TALLINN UNIVERSITY OF TECHNOLOGY
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TALLINNA TEHNIKAÜLIKOOL

THE INFLUENCE OF GREY ALDER (*ALNUS INCANA*) AND BLACK ALDER (*ALNUS GLUTINOSA*) VENEER MOISTURE CONTENT ON THE VENEER SURFACE WETTABILITY AND PLYWOOD STRENGTH PROPERTIES

HALL LEPA (*ALNUS INCANA*) JA SANGLEPA (*ALNUS GLUTINOSA*) SPOONI NIISKUSSISALDUSE MÕJU SPOONI MÄRGAVUSOMADUSTELE JA VINEERI TUGEVUSOMADUSTELE

MASTER THESIS

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AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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THESIS TASK

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Thesis topic:

The influence of grey alder (Alnus incana) and black alder (Alnus glutinosa) veneer moisture content on the veneer surface wettability and plywood strength properties

Hall lepa (Alnus incana) ja sanglepa (Alnus glutinosa) spooni niiskussisalduse mõju spooni märgavusomadustele ja vineeri tugevusomadustele

Thesis main objectives:

1. Work out drying process to get veneer sheets with target moisture content
2. Find out the best moisture content range for adhesive bond formation for grey alder and black alder veneer
3. Compare grey alder and black alder moisture content impact to veneer surface wettability and plywood strength properties

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PREFACE

The aim of this research was to find out how grey alder and black alder veneer moisture content affects plywood strength properties. Strength properties were tested according to European standards. Veneer properties were evaluated by wettability and cross-section tensile strength test. Plywood properties were evaluated by shear strength and bending strength test.

Practical part of the present thesis was performed in Tallinn University of Technology, Laboratory of Wood Technology. The author thanks supervisor Heikko Kallakas for good supervising.

Keywords: Grey alder, Black alder, Veneer, Plywood, Moisture effect on plywood strength properties

List of abbreviations and symbols

CA – Contact Angle

FSP – Fibre Saturation Point

Long. – Longitudinal

LPF – Lignin-based Phenol-Formaldehyde

MC – Moisture Content

MF/MUF-Melamine-Formaldehyde/Melamine-Urea-Formaldehyde

MOE – Modulus of Elasticity

MUPF-Melamine-Urea-Phenol-Formaldehyde

Per. – Perpendicular

PF – Phenol-Formaldehyde

PF/PUF-Phenol-Formaldehyde/Phenol Urea Formaldehyde

UF – Urea-Formaldehyde

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INTRODUCTION

Birch is a widely spread wood species in the Nordic region. It is also one of the most commonly used species in plywood production. However, there are more wood species which have not been researched as much.

Grey alder (*Alnus incana*) and black alder (*Alnus glutinosa*) are wood species which belong to the birch family. Birch has a higher density and is more widely spread than alder, but it cannot be left unmarked that those two alder species cover more than 12% of the Estonian forest land [1].

The aim of this research was to find out how grey alder and black alder veneer moisture content (MC) affects plywood strength properties. Plywood panels were made from the veneers that were dried between certain MC range and with two different types of adhesives. Strength properties were tested according to European standards.

This thesis is divided into three chapters. First chapter gives a more general overview of plywood production and gives a brief overview about plywood production in Estonia. The first chapter is about adhesives that are most commonly used in plywood production and gives an overview of the properties of grey alder and black alder. Veneer drying is one of the most important steps in plywood production because the strength properties of plywood highly depend on that. In addition, the essence of bond formation between wood and adhesive is covered in more detail.

Second part is about materials and processing methods that were used in this research. Second chapter brings out the test plan of this research, in which all of the production parameters are outlined. Production steps and methods are also explained more precisely. Second chapter ends with a description of analysis and testing methods.

Third part is about the results and analysis of this research. Grey alder and black alder veneer properties are evaluated by tensile strength test and wettability. Plywood strength properties are evaluated by bending test and adhesion is evaluated by shear strength test.

1 LITERATURE REVIEW

1.1 Plywood production

The history of plywood reaches back over thousands of years when the Egyptians and the Chinese used veneered artefacts. Veneers were made by sawing and slicing until peeling was discovered. Lathe with spindles was patented in the beginning of the 19^{th} century [2].

The wood veneer industries all over the world uses over a thousand different wood species to make products for different demands, starting from sliced decorative face veneer and ending with plywood panels from rotary-cut veneer [3]. Total plywood and veneer-based panel production in the world is approximately 50000000 m^3/year [4]. It is believed, that more than 80% of all veneer is produced by rotary cut. This is because of the plywood production capacity [5].

Most of the wood species can be successfully cut into veneer, although hardwoods are easier to cut into veneer than softwoods. The reason for that is that hardwoods can be bent more easily than softwoods. Better bending properties are not fully understood, but it is thought to be related with the lignin essence and its quantity. Hardwoods have less lignin than softwoods, but also the lignin in hardwoods is more thermoplastic than lignin in softwoods. Better bending properties reduce the depth of lathe checks which makes for higher quality veneer, especially when we are talking about rotary cut veneer, where the veneer sheet has to bend over the knife [3].

A successful veneer production depends highly on three criteria:

- A supply of suitable logs
- Good processing techniques
- Good sales organization

Each of those points has an important role in successful production. However, more important factors are sufficient supply of the logs and proper processing techniques. The logs must have certain characteristics, depending on the end use, that will ensure that the veneer is of quality [3]. The end use of the plywood depends highly on the quality of the panel. Most commonly it is used in construction, furniture, vehicles and packaging [2].

1.2 Plywood production in Estonia

Veneer and plywood production have been in Estonia for a long time. Its early years can be considered the end of the nineteenth century when the Luther family started their own company Luterma, which produced caskets. The company later expanded into mass production of chair bases and office furniture. In 1890 Lutermas chemist Oscar Paulsen invented water proof adhesive which helped expand the use of plywood even more. Luterma was successful until the World War II [6].

According to Estonian Forest and Wood Industries Association there are six companies in Estonia who are directly involved to veneer and plywood production: 1) Valmos OÜ, 2) UPM-Kymmene Otepää OÜ, 3) Tarmeko Spoon AS, 4) Kohila Vineer OÜ, 5) Balti Spoon OÜ and 6) Estonian Plywood AS. Most of those companies are focused on birch veneer and plywood production, although, couple of them have pointed out that they also use spruce and alder as raw material [7].

1.3 Plywood adhesives

There are many different adhesives currently used in wood-based panel industry [8]. The proper choice of the adhesive depends highly on the requirements of the final product. Some properties are largely dependent on the type of adhesive e.g. climate resistance [9]. The biggest volume of wood adhesives are represented by the formaldehyde based resins. Formaldehyde adhesives are prepared by reacting formaldehyde with various chemicals such as urea, melamine, phenol, resorcinol, or combination thereof. In plywood production Urea-Formaldehyde (UF), Melamine-Formaldehyde/Melamine-Urea-Formaldehyde (MF/MUF), Melamine-Urea-Phenol-Formaldehyde (MUPF), Phenol-Formaldehyde/Phenol Urea Formaldehyde (PF/PUF) are most common, but natural adhesives also used [8]. Since Phenol-Formaldehyde (PF) and Lignin-based Phenol-Formaldehyde (LPF) adhesives are used in this research, the following discussion will be focused on those.

PF resin is the reaction product of phenol with formaldehyde. It can be divided into two major groups based on the molar ratio of the two substance. If there is more formaldehyde than phenol in the resin then it is called *resole*. That kind of resin is rich of methylol groups which are good reactants without any additional substances. Resole resin is always ready for curing, it only needs the proper environment e.g. heat. One of the disadvantage of this kind of resin can be considered limited shelf life [10].

When there is less formaldehyde than phenol and the ration is greater than 1 then this kind of resin is called *novolac*. The resin will be lacking of methylol groups which means it is unable to polymerize on its own. It will need a hardener for polymerization [10].

Phenolic resins have high-temperature resistance, high physical strength and good dimensional stability [11]. Most of the resins contains certain types of additives which may modify the properties or lower the cost of the adhesive. Lignin can be considered as an important additive. It has been used as a binder, in its natural and derived state, for a long time. Market has emerged lignin based PF resins where derived lignin substitutes phenol without serious loss of the durability. LPF adhesives tend to be cheaper but they also need a longer curing time [10], [12].

