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

EFFECT OF DIFFERENT HARDWOOD SPECIES AND VENEER THICKNESS ON BENDING PROPERTIES OF PLYWOOD

ERINEVATE LEHTPUULIIKIDE JA SPOONI PAKSUSE MÕJU VINEERI PAINDEOMADUSTELE

MASTER THESIS

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Tallinn 2021

AUTHOR’S DECLARATION

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THESIS TASK

Student: Tolgay Akkurt, 194313KVEM

Study programme: KVEM - Technology of Wood Plastic and Textiles

main speciality: Wood technology

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Thesis topic:

(in English) Effect of different hardwood species and veneer thickness on bending properties of plywood.

(in Estonian) Erinevate lehtpuuliikide ja spooni paksuse mõju vineeri paindeomadustele

Thesis main objectives:

1. To make plywood from different wood species like black alder and aspen and to compare their bending strength, density and glue consumption amounts with birch plywood
2. To make plywood combinations with face veneers birch and middle veneers either aspen or black alder and determine effect of combination on bending strength, modulus of elasticity and density properties and compare them with pure samples of plywoods of these species.
3. To produce different thicknesses plywoods to see thickness effect on density and bending strength properties of plywoods
4. To compare bending strength and density properties of plywood which are produced from different thickness of veneer layers.
5. To investigate modulus of elasticity of these plywoods and compare them with birch plywood

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Choosing the thesis topic	02.2020
2.	Literature reviews for covered topics	20.05.2020
3.	Some trial veneer productions and plywood productions	25.06.2020
4.	Preparation of veneers	28.02.2021
5.	Production of plywood	01.04.2021
6.	Testing of specimens	10.05.2021

	Writing literature overview	14.05.2021
7.	Pre defence submission	09.05.2021
8.	Pre defence presentation	14.05.2021
9.	Revising of thesis	24.05.2021
10.	Defence of thesis	02.06.2021

Language: English **Deadline for submission of thesis:** "24" May, 2021a

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1. INTRODUCTION

Plywood is one of the most widely used wood based composite product. It is constructed by combining layers of veneers with using glue as a binder. Generally, it is made of odd number layers and these layers are constructed crosswise to each other according to grain directions of veneers to give the maximum strength to plywood in both directions. In history first plywood evidences was in Egypt 2600 BC, then it evolved and industrialised in twentieth century ([1], [2], [3]). In contemporary world, plywood and its logic lead to other wood-based products such as LVL (laminated veneer lumber) and now it is produced in controlled and automated environment with technology and knowledge heritage.

In Estonia, timber and wood-based products are one of the biggest contributors to country economy (7%). In Baltic and Nordic regions of European silver birch is the most common species (*Betula pendula* Roth.) and Downy birch (*Betula pubescens*) in plywood production. Also, 51% of land of Estonia is covered with forests, of which 29% is birch, 6% is aspen and 4% is black alder, which are the species that are researched in this thesis. 5% of total number of employees in Estonia work in forest and timber industries [4].In many countries there are products of spruce, pine, birch, poplar plywoods. Also, there are many plywood companies producing plywood from different thickness of veneers [5] [6]. These are the reasons why in this research alternatives to these species and their bending and density properties was investigated.

The aim of this thesis is to study the effect of different hardwood species, different veneer thickness and the combination of them with birch face veneers in plywood production practice on bending properties, glue consumption and density.

The objectives for this thesis can be summarized as following:

1) To produce veneer and plywood from different species and to examine effect of this on the plywood bending and density properties and to create an understanding of the changes on properties according to the final use of plywood compared with birch control samples
2) To evaluate effects of combining of top and bottom face veneers from birch veneers and middle layers are from aspen or black alder on plywood bending strength and density properties.
3) To investigate the effects of different veneer thicknesses to the bending strength and density properties of plywood.

4) to evaluate how the different veneer thickness and number of glue lines effect the bending strength and density properties for the different thicknesses of plywood samples.

During the thesis, effects of using veneers of different species and thicknesses, different layup combinations and thickness change over bending strength, glue consumption and density properties of plywood production and either these veneers can be used or not in practice in plywood production will be investigated. To achieve that samples must be prepared according to related standards and statistical methods, also sampling must be done for different logs to get mean values for results. Moisture content, relative humidly, temperature effects, processing differences, characteristics of different species, adhesion properties, drying durations, physical surface properties, knots, quality of veneers, lathe checks etc., should be carefully noted and any kind of change in conditions should be taken into account when considering final results.

In the research, three species of wood will be investigated for 2 different veneer thicknesses and different thicknesses of plywood will be prepared. Species are Black Alder (*Alnus glutinosa*), Aspen (*Populus tremula*) and Birch (*Betula pendula* Roth.) and Downy birch (Betula pubescens). The thicknesses are 1.5 mm and 2.6 mm for aspen veneers and 1.5 mm for birch and black alder veneers. In addition, pure and combination lay- up schemes will be prepared for these species; the combination will be constructed as top and bottom face veneers are from 1.5 mm birch veneers and middle layers will be prepared from 1.5 mm and 2.6 mm aspen veneers and 1,5 mm black alder veneers. Also, to see thickness effect on strength properties plywood samples with different thickness like 6.5 mm, 9 mm, 12 mm, 15 mm and 18 mm will be prepared. For all these thicknesses; pure and combination samples will be investigated according to related standards for bending and density.

2. LITERATURE OVERVIEW

The literature overview in chapter is divided into three sections. First section is about wood species that are used in this thesis search, second section gives information about plywood market and plywood usage areas, third section will give information about strength properties of plywood and effects of combinations.

Since wood is anisotropic material and strength of it is also dependent on many variables as species, moisture content, knots etc., lay-up schemas for different species and different directions (grain direction or perpendicular), the right wood species, veneer thickness and combinations of them should be decided carefully according to intend of production. In production and end use what will be looked for, is it a stronger, or more environmental or lighter or heavier, or thicker, thinner or economical or sustainable plywood will be at the end use. In this research alternative wood species and veneer thickness will be investigated to find answer for research question what is the effect of plywood lay-up design parameters on bending strength, glue consumption, density properties.

2.1 Wood Species

Some species used in plywood production in industry are cedar, redwood, pine, spruce, Douglas fir, birch, beech, oak, maple, walnut, poplar, obeche, balau, mountain ash, basswood etc. Most common ones are can be counted as birch, pine, Douglas fir, spruce, poplar. In Baltic and Nordic region mostly Birch, spruce and poplar veneers are used in plywood production ([2], [5], [6] ,[7], [8], [9], [10], [11], [12], [13]). Most common species of Estonian forests and their area percentage in total forest area is shown in Figure 1 [4].

Total area shares of species which are investigated in this thesis makes up 39% of Estonian forests. Total number of employees working in wood industry in Estonia is 32930 in the year 2018. [4]. These values show how important to utilize different species in plywood production.

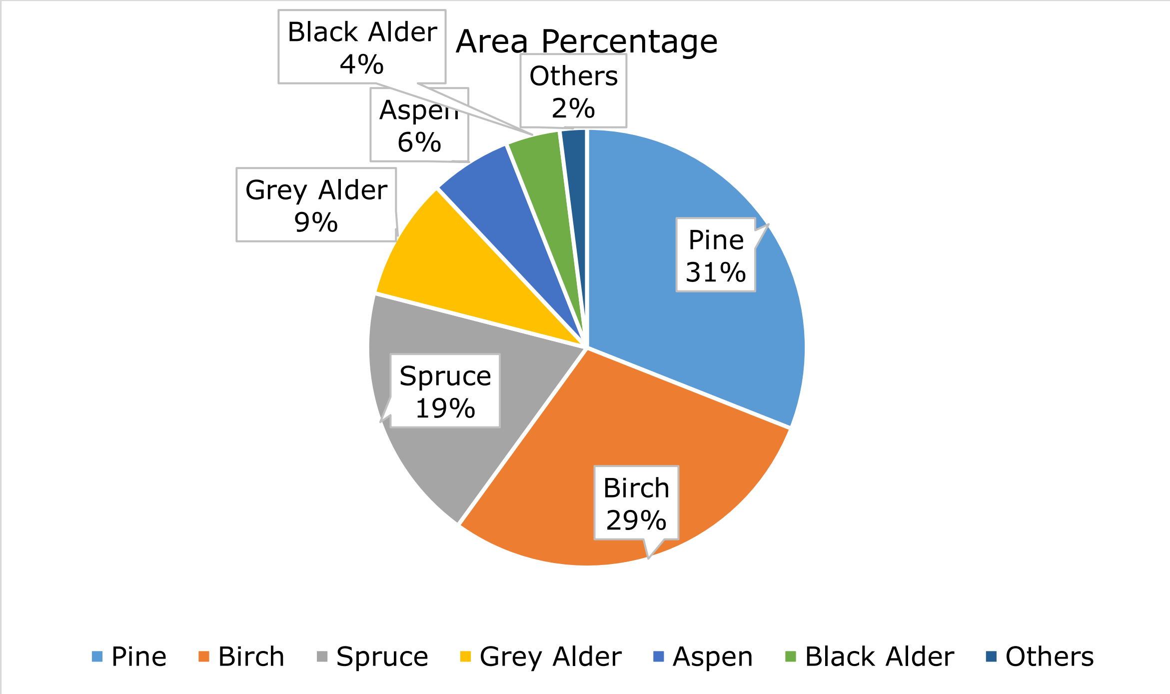

Figure 1 Area share of species in Estonian forests [4]

2.2 Plywood Market

Some plywood and veneer production companies which is located at north and east of Europe (Estonia, Latvia, Finland, Russia, Ukraine and Poland) are Koskisen OY, UPM plywood, Metsä wood, Latvijas Finieris Ltd, Stiga RN forest, United Panel group (UPG), Sagezha Group, Sveza, Odek, Paged, Estonian Plywood Ltd. Most of these companies produce birch plywood. Metsä Group and UPM also produce spruce plywood. There are also sliced and rotary peeled veneer producers in Estonia like Tarmeko Spoon Ltd, Valmos Ltd, Balti Spoon (Möhring Group). Balti Spoon Ltd have birch, oak, ash, pine, larch, beech veneer productions ([2], [5], [6], [8] , [9] , [10] [14], [12]) . Generally, plywood products have sizes of 1250 mm x 2500 mm and with thickness range of 4 mm to 50 mm.

Some of these companies also produces plywood from different thicknesses of veneers, Metsä wood and UPM plywood companies use 3 mm spruce veneers for their plywood production [5] [6]. In Figure 2, samples of spruce and birch plywoods were shown. There is no data for strength properties of these plywoods but weight data is 8.1 kg/m² for spruce plywood of 15 mm and 12.2 kg/m² for birch plywood of 15 mm.

Figure 2 Wisa Company plywood samples, left one from 5 layer of 3 mm spruce veneers and right one is from 11 layers 1.5 mm birch veneers [5]

Plywood as a wood-based material is used in many areas like construction, furniture, transportation vehicles, parquet, packaging, formwork systems, shelves, scaffolding materials, traffic signs etc. [10] [21]. Depending on the end use, loading direction, strength properties etc; the thickness and type of plywood is decided. Thickness like 6.5 mm are used in parquet industry while thickest ones are used generally in load carrying structural elements or transportation vehicle decks. Mid-size thicknesses are generally preferred by furniture producers and formworks. In this research, the thicknesses are 6.5 mm, 9 mm, 12 mm, 15 mm and 18 mm, so it can be said research results apply for almost all type of end uses.

2.3 Density, Strength properties and Lay-up combination

Wood is a hygroscopic, anisotropic, non-homogenous and cellular material. Its strength properties change with direction, moisture content, discontinuity (like knots), wood cell type (Late wood, early wood), due to location of wood piece as heartwood or sapwood, type of loading etc [15] [16]. Plywood is wood polymer composites and depending on its glue type and veneer type according to above properties also plywood strength is affected [15]. When giving results about some properties of wood all parameters should be noted and given. In this thesis, four properties of plywood were investigated as glue consumption, density, bending strength (modulus of rupture) and modulus of elasticity.

2.3.1 Density of plywood

"Density, mass of a unit volume of a material substance. The formula for density is d=M/V, where d is density, M is mass, and V is volume." [15]. The difference from this general definition in wood, when giving a density the moisture content should also be given since density of changes with moisture content. To determine density of plywoods in this research, standard of EN323 [24] was used. In the standard the conditioning of samples were given but there is no suffix used in density result to show the moisture content of wood. The given conditions are relative humidity of (65±5) % and (20±2) °C. for this standard from wood handbook [16]figure 4-1 equilibrium moisture content of plywoods can be excepted as 12 %. Since all specimens were tested after conditioned as in standard, it can be said that results are comparable.

In the below Table 1 some densities of plywoods from companies were given, in densities some of them found directly from company product brochures or handbooks and some of them was calculated from the given data kg /m² by converting it to kg/m³ by dividing them to given thickness ([9], [6], [18], [19], [20]).

Table 1 Some plywood types and densities ([9], [6], [18], [19], [20]).

	Plywood Density kg/m³		
Company Name	**Birch**	**Spruce**	**Poplar**
Latvijas Finieris	670-720		
Handbook of Finnish plywood	680	460	
Metsa Plywood	680	460	
EuroPlywood			450
Tarakçıoğulları			480-550

Also, in handbook of Finnish plywood at table 2.3, it can be observed that for the plywoods for which thicker veneers used in production, density and weight of plates is lower than the plywoods for which thin veneers used [18]

2.3.2 Bending properties of plywood and lay-up effects

Bending strength for wood products can be described shortly as the ability of a material to resist flexural forces. For this research standard EVS-EN 310:2002 was used to determine bending strength of plywood specimens. It is an important design property for a material which will carry loads in useful life. Producers need bending strength properties for their design of products.

There are two basic test methods for determining bending strength of a material which are 3 point bending test and 4 point bending test. 3 point bending test results is not used as reference for load bearing structures but the give reference values about the capacities. the materials tested in three point bending tests exposed to both flexural and shear forces. In four bending tests, materials exposed to just pure bending forces. That is why in most of load carrying products bending strength results of 4 point bending test taken into consideration. Four point bending test standard for wood products is EN789 [21].

In literature, generally 4 point bending test results and characteristic strengths for bending strength and modulus of elasticity are given. In this research, for the results comparison of three point bending tests Latvijas Finieris plywood handbook [10] was used in section 3.4 of this thesis.

For four point bending strength and modulus of elasticity in handbook of Finnish plywood [18], different lay-up schemas and combinations of coniferous tree veneers and birch veneers, pure birch and pure spruce plywood properties were investigated. This handbook is one of the most referenced handbooks for plywood production. That’s why some related information regarding this thesis will be discussed here. In the handbook different species plywoods were tested and compared with each other according their strength values. Also, they have tested the samples to get results for truck floors and concrete formwork plywoods according to usage purpose. Their search is generally on comparing pure birch samples with thick and thin veneer coniferous plywood and combination of birch veneer and coniferous veneer together. The handbook [18]values show that when the thickness of plywood increases bending strength of plywood gets close to each other in perpendicular and parallel directions to grain. Considering given values of strength in table 3.2 of the handbook following Figure 3 was obtained.

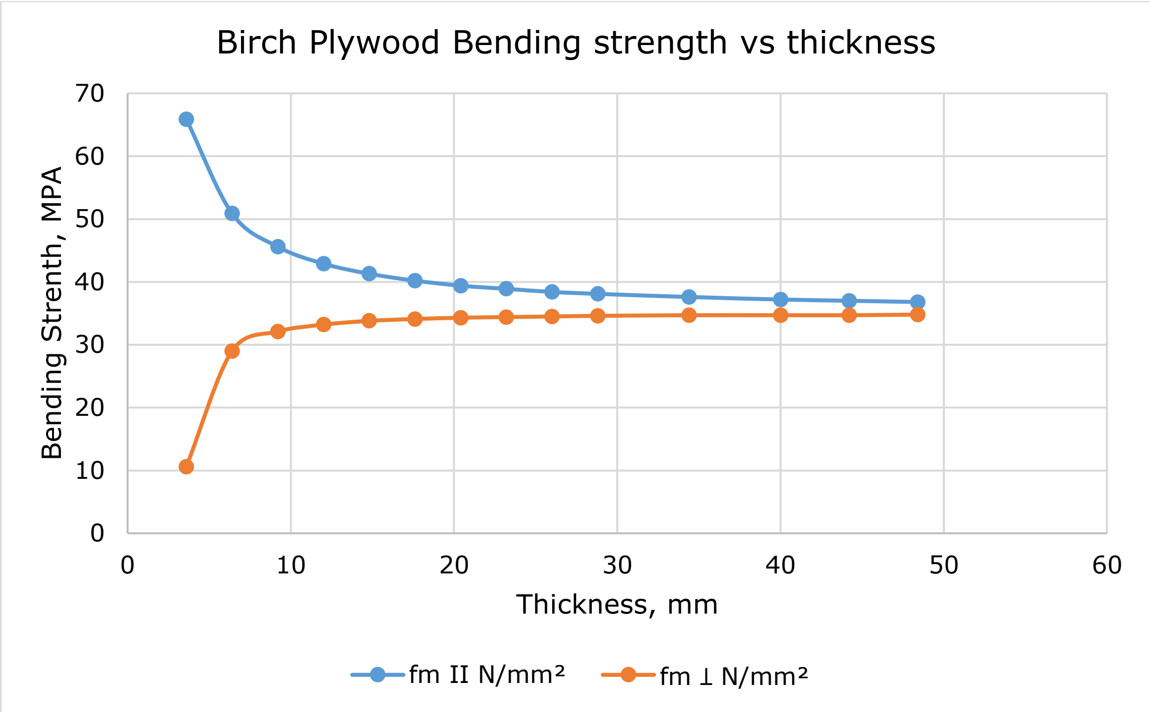

Figure 3 From handbook of Finnish plywood bending strength properties of birch plywood in grain and perpendicular direction [18]

As it can be seen from the Figure 3, for 12 mm thick birch plywood (in which grain direction bending strength is 42.9 MPa and in crosswise 33.2 MPa) 23% difference in strength values between grain direction strength and perpendicular direction strength. After that thickness the thicker the plywood the closer the bending strength values in both directions. From Figure 3, it can be concluded that in case the loading is planar to use thick plywoods gives better results in both directions, however, when the loading is just in one direction as in case of some loadings like construction or transportation decks, it can be more useful to utilize more layers just in one direction. The same trend of results also can be found in Latvijas Finieris handbook of plywood for either three point bending results and four point bending results [9]. Also, same trend is seen in combi plywood, combi mirror plywood and conifer plywood strength values of handbook of Finnish plywood [18]

In addition, in case of thick and thin veneer plywood comparisons can be found in handbook of Finnish plywood from tables of 3.5 and 3.6 handbook of Finnish plywood following Figure 4 was obtained [18].

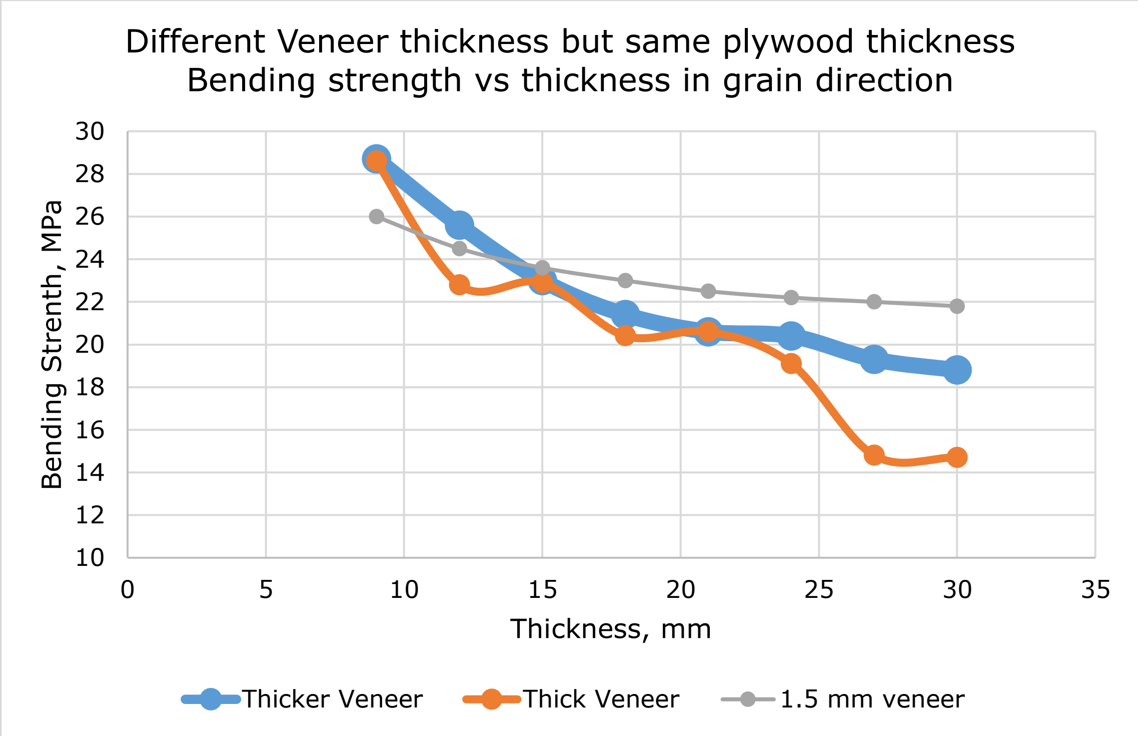

Figure 4 Different veneer thickness but same plywood thickness in grain direction strength vs thickness [18]

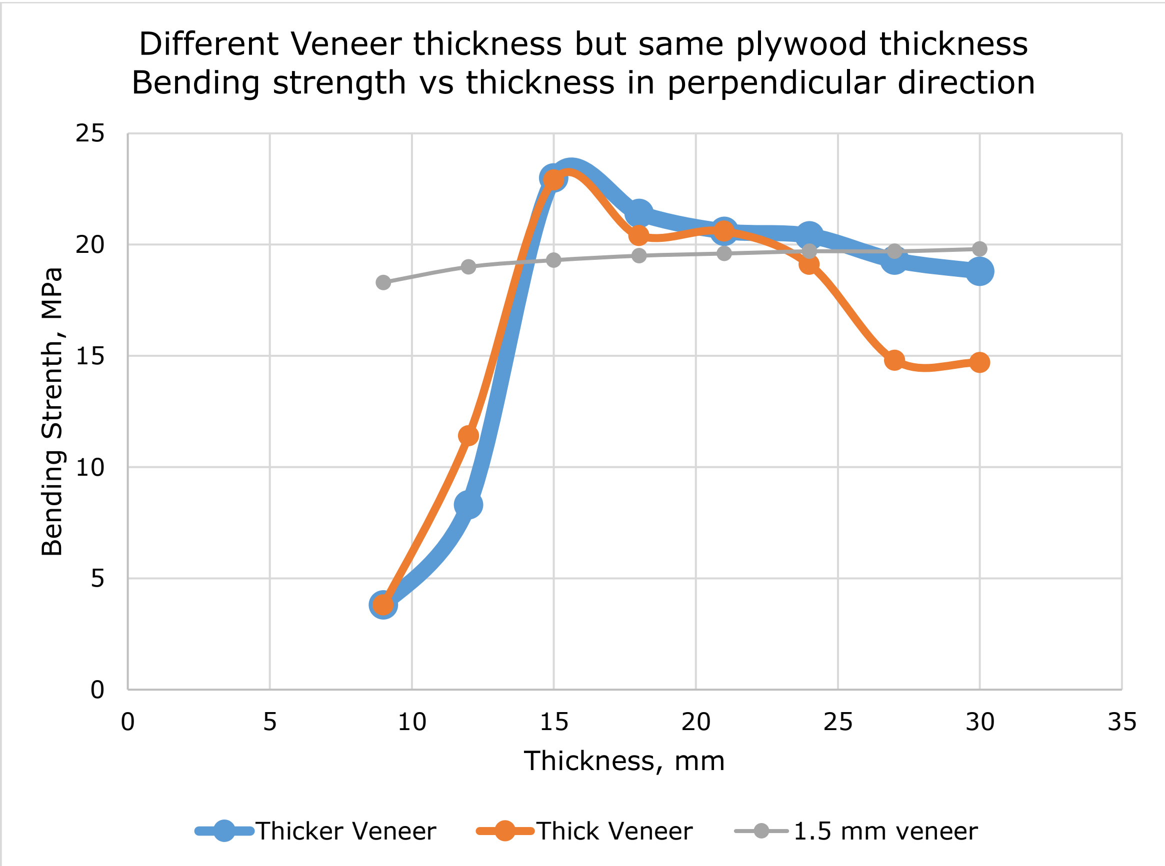

Figure 5 Different veneer thickness but same plywood thickness in perpendicular direction strength vs thickness [18]

As it can be seen from above Figure 5, for thicker and thinner veneers in grain direction the values are close to each other in lower thickness but in perpendicular direction there is big difference between values in thin plywoods. So, from these results, it can be said instead of thin veneers when there is one dimensional loading thick veneer can be utilized. Which was investigated in this research also.

Another point needs to be noticed in results of handbook of Finnish plywood is that, conifer plywood shows 43% less strength when compared to birch plywood. In this handbook, also, the combinations of conifer veneers and birch veneers were tested for bending strengths. Results generally shows that, in which direction the coniferous veneer used, the plywood lost strength in that direction. Unexpectedly and abnormally; in which direction conifer veneers were used plywood showed exactly the same strength values with pure conifer plywood in that direction and exactly the same strength values with pure birch veneer plywood in the other direction. In this thesis combinations of birch face veneers with middle layers either aspen or black alder were investigated.

Effect of layup was shown in some researches, and all showed that utilizing lay up in one direction more layer can increase bending strength properties in that direction. For usage of one directional loading these combinations can be utilized in plywood production [18].

3. MATERIALS AND METHODS

Materials and methods section give information about which materials, tools and machines used, how the peeler blocks prepared, veneers peeled, plywood manufactured, panels sampled, test specimens prepared and tested.

3.1 Materials

Log choosing done according to the thesis plan, appropriate species were chosen from log yard. Logs were ordered from RMK (State Forest Management Centre, they are checked by RMK according to RMK log standards) and used in veneer production during autumn and spring semesters of 2020/2021. The logs are from Türi /Jarva region and mean age of trees were 59 years with class I. The log lengths were around 3m. The logs were visually sorted and logs which has less knots, no crooked body and no decay were chosen for veneer production. The chosen logs were cut to the desired peeler block length (for TalTech laboratory of wood technology peeling machine 1200-1400 mm) with the chainsaw and are put to the log soaking bath.

