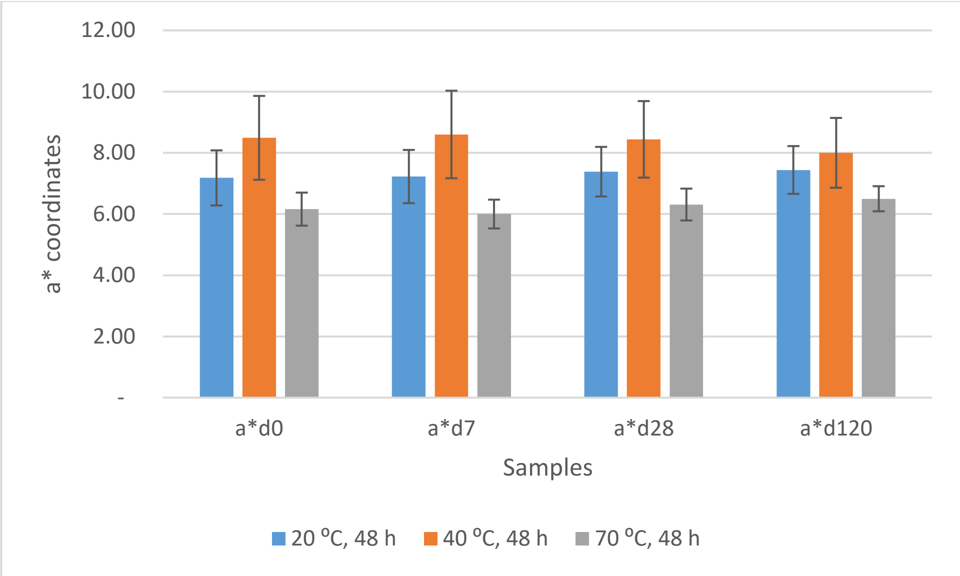

Figure 3.9 a* (red) coordinates for dried birch veneer samples from logs soaked for 20 °C, 40 °C, and 70 °C at different intervals (0, 7, 28, and 120) days after drying

Figure 3.9 shows there were no clear differences within 120 days' time intervals in the a* values of the birch veneers across the various veneer production parameters. Even though the lightness values dropped a little after 28 days but not enough to cause any serious change in the veneer colours.

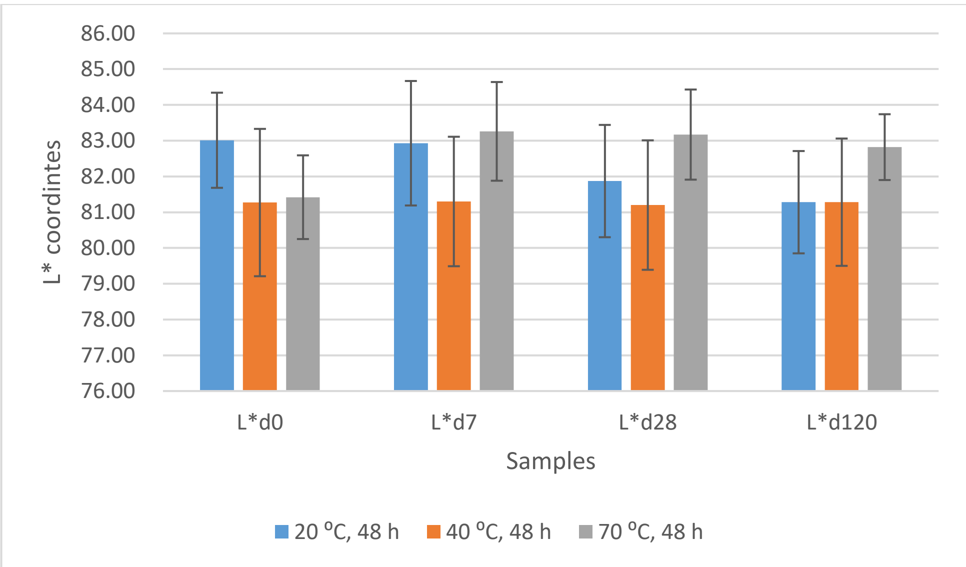

Figure 3.10 L* (lightness) coordinates for dried birch veneer samples from logs soaked for 20 °C, 40 °C, and 70 °C at different intervals (0, 7, 28, and 120) days after drying

The grey alder veneer samples have shown no significant difference in L* and b* coordinates after 120 days of drying. There was however, a slight drop in the a* values of the samples of 20 °C and 40 °C after 120 days of storage as it can be seen in Figure 3.11.