1.4 Bond formation

Bond between adhesive and wood can be imagined as system of links as it is shown in Figure 1.1. Link system contains wood (links 8 and 9), wood surface (links 6 and 7), wood-adhesive interface (links 4 and 5), bond line boundary layer (links 2 and 3) and glue-line itself (link 1). The strength of a bond is affected by various parameters such as: 1) wood MC (Moisture Content), 2) mechanical properties of wood, 3) adhesive type and 4) environmental conditions where material is used [9].

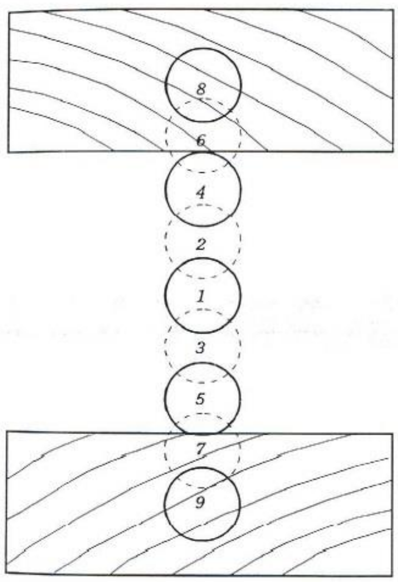


Figure 1.1. Schematic adhesive bond between two substrates [10]

Proper bond formation depends on number of processes. The adhesive must wet the wood across its surface and penetrate to its porous structure. It must be able to form a bond with the wood by mechanical interlocking or even chemically [13]. Efficient mechanical interlocking occurs when an adhesive penetrates beyond the surface into wood two to six cells deep. When adhesive penetrates deeply into cell cavities it may be able to develop a water-resistant bond. Good bond can be considered if the wood breaks away from the adhesive joint and bond strength can be considered equal to the strength of the wood itself [14].

Gluing the wood can be considered as wetting the wood surface with the liquid adhesive. There are no direct correlations between the contact angles (CA) and bonding strength, however, wetting may help to predict the penetration of adhesive. The CA can be measured between the liquid droplet and the surface. Low CA ($\Theta < 45°$) show that surface is favourable for wetting and CA over 90° indicate incomplete wetting [9].

Surface free energy is influenced by various factors. Important factors are thought to be: wood species and amount of its inherent chemicals, MC of the wood, cutting direction and direction of the spreading of the droplet during the CA measuring [9].

Surface of the veneer is complex and heterogeneous. It contains woods main polymeric substances such as cellulose, hemicellulose and lignin but also wood extractives [14].

MC of wood affects adhesive penetration and bond formation. Generally the favourable MC before gluing for wood material is 6-14% and even above and below this range. Condition where MC of the wood is too low can lead to that wood absorbing water too quickly and adhesive cannot flow and penetrate into the wood correctly, which results in poor bond strength. When wood MC is too high then the adhesive and water cannot penetrate into the wood properly. Hot pressing may lead to formation of blows, because excess moisture starts to boil and cause vapour pressure between the veneer sheets. Result of that is weakened adhesive film. The optimal MC range depends highly on specific product and type of adhesive. The best product performance is achieved by practical experience [15].

1.5 Grey alder

Grey alder *(Alnus incana)*, is a species of alder which is widely spread. Alder (*Alnus)* is a species of tree that belongs to the birch family *Betulaceae* [16], [17]. There are 30 to 35 species in the genus *Alnus*. Alder is distributed throughout the North Temperate Zone. It is native to most parts in Europe, Asia, Western Siberia and Caucasian, but also widely spread in North America and some of the species can be found in Central and South America [16], [18].

According to the Ministry of the Environment 2017 data 8,8% (205000 ha) of the area of the Estonian forests is covered with grey alder stands, which makes it 4th most spread wood species after pine, birch and spruce [19].

Grey alder is a fast growing wood species, its bulk majority of stands is achieved at the age of 12-13. Biomass growth is biggest in 5 to 12 years old trees after that it slows down. Fast growing alder has short life span compared to other species, it rarely grows older than 50 to 70 years. Official harvesting age for grey alder is 30 years [18]. However, optimal harvesting age for grey alder is between 15 to 25 years [18], [1].

Table 1.1. Properties of grey alder [20]

Property	Grey alder (*Alnus incana*)
Shrinkage, %	14,5
Average dried weight, kg/m^3	500-530
Janka hardness, Janka	370
Longitudinal compressive strength, MPa	41
Elastic modulus, GPa	10
Modulus of rupture, MPa	81

1.6 Black alder

Black alder *(Alnus glutinosa)*, just as grey alder, belongs to the Genus *Alnus*, family *Betulaceae*. Black alder is distributed all over Europe from Ireland to western Siberia. In addition it can be found in South and North Africa, Caucasia and is distributed to some places in USA and Canada as a foreign species [21], [22].

Black alder usually reaches a height of 25 to 30 m and in rare cases can grow up to 40 m high. The trunk diameter of old trees ranges from 35 to 40 cm [21], [22]. Trees usually grow 100 to 150 years old [22], and average stemwood density of black alder is around 495 kg/m^3 [23].

Alder belongs to species of monoecious trees. It means that male and female flowers are found in same tree. Flowers, which are called catkins appear between February and April. Male catkins are yellow and pendulous and female catkins are green and oval-shaped. Pollen is distributed by wind after what, the female catkins gradually become woody, cone-like fruits in winter. To release seeds, those cone-like fruits open up and seeds will be dispersed by wind and water [17].

According to the Ministry of the Environment 2017 data black alder is 6th most widely spread tree species in Estonian forests, including 3,7% of the forestland [1].

The bark on black alder is dark and fissured, usually covered in lichens. Leaves are commonly 3 to 9 cm long, green or dark green, with serrated edges and indented tip [17].

Table 1.2. Properties of black alder [23]

Property	**Black alder (*Alnus glutinosa*)**
Shrinkage, %	13,6-14,7
Average dried weight, kg/m^3	550
Janka hardness, Janka	370
Modulus of rupture, MPa	78-95
Elastic modulus, GPa	9-12
Longitudinal compressive strength, MPa	39-52

1.7 Water in wood

There are three different states that water can exist in wood. First one is called bound water. In this type the water molecules are bounded to the cell wall chemically. Bound water can be removed by breaking down hydrogen and van der Waal bonds. This can be achieved by the heat which helps to break down the chemical bonds. Bound water starts to evaporate below the Fibre Saturation Point (FSP). The second is called free liquid water. This type of water is found in cavities such as lumens and spaces between the cells. Third type of water that occurs in wood is water vapour. It can be found in the cavities that are not fully filled with free water [24]. Following Figure 1.2 describes water evaporation from wood, where: 1) free water, 2) water vapour and 3) bound water.

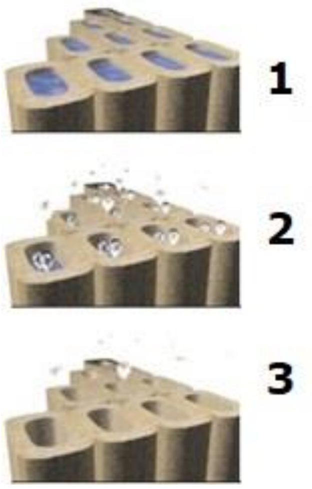


Figure 1.2. Free and bound water evaporation from wood cells [25]

There are many different options for wood drying. Wood drying involves several thermodynamic processes [26].

1.7.1 Veneer drying

When the veneer enters to the drying chamber the heat is transferred as circulating air to its surface [25]. Heat can be transferred into the veneer middle layers by using water vapour steam. Water has a better heat and mass transfer than regular dry air. Superheated steam can absorb more water vapour until it is saturated [27].

Veneer drying is different from wood drying because drying time is shorter and temperature is above 100°C [26]. Plywood mills use generally either roller dryers or screen dryers. Principle of both dryers is the same, hot air is blown through the jet boxes or nozzles onto both sides of the veneer. It is a rapid process where veneer moves through the drying chambers different zones [2]. In first zones, when the MC is high, veneer is dried at elevated temperatures over 149°C. Last zone (or zones) of the chamber are for cooling [28].

Due to the fact that veneer drying is rapid process it is necessary that environment of the drying chamber is controlled. Mixing steam with hot air helps to prevent things like over drying, drying stresses, too rapid evaporation but it also makes dried veneer MC more unified. Drying chamber air humidity is given as the amount of steam per one kilogram of dry air. Mixture ratio depends highly on drying parameters and type of wood, but is generally between 400-1000 g/kg [2]. Dew point sensor helps to keep the track on drying conditions [27]. For birch veneer the final MC target is generally 3-4% [29].