The logs were brought to log yard in October 2020, and they were cut for peeling from 7th of December to 25th of March. During this time, they were outside and exposed to weather conditions without protection season was rainy and in sunny days they were watered not to let them to crack. During this period weather was mostly rainy and snowy (temperature mean values was 0.8°C for October,1.8°C for November,5.4°C for December and precipitation was 103 mm for October,100 mm for November, 79 mm for December) [22], so there was no cracking or splitting problems due to the fast drying. Logs were from three species as birch, black alder and aspen. Their average dried densities are 640 kg/m³ for birch, 535 kg/m³ for black alder and 450 kg/m³ for aspen logs [23]

For the thesis only veneers of thickness 1.5 mm and 2.6 mm were prepared. Logs of black alder, aspen and birch used. Total 9 peeler blocks of aspen for 1.5 mm aspen veneers, 14 peeler blocks of black alder for 1.5 mm black alder veneers, 10 peeler blocks of birch for 1.5 mm birch veneers and 3 peeler blocks of aspen for 2.6 mm aspen veneers were peeled for veneer production. Peeled aspen veneers had rough surface and white colour and produced more dust than others, birch veneers had smooth surface with white-yellow colour, black alder veneers had smooth surface with more knots then others and yellow when they were wet and dark orange brown colour when dried. When comparing knots, least number of knots was observed with birch and most was with black alder. 2.6 mm thick aspen veneers attained a curvature after drying. Also, curvature properties of veneers changed with the location of veneer in the log. Near the core, more curvature was observed due to heartwood and sapwood difference. For cutting of logs to peeler log sizes, chainsaw of the laboratory was used, for carrying logs a carry car was used. To move logs log grabbers were used and a telfer was used to put and take out logs from soaking bath. To measure temperature and moisture; infrared thermometer and for moisture content hydromette HT85T model hydrometer were used. These parameters were necessary to understand veneer properties and to understand later the effect of them on veneer quality. Other tools and materials, which were used during thesis works, is explained in method parts with details in related sections.

3.2 Methods

Process of making veneer and plywood, sampling and testing of them is described in following Figure 6 and sub items of this chapter.

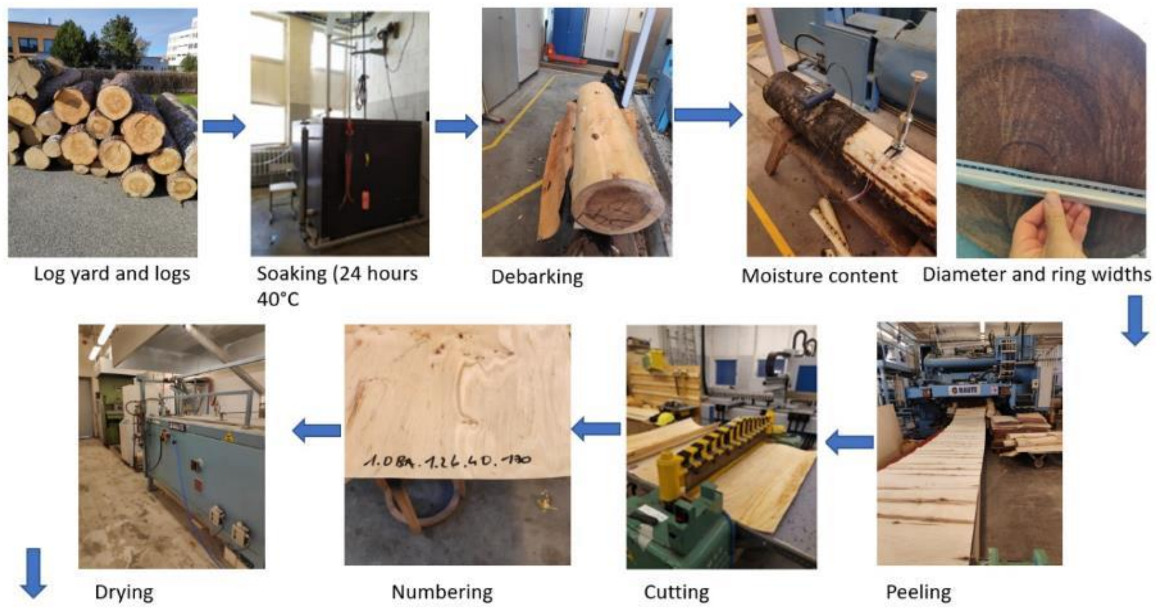

Figure 6 Plywood production and specimen testing dteps from log yard to tested specimens

3.2.1 Making of veneer

The description for making of veneer is described in following sub items. All the quantities and values given in following sub items can be found in appendices table 11.

Soaking temperature for this thesis was chosen as 40°C and soaking time is 24 hours. During making of veneers some logs stayed longer than this duration because of weekends and other problems with soaking bath (like electricity cut or automatic stop of heating after some duration). However, in industrial production also logs can stay in soaking 2-4 days in production.

Debarking of logs: After one day of soaking, logs were debarked with debarking knives and placed for rotary peeling. While debarking bigger knots were cut with hand axe to protect both peeling lathe and saving time.

Log parameters: Before peeled all logs are tested for temperature and moisture content in outer face and in the core. As a final step before peeling, logs are controlled for log diameter, log length, heartwood and sapwood ring widths. Then, with the speed of 60 rpm and arranged thickness the logs are peeled for veneer production. The log parameters given in appendices section are summarized below. As it can be seen from Table 2 peeler blocks never reached to 40°C after 24h of soaking and logs for 2.6 mm Aspen were chosen bigger to get enough veneer for plywoods for per log.

Table 2 Log Parameters

Log parameters	**Aspen 1.5 mm**	**Birch 1.5 mm**	**Black Alder 1.5 mm**	**Aspen 2.6 mm**
Av. Length of peeler Log (cm)	134	138	137	136
Av. Diameter of log (cm)	31.9	23.8	25.9	36.3
Av. Annual Ring width (heartwood) (mm)	3.0	2.7	3.1	4.1
Av. Annual Ring width (sapwood) (mm)	3.6	2.0	2.4	2.7
Av. Peeler Log Moisture Content (%)	72.2	66.3	73.4	77.2
Av. Peeler Log Temperature (°C)	31.5	32.0	31.1 °	31.8
Soaking Temperature (°C)	40.0	40.0	40.0	40.0
Soaking Duration (h)	24	24	24	24

Veneer information: In this research; the thicknesses of 1.5 mm and 2.6 mm veneer samples for aspen, and 1.5 mm veneer samples for black alder and birch were prepared. For veneer peeling Raute 3HV66 peeling machine was used. Peeling speed was 60rpm and knife angle was 20° with a compression rate of 10%. All of these parameters carefully noted for every log and veneer. Below Table 3 gives information about veneers. In veneer peeling process, aspen veneers produced more dust than others and surfaces of aspen were rougher than black alder and birch.

Photo	Properties
	Dimensions of the machine are 850cm x 290cm x 400 cm and engine power is 66kW. The weight is 17000 kg (Randla, 2017).

Figure 7 Peeling Machine Raute and its properties

All parameters for produced veneers are summarized in below Table 3.

Table 3 Produced Veneer Parameters

Veneer parameters	Aspen	Birch	Black Alder	Aspen 2.6 mm
Veneer Thickness (mm)	1.5	1.5	1.5	1.5
Drying temperature, °C	170.0	170.0	170.0	170.0
Drying time (s)	170	168	173	360
Total number of veneers	438	347	435	146
Dried veneers	438	347	435	146
Veneer Dimensions' cm	45x90	45x90	45x90	45x90

For the research total 1366 veneers with dimensions of 450 mm x900 mm were prepared. For every species number of veneers given in above table. When these veneers were cut to 2 pieces to make plywood total number of veneers reached to 1366x2=2732 with dimensions of 420 mm x 420 mm after drying. For the research total 1366 veneers with dimensions of 450 mm x900 mm were prepared. For every species number of veneers given in above table. When these veneers were cut to 2 pieces to make plywood total number of veneers reached to 1366x2=2732 with dimensions of 420 mm x 420 mm after drying.

3.2.2 Veneer cutting, drying, storing and conditioning

For the research, veneers were cut to the 900 mm x 450 mm sizes. During cutting big defects and knot parts also any other defected parts of veneers were cut out. Also, some logs were totally rotted inside and veneers from these logs were eliminated and new logs were peeled. During peeling of aspen logs, some logs started to rotate freely between spindles and couldn't be peeled. Prepared samples were marked for thickness, species, number of log specimen, number of veneer specimen, soaking temperature, drying temperature and duration as 1.5.BA.1.17.70.170.24, here 1.5 shows thickness, BA shows species as Black Alder, 1 shows log number, 17 is the veneer number, 70 is soaking temperature, 170 is drying temperature and finally 24 shows the drying duration. Cutting and numbering system were explained in detail in appendices Figure 35.

All the numbering was marked on top of the veneer when it is used for lay-up it was possible to know place of lathe checks for further sampling. The veneers were dried with 170°C to reach to a moisture content of 4 to 5%. 4 to 5 % of moisture content is necessary for proper bonding of glue and veneer. To check moisture content, small pieces of samples like 2cm x2cm were cut from dried veneers and dried totally to 0% moisture content in an oven which is at 130 °C. Since all species have different properties, logs have different moisture contents and veneers have different thicknesses; drying time for every species and veneer thickness varied. As it can be seen from Table 3 drying time for 2.6 mm aspen was longer than the others and drying time also varied according to veneer place in log; as it from heartwood or sapwood. Above, Table 3 gives just the mean values. Drying time arranged considering all above variables. After drying the width of the veneers shrank to 410 ~420 mm from 450 mm. which is in conformity with 6-10% average shrinkage in tangential direction. The cutting guillotine and drier properties were given below figures [23].

Photo	Properties
	For veneer cutting guillotine Wärtsilä VAL1000CP was used. The measurements of the machine are 180x170x115 cm and weight is 200kg. Maximum veneer length that can be cut with this tool is 900 mm.

Figure 8 Cutting guillotine and roperties

Photo	Properties
 	The dimensions of the drier are 320x200x200 cm and weight 1200 kg. Steam generator Fulton produces water steam used by veneer drier Raute and needs connection with water and sewage system. The measurements are 150x100x200 cm and weight is 230 kg. The capacity is 36kW (Randla, 2017)

Figure 9 Drier and properties

Veneers were stored in Taltech laboratory of wood technology storage room to keep veneers at a stabilized temperature and humidity. The conditions at conditioning room was 25°C and 20% RH. Veneers were stored in shelves and room conditions was checked with thermometer and humid meter. From wood handbook [23] chapter 4, page 4-3, figure 4-1, equilibrium moisture content of veneers can be found as 4 to 5% for these conditions.

3.2.3 Veneer lay-up, gluing and plywood making

Sorting of veneers: veneers were sorted for face and middle veneers. Due to the time limitation of the research, necessity of too much veneers and lack of pure clean veneers, veneers with knot holes and cracks also used in plywood production. Also, some veneers with sound knots were used as face veneers since there was not enough smooth and clean veneers.

Cutting to final size: Previously prepared and dried veneers were cut to the proper sizes for plywood production. In the laboratory, after drying the veneer dimensions reached to 900 mm x 420 mm. To avoid stitching and not having the possibility of wider veneers in crosswise direction, these veneers were cut to the size of 420 mm to 420 mm. Because of this second cutting, the plywoods were numbered as P12-1 and 12-2 in which first number shows the plywood number which was laid up from same veneers second number shows that they are from same plywoods but with different time and gluing operation. So even the veneers were same for these plywoods glue consumption slightly differ from each other.

Preparation for laying up: veneers prepared for laying up as bottom veneers will be upside down and all other layer’s tight face were up. Veneer layup was done carefully to set all layers crosswise to each other in grain direction. In the thesis, it was proposed to prepare plywood with just black alder veneer, plywood with just aspen veneer, plywood with just birch veneer. Also, as combination plywood top and bottom layers are birch and middle ones as aspen and black alder. All combination lay-up schemas are given in

Table 4. All veneers prepared according to plywood type, direction of veneer and gluing order.

Table 4 Plywood types

Lay-up	**Combination style**
I-I-I-I-I	Pure aspen, 1.5 mm veneer
I-I-I-I-I	Pure birch, 1.5 mm veneer
I-I-I-I-I	Pure black alder, 1.5 mm veneers
I-I-I-I-I	Combi, Top and bottom face birch middle layers aspen
I-I-I-I-I	Combi, Top and bottom birch middle layers black alder
I-I-I-I-I	Pure aspen 2.6 mm veneer
I-I-I-I-I	Combi, Top and bottom face birch middle layers 2.6 mm aspen

I- Aspen 1.5 mm veneer, I- Birch 1.5 mm veneer,

I-Black Alder 1.5 mm veneer, I- Aspen 2.6 mm veneer

Number of necessary veneers: During veneer and plywood production continuing, manufactured veneers was stored according to the thickness and species type. In this thesis, 1.5 mm and 2.6 aspen veneers and 1.5 mm black alder and birch veneers were prepared and used. The research plan was to include 6 different plywood thicknesses which are 6.5 mm, 9 mm, 12 mm, 15 mm, 18 mm and 21 mm. also plywoods would be prepared for 3-point and 4-point bending tests. Later on, due to the limitations in laboratory conditions, it is decided that maximum achievable thickness for plywood bending tests is 18 mm for EN310. Then as final decision, it is decided to prepare 6.5 mm, 9 mm, 12 mm, 15 mm, 18 mm thicknesses of plywood be prepared for black alder, aspen and birch and tested for 3 point bending test properties and densities. Also, plywood samples for veneer thicknesses of 1.5 mm and 2.6 mm will be manufactured for different layout schemas under hot pressures of 1.4 MPa. For this following Table 5 and

Table 6 were prepared to find necessary amount of veneers.

In the following Table 5 and

Table 6, we can see how many veneer layers are necessary 6.5 mm, 9 mm, 12 mm, 15 mm, 18 mm thick plywoods for veneer thicknesses of 1.5mm, and 2.6 mm. In calculation of necessary number of veneers, it is also considered for preparation of test samples. Drier has a limitation in width of 450 mm and after drying veneers width changes between 420 mm to 430 mm. and hot pressure has limitation of 900 mm x900 mm and with veneers of 420 mm x 420 mm we can reach maximum of 18mm thickness for 3P bending tests. planned 21 mm thick plywood cannot be tested or constructed at university wood laboratory. In addition to above, because of time limitation screw withdrawal and bonding tests will not be conducted as they are proposed to be evaluated before. These tests from same plywood samples will be conducted some other time to create complete understanding of results.

Table 5 Number of needed veneers for 5 different thickness for every species

Plywood Thickness	**For 1.5 mm veneers needed number of layers**	**Expected plywood thick. (mm)**	**Finnish plywood hand book thick.**	**For 2.6 mm veneers needed number of layers**	**Expected plywood thick.**	**Finnish plywood hand book thick.**
6.5 mm	5	7.5	6.5	3	8.4	6.8
9.0 mm	7	10.5	9.2			
12.0 mm	9	13.5	12	5	13	12.4
15.0 mm	11	16.5	14.8			
18.0 mm	13	19.5	17.6	7	18.2	17.6
Extra necessary amount for 18 mm	13			7		
Total amount	**58**			**22**		

In Table 5, extra necessary amount comes from 18 mm thickness plywoods since the amount must be doubled because of plywood dimensions can be reached is maximum 420 mm x 420 mm and these dimensions is not enough to get necessary number of samples for bending tests which will be explained in testing part of this chapter.

If we consider statistical measurements and considering 4 different logs should be prepared to see effect of different logs sampling and having reasonable comparable results, above numbers must be multiplied by 4.

Table 6 total needed number of veneers according to species

	Necessary number of veneers for aspen per sample	Necessary number of samples	Necessary number of total veneers
ASPEN 1.5 mm	104	4	416
ASPEN 2.6 mm	30	4	120
BIRCH 1.5 mm	86	4	344
Black Alder 1.5 mm	104	4	416

Preparation of glue: Phenol formaldehyde glue was used in this research. The brand of glue is Prefere Resins Finland OY. The information about glue was obtained from producers document of training for plywood gluing, May 2015. Glue mix as weight percentage is composed of 68% resin 14J021, 14% hardener 24j662, %18 of water. Some detailed information for this receipt components is as flows:

Table 7 glue mix components properties

	Resin: Prefere 14j021	**Hardener 24j662**
Appearance:	reddish brown liquid	white powder, dusty
Specific weight, kg/m³:	1200	
Solid content:	49%	
Hazardous components:	phenol <0.1 %, formaldehyde <0.1% concentration of sodium hydroxide 7-8%	
Functions		gives correct viscosity level, decreases shrinkage of glue seam, makes glue seam more elastic and more filling, improves pre-press tack, accelerates and / or attenuates penetration of glue.
Moisture	3-10%	

Target of gluing: to bond together two or more pieces with adhesive. In addition, requirements for durable glue seam is given as:

- Glue must moisten both surfaces of combining veneers
- Glue must penetrate 3-4 cells into veneer
- Hardened glue seam must be stronger than wood.

Optimum amount of glue usage given by producer is 150-165 g/m³, in this research, the target glue consumption is assumed to be 160 g/m³. Some other information given in producers document are shown in Table 8

Table 8 Suggested and maximum limits given by glue producer

Parameter	**Suggested**	**Maximum**
Lay-up time (min)	15-25	30
Time between lay-up and pre-press (min)	1-5	8
Pre pressing		**Limit**
Time (min)	8	5-10
Pressure (MPa)	0.8	0.5-1.0
Time between presses (h)	0.5-6	6
Hot pressing		
Pressure (MPa)	1.5 to 1.8	
Temperature (°C)	128 ± 2	

After necessary amount of glue components are calculated and prepared, firstly resin placed under stirrer and stirring is started then half of the hardener is poured on resin slowly. Later, when half of the hardener and resin mixed the water is added to the mix. As last step, other half of the hardener amount is added to the glue mix. This glue mix was stirred at least one hour with 1500rpm.

During glue application, amount of glue that is spread on veneers varied almost 30% due to the characteristic of roller glue spreader, which is sensitive to veneer species, veneer thickness and veneer location (heartwood or sapwood). Most glue consumption was noted with aspen veneers. Also, 2.6 mm of aspen veneers had curvature which caused uneven gluing. When there are uneven or not glued regions on veneer, these parts were glued with paint brush.

Laying up: Just first face veneer upside down and all layers placed on top of it is crosswise to each other. And every even number layer veneer glued from both face with glue roller. Before and after gluing weights were taken and glue amount is calculated as difference between these weights and noted. After necessary of layers for determined. The glue consumption for every layer and total amount of glue used for every plywood can be found in appendices Table 32. When laying up, between each plywood layer stacks a paper was placed to protect and separate plywoods from each other during cold press. Lay-up time (15-25 min) and time between layup and pre pressing (1-5 min) never exceeded the time given by producer. When there is time problem instead of 4 to 5 plywood just 3 plywood were prepared for cold pressing considering these time limitations given in Table 8.

Photo	Properties
	Adhesive roller Black Bros 22-D can move on the wheels. The dimensions of this machine are 190x80x140 cm. sensitive to curvature and roughness of the veneers. The gap between rollers can be adjusted with side wheel for veneer thickness. And amount of glue between rollers can be adjusted for top and bottom from side keys.

Figure 10 Glue roller and properties

3.2.4 Cold and hot pressing

Laid-up veneers are put on a steel plate and they are placed with a baking paper at top and bottom, to prevent sticking to plates also, paper is placed between the plywoods during cold press. For cold pressing, depending on the plywood thickness 3 to 5 laid up plywood are pressed together with 0.5 MPa pressure and 10 minutes duration. Cold press is necessary to spread glue to both veneers and flattening of veneers. After cold pressing, the press is set up for heating and for 25 minutes until it reaches necessary hot pressure temperature of 130°C. After press reaches to desired temperature, the plywood is placed between steel plates with baking paper on top and bottom and placed in hot press one by one and pressed. The hot-pressing time changes depending on the plywood thickness. In this thesis, time was evaluated with the formula 3min+ 0.5 x plywood thickness (in mm). To be on the safe side and one more minute added to press time.

Table 9 Hot press times according to thickness

Thickness (mm)	**Time (min)**
6.5	7
9	9
12	11
15	12
18	13

All the data about plywoods were given in Table 32. At the beginning of experiments some plywoods produced in hot press with 1.8 MPa, but for aspen plywoods the thickness of plywood was much less than expected. After this observation hot press is rearranged for 1.4 MPa for maximum and all plywoods are prepared with this regime and plywood thicknesses reached for desired values. At this point of research, it was necessary to decide for a dilemma either the pressure would be kept constant but the thickness for every species and veneer thickness would change or the thickness would be kept constant and pressure had to be arranged for each species and thickness. Since, the latter needs much more time and analyse for the sake of the research to be completed on time former was chosen.

When the pressure was checked on hydraulic it was showing 20 bar pressure for cylinders. As a simple calculation we can calculate real pressure for 420 mm x420 mm plywood dimensions as follows:

- 20bar=2MPa and there is two cylinders in hot press with diameter of 300 mm. Then total load must be equal: 2 N/mm² x 2 (two cylinders) x π x (300/2) ² / 420x420=1.60 MPa. So, the real pressure was somewhere between 1.4MPa (shown on press program) ~1.6MPa (calculated as theoretically)

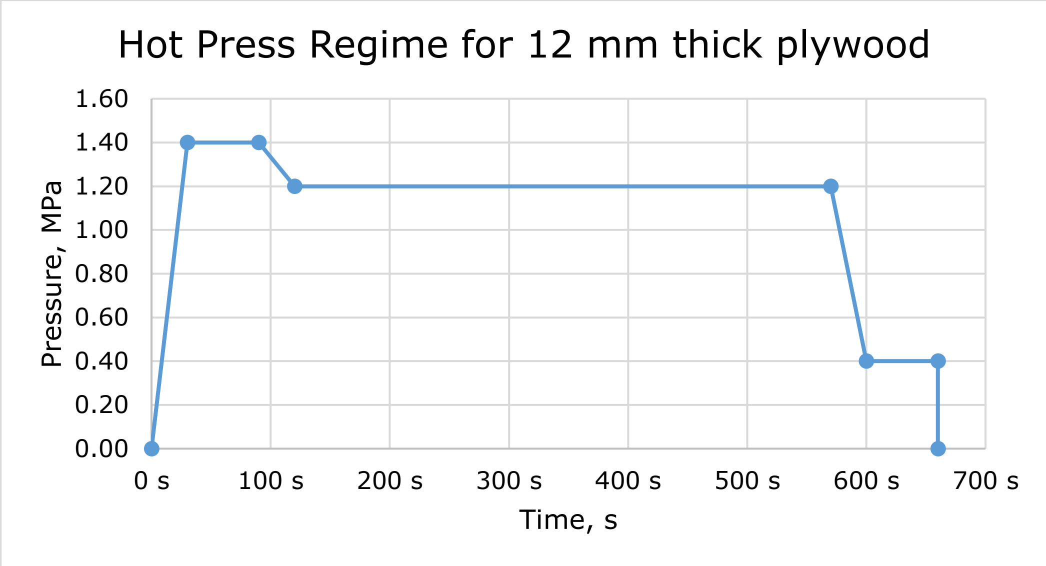

Figure 11 Hot Pressure Regime

Number of plywoods: pressed plywoods are cut from their edges to get smooth edges and to get rid of not overlapping veneer regions. Final dimensions of plywoods obtained was around 400 mm x400 mm. Total number of necessary plywoods was determined considering 5 different thickness, 3 pure samples of 1.5 mm and species of Black Alder, Aspen, Birch and 2.6 mm of Aspen veneer plywood and combinations of Birch-Alder and Birch-Aspen. Combination plywoods has face veneers from Birch middle veneers from either Aspen or Black Alder. Necessary amount of plywoods tabulated as following Table 10.

Table 10 Number of necessary plywoods

Plywood Thickness	Needed number of plywoods for aspen	Needed number of plywoods for black alder	Needed number of plywoods for aspen 2.6 mm	Needed number of plywoods for birch	Needed number of plywoods for Combi 1.5 mm	Needed number of plywoods for Combi 2.6 mm
6.5 mm	4	4	4	4	8	
9.0 mm	4	4		4	8	4
12.0 mm	4	4	4	4	8	
15.0 mm	4	4		4	8	4
18.0 mm	8	8	8	8	16	
Total plywood number	24	24	16	24	48	8

Total 144 plywood was proposed for dimensions of 900 mm x450 mm but later on due to the laboratory equipment dimension limitations proposed sized changed to the 450 mm x 450 mm veneers and the total number of needed plywoods was doubled and 288 plywood with dimensions 400 mm x400 mm were prepared for thesis tests.

For thickness of 18 mm plywood and dimensions of 400 mm x400 mm, it is not possible to get six bending sample in grain direction and six sample in perpendicular direction. That's why the number of plywoods with dimensions of 400 mm x400 mm of 18 mm thick plywood is double the other thicknesses but the total bending samples are equal for all thicknesses. In the plywood numbering system, the important point is that for any plywood number there is two sub number which are 1 and 2 and these sub numbers shows these plywoods are produced from same veneers but gluing is done separately so even the veneers are same; total glue consumption can be different. Also, a special condition for 18 mm; they are produced not just from 2 plywoods they are produced from 4 plywoods for every log since the biggest dimensions for sampling was obtained for the thickest plywood. Which will be explained in the following sections.

3.3 Test standards and sampling

In this research, mainly five standards were used to determine dimensions, number of test specimens and to determine their strength and density properties. Other than these five standards, also for further researching; samples for bonding quality and screw withdrawal tests were prepared in addition to the concept of this thesis. All these standards and methods will be explained in the following chapters.

3.3.1 Determination of dimension of test pieces

When determining the dimensions of test pieces EN325: Wood-based panels - Determination of dimensions of test pieces standard was used. For dimension measurements, tools described in standard were used. Their reading was allowing to 0.01 mm. All specimens were conditioned with temperature of (20 ± 2) °C and a relative humidity of (65 ± 5) % (ILKA climate chamber). When applying the standard, there was a problem with weight readings. Standard says "constant mass is considered to be reached when the results of two successive weighing operations, carried out in an internal of 24h, do not differ by more than 0.1% of the mass of the test piece." However, the balances used in this research had a precision of 0.01 g., when we consider pieces of 10g; 0.1% is equal to 10*0.1/100=0.01g and this created a problem at measuring so, for light weight samples for the sake of the research bigger mass difference values till 0.3% of weight was considered to be normal. Thickness, length and width of samples were measured as described exactly in standard [24].