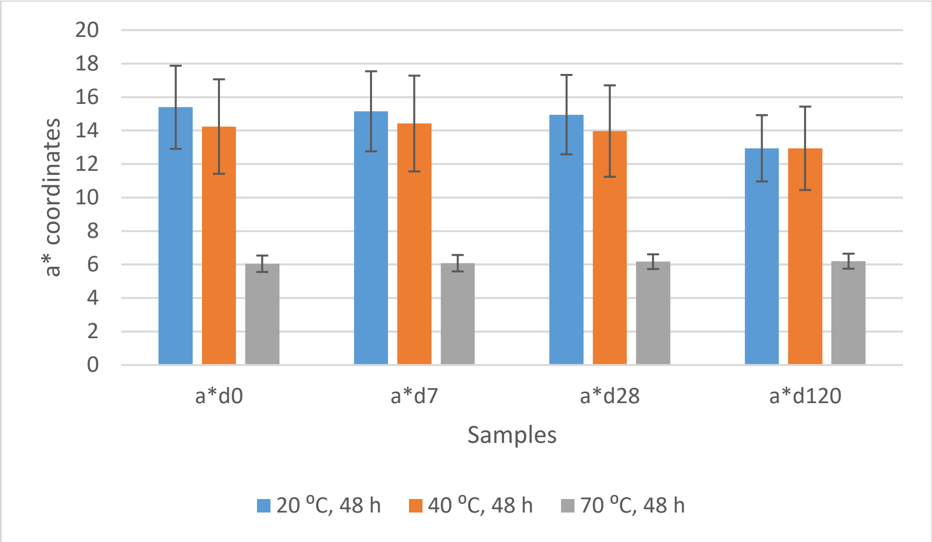

Figure 3.11 a* (red) coordinates for dried grey veneer samples from logs soaked for 20 ºC, 40 ºC, and 70 ºC at different intervals (0, 7, 28, and 120) days after drying

Generally, the literature studied shows that it may take up to 12 hours for the heat to penetrate the core (Pith) of the wood, this will majorly depend on the diameter of the logs being considered.

Figure 3.12 shows that the L* values of the birch samples soaked for 24 h at 20 ºC had very clear and significant differences with those ones soaked for 48 h with the same temperature. This phenomenon improved slightly with 40 ºC and was almost nonexistent in the samples soaked at 70 ºC. It could be concluded that the higher temperature had a greater impact on the structural composition of the wood colour than the lower soaking temperatures of 20 ºC and 40 ºC across the two different soaking durations of 24 h and 48 h.

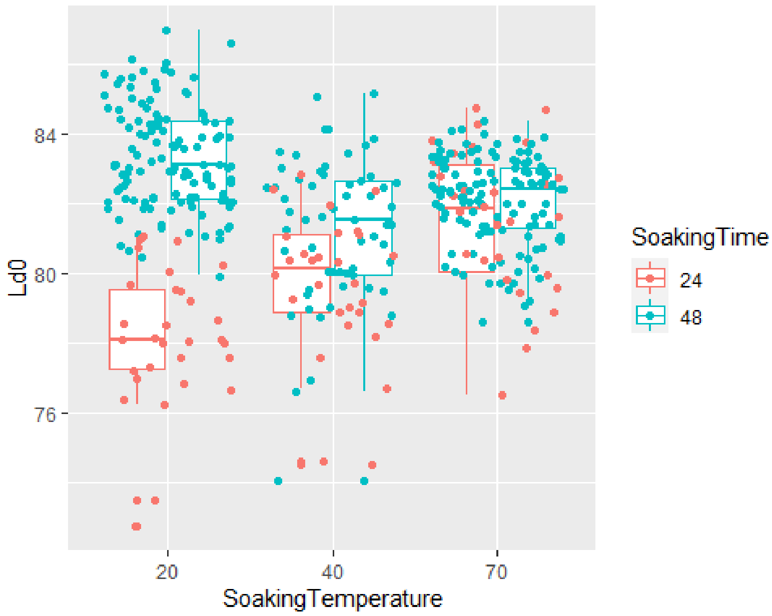

Figure 3.12 L* (lightness) coordinates of the birch samples with 24 h and 48 h soaking duration.

Figure 3.13 shows that a* values birch samples, following trend, clearly different from 20 ºC and a little bit clear with 40 ºC and almost nonexistent with 70 ºC samples.