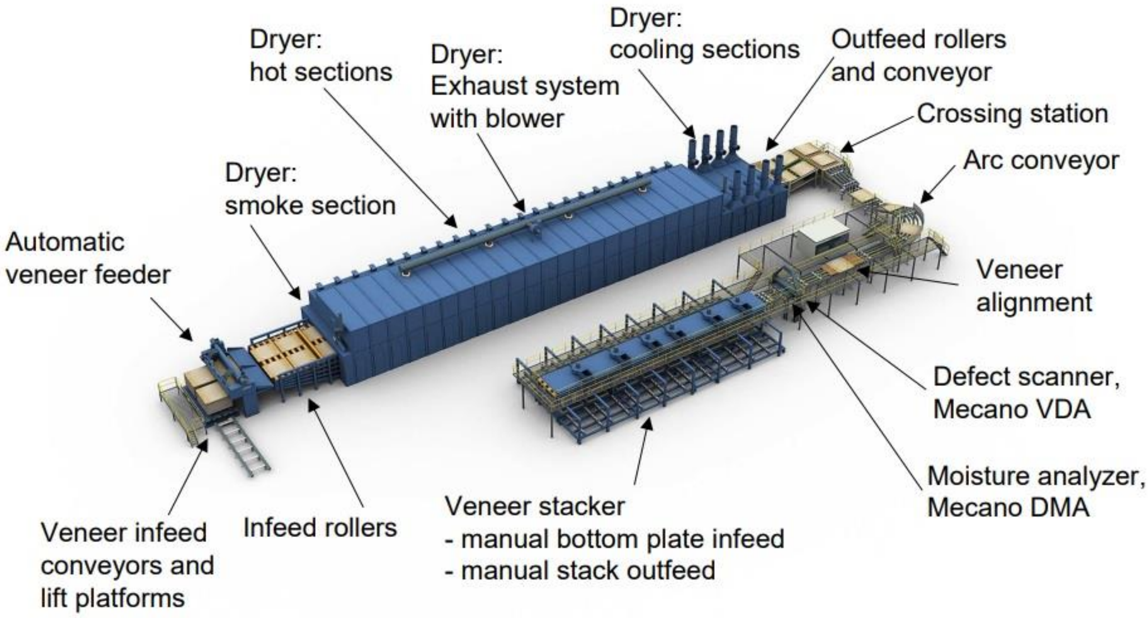


Figure 1.3. RAUTE roller dryer with sorting line [30]

Roller dryer: Roller dryers may contain 4-6 decks made up of pairs of rollers. Clipped veneer sheets enter in drying chamber by feeder and are distributed onto the decks with ejection rollers. Veneer sheets pass different zones which move the veneers forward in an even flow until discharging. Veneer sheets can be graded by quality, MC and dimensions before drying. Roller dryer drying speed is 5-12 m/min [2].

Screen dryer: In screen drier veneer mat is transferred into the dryer straight from the peeling line. Screen dryers are more efficient and need fewer labour. Drying speed can reach up to 90 m/min. Clipping takes place after drying which give more accurate cutting dimension. However, the energy consumption is higher than roller dryers and breakage of the wire mesh can damage the mat [2].

2 MATERIALS AND METHODS

Plywood manufacturing consists of many different technological steps. Tallinn University of Technology, Laboratory of Wood Technology has a complete laboratory scale plywood production line. This production line contains of all machines and equipment that are necessary for plywood production.

Following Figure 2.1 describes simplified form of plywood manufacturing steps that is used in this research. All of those production steps are covered in more detail in chapter 2.2 Material and processing methods.

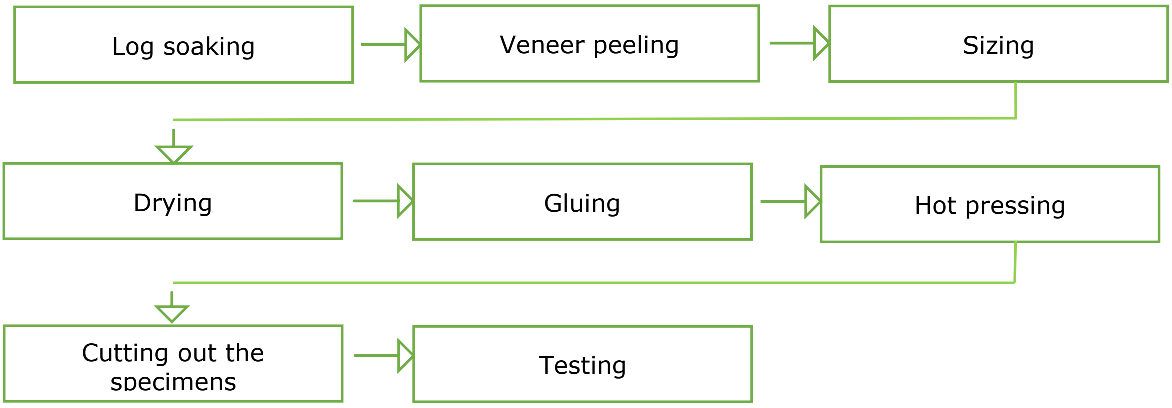


Figure 2.1. Overall plywood manufacturing scheme that is used in this research

Veneer and plywood properties are tested according to the European Standards. Veneer properties are evaluated by wettability and crosswise tensile strength. Plywood strength properties are evaluated by shear strength of adhesive joint and bending strength.

2.1 Test plan

Following tables illustrate the test plan of this study. Table 2.1 shows the main production parameters that were used for making plywood panels. It is divided into two parts. First part is related to grey alder plywood panel production and second part is related to black alder plywood panel production.

In total, three different grey alder and three different black alder logs were used. All of them were soaked in a bath of water for 24 to 48 hours at 40°C. Veneer sheets were glued together by using two different adhesives: 1) PF resin and 2) LPF resin. In one day there was produced plywood panels from one wood species, with one MC range and with two adhesives. In total, there were 6 plywood panels produced per day. Panels were marked with letter and number combinations where letter shows the target MC and number marks the adhesive type. E.g. I1 stands for grey alder plywood panel that was made from veneer 0-4% of MC.

Table 2.1. Test plan with production parameters

Plywood material	Grey alder						Black alder					
Resin	PF			LPF			PF			LPF		
Soaking temperature, °C	40											
Drying temperature, °C	155											
Humidity of the dryer air	600-700 g/kg											
Amount of resin, g/m²	140-150											
Curing temperature, °C	130											
Hot pressing time, min	9											
Drying time, s	330	300	270	330	300	270	270	240	210	270	240	210
Target of MC, %	0-4	4-8	8-12	0-4	4-8	8-12	0-4	4-8	8-12	0-4	4-8	8-12
Quantity of plywood panels	3	3	3	3	3	3	3	3	3	3	3	3
Marking of the plywood panel	I	J	K	I	J	K	X	Y	Z	X	Y	Z
Marking of adhesive type	1			2			1			2		

Figure 2.2 describes specimen cut out plan from plywood panel, where Z describes outer layer grain direction. From each panel 6 shear strength specimen (25*130 mm) and 4 bending strength specimen (50*190 mm) were cut. One test group consists of 18+18 shear strength specimens and 12 bending strength specimen where half were cut out perpendicularly.

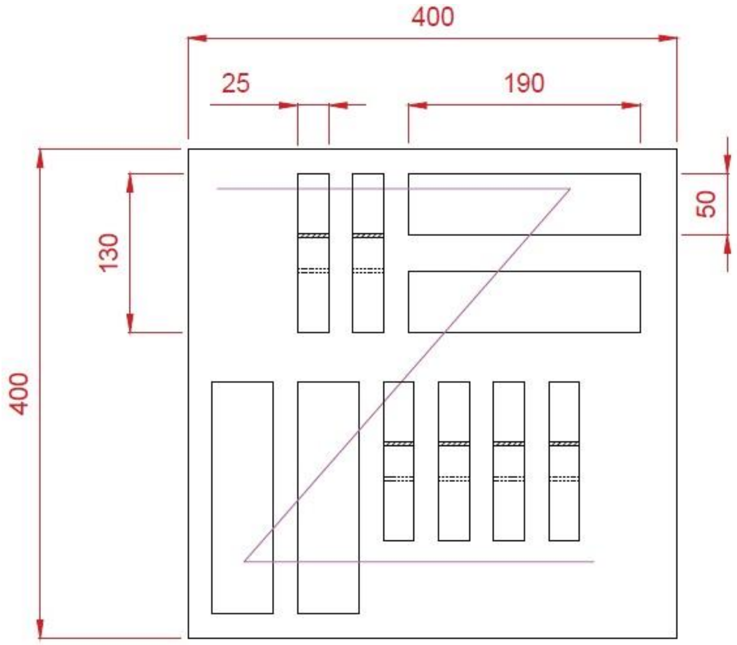


Figure 2.2. Specimens cut out plan form plywood panel in millimetres

Table 2.2 points out more precisely the activities of the analysis and testing part and time consumption. Sizes and numbers of test pieces are also outlined.

