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

EFFECT OF FIRE-RETARDANT TREATMENT ON COMMON ASPEN *(POPULUS TREMULA)* AND SILVER BIRCH (*BETULA PENDULA ROTH*) VENEER PROPERTIES

TULETÕKKEAINEGA TÖÖTLEMISE MÕJU HARILIKU HAAVA (*POPULUS TREMULA*) JA ARUKASE (*BETULA PENDULA)* SPOONI OMADUSTELE

MASTER'S THESIS

Student's name: Adekunle Olusoji

Student's code: 195039KVEM

Supervisors: Jaan Kers, professor
Alar Just, professor

Tallinn 2021

(*On the reverse side of title page*)

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Department of Materials and Environmental Technology

THESIS TASK

Student: Adekunle Oluseyi Olusoji, 195039KVEM.

Study programme: KVEM, Technology of Wood, Plastic and Textiles (code and title)

main speciality: Wood Technology

Supervisor(s): Professor, Jaan Kers, +372 620 2910

Professor, Alar Just, +372 620 2411

Thesis topic:

(in English) Effect of fire-retardant treatment on common aspen (*Populus tremula*) and silver birch (*Betula pendula Roth*) veneer properties.

(in Estonian) Tuletõkkeainega töötlemise mõju hariliku haava (*Populus tremula*) ja arukase (*Betula pendula Roth)* spooni omadustele*.*

Thesis main objectives: The objective of this research to accomplish the main aim are:

1. To prepare 1.5 mm thickness Populus tremula and Betula pendula veneers and carry out the impregnation tests by using different methods and fire-retardant chemicals.
2. To evaluate the effect of fire-retardant chemical treatment of veneer samples from two wood species against fire
3. To study the bonding properties of veneer samples after the fire-retardant treatment and shear strength of the glued joint.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Log peeling and preparation of veneer samples and conditioning.	February 17, 2021.
2.	Treatment of fire retardants with fire retardant chemicals.	February 25, 2021.
3.	Fire test, lap shear test and writing of thesis	May 23, 2021.

Language: English **Deadline for submission of thesis: "**25" May 2021 a

Student: Adekunle Olusoji .... "......." ....20…. a
/signature/

Supervisor: Jaan Kers .... "......." ....20…. a
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Co - supervisor: Alar Just .... "......."............................20…. a
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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Asp – Aspen

B – Burnblock fire-retardant

Bir – Birch

C – Solid content

FR – Fire-retardant

I – Impregnation

LPF – Lignin Phenol formaldehyde adhesive

P – Palonot fire-retardant

PF – Phenol formaldehyde adhesive

R – Roller spreader

S – Spray application

U – Ultra fire-retardant

UF – Urea formaldehyde

WG – Weight gain

PREFACE

Fire protection is often required for plywood to be used for construction purposes. Organic and inorganic fire-retardant (FR) salts are used to treat veneer or plywood to incorporate fire resistance. Vacuum/pressure impregnation, roller spreader and spraying were the methods used to apply fire-retardant chemical on veneer samples used in this research. In this study, three different fire-retardant chemicals were used (Palonot, Ultra and Burnblock) to treat aspen and birch wood veneers. Dry retention (weight gain) was measures and the treated veneer samples were tested for fire, and lap shear strength. Vacuum impregnation was found out to me be the overall effective method of treating the veneer samples. It was found out that veneer samples treated with Palonot (P) gave superior properties. The solid content of Palonot was more than Ultra and Burnblock (B) fire-retardants and this was proportional to the fire protection given. Phenol formaldehyde (PF) and Lignin phenol formaldehyde (LPF) adhesives were used to prepare veneers for lap shear strength test under the controlled processing parameters: Pressure of 2 MPa, temperature of 130 °C, time of 5 min 55 s for phenol formaldehyde and 8 min 30 s for Lignin phenol formaldehyde adhesive, glue spread rate was 126 g/m^2. Lap shear strength test showed that fire retardant treated birch veneer samples gave better shear strength properties compared to treated aspen samples. These tests proved that vacuum impregnation method can be used to treat veneers with these fire-retardants without altering the bonding properties badly.

Keywords: fire-retardant, impregnation, lap shear strength, adhesive, master's thesis.

1. INTRODUCTION

Wood is a foremost material for construction used in the construction of human shelter, paper making, weapon construction and as firewood. The wide use of wood stems from its ready availability, renewability, and ease of working with, etc. It is renewable and offers a continuous supply of raw materials for various applications most especially the construction company. With improvements in technology, engineered wood panel products (wood composites) are developed and are adapted for a wide range of purposes. Wood composite such as plywood particleboard and blockboard are widely adapted for use as non-loadbearing components such as wall partitioning, flooring, and ceiling (Samani & Khali, 2016).

Plywood is an important and major raw material used for making different types of furniture. It is produced by bonding layers of wood crosswise with an adhesive. We have the interior and the exterior grade plywood which are differentiated by the adhesive used in bonding the plywood. Phenol formaldehyde (PF) adhesives is used for producing plywood that will be used in exterior condition while urea formaldehyde (UF) is used for plywood that are meant for indoor purposes or lower moisture interaction areas. There has been attempt in the past to use bio adhesive in the production of plywood and other panel products. However, the strength properties of plywood produced with bio adhesive are inferior in comparison with the formaldehyde-based resins. During chemical pulping of wood for paper production, large amount of lignin is deposited in the spent liquor. This lignin is partially substituted for phenol in phenol formaldehyde resins and used in the production of plywood. Different percentage replacement has been done in the past (Klašnja & Kopitović, 1992) with different properties with respect to percentage replacement.

The properties of plywood are superior to that of solid wood. It has a large surface area, and the inherent anisotropic nature of wood is reduced in plywood. Plywood is used for structural application, furniture making, and automobile floor. The use of plywood for these purposes means that its quality and performance enhancement become a necessity for it to perform optimally. Fire treated plywood are becoming more popular and gaining ground in the construction industry. They are very useful in their application for construction and furniture industry (Demir et al., 2014). In incorporating fire resistance into plywood, individual veneer can be impregnated and this type of treatment protects the whole section of the panel against fire (Kawalerczyk et al., 2019). However, the bonding strength and strength properties of plywood is significantly impacted negatively by the treatment with fire-retardant chemicals, and this limits its application. Fire-retardant (FR) plywood can be made by treating the plywood or veneers for making plywood. The impregnation of veneer with fire-retardant chemical will be preferred if a strong glue bond could be obtained (Samani & Khali, 2016).

The motivation for this project was the interest of several companies towards testing the products (fire retardant chemicals). The interest of the author for this project was to test the effectiveness of fire retardants with the sole aim of recommending method(s) of treatment of veneers.

1.1 Aim and objectives

The aim of this master's thesis is to study the effect of fire-retardant treatment on *Populus tremula* and *Betula pendula* veneer fire resistance and adhesion properties.

The objectives of this research to accomplish the main aim are:

- To prepare 1.5mm thickness *Populus tremula* and *Betula Pendula* veneers and carry out the impregnation tests by using different methods and fire-retardant chemicals.
- To evaluate the effect the fire-retardant chemical treatment of veneer samples from two wood species against fire
- To study the bonding properties of veneer samples after the fire-retardant treatment and shear strength of the glued joint.

2. LITERATURE REVIEW

2.1 Plywood

Plywood is one of the wood panel products that can be used for wide range of applications. Various types of application is made possible by the mechanical properties offered by the layered construction (Kawalerczyk et al., 2019). Plywood and other wood-based composites are used in the production of furniture, engineered flooring, housing and other products etc (Demir et al., 2014). However, the flammability of plywood limits its potential application for many purposes. Many times, the fire performance of plywood can be viewed as a setback (Khatua et al., 2017). The chemical composition of wood makes it susceptible to degradation by fire. Due to this shortcoming, there was justification to develop panel materials with superior fire protection properties. Fire-retardant plywood production involves two types of processes: the first method involves incorporating the fire safety during the plywood production while the second method gives fire protection to the finished product (Cheng & Wang, 2011). It will be generally expected for fire treated plywood panels to be less combustible than untreated plywood panels.

2.2 Formaldehyde based resins

Formaldehyde based resins are part of the foremost petroleum derived adhesive used in the production of wood-based products. Urea-formaldehyde resins (UF) are widely used in wood panel production because of its low cost, excellent bonding strength and high production reactivity (Ferreira et al., 2017). However, formaldehyde is carcinogenic and poses great damage to human health.

Phenol formaldehyde (PF) adhesives are widely used in the production of wood-based panel products such as plywood, glue laminated lumber, particleboard, and veneer laminated lumber etc. Phenol Formaldehyde resins were the first type of adhesives to be produced on an industrial scale. The curing reaction of phenol with formaldehyde can be carried out under alkaline or acidic conditions (Ghorbani et al., 2016).

Recent research works are tending towards developing bio-based products that are friendly to the environment. It is a matter of necessity for adhesive producers to find economically feasible solution to adhesive production (Ferreira et al., 2017). Bio-based adhesives have properties inferior relative to petroleum derived adhesives.

2.3 Lignin phenol formaldehyde resins

In the last 25 years, lignin has been researched as a potential alternative to petrochemicals in the original phenol formaldehyde resin due to similarities in structure. Replacing phenol with large percentage of lignin affects the curing time of the adhesive considerably. Due to its low price, ready availability, eco friendliness and abundancy, there is increased interest to make adhesive with lignin (Younesi-Kordkheili & Pizzi, 2018). Nowadays, production of plywood with lignin-based adhesive is a focused research area. However, there is slow chemical reaction between lignin and phenol formaldehyde; this is partly due to mixture of their phenolic core moieties by aliphatic side chain and less active aromatic sites available for methylolation reaction. To solve the problem of lignin reactivity, scientist have attempted to first, modify lignin to make the reactive sites accessible and second, to introduce lignin phenolation, demethylation, and methylolation. Only the second method has been industrialized for the production of adhesive for plywood making (Ghorbani et al., 2016).

Kraft lignin is the best replacement of phenol because it has more free-ring position with greater thermal decomposition temperature than other lignin types. The substitution of lignin is limited to lower levels because lignin is less reactive with formaldehyde when compared to phenol. Hence, modification is required to improve its reactivity when substituted to produce phenol formaldehyde adhesives (Ferdosian et al., 2017). A new type of bio-based lignin adhesive is NeoLigno manufactured by Stora Enso. This adhesive is suitable to produce particleboard and insulation boards. NeoLigno is a binder made from full bio-based organic polymer from wood. This adhesive gives a high bonding strength that can be compared to traditional binders (Stora Enso, 2015).

2.4 Fire safety in buildings

Fire safety is of great concern in buildings, most especially those made with wood. Different types of chemicals are used to give wood a level of fortification against fire incidence. Fire incidences cannot be totally prevented. Practical steps have however been put in place to study the behaviour of fire and to reduce its impact to manageable levels.

2.4.1 Stages of fire development

Basic theory of combustion forms the basis for fire studies (Alarifi et al., 2016). Compounds of boron are usually considered good fire retardants because of its properties such as preservative effectiveness, neutral PH, and less negative impact on the strength properties of wood unlike other fire-retardant chemicals (Demir et al., 2014). Treatment of plywood with fire retardant chemicals help to lower the rate of spread of the flame on the surface and also reduce the amount of potential heat (Bekhta et al., 2016). Plywood panels to be used for protection against fire should conform with EN 636 and EN 13986 standards.

Information and knowledge about the basic behaviour of fire, occupants and building during a fire is very important to be very prepared against fire incidence or to develop safety strategies. An adequate fire strategy will take into consideration, life, properties and neighbouring buildings and structures.

Figure 1 below showed the stages involved in fire development in a typical room condition. After ignition, the fire spreads rapidly, then very slowly (smouldering fire), or it can self-extinguish but this is largely dependent on the arrangement and proximity of combustible materials to the flame source. Moveable items like furniture, equipment, goods etc, form the essential fire load in the developing phase of fire, when safety of life is most important. The products of the combustion process are energy, gases, and smoke. Heat energy release is the cause of structural damage in buildings while gases and smoke are the cause of loss of lives.