3.3.2 Thickness checks of plywoods

Thickness checks were applied to plywood according to EN315: Plywood. Tolerances for dimensions [25]. In table 1 of this standard, it is explained how to calculate tolerances for thicknesses. For panels which are not sanded:
For thickness (t) ≥3 mm and ≤12 mm thickness tolerance within one panel is 1 mm.
For thickness (t) >12 mm and ≤25 mm thickness tolerance within one panel is 1.5 mm.
And tolerances on nominal thickness for all thickness in this research is calculated with following formulas.

Thickness of the panel cannot be higher 0.8 mm +0.03 mmx t of the expected thickness and it cannot be lower than -0.4 mm-0.03 mm x t of the expected thickness. Considering these conditions and the thesis plywood thicknesses of 6.5 mm, 9 mm, 12 mm, 15 mm and 18 mm following table was constructed for thickness checks.

Table 11 Thickness check table

Thickness (mm)	**Max (mm)**	**Min (mm)**
6.5	7.495	5.905
9	10.07	8.33
12	13.16	11.24
15	16.25	14.15
18	19.34	17.06

3.3.3 Sampling, cutting and inspection

Number of specimens for every test and dimensions of specimen and inspections were applied according to “EN 326-1 Wood-based panels - Sampling, cutting and inspection - Part 1: Sampling and cutting of test pieces and expression of test results” [32]. In this standard at page 3 table 1 shows the necessary numbers for sampling; m shows the number of specimens needed to be cut from every plywood panel and the panel dimensions for standard must be longer than 1600 mm in length and wider than 800 mm in width in Figure1 of standard. However, most of the plywood produced in industry has shorter length than given in the standard so in this thesis assumption figure can be drawn in wrong directions. In addition, Taltech laboratory of wood technology, due to reasons explained in production of plywood part in previous chapter our panels have dimensions around 400 mm x400 mm after cutting edges.

This limitation created some violations in applying rules of this standard as minimum distances between samples and number of samples that should be taken from each panel. Even, it is not possible to apply distances to each sample to get same amount of sample as standard implies veneers are produced with dimensions and 450 mm x 900 mm and from the same veneers two plywood were produced and they are numbered as same plywood number but with a sub number as 1 and 2 to show that these plywoods were produced from same plywood. With this way necessary number of samples were obtained from two plywood panel as panel with numbers as P21-1 and P21-2, which shows same veneers but different gluing applications.

3.3.4 Determination of bending properties

For bending and modulus of elasticity determination "EN 310 Wood-based panels - Determination of modulus of elasticity in bending and bending strength" [27]. standard was used. Standard specifies the method for determining apparent modulus of elasticity in flatwise bending and bending strength of wood-based panels of nominal thickness equal to greater than 3 mm. Our samples were all thicker than 3 mm since we will do at least five-layer veneer plywood with minimum veneer thicknesses of 1.5 mm which makes the minimum plywood thickness 6.5 mm.

The value calculated is the apparent modulus: it is not the true modulus since it can be seen from the figure below the test method includes shear as well as bending. Bending moment is calculated at maximum force Fmax. The values calculated from this standard cannot be used for plywoods which will be used as load carrying members or structural purposes. For this "EN789 Timber Structures-Test Methods- Determination of mechanical properties of wood-based panels" [21]. (for structural methods) must be used as a standard. Since, that standard uses four point bending test to determine modulus of elasticity and bending strength. Four point bending strength creates constant moment between two equal loads and zero shar force and this gives pure bending strength and true modulus of elasticity.

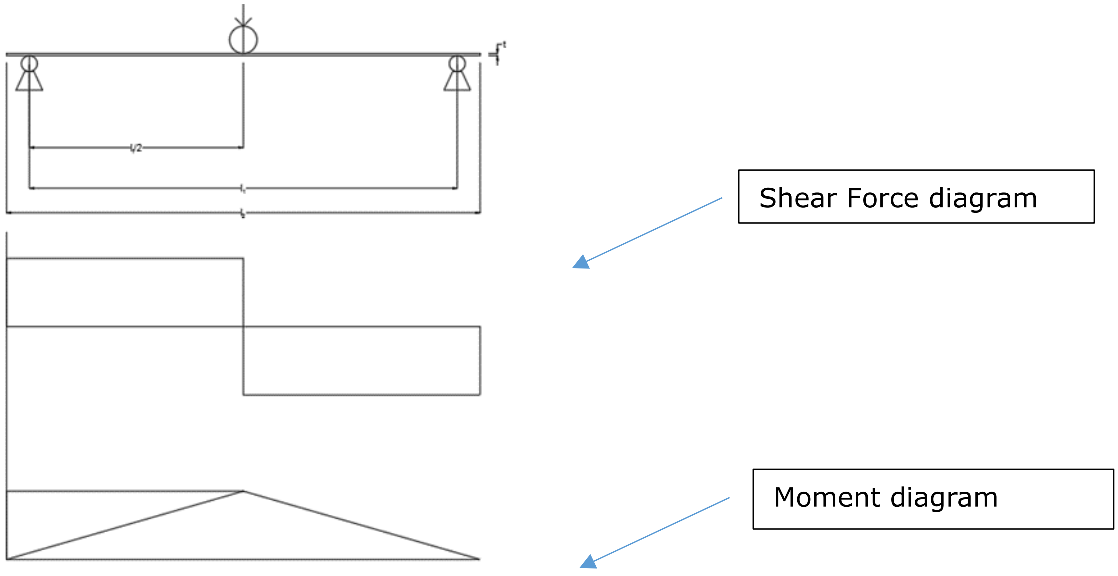

Figure 12 Shear force and bending moment diagrams for 3-point bending tests

- The width of the specimen must be: 50±1 mm
- The length of the specimen must be: 20 times nominal thickness but with conditions of maximum 1050 mm and minimum 150 mm.

According to above standard conditions, for this research samples was checked for the nominal thicknesses and specimen lengths for 3-point bending test is found as in Table 12.

Table 12 Specimen Length table according to the nominal thickness of the test specimen

Plywood Specimen Thickness, mm	**Specimen Length (mm)**	**Length between supports (mm)**
from 1 to 7.5 mm	150	200
9	180	230
12	240	290
15	300	350
18	360	410

In the **Error! Reference source not found.**, sample dimensions were shown for the plywood thicknesses of 6.5 mm, 9 mm, 12 mm, 15 mm and 18 mm which will be used in this research. According to prepared specimens, bending strength and elastic modulus can be calculated from the standard.

In this research, samples from total seven different plywood types were tested. The samples were carefully obtained from different logs each from at least 4 different logs, and from each log there were 12 specimen 6 of which in grain and 6 from perpendicular to grain direction. Also, there were 7 different types of plywood which are pure aspen with 1.5 mm veneers, pure aspen with 2.6 mm veneers, pure birch, pure black alder plywoods and combi alder, combi aspen with 1.5 mm veneers, and combi aspen with 2.6 mm veneers. the combi refers to the plywoods which has just face veneers as birch, for example, if the name is combi aspen means faces are with birch veneers and middle parts with aspen veneers. In addition, five different thicknesses were sampled and tested, which are 6.5 mm, 9 mm, 12 mm, 15 mm and 18 mm.

For pure aspen plywoods with 2.6 mm veneer thickness, just three out five thicknesses of the plywood could be obtained which are 6.5 with 3 layers, 12 mm with 5 layers and 18 mm with 7 layers. For combi aspen plywoods with 2.6 mm veneer thickness, just two thicknesses could be obtained which are 9 mm as 2 faces with 1.5 mm birch and 3 layers with 2.6 mm aspen veneers in the middle total 5 layers and 15 mm with 1.5 mm birch and 5 layers with 2.6 mm aspen veneers in the middle total 7 layers. By considering above descriptions instead of 7 sets for every thickness we had 6 sets with these 2.6 mm aspen veneers involved for pure aspen and combi aspen 2.6 mm because we can reach thickness of 6.5 mm, 12 mm and 18 mm with pure aspen 2.6 mm and thickness of 9 mm and 15 mm with combi aspen 2.6 mm. That's why:

Total need for specimen can be calculated as:

- 6 set of different type plywoods x 5 different thicknesses x 4 samples from different logs (to include veneer quality effect which can change from log to log) x 12 specimen from each plywood=6x5x4x12=1440 samples.

According to "EN 310 Wood-based panels - Determination of modulus of elasticity in bending and bending strength" [33] all test specimens were conditioned at temperature of (20 ± 2) °C and a relative humidity of (65 ± 5) % at least 24 h as mentioned in standard. Thickness was measured at the point of intersection of diagonals of specimen and the width was taken as centre width of the specimens.

For the purpose of this test all specimens were numbered from BE-1 to BE-12, in which first letters show the bending strength test and number shows the specimen number.
First 6 of these 12 specimens are in longitudinal direction and second 6 are in perpendicular direction. In addition to this for every direction first 3 specimens are tested

as top side up and other 3 specimen were tested upside down. The cross section of plywoods was shown in figure below. These specimens are turned as top face at the bottom for these upside-down tests. Modulus of elasticity and bending strength values were calculated according to the formulas as given in EN310 [27]

$$f_m = \frac{3 \times F_{max} \times l_1}{2 \times b \times t^2} \qquad (1)$$

Where l_1 is the distance between supports in mm, F_{max} is the maximum load in N, b is width in mm and t is the thickness in mm. Result is obtained as bending strength f_m in N/mm² or MPa.

For modulus of elasticity formula is:

$$E_m = \frac{l_1^3 \times (F_2 - F_1)}{4 \times b \times t^3 (a_2 - a_1)} \qquad (2)$$

Where F_2 and F_1 are the forces in N where the load is approximately equal to 40% and 10% of the maximum load respectively. And a_2 and a_1 are the deflections at the moment of application of F_2 and F_1 respectively their unit is mm.

For bending testing, Zwick/Roell brand 50kN load capacity testing machine was used.

3.3.5 Determination of plywood density

The standard EN323: Wood-based panels; determination of density was used to determine densities of plywood specimens [28]. For each plywood panel 6 specimen were prepared except for 12 mm, and 15 mm plywoods. Because of plywood dimension limitations just 4 samples were taken for 12 mm and 15 mm plywoods. Total number of prepared density samples therefore is 624. All densities were measured after conditioning of specimens in relative humidity of 65±5% and 20±2°C. Also, for 18 mm plywoods there was problem of space and this time also plywoods composed of different veneers sets. To determine density all specimen dimensions were taken as width, length and thickness to find the volume and weight was taken with balance with precision to 0.01 mm to get the weight and density was calculated with following formula:

$$\rho = \frac{m}{b_1 * b_2 * t} * 10^6 \qquad (3)$$

where m is the weight in grams, and b_1, b_2 and t are width, length and thickness in mm. and result is in kg/m³ with conversion factor of 10^6.

Figure 13 measuring of thickness of specimens

Samples are conditioned and prepared according to EN326-1 and for every board 6 samples must be prepared and the sizes are according to EN323 as 50 mm x50 mm [26] [28].

3.3.6 Final scheme of boards for sampling according to the plywood thicknesses

Finally, considering all above standards and considering peeled veneers has dimensions of 450 mm x 450 mm before drying and after dying 420 mm x 420 mm and after construction and cutting edges of plywood, they were around 390 mm x390 mm, following lay-up schemas can be constructed for sampling.

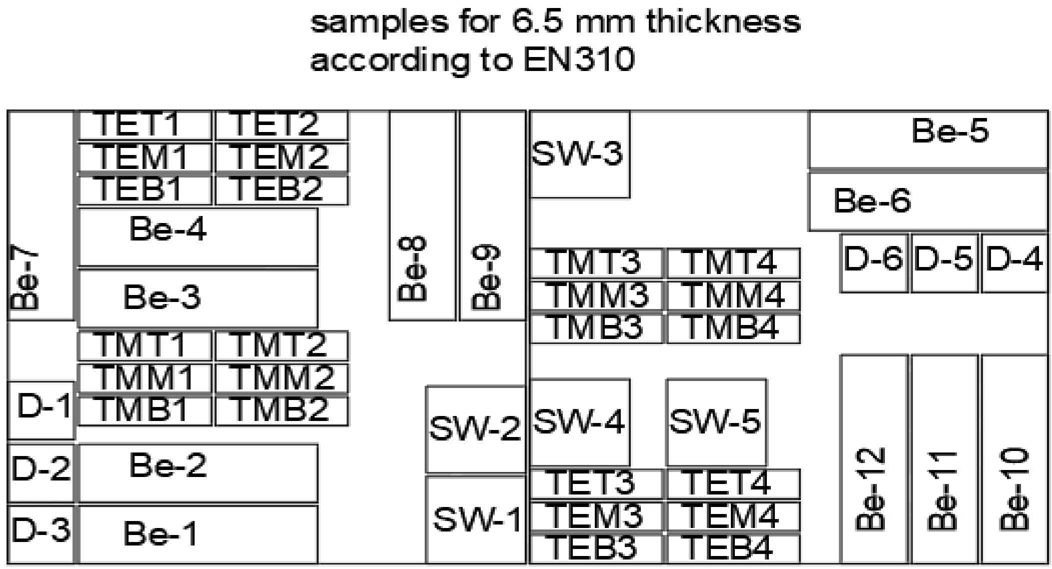

Figure 14 specimen placement in 6.5 mm plywood boards

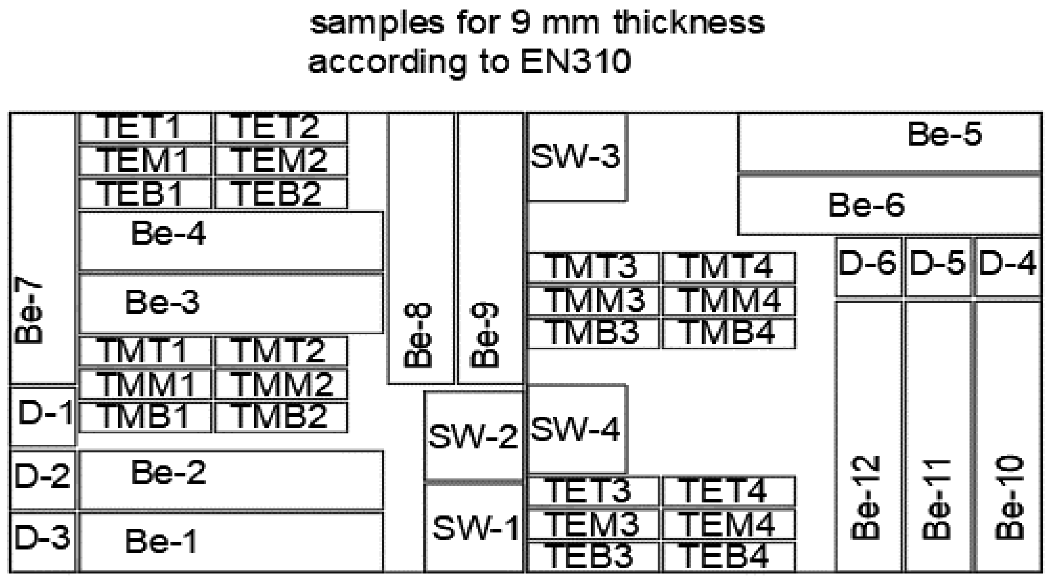

Figure 15 - specimen placement in 9 mm plywood boards

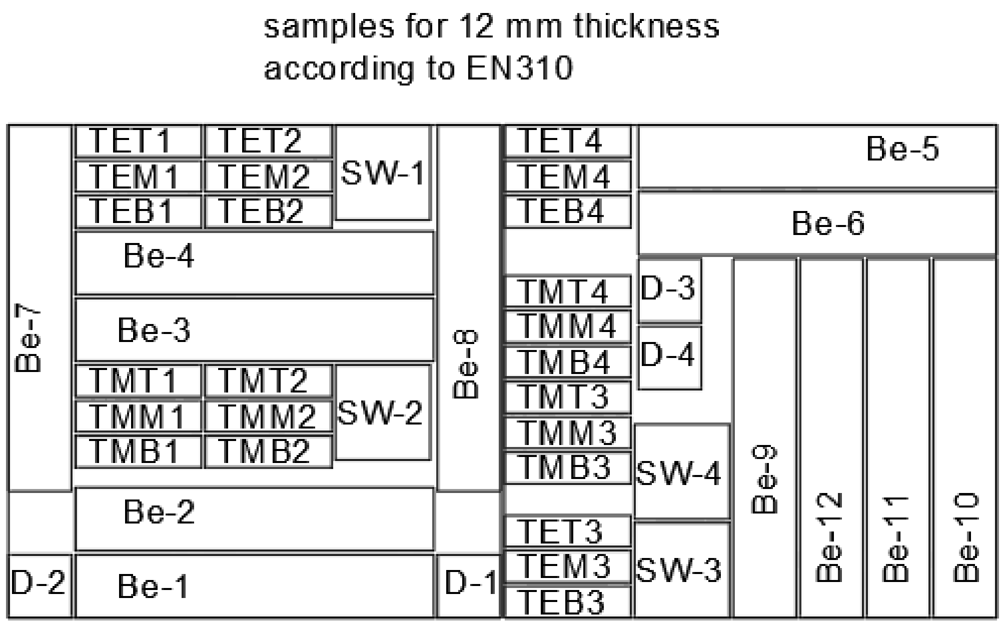

Figure 16 specimen placement in 12 mm plywood boards

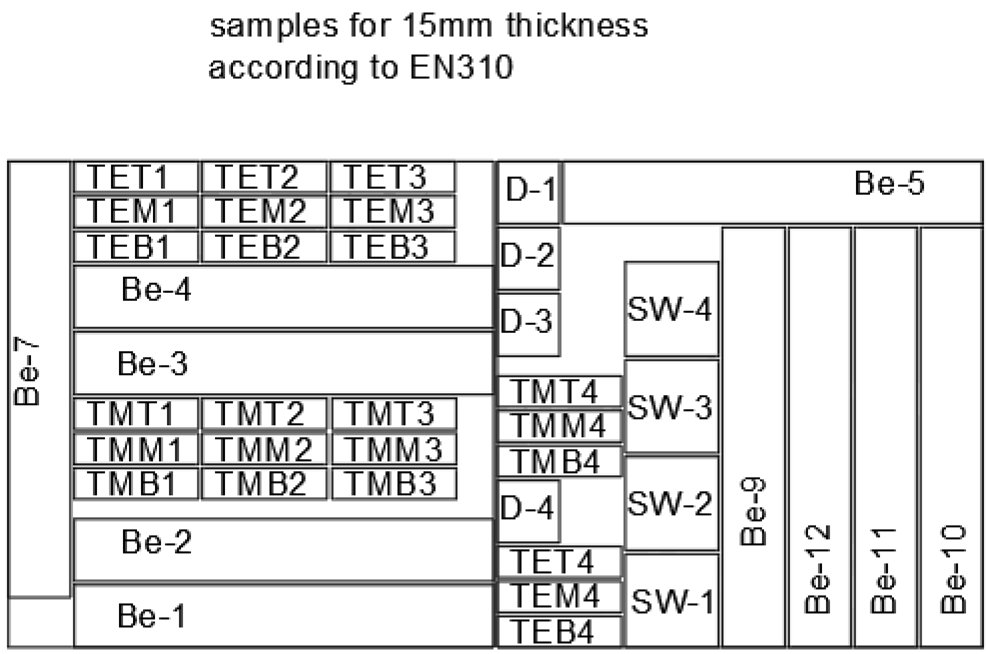

Figure 17 specimen placement in 15 mm plywood boards

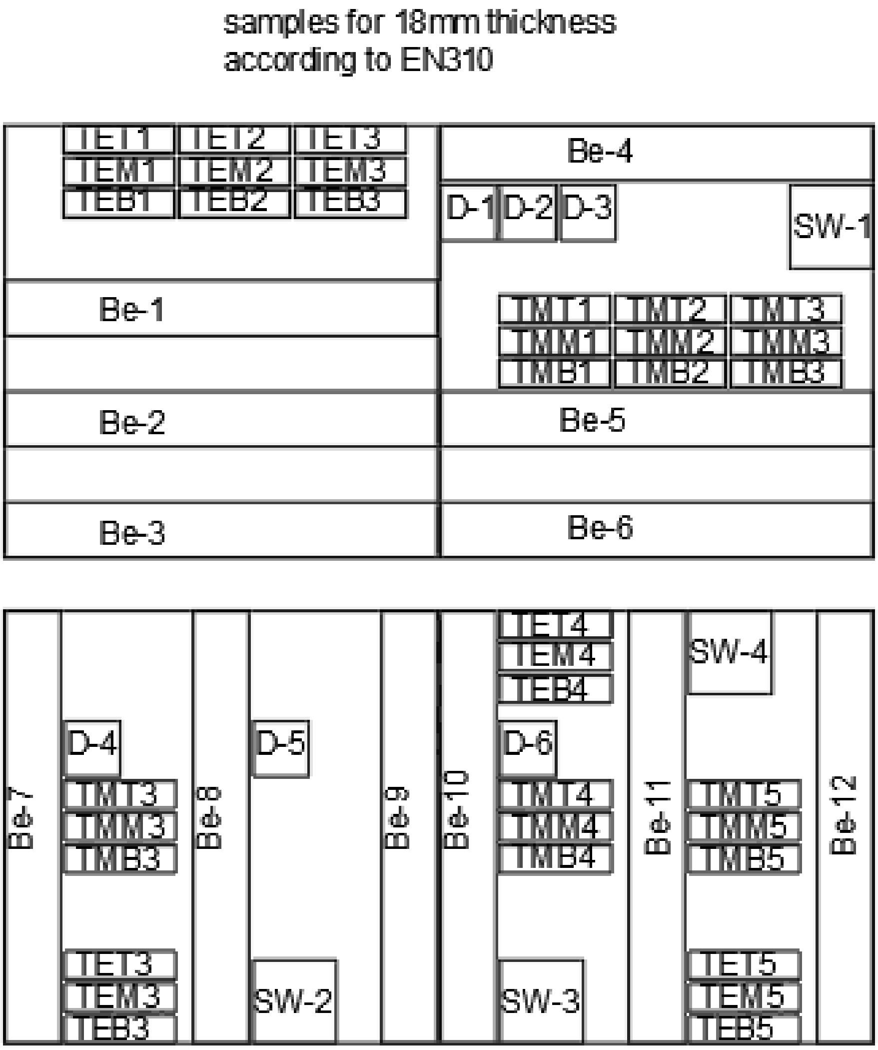

Figure 18 specimen placement in 18 mm plywood boards.

On the above Figure 18 specimen placement in 18 mm plywood boards.:

- Be-Bending
- SW-Screw Withdrawal
- D-Density

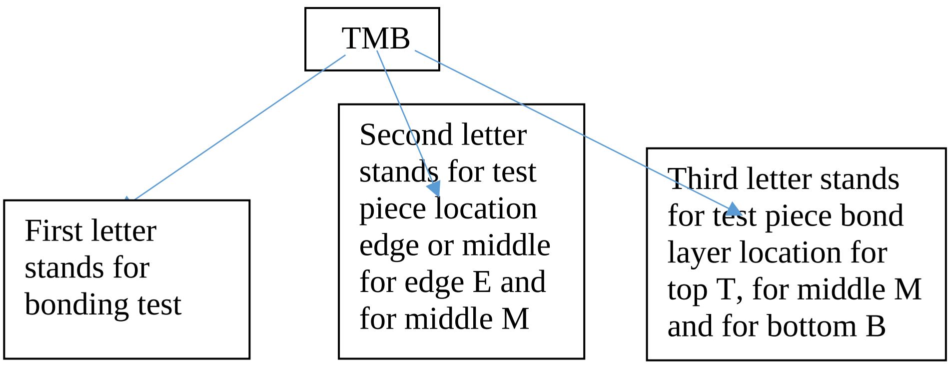

Table 13 Necessary number of test samples

TEST	**NECESSARY NUMBER OF SAMPLES PER TEST**	**TOTAL NUMBER OF PLYWOOD PLATES**	**NECESSARY NUMBER OF SAMPLES FOR TEST**
BENDING	12	120	1440
DENSITY	6	120	720
TOTAL NUMBER OF TEST SAMPLES			**2160**

4. RESULTS AND ANALYSIS

For species of birch, black alder and aspen; number of prepared veneers were tabulated in the appendices Table 31 . Also produced plywood from these veneers are tabulated in Table 32. This chapter is divided to three items as glue consumption, density properties and bending properties. Last item also dived to two sub item as bending properties and modulus of elasticity calculations.

4.1 Thickness checks for plywoods

When the plywood thicknesses controlled according to limit conditions given in chapter 2.3.2,

Table 11. All plywood samples with thickness 6.5 mm had a thickness in range of limits. For 9 mm 2 out of 48 plywoods with numbers 99-2 and 100-2 thickness was 1% thicker than limits and they were both C-Aspen plywoods with 2.6 mm aspen veneers. For 12 mm all samples were within thickness limits. For 15 mm 4 out of 48 plywood with numbers 89-1, 89-2, 130-1 and 130-2 were below minimum limit. For the plywood 130-1 and 130-2 thickness was 13.22 mm on average which is much lower than the minimum limit of 14.15 mm and they were both C-Aspen plywood with 1.5 mm aspen veneers. For the plywood 89-1 and 89-2 thickness was 13.55 mm on average which is lower than the minimum limit of 14.15 mm and they were both C-Aspen plywood with 2.6 mm aspen veneers. For 18 mm 18 out of 96 plywoods with numbers 21-1, 73-1, 73-2, 74-1, 74-2, 75-1, 75-2, 76-1, 76-2, 113-1, 113-2, 114-1, 114-2, 115-1, 115-2, 116-1, 116-2, and 140-1 thickness were above limits. For the plywood 21-1 thickness was 16.47 mm on average which is much lower than the minimum limit of 17.6 mm and this was pure Aspen plywood with 1.5 mm aspen veneers. For the plywood 73-1, 73-2, 74-1, 74-2, 75-1, 75-2, 76-1, 76-2, 113-1, 113-2, 114-1, 114-2, 115-1, 115-2, 116-1, and thickness was 16.3 mm on average which is much lower than the minimum limit of 17.6 mm and they were all pure-aspen plywood with 2.6 mm aspen veneers. For the plywood 140-1 thickness was 16.99 mm on average which is much lower than the minimum limit of 17.6 mm and this was pure Aspen plywood with 1.5 mm aspen veneers.

4.2 Glue consumption

For the glue consumption following results were obtained from produced plywoods. These results are the summary of data for glue consumption which was given in appendices Table 32*.*

Table 14 average glue consumptions, standard deviations, coefficient of variations and max. and min. values of glues consumption according to plywood type

Plywood Type	**Average Glue Cons., g/m²**	**Standard Deviation, g/m²**	**Coef. of variation**	**Max, g/m²**	**Min, g/m²**
Alder	156	7	5%	169	143
Aspen	177	10	6%	200	156
Aspen2.6 mm	196	13	7%	232	185
Birch	152	6	4%	162	141
Combi Alder	156	6	4%	168	143
Combi Aspen	187	7	4%	201	172
Combi Aspen 2.6 mm	185	5	3%	192	178

The results are shown in Table 14, the lowest glue consumption result was 152 g/m² with birch plywood and the highest consumption result was 196 g/m² with aspen plywood which has 2.6mm thick aspen veneers.