Table 2.2. Test plan with time consumption and with the number of specimens

Activity	Method	Duration, h	Specimen size, mm	Number of specimens	Unit
Plywood making		42	400*400	36	Panel
Time dependence of contact angles	EVS-EN 828:2013 [31]	6	100*20	180	Recordings
Measuring contact angles	EVS-EN 828:2013 [31]	7	100*20	180	Drops
Cross section tensile strength		2	50*150	30	Specimens
Testing shear strength	EVS-EN 314-1:2005 [32] and EVS-EN 314-2:1999 [33]	6	130*25	156	Specimens
Testing bending strength	EVS-EN 310:2002 [34]	6	190*50	104	Specimens

2.2 Materials and processing methods

2.2.1 Logs

Grey alder and black alder wood properties were discussed more precisely in chapters 1.5 and 1.6. Logs that were used in this research were cut down and brought to the Tallinn University of Technology, Laboratory of Wood Technology in the beginning of March. Grey alder logs were 2.5 meters long and black alder logs were 3 meters long. Logs were 15 to 30 cm in diameter.

Figure 2.3. Black alder and grey alder logs in Laboratory of Wood Technology log storage

Logs were stored in snowy conditions to avoid drying. For soaking the logs they were cut to 1.2 meter in length with a chainsaw and transported to the soaking basin.

2.2.2 Soaking

Soaking or preconditioning the logs in elevated temperatures is one of the first steps in the veneer and plywood production chain.

Cutting veneer from a heated log has multiple advantages. Heat makes the wood fibres softer which helps the veneer knife to slip through the wood more easily. The more easily knife cuts through the wood, the better the quality of the veneer will be [3].

Veneer that is peeled from preconditioned log will have a smoother surface. Smooth face veneer requires less sanding and reduces glue consumption in plywood production. It also has an impact to the cutting knife because softened knots help reduce knife-wear. In addition there has been observed that log heating before the peeling reduce the lathe check depth in the loose side of the veneer which is directly connected to the veneer quality [3].

Figure 2.3. Grey alder log in the bath

However, there are some disadvantages that are related to the log heating before peeling. Overheating can cause fuzzy veneer surface and heating in dry steam can cause end-checks to the logs [3]. For this research the soaking water temperature was set to 40°C. Soaking time was 24 to 48 hours.

2.2.3 Debarking

Debarking is an essential process before veneer peeling. The debarkers main objective is to remove the bark, but also foreign objects like sand and soil, which are stuck on the log surface and may dull the peeling knife. The bark is removed right down to the cambium by avoiding damaging the log surface [2].

In most of the cases debarking is done after block heating because the bond strength between the wood and the bark decreases when the temperature rises. One of the reasons for that may be the fact that cellular strength in the cambium grows when the temperature drops. Successful debarking also depends on the strength of the bark which varies considerably between different species [2].

Figure 2.4. Debarking process with cutting knife

Rotor debarkers are most widely used in the industry. The cut off bark itself may be used in energy making for the production.

2.2.4 Veneer peeling

After debarking the log it can be mounted on the lathe where veneer peeling was done. The main function of the lathe is to rotate the log by the spindles while the cutting knife carriage, which is laying parallel to the grain, moves towards the log core [2], [35].

Figure 2.5. Veneer peeling with RAUTE lathe

Veneer lathe can be double and triple spindle or without spindles. Double spindle lathe is used for short blocks, while triple spindle lathes are used for longer blocks or softwood blocks. There are also spindleless lathes which have the advantage of cutting down the log into smaller diameter core than lathes with spindles do. Conventionally, lathes with spindles are used [2].

Firstly, the block will be rounded into cylinder shape form. Round-up speed is usually higher and the veneer is thicker than in peeling process. Industrial peeling speed varies between 250-300 m/min and veneer thickness depends on the end use of the veneer. As the peeling process starts, thin sheet of veneer is peeled off as a long continuous ribbon [35]. During that process veneer passes the gap between the pressure bar and cutting knife as it is shown in Figure 2.6.

The presence of the pressure bar in a peeling process is necessary because otherwise the veneer could split away ahead of the knife and the surface would be very rough. The pressure bar compresses the wood so that the gap, through which the veneer must get through, is 80-90% of the nominal thickness of the veneer [35].

Veneer is characterized by the presence of the lathe checks, which appear on the side where the knife cuts. Depth of the lathe checks directly affect the veneers quality. Side where the lathe checks appear is called loose side and side without lathe checks is called the tight side [28]. Figure 2.6 describes peeling parameters of this research.

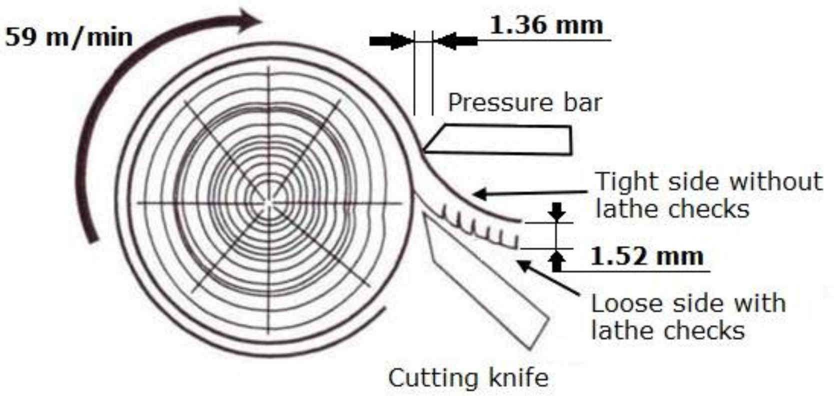


Figure 2.6. Veneer peeling parameters [36]

Peeling process: Block will be taken between the spindles. Spindles start turning and knife carriage will be moved towards the pack. When the peeling knife is close enough then the first step of rounding-up the log can be started. From that moment knife carriage automatically moves towards to the pack and starts peeling 2 mm thick veneer sheet. As soon as pack has reached a cylindrical shape operator has to stop round-up process by himself. Now, the pressure bar has to be locked and peeling process can be started. Veneer was peeled 59 m/min with a thickness of 1.52 mm. Gap between pressure bar and log was 1.36 mm.

2.2.5 Sizing

Sizing is production step where veneer sheets are cut to the required size. Sizing was done with air pressure guillotine PM82. Limiter was fixed to 450 mm from the knife to get veneer sheets with the same size. This step may take place before the drying when it comes to roller dryer.

Figure 2.7. Veneer sizing with guillotine PM82

2.2.6 Veneer drying

Veneer drying is one of the most important step in plywood production. The purpose of drying is to lower moisture content in veneer sheets to the level that is wanted for the gluing operation. Usually plywood production uses veneer sheets that are 2-6% of MC before gluing, but it depends highly on wood species and type of adhesive. Drying temperature has also influence on veneers surface properties. It has been found that smoothest surface is obtained at 150°C for alder veneers [37].

Veneer dryer scheme is outlined in Figure 2.7. It consists of: 1) Fulton water vapour generator, 2) Steam tube, 3) Weighing scale 4) Vaisala DMT346 Dewpoint transmitter, 5) Computer for process monitoring and 6) Temperature regulator.

Figure 2.8. RAUTE Veneer dryer in Laboratory of Wood Technology

Drying process: Water vapour generator (1) has to be switched on. Taps has to be open to ensure that water can freely fill the generators water tank. Vapour pressure can be changed from dedicated button. For this research the water vapour pressure was set to 3.5 bars. At the same time, the veneer dryer can be switched on. Temperature of the dryer can be adjusted with temperature regulators (6). Drying temperature was set to 150°C. When the machines have achieved the required parameters, the steam tube (2) can be opened. Hot water steam is mixed with the hot air in the drying chamber. This mixture of steam and hot air is circulated in the dryer by the generator and pressed through jet tubes onto veneers surface from both sides. Drying chamber parameters, such as temperature and water vapour density, can be monitored from the computer (5).