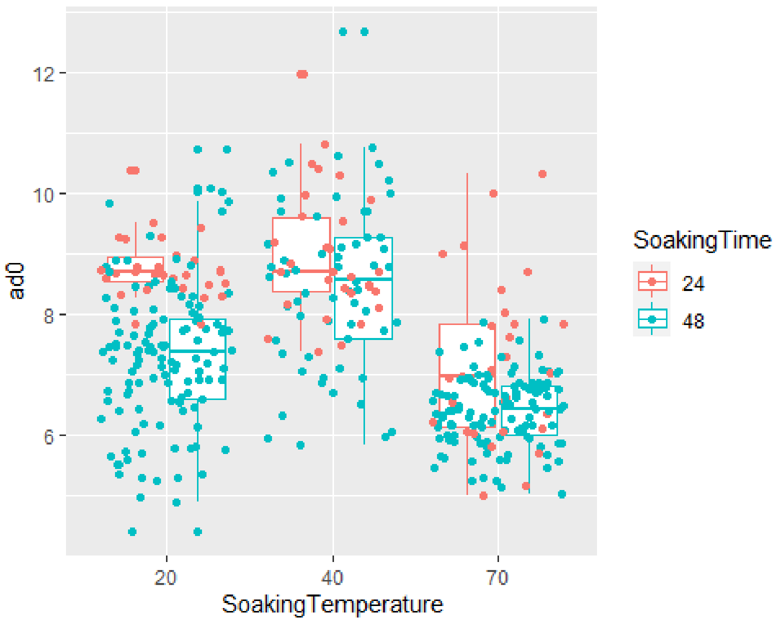

Figure 3.13 a* (red) coordinates of the birch samples with 24 h and 48 h soaking duration.

Figure 3.14 shows that b* had slightly different trend compared to a* and L* discussed above. This time, the colour three soaking temperatures appear to have the same effect on the yellowing of the birch veneers across 24 h and 48 h soaking times.

One thing remains clear that there is the very notably deyellowing effect of 70 ºC log soaking temeperature.

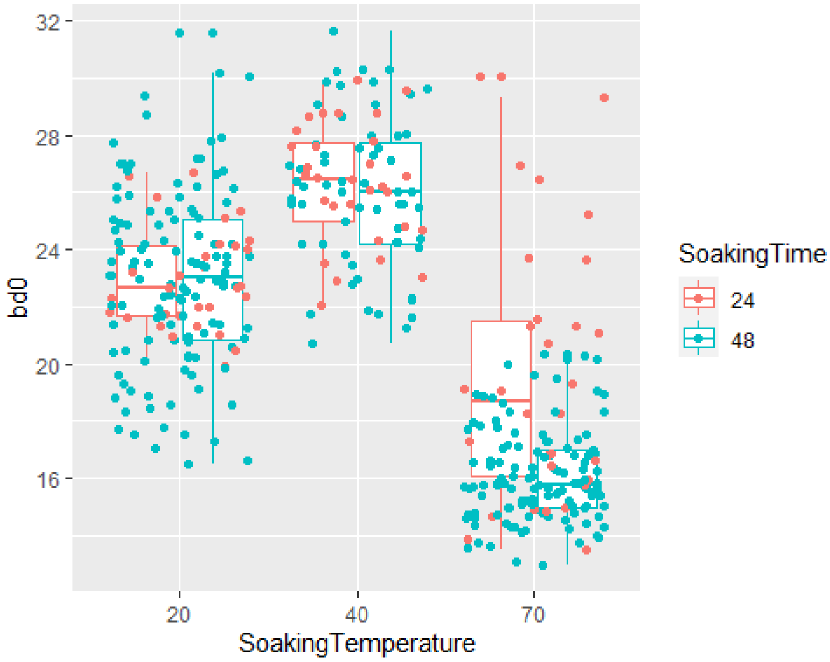

Figure 3.14 b* (yellow) coordinates of the birch samples with 24 h and 48 h soaking duration.

Of course, there could be other factors, which could affect such as seasonal variations on the harvesting and processing of the material with the 24 h samples mainly from Autumn/Winter logs while the 48 h samples were processed from Spring/summer logs. Interestingly, the colour of wood from different seasons has a similar trend as shown by (Rohumaa et al., 2014) on contact angle measurements. The studies by (Rohumaa et al., 2014) have shown that the material felled in different seasons and soaked at higher temperature (70 ºC) had similar wetting properties, oppositely the same material soaked at 20 ºC showed remarkably differences in wettability.