Choosing birch plywood as reference plywood, alder plywood and combi alder plywood (which has face veneers as birch) has the closest results to aspen plywood with 2.4% higher glue consumption. In glue consumption point of view, these two types of plywood will not have a remarkable effect on plywood production. In aspen plywood with 1.5 mm aspen veneer, glue consumption is 15.8% higher than birch plywoods and for aspen plywood with 2.6 mm aspen veneer glue consumption difference is 28.3% higher than birch plywood. For combi plywoods with 1.5 mm and 2.6 mm aspen veneer, glue consumptions are 25% and 21.6% higher than birch plywood.

As it can be seen from above comparisons aspen plywood depending on its rough surface consumes around 16 to 30% more glue in production per veneer layer. Another point that should be covered is comparison of total glue consumption because in the research different thickness of veneers were used for plywoods 26mm aspen veneer plywood and combi aspen plywood with 26mm aspen veneers. Total glue consumption results are given in following Figure 19.

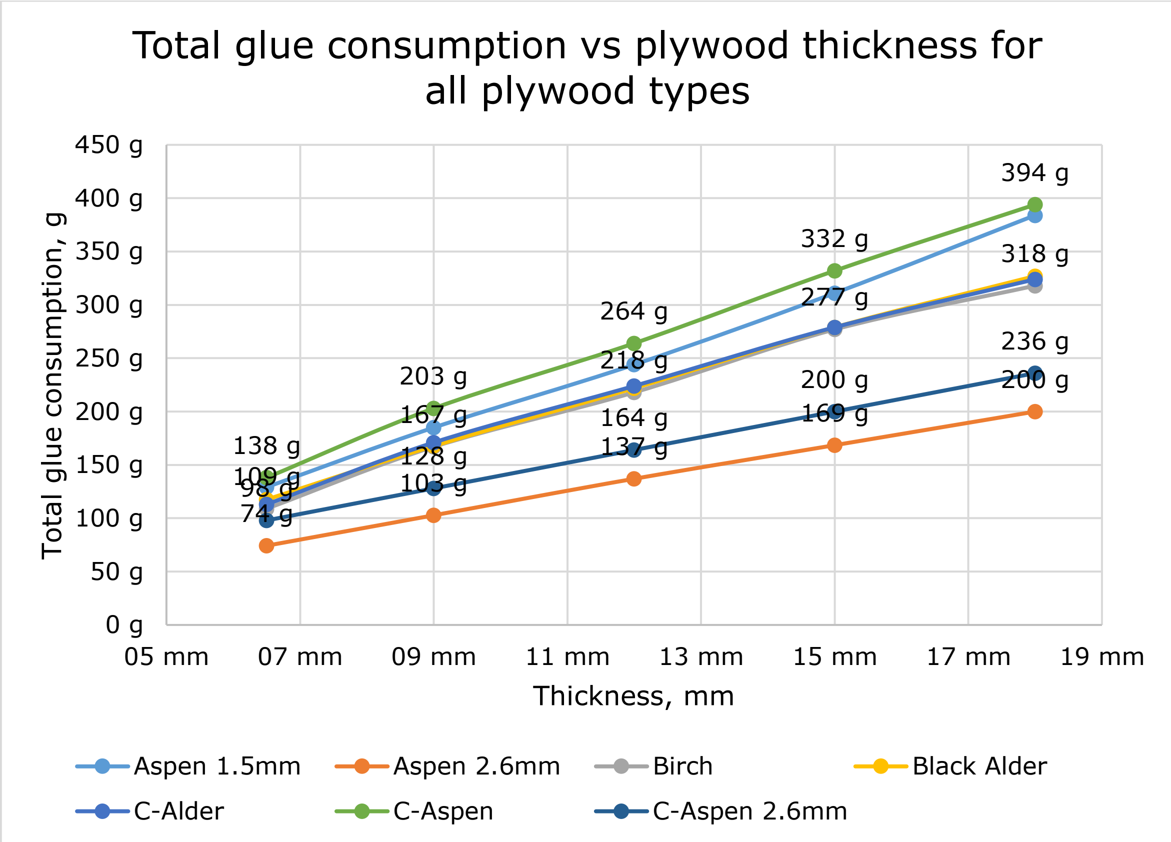

Figure 19 Total glue consumption vs plywood thickness for all plywood types

In Figure 19, total glue consumption for same plywood thickness is highest at combi aspen and aspen 1.5 mm veneer plywoods, very close results were obtained at alder, combi alder and birch plywoods and lowest glue consumption with 2.6 mm aspen plywoods and 2.6 mm aspen veneer combi plywoods with 34~40% lower results.

4.3 Plywood Density

Densities according to species tested in this research were given in section 2.1. Aspen has the lowest and birch has the highest density in three species. However, in section 3.1 it was mentioned that aspen samples compressed more than others and final thickness of aspen plywoods are lower than others. Also, in section 3.2, the results showed that aspen plywoods had the highest glue consumptions. With the effect of these two parameters, densities of specimens gave results different than section 2.1 where the density of aspen, black alder and birch were given. Some of density test results were given in appendix Table 33. And in the following Table 15 results of density tests are shown. In table and graph, the values for missing thickness for plywoods of aspen 2.6 mm veneer and combi aspen with 2.6 mm veneer were interpolated.

Table 15 Density change with plywood thickness,

Veneer thickness	Specie	Density, kg/m³ change with plywood thickness				
		6.5 mm	9 mm	12 mm	15 mm	18 mm
1.5	Aspen	636.9	642.5	640.8	641.8	649.6
1.5	Birch	694.8	702.1	706.8	717.2	704.3
1.5	Black alder	586.1	582.8	583.5	586.6	566.6
1.5	C-alder	615.0	602.0	608.2	599.7	576.0
1.5	C-aspen	607.6	654.2	633.7	662.3	640.1
2.6	C-aspen 2.6	621.7*	610.9	598.0*	585.1	572.2*
2.6	Aspen 2.6	550.1	548.7*	547.1	535.4*	523.6

Note: * interpolated values

Densities of plywoods fluctuated with thicknesses but results didn't show any relation between density and plywood thickness. After this result instead of thickness consideration all specimen's average density were calculated according to plywood types taking into consideration all thickness and following results were obtained.

Table 16 Average densities and statistics including all thicknesses

Specie	Av. Density, ρ kg/m³	Standard deviation, kg/m³	Coefficient of variation	Max, kg/m³	Min, kg/m³	Comp. with Birch
Aspen	643.5	15.5	2.4%	672.7	616.0	-9%
Birch	704.9	29.7	4.2%	773.9	646.5	0%
Black alder	578.7	33.1	5.7%	629.9	531.8	-18%
C-alder	596.1	28.9	4.9%	668.3	555.5	-15%
C-aspen	639.7	30.4	4.7%	700.1	573.5	-9%
C-Aspen 2.6mm	598.0	18.1	3.0%	624.0	574.3	-15%
Aspen 2.6mm	548.5	20.6	3.8%	590.1	505.8	-22%

Birch plywood has the highest density with 705 kg/m³ and aspen plywood with 2.6 mm veneers has the lowest density with 549kg/m³. Also, considering densities black alder, combi alder and aspen and combi aspen plywoods with 2.6mm veneers are 15 to 22% lighter than birch plywoods.

4.4 Bending properties

This chapter will be divided into 2 different sub chapters as bending strength and modulus of elasticity.

4.4.1 Bending strength

Bending strength tests were conducted as explained in materials and methods section 3.3.4 according to EN310 standard [27]. The average of 48 specimens for every thickness for every type of plywood were tabulated as a summary under each type of plywood and related thickness vs bending strength graphs were constructed as follows:

For pure Aspen plywoods with 1.5 mm aspen veneers

Table 17 Bending strength results for Aspen 1.5 mm veneer plywood

Expected thickness, mm	t mean mm	$f_{m\,II}$ N/mm²	$f_{m\,\perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
6.5	6.77	95.17	41.33	5.27	6%	4.21	10%
9	9.42	87.22	53.75	5.38	6%	4.18	8%
12	12.06	87.07	60.18	7.13	8%	4.31	7%
15	14.95	80.1	65.61	7.69	10%	8.14	12%
18	17.51	79.32	62.01	4.24	5%	5.44	9%

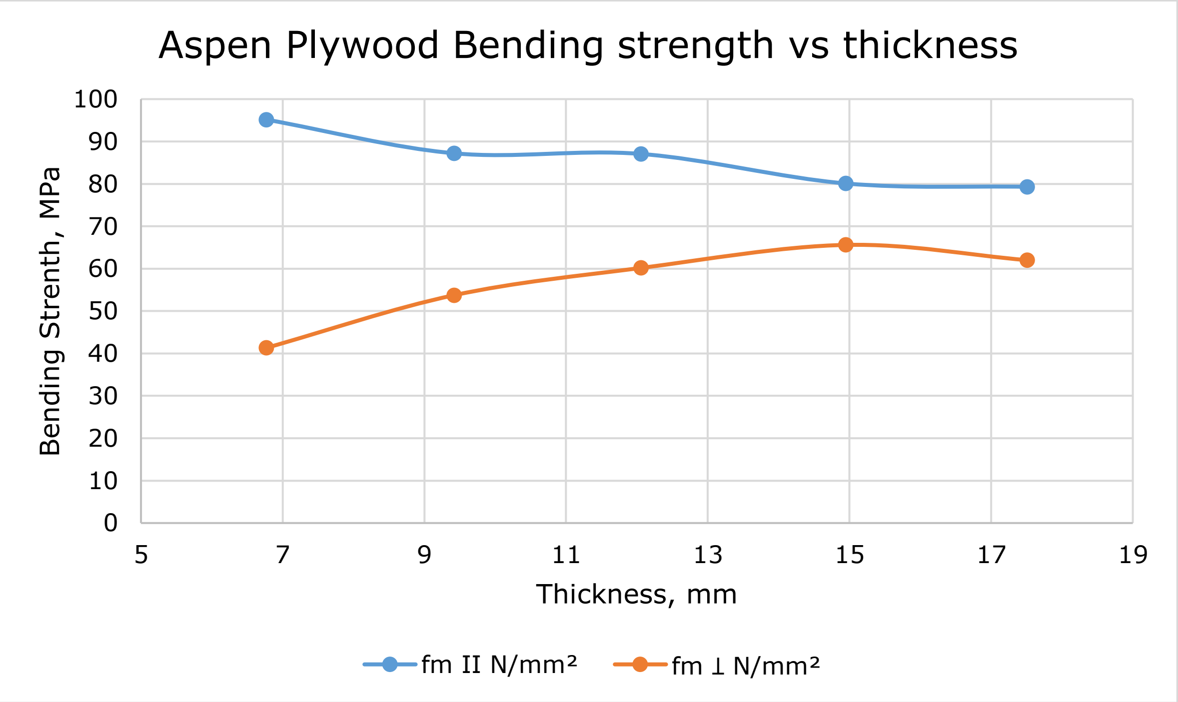

Figure 20 Bending strength results for Aspen 1.5 mm veneer plywood

For pure Aspen plywoods with 2.6 mm aspen veneers

Table 18 Bending strength results for Aspen 2.6 mm veneer plywood

Expected thickness, mm	t mean mm	$f_{m\ II}$ N/mm²	$f_{m\ \perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
6.5	7.14	98.46	20.58	9.12	9%	2.24	11%
12	11.72	80.78	37.33	8.06	10%	2.9	8%
18	16.4	74.89	45.87	5.56	7%	4.7	10%

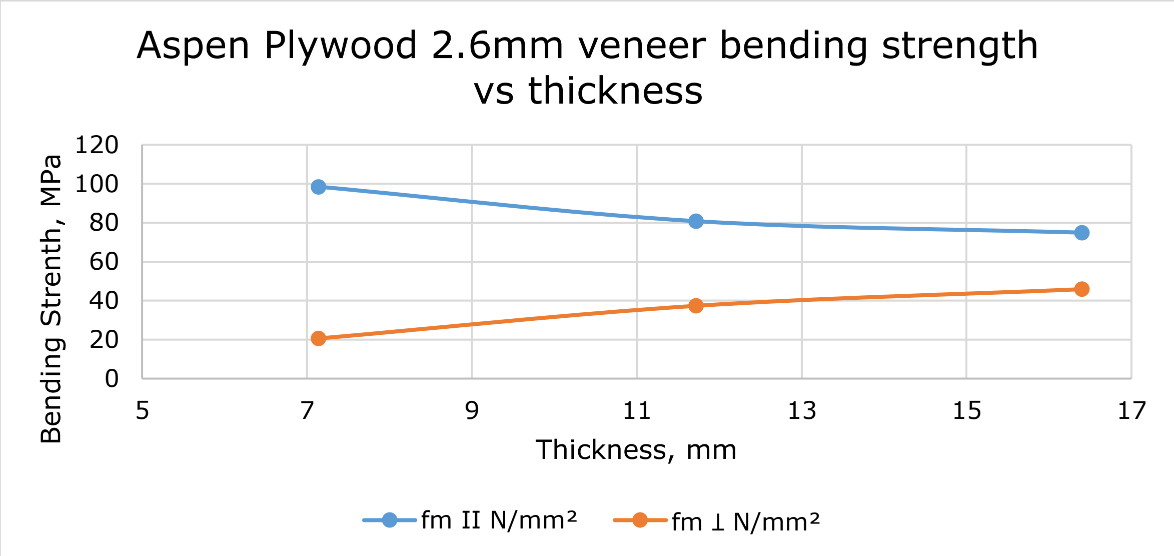

Figure 21 Bending strength results for Aspen 2.6 mm veneer plywood

For pure Birch plywoods with 1.5 mm aspen veneers

Table 19 Bending strength results for birch 1.5 mm veneer plywood

Expected thickness, mm	t mean mm	$f_{m\ II}$ N/mm²	$f_{m\ \perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
6.5	7.01	120.23	53.8	6.27	5%	3.03	6%
9	9.74	119.11	68.03	14.33	12%	7.84	12%
12	12.3	116.8	71.32	11.49	10%	6.57	9%
15	15.28	109.59	76.5	9.8	9%	8.85	12%
18	17.4	99.13	71.6	7.58	8%	5.13	7%

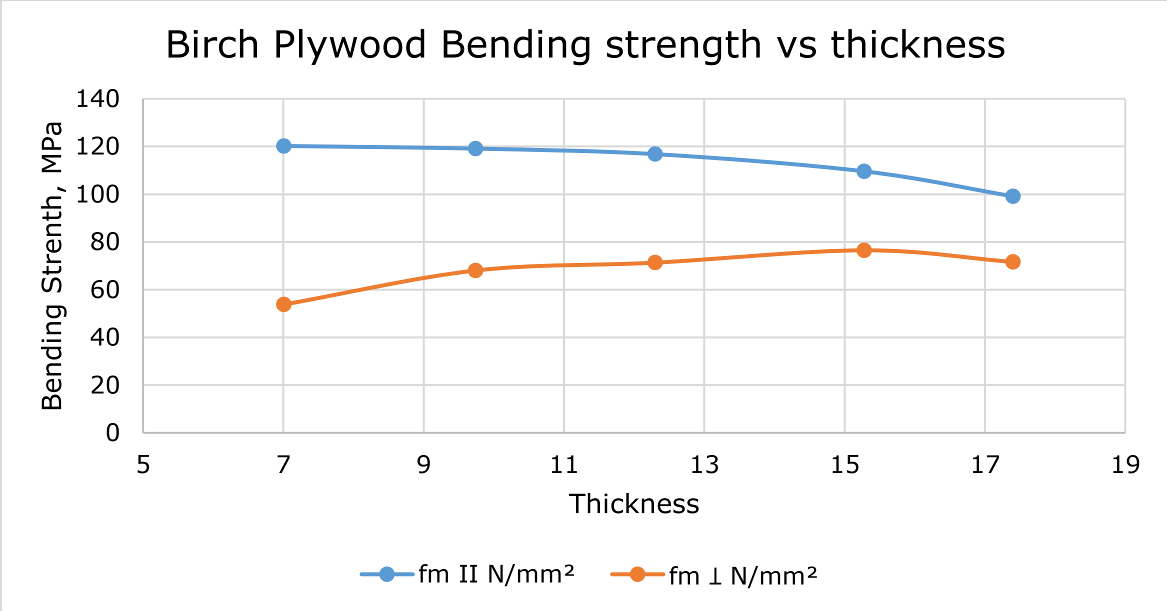

Figure 22 Bending strength results for birch1.5 mm veneer plywood

For pure black alder plywoods with 1.5 mm aspen veneers

Table 20 Bending strength results for black alder 1.5 mm veneer plywood

t mean mm	**$f_{m\ II}$ N/mm²**	**$f_{m\ \perp}$ N/mm²**	**Std. Dev. In II, N/mm²**	**Coef. Of Var. in II, N/mm²**	**Std. Dev. In ⊥, N/mm²**	**Coef. Of Var. in ⊥, N/mm²**
6.9	97.51	45.64	12.17	12%	5.13	11%
9.68	80.69	51.42	8.29	10%	7.18	14%
12.6	78.5	52.76	9.35	12%	7.16	14%
15.45	72.79	54.87	12.09	17%	7.3	13%
18.21	64.65	50.95	8.39	13%	7.71	15%

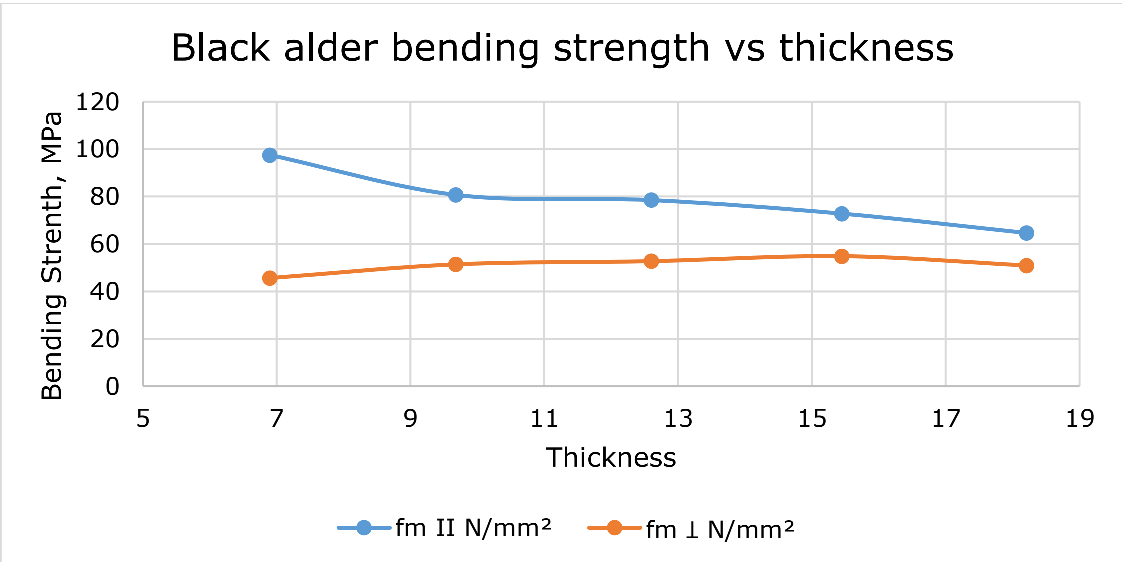

Figure 23 Bending strength results for black alder 1.5 mm veneer plywood

For combi black alder plywoods with 1.5 mm aspen veneers

Table 21 Bending strength results for combi alder 1.5 mm veneer plywood

t mean mm	$f_{m\ II}$ N/mm²	$f_{m\ \perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
7.01	115.08	40.53	6.31	5%	5.22	13%
9.74	100.34	42.91	6.39	6%	3.84	9%
12.7	95.53	53.03	7.73	8%	6.88	13%
15.31	85.43	53.17	7.13	8%	5.04	9%
18.3	76.88	49.15	6.79	9%	5.79	12%

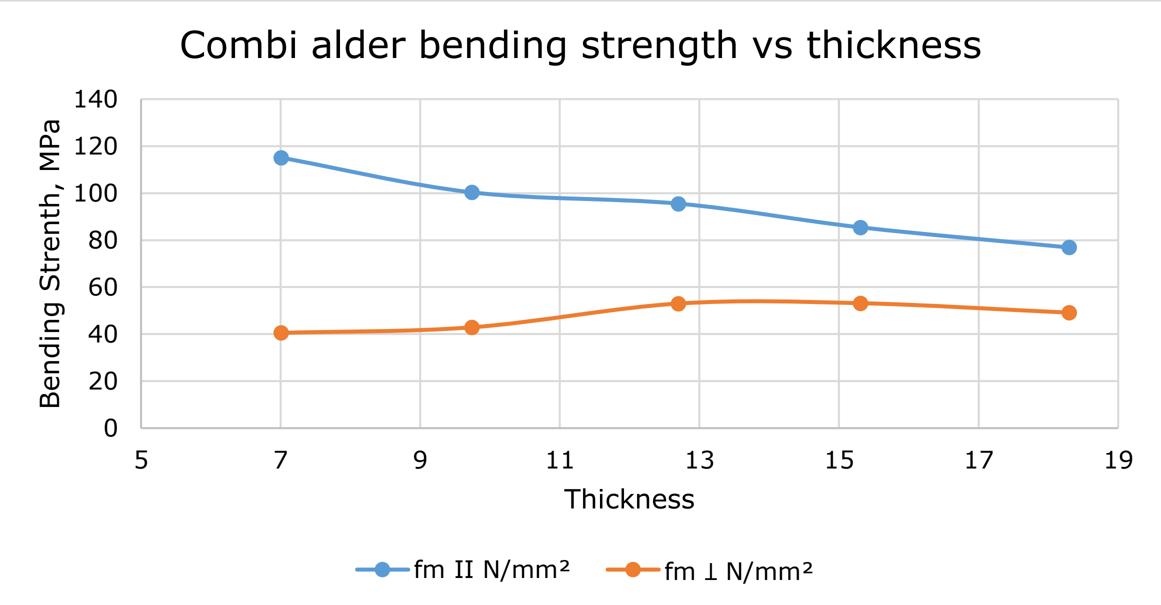

Figure 24 Bending strength results for combi alder 1.5 mm veneer plywood

For combi aspen plywoods with 1.5 mm aspen veneers

Table 22 Bending strength results for combi aspen 1.5 mm veneer plywood

t mean mm	$f_{m\ II}$ N/mm²	$f_{m\ \perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
6.87	96.08	44.55	18.52	19%	1.6	4%
9.18	101.51	55.61	9.15	9%	5.73	10%
11.98	87.12	52.61	4.32	5%	3.69	7%
14.25	82.07	57.88	6.74	8%	5.48	9%
17.49	79.74	57.92	6.42	8%	3.54	6%

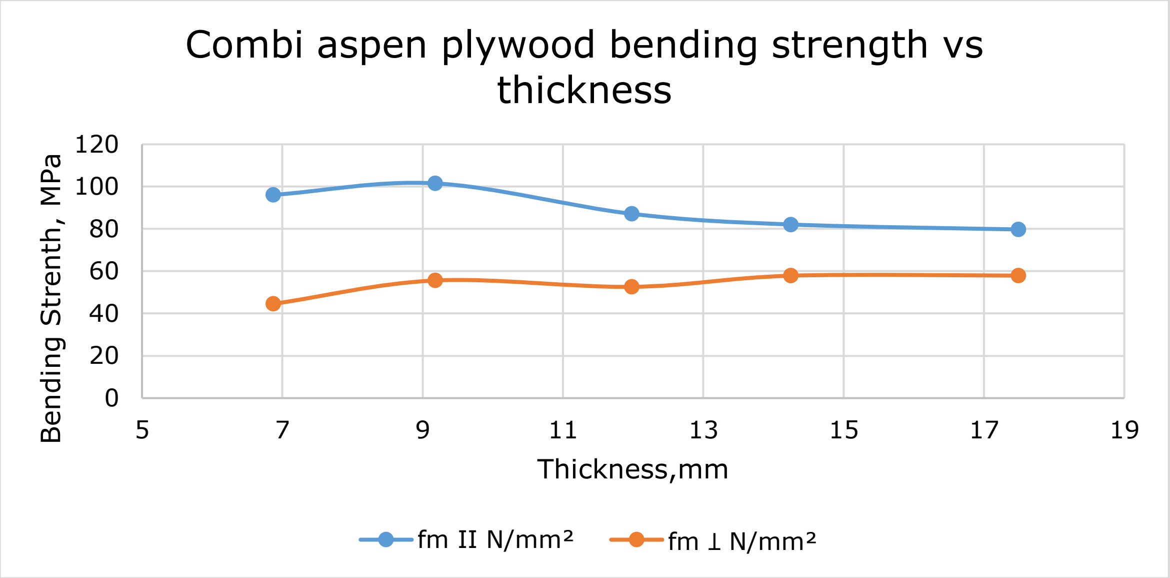

Figure 25 Bending strength results for combi aspen 1.5 mm veneer plywood

For combi aspen plywoods with 2.6 mm aspen veneers

Table 23 Bending strength results for combi aspen 2.6 mm veneer plywood

t mean mm	$f_{m\,II}$ N/mm²	$f_{m\,\perp}$ N/mm²	Std. Dev. In II, N/mm²	Coef. Of Var. in II, N/mm²	Std. Dev. In ⊥, N/mm²	Coef. Of Var. in ⊥, N/mm²
9.71	95.72	58.59	4.27	4%	4.28	7%
14.35	81.88	59.27	3.87	5%	5.24	9%

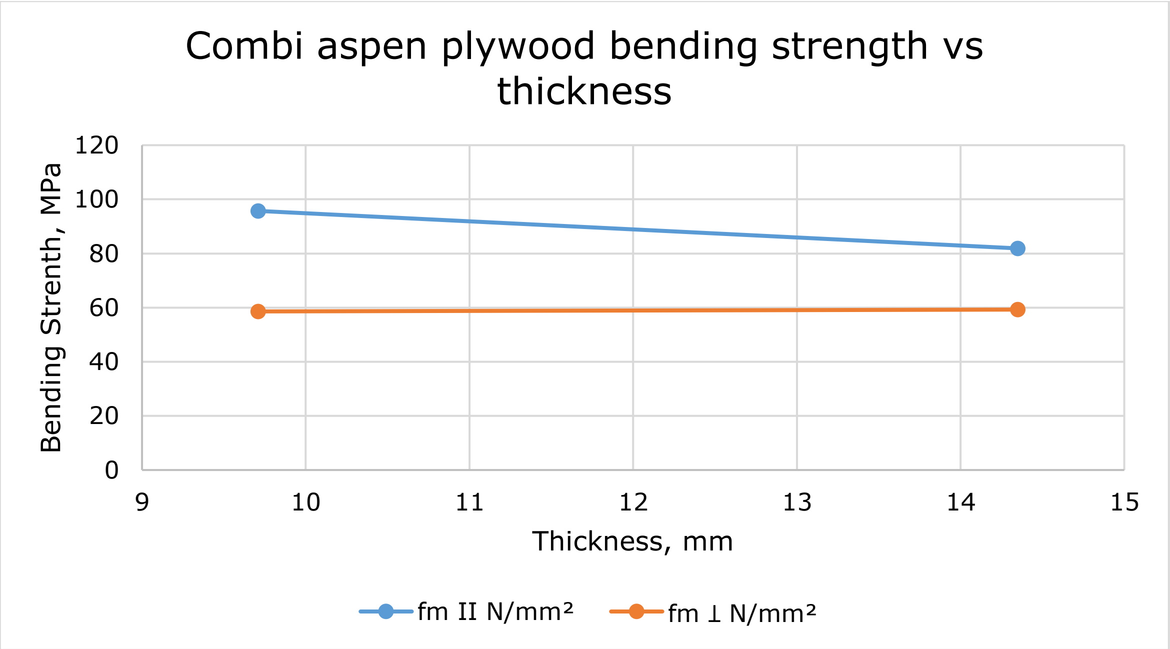

Figure 26 Bending strength results for combi aspen 2.6 mm veneer plywood

In all tables and graphs above for bending strength, the results show that the thicker the thickness, the lower the bending strength in grain direction and vice versa in perpendicular direction in the standard lay-up plywoods.