Laboratory of Wood Technology uses a veneer dryer in which the veneer sheets can be loaded from the top. Three 450*450 mm veneer sheets can be fit into the machine and dried at once. When veneer sheets are loaded into the frame, the drying process can be started. Frame has to be moved to the dryer manually. Now, when the drying process has started, frame with veneer sheets starts to move up and down between the hot steam tubes. At the same time veneer sheets are weighted which can be monitored in the computer.

MC after drying is important. Drying time for certain MC had to find out experimentally. Since the moisture is distributed in the wood unevenly, generalization in one veneer sheet is necessary. Ten veneer sheets form both wood species were dried to 0% of MC. Results were transferred into the time and mass graph where MC percentage in certain time was calculated.

2.2.7 Adhesive mixing and veneer gluing

In this research, two different adhesives were used: 1) PF and 2) LPF. Both adhesives were mixed together in the proportions prescribed by the manufacturer. For adhesive mixing three components are needed: 1) resin, 2) hardener and 3) water. The two adhesive resin and hardener properties are described in Table 2.1 and 2.2.

Table 2.1 Specification of PF adhesive components [38]

Specification	**Prefere 14J021 resin**	**Prefere 24J662 hardener**
Product type	Liquid	Solid (powder)
Information on ingredients, %	Phenol, polymer with formaldehyde ≥25 - ≤50 Sodium hydroxide ≤10 Methanol ≤0.3 Formaldehyde <0.1	Limestone ≥25 - <50 Cellulose ≥10 - <25 Sodium carbonate ≥5 - <10 Starch ≥5 - <10
Applications	Woodworking industry	

PF adhesive recipe: 68 wt. % Prefere 14J021 resin is mixed with 14 wt. % of Prefere 24J662 hardener and 18 wt. % of water. All those components were mixed together with a dedicated stirrer.

Table 2.2 Specification of LPF adhesive components [39]

Specification	Prefere EXPH 051 resin	Prefere EXPH 9500 hardener
Product type	Liquid	Solid (powder)
Information on ingredients, %	Phenol, polymer with formaldehyde ≥10 - <25 Sodium hydroxide ≥5 - <10 Methanol ≥0,1 - <0,3	Starch ≥25 - <50 Limestone ≥25 - <50 Cellulose ≥5 - <10 Sodium carbonate ≥5 - <10
Applications	Woodworking industry	

LPF adhesive recipe: 73 wt. % Prefere EXPH 051 resin is mixed with 13 wt. % of Prefere EXPH 9500 hardener and 14 wt. % of water. Components were mixed together with VELP scientifica stirrer as it is shown in Figure 2.8.

Figure 2.9. Adhesive mixing

Adhesive consumption was set to 150 g/m^2. In total, 2.3 kg PF adhesive and 2.3 kg LPF adhesive was made. It included a 1.5 coefficient for the loss of adhesive in the process.

Gluing operation was done with roller glue machine. This machine covers veneer sheets with adhesive one by one from both sides, which means that the second, fourth and sixth sheet in the panel will be covered with adhesive. Veneer layers are put together perpendicularly up to another.

Figure 2.10. Black Brothers roller gluing machine filled with adhesive

Figure 2.11 describes the veneer band after peeling and how the plywood panel is put together. Darker colours are a mark the outer part of the wood and lighter colours mark the core wood. The numbers show the veneers sheets that are used for making one plywood panel. Veneer sheets with numbers 1, 3, 5 are used for making plywood panels with PF adhesive and 2, 4, 6 are used for making plywood panels with LPF adhesive. This is necessary to get plywood panels with similar wood properties as possible.

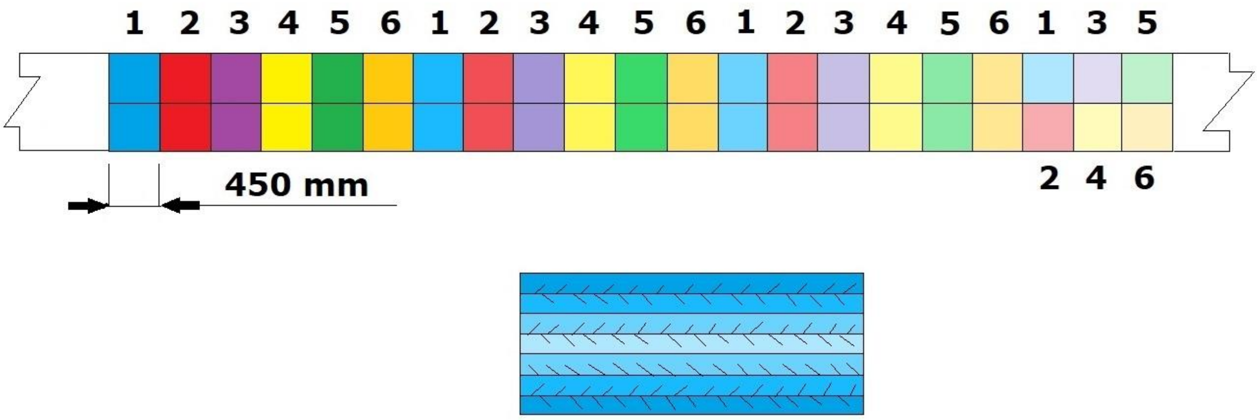


Figure 2.11. Veneer sheets placement in a 7-ply plywood panel

2.2.8 Pressing

Generally the plywood production industry uses cold press prior to final pressing in the hot press. This action makes panel loading to the hot press easier and reduces veneer sheets from shifting. Factories are also using plywood presses with multi openings, where up to 40 plywood panels can be pressed simultaneously. Two main purposes of pressing procedure are: 1) bringing the veneer layers tightly together 2) to heat the adhesive to the temperature which is required for resin polymerization.

In this research, only hot pressing was used to produce plywood panels. After gluing, the glued veneer sheets are loaded between the hot plates. Pressing procedure was started manually from a dedicated button. Pressing time was calculated according to Equation 2.1 and temperature was set to 130°C. Pressure changed automatically according to the program: 75 seconds pressure was 1.8 MPa, 375 seconds pressure was 1.4 MPa and 90 pressure was 0.4 MPa. All plywood panels were made with same pressing parameters.

$$\text{Pressing time}=3\text{ min}+0.5*\text{thickness of plywood panel (mm)} \quad (2.1)$$

Figure 2.12. INFOR hydraulic hot press

When the pressing cycle ends, hydraulic press opens instantly. Plywood panel has to be removed as quickly as possible to avoid burning.

The plan was to make 6 plywood panels per day as it is shown in Table 2.1. Unfortunately, some complications arose with the plywood panels that were made from veneer sheets with 8-12% of MC. In that MC range, only 4 out of 12 plywood panels were made successfully. Figure 2.11 illustrates the problem that occurred after pressing veneer sheets in which the MC was too high. Water stared boiling during the pressing and caused a vapour bubble that caused buckling.

Figure 2.13. Example of buckled plywood panel after pressing

After pressing, plywood panels were marked according to the marking system and cut to dimensions of 400*400 mm with a table saw.

2.3 Analysis methods

2.3.1 Contact angle measurements

CA is the angle that forms between the body of a liquid substance and a solid surface interface. It is used to determine the surface tension of a liquid and for calculating the surface free energy which helps to predict adhesion properties. This is geometrically described in Figure 2.14 [2], [40].

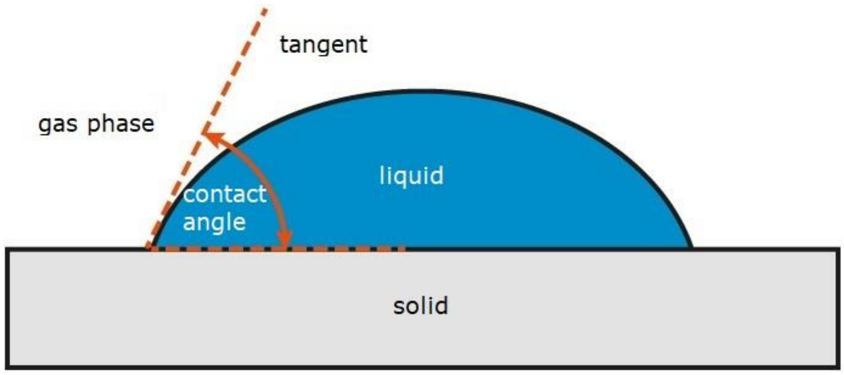


Figure 2.14. Contact angle formation between a solid surface and a liquid [41].