The samples soaked for 48 hours were subjected to series of additional colour measurements after drying to see how the colour will change and in which direction. The samples were stored in the conditioned room. After 120 days, none of the samples showed any notable change, although L* values for aspen altered a little but not enough to cause any serious difference in the overall colour. This suggests that with the dry moisture content of 3-6%, veneer colour remains constant. Although, it should be expected that if the materials are subjected to use, there may be some form of discoration caused by weathering factors or due to wear and tear.

3.2.3 Effects of Delayed Drying of Veneer Colour

Figure 3.15 shows the lightness values for two sets of the birch veneer samples. The lightness was lower on both wet sets of the samples (L* w0 (1) and the second set L*w0 (2)) than on the dry samples. There are no significant differences between the dried samples of the two sets. However, the standard deviation decreased after the drying.

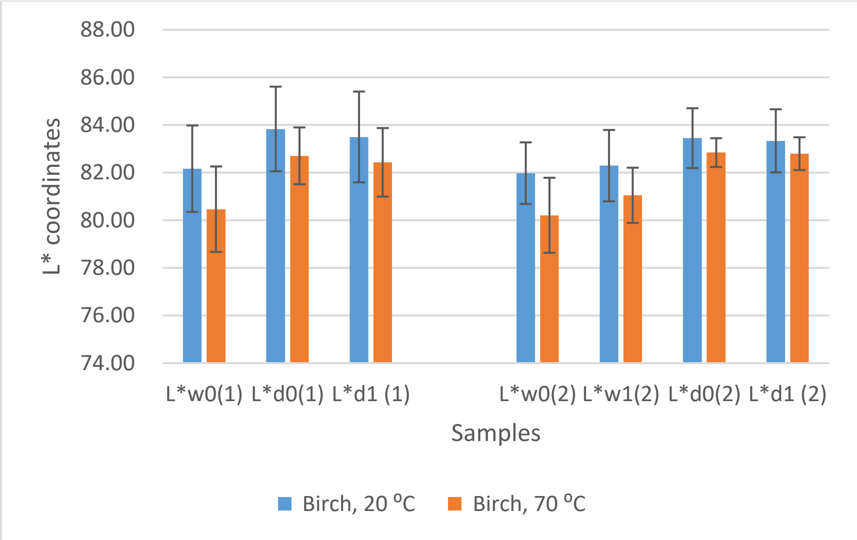

Figure 3.15 Colour coordinate L* values for 1mm birch samples with different drying time after peeling (1) first set dried immediately after peeling and (2) dried after 24 h. Where Lw0 is wet veneer, Lw1 is wet veneer after 24 h, Ld0 is freshly dried veneer, and Ld1 is dried veneer after 7 days

Figure 3.16 and 3.17 show the a* (green to red) and b* values for the birch veneer samples. The changes occured with delayed drying time. However, the stadard deviation of the samples soaked at 70 ºC was remarkably lower than of those ones from 20 ºC.

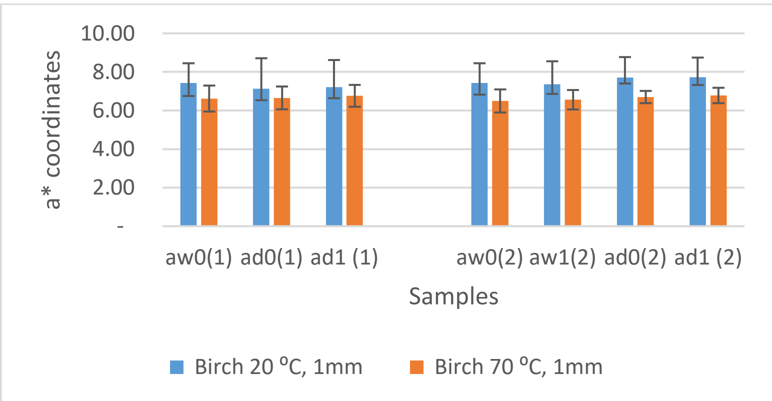

Figure 3.16 Colour coordinate a* values for 1mm birch samples with different drying time after peeling (1) first set dried immediately after peeling and (2) dried after 24 h. Where aw0 is wet veneer, aw1 is wet veneer after 24 h, ad0 is freshly dried veneer, and ad1 is dried veneer after 7 days