In the following Figure 27 for every type of plywood, and every thickness summary of bending results in both directions were graphed to have a better understanding and comparison between plywood types. Also, in following Table 24 all bending test results above are compared with birch plywood as a reference and bending strength difference in grain direction were given in percentages of birch plywood bending strength.

Table 24 Comparison of bending test results (MOR modulus of rupture) in grain direction by accepting birch plywood as reference and all values shows reduction in stregh comparing to birch plywood

t mean mm	**Aspen**	**Aspen 2.6**	**Birch**	**Black Alder**	**C-Alder**	**C-Aspen**	**C-Aspen 2.6**
6.5	21%	18%	0%	19%	4%	20%	11%
9	27%	24%	0%	32%	16%	15%	20%
12	25%	31%	0%	33%	18%	25%	24%
15	27%	29%	0%	34%	22%	25%	25%
18	20%	24%	0%	35%	22%	20%	31%
Average	**24%**	**25%**	**0%**	**30%**	**17%**	**21%**	**22%**

From Figure 27 below, considering all thickness on average, birch plywoods has the highest bending strength in all thicknesses and black alder has the lowest bending strength in all thicknesses except 6.5 mm thickness in grain direction. On the average, birch plywoods are 24% stronger than pure aspen 1.5 mm, 25% stronger than pure aspen 2.6 mm, 30% stronger than black alder, 17% stronger than combi black alder and 21% stronger than combi aspen 1.5 mm and ~22% stronger than combi aspen 1.5 mm 2.6 mm in grain direction considering bending strength.

In following Table 25, all bending test results above are compared with birch plywood as a reference and bending strength difference in grain direction were given in percentages of birch plywood bending strength.

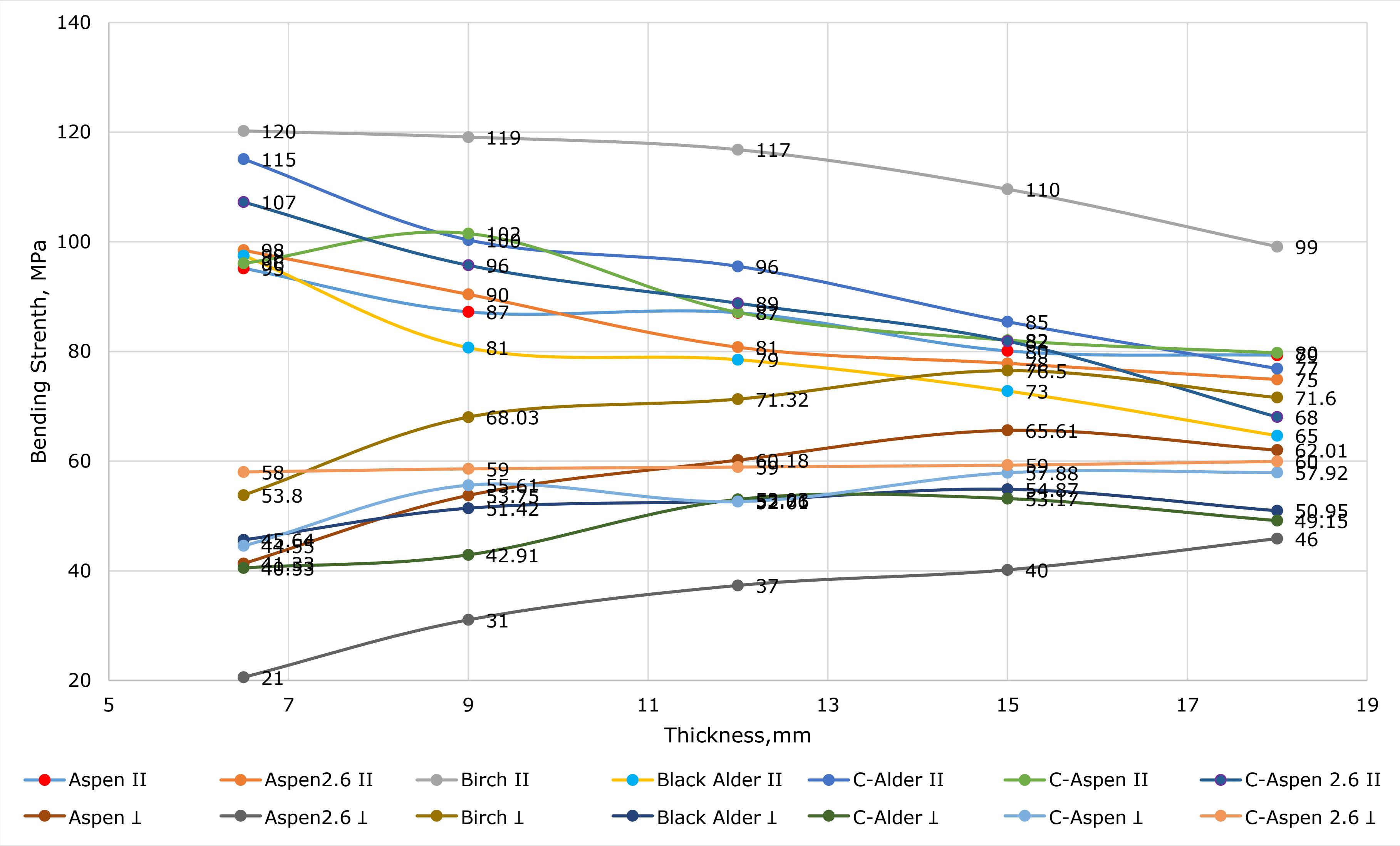

Figure 27 Different plywood types and plywood thickness bending strength vs thickness in grain and perpendicular direction

Table 25 Comparison of bending test results (MOR modulus of rupture) in perpendicular direction by accepting birch plywood as reference and all values shows reduction in stregh comparing to birch plywood

t mean mm	Aspen	Aspen2.6	Birch	Black Alder	C-Alder	C-Aspen	C-Aspen 2.6
6.5	23%	62%	0%	15%	25%	17%	8%
9	21%	59%	0%	24%	37%	18%	14%
12	16%	48%	0%	26%	26%	26%	17%
15	14%	46%	0%	28%	30%	24%	23%
18	13%	36%	0%	29%	31%	19%	16%
Average	**17%**	**50%**	**0%**	**25%**	**30%**	**21%**	**12%**

From above Table 25 and Figure 27, considering all thickness on average, birch plywoods has the highest bending strength in all thicknesses in perpendicular direction and combi aspen 2.6 mm veneer has the lowest bending strength in all thicknesses. On the average, birch plywoods are 17% stronger than pure aspen 1.5 mm, 50% stronger than pure aspen 2.6 mm, 25% stronger than black alder, 30% stronger than combi black alder and 21% stronger than combi aspen 1.5 mm and 12% stronger than combi aspen 2.6 mm in grain direction considering bending strength. In case of 2.6mm pure aspen plywood, the lowest value is obtained with 6.5 mm thick aspen plywood and it is 62% lower than birch plywood bending strength in this direction.

In following Figure 28, bending test results of pure aspen 1.5 mm veneer plywood and pure aspen 2.6 mm veneer are compared in grain and crosswise direction to see effect of using thicker veneers on bending strength. In the table, the results were interpolated for missing thickness of 9 mm and 15 mm for 2.6 mm veneer aspen plywood. The values show that for 2.6 mm aspen veneer plywood and 1.5 mm aspen plywood bending strength in grain direction almost equal to each other but in cross wise direction there is big difference in strength values.

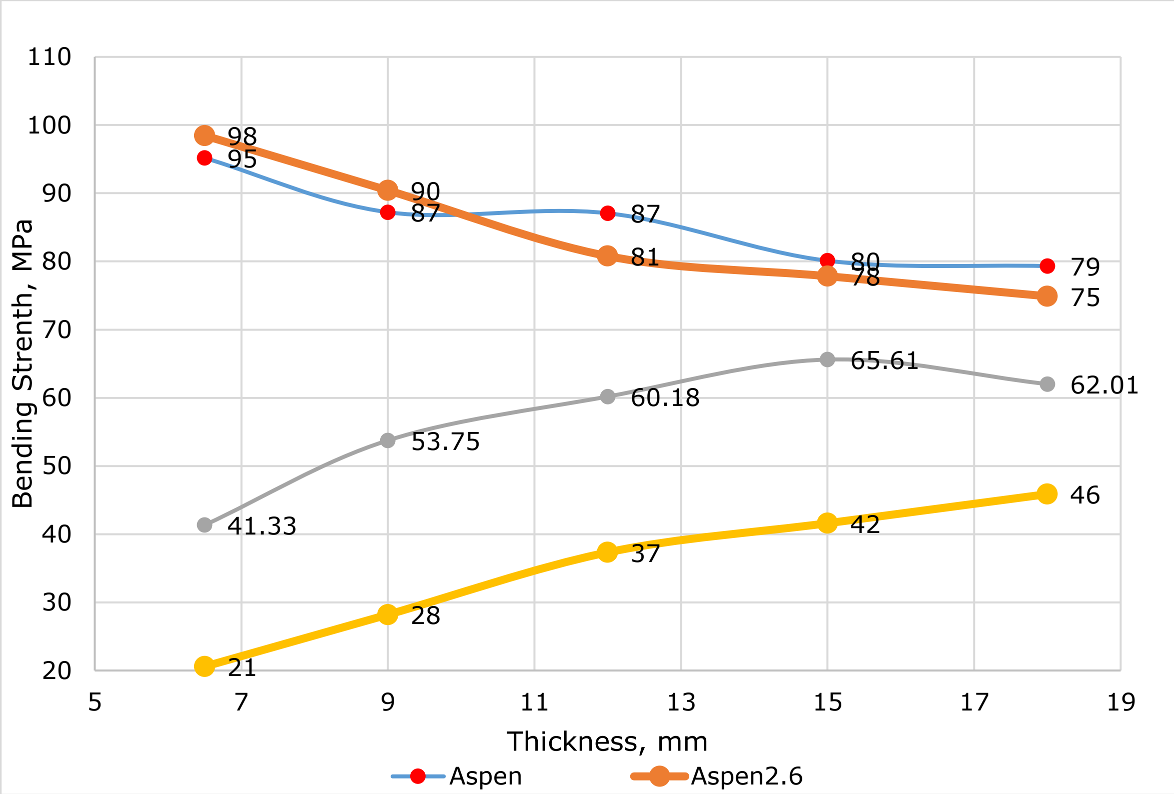

Figure 28 Comparison of Aspen 1.5 mm thick veneer plywood and 2.6 mm thick veneer plywood

In following Figure 29, all bending test results of pure aspen 1.5 mm veneer plywood and combi aspen 1.5 mm veneer are compared in grain and crosswise direction to see effect of using birch face veneers effect on bending strength.

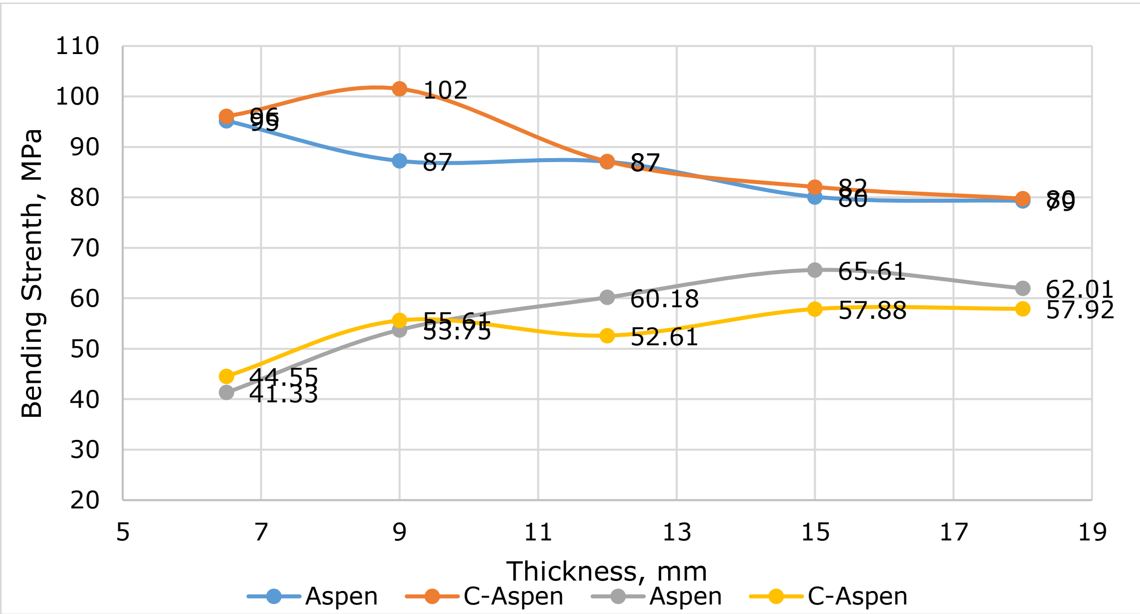

Figure 29 Comparison of Aspen and Combi aspen plywoods bending strength in both directions

There is no significant difference on bending strength point of view between aspen and combi aspen plywoods.

In following Figure 30, all bending test results of pure black alder 1.5 mm veneer plywood and combi black alder 1.5 mm veneer are compared in grain and crosswise direction to see of using birch face veneers effect on bending strength.

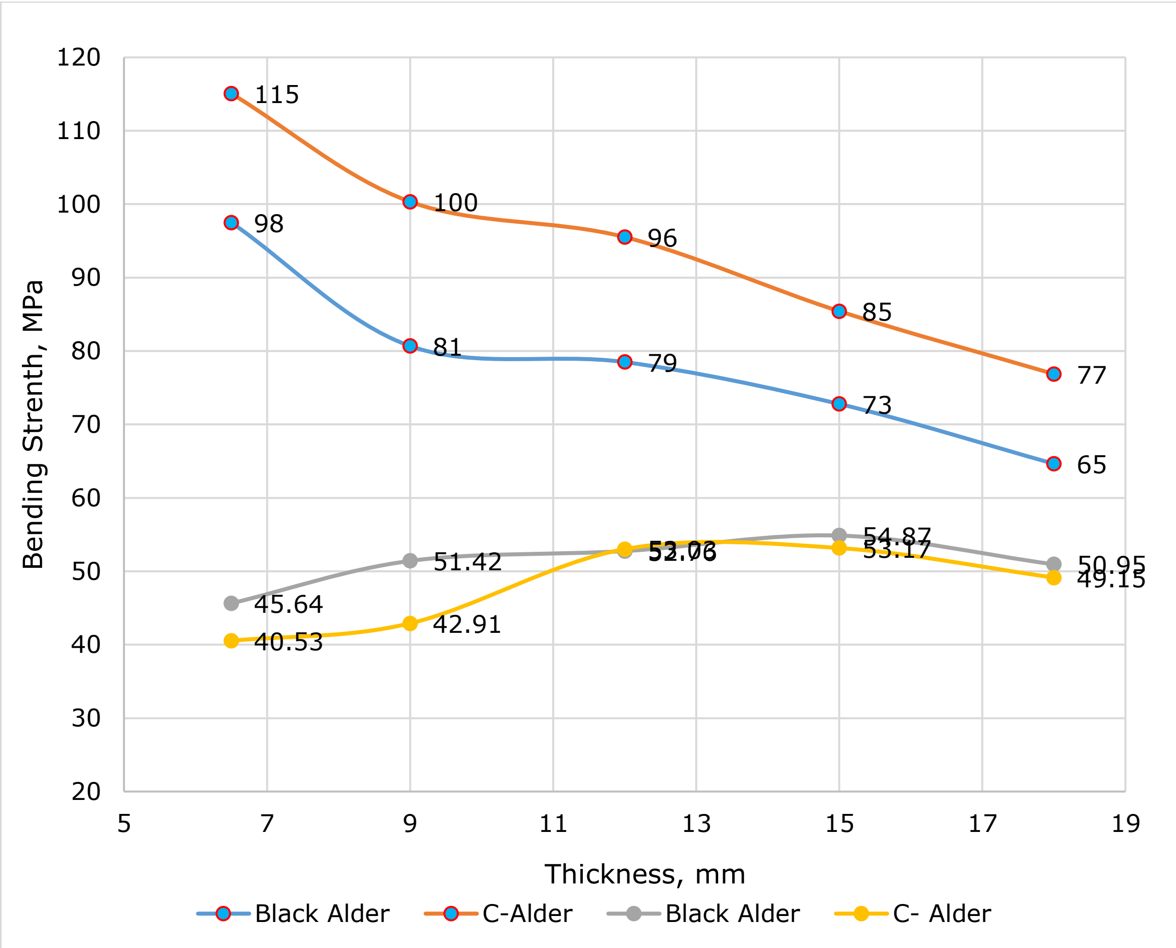

Figure 30 Comparison of black alder and Combi black alder plywoods bending strength in both directions

The results show that using face veneers as birch and middle layers as alder creates a 20% strength gain in grain direction while there is almost no change in crosswise direction. Which is an expected result since there is no birch veneers in crosswise direction.

In the following tables the results which obtained from this research, test specimens were compared with the strength values given in Latvijas Finiers plywood handbook page 42, in the standard deviation and coefficient of variation were not given but average values and lower 5% percentile quantile values were given from these two-table standard deviation were obtained by putting values in the following formula

$$z = \frac{x-\mu}{\sigma} \qquad (4)$$

Where z=-1.645 for lower 5%percentile, x is obtained from values given in 5% values in handbook, μ is the average values given in handbook and σ is the standard deviation obtained from above formula.

4.4.2 Modulus of elasticity

In the following tables modulus of elasticity values were tabulated as summary. For all thicknesses and plywood types, given values are average values of specimens for that thickness and type. For one type of plywood and for every thickness of that plywood 6 specimen for one direction were cut and 4 different plywoods were constructed for tests which makes 24 specimens for each direction with a total of 48 in both directions. In the table below all averages are averages of 24 specimens.

Table 26 modulus of elasticity results of thesis in grain direction

t mean mm	**Aspen N/mm²**	**Aspen 2.6 N/mm²**	**Birch N/mm²**	**Black Alder N/mm²**	**C-Alder N/mm²**	**C-Aspen N/mm²**	**C-Aspen 2.6 N/mm²**
6.5	11918.0	12859.0	13490.0	10236.0	12893.0	11210.0	11698.2
9	11368.0	11794.5	12803.0	8552.0	11863.0	10834.0	11149.0
12	10661.0	10517.0	12637.0	8679.0	10829.0	9544.0	10819.5
15	9536.0	10475.5	12545.0	8408.0	10446.0	10327.0	10490.0
18	10022.0	10434.0	10775.0	7613.0	8804.0	9048.0	9831.0

Comparison of modulus of elasticity values with the values of reference birch plywoods were tabulated in the following table.

Table 27 Modulus of elasticity results of thesis in grain direction with comparison of reference birch plywood in thesis. All values shows reductin in MOE comparing to birch plywoods

t mean mm	Aspen N/mm²	Aspen 2.6 N/mm²	Birch N/mm²	Black Alder N/mm²	C-Alder N/mm²	C-Aspen N/mm²	C-Aspen 2.6 N/mm²
6.5	12%	5%	0%	24%	4%	17%	13%
9	11%	8%	0%	33%	7%	15%	13%
12	16%	17%	0%	31%	14%	24%	14%
15	24%	16%	0%	33%	17%	18%	16%
18	7%	3%	0%	29%	18%	16%	9%
Average	**14%**	**10%**	**0%**	**30%**	**12%**	**18%**	**13%**

Above results are in conformity with bending strength values of same specimens, the highest results were obtained with birch plywoods then aspen and least values were obtained from black alder.

Table 28 modulus of elasticity results of thesis in perpendicular direction

t mean mm	Aspen N/mm²	Aspen 2.6 N/mm²	Birch N/mm²	Black Alder N/mm²	C-Alder N/mm²	C-Aspen N/mm²	C-Aspen 2.6 N/mm²
6.5	3413.0	1027.0	4455.0	3298.0	2940.0	3821.0	5165.8
9	4865.0	2092.5	5737.0	4188.0	3543.0	4889.0	5715.0
12	5907.0	3371.0	6609.0	4662.0	4669.0	5132.0	6044.5
15	6781.0	4006.5	7222.0	5016.0	4949.0	6199.0	6374.0
18	6698.0	4642.0	7154.0	5080.0	4928.0	6211.0	7033.0

Table 29 Modulus of elasticity results of thesis in perpendicular direction with comparison of reference birch plywood in thesis. All values shows reductin in MOE comparing to birch plywoods

t mean mm	Aspen N/mm²	Aspen 2.6 N/mm²	Birch N/mm²	Black Alder N/mm²	C-Alder N/mm²	C-Aspen N/mm²	C-Aspen 2.6 N/mm²
6.5	23%	77%	0%	26%	34%	14%	16%
9	15%	64%	0%	27%	38%	15%	0%
12	11%	49%	0%	29%	29%	22%	9%
15	6%	45%	0%	31%	31%	14%	12%
18	6%	35%	0%	29%	31%	13%	2%
Average	**12%**	**54%**	**0%**	**28%**	**33%**	**16%**	**1%**

In crosswise direction highest difference from birch plywood obtained from 2.6 mm aspen plywoods, which is normal with smaller thicknesses in crosswise direction there is less amount of veneers.

5. DISCUSSIONS

In section 2.3.2 thickness checks of plywoods, it was mentioned that aspen plywoods compressed more than other two species and final thickness of aspen plywoods were lower than the others. Some plywoods proposed for 18 mm reached 14.5 mm thickness in aspen 2.6 mm veneer plywoods even less than thickness of proposed 15 mm plywoods. This can be explained with press parameters, as mentioned in section **Error! Reference source not found.**, all plywoods were compressed with same pressure and press time, this caused different species to compress different amounts. Low density species compressed more than the others as in this case aspen has the lowest density veneers. This resulted less thickness contributed to the higher density results in aspen plywoods since in density calculations volume is in denominator of density formula (**Error! Reference source not found.**). And this shows, aspen veneers densified more than black alder and birch veneers since final results of thicknesses for proposed plywood thickness has lowest values for aspen plywoods. Also, this phenomenon more obvious with 2.6mm aspen veneers since they reached to lowest thicknesses.

This resulted less thickness contributed to less strength evaluations in bending properties in aspen 2.6mm plywoods since the thickness has squared effect on denominator in bending formula (**Error! Reference source not found.**). This can be due to the not changing pressure parameters. If the pressure parameters for all these three species is investigated and the optimum pressure is determined, thickness could be kept almost constant for all three species and results would be better comparable. In addition, for 18 mm plywoods some specimens of aspen 2.6 mm veneer plywoods has less than 15mm thickness but they were tested as mentioned in standard at span length of 20 times of thickness 18 mm. This also caused changes in bending strength calculations.

Glue consumption results varied depending on specie and veneer thickness as expected. Glue consumptions were higher for aspen veneers than black alder and birch veneers. This is due to different surface roughness of these species, when the veneer has rougher surface glue consumption is higher. From Table 14 , aspen veneers with 2.6 mm has 28 % more glue consumption than birch plywoods and birch and alder plywoods has very similar glue consumptions. This over consumption of glue in aspen plywoods also contributed to higher density results in plywood. Aspen plywood and combi aspen plywood showed higher density results comparing to black alder plywood and combi alder plywood. This can be explained with high glue consumption and lowest thickness of aspen plywoods. (exact value couldn’t be found in specifications for glue mix but in prefere training for plywood gluing manual the resin specific gravity is given as 1.2 kg/l = 1200 kg/m³ higher than all densities of species used in this research) However, combi aspen plywoods with 2.6 mm veneers got higher densities than black alder and combi alder plywoods even they have less total glue consumption than those plywoods for the same thickness. The difference is higher between combi aspen and black alder plywoods. This can be explained with three reasons, first in combi aspen birch veneers have higher density than black alder veneers, second 2.6 mm aspen veneers are compressed more than black alder veneers and final thickness is lower and third there is a probability that black alder logs in this experiment had lower densities than mentioned in section 2.1.

Glue roller was used for gluing of veneers. This caused variations in total glue consumption per veneer layer. Glue rollers are sensitive to surface roughness, thickness and curvature of veneers. As it can be seen from results aspen veneers has more glue consumption than other two species. Also, for 2.6 mm aspen average glue consumption was higher than 1.5 mm aspen veneers. This can be explained by roughness of thicker veneers and curvature of them after drying. Because of these reasons, aspen plywood results are difficult to compare with birch and black alder since these two almost used same amount of glue. Between three species as solid wood considering density, aspen is the lightest one but in plywood results aspen plywood was second heavy plywood after birch plywood. This result definitely affected by over consumption of glue by aspen veneers. If curtain or extrusion type of gluing system was used and total amount of glue per veneer kept constant the results could be evaluated better without considering total glue consumption effect. Also considering densities black alder, combi alder and aspen and combi aspen plywoods with 2.6mm veneers are 15 to 22% lighter than birch plywoods. Density values obtained from websites of some plywood producers for birch plywood are shown in following Table 30

Table 30 Average density values from companies for their birch plywood production ([11], [9], [18], [6], [14], [29]).