Tangent is drawn from the contact point along the gas-liquid-solid interface. If the CA between a solid and a liquid is smaller than 90° then the liquid will wet the surface and spread over it. If the CA is over the 90° the liquid will stay on the surface as a droplet. CA highly depends on the nature of the liquid that is placed on the surface, but also on the characteristics of the solid surface itself [40].

Because of the nature of wood is anisotropic and quite complex, it makes the CA measurements more difficult. There are many characteristics that may affect the measurements. Porosity, surface roughness, chemical heterogeneity, hygroscopic nature and extractives are some factors that may affect the results. In addition to these characteristics, measurements are dependent on time. Drop of a liquid is absorbed into the surface and the size of the drop is in constant change [42].

2.3.1 Sessile drop method

The method of measuring CAs is called sessile-drop goniometry. Instrument, that was used for this research was a video-supported contact angle measuring instrument Data Physics OCA 20. This device is connected to the computer where the process can be monitored at a live screen and subsequently analysed with software SCA 20. Testing system consisted of 1) syringe units for liquid dosing, 2) measuring stage which is adjustable in three axis, 3) lens mount with adjustable tilt, 4) six-fold power zoom lens, 5) video system with adapter and camera, 6) back lighting, 7) built-in digital temperature display and 8) screen presenting the image [42].

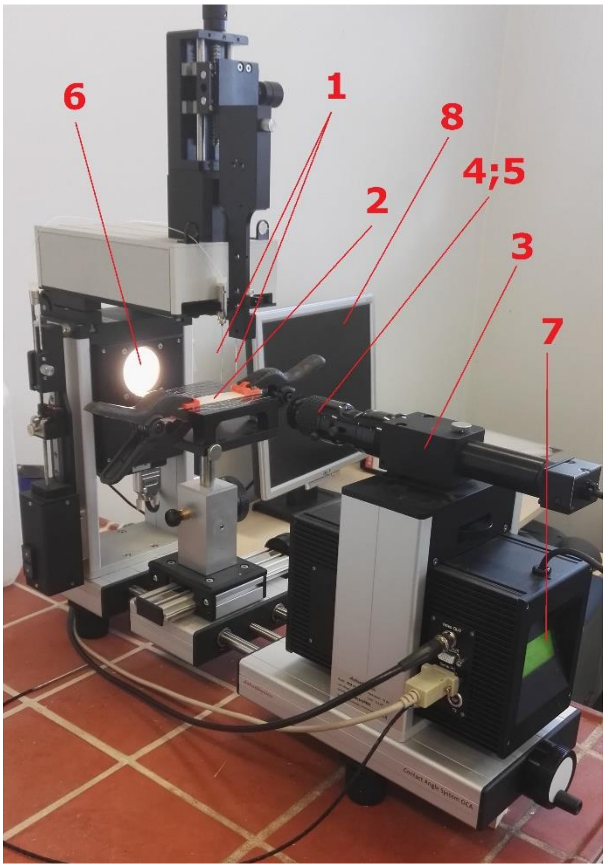


Figure 2.15. Data Physics OCA 20 contact angle measuring instrument

Aim of this test was to measure the CAs for the veneers that were cut from different logs and compare the results of grey alder and black alders wettability of dried veneer with different liquids. Comparing the veneers was done based on European standard EVS-EN 828:2013 [31]. Three solutions were chosen for testing: water, glycerol and ethylene glycol.

Preparation of test procedure: The measuring instrument and analysis software SCA 20 needs to be switched on. Veneer sample is placed on the stage and fixed with the claps. The sample that is placed on the stage, has its grain direction crosswise to the cameras filming direction. This is necessary because otherwise the liquid drop may get stuck on the peak and this affects the results [31]. Veneer sample has to be fixed straight and properly to avoid its possible movement. Testing syringe is filled with the liquid and attached to its place. The image has to be as sharp as possible, it can be adjusted with zoom.

Test procedure: After the steps above, the preparation specimen is ready for testing. One drop of liquid is dripped onto the specimen. The video needs to be at least 15 seconds [31]. 20 seconds was the set time limit in this research. Video was replayed and CAs were measured from droplet formation and after every second with the software.

For the calculations it is important to collect and to get the average of the CAs measured during the test. Surface tension, disperse and polar proportion for each liquid are given data in EVS-EN 828:2013 [31].

For the surface free energy calculations the Young-Dupre formula is needed. The Young-Dupre formula 2.1 defines the work of adhesion obtained during wetting:

$$Wad = \sigma L + \sigma L * cos\Theta = \sigma L * (1 + cos\Theta) \tag{2.2}$$

Where,

σL is surface tension,

cos θ is the measured contact angle average [31].

Next, the surface free energy was calculated according to the formula 2.2.

$$\gamma_{SL} = \sigma_S + \sigma_L - 2 * \left(\sqrt{\sigma_S^D * \sigma_L^D} + \sqrt{\sigma_S^P * \sigma_L^P} \right) \tag{2.3}$$

Where,

σ_S is equal to work of adhesion;

$\sqrt{\sigma_S^D * \sigma_L^D}$ is disperse proportion,

$\sqrt{\sigma_S^P * \sigma_L^P}$ is polar dispersion [31].

2.3.2 Veneer crosswise tensile strength

Tensile strength shows the maximum amount of force that the material can withstand before it breaks. As a part of this research, dried veneers crosswise tensile strength was tested. The purpose of the test was to compare dried grey alder and black alder veneer tensile strength properties. Tensile strength is calculated according to the formula 2.3. It shows the force per cross-section area and its unit of measure is N/mm^2.

Tensile strength was measured with Instron 5866 (in Figure 2.21). Parcel distance was set to 50 mm, tensile speed was 10 mm/min and force sensor 500 N.

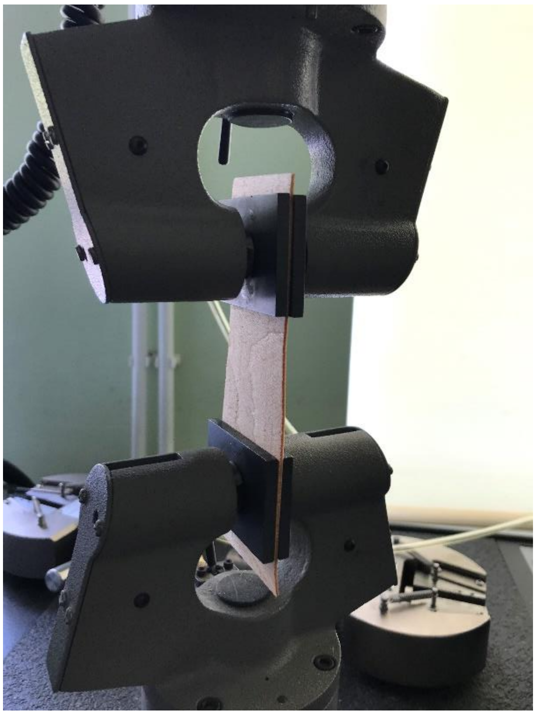


Figure 2.16. Veneer cross-section tensile strength test with Instron 5866

For this test, the specimens were cut with a guillotine right after drying process and marked according to the wood species and percent of MC. For each MC range five tensile strength specimens were selected. Specimens were hermetically sealed into a plastic bag for the time of testing. In total, 30 pcs of specimens were tested.

Test procedure: Specimen needs to be fixed between the clamps of the Instron 5866. Test has to be start manually by giving a command on the computer or console. Upper claw starts to tensile the specimen as long as it cracks and then the computer calculates the force. Specimen width and thickness was measured as close to the cracked parts as possible.

For tensile strength calculations the maximum load was divided with the sum of multiply of width and thickness. The formula is shown in equation 1.

$$\sigma = \frac{F}{A} \tag{2.4}$$

Where,

F is maximum load, N

A is width and thickness multiplied, mm^2.