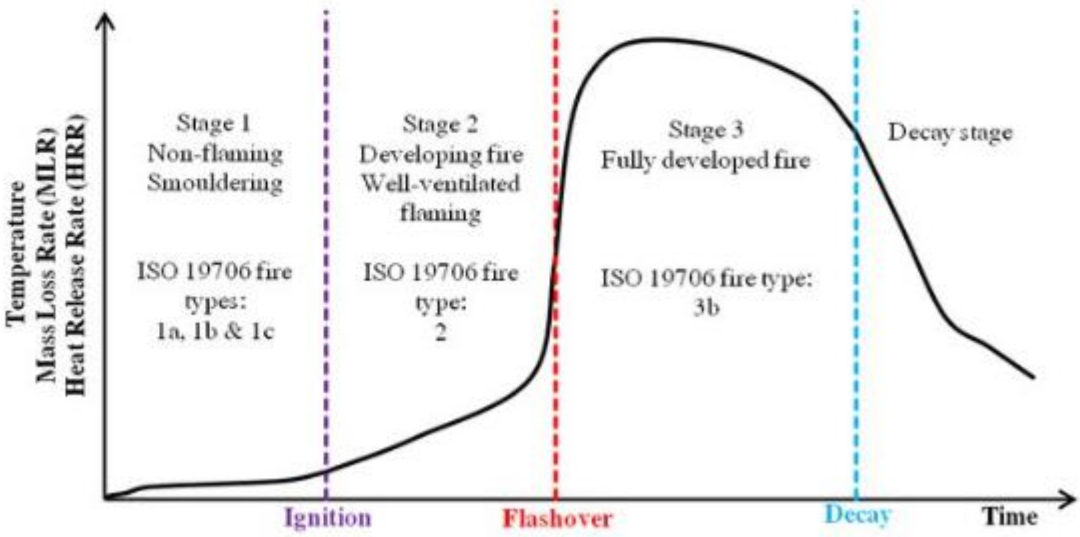

Figure 1. Stages of fire development (Alarifi et al., 2016)

2.4.2 Fire resistance – structural fire performance

Wood and wood composites degrade thermo-mechanically with heat transfer and weight. The combustion of wooden materials involves ignition, pyrolysis, radiation, and formation of char. The wood undergoing pyrolysis can be called char, and the wood underneath retains wood original properties. The char however contributes nothing to the strength of the wooden structure. Therefore, charring depth and charring rate has been used for evaluating thermomechanical degradation and resistance to fire. Fire tests are usually performed using ASTM and ISO standards. Cone calorimeter or other small equipment with

controlled heat flux are used. Research has shown that the charring of wood is higher when the fire starts than average charring of the entire burning process (Qin et al., 2021).
To resist fire, structural elements like wall must withstand a fully developed flame and fulfil certain performance requirements. If the fire exposure is in line with the standard time-temperature curve, the performance required of the wooden structure are load bearing capacity (R), integrity (E) and insulation (I). The tests performed according to EN standards on the building elements designed to withstand fire are tabulated in table 1 below (SP Technical Research Institute of Sweden, 2010).

Table 1. Overview of the European performance classes for the fire resistance of building elements (SP Technical Research Institute of Sweden, 2010)

Building element	Load bearing R	Separating E	Insulating I	Time min	Test method
Wall elements	X	X	X	15-360	EN 1363-1[3.31], EN 1364-1[3.15] or EN 1365-1[3.19]
Floor elements	X	X	X	15-360	EN 1363-1[3.13], EN 1364-2[3.16] or EN 1365-2[3.20]
Beams	X	-	-	15-360	EN 1363-1[3.13], EN 1365-3[3.21]
Columns	X	-	-	15-360	EN 1363-1[3.13], EN 1365-4[3.22]
Balconies and walkways	X	-	-	15-360	EN 1363-1[3.13], EN 1365-5[3.23]
Stairs	X	-	-	15-360	EN 1363-1[3.13], EN 1365-6[3.24]
Doors and shutter assemblies	-	X	X	15-240	EN 1634-1[3.25], EN 1634-3[3.26]

2.5 Fire-retardant chemicals

Fire-retardant chemicals used for treating wood are combinations of organic and inorganic salts. Common inorganic salts used include monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium sulphate, ammonium polyphosphate, borax, and boric acid (Russell et al., 2004). These salts are cheap and can be used to impregnate wood using pressure. They are combined in different formulations to get improved result. These chemicals reduce the rate of travel of flame across the surface of wooden material and reduce amount of heat. Based on the formulation, a fire retardant can act chemically or physically in the solid, liquid, or gaseous state to slow down the burning process. During combustion, fire retardant chemicals lower the thermal degradation temperature and increase the amount of char and lower that amount of volatile, combustible vapours (Samani & Khali, 2016).

2.6 Effect of fire treatment on bonding properties of plywood

Veneers treated with fire-retardant chemicals usually exhibit poor bonding properties. For strong bond to be formed, adhesive must be able to penetrate the surface of veneer and wet it sufficiently. It has been found out that the bonding strength of poplar plywood bonded with phenol formaldehyde adhesive and treated with FRW-1 reduced by 25.3% (Cheng & Wang, 2011). The main constituents of the FRW-1 fire retardant are boric acid 20%; guanyl urea phosphate (GUP) 50%; ammonium dihydrogen phosphate 30%. Recently researchers found out that the bonding strength of birch plywood treated with potassium carbonate was decreased by 22% when compared to the control sample (Kawalerczyk et al., 2019).

There is coating of the veneer with fire retardant salt which tend to prevent the adhesive from wetting the surface. Increasing the polymerization of the adhesive is a general solution used. Diffusive impregnation of moist veneer as opposed to capillary impregnation of dry veneer makes the surface of the veneer relatively free of fire retardant chemicals and ensure good penetration (Bekhta et al., 2016).

Another way to enhance the bonding strength of the wood or veneer is to treat the surface in order to activate it (Žigon et al., 2021).

2.7 Effect of fire-retardant treatment on strength properties of wood

Treating wood with fire retardant chemicals lower its strength properties considerably. Fire-retardant chemicals usually consist of organics or inorganic salts. (Samani & Khali, 2016). The presence of these organic salts and acids in wood increases the temperature at which wood ignites and at the same time decrease the rate of burning but decrease strength.

Treatment of beech veneer with fire retardant chemical caused a decrease in shear strength of the plywood by about 20% (Kawalerczyk et al., 2019). The magnitude of strength reduction depends on the type of chemical used and the significance of this side effect depends on the application of the product (LEVAN & WINANDY, 1990). Wood treated with fire-retardant chemicals become brash, brittle and breaks easily. According to previous research, the fire retardant chemicals are mainly confined to the cell lumen, trachea and around the pit when impregnation was done under ambient temperature and pressure and this is responsible for the loss of strength in the treated veneer (Cheng & Wang, 2011).

3. MATERIALS AND METHODS

3.1 Experimental design

Experiment was designed to use three different types of fire-retardant chemicals and veneers from two wood species. Three methods of treatments were used which were impregnation, roller coating and spraying. In total 60 samples were prepared for fire test, with 3 control samples each for the wood species. Birch veneer was chosen because it is the major wood specie used for plywood manufacturing in Estonia while Aspen was selected for its ability to take up chemicals into its void cell lumen and thought of as being more impregnatable. Veneer thickness of 1.5 mm was chosen because it is the standard veneer thickness for plywood making in Estonia. For samples prepared with roller and spraying application, veneer sheets of approximately 800 mm x 450 mm were used. Test samples of dimension 100 mm x 100 mm were cut from the treated sheets after chemical application. The wet retention targeted was 240 g/m^2 (± 10 g). Experimental design is shown in table 6 below. Thickness of veneer is 1.5 mm.

Meaning of symbols used in Table 2 are explained in List of abbreviations and symbols.

Table 2. Experimental design

Fire-retardant		PALONOT						ULTRA						BURNBLOCK					
Wood Specie		**Aspen**			**Birch**			**Aspen**			**Birch**			**Aspen**			**Birch**		
Method of Treatment		**I**	**R**	**S**	**I**	**R**	**S**	**I**	**R**	**S**	**I**	**R**	**S**	**I**	**R**	**S**	**I**	**R**	**S**
S/N	**Sample Label**																		
1	Asp-P-I	3																	
2	Asp-P-R		3																
3	Asp-P-S			3															
4	Bir-P-I				3														
5	Bir-P-R					3													
6	Bir-P-S						3												
7	Asp-U-I							3											
8	Asp-U-R								3										
9	Asp-U-S									3									
10	Bir-U-I										3								
11	Bir-U-R											3							
12	Bir-U-S												3						
13	Asp-B-I													3					
14	Asp-B-R														3				
15	Asp-B-S															3			
16	Bir-B-I																3		
17	Bir-B-R																	3	
18	Bir-B-S																		3

Palonot and Ultra FR are prepared by manufactures as ready to use liquids that are miscible with water while Burnblock FR came as solute. According to the manufacturer of Burnblock FR, 5 kg of the salt is to be mixed with 22 litres of water. All these chemicals can be diluted and used according to the targeted weight gain.

Table 3. Fire retardant chemicals

S/N	FR Chemical	Form	Mixing formula	Mixing liquid
1	Palonot	Solution	Ready to use	Water
2	Ultra	Solution	Ready to use	Water
3	Burnblock	Solute	5 kg to 22 litres of water.	Water

Veneer samples were prepared for treatment. The wood veneer used was rotary peeled aspen and birch veneer of 1.5 mm thickness. The peeling was performed using the RAUTE peeling machine. The logs were soaked at a temperature of 40 °C for 24 h. It was then dried using the RAUTE veneer drying machine set at 170 °C. Veneer sheets were conditioned to moisture content of 4-5% and stored in the storage room at average temperature of 29 °C and R.H. 25%.

Figure 2. Overview of veneer production processes

The veneer samples to be treated by impregnation were cut to size 100 mm x 100 mm and treated with fire-retardant chemicals in the autoclave. The inner dimension(s) of the autoclave are as follows: (diameter 270 mm, height = 540 mm).

Veneer samples are placed in a rack (holder) to submerge the samples with weight and allow treatment for cell wall penetration on both surfaces. Roller coater and spray gun treatment methods were also be used to apply fire retardant chemicals to veneer sheets as described in the experimental design. These treated veneer samples were dried in the oven and then conditioned.

3.2 Determination of solid content of fire retardants

Solid content of fire-retardant chemicals was determined by oven drying the FR chemicals. Petri dishes were oven dried for 30 min and placed in the desiccator for 15 min. Equal mass of the chemicals were measured into the petri dishes and placed in an oven set at 103 °C and dried until constant mass was achieved. It was then cooled in the desiccator for 15 min and weighed to the nearest 0.1 mg. Solid content was calculated using equation (1) and recorded.

$$C = \frac{m_3 - m_1}{m_2 - m_1} x100 \qquad (1)$$

Where:

C = Solid content (%)

m_1 = mass of petri dish (g)

m_2 = mass of petri dish + FR before oven drying (g)

m_3 = mass of petri dish + FR after oven drying (g)

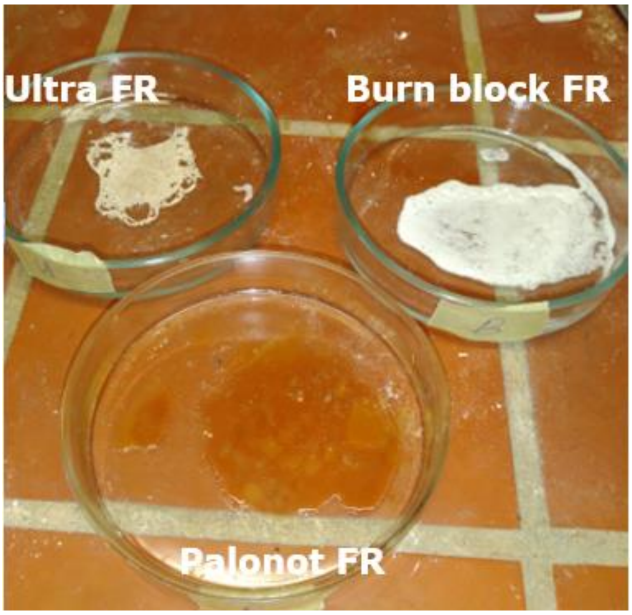

Figure 3. Solid content of FR determination

3.3 Veneer treatment with fire-retardant

Veneer samples were treated by pressure impregnation, spraying and roller coater application. For the impregnated samples, veneer sheets were cut to 100 mm x 100 mm, dried in an oven set at 103 °C until there was no change in mass and treated in an autoclave under normal room condition. Palonot, Ultra, and Burnblock fire-retardant chemicals were used, these are commercially available in Etonian market. Vacuum of 0.65 bar was used. The samples were impregnated for 15 min and were lightly dabbed with paper to remove excess fire-retardant chemicals. It was dried in the oven set at 103 °C until constant weight was achieved. Samples were then conditioned and stored in the drying room.

For samples prepared with roller coater application, veneer sheets were placed on a clean table and rubber roller coater was used to apply the chemicals. A spread rate of 240±10 g/m^2 was delivered to the surface. It was then oven dried and the oven dry mass recorded. Sprayed samples were prepared by using gravity type spraying gun. Same spread rate mentioned above was used. 100 mm x 100 mm size veneers were then cut out from fire retardant treated veneer sheets.