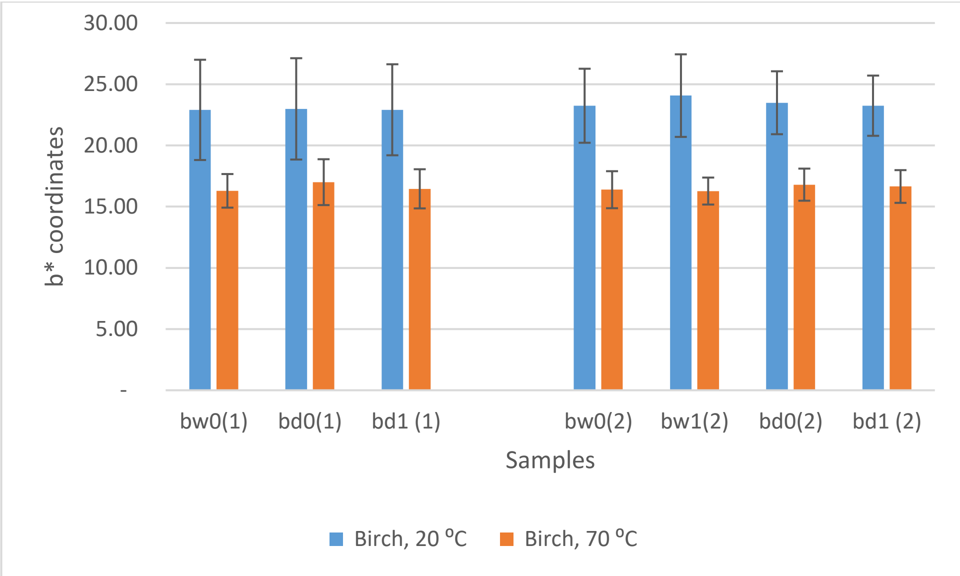

Figure 3.17 Colour coordinate b* values for 1mm birch samples with different drying time after peeling (1) first set dried immediately after peeling and (2) dried after 24 h. Where bw0 is wet veneer, bw1 is wet veneer after 24 h, bd0 is freshly dried veneer, and bd1 is dried veneer after 7 days

The aspen logs soaked at 70 °C displayed similar trend like the birch log discussed above. The dried veneer has shown no significant different in all the colour space values of L* a* and b* between the samples dried immediately and those ones dried 24 h later.

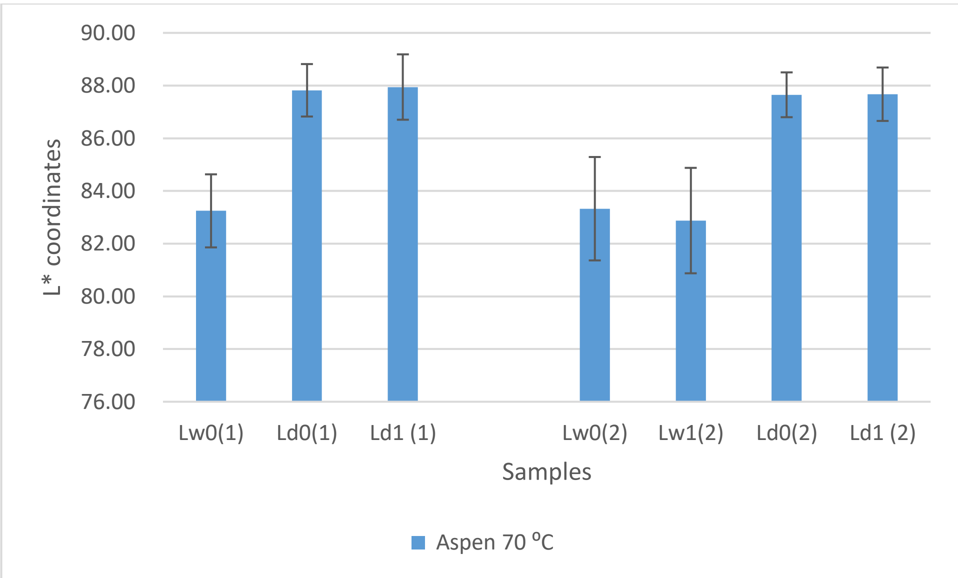

Figure 3.18 Colour coordinate L* values for 1mm aspen samples with different drying time after peeling (1) first set dried immediately after peeling and (2) dried after 24 h. Where Lw0 is wet veneer, Lw1 is wet veneer after 24 h, Ld0 is freshly dried veneer, and Ld1 is dried veneer after 7 days