Company	Av. Density kg/m³
Estonian Plywood AS	640-750
AS Latvijas Finieris	670-750
Metsä Wood	680
Handbook of Finnish plywood	680
Sveza Company	640-700
UPM-Kymmene Oyj	680

In this research results average value for density of birch plywoods considering all thicknesses is 705 kg/m³ on average. Which is in the range of companies' values ([11], [9], [18], [6], [14], [29]). Also, when test results investigated for same species and same thickness of plywood it was seen that glue consumption didn't affected bending properties so much. For some plywoods which have more glue consumption showed less strength results while some showed higher. There was no evidence of relation between more or less glue consumption and strength properties of plywood. In reality, there should be some lower limit and over limit for this to which extend it doesn't affect strength should be investigated. In addition, for every species minimum and maximum glue consumption limit should be determined.

In this thesis, parameters like soaking temperature, peeling parameters and drying time regime for different species were not investigated. All of these three species were soaked at 40°C. However, could it change the peeling and roughness properties if the soaking temperature was adjusted according to the species properties and finally could it effect veneer quality and bending strength properties of plywoods which are done from these veneers. In addition, could peeling parameters be changed to get better results for lathe checks and less cracks by changing these could it be changed final quality of veneers? Drying time for veneers was not possible to control for all veneers. In storage room, it was assumed that they will reach to equilibrium moisture content around 4-5% but if some veneers over dried did it affect the structural integrity of veneer. Can some veneers have less strength than the others? All these points should also be investigated and parameters for these should be set to get better understanding of bending properties.

For bending tests, 3 point bending tests was conducted in the thesis. For structural purposes 4-point bending tests and standard EN789- Timber structures - Test methods - Determination of mechanical properties of wood-based panels are used to determine bending properties. In most of resources like handbook of Finnish plywood and latvias finieries plywood handbook, 4 point bending results are given. This is due to the shear force effects in 3 point bending tests and it is not eliminated to get pure bending strength. For to get better results and comparison the 4 point bending tests should be conducted for these thickness and plywood types.

Another point in the results is do combinations really change results? For pure aspen 1.5 mm and combi aspen results do not change so much while for pure black alder and combi black alder plywoods results show that combi black alder always gives better results than pure black alder. This can be result of better interaction between black alder and aspen while there is no so significant change in results with aspen and birch. In crosswise direction highest difference from birch plywood obtained from 2.6 mm aspen plywoods, which is normal with smaller thicknesses in crosswise direction there is less amount of veneers. The point that should be noted in the results for both bending strength and modulus of elasticity is combination alder showed better results than combination aspen in grain direction and vice versa in crosswise direction. This can be explained with good interaction of both black alder and birch veneers they almost have same surface roughness veneers and aspen and birch interaction was not so effective as black alder and birch in grain direction. For the perpendicular direction, the results were opposite because in this direction there was no birch veneers and species bending strength tests gave results as in the pure aspen and pure black alder plywoods where aspen had higher strength in perpendicular direction. The results show that using face veneers as birch and middle layers as black alder creates a 20% strength gain in grain direction comparing to pure black alder plywood while there is almost no change in crosswise direction. Which is an expected result since there is no birch veneers in crosswise direction.

The results also show that, for 2.6 mm aspen veneer plywood and 1.5 mm aspen plywood bending strength in grain direction almost equal to each other but in cross wise direction there is big difference in strength values. This can be neglected in plywood uses where the crosswise strength is not so much important since 2.6 mm veneer plywood uses much less glue comparing to 1.5 mm veneer plywood also in cost calculations there will be more effect and weight will be less than 1.5 mm veneer plywood. Also, there is no significant difference on bending strength point of view between aspen and combi aspen plywoods. Only difference can be combi aspen plywoods will have smooth face veneers and be visually attractive and more durable.

From **Error! Reference source not found.** and **Error! Reference source not found.** in appendices , it can be concluded that the results obtained during this research are almost equal to riga ply factory values given in handbook in crosswise direction and higher in the grain direction. And standard deviation and coefficient of variation is smaller in this research which shows the specimens showed similar properties with each other more than riga ply factory results as shown in Figure 31 below. Also from **Error! Reference source not found.** and **Error! Reference source not found.** in appendices, it can be concluded also for modulus of elasticity similar results were obtained, from this research and riga ply factory results as shown in

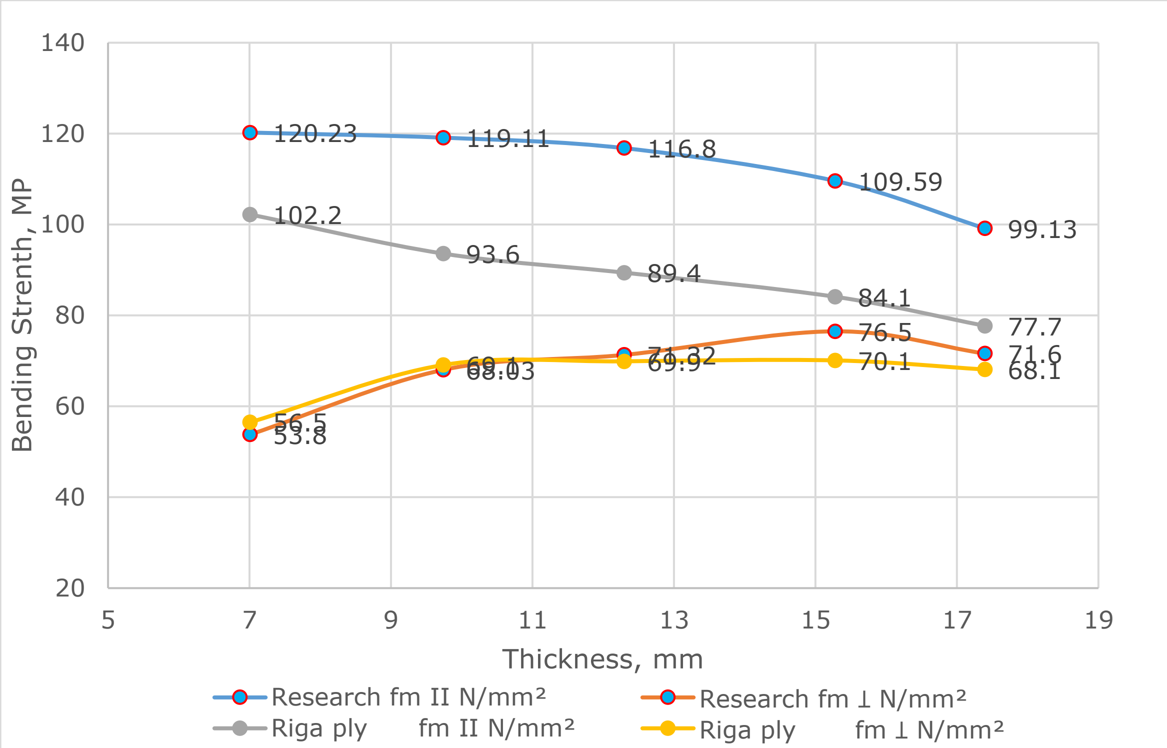

Figure 31 Comparison of Riga ply results with thesis results for bending strength in both directions

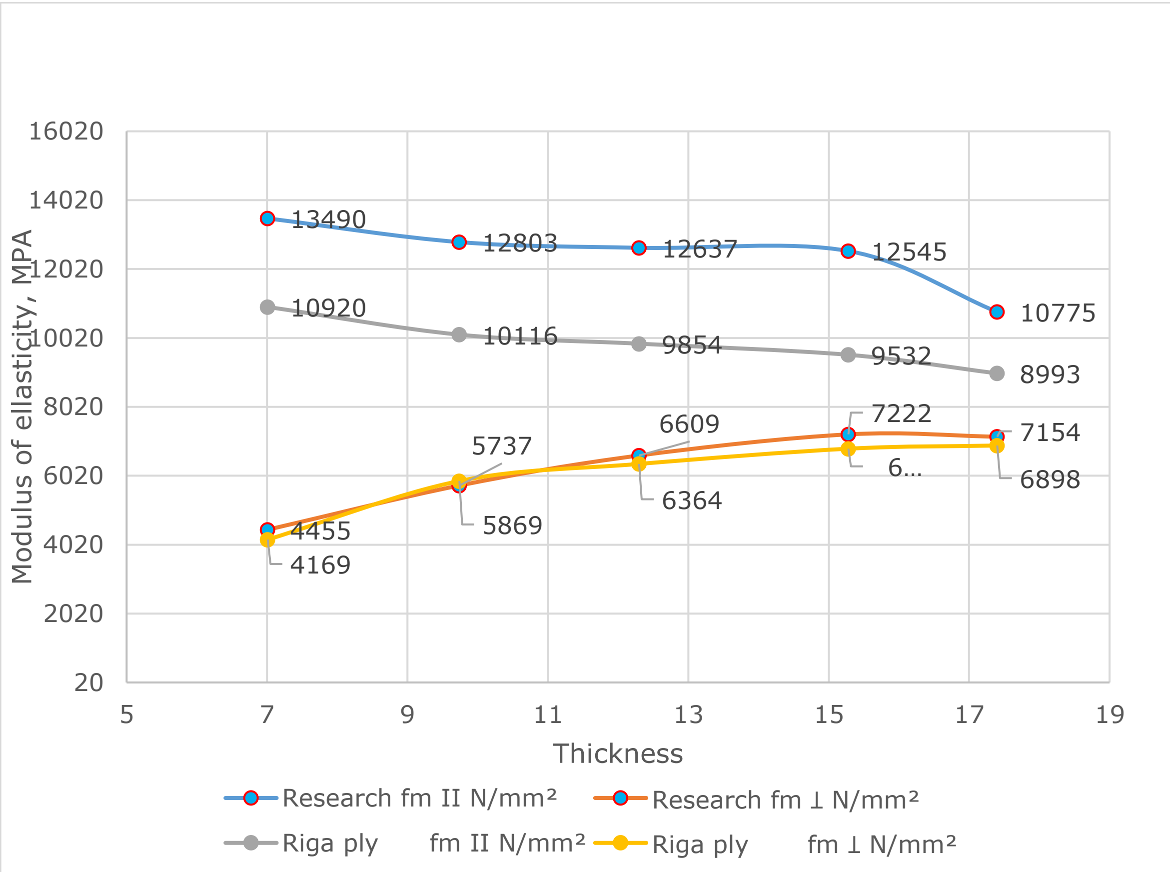

Figure 32 Modulus of elasticity results comparison of this thesis and riga ply

When the thickness is increased bending strength in grain and crosswise direction gets close to each other with an asymptomatic behaviour. The strength in grain direction decreases while thickness is increasing and vice versa in cross wise direction. Which is an expected result since number of layers in crosswise direction over number of layers in grain direction ratio increases with plywood thickness increase. This condition is favourable in two-dimensional loading conditions, however in loading conditions of one-dimensional loading, like plywoods used for trucks where generally loading in one direction, crosswise layer setup is questionable. In these plywoods instead of every layer crosswise to each other, less layers could be used in crosswise direction and bending strength can be increased in loading direction with more layers in grain direction. This principle is the main principle of LVL production all layers in one direction.

In case of 2.6mm pure aspen plywood, the lowest value is obtained with 6.5 mm thick aspen plywood and it is 62% lower than birch plywood bending strength in this direction, which is an expected result because this plywood has just one layer in perpendicular direction in total 3 layer. So, this layer is in the middle and on the neutral axis and being just one layer creates weakness in bending strength capacity. Here another important point which deserves attention is the bending strengths of combi black alder and black alder plywoods since they have same amount and same location of black alder veneers in perpendicular direction. These results show that combi black alder plywoods showed less strength than pure black alders. The logical explanation for this reason is during plywood layups the last plywoods prepared were combi plywoods (combi aspen and combi alder) and this caused no chance of sorting better veneers and generally veneers from heartwood side with big knots or knot holes were used in production of these plywoods. In addition, the face veneers must be best quality both for visual aspects also for bending properties since they endure most of the loads by being at top and bottom and having the biggest moment arm to stand against bending forces. Not having chance of sorting better face veneers because of lack of quality veneers definitely had effect on final results. Final bending property results could have changed, if there was chance to have more veneers to sort, better patching system and stitching. These can be other reasons for some fluctuations between bending test results. To understand better the effects of these changes, tests for 2.6 mm birch and 2.6mm black alder samples must be conducted also.

Also, during thesis tests it is observed black alder is very brittle and aspen is the most ductile between the three species plywoods. In most of engineering structures or load bearing materials, it is expected materials should be ductile and in conditions like earthquake or extreme loading it is expected to hear some failure noises from materials or structural parts. In bending strength tests, all black alder specimens failed suddenly without any before sound and they didn’t carry any load after ultimate force. Birch samples in that point was better than black alder. However, aspen samples had failure noises before ultimate failure and they continued to carry load after ultimate loading. Which brings us to the engineering concept of toughness, even a material is less strong than other, it can be tougher than other material. Aspen specimens showed better toughness in tests. It shows damping energy capability is better for aspen. Some photos are below for black alder and aspen specimens after tested. During tests, there was 6 specimens in 1440 which are totally broken and all of them was black alder samples. Aspen specimens bended and deflected much but never broken.

Figure 33 black alder samples

Figure 34 Aspen samples

During sampling, also specimens for bonding tests and screw withdrawal tests were prepared however due to the time limitation they were not tested. They should also be tested and bonding strength and screw withdrawal capacity should be investigated to have a better understanding these species can be used instead of birch plywoods according to the last usage places of them.

6. CONCLUSIONS

In this research, the aim was to introduce different wood species veneers, different veneer thicknesses and some combinations of these species in plywood production and to compare effects of these changes with standard plywood on bending strength and density properties. Three hardwood species, aspen, birch and black alder, two veneer thickness as 1.5 mm and 2.6 mm and five different plywood thickness as 6.5 mm, 9 mm, 12 mm, 15 mm, 18 mm was investigated in the research. Total 7 type of plywood were prepared: pure aspen with 1.5 mm veneers, pure aspen with 2.6 mm veneers pure black alder with 1.5 mm veneer, pure birch with 1.5 mm veneer, combi aspen with 1.5 mm veneers, combi aspen with 2.6 mm aspen veneers and black alder with 1.5 mm veneer.

From the research, according to the results following conclusions can be extracted:

- In thickness point of view, in plywood production less pressure in hot press can be applied for aspen plywoods, for birch and black alder plywoods 1.4MPa~1.6MPa hot pressure gives results in allowable thickness limits according to EN315 [31]. By changing pressure parameters lower density and thicknesses in limits for aspen plywoods can be reached.
- In glue consumption per layer, highest consumption is observed at plywoods in which 2.6 mm aspen veneers used (22~29 % more than birch) and second is aspen plywoods with 1.5 mm including combinations (16~22% more than birch) and black alder and birch glue consumption did not vary so significantly (3% more for black alder). However, it should be noted that for plywoods with 2.6 aspen veneers total glue consumption 33~40% lower than pure birch plywood in all thicknesses. In cost calculations for production, it should be noted that aspen plywoods needs more glue for same plywood thickness but aspen logs are cheaper than birch logs. In addition, when 2.6 mm aspen were utilized in plywood both total glue consumption and log prices are lower than birch logs and birch glue consumption. Aspen plywood glue consumption can be adjusted by changing glue spread method. Within the range of our experiments, there was no relation (correlation =0.36) between glue and strength, indicating that strength was determined by veneer properties not with glue consumption. Therefore, it should be possible with lower spread rates to achieve same strength with lower density and lower costs as long as enough wetting and penetration of glue provided. In addition, this can lead to lower densities and lighter plywoods.
- In density properties, the highest density in average considering all thicknesses was reached with birch plywoods, second with aspen plywoods with 1.5 mm

veneers and third with black alder plywoods. As solid wood densities, aspen has the lowest density but, in the research, it was the second highest after birch this can be result of more compression and having less thickness with more glue consumption. These results can be re-evaluated with further researches by using different type of glue spreading and trying to apply equal amount of glue to every veneer. Also, in density aspen plywoods and aspen combi plywood with 2.6 mm veneers showed the lowest density values. Using thicker veneers in production can reduce glue consumption amount and result in lower density and lighter and cheap products for the plywoods there is no need for high strength in crosswise direction.

- In bending strength for average of all thicknesses, birch plywoods has the highest bending strength, pure black alder has the lowest strength 30% lower than birch plywoods on the average and all other 5 different plywood types had 17~22% less values in comparing with birch plywoods in grain direction. In crosswise direction, birch plywoods has the highest bending strength values and aspen plywoods with 2.6 mm thick veneers has the lowest strength values. However, in combination plywood of which face veneers are birch and middle veneers are aspen 2.6 mm veneers has the highest crosswise strength after pure birch plywood. These results show that birch plywoods are strongest between these plywood types but considering end use and direction of loading as it is one dimensional or two-dimensional loading aspen plywoods or combi aspen plywoods can be utilized instead of birch plywoods if there is no need for so high strength in bending. In addition, it should be noted that in results and analysis part, for all plywoods grain direction bending strength in grain and crosswise directions gets closer to each other when the plywood gets thicker. We can conclude that in the situations when there are just one-dimensional loading crosswise layer numbers can be decreased and plywood can be utilized to be strong in one direction for two-dimensional loading better to use thicker plywoods. For parquet production since the thickness is 6.5 mm, from the results it can be concluded that 2.6 mm pure aspen plywood should not be used for parquet since it has just 3 layers and just one layer of them in crosswise direction it has very low crosswise bending strength. Also, from Table 24 and Table 25, it can be concluded that while pure aspen and combi aspen plywoods do not show significant difference comparing to birch plywoods in bending strength. Using face veneers as birch veneers did not change the bending strength while in black alder and combi black alder bending strength comparison, combi black alder samples showed significant difference (20% higher bending strength) comparing to pure black alder samples, however for both species in crosswise direction there was no change and this was an expected result since there was no birch veneer in lay-up in perpendicular direction.

- For aspen plywoods one drawback is surface quality and roughness, for the end uses like furniture or where surface need to be smooth combi aspen plywoods can be utilized better than poor aspen plywoods.
- Modulus of elasticities of all plywoods gave results like bending strength results so the conclusions for bending strength is valid also for modulus of elasticity values.
- In toughness point of view where the end use necessitates ductile materials, as explained in discussions section, either aspen or birch plywoods should be preferred since black alder shows very brittle behaviour.
- When workability or productivity considered, it was observed during tests that aspen produces much more dust than birch or black alder but it has bigger logs than other two species. Also, sometimes aspen logs cannot be peeled due to weak structure of it, when spindles try to turn logs it doesn't turn for peeling.

As summary of all conclusions, it is appropriate to say that when considering these alternative hardwood species and different veneer thickness in plywood production, it is good to keep in mind all of the aspects above, end use, costs and proximity of log yard for transportation etc. Aspen plywoods, use more glue but they are lighter and aspen logs are cheaper but their strength is lower. Plywoods which has 2.6 mm veneers has less glue consumption in total but less strong in cross wise direction. So, depending on end use these hardwoods can be utilized in plywood production instead of birch plywoods

SUMMARY

In this research, the aim was to introduce different wood species veneers, different veneer thicknesses and some combinations of these species in plywood production and to compare effects of these changes with standard plywood on bending strength and density properties. Factors influencing plywood properties were investigated including species like common aspen (*Populus tremula*), black alder (*Alnus glutinosa*) and silver birch (*Betula pendula* Roth) using different veneer thicknesses. Common veneer thickness used for most of wood species was 1.5mm and for aspen two veneer thicknesses 1.5mm and 2.6mm were used. In total five different plywood thickness as 6.5 mm, 9 mm, 12 mm, 15 mm, 18 mm were prepared for tests in this research. In total 7 type of plywood´s were prepared: from aspen with 1.5 mm veneers and with 2.6 mm veneers, from black alder with 1.5 mm veneers, from birch with 1.5 mm veneer. Plywood was produced from single wood species (birch, black alder, aspen) from 1.5mm thick veneers, 2.6mm thick aspen veneers and also in combinations of these species. In plywood lay-up combinations different wood species and different thicknesses were used: combi aspen with 1.5 mm veneers, combi aspen with 2.6 mm aspen veneers and black alder with 1.5 mm veneers.

The influence of the technological processing parameters to the veneer surface roughness and glue consumption in two-sided roller coating of veneers was analysed. In aspen plywood lay-up the glue consumption was measured and its influence to the plywood strength was analysed. Density, bending properties and glue consumption of plywoods of different thicknesses list then were recorded. It was found out that plywood density could be reduced by both species substitution and by using thicker veneers. The penalty in strength and stiffness associated with species effects was quantified. Plywood bending stiffness and strength followed similar trends throughout the data sets Differences in veneer surface characteristics and glue spreadability was discussed.

The effect of wood species to the workability in technological process and plywood brittleness and toughness in bending was analysed and sufficient conclusions were drawn that different hardwood species can be used in plywood production and optimal bending strength and stiffness properties can be achieved.

KOKKUVÕTE

Selles uuringu eesmärgiks oli tutvustada uusi võimalusi vineeri tootmiseks, kasutades erinevate puiduliikide spooni, erinevaid vineeripaksusi ja mõningaid nende liikide kombinatsioone ning võrrelda nende muudatuste mõju standardse kasevineeri paindetugevuse ja tihedusega. Uuritikuidas mõjutab erinevate puiduliikide harilik haab (*Populus tremula*), must lepp (*Alnus glutinosa*) ja kask (*Betula pendula* Roth) kasutamine vineeri omadusi mõjutavaid tegureid, sealhulgas võrreldes 2,6 mm versus 1,5 mm paksusest haavaspoonist valmistatud vineeride omadusi. Samuti uuriti nende liikide kombinatsioone. Määrati viie erineva paksusega vineeride tihedus, painduvusomadused ja liimikulu. Leiti, et vineeri tihedust saab vähendada nii kase asendamisega kergemate puiduliikidega ja vähendades liimikulu paksema spooni kasutamise abil. Kvantifitseeriti puiduliikide mõjud vineeride paindetugevusele ja paindejäikusele. Andmekogumi analüüsi tulemusena selgus, et vineeri paindejäikus ja -tugevus järgisid sarnaseid trende. Uurimistöös arutletaks ka hapra ja sitke purunemise, töödeldavuse, pinnaomaduste ja liimi levitatavuse erinevuste üle. Uurimistöö tulemusena selgus, et vineeri tootmisel saab kasutada erinevaid lehtpuuliike ning on võimalik saavutada optimaalsed paindetugevuse ja jäikuse omadused.

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APPENDICES

In appendices, some of the information for density tests and none of the bending test results weren’t added due to the huge amount of data all are filed as excel files.