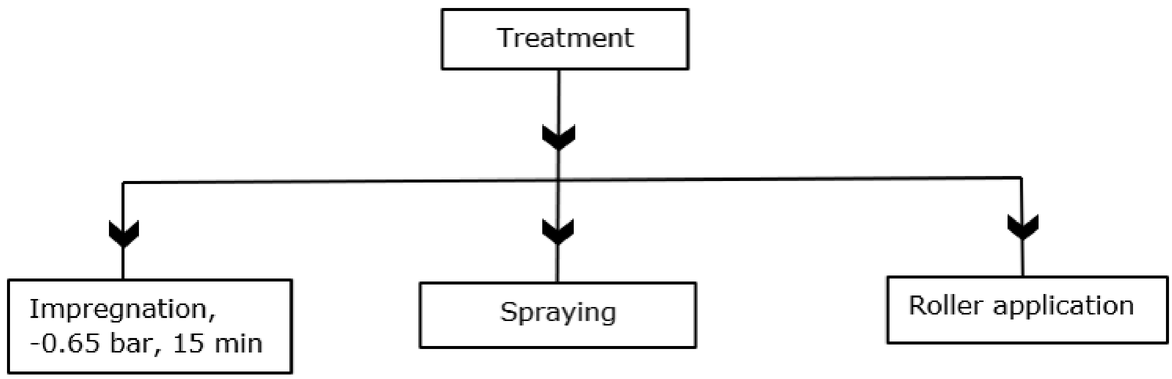

Figure 4. Veneer treatment with fire retardants by using different treatment methods.

Weight gain based on oven dried weights was calculated from the formula:

$$WG(g) = W_2 - W_1 \qquad (2)$$

Percentage of weight gain is calculated from:

$$WG(\%) = \frac{W_2 - W_1}{W_1} x100 \qquad (3)$$

Where W_1 = Initial oven dried weight of specimen before impregnation

W_2 = Final oven dried weight of specimen after impregnation

Retention/Absorption (kg/m^3) was calculated using formula (4):

$$Absorption = \left[\frac{(m_2 - m_1)}{V}\right] * C \qquad (4)$$

Where m_1 = Initial weight before FR treatment (kg)

m_2 = Final weight after FR treatment (kg)

V = Volume of veneer (m^3)

C = Concentration (%)

3.4 Calculation of spread rate

The targeted spread rate was 240 g/m^2 based on recommendation by Palonot company. Based on the area of the veneer sheets, appropriate amount of veneer was delivered to the surface of veneer. Table 4 below showed the amount of FR chemical for roller spreader and spraying methods. All FR liquids have same spread rate. Spread rate was calculated as shown below:

Targeted spread rate = 240 g/m^2

Birch

Area of veneer sheet = 0.848 x 0.423 = 0.359 m^2

0.359 m^2 x 240 g/m^2 = 86.16±10 g

Aspen

Area of veneer sheet= 0.99 x 0.417 = 0.413 m^2

0.413 m^2 x 240 g/m^2 = 99.12±10 g

Table 4. Fire retardant spread rate.

S/N	Veneer	Area (m^2)	Amount of FR (g)
1	Birch	0.359	86.16±10
2	Aspen	0.413	99.12±10

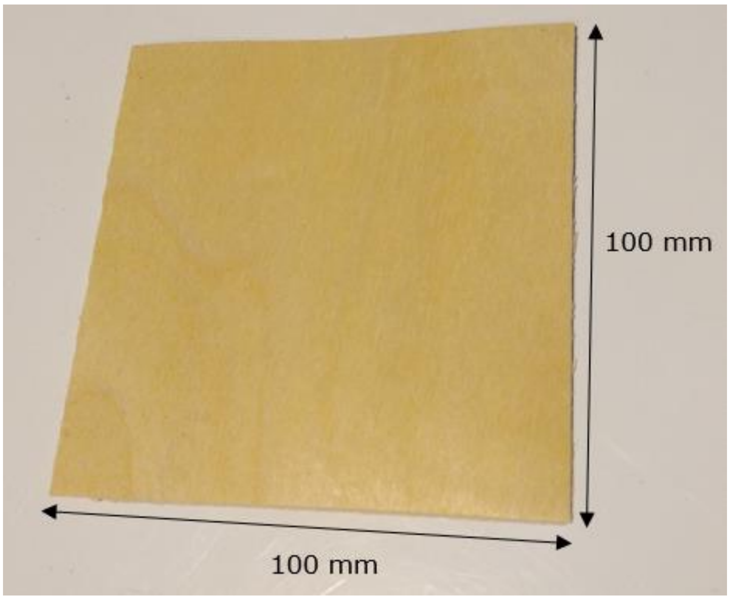

Figure 5. Dimension of specimen

Figure 6. Veneer samples in wooden rack

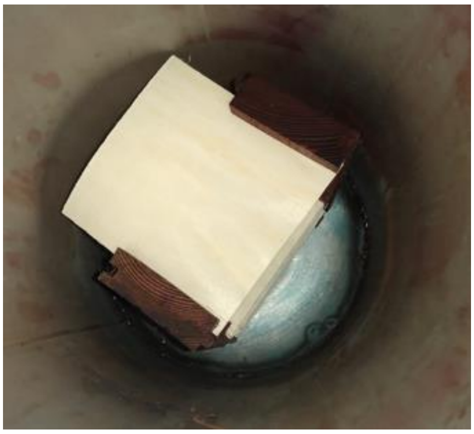

Figure 7. Veneer samples in autoclave

Figure 8. Oven drying of veneer samples before and after fire retardant treatment.

3.5 Preparation of samples for fire testing

The treated veneer samples were prepared for fire test. Veneer samples were placed on wooden blocks of dimension 100 mm x 100 mm x 45 mm with respect to the dimension of the fire test equipment holder (See Figure 9). Aluminium tape was used to secure the samples to the block and thermocouple wire, sandwiched between the veneer and wooden block as shown in Figure 11 below. The samples were placed in the conditioning chamber at 23 °C and relative humidity of 50%, according to ISO 5660-1 2015. Three replicates each were made. The samples were conditioned for at least one week before fire test. Heat flux of 50 kW/m^2 was used and the veneer, placed 25 mm from the cone heater. Ignition and basic protection times were measured and recorded. The test was stopped immediately the veneers decayed and exposed the solid wood holder beneath.

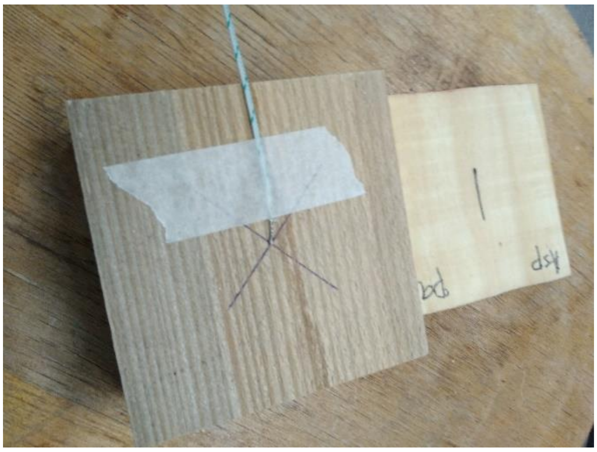

Figure 9. Fixing of thermocouple

Figure 10. Sandwiching of thermocouple in-between wood and veneer

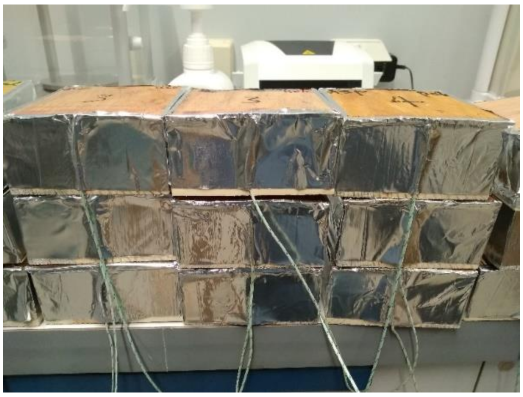

Figure 11. Wrapping of sample with aluminium tape

Figure 12. Cone heater

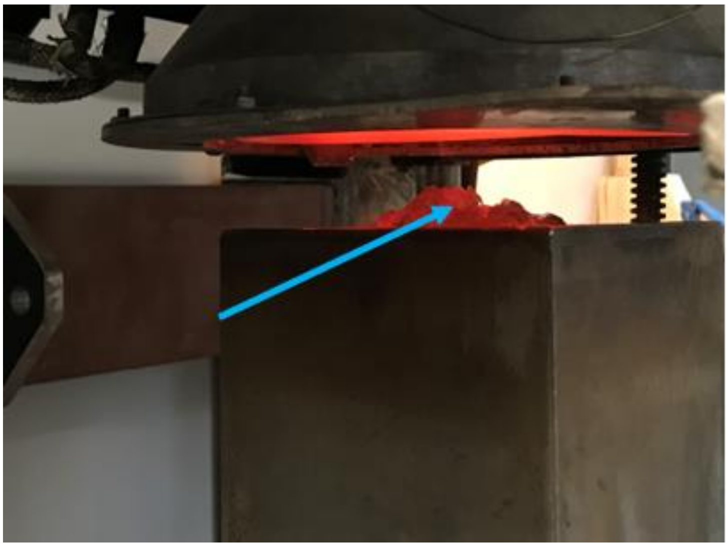

Figure 13. Formation of the protective layer on burning veneer surface.

3.6 Lap shear strength test

Impregnated veneer samples were prepared for adhesion test according to DIN EN 205 standard. Two drops of 6.3 µl of Phenol formaldehyde (PF) and Lignin phenol formaldehyde (LPF) glues were used. This corresponds to spread rate of 126 g/m^2. Micropipette was used to deliver the adhesives to an area of 20 mm x 5 mm at one end of the sample and another, used to rub the drops to ensure even distribution. Pressing parameters are shown in the Table 5 below:

Table 5. Adhesive recipe and pressing parameters.

PHENOL FORMALDEHYDE (PF)	**Pressing Parameter**	
Substance	**Temp.**	**Pressing time**
Resin 14J021	130 °C	5 min 55 s
Hardener 24J662		
Water		
LIGNIN PHENOL FORMALDEHYDE (LPF)	**Pressing Parameter**	
Substance	**Temp.**	**Pressing time**
Resin 14W451	130 °C	8 min 30 s
Hardener EXPH 9500		
Water		

Carver hot press machine of 150 mm x 150 mm was used to make the bond. A pressure of 2 MPa was used. After pressing, the samples were conditioned in the climate chamber set at 20 °C and R.H. of 65% for minimum of 48 h. Lap shear strength test was carried out using ZwickRoell Z050 machine according to DIN EN 205 standards. The pressing time for LPF was increased to 8 min 30 s because of the fire-retardant chemical in the veneer samples which prevented the strips from bonding at pressing time of 5 min 55 s. Several preliminary tests were carried out before arriving at pressing time of 8 min 30 s for LPF.

4. RESULTS AND DISCUSSION

4.1 Solid content of fire retardants

The results for solid content of FR chemicals are presented in Table 6 below. Palonot FR has the highest solid content of 44.93%, while Ultra FR and Burnblock FR have solid content of 30.88% and 13.74% respectively. The solid content is the active component of the FR; hence the amount of solid content determines the effectiveness of the fire treatment.

Table 6 Determination of solid content of FR

S/N	Fire Retardant	m_1 (g)	m_2 (g)	m_3 (g)	Solid Content (%)
1	Palonot	96.78	98.85	97.71	44.93
2	Ultra	100.57	102.74	101.24	30.88
3	Burn block	100.36	102.47	100.65	13.74

Where:

m_1 = mass of petri dish (g)

m_2 = mass of petri dish + FR before oven drying (g)

m_3 = mass of petri dish + FR after oven drying (g)

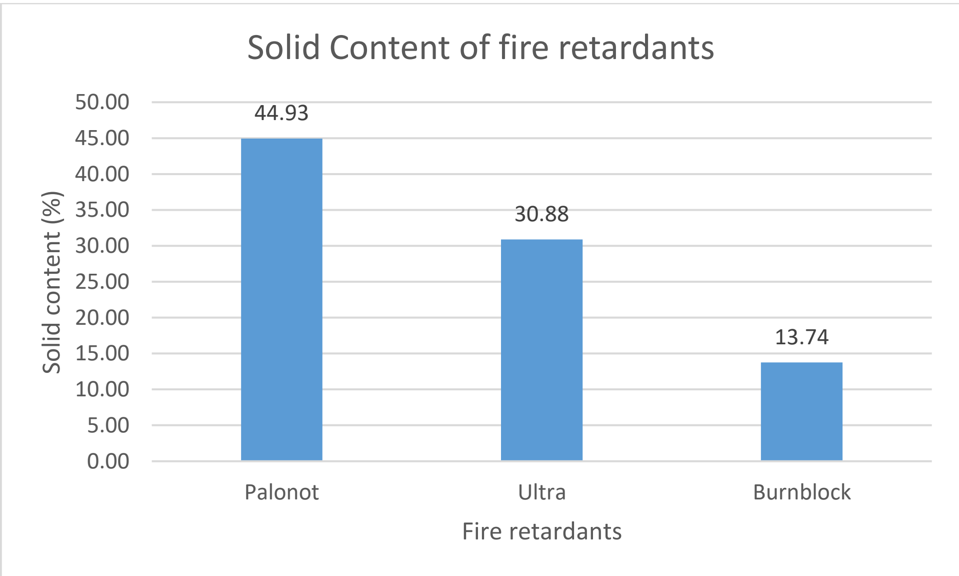

Figure 14. Solid content of fire-retardants

The result above shows that the concentration of the FR chemicals used was 44.9%, 30.8% and 13.7% for Palonot, Ultra and Burnblock FR, respectively. These concentrations are higher than the concentrations of FR chemicals that was used by other researchers (Demir et al., 2014; Samani & Khali, 2016) which was 5%.