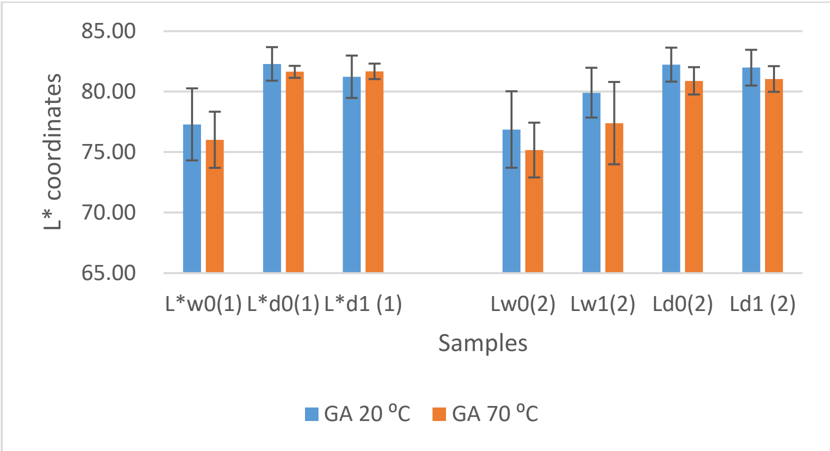

Figure 3.19 Colour coordinate L* values for 1mm grey alder samples with different drying after peeling (1) first set dried immediately after peeling and (2) dried after 24 h. Where Lw0 is wet veneer, Lw1 is wet veneer after 24 h, Ld0 is freshly dried veneer, and Ld1 is dried veneer after 7 days

Figure 3.19 shows the lightness values for the grey alder samples soaked at 20 °C and 70 °C. Again, the results show similar trend to the birch and black alder samples. Here, the standard deviation for both sets of samples becomes remarkably smaller with the the dried samples. This applies also to the colour coordinate of a* and b* values.

Figure 3.20 shows L* values for the black alder logs demonstarting the same trend with other wood species tested. This also applies to the a* and b* colour coordinate values. Here also, the standard deviations of dry samples remained low in dry veneer.

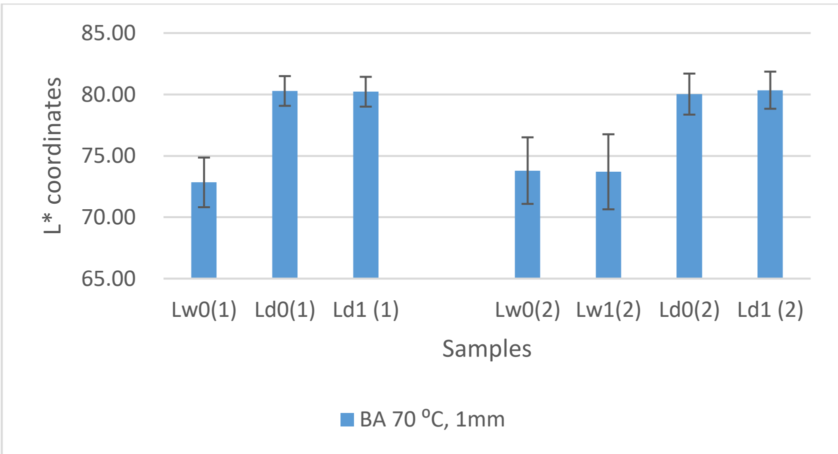

Figure 3.20 Colour coordinate L* values for 1mm black alder samples with different drying time after peeling (1) first set dried immediatetely after peeling and (2) dried after 24 hours. Where Lw0 is wet veneer, Lw1 is wet veneer after 24 h, Ld0 is freshly dried veneer, and Ld1 is dried veneer after 7 days

CONCLUSIONS

The wood logs from four wood species, aspen, birch, grey and black alder, were thermally pretreated (log soaking) at soaking temperatures of 20 ºC, 40 ºC and 70 ºC for 24 h and 48 h. All logs were rotary peeled into veneer mats to produce three sets of samples. The first set of samples was 1.5mm dried veneer samples (4.5 ± 1.5% mc) soaked for 48 h with the different soaking temperatures to test how log soaking duration affects veneer colour. The second set, 1.5mm dried veneer samples (4.5 ± 1.5% mc) soaked for 48 h at the different soaking temperatures to test how log soaking temperatures affect veneer colour. The third set of the samples was 1mm wet veneers (later dried to 4.5 ± 1.5% of mc after the initial colour measurement) soaked for 48 h at soaking temperatures of 20 ºC, and 70 ºC to test how the delay in veneer drying affects colour.