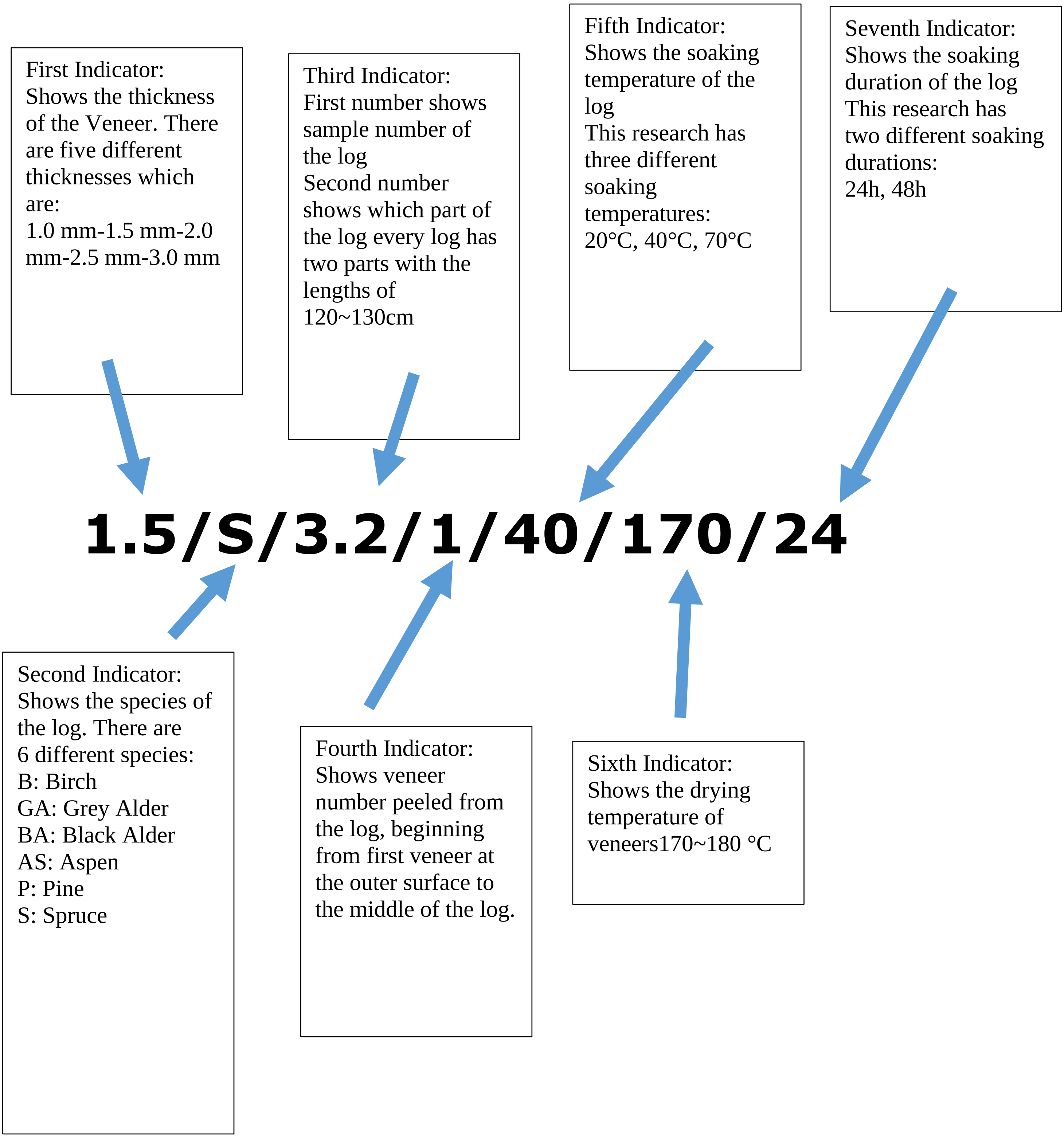

Figure 35 Coding system of veneers

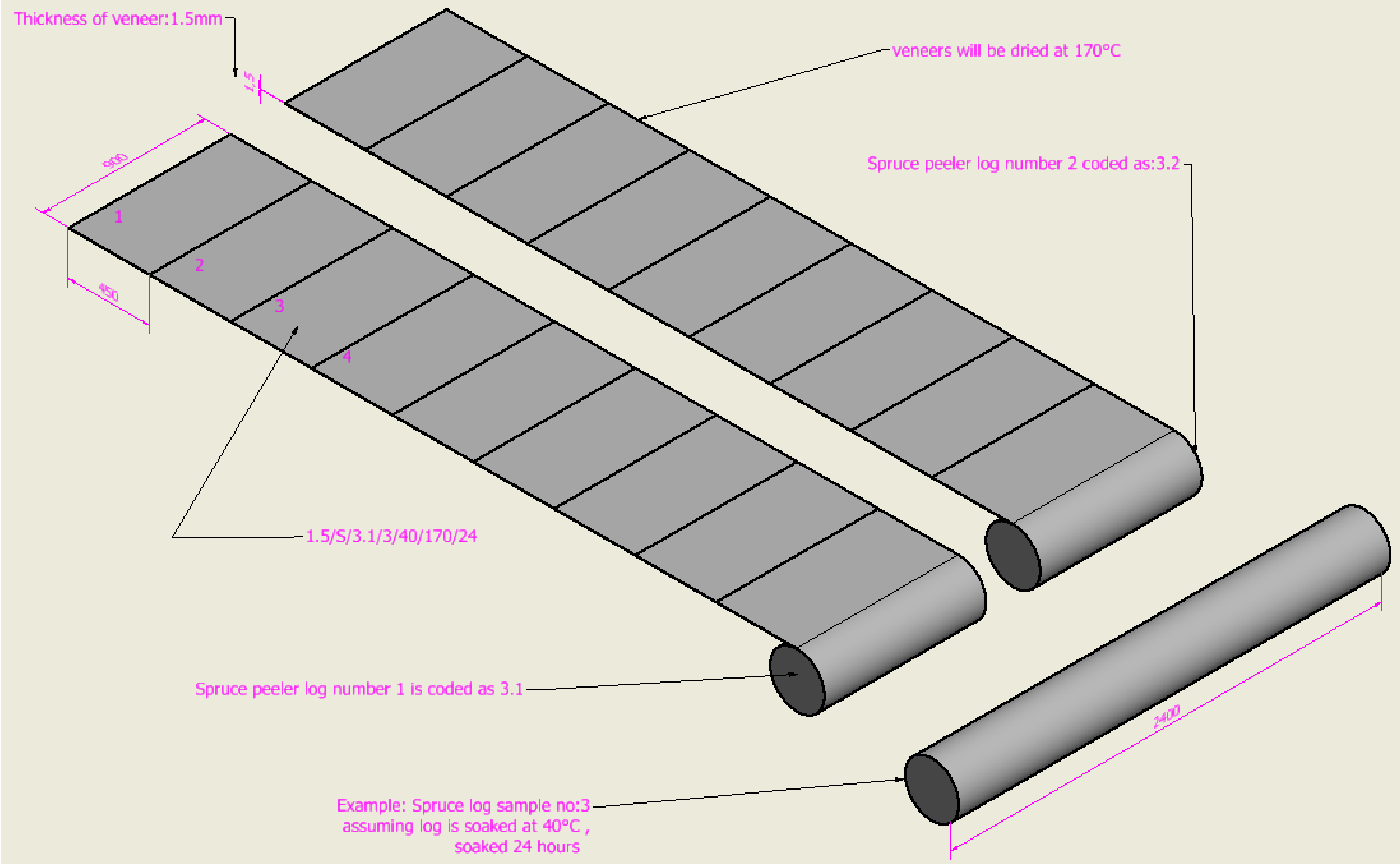

Figure 36 Schematic view of veneer production and numbering

Table 31 Log and veneer parameters for 2020 spring For Aspen, Birch, Black Alder

Log parameters	1	2	3	4	5	6	7	8	9
Sample code/number	1.5.AS.40.24.1	1.5.AS.40.24.2	1.5.AS.40.24.3	1.5.AS.40.24.4	1.5.AS.40.24.5	1.5.AS.40.24.6	1.5.AS.40.24.7	1.5.AS.40.24.8	1.5.AS.40.24.9
Length of Log		310.00 cm	310.00 cm	310.00 cm	310.00 cm	310.00 cm	310.00 cm	310.00 cm	
Length of peeler Log	136.00 cm	130.00 cm	136.00 cm	136.00 cm	137.00 cm	138.00 cm	135.00 cm	133.50 cm	128.00 cm
Diameter of log	30.50 cm	45.00 cm	24.75 cm	23.25 cm	25.25 cm	24.00 cm	38.00 cm	31.50 cm	45.00 cm
Annual Ring width (heartwood)	2.1 mm	5.0 mm	1.2 mm	3.1 mm	3.0 mm	2.6 mm	3.1 mm	3.1 mm	3.48 cm
Annual Ring width (sapwood)	3.3 mm	2.8 mm	4.8 mm	3.5 mm	4.7 mm	2.8 mm	3.1 mm	1.6 mm	5.8 mm
Date of Soaking	7.12.20	9.12.20	10.12.20	10.12.20	14.12.20	14.12.20	15.12.20	15.12.20	24.3.21
Date of Peeling	8.12.20	10.12.20	11.12.20	11.12.20	15.12.20	15.12.20	16.12.20	16.12.20	25.3.21
Peeler Log Moisture Content	69.7%	75.5%	70.7%	78.4%	72.5%	69.2%	69.4%	68.3%	75.9%
Peeler Log Temperature	29.1 °C	30.5 °C	33.0 °C	33.1 °C	31.0 °C	32.0 °C	32.2 °C	29.2 °C	33.0 °C
Soaking Temperature	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C
Soaking Duration	24 h	24 h	24 h	24 h	24 h	24 h	21 h	21 h	24 h
Veneer parameters									
Sample code/number	1.5.AS.40.24.1	1.5.AS.40.24.2	1.5.AS.40.24.3	1.5.AS.40.24.4	1.5.AS.40.24.5	1.5.AS.40.24.6	1.5.AS.40.24.7	1.5.AS.40.24.8	1.5.AS.40.24.9
Veneer Thickness	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm
Drying temperature, °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C
Drying time (s)	150 s	210 s	180 s	150 s	180 s	150 s	180 s	150 s	180 s
Total number of veneers	29	20	42	37	44	28	65	53	120
Dried veneers	29	20	42	37	44	28	65	53	89
Veneer Dimensions' cm	45x90	45x90	45x90	45x90	45x90	45x90	45x90	45x90	45x90

Log parameters	1	2	3	4	5	6	7
Sample code/number	1.5.BA.40.24.1	1.5.BA.40.24.2	1.5.BA.40.24.3	1.5.BA.40.24.4	1.5.BA.40.24.5	1.5.BA.40.24.6	1.5.BA.40.24.7
Length of Log							
Length of peeler Log	140.00 cm	138.00 cm	137.00 cm	139.00 cm	137.00 cm	137.00 cm	132.50 cm
Diameter of log	23.00 cm	21.50 cm	20.50 cm	23.50 cm	26.00 cm	28.00 cm	29.00 cm
Annual Ring width (heartwood)	2.7 mm	3.5 mm	3.9 mm	4.4 mm	5.2 mm	2.3 mm	2.9 mm
Annual Ring width (sapwood)	2.3 mm	2.1 mm	2.1 mm	1.9 mm	3.3 mm	1.8 mm	4.3 mm
Date of Soaking	21.12.20	21.12.20	22.12.20	22.12.20	5.1.21	5.1.21	6.1.21
Date of Peeling	22.12.20	22.12.20	23.12.20	23.12.20	6.1.21	6.1.21	7.1.21
Peeler Log Moisture Content	74.5%	74.8%	75.0%	77.2%	67.8%	68.9%	71.5%
Peeler Log Temperature	32.0 °C	32.0 °C	32.8 °C	31.5 °C	30.0 °C	28.5 °C	26.3 °C
Soaking Temperature	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C
Soaking Duration	24 h	24 h	22 h	22 h	22 h	22 h	22 h
Veneer parameters							
Sample code/number	1.5.BA.40.24.1	1.5.BA.40.24.2	1.5.BA.40.24.3	1.5.BA.40.24.4	1.5.BA.40.24.5	1.5.BA.40.24.6	1.5.BA.40.24.7
Veneer Thickness	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm
Drying temperature, °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C
Drying time (s)	180 s	160 s	190 s	170 s	180 s	160 s	180 s
Total number of veneers	34	23	22	31	20	17	38
Dried veneers	34	23	22	31	20	17	38
Veneer Dimensions' cm	45x90	45x90	45x90	45x90	45x90	45x90	45x90

Log parameters	8	9	10	11	12	13	14
Sample code/number	1.5.BA.40.24.8	1.5.BA.40.24.9	1.5.BA.40.24.10	1.5.BA.40.24.11	1.5.BA.40.24.12	1.5.BA.40.24.13	1.5.BA.40.24.14
Length of Log							
Length of peeler Log	140.00 cm	137.00 cm	138.00 cm	139.00 cm	143.00 cm	130.50 cm	138.00 cm
Diameter of log	24.25 cm	33.00 cm	25.75 cm	23.50 cm	33.00 cm	28.50 cm	22.50 cm
Annual Ring width (heartwood)	3.5 mm	1.3 mm	1.4 mm	3.4 mm	3.6 mm	3.3 mm	2.3 mm
Annual Ring width (sapwood)	3.2 mm	1.9 mm	1.5 mm	3.0 mm	2.8 mm	1.5 mm	2.2 mm
Date of Soaking	6.1.21	7.1.21	7.1.21	11.1.21	11.1.21	13.1.21	18.1.21
Date of Peeling	7.1.21	8.1.21	8.1.21	12.1.21	12.1.21	15.1.21	19.1.21
Peeler Log Moisture Content	75.8%	74.0%	84.1%	68.9%	77.0%	70.1%	68.5%
Peeler Log Temperature	26.4 °C	32.5 °C	32.7 °C	32.4 °C	32.0 °C	32.5 °C	33.2 °C
Soaking Temperature	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C
Soaking Duration	22 h	22 h	22 h	22 h	22 h	48 h	23 h
Veneer parameters							
Sample code/number	1.5.BA.40.24.8	1.5.BA.40.24.9	1.5.BA.40.24.10	1.5.BA.40.24.11	1.5.BA.40.24.12	1.5.BA.40.24.13	1.5.BA.40.24.14
Veneer Thickness	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm
Drying temperature, °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C
Drying time (s)	160 s	180 s	160 s	180 s	170 s	185 s	170 s
Total number of veneers	31	43	18	27	53	54	24
Dried veneers	31	43	18	27	53	54	24
Veneer Dimensions' cm	45x90	45x90	45x90	45x90	45x90	45x90	45x90

Log parameters	1	2	3	4	5	6	7	8	9	10
Sample code/number	1.5.B.40.24.1	1.5.B.40.24.2	1.5.B.40.24.3	1.5.B.40.24.4	1.5.B.40.24.5	1.5.B.40.24.6	1.5.B.40.24.7	1.5.B.40.24.8	1.5.B.40.24.9	1.5.B.40.24.10
Length of Log										
Length of peeler Log	140.00 cm	132.00 cm	138.00 cm	141.00 cm	141.00 cm	139.00 cm	133.00 cm	137.00 cm	134.00 cm	131.00 cm
Diameter of log	26.50 cm	21.75 cm	22.25 cm	21.25 cm	30.50 cm	19.50 cm	25.00 cm	20.50 cm	32.00 cm	19.00 cm
Annual Ring width (heartwood)	3.7 mm	2.1 mm	3.2 mm	2.5 mm	3.0 mm	2.6 mm	3.4 mm	3.3 mm	2.4 mm	1.0 mm
Annual Ring width (sapwood)	1.8 mm	1.4 mm	2.5 mm	2.1 mm	2.0 mm	1.6 mm	1.9 mm	2.2 mm	3.1 mm	1.0 mm
Date of Soaking	19.1.21	19.1.21	20.1.21	20.1.21	21.1.21	21.1.21	22.1.21	22.1.21	23.3.21	25.3.21
Date of Peeling	20.1.21	20.1.21	21.1.21	21.1.21	22.1.21	22.1.21	25.1.21	25.1.21	24.3.21	26.3.21
Peeler Log Moisture Content	62.4%	53.0%	57.4%	67.1%	63.1%	54.5%	72.1%	71.1%	74.8%	73.0%
Peeler Log Temperature	31.5 °C	32.3 °C	33.4 °C	31.5 °C	32.4 °C	31.0 °C	31.0 °C	32.7 °C	30.0 °C	34.0 °C
Soaking Temperature	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C	40.0 °C
Soaking Duration	22 h	22 h	24 h	24 h	24 h	23 h	70 h	70 h	24 h	24 h
Veneer parameters										
Sample code/number	1.5.B.40.24.1	1.5.B.40.24.2	1.5.B.40.24.3	1.5.B.40.24.4	1.5.B.40.24.5	1.5.B.40.24.6	1.5.B.40.24.7	1.5.B.40.24.8	1.5.B.40.24.9	1.5.B.40.24.10
Veneer Thickness	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm
Drying temperature, °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C	170.0 °C
Drying time (s)	170 s	160 s	170 s	160 s	160 s	170 s	170 s	160 s	180 s	180 s
Total number of veneers	45	20	31	19	66	14	31	23	76	22
Dried veneers	45	20	31	19	66	14	31	23	76	22
Veneer Dimensions' cm	45x90	45x90	45x90	45x90	45x90	45x90	45x90	45x90	45x90	45x90

Log parameters	1	2	3
Sample code/number	2.6.AS.40.24.1	2.6.AS.40.24.2	2.6.AS.40.24.3
Length of Log			
Length of peeler Log	139.00 cm	138.00 cm	130.00 cm
Diameter of log	41.00 cm	30.00 cm	37.75 cm
Annual Ring width (heartwood)	3.2 mm	2.6 mm	6.5 mm
Annual Ring width (sapwood)	2.0 mm	1.8 mm	4.4 mm
Date of Soaking	11.2.21	15.2.21	23.2.21
Date of Peeling	12.2.21	16.2.21	25.2.21
Peeler Log Moisture Content	81.2%	79.0%	71.5%
Peeler Log Temperature	33.0 °C	31.8 °C	30.5 °C
Soaking Temperature	40.0 °C	40.0 °C	40.0 °C
Soaking Duration	24 h	22 h	46 h
Veneer parameters			
Sample code/number	2.6.AS.40.24.1	2.6.AS.40.24.2	2.6.AS.40.24.3
Veneer Thickness	2.6 mm	2.6 mm	2.6 mm
Drying temperature, °C	170.0 °C	170.0 °C	170.0 °C
Drying time (s)	360 s	360 s	360 s
Total number of veneers	64	31	51
Dried veneers	58	31	51
Veneer Dimensions' cm	45x90	45x90	45x90

Table 32 Produced plywood data and glue consumption

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
49-1	10.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	109.3 g	154.9 g/m²	156.0 g/m²	7.3 g/m²
49-2	10.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	109.5 g	155.2 g/m²		
50-1	11.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	112.1 g	158.9 g/m²		
50-2	11.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	121.2 g	171.7 g/m²		
51-1	11.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	118.7 g	168.3 g/m²		
51-2	11.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	120.1 g	170.1 g/m²		
52-1	11.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	125.4 g	177.8 g/m²		
52-2	12.03.2021	Alder	6.5 mm	5		1.5 mm	160.0 g/m²	110.7 g	156.9 g/m²		
61-1	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	166.6 g	157.4 g/m²		
61-2	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	172.6 g	163.0 g/m²		
62-1	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	161.0 g	152.1 g/m²		
62-2	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	168.8 g	159.5 g/m²		
63-1	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	168.5 g	159.2 g/m²		
63-2	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	171.4 g	161.9 g/m²		
64-1	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	166.1 g	156.9 g/m²		
64-2	15.03.2021	Alder	9.0 mm	7		1.5 mm	160.0 g/m²	167.5 g	158.2 g/m²		
45-1	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	241.8 g	171.4 g/m²		
45-2	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	229.1 g	162.3 g/m²		
46-1	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	219.6 g	155.6 g/m²		
46-2	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	216.3 g	153.3 g/m²		
47-1	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	218.1 g	154.5 g/m²		
47-2	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	214.2 g	151.8 g/m²		
48-1	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	219.8 g	155.8 g/m²		
48-2	10.03.2021	Alder	12.0 mm	9		1.5 mm	160.0 g/m²	219.5 g	155.5 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
57-1	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	267.6 g	148.2 g/m²		
57-2	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	272.2 g	150.7 g/m²		
58-1	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	285.3 g	158.0 g/m²		
58-2	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	285.2 g	157.9 g/m²		
59-1	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	279.5 g	154.8 g/m²		
59-2	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	281.2 g	155.7 g/m²		
60-1	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	279.7 g	154.9 g/m²		
60-2	12.03.2021	Alder	15.0 mm	11		1.5 mm	160.0 g/m²	277.8 g	153.8 g/m²		
101-1	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	314.8 g	145.2 g/m²		
101-2	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	313.9 g	144.9 g/m²		
102-1	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	301.6 g	139.1 g/m²		
102-2	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	317.8 g	146.6 g/m²		
103-1	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	318.5 g	147.0 g/m²		
103-2	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	317.2 g	146.4 g/m²		
104-1	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	328.9 g	151.8 g/m²		
104-2	22.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	326.2 g	150.5 g/m²		
53-1	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	337.6 g	155.8 g/m²		
53-2	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	339.2 g	156.5 g/m²		
54-1	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	329.8 g	152.2 g/m²		
54-2	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	327.5 g	151.1 g/m²		
55-1	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	342.5 g	158.0 g/m²		
55-2	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	345.1 g	159.3 g/m²		
56-1	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	338.9 g	156.4 g/m²		
56-2	11.03.2021	Alder	18.0 mm	13		1.5 mm	160.0 g/m²	332.3 g	153.3 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
1-1	18.01.2021	Aspen	6.5 mm	5	6.62 mm	1.5 mm	160.0 g/m²	142.3 g	201.6 g/m²	176.6 g/m²	10.0 g/m²
1-2	18.01.2021	Aspen	6.5 mm	5	6.66 mm	1.5 mm	160.0 g/m²	139.8 g	198.1 g/m²		
2-1	18.01.2021	Aspen	6.5 mm	5	6.75 mm	1.5 mm	160.0 g/m²	126.0 g	178.6 g/m²		
2-2	18.01.2021	Aspen	6.5 mm	5	6.72 mm	1.5 mm	160.0 g/m²	127.2 g	180.3 g/m²		
3-1	18.01.2021	Aspen	6.5 mm	5	6.78 mm	1.5 mm	160.0 g/m²	131.0 g	185.7 g/m²		
3-2	18.01.2021	Aspen	6.5 mm	5	6.70 mm	1.5 mm	160.0 g/m²	130.8 g	185.4 g/m²		
4-1	18.01.2021	Aspen	6.5 mm	5	6.88 mm	1.5 mm	160.0 g/m²	114.2 g	161.8 g/m²		
4-2	18.01.2021	Aspen	6.5 mm	5	6.72 mm	1.5 mm	160.0 g/m²	122.2 g	173.1 g/m²		
5-1	26.01.2021	Aspen	9.0 mm	7	9.37 mm	1.5 mm	160.0 g/m²	177.5 g	167.7 g/m²		
5-2	26.01.2021	Aspen	9.0 mm	7	9.40 mm	1.5 mm	160.0 g/m²	178.0 g	168.2 g/m²		
6-1	26.01.2021	Aspen	9.0 mm	7	9.40 mm	1.5 mm	160.0 g/m²	199.8 g	188.8 g/m²		
6-2	26.01.2021	Aspen	9.0 mm	7	9.41 mm	1.5 mm	160.0 g/m²	191.2 g	180.6 g/m²		
7-1	26.01.2021	Aspen	9.0 mm	7	9.37 mm	1.5 mm	160.0 g/m²	187.9 g	177.5 g/m²		
7-2	26.01.2021	Aspen	9.0 mm	7	9.34 mm	1.5 mm	160.0 g/m²	191.1 g	180.5 g/m²		
8-1	26.01.2021	Aspen	9.0 mm	7	9.26 mm	1.5 mm	160.0 g/m²	177.2 g	167.4 g/m²		
8-2	26.01.2021	Aspen	9.0 mm	7	8.81 mm	1.5 mm	160.0 g/m²	178.6 g	168.7 g/m²		
10-1	28.01.2021	Aspen	12.0 mm	9	12.22 mm	1.5 mm	160.0 g/m²	234.1 g	165.9 g/m²		
10-2	28.01.2021	Aspen	12.0 mm	9	12.26 mm	1.5 mm	160.0 g/m²	224.7 g	159.2 g/m²		
11-1	28.01.2021	Aspen	12.0 mm	9	12.30 mm	1.5 mm	160.0 g/m²	253.0 g	179.3 g/m²		
11-2	28.01.2021	Aspen	12.0 mm	9	12.25 mm	1.5 mm	160.0 g/m²	250.6 g	177.6 g/m²		
12-1	28.01.2021	Aspen	12.0 mm	9	11.99 mm	1.5 mm	160.0 g/m²	255.2 g	180.8 g/m²		
12-2	28.01.2021	Aspen	12.0 mm	9	11.60 mm	1.5 mm	160.0 g/m²	251.6 g	178.3 g/m²		
9-1	28.01.2021	Aspen	12.0 mm	9	12.18 mm	1.5 mm	160.0 g/m²	244.1 g	173.0 g/m²		
9-2	28.01.2021	Aspen	12.0 mm	9	12.30 mm	1.5 mm	160.0 g/m²	236.1 g	167.3 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
13-1	29.01.2021	Aspen	15.0 mm	11	15.29 mm	1.5 mm	160.0 g/m²	348.0 g	192.7 g/m²		
13-2	29.01.2021	Aspen	15.0 mm	11	15.23 mm	1.5 mm	160.0 g/m²	328.6 g	182.0 g/m²		
14-1	29.01.2021	Aspen	15.0 mm	11	15.06 mm	1.5 mm	160.0 g/m²	296.9 g	164.4 g/m²		
14-2	29.01.2021	Aspen	15.0 mm	11	15.15 mm	1.5 mm	160.0 g/m²	303.1 g	167.8 g/m²		
15-1	29.01.2021	Aspen	15.0 mm	11	15.11 mm	1.5 mm	160.0 g/m²	279.1 g	154.5 g/m²		
15-2	29.01.2021	Aspen	15.0 mm	11	15.02 mm	1.5 mm	160.0 g/m²	284.1 g	157.3 g/m²		
16-1	29.01.2021	Aspen	15.0 mm	11	14.86 mm	1.5 mm	160.0 g/m²	317.1 g	175.6 g/m²		
16-2	29.01.2021	Aspen	15.0 mm	11	14.85 mm	1.5 mm	160.0 g/m²	327.5 g	181.4 g/m²		
17-1	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	374.5 g	172.8 g/m²		
17-2	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	367.5 g	169.6 g/m²		
18-1	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	382.8 g	176.6 g/m²		
18-2	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	372.9 g	172.1 g/m²		
19-1	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	386.2 g	178.2 g/m²		
19-2	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	385.3 g	177.8 g/m²		
20-1	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	385.5 g	177.9 g/m²		
20-2	02.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	360.0 g	166.1 g/m²		
21-1	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	383.1 g	176.8 g/m²		
21-2	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	375.6 g	173.3 g/m²		
22-1	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	393.5 g	181.6 g/m²		
22-2	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	402.0 g	185.5 g/m²		
23-1	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	399.4 g	184.3 g/m²		
23-2	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	398.5 g	183.9 g/m²		
24-1	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	408.1 g	188.3 g/m²		
24-2	03.03.2021	Aspen	18.0 mm	13		1.5 mm	160.0 g/m²	411.9 g	190.1 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
65-1	12.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	67.4 g	190.9 g/m²	195.5 g/m²	15.6 g/m²
65-2	12.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	88.5 g	250.9 g/m²		
66-1	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	69.5 g	196.9 g/m²		
66-2	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	66.5 g	188.5 g/m²		
67-1	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	75.5 g	213.9 g/m²		
67-2	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	88.3 g	250.1 g/m²		
68-1	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	69.9 g	198.2 g/m²		
68-2	15.03.2021	Aspen	6.5 mm	3		2.6 mm	160.0 g/m²	68.7 g	194.7 g/m²		
69-1	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	134.8 g	191.1 g/m²		
69-2	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	137.6 g	195.1 g/m²		
70-1	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	135.4 g	191.9 g/m²		
70-2	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	140.1 g	198.5 g/m²		
71-1	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	137.4 g	194.8 g/m²		
71-2	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	137.2 g	194.4 g/m²		
72-1	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	139.4 g	197.5 g/m²		
72-2	15.03.2021	Aspen	12.0 mm	5		2.6 mm	160.0 g/m²	134.7 g	190.8 g/m²		
113-1	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	203.1 g	191.9 g/m²		
113-2	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	196.2 g	185.4 g/m²		
114-1	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	198.7 g	187.8 g/m²		
114-2	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	201.6 g	190.4 g/m²		
115-1	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	200.0 g	189.0 g/m²		
115-2	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	200.7 g	189.6 g/m²		
116-1	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	205.2 g	193.9 g/m²		
116-2	23.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	197.5 g	186.6 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
73-1	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	193.1 g	182.4 g/m²		
73-2	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	198.9 g	187.9 g/m²		
74-1	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	209.5 g	197.9 g/m²		
74-2	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	202.2 g	191.0 g/m²		
75-1	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	197.1 g	186.2 g/m²		
75-2	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	199.1 g	188.1 g/m²		
76-1	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	191.8 g	181.2 g/m²		
76-2	16.03.2021	Aspen	18.0 mm	7		2.6 mm	160.0 g/m²	199.2 g	188.2 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
29-1	04.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	107.7 g	152.6 g/m²	152.4 g/m²	6.7 g/m²
29-2	04.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	108.6 g	153.9 g/m²		
30-1	05.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	99.5 g	141.0 g/m²		
30-2	05.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	120.9 g	171.3 g/m²		
31-1	09.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	107.5 g	152.3 g/m²		
31-2	09.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	111.6 g	158.1 g/m²		
32-1	09.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	107.1 g	151.7 g/m²		
32-2	09.03.2021	Birch	6.5 mm	5		1.5 mm	160.0 g/m²	109.2 g	154.7 g/m²		
37-1	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	170.4 g	161.0 g/m²		
37-2	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	170.2 g	160.8 g/m²		
38-1	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	172.0 g	162.5 g/m²		
38-2	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	170.3 g	160.9 g/m²		
39-1	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	151.0 g	142.6 g/m²		
39-2	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	161.3 g	152.4 g/m²		
40-1	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	170.4 g	161.0 g/m²		
40-2	05.03.2021	Birch	9.0 mm	7		1.5 mm	160.0 g/m²	173.3 g	163.7 g/m²		
33-1	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	219.4 g	155.4 g/m²		
33-2	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	224.5 g	159.1 g/m²		
34-1	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	222.3 g	157.5 g/m²		
34-2	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	220.3 g	156.1 g/m²		
35-1	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	208.5 g	147.7 g/m²		
35-2	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	214.0 g	151.7 g/m²		
36-1	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	219.3 g	155.4 g/m²		
36-2	05.03.2021	Birch	12.0 mm	9		1.5 mm	160.0 g/m²	218.4 g	154.7 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
25-1	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	276.7 g	153.2 g/m²		
25-2	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	265.5 g	147.0 g/m²		
26-1	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	274.8 g	152.1 g/m²		
26-2	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	282.6 g	156.5 g/m²		
27-1	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	280.5 g	155.3 g/m²		
27-2	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	286.4 g	158.6 g/m²		
28-1	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	273.2 g	151.3 g/m²		
28-2	04.03.2021	Birch	15.0 mm	11		1.5 mm	160.0 g/m²	278.8 g	154.4 g/m²		
141-1	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	301.2 g	139.0 g/m²		
141-2	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	310.1 g	143.1 g/m²		
142-1	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	311.0 g	143.5 g/m²		
142-2	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	308.2 g	142.2 g/m²		
143-1	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	309.9 g	143.0 g/m²		
143-2	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	312.9 g	144.4 g/m²		
144-1	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	317.1 g	146.3 g/m²		
144-2	01.04.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	319.1 g	147.3 g/m²		
41-1	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	331.3 g	152.9 g/m²		
41-2	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	324.4 g	149.7 g/m²		
42-1	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	325.8 g	150.3 g/m²		
42-2	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	324.5 g	149.7 g/m²		
43-1	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	325.5 g	150.2 g/m²		
43-2	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	328.5 g	151.6 g/m²		
44-1	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	321.5 g	148.3 g/m²		
44-2	09.03.2021	Birch	18.0 mm	13		1.5 mm	160.0 g/m²	321.8 g	148.5 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
81-1	16.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	108.5 g	153.8 g/m²	155.5 g/m²	7.7 g/m²
81-2	16.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	109.3 g	154.9 g/m²		
82-1	17.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	108.3 g	153.5 g/m²		
82-2	17.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	122.6 g	173.7 g/m²		
83-1	19.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	126.6 g	179.5 g/m²		
83-2	19.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	109.3 g	154.9 g/m²		
84-1	19.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	106.1 g	150.4 g/m²		
84-2	22.03.2021	C-Alder	6.5 mm	5		1.5 mm	160.0 g/m²	113.0 g	160.1 g/m²		
93-1	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	169.8 g	160.4 g/m²		
93-2	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	173.9 g	164.3 g/m²		
94-1	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	178.4 g	168.6 g/m²		
94-2	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	176.4 g	166.6 g/m²		
95-1	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	175.2 g	165.6 g/m²		
95-2	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	172.6 g	163.1 g/m²		
96-1	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	172.7 g	163.1 g/m²		
96-2	18.03.2021	C-Alder	9.0 mm	7		1.5 mm	160.0 g/m²	146.7 g	138.6 g/m²		
77-1	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	218.4 g	154.8 g/m²		
77-2	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	223.2 g	158.1 g/m²		
78-1	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	225.5 g	159.8 g/m²		
78-2	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	219.9 g	155.8 g/m²		
79-1	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	221.8 g	157.1 g/m²		
79-2	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	219.0 g	155.2 g/m²		
80-1	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	225.4 g	159.7 g/m²		
80-2	16.03.2021	C-Alder	12.0 mm	9		1.5 mm	160.0 g/m²	235.3 g	166.7 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layers	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
85-1	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	275.2 g	152.4 g/m²		
85-2	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	278.3 g	154.1 g/m²		
86-1	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	278.6 g	154.2 g/m²		
86-2	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	280.5 g	155.3 g/m²		
87-1	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	276.5 g	153.1 g/m²		
87-2	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	276.6 g	153.2 g/m²		
88-1	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	279.8 g	154.9 g/m²		
88-2	17.03.2021	C-Alder	15.0 mm	11		1.5 mm	160.0 g/m²	281.4 g	155.8 g/m²		
117-1	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	327.1 g	150.9 g/m²		
117-2	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	328.4 g	151.5 g/m²		
118-1	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	326.8 g	150.8 g/m²		
118-2	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	324.0 g	149.5 g/m²		
119-1	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	328.6 g	151.6 g/m²		
119-2	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	324.9 g	149.9 g/m²		
120-1	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	329.8 g	152.2 g/m²		
120-2	23.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	336.0 g	155.0 g/m²		
125-1	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	336.1 g	155.1 g/m²		
125-2	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	326.6 g	150.7 g/m²		
126-1	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	325.0 g	150.0 g/m²		
126-2	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	325.4 g	150.1 g/m²		
127-1	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	309.1 g	142.6 g/m²		
127-2	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	311.5 g	143.7 g/m²		
128-1	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	317.0 g	146.3 g/m²		
128-2	29.03.2021	C-Alder	18.0 mm	13		1.5 mm	160.0 g/m²	314.3 g	145.0 g/m²		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layer	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m^2	Avarage Glue Cons., g/m^2	Standard Deviation
108-1	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	135.7 g	192.3 g/m^2	187.4 g/m^2	8.3 g/m^2
108-2	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	130.3 g	184.7 g/m^2		
105-1	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	142.6 g	202.0 g/m^2		
105-2	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	141.1 g	199.9 g/m^2		
106-1	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	143.7 g	203.7 g/m^2		
106-2	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	137.6 g	195.0 g/m^2		
107-1	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	141.0 g	199.8 g/m^2		
107-2	22.03.2021	C-Aspen	6.5 mm	5		1.5 mm	160.0 g/m^2	132.8 g	188.3 g/m^2		
109-1	22.03.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	204.2 g	192.9 g/m^2		
109-2	23.03.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	199.5 g	188.5 g/m^2		
110-1	29.03.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	212.1 g	200.4 g/m^2		
110-2	31.03.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	206.9 g	195.5 g/m^2		
111-1	01.04.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	199.7 g	188.6 g/m^2		
111-2	01.04.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	201.8 g	190.7 g/m^2		
112-1	01.04.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	202.4 g	191.2 g/m^2		
112-2	01.04.2021	C-Aspen	9.0 mm	7		1.5 mm	160.0 g/m^2	193.9 g	183.2 g/m^2		
133-1	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	266.6 g	188.9 g/m^2		
133-2	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	250.3 g	177.3 g/m^2		
134-1	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	268.6 g	190.3 g/m^2		
134-2	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	280.7 g	198.9 g/m^2		
135-1	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	264.1 g	187.1 g/m^2		
135-2	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	270.6 g	191.7 g/m^2		
136-1	30.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	264.0 g	187.0 g/m^2		
136-2	31.03.2021	C-Aspen	12.0 mm	9		1.5 mm	160.0 g/m^2	249.9 g	177.1 g/m^2		