4.2 Treatment of veneer samples with fire-retardants

Table 7 and 8 below showed the results for retention (kg/m^3) obtained from application of fire-retardant chemicals on Aspen and Birch wood veneers using rubber roller and spray gun, respectively. Samples treated with Palonot fire-retardant have the highest dry retention (weight gain) of the chemical while Burnblock has the least.

Table 7. Veneer samples coated with roller coater spreader from one side.

S/N	SAMPLE(S)	WG (kg)	Avg. WG (%)	Avg. WG (kg/m^3)	STDV	FR CHEMICAL
1	Bir-P-R	0.01643	4.90	13.7	1.2	Palonot
2	Asp-P-R	0.03078	9.62	22.3	4.4	
3	Bir-U-R	0.00391	1.16	2.2	0.07	Ultra
4	Asp-U-R	0.00537	1.72	2.7	0.83	
5	Bir-B-R	0.00328	0.99	0.8	0.42	Burnblock
6	Asp-B-R	0.00499	1.55	1.1	0.39	

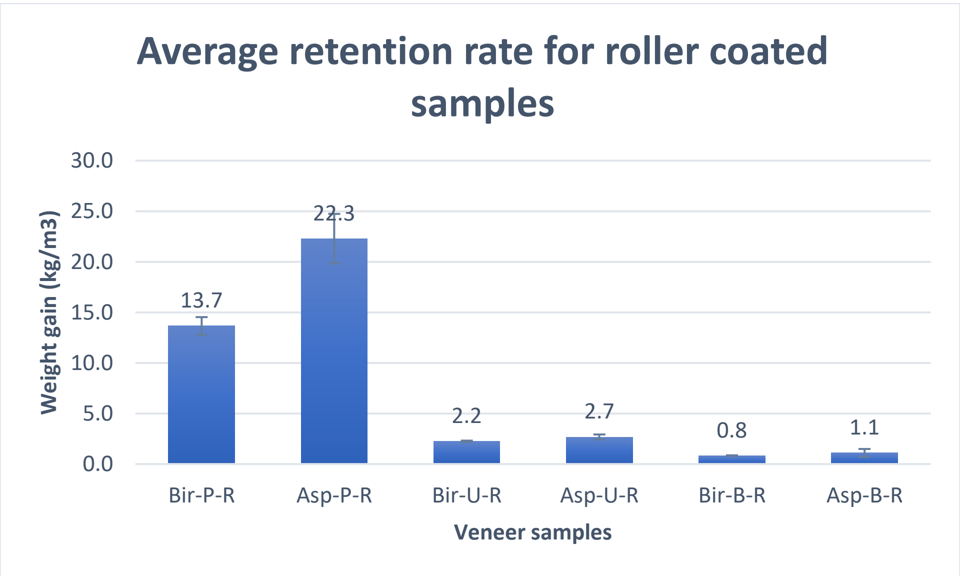

Figure 15. Dry retention values for roller application samples

Table 8. Veneer samples with spray application

S/N	SAMPLE(S)	WG (kg)	WG (%)	Avg. WG (kg/m³)	STDV	FR CHEMICAL
1	Asp-P-S	0.02879	8.98	20.8	5.08	Palonot
2	Bir-P-S	0.04548	14.28	38.0	7.1	
3	Asp-U-S	0.01326	4.23	6.6	2.22	Ultra
4	Bir-U-S	0.01001	2.99	5.7	2.02	
5	Asp-B-S	0.00401	1.26	0.9	0.85	Burnblock
6	Bir-B-S	0.00411	1.24	1.0	1.1	

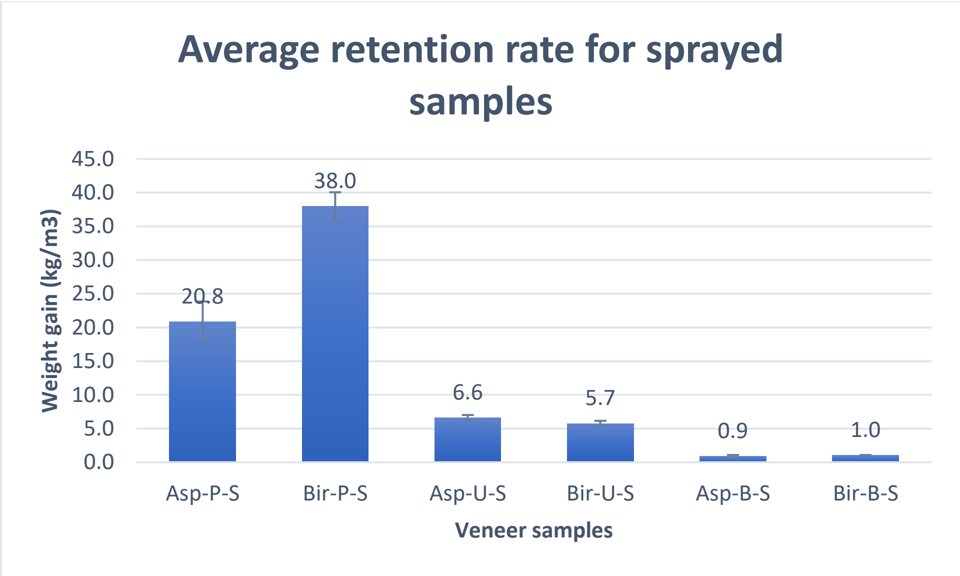

Figure 16. Dry retention values for sprayed samples

From Table 7 and 8, right quantity of chemical was delivered to the surface of the veneer (240 g/m^2). Generally, samples treated with Palonot FR have the highest dry retention for all the methods of treatment. With the roller application, the percentage weight gain for samples treated with Ultra and Burn block appeared to be identical but for sprayed samples, percentage weight gain for samples treated with Ultra fire-retardant was higher than that of Burn block.

Figure 15 (above) displayed the veneers treated by rubber roller spreader method. The average weight gain of birch and aspen veneer treated with Palonot FR was higher than that of Ultra FR and Burnblock FR. Asp-P-R and Bir-B-R have weight gain of 22.3 kg/m^3 and 13.7 kg/m^3, respectively. Average weight gain (dry retention) values for samples treated with Ultra FR and Burnblock FR are similar and much lower than Palonot FR.

For samples treated by spray application (Figure 16), the dry retention values for samples impregnated with Palonot FR were the highest. Asp-P-S has weight gain of 20.8 kg/m^3 and Bir-P-S, 38 kg/m^3. Burnblock FR was least retained in the wood veneers, the weight gain was 0.9 kg/m^3 and 1 kg/m^3 for aspen and birch veneers, respectively.
The results obtained from roller spreader and spray treatment follows the same trend as those obtained from impregnation with Palonot FR uptake the highest, and Burnblock, the least.

Table 9 below shows the result for veneer samples impregnated with fire retardant chemicals. The average weight gain for birch veneers impregnated with Palonot (Bir-P-I) was 47 kg/m^3 which represents a percentage weight gain of 16.87%. This represents the highest values for the impregnated birch veneers for all the groups. Of all the impregnated veneers, aspen (Asp-P-I) impregnated with Palonot has the highest average weight gain and percentage weight gain of 68.8 kg/m^3 and 32.03% respectively. Retention of Palonot by the Aspen veneer is higher than all the veneer samples impregnated. Values obtained for Bir-U-I indicated an average weight gain of 18.6 kg/m^3 and this represents a percentage increase of 9.82%. Similarly, weight gain and percentage weight gain for Aspen veneers impregnated with Ultra FR (Asp-U-I) was 25.6 kg/m^3 and 16.91% respectively. Veneers impregnated with Burnblock FR has the least dry retention of 5.7 kg/m^3 and 4.3 kg/m^3 for Bir-B-I and Asp-B-I, respectively.

The results showed that for impregnation, Palonot FR was retained more than other FR chemicals while Burnblock was retained the least by veneers. This agrees with the results gotten from the solid content determination presented in table 8 above. This showed that the dry retention values (weight gain) are directly proportional to the solid content of the FR chemicals used for impregnating wood veneers. Fire retardant absorption of birch veneers impregnated with Palonot FR (47 kg/m^3) agrees with what was recorded in literature by impregnating birch veneers samples (BB_d) by diffusion method (Bekhta et al., 2016). For Ultra FR and Burnblock FR, the absorption by birch samples was less than what was recorded in literature.

Table 9. Impregnation of veneer samples

S/N	Specimen	Avg. WG (kg)	Avg. WG (%)	Avg. WG (kg/m3)	STDV	FR CHEMICAL
1	Bir-P-I	0.00157	16.87	47	7.2	Palonot
2	Asp-P-I	0.0023	32.03	68.8	7.4	
3	Bir-U-I	0.0009	9.82	18.6	1.2	Ultra
4	Asp-U-I	0.00124	16.91	25.6	2.2	
5	Bir-B-I	0.00062	6.83	5.7	0.2	Burnblock
6	Asp-B-I	0.00047	6.33	4.3	0.1	