2.3.3 Shear strength of the adhesive joint

Shear strength shows the load that an item is able to withstand in a parallel direction to the face of the material. Adhesives tends to have a high shear strength. Plywood shear strength shows its ability to resist forces that cause the internal structure of the veneers to slide. Shear strength test of the adhesive joint was performed according to the European standards EVS-EN 314-1:2005 [32] and EVS-EN 314-2:1999 [33]. Plywood specimens were pre-treated according to class 2 requirements.

Figure 2.17. Shear strength specimen testing with Instron 5866

For this test, 6 specimens were cut form 400*400 mm plywood panels according to the cut out plan Figure 2.2. Ten test pieces were cut out from each plywood panel. In total 168 shear strength specimens were cut out from 28 plywood panels. Shear strength speed was 10 mm/min and force sensor 10 kN.

Test procedure: Test pieces were directed to the pre-treatment after cutting. Pre-treatment included 24 hours immersion in water (at 20±3°C). Afterwards specimens were sent to immerse for 6 hours is boiling water, which was followed by cooling water (at 20±3°C), for at least 1 hour [32]. After pre-treatment, specimens were tested with Instron 5866 one by one, similarly to the tensile test.

Shear strength is calculated with a formula shown in equation 2.4.

$$\tau = \frac{F}{A} \quad (2.5)$$

Where,

τ is shear strength,

F is force applied,

A is the cross-sectional area of material with area parallel to the applied force vector [32].

2.3.4 Bending strength of the plywood

Bending strength shows the materials ability to resist deformation under load. Most frequently, the transverse bending test is used by applying a three-point flexural test technique. Specimen is placed equally on the supports and force is applied in the centre of the specimen until it breaks. Force and extension is registered by the computer. This test was performed with universal testing machine Instron 5866 and according to standard EVS-EN 310:2002 [34].

Figure 2.18. Plywood specimens bending strength test with Instron 5866

Plywood is a complex and an anisotropic material. Its layers always have their wood grain rotated up to 90° to one another which also affects its strength properties in different directions. For this purpose, bending strength was tested both directions – 1) force is applied to the outer part perpendicularly to the grain direction and 2) force is applied to outer part longitudinally to the grain direction.

For the bending strength test, 4 test pieces were cut out from 400*400 mm plywood panel according to the cut out plan Figure 2.2. In total, 112 specimens were tested. Bending speed was 10 mm/min and force sensor 10 kN.

Test procedure: Two contrivances were attached to the claws of Instron 5866. The test piece was put on top of the lower supports with the span set to 140 mm. When the test was started and force was applied to the specimen until its rupture. Computer registered the force that was applied and extension of the specimen in every single unit of time until the breakage. Afterwards, results were used to calculate bending strength and Modulus of elasticity (MOE) of the plywood specimens.

$$fm = \frac{3 * F_{max} * l_1}{2 * b * t^2} \qquad (2.6)$$

Where,

F_{max} is maximum compressive load, N

l_1 is distance between centres of supports, mm

b is the width of specimen, mm

t^2 is thickness of the specimen, mm [34].

3 RESULTS AND DISCUSSION

3.1 Veneer crosswise tensile strength

Cross section tensile strength was tested for both, grey alder and black alder veneers, that were dried in certain MC ranges and were used in plywood panels. In every MC range, tensile strength of 5 specimen was tested and an average tensile strength was calculated. The following Figure 3.1 describes the results of the cross section tensile strengths.

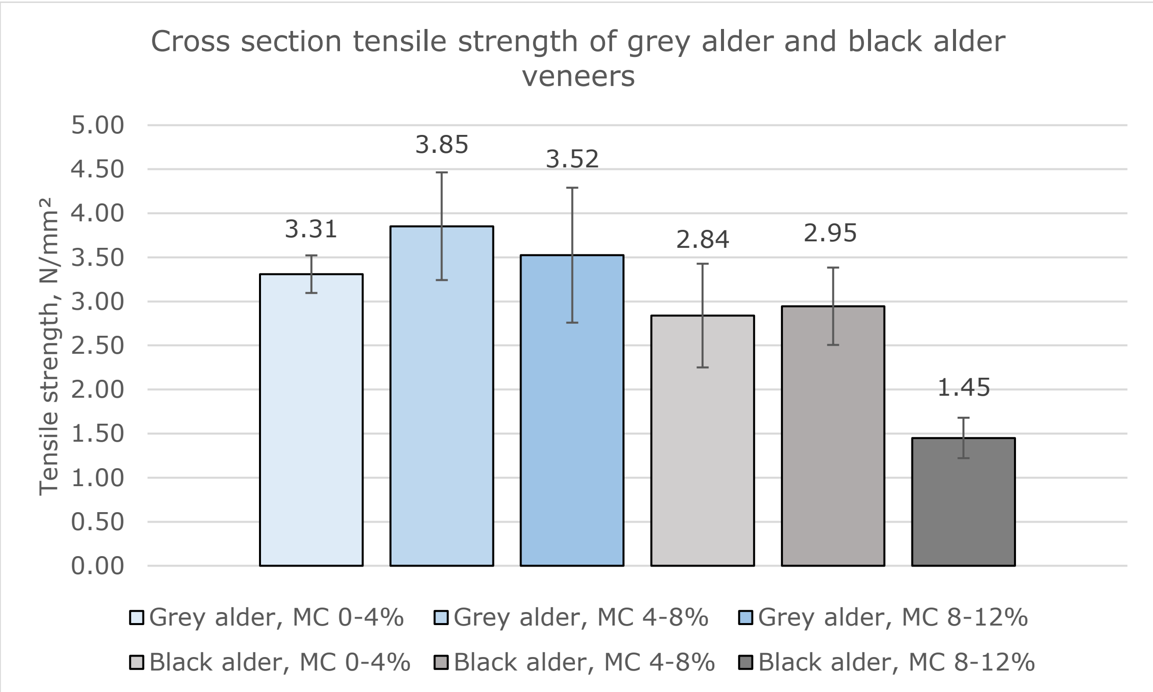


Figure 3.1. Cross section tensile strength of the veneers

Test results show that grey alder veneer can withstand greater stress than black alder veneer when it is torn apart. The test shows that grey alder veneer test pieces, in between every MC range that they were dried, showed higher tensile strength compared to the black alder specimens.

The highest tensile strength according to the test was measured in grey alder veneers with 4-8% of MC, where the 5 test piece average was measured 3.85 N/mm^2 while the lowest tensile strength was measured in black alder specimens with 8-12% of MC, where average strength was only 1.45 N/mm^2. Unfortunately, plywood making from black alder veneer with 8-12% MC failed and it remains unclear why it showed the lowest tensile strength and how it would have acted in plywood.

According to the wood strength data as it is shown in the Table 1.1 and 1.2 it can be seen that grey alder could have higher tensile strength. It have been also found in previous research that grey alder has higher tensile strength [43]. These results are in correlation with this thesis experimental results where grey alder cross-wise tensile strength showed higher tensile strength.

3.2 Contact angle measurements

CA measurements can be used to describe the wetting properties of the veneer surface. Wetting properties were evaluated with three different liquids selected from European standard EVS-EN 828:2013 [31]. Liquids that were used for wettability tests and for CA measurements were distilled water, ethylene glycol and glycerol.

In this test, two different wood species, grey alder and black alder, veneers with three different MC range were tested. From each liquid ten drops each of three different liquids were dripped onto veneer surface. Test specimens were selected form five different veneer sheets. Liquid absorption was evaluated during 20 seconds and CA change was measured after every second. After measurements, average results were used to calculate adhesion characterizing parameters.

Following three charts describe CA change in time.