All the above was necessary to achieve the main objectives of this study which was to provide answers to the following research questions:

1. What are the effects of different log soaking temperatures on veneer colour?
2. Does the log soaking duration affect veneer colour?
3. Does delaying in drying of veneer have any impact on colour of dry veneers?

After the review of the results obtained, the following conclusions were made:

1. Increased log soaking temperature affects veneer colour mostly by making them lighter. Especially, when the logs are soaked t temperature above 40 ºC, this lighting effect of high soaking temperatures was caused majorly due to an increase in L* coordinates and decrease in b* (yellow) coordinates of the dried veneer sample specimens. The de-yellowing effect on the colour of veneer surfaces occasioned by high soaking temperatures seems to be the primary cause of alteration in colour. The a* (red) appeared not to vary as much across the different log soaking temperatures. The phenomenon is more noticeable with birch and the alder wood species and less with the aspen samples. These results agree with the research by (Bonifazi et al., 2015; Rosu et al., 2010). Their studies have shown that the elevated temperature leads to complex chemical reactions, always leading to photodegradation of lignin and extractives. It can be agreed that log soaking temperatures below 40 ºC are not enough to trigger such reactions on the wood materials.

2. The soaking duration of logs before veneer peeling was seen not to influence the colour of dried veneers produced from the different wood species as much as the different soaking temperatures, especially at higher soaking temperatures from 40 ^{0}C. The trends identified in the veneer samples soaked for 24 h were similar, lightening, and de-yellowing of colour with increased log soaking temperature. However, the values cannot be compared effectively because the two sets of the samples were produced from the logs that were not harvested or processed from the same season, which could influence the colour results obtained. It could be investigated if the changes in log soaking time from 24 h to 48 h affect other properties of wood differently but would be done in the same period with the same log characteristics. Also, veneer colour will not change colour when it was dried to a moisture content below 5% when they have not been put to any form of use. The samples could be stored safely in a conditioned room to be sure it will retain the colour. This might be an interesting discovery to woodworkers to know that the material colour will be intact if it is stored in good conditions without exposure to any weathering agent.

3. When the veneer mats are rotary peeled, a delay in drying time would not lead to any notable changes in the dried veneer's colour as it is seen in the results obtained. This was the case with all the sample species tested. Although there were differences between the fresh wet veneer samples and the wet ones after 24 hours, these changes could be because, within 24 h, the wet samples may have lost some moisture through evaporation, which affects the colour. One thing was clear though, the low standard deviations values were observed on the dried veneer samples which were not so noticeable in the wet samples. This suggests that wet veneer (or maybe even solid wood) changes colour rapidly and not having a harmonious colour tone before the samples are subjected to heat during drying. This seemingly rapid colour change on the wet surface could be because of some form of chemical reactions triggered by the moist surface of the veneer exposed to the atmospheric conditions. These reactions certainly will not be possible upon drying and such could be the reason the dried veneer had less variations on their colour coordinates.

SUMMARY

In veneer production, wood logs are hydrothermally pre-treated (soaked or steamed) to soften the wood material for more effective production. When wood logs are heated up during pre-treatment before being rotary peeled into veneer mat, there are alterations in their physical and chemical properties. The study is aimed at determining the effect of hydrothermal pre-treatment on peeled veneer colour. The study aims to answer to the following questions: a) How does the log soaking temperature affect the colour of Estonian hardwoods? b) How does the soaking duration affect the colour throughout the veneer mat? c) How does the delay in drying of veneer affect the colour of Estonian hardwoods?

In this study birch, aspen, black and grey alder wood logs were used. The logs were soaked at 20 ºC, 40 ºC, and 70 ºC for 24 h and 48 h. Following the soaking process, the logs were rotary peeled into veneer mats and subsequently dried at 170 °C to a moisture content not exceeding 5%. Colour measurements were performed using CIELab colour space to determine the effects of these pre-treatment variables on veneer colour.