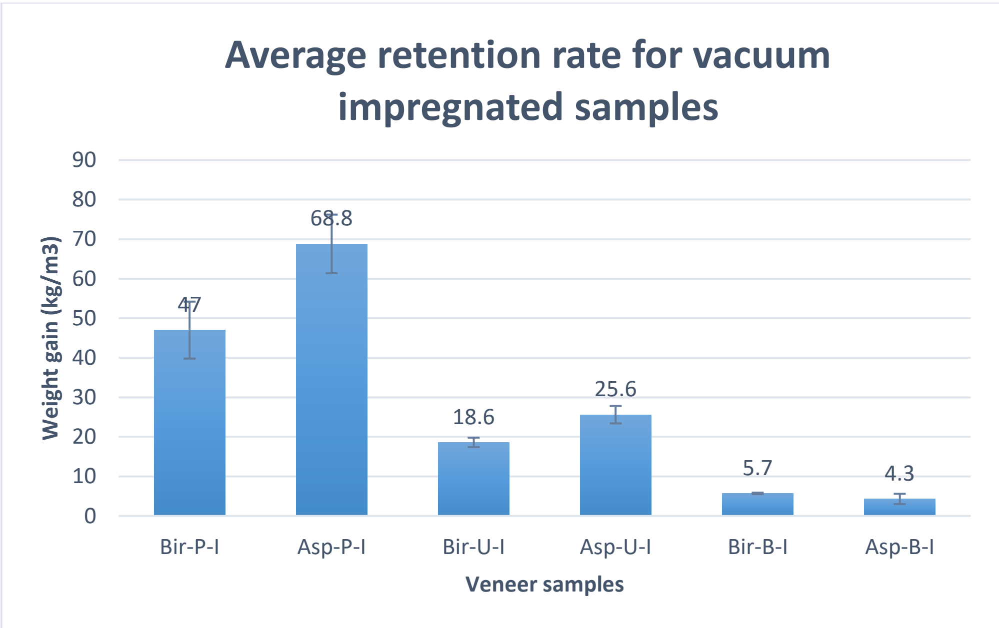

Figure 17. Average dry retention and standard deviation for impregnated samples

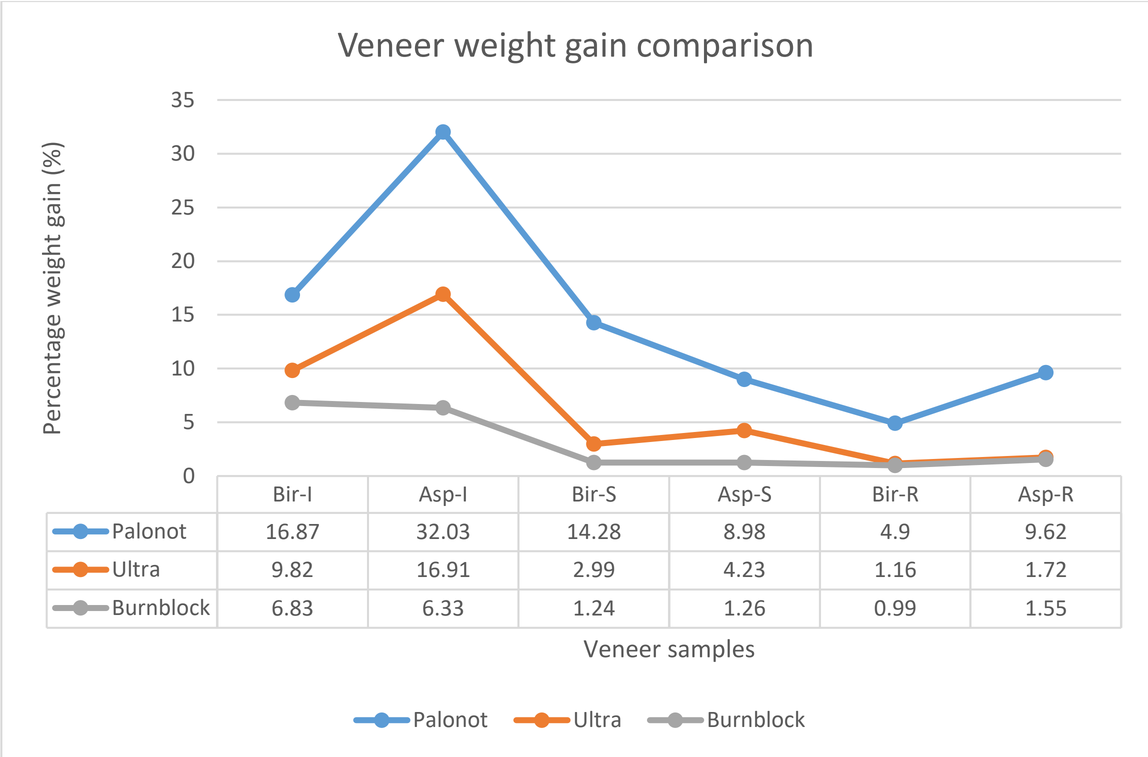

Figure 18. Comparison of different treatment methods

Figure 18 above showed the graphical comparison of the three methods of treatment. It was clear that dry retention for Palonot FR was highest and Burn block FR, the least for all veneer samples that were treated by impregnation, roller spreader or spraying.

4.3 Results from fire test

4.3.1 Basic fire protection time

The fire test results showed that different treated samples gave unique protection times. Basic protection time refers to the time taken for fire to burn the treated veneer and expose the wood below to combustion. A total of 60 samples were tested. Three samples each were tested to get a reliable result, this agrees with (Kallakas et al., 2019). The combustion dynamics of the treated veneers with FR chemicals differs greatly. Veneers treated with Palonot FR gave impressive results. Asp-P-R, Asp-P-I and Asp-P-S gave an average ignition time of 11.3, 15.7 and 14.7 s, respectively. Birch veneers treated with Palonot FR gave higher ignition time of 27, 19.3 and 23.7 s, respectively. For samples treated with Palonot FR, after ignition, the samples burned for about additional 10 s and the fire went out. A protective layer was seen formed on the surface of the veneers before the fire went off (Figure 13). These prevented further flaming of the veneer. At decay, the veneer ignited again, and the test was stopped, there was no smouldering whatsoever on the veneer samples.

Aspen samples treated with Ultra FR, Asp-U-R, Asp-U-I and Asp-U-S gave ignition time of 10.3, 12.7 and 12 s, respectively. Bir-U-R, Bir-U-I and Bir-U-S gave ignition time of 17, 20.7 and 15 s respectively.

For veneers treated with Burn block, Asp-B-R, Asp-B-I and Asp-B-S gave ignition time of 10.7, 12, and 8.7 s respectively while Bir-B-R, Bir-B-I and Bir-B-S gave average ignition time of 13, 15 and 16.3 s, respectively. These ignition times when compared with the control samples showed that the use of fire retardant slowed down the ignition time considerably for veneer samples treated with Palonot FR.

The Figures below (19-22) show the tested sample and what is left after fire test.

Figure 19. Veneers treated with Palonot FR after fire test.

The Figure 19 Above showed that for the samples treated with Palonot, Impregnation is the best method of treatment for aspen samples while roller application gave the highest ignition time for birch samples. Veneers samples charred and remained together as a whole piece as indicated in the picture.

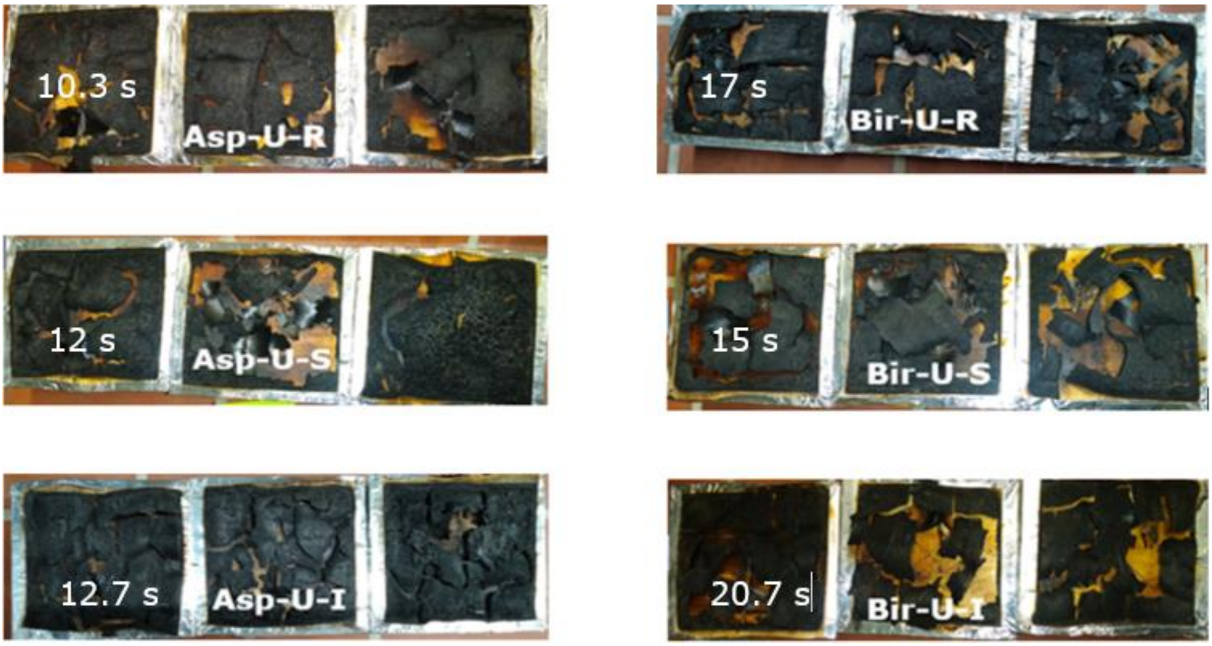

Figure 20. Veneers treated with Ultra FR after fire test.

Figure 20 above indicated that the ignition of 12.7 s was the highest for impregnated aspen samples. Impregnated birch veneer samples for Ultra gave the highest ignition value of 20.7 s. This suggested that for Ultra FR, impregnation is recommended as treatment method. A visual comparison of the veneer samples treated with Ultra FR with the samples treated with Palonot FR showed that Ultra treated samples broke into small pieces and exposed the wood below during the fire test, this suggests that Palonot FR offered more protection than Ultra FR.

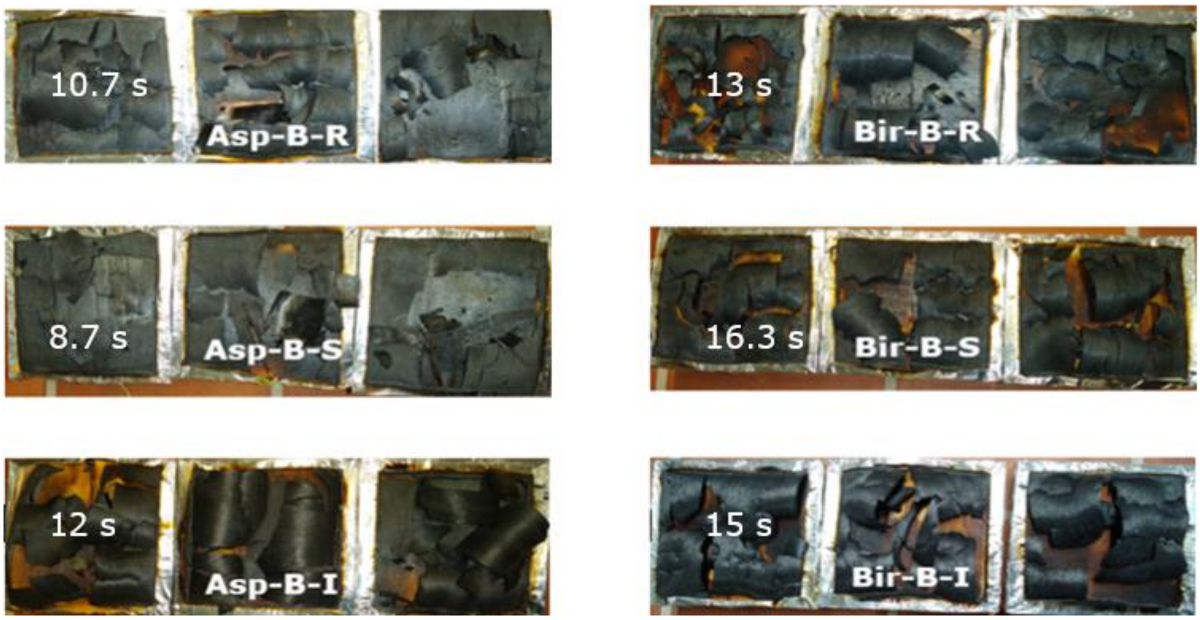

Figure 21. Veneers treated with Burn block FR after fire test

A look at Figure 21 showed that impregnated aspen samples with Burnblock gave the highest ignition time of 12 s. Spraying appeared to be the most effective method of treating birch samples with Burn block FR as the sprayed samples have average ignition time of 16.3 s. These veneer samples treated with Burnblock displayed behaved like samples treated with Ultra FR, breaking into pieces to expose the wood below.

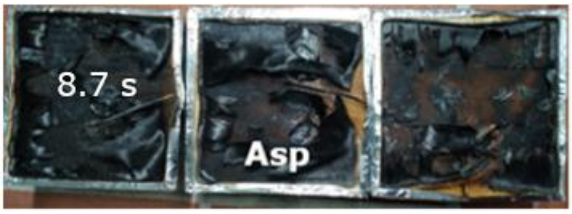

Figure 22. Veneer control samples

Figure 22 showed the control veneer samples with ignition time of 8.7 s and 12.3 s for aspen and birch veneers, respectively. After the test was completed, there was smouldering of the control samples, fire was put off with water. This showed that treatment of the samples with fire-retardant chemicals prevented smouldering after the source of irradiance was put away.

Generally, the ignition times for treated birch samples were higher than that of aspen. This may be attributed to the densities of the two wood species.

Results for ignition and basic protection time was presented in Figure 23. Veneers treated with Palonot FR clearly gave higher ignition time relative to Ultra and Burnblock FR.