Plywood No	Date	Specie	Proposed Plywood Thicknes	Total Number of Layer	Finished Plywood Thicknes	Veneer Thickne	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m^2	Avarage Glue Cons., g/m^2	Standard Deviation
129-1	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	350.4 g	194.0 g/m^2		
129-2	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	355.2 g	196.7 g/m^2		
130-1	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	309.3 g	171.3 g/m^2		
130-2	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	320.6 g	177.5 g/m^2		
131-1	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	334.8 g	185.4 g/m^2		
131-2	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	332.6 g	184.2 g/m^2		
132-1	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	328.9 g	182.1 g/m^2		
132-2	30.03.2021	C-Aspen	15.0 mm	11		1.5 mm	160.0 g/m^2	318.8 g	176.5 g/m^2		
121-1	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	391.7 g	180.7 g/m^2		
121-2	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	426.9 g	197.0 g/m^2		
122-1	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	398.4 g	183.8 g/m^2		
122-2	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	404.4 g	186.6 g/m^2		
123-1	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	396.4 g	182.9 g/m^2		
123-2	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	403.9 g	186.4 g/m^2		
124-1	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	388.8 g	179.4 g/m^2		
124-2	29.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	417.3 g	192.6 g/m^2		
137-1	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	403.8 g	186.3 g/m^2		
137-2	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	412.7 g	190.4 g/m^2		
138-1	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	380.7 g	175.7 g/m^2		
138-2	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	389.5 g	179.7 g/m^2		
139-1	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	369.1 g	170.3 g/m^2		
139-2	31.03.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	374.2 g	172.7 g/m^2		
140-1	01.04.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	402.4 g	185.7 g/m^2		
140-2	01.04.2021	C-Aspen	18.0 mm	13		1.5 mm	160.0 g/m^2	397.9 g	183.6 g/m^2		

Plywood No	Date	Specie	Proposed Plywood Thickness	Total Number of Layers	Finished Plywood Thickness	Veneer Thickness	Proposed glue consumption	Total Glue Amount, g	Avarage Glue Cons., g/m²	Avarage Glue Cons., g/m²	Standard Deviation
100-1	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	123.1 g	174.4 g/m²	185.3 g/m²	6.1 g/m²
100-2	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	128.5 g	182.1 g/m²		
97-1	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	124.7 g	176.7 g/m²		
97-2	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	128.2 g	181.7 g/m²		
98-1	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	124.3 g	176.2 g/m²		
98-2	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	133.4 g	189.1 g/m²		
99-1	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	129.1 g	183.0 g/m²		
99-2	19.03.2021	C-Aspen	9.0 mm	5		2.6 mm	160.0 g/m²	135.8 g	192.4 g/m²		
89-1	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	194.3 g	183.6 g/m²		
89-2	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	198.6 g	187.6 g/m²		
90-1	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	204.3 g	193.0 g/m²		
90-2	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	202.2 g	191.1 g/m²		
91-1	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	205.5 g	194.2 g/m²		
91-2	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	195.2 g	184.4 g/m²		
92-1	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	198.7 g	187.8 g/m²		
92-2	18.03.2021	C-Aspen	15.0 mm	7		2.6 mm	160.0 g/m²	199.1 g	188.2 g/m²		

Table 33 Density Test results

veneer thickne	specie	plywood thickn	Plywood numb	Sample Numb	Thickness, t (mr	Length, b1 (mı	Width, b2 (mı	Mass1, m (	Mass2, m (	Av. Mass, m (	Density, ρ (kg/m
1.5	aspen	6.5	P-1	D1	6.81	50.12	50.17	11.19	11.17	11.18	652.9
1.5	aspen	6.5		D2	6.61	49.96	50.16	10.86	10.85	10.86	655.3
1.5	aspen	6.5		D3	6.56	49.82	50.28	10.55	10.55	10.55	642.0
1.5	aspen	6.5		D4	6.71	50.14	50.28	11.08	11.07	11.08	654.7
1.5	aspen	6.5		D5	6.69	50.01	50.10	11.16	11.17	11.17	666.1
1.5	aspen	6.5		D6	6.61	50.20	50.22	10.94	10.95	10.95	656.8
1.5	aspen	6.5	P-2	D1	6.65	50.12	50.23	10.39	10.39	10.39	620.6
1.5	aspen	6.5		D2	6.52	50.16	50.16	10.58	10.56	10.57	644.3
1.5	aspen	6.5		D3	6.59	50.08	50.08	10.58	10.57	10.58	639.8
1.5	aspen	6.5		D4	6.78	50.08	50.14	10.71	10.71	10.71	629.1
1.5	aspen	6.5		D5	6.81	50.14	50.41	10.54	10.52	10.53	611.8
1.5	aspen	6.5		D6	6.57	50.39	50.40	10.54	10.53	10.54	631.4
1.5	aspen	6.5	P-3	D1	6.89	49.99	50.09	11.00	11.00	11.00	637.6
1.5	aspen	6.5		D2	6.78	50.17	50.32	10.76	10.75	10.76	628.3
1.5	aspen	6.5		D3	6.71	50.18	50.18	10.92	10.90	10.91	645.7
1.5	aspen	6.5		D4	6.63	50.17	50.33	11.10	11.09	11.10	662.7
1.5	aspen	6.5		D5	6.72	50.14	50.23	10.94	10.94	10.94	646.4
1.5	aspen	6.5		D6	6.88	50.16	50.16	11.18	11.18	11.18	645.9
1.5	aspen	6.5	P-4	D1	7.00	50.02	50.16	10.29	10.28	10.29	585.7
1.5	aspen	6.5		D2	6.97	50.07	50.16	10.17	10.16	10.17	580.7
1.5	aspen	6.5		D3	6.87	50.08	50.08	10.23	10.24	10.24	594.0
1.5	aspen	6.5		D4	6.75	50.10	50.10	10.88	10.90	10.89	642.8
1.5	aspen	6.5		D5	6.74	50.06	50.14	11.03	11.03	11.03	652.0
1.5	aspen	6.5		D6	6.80	50.06	50.12	11.23	11.24	11.24	658.5
2.6	aspen	6.5	P-65	D1	7.18	51.22	50.11	10.99	10.98	10.99	596.1
2.6	aspen	6.5		D2	7.24	51.27	50.19	10.56	10.55	10.56	566.6
2.6	aspen	6.5		D3	7.34	50.11	51.36	11.48	11.48	11.48	607.7
2.6	aspen	6.5		D4	6.71	50.24	49.72	9.93	9.93	9.93	592.4
2.6	aspen	6.5		D5	6.76	50.36	50.01	9.85	9.85	9.85	578.6
2.6	aspen	6.5		D6	6.86	50.33	50.20	10.04	10.04	10.04	579.3
2.6	aspen	6.5	P-66	D1	7.34	51.43	50.38	9.68	9.66	9.67	508.7
2.6	aspen	6.5		D2	7.36	50.36	51.41	9.66	9.64	9.65	506.4
2.6	aspen	6.5		D3	7.39	51.25	50.30	9.57	9.57	9.57	502.3
2.6	aspen	6.5		D4	7.20	49.98	50.52	9.67	9.67	9.67	531.9
2.6	aspen	6.5		D5	7.14	50.32	50.16	9.40	9.40	9.40	521.6
2.6	aspen	6.5		D6	7.13	50.47	50.30	9.32	9.32	9.32	514.9
2.6	aspen	6.5	P-67	D1	7.21	50.29	51.40	10.30	10.30	10.30	552.7
2.6	aspen	6.5		D2	7.25	50.33	51.46	10.35	10.35	10.35	551.2
2.6	aspen	6.5		D3	7.25	50.15	51.11	10.17	10.15	10.16	546.7
2.6	aspen	6.5		D4	7.18	49.81	50.30	9.95	9.95	9.95	553.1
2.6	aspen	6.5		D5	7.20	50.47	50.12	9.91	9.91	9.91	544.1
2.6	aspen	6.5		D6	7.20	50.39	50.10	10.03	10.03	10.03	551.8
2.6	aspen	6.5	P-68	D1	7.24	50.98	50.39	10.32	10.32	10.32	554.9
2.6	aspen	6.5		D2	7.26	50.63	51.12	10.18	10.18	10.18	541.8
2.6	aspen	6.5		D3	7.26	51.32	50.34	10.61	10.61	10.61	565.7
2.6	aspen	6.5		D4	7.32	50.34	50.12	9.62	9.62	9.62	520.9
2.6	aspen	6.5		D5	7.26	50.14	50.58	9.56	9.56	9.56	519.2
2.6	aspen	6.5		D6	7.27	50.45	49.95	9.57	9.57	9.57	522.4

veneer thickne	specie	plywood thickn	Plywood numb	Sample Numb	Thickness, t (mr	Length, b1 (mı	Width, b2 (mı	Mass1, m (	Mass2, m (	Av. Mass, m (	Density, ρ (kg/m
1.5	birch	6.5	P-29	D1	6.99	51.25	50.18	13.09	13.07	13.08	727.6
1.5	birch	6.5		D2	6.98	51.42	50.19	13.07	13.05	13.06	725.0
1.5	birch	6.5		D3	6.96	51.27	50.24	13.18	13.16	13.17	734.6
1.5	birch	6.5		D4	7.13	50.33	50.24	13.26	13.26	13.26	735.5
1.5	birch	6.5		D5	7.03	50.44	50.16	13.76	13.76	13.76	773.6
1.5	birch	6.5		D6	7.00	50.31	50.35	13.63	13.63	13.63	768.7
1.5	birch	6.5	P-30	D1	7.17	50.42	51.27	12.46	12.44	12.45	671.7
1.5	birch	6.5		D2	7.13	50.22	51.20	12.39	12.37	12.38	675.3
1.5	birch	6.5		D3	7.14	50.50	51.24	12.56	12.54	12.55	679.3
1.5	birch	6.5		D4	7.20	50.13	50.52	12.66	12.66	12.66	694.3
1.5	birch	6.5		D5	7.24	50.36	50.11	12.85	12.85	12.85	703.3
1.5	birch	6.5		D6	7.18	50.05	50.39	12.75	12.75	12.75	704.1
1.5	birch	6.5	P-31	D1	7.01	50.17	51.45	12.55	12.54	12.55	693.3
1.5	birch	6.5		D2	7.05	50.25	51.45	12.40	12.38	12.39	679.8
1.5	birch	6.5		D3	7.08	51.01	50.09	12.32	12.31	12.32	680.8
1.5	birch	6.5		D4	6.94	50.49	50.10	12.35	12.35	12.35	703.5
1.5	birch	6.5		D5	6.92	50.18	50.41	12.44	12.44	12.44	710.7
1.5	birch	6.5		D6	6.91	50.31	50.08	12.26	12.26	12.26	704.2
1.5	birch	6.5	P-32	D1	7.04	50.32	51.40	12.69	12.67	12.68	696.4
1.5	birch	6.5		D2	7.06	50.16	51.32	12.72	12.71	12.72	699.6
1.5	birch	6.5		D3	7.11	51.34	50.40	12.41	12.39	12.40	674.0
1.5	birch	6.5		D4	7.07	50.20	50.36	12.47	12.47	12.47	697.7
1.5	birch	6.5		D5	7.02	50.17	50.38	12.41	12.41	12.41	699.4
1.5	birch	6.5		D6	6.96	49.99	50.43	12.45	12.45	12.45	709.6
1.5	Black alder	6.5	P-49	D1	7.14	51.36	50.20	11.09	11.07	11.08	601.9
1.5	Black alder	6.5	P-49	D2	7.16	50.21	51.47	11.35	11.34	11.35	613.1
1.5	Black alder	6.5	P-49	D3	7.21	51.43	50.06	11.45	11.44	11.45	616.6
1.5	Black alder	6.5	P-49	D4	7.07	50.18	49.73	10.99	10.99	10.99	622.9
1.5	Black alder	6.5	P-49	D5	7.05	50.25	50.36	11.07	11.07	11.07	620.5
1.5	Black alder	6.5	P-49	D6	7.05	50.34	50.26	11.26	11.26	11.26	631.3
1.5	Black alder	6.5	P-50	D1	6.77	51.19	50.33	9.48	9.47	9.48	543.2
1.5	Black alder	6.5	P-50	D2	6.74	50.41	51.45	9.31	9.30	9.31	532.3
1.5	Black alder	6.5	P-50	D3	6.81	50.26	51.23	9.40	9.39	9.40	535.8
1.5	Black alder	6.5	P-50	D4	6.57	49.94	50.21	9.22	9.22	9.22	559.7
1.5	Black alder	6.5	P-50	D5	6.60	50.25	50.04	9.43	9.43	9.43	568.2
1.5	Black alder	6.5	P-50	D6	6.59	50.26	50.26	9.38	9.38	9.38	563.5
1.5	Black alder	6.5	P-51	D1	7.08	51.19	50.30	10.13	10.11	10.12	555.1
1.5	Black alder	6.5	P-51	D2	7.04	51.16	50.32	10.38	10.36	10.37	572.2
1.5	Black alder	6.5	P-51	D3	7.05	51.31	50.27	10.45	10.43	10.44	574.1
1.5	Black alder	6.5	P-51	D4	6.82	50.36	49.90	10.64	10.64	10.64	620.8
1.5	Black alder	6.5	P-51	D5	6.84	50.12	50.34	10.40	10.40	10.40	602.6
1.5	Black alder	6.5	P-51	D6	6.84	50.35	50.36	10.48	10.48	10.48	604.3
1.5	Black alder	6.5	P-52	D1	7.03	50.74	51.35	11.67	11.66	11.67	636.9
1.5	Black alder	6.5		D2	6.99	50.34	51.47	11.46	11.45	11.46	632.5
1.5	Black alder	6.5		D3	7.05	51.29	50.17	11.26	11.25	11.26	620.4
1.5	Black alder	6.5		D4	7.27	49.86	50.38	11.20	11.20	11.20	613.3
1.5	Black alder	6.5		D5	7.21	50.48	50.23	11.12	11.12	11.12	608.3
1.5	Black alder	6.5		D6	7.17	50.36	50.37	11.28	11.28	11.28	620.2

veneer thickne	specie	plywood thickn	Plywood numb	Sample Numb	Thickness, t (mr	Length, b1 (mı	Width, b2 (mı	Mass1, m (	Mass2, m (	Av. Mass, m (	Density, ρ (kg/m
1.5	C-alder	6.5	P-81	D1	7.2	51.34	50.4	11.23	11.2	11.22	602.0
1.5	C-alder	6.5		D2	7.24	51.16	51.19	10.94	10.93	10.94	576.7
1.5	C-alder	6.5		D3	7.28	51.05	50.17	11.3	11.27	11.29	605.2
1.5	C-alder	6.5		D4	7.17	50.31	49.84	11.13	11.13	11.13	619.1
1.5	C-alder	6.5		D5	7.15	49.96	50.35	11.2	11.2	11.20	622.7
1.5	C-alder	6.5		D6	7.14	50.3	50.25	11.39	11.39	11.39	631.1
1.5	C-alder	6.5	P-82	D1	6.99	50.2	51.46	12.23	12.22	12.23	677.0
1.5	C-alder	6.5		D2	6.98	51.27	50.22	12.16	12.15	12.16	676.3
1.5	C-alder	6.5		D3	7.05	50.26	51.29	11.84	11.84	11.84	651.5
1.5	C-alder	6.5		D4	7.29	49.87	50.25	11.73	11.73	11.73	642.1
1.5	C-alder	6.5		D5	7.22	50.36	50.13	11.89	11.89	11.89	652.3
1.5	C-alder	6.5		D6	7.17	49.8	50.45	11.87	11.87	11.87	658.9
1.5	C-alder	6.5	P-83	D1	7.01	51.13	50.3	11	10.98	10.99	609.6
1.5	C-alder	6.5		D2	7.05	51.59	50.31	10.86	10.83	10.85	592.7
1.5	C-alder	6.5		D3	7.06	51.2	50.18	10.73	10.73	10.73	591.6
1.5	C-alder	6.5		D4	6.87	49.65	50.38	10.47	10.47	10.47	609.3
1.5	C-alder	6.5		D5	6.89	50.12	50.42	10.77	10.77	10.77	618.6
1.5	C-alder	6.5		D6	6.88	50.41	50.09	10.55	10.55	10.55	607.3
1.5	C-alder	6.5	P-84	D1	7.03	51.32	50.2	10.93	10.91	10.92	602.9
1.5	C-alder	6.5		D2	7.06	50.16	51.41	10.88	10.87	10.88	597.3
1.5	C-alder	6.5		D3	7.11	51.55	50.08	10.96	10.94	10.95	596.6
1.5	C-alder	6.5		D4	7.15	49.67	50.01	10.71	10.71	10.71	603.0
1.5	C-alder	6.5		D5	7.07	50.38	50.33	10.71	10.71	10.71	597.4
1.5	C-alder	6.5		D6	7.03	49.96	50.39	10.66	10.66	10.66	602.3
1.5	C-aspen	6.5	P-105	D1	6.97	50.3	51.47	10.75	10.74	10.75	595.5
1.5	C-aspen	6.5		D2	6.99	50.22	51.31	10.69	10.69	10.69	593.5
1.5	C-aspen	6.5		D3	7.03	51.28	50.22	10.76	10.75	10.76	594.1
1.5	C-aspen	6.5		D4	6.97	50.26	49.39	10.64	10.64	10.64	615.0
1.5	C-aspen	6.5		D5	6.95	50.39	50.46	10.87	10.87	10.87	615.1
1.5	C-aspen	6.5		D6	6.92	50.48	50.15	10.45	10.45	10.45	596.5
1.5	C-aspen	6.5	P-106	D1	6.91	50.48	51.4	11.76	11.74	11.75	655.4
1.5	C-aspen	6.5		D2	9.94	51.38	50.25	11.61	11.6	11.61	452.2
1.5	C-aspen	6.5		D3	7.02	51.35	50.34	11.86	11.85	11.86	653.3
1.5	C-aspen	6.5		D4	6.77	50.35	49.78	11.65	11.65	11.65	686.6
1.5	C-aspen	6.5		D5	6.77	50.48	50.06	11.8	11.8	11.80	689.7
1.5	C-aspen	6.5		D6	6.77	50.24	50.55	11.84	11.84	11.84	688.6
1.5	C-aspen	6.5	P-107	D1	6.79	51.64	50.32	11.94	11.92	11.93	676.2
1.5	C-aspen	6.5		D2	6.8	50.2	51.56	12.05	12.03	12.04	684.1
1.5	C-aspen	6.5		D3	6.87	51.25	50.36	11.82	11.81	11.82	666.3
1.5	C-aspen	6.5		D4	6.77	50.28	50.22	11.55	11.55	11.55	675.6
1.5	C-aspen	6.5		D5	6.74	50.38	46.61	10.88	10.88	10.88	687.4
1.5	C-aspen	6.5		D6	6.75	49.87	50.27	11.74	11.74	11.74	693.8
1.5	C-aspen	6.5	P-108	D1	7.19	51.57	50.19	10.72	10.71	10.72	575.8
1.5	C-aspen	6.5		D2	7.15	51.4	50.17	10.75	10.73	10.74	582.5
1.5	C-aspen	6.5		D3	7.23	51.4	50.22	10.5	10.49	10.50	562.3
1.5	C-aspen	6.5		D4	6.87	50.3	50.32	10.35	10.35	10.35	595.2
1.5	C-aspen	6.5		D5	6.88	50.36	50.32	10.41	10.41	10.41	597.1
1.5	C-aspen	6.5		D6	6.89	50.29	50.1	10.28	10.28	10.28	592.2