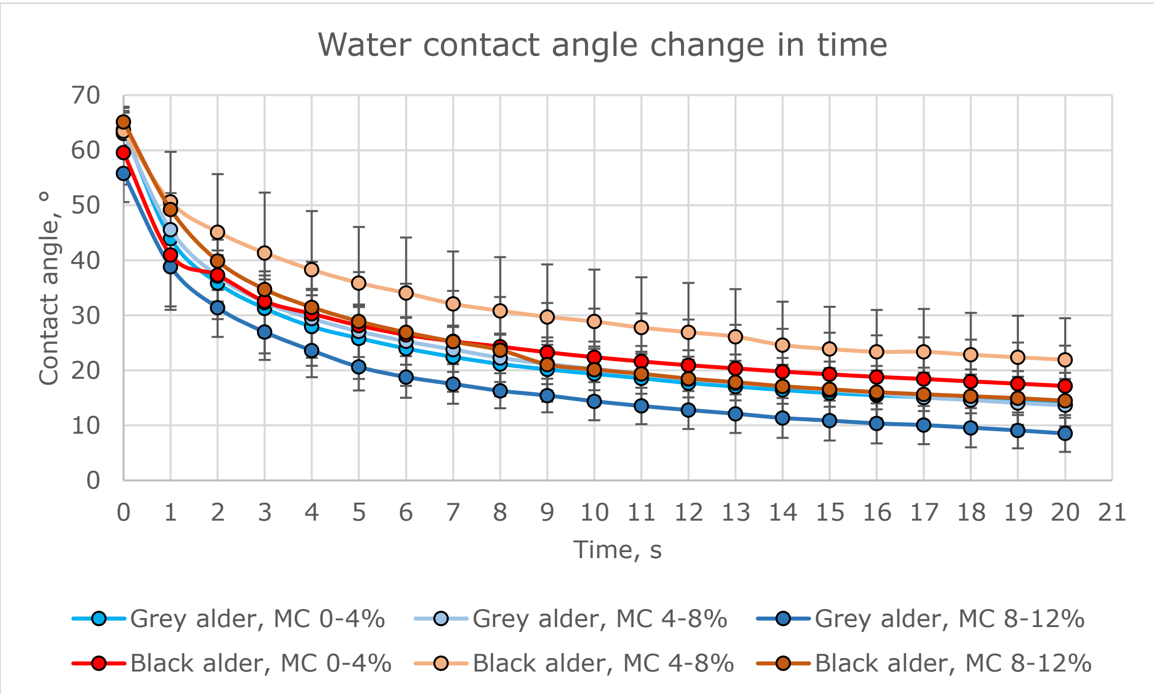


Figure 3.2 Water contact angle curves change on veneers surface during 20 seconds

The biggest CA that was measured with distilled water was measured 65° that formed on black alder surface with MC of 8-12%. The lowest CA that were measured was 55° which formed on grey alder surface with MC of 8-12%. All other CA that were measured were in range between 55°- 65°with small differences. Water absorption was greatest during the first second, after which water absorption gradually decreased. Water absorption can be considered fairly even in all specimens.

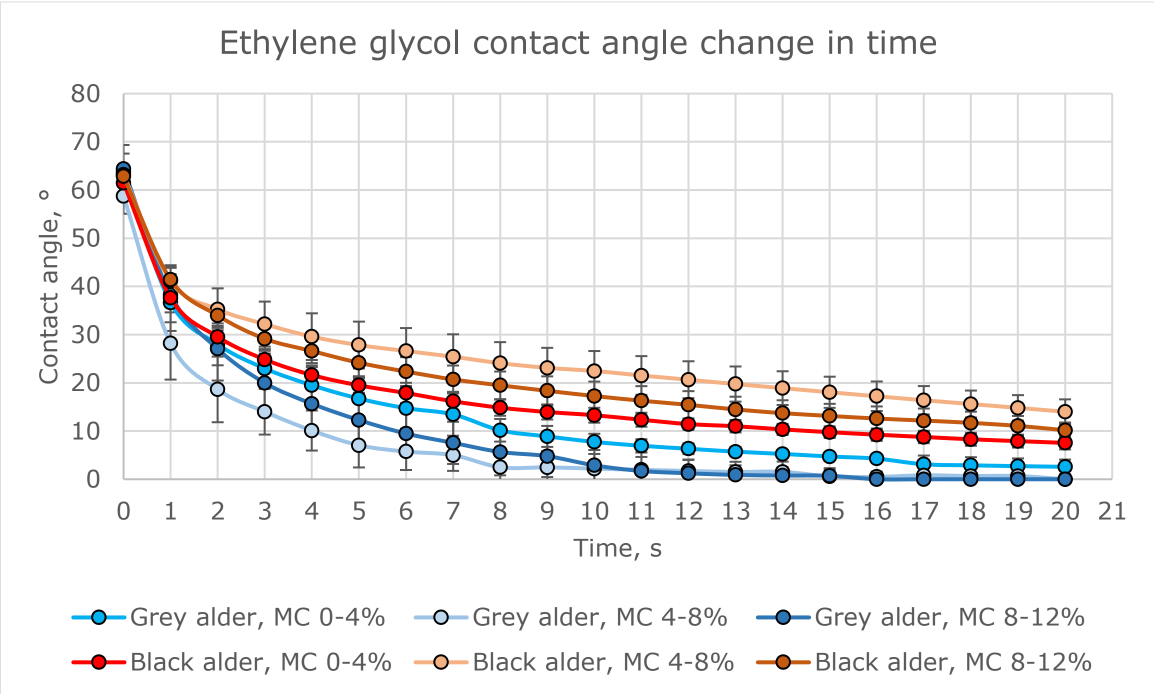


Figure 3.3 Ethylene glycol contact angle curves on veneers surface during 20 seconds

The biggest CA measured with ethylene glycol, was 64°, which formed on grey alder 8-12% of MC. The lowest CA was 58° which formed on grey alder 4-8% of MC. At the time of the ethylene glycol droplet formation, CAs were numerically closer than they were with water. Liquid absorption was greatest during first second after that, it decreased significantly.

Wettability test with ethylene glycol showed that grey alder absorbs liquid faster than black alder. This can be concluded, because in two cases ethylene glycol completely absorbed into the surface and CA could not be measured in last seconds while liquid droplet remained on the black alder surface in all three cases.

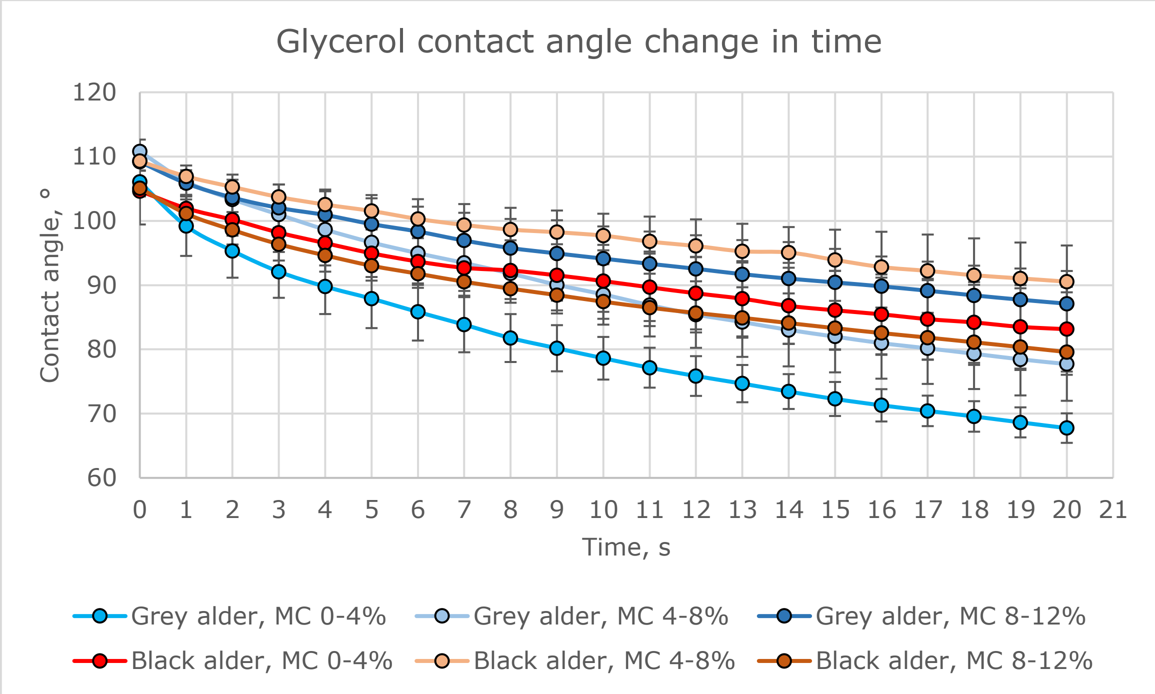


Figure 3.4 Glycerol contact angle curves on veneers surface during 20 seconds

Wettability test with glycerol showed that liquid absorption was greatest in grey alder specimen with 0-4% of MC. Liquid absorption was slowest in black alder with 4-8% of MC. In other cases glycerol absorption was fairly even.

Average CA was calculated for every liquid. Average results were used to calculate surface free energy for grey alder and black alder veneers. Following chart describes the surface free energy results of two different wood species with different MC.