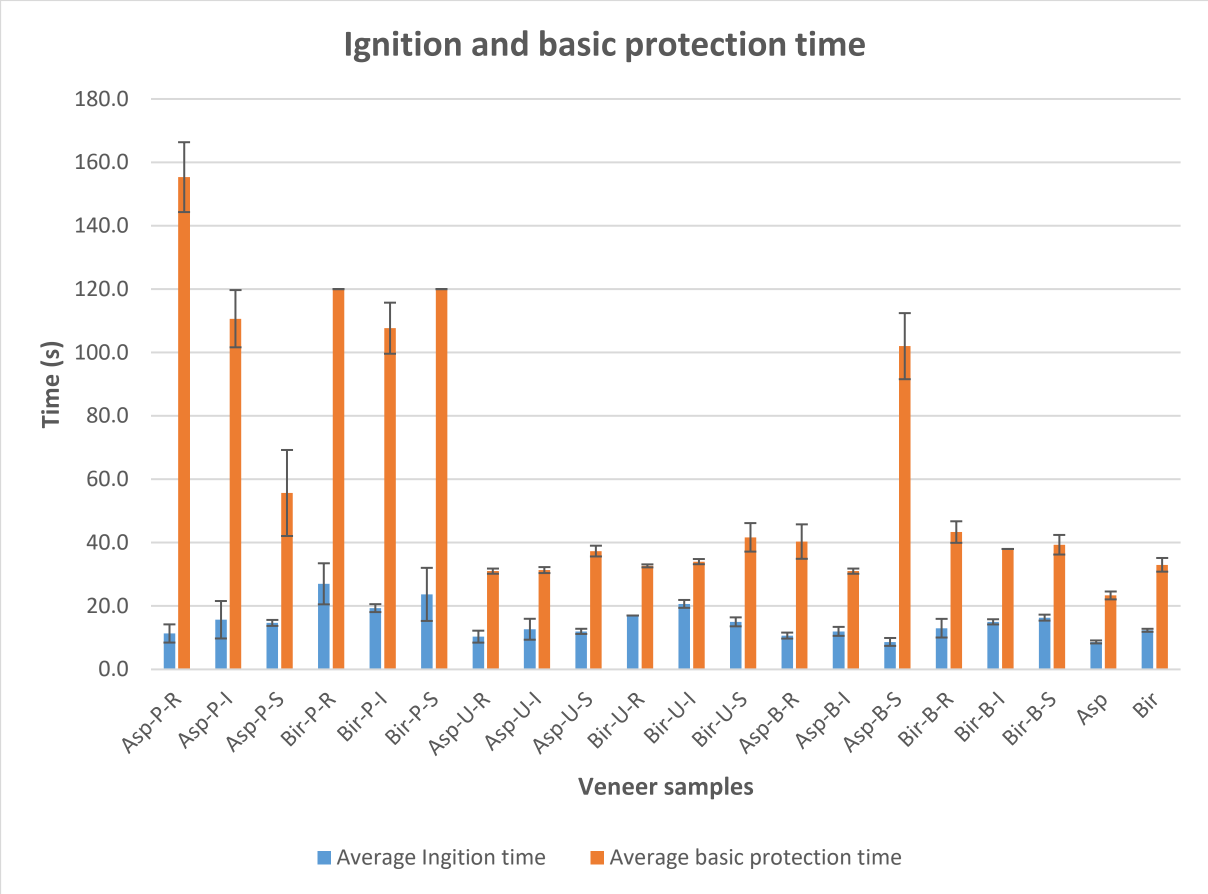

Figure 23. Average Ignition time and Decay time

The Figure above (Figure 23) indicated clearly that the Palonot FR gave good protection to the veneers compared to other FR chemicals. Roller coated aspen samples gave the highest basic protection time while spraying gave the least protection. For birch samples treated with Palonot FR, the basic protection time for samples coated with roller and sprayed sample have about the same protection while the impregnation gave the least protection. The basic protection given by Ultra FR and Burn block FR are comparable. Aspen sprayed samples treated with Burn block however have a higher protection time. Again, there was correlation between the chemical absorption of the FR chemicals and fire protection given to veneer samples.

4.3.2 Temperature and time curve for fire test

Figures 24-26 shows the temperature and basic protection time curve for treated and untreated veneer samples. 270 °C and 300 °C are considered coincide with the basic protection time of a wooden material (SP Technical Research Institute of Sweden, 2010).

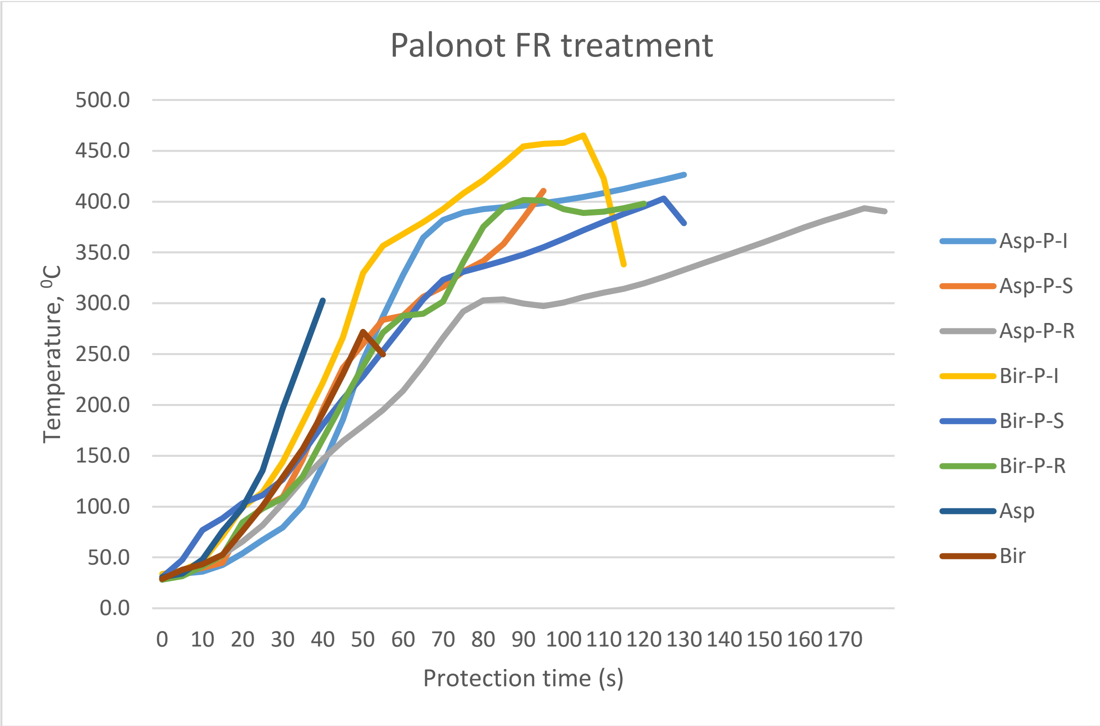

Figure 24. Fire test for veneer samples treated with Palonot FR.

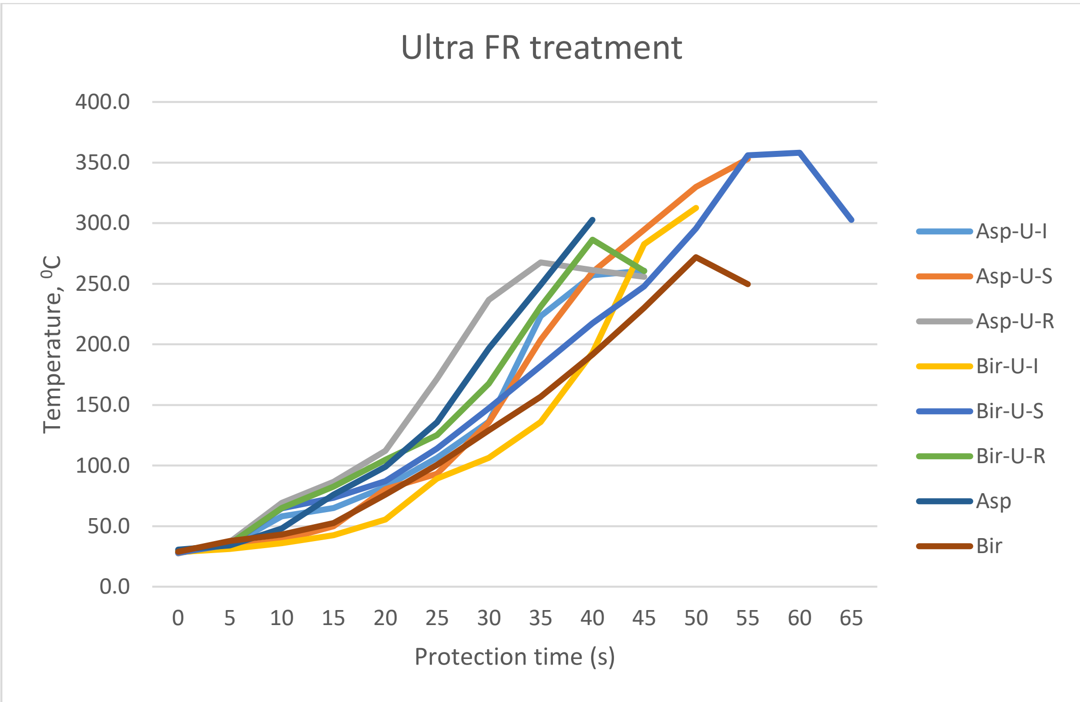

Figure 25. Fire test for samples treated with Ultra FR

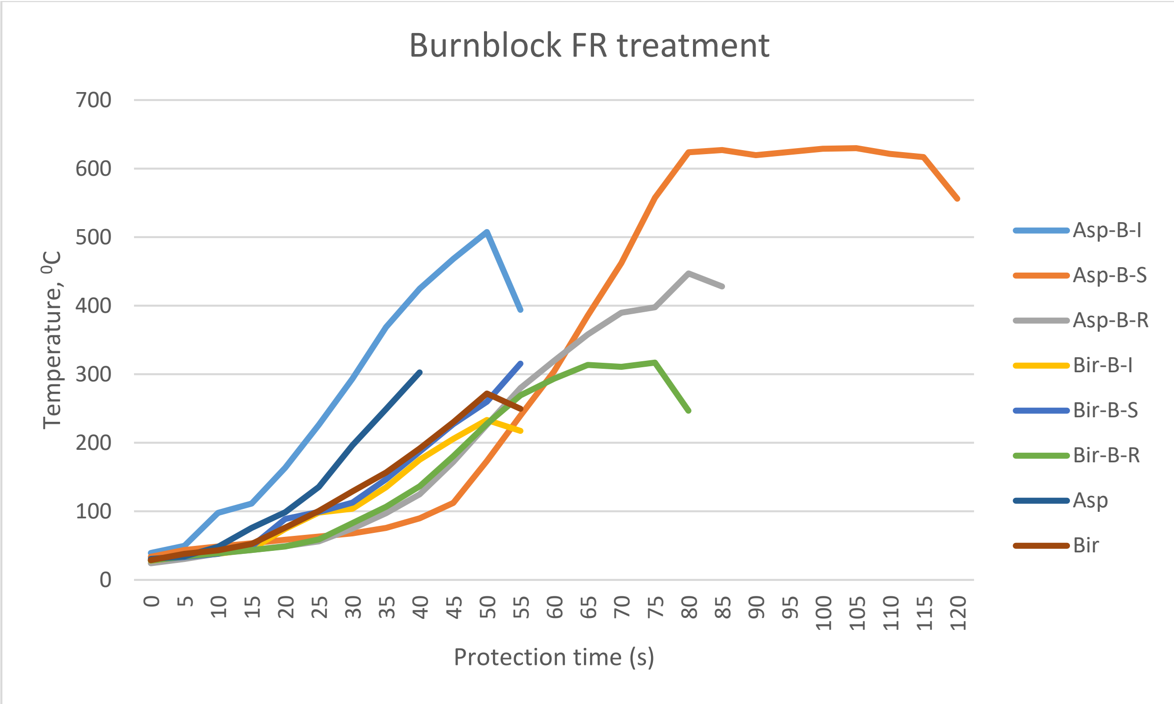

Figure 26. Fire test for samples treated with Burnblock FR

The temperature measurement showed how the temperature of the protected wood measured in-between the treated wood and the solid wood (protected wood). Treated veneer samples, gave different protections depending on the type of FR chemical used for treatment. Samples treated with Palonot performed well. Asp-P-R (Figure 24) gave an outstanding result for the group, the FR gave protection above 170 s with relatively low temperature rise. Other samples also performed well, protecting the veneer as the temperature increased. Both Aspen and Birch control samples decayed at relatively low temperatures and time. This test showed that Palonot FR offered fire basic fire protection to wood. Figures 25 and 26 gave protection times lower than Palonot FR treated samples. Samples treated with Ultra FR gave a decayed time close to that of control samples. Asp-B-S, Asp-B-R and Bir-B-R gave stood out from the samples treated with Burnblock. Generally, the basis of basic protection time, Burnblock performed better than Ultra FR.

4.4 Lap shear strength test results

Results for lap shear strength test are shown in Table 10 below. Birch control samples gave the highest strength values as expected. The Shear strength for birch treated samples is significantly higher than aspen samples. Asp-U-LPF gave the least lap joint strength of 2.5 MPa while Bir-B-LPF gave highest value of 7.3 MPa of the treated samples.

Bir-P-LPF samples gave lap shear strength values closer to zero. Most of the samples in this group got delaminated when fixing to tensile testing machine.

Birch control samples bonded with phenol formaldehyde and lignin phenol formaldehyde gave lap shear strength of 9.7 MPa and 9.6 MPa which are quite close. The results showed that the adhesion properties of untreated and treated birch veneers are better than aspen veneers.