The results of the study show that the log soaking temperature has significantly influenced birch, black and grey alder veneers colour. Increased log soaking temperature affects veneer colour mostly by making them lighter. Especially when logs are soaked with a temperature above 40 ºC, this lightening effect of high soaking temperatures was caused majorly due to an increase in L* (lightness) coordinates and decrease in b* (yellow) coordinates of the dried veneer sample specimens. The de-yellowing effect on the colour of veneer surfaces occasioned by high soaking temperatures seems to be the primary cause of alteration in colour. The colour coordinate a* (red) appeared not to vary as much across the different log soaking temperatures. The phenomenon is more noticeable with birch and the alder wood species and less on the aspen samples.

The soaking duration of logs before veneer peeling was seen not to influence the colour of dried veneers produced from the different wood species as much as the different soaking temperatures, especially with higher soaking temperatures from 40 ºC. The trends identified in the veneer samples soaked for 24 h were similar, lightening, and de-yellowing of colour with increased log soaking temperature.

When veneer mats are rotary peeled, a delay in drying time would not lead to any notable changes in the dried veneer's colour as seen in the results obtained. This was the case with all the sample species tested. Although there were differences between the fresh wet veneer samples and the wet ones after 24 hours, these changes could be because, within the 24 h, the wet samples may have lost some moisture through evaporation, which will affect the colour. One thing was clear though, the low standard deviation values seen on the dried veneer samples which were not so in the wet samples. This suggests that wet veneer changes colour rapidly and as such not having a harmonious colour tone before they are subjected to heat during drying. This seemingly rapid colour change on the wet surface could be because of some form of chemical reactions triggered by the moist surface of the veneer exposed to the atmospheric conditions. These reactions certainly will not be possible upon drying and such could be the reason the dried veneer had less variations on their colour coordinates.

KOKKUVÕTE

Spooni tootmisel töödeldakse treipakke hüdrotermiliselt (leotatakse või aurutatakse), et pehmendada puitmaterjali efektiivsemaks tootmiseks. Antud uurimustöö eesmärk on määrata hüdrotermilise eeltöötluse mõju spooni värvile. Uuringu eesmärk on vastata järgmistele küsimustele: a) Kuidas mõjutab palgi leotustemperatuur spooni värvust?, b) Kuidas mõjutab leotamise kestus spooni värvust palgi läbilõikes?, c) Kuidas viivitus spooni kuivamisel mõjutab spooni värvust?

Selles uuringus kasutati kase, haava, hall lepa ja sanglepapuid. Palke leotati temperatuuridel 20 °C, 40 °C ja 70 °C 24 ja 48 tundi. Pärast leotamisprotsessi treiti palgid spoonimatiks ja kuivatati seejärel temperatuuril 170 ° C kuni niiskusesisalduseni 5%. Värvimõõtmised viidi läbi CIELab värviruumi abil, et teha kindlaks nende eeltöötluste mõju spooni värvile.

Uuringu tulemused on näidanud, et palgi leotustemperatuur on oluliselt mõjutanud kase, haava, hall lepa ja sanglepa värvust. Kõrgendatud palkide leotamistemperatuur mõjutab spooni värvi enamasti heledamaks muutes. Eriti kui palke on leotatud temperatuuriga üle 40 ºC, põhjustas see kuivatatud spooni värvuskoordinaatide L* (heleduse) väärtuste suurenemise ja b* (kollaste) väärtuste vähenemise. Kõrge leotustemperatuuri tõttu tekkiv spoonipindade kollakuse vähenemine näib olevat värvimuutuste peamine põhjus.

Palkide leotamise kestus enne spooni valmistamist ei mõjutanud erinevatest puiduliikidest valmistatud spoonide värvust, eriti kõrgemate leotustemperatuuride korral alates 40 ºC.
Tulemused näitavad, et spooni kuivamisaja viivitamine märkimisväärseid muutusi kuivatatud spooni värvuses ei põhjusta. Nii oli see kõigi testitud puuliikide puhul. Ehkki märgade spooni katsekehade vahel oli 24 tunni pärast erinevusi, võisid need muutused olla tingitud sellest, et 24 tunni jooksul võisid märjad katsekehad veidi niiskust kaotada, mis mõjutab värvuse muutusi. Samas, kuiva spooni puhul täheldati tunduvalt madalamat standardhälvet väärtustes, kui märjal spoonil. See viitab sellele, et märg spoon muudab kiiresti värvi ja seetõttu puudub sellel ühtlane värvitoon enne, kui neid kuivatamise ajal kuumutatakse.

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