Table 10. Lap shear strength test

S/N	Specimen	l (mm)	b (mm)	A (mm2)	Average shear strength (MPa)	Standard deviation
1	Asp-PF	5	20	100	3.6	0.9
2	Bir-PF	5	20	100	9.7	0.8
3	Asp-P-PF	5	20	100	3.6	1.6
4	Bir-P-PF	5	20	100	6.7	2.0
5	Asp-U-PF	5	20	100	2.8	1.0
6	Bir-U-PF	5	20	100	6.3	1.6
7	Asp-B-PF	5	20	100	3.3	1.0
8	Bir-B-PF	5	20	100	5.0	1.7
9	Asp-LPF	5	20	100	5.0	0.9
10	Bir-LPF	5	20	100	9.6	0.7
11	Asp-P-LPF	5	20	100	3.0	0.5
12	Bir-P-LPF	5	20	100	-	-
13	Asp-U-LPF	5	20	100	2.5	0.8
14	Bir-U-LPF	5	20	100	6.2	1.1
15	Asp-B-LPF	5	20	100	3.1	0.4
16	Bir-B-LPF	5	20	100	7.3	1.5

The information presented in Table 10 are shown in Figures 27 and 28 below. The results from the lap shear strength test showed that treatment with fire-retardants lowered glue bond strength compared with the control samples. Veneers treated with LPF and pressed for 5 min 55 s displayed lower bond strength and delaminated when removed from press plate. Pressing time was increased to 8 min 30 s after several trials with different pressing time and the strength of bond developed was comparable to samples bonded with PF.
Examining the mode of failure of the veneers in shear shows that Bir-P-LPF samples was purely adhesive failure with samples falling apart before testing. Birch control samples bonded with PF and LPF have 75% wood failure. Bir-P-LPF, Bir-U-PF, Bir-P-PF also have 75% wood failure. This is an indication of quality joint as the failure occurred in the veneer material and not in the adhesive. Asp-LPF, Bir-B-PF, and Bir-U-LPF have 50% wood failure.

Other samples had 25% wood failure. These results showed that treated samples with higher percentage of wood failure are recommended for use if the mode of treatment of veneer with FR chemicals before making plywood is impregnation.

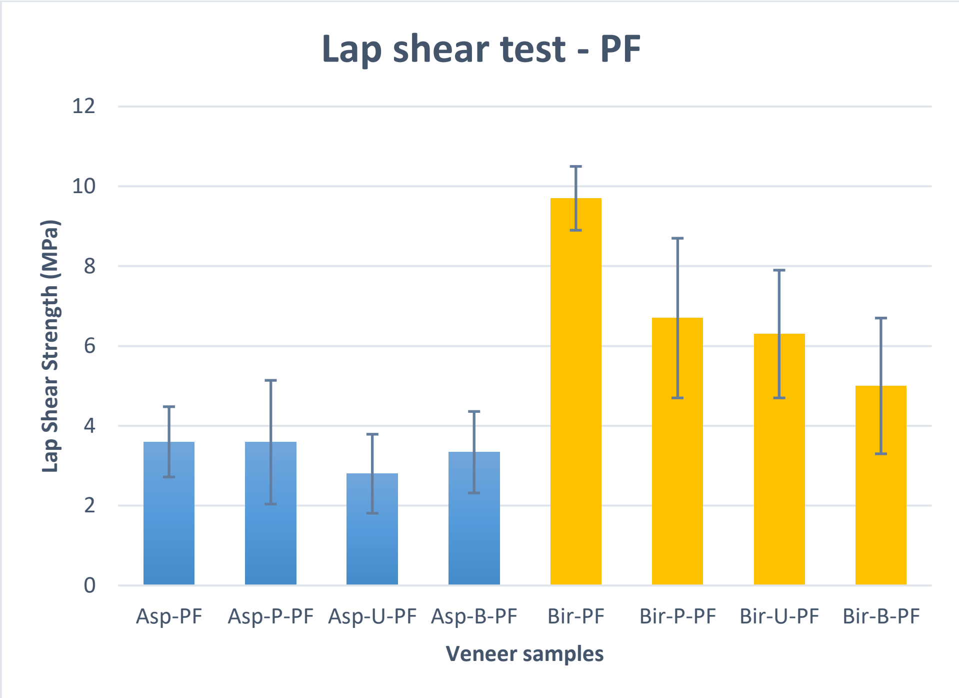

Figure 27. Shear strength for samples bonded with phenol formaldehyde.

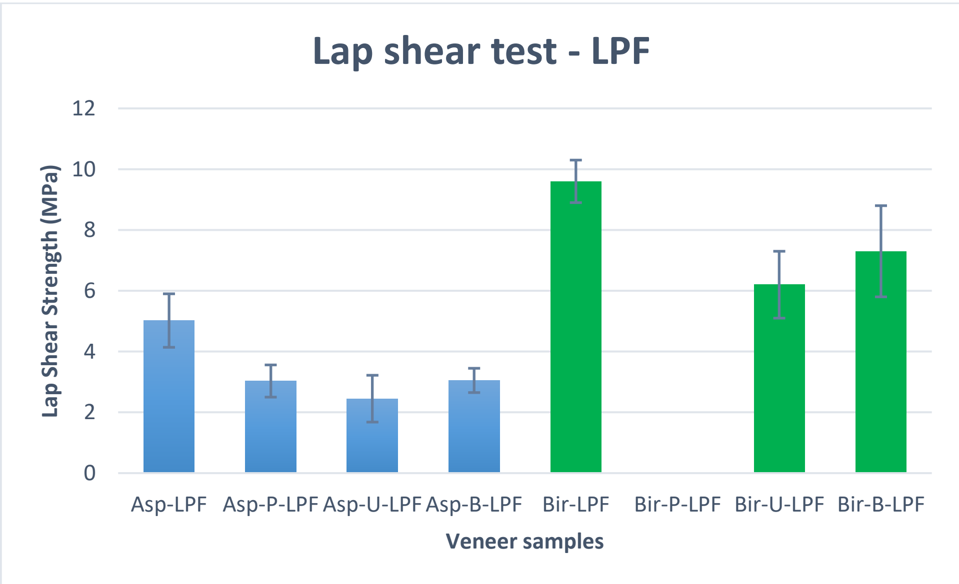

Figure 28. Shear strength for samples bonded with phenol formaldehyde.

Lap shear strength test showed that there was a decrease of 22% and 8.3% for Asp-U-PF and Asp-B-PF respectively compared to the reference. The effect of Ultra FR on the aspen veneers was more than that of Burnblock FR as indicated by the percentage decrease. Asp-P-PF had the same bond strength with the reference sample; this shows that Palonot does not have significant effect on the bonding properties aspen veneers. This test also suggested that impregnation as a method of treatment can be used to treat aspen veneers and PF adhesive used for gluing the veneer sheets.

The percentage decrease in lap shear strength for treated aspen samples bonded with LPF was more than that of aspen samples bonded with PF. Asp-P-LPF, Asp-U-LPF, and Asp-B-LPF has percentage decrease of 40%, 50% and 38% respectively. Ultra FR has the highest negative effect on the bonding quality. This showed that Ultra FR may be applied to veneers to make plywood either by roller application or spraying. Generally, LPF adhesive appears not to be compatible with treated aspen veneer samples because of the percentage decrease in shear strength. Treated birch veneer samples gave higher lap shear strength value when compared with the treated and untreated aspen samples. Bir-P-PF, Bir-U-PF and Bir-B-PF had percentage decrease of 30%, 35% and 49% respectively. However, with these percentage decrease, the recorded lap shear strengths for treated birch samples bonded with PF are significantly higher than aspen treated samples. Treated birch samples gave values greater that aspen control samples. Treated birch veneers bonded with LPF adhesive displayed superior bond strength when compared with other vacuum impregnated samples. Percentage decrease in lap shear was 35% and 24% for Bir-U-LPF and Bir-B-LPF, respectively. However, Bir-P-LPF showed that LPF cannot be used to bond birch samples impregnated with Palonot FR, the lap shear strengths given in this group is closer to zero. Bonding quality was reduced more than 20% when compared to what was found in literature (Kawalerczyk et al., 2019). However, lap shear test results is quite better when compared with (Bekhta et al., 2016) as shear values recorded for treated samples were more than 2 MPa.

ANOVA statistical analysis indicated that the impregnation of veneer samples with fire-retardant chemicals have significant effect on the bonding properties of the veneers. However, ANOVA showed that there was no significant effect of FR chemicals on the bonding properties of aspen samples bonded with PF adhesive. This test shows that impregnating individual veneers before bonding to make plywood can provide adequate fire protection to the cross section of the plywood without affecting the bonding strength badly.

CONCLUSIONS

The main purpose of this thesis work was to treat wood veneers from two wood species with fire retardant chemicals, test for fire resistance and the effect of FR chemicals on the bonding properties of the wood veneers. Solid content of FR chemicals was determined, and the results showed that Palonot has the highest amount of solid content and Burnblock has the least. The results obtained explained why the weight gain for samples treated with Palonot was more than that of other samples treated with Ultra and Burn block FR. Generally, Aspen veneers have the highest weight gain than birch veneers for all the samples impregnated.

Although, the samples impregnated with vacuum pressure had the highest amount of chemical uptake, spraying and roller spreader are energy efficient method that can be applied to mass production of fire-retardant plywood. However, fire retardants with high concentration are recommended for these processes to ensure adequate retention and subsequently, fire protection.

The amount of FR chemical taken up by the veneers determined the resistance to fire. Veneers treated with Palonot FR displayed highest resistance. These samples, extinguished after ignition and charred, preventing further flaming until decay. After the treated samples were removed from cone heater, smouldering stops immediately but in the control samples, smouldering and burning continued until the fire was put out. The investigated fire-retardant chemicals showed that these fire retardants provided protection to wood veneers and the level of protection is proportional to the concentration of the solutions. Therefore, higher concentration in the range of 45-50% is recommended for spraying and roller spreader methods.

Lap shear strength test revealed that the adhesion properties of veneers is impacted by treatment with fire-retardant chemicals. Birch veneers treated Palonot and bonded with lignin phenol formaldehyde adhesive gave shear strength values closer to zero. Most of the veneers in these group delaminated even before the test. Therefore, one can conclude that birch veneers treated with Palonot is not suitable to be bonded with lignin phenol formaldehyde adhesive. Other impregnated birch veneers gave impressive results than treated aspen samples, treated veneers gave 25–70% wood failure when examined. Shear strength values were better than what was found in literature. Thus, it can be concluded that veneers can be treated with these fire-retardants by impregnation for making fire retardant plywood.

SUMMARY

Plywood is an important wood-based panel material used for constructional purposes, transportation sector and furniture industry. It is produced by bonding layers the wood veneers crosswise together to form a strong and rigid material by hot pressing. Due to its many applications, plywood is required to fulfil some performance criteria. Being a combustible material, plywood is treated with fire-retardant chemicals to incorporate fire protection. This can be done by either treating readymade plywood panels or impregnation of the veneer sheets with fire retardant chemicals and then bonding them as top layers or top and core layers of plywood. Impregnating veneer samples with fire retardant chemicals has an impact to the bonding properties of the veneers.

This master thesis was focused on preparation of 1.5 mm aspen and birch veneer samples for impregnation tests by different methods and different fire-retardant chemicals, to evaluate the effect of fire-retardant chemical to the fire resistance properties and to study the bonding properties of veneer samples after treatment with fire retardant. In this project, three types of fire retardants (Palonot, Ultra and Burnblock FR) were used to treat wood veneers and two common wood species, aspen (*Populus tremula*) and Silver birch (*Betula pendula Roth*) were used. Phenol formaldehyde and lignin phenol formaldehyde adhesives were used to bond the veneer samples for lap shear strength test.

Three methods of veneer treatments were used. These are, vacuum impregnation, roller coater and spray coating. The impregnation was carried under vacuum pressure of -0.65 bar, at room temperature; rubber roller coater was used to apply fire-retardant chemicals and gravity type spray gun was used to apply chemical on the sprayed samples. Percentage of the solid content of the fire retardants were determined by oven drying method. After treatment of the veneer samples, fire resistance and lap shear strength tests were carried out to determine the effect of the fire-retardants on fire resistance and bonding strength, respectively.

The solid content is the active content of the fire-retardant and higher percentage implied better fire protection. Results from the solid content determination showed that Palonot fire-retardant had the highest concentration of solids followed by Ultra and Burnblock. Generally, vacuum impregnated samples had the highest FR retention when compared to other methods of treatment. Samples treated with Palonot FR performed better during fire test, giving higher protection time. The performance of Palonot FR is directly linked to the solid content of the chemical. Also, samples treated with Palonot charred and remained together while samples treated with Ultra and Burnblock FR charred and broke into pieces during fire test. It is recommended that if spraying or roller coater is to be used for treatment, fire-retardants with higher concentrating should be used.

Treatment of veneer with fire retardant impacted the bonding properties of the veneers. Treated birch samples gave impressive results compared with the aspen samples. However, the lap shear strength recorded was higher than the values found in literature. In comparison with other treatment methods the vacuum impregnation can be used for fire retardant treatment as the lap-shear tests gave sufficiently good bond strengths.

The aim of this master thesis was accomplished. The influence of different treatment methods and different fire-retardant chemicals to the fire resistance and bond strength properties of birch and aspen veneers were determined. The analysis of the obtained test results enabled to make recommendations for selecting the sufficient fire-retardant chemicals and treatment methods to increase the fire resistance properties of birch and aspen veneers by maintaining the sufficient bond strength.

KOKKUVÕTE

Vineer on oluline puidupõhine plaatmaterjal, mida kasutatakse laialdaselt nii ehituslikel eesmärkidel, transpordisektoris ja mööblitööstuses. Seda toodetakse õhukeste liimiga kaetud spoonikihtide ladumisega piki- ja ristisuunaliselt ning kuumpressitakse seejärel tugevaks ja jäigaks materjaliks. Erinevate kasutusalade tõttu peab vineer vastama erinevatele materjali valikukriteeriumitele. Kuna puit on põlev materjal, töödeldakse vineeri tuletõkkeainetega, et vähendada süttivust ja suurendada tulepüsivust. Vineeri tulepüsivust saab suurendada nii juba valmistatud vineeritahvlite töötlemisel tuletõkkeainega kui ka spoonilehtede immutamisel tuld tõkestava keemilise ainega ja liimides töödeldud spoonilehti välimisteks kihtideks või nii välimisteks kui ka sisekihtideks. Spoonilehtede immutamine tuld tõkestavate kemikaalidega mõjutab spoonipinna nakkuvust puidu liimidega.

Magistritöö fookuseks oli valmistada 1,5 mm paksused haava ja kasespooni proovid ja töödelda neid erinevate tuletõkkeainetega, kasutades erinevaid töötlusmeetodeid uurimaks nende mõju spooni tulepüsivusele ja puidupinna liimiga nakkuvusele pärast keemilise vahendiga töötlemist. Selles projektis kasutati hariliku haava (*Populus tremula*) ja arukase (*Betula pendula Roth*) spoonide töötlemiseks kolme eritüüpi tuletõkkeaineid (Palonot, Ultra ja Burnblock FR). Kemikaalidega töödeldud spoonipinna adhesiooni ehk nakkuvusomaduste ja liimliite nihketugevuse katsetamiseks kasutati fenoolformaldehüüdliimi (PF) ja ligniin-fenoolformaldehüüdliime (LPF).
Kasutati kolme spooni töötlemisemeetodit: vaakumimmutus, käsirulliga katmine ja pihustamine. Impregneerimine viidi toatemperatuuril vaakumiga -0,65 bar; tuletõkkeainete pealekandmiseks kasutati kummirulli ja pihustamiseks ülakopsikuga pihustuspüstolit. Tuletõkkevõõpade kuivainesisaldus protsentides määrati kuivatusahjus. Pärast spooni proovide töötlemist viidi läbi tulekatsed ja liimliidete nihketugevuskatsed, et määrata kindlaks tuletõkkeainete mõju vastavalt spooni tulepüsivusele ja spoonipinna liimiga nakkumisele ning liimliite nihketugevusele.
Kuivainesisaldus näitab tuletõkkeaine aktiivkomponentide osakaalu ja suurem protsent lubab eeldada paremaid tulekaitseomadusi. Kuivainete sisalduse määramise tulemused näitasid, et Palonoti tuletõkkeaine kuivaine sisaldus oli suurim ja sellele järgnesid Ultra ja Burnblock. Üldiselt olid vaakumimmutatud proovidel paremad tulekaitseomadused võrreldes kummirulliga katmisel ja pihustamise teel kaetud proovidega. Seega on nende meetodite puhul soovitatav suurendada kuivaine kontsentratsiooni tuletõkkevõõbas Palonot FR-ga töödeldud proovid andsid tulekatsetes pikemaajalise tulekaitse kuna söestunud spoonipind jäi terviklikuks ega purunenud väikesteks tükkideks nagu Ultra ja Burnblockiga töödeldud katsekehade puhul.

Spooni töötlemine tuletõkkeainega mõjutas spoonipinna naket puiduliimidega. sidumisomadusi. Töödeldud kaseproovid andsid haavaproovidega võrreldes paremaid tulemusi. Tuletõkkeainega töödeldud spoonidest valmistatud liimliidete nihketugevused oli siiski suuremad kui kirjandusest leitud väärtused. Tuletõkkeainetega töötlemisel andis vaakumimmutus tugevamad liimliited võrreldes teiste töötlemismeetoditega. Kokkuvõtteks võib öelda, et käesoleva magistritöö eesmärk sai täidetud. Määrati erinevate töötlemismeetodite ja erinevate tuletõkkeainete mõju kase- ja haavaspoonide tulepüsivusele ja pinna nakketugevuse omadustele. Saadud testitulemuste analüüs võimaldas anda soovitusi tuletõkke kemikaalide ja töötlemismeetodite valimiseks nii, et kase- ja haavaspoonidele tulepüsivusomadused suureneksid, kuid säiliks piisav liimliite nihketugevus.

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APPENDIX 1

Table 11. 1.5mm Birch veneer samples impregnated with Palonot FR

S/N		Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1		9.34	14.83	11.14	1.80	19.27
2		9.23	16.95	10.92	1.69	18.31
3		8.89	16.83	10.56	1.67	18.79
4		9.34	16.21	10.97	1.63	17.45
5		9.55	15.91	11.27	1.72	18.01
6		9.92	16.21	11.67	1.75	17.64
7		9.55	16.18	10.87	1.32	13.82
8		9.33	16.49	11.09	1.76	18.86
9		9.18	15.69	10.20	1.02	11.11
10		8.77	15.26	10.12	1.35	15.39
		Average			**1.57**	**16.87**
		SD			**0.24**	

Table 12. 1.5mm Aspen veneer samples impregnated with Palonot FR

S/N	Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1	7.26	16.64	9.68	2.42	33.33
2	7.19	16.40	9.44	2.25	31.29
3	7.56	17.61	10.02	2.46	32.54
4	6.75	15.92	9.03	2.28	33.78
5	7.30	16.46	9.57	2.27	31.10
6	7.62	18.20	10.35	2.73	35.83
7	6.82	13.14	8.51	1.69	24.78
8	6.87	16.31	9.22	2.35	34.21
9	7.11	16.30	9.37	2.26	31.79
10	7.18	16.36	9.45	2.27	31.62
	Average			**2.30**	**32.03**
	SD			**0.25**	

Table 13. 1.5 Birch veneer samples impregnated with Ultra FR

S/N	Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1	9.13	16.03	10.11	0.98	10.73
2	9.15	16.47	10.02	0.87	9.51
3	9.21	16.68	10.10	0.89	9.66
4	9.30	16.71	10.19	0.89	9.57
5	9.32	16.38	10.30	0.98	10.52
6	9.33	16.23	10.14	0.81	8.68
7	9.39	16.80	10.25	0.86	9.16
8	8.87	16.19	9.72	0.85	9.58
9	9.25	16.66	10.20	0.95	10.27
10	9.17	16.30	10.13	0.96	10.47
	Average			**0.90**	**9.82**
	SD			**0.06**	

Table 14. 1.5mm Aspen veneer samples impregnated with Ultra FR

S/N	Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1	7.01	16.52	8.43	1.42	20.26
2	7.10	16.17	8.24	1.14	16.06
3	6.89	16.37	8.09	1.20	17.42
4	7.91	17.17	9.09	1.18	14.92
5	7.77	16.83	9.11	1.34	17.25
6	6.97	15.94	8.11	1.14	16.36
7	7.69	17.35	8.88	1.19	15.47
8	7.40	16.48	8.52	1.12	15.14
9	7.80	17.12	9.19	1.39	17.82
10	7.12	16.78	8.43	1.31	18.40
	Average			**1.24**	**16.91**
	SD			**0.11**	

Table 15. 1.5mm Birch veneer samples Impregnated with Burnblock FR

S/N	Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1	9.08	15.99	9.70	0.62	6.83
2	9.37	16.46	10.00	0.63	6.72
3	9.27	16.01	9.86	0.59	6.36
4	9.17	16.36	9.79	0.62	6.76
5	9.09	16.24	9.72	0.63	6.93
6	8.96	16.15	9.59	0.63	7.03
7	9.17	16.11	9.76	0.59	6.43
8	9.03	16.21	9.64	0.61	6.76
9	9.23	16.25	9.88	0.65	7.04
10	8.84	15.91	9.50	0.66	7.47
	Average			**0.62**	**6.83**
	SD			**0.02**	

Table 16. 1.5mm Aspen veneer samples impregnated with Burnblock FR

S/N	Mass before impregnation(W1)	Mass after impregnation	Mass after drying(W2)	WG (g)	WG (%)
1	7.07	15.87	7.79	0.72	10.18
2	7.96	16.23	8.57	0.61	7.66
3	7.71	13.80	8.08	0.37	4.80
4	6.82	14.36	7.37	0.55	8.06
5	8.10	16.41	8.72	0.62	7.65
6	7.27	15.06	7.67	0.40	5.50
7	7.57	15.37	7.87	0.30	3.96
8	7.48	15.14	7.78	0.30	4.01
9	7.26	14.98	7.62	0.36	4.96
10	7.18	14.76	7.65	0.47	6.55
	Average			**0.47**	**6.33**
	SD			**0.14**	

Table 17. Ignition and decay time

S/N	Samples	Ignition time				Decay time (dt)			
		t1 (s)	t2 (s)	t3 (s)	Average Ingition time (s)	dt1 (s)	dt2 (s)	dt3 (s)	Average decay time (s)
1	Asp-P-R	8	11	15	11.3	169	155	142	155.3
2	Asp-P-I	12	11	24	15.7	112	99	121	110.7
3	Asp-P-S	16	14	14	14.7	38	71	58	55.7
4	Bir-P-R	18	30	33	27.0	120	120	120	120.0
5	Bir-P-I	21	19	18	19.3	119	101	103	107.7
6	Bir-P-S	35	21	15	23.7	120	120	120	120.0
7	Asp-U-R	9	9	13	10.3	31	30	32	31.0
8	Asp-U-I	17	9	12	12.7	32	30	32	31.3
9	Asp-U-S	12	13	11	12.0	35	38	39	37.3
10	Bir-U-R	17	17	17	17.0	33	32	33	32.7
11	Bir-U-I	21	22	19	20.7	33	34	35	34.0
12	Bir-U-S	13	16	16	15.0	48	39	38	41.7
13	Asp-B-R	10	12	10	10.7	36	48	37	40.3
14	Asp-B-I	11	14	11	12.0	31	32	30	31.0
15	Asp-B-S	9	10	7	8.7	88	105	113	102.0
16	Bir-B-R	10	17	12	13.0	40	48	42	43.3
17	Bir-B-I	15	16	14	15.0	38	38	38	38.0
18	Bir-B-S	15	17	17	16.3	35	41	42	39.3
19	Asp	9	9	8	8.7	25	22	23	23.3
20	Bir	12	13	12	12.3	30	35	34	33.0

APPENDIX 2

FIRE-RETARDANT PLYWOOD MANUFACTURERS IN EUROPE

Table 18. Fire-retardant plywood manufacturers in Europe

PLYWOOD MANUFACTURER/COUNTRY	WOOD SPECIE	TYPE OF ADHESIVE	DENSITY (Kg/m^3)	BOARD SIZE (mm)	FIRE CLASS	PROCESS	PATENTS
UPM, FINLAND	Spruce	Phenol-formaldehyde		1000X2000/2500/3000, 1220/1250x2440/2500, 1500/1525x2500/3000/3050/3660	B	Surface impregnation	The fire retardant (300) is a liquid fire retardant solution (300) that comprises an acid comprising phosphorus or an acid salt compound comprising phosphorus; preferably, - the liquid fire retardant solution (300) comprises at least one of • 1-hydroxyethylidene-1,1-diphosphonic acid (HEDP) or salt thereof, • ethylenediaminetetramethylenephosphonic acid (EDTMP) or salt thereof, • diethylenetriaiminepentamethylenephosphonic acid (DTPMP) or salt thereof; preferably, • the fire retardant (300) comprises at most 1 ppm, or is free from, each one of a heavy metal, boron, a halogenated compound.

METSA WOOD, FINLAND	Spruce	Phenol-formaldehyde	470-540	2400/2440/2500x 1200/1220/1250	B	Surface impregnat-ion	
ODEK, UKRAIN	Birch, Alder	Phenol-formaldehyde	720-820	1250x2500, 1220x2440	B	Veneer Impregnat-ion	
PAGED, POLAND	Birch	Phenol-formaldehyde	720-880	1250x1500/2500, 1500x3000	B	surface impregnat-ion or filmed with high density phenolic film	
GARNICA, SPAIN	Poplar	Phenol-formaldehyde	460 - 520	2500x1220, 3100x1530	A	Impregnat-ion	
HESS, SWITZERLAND	Beech, Ash, Poplar, Fir		730	2550x 1250, Other dimensions upon request.	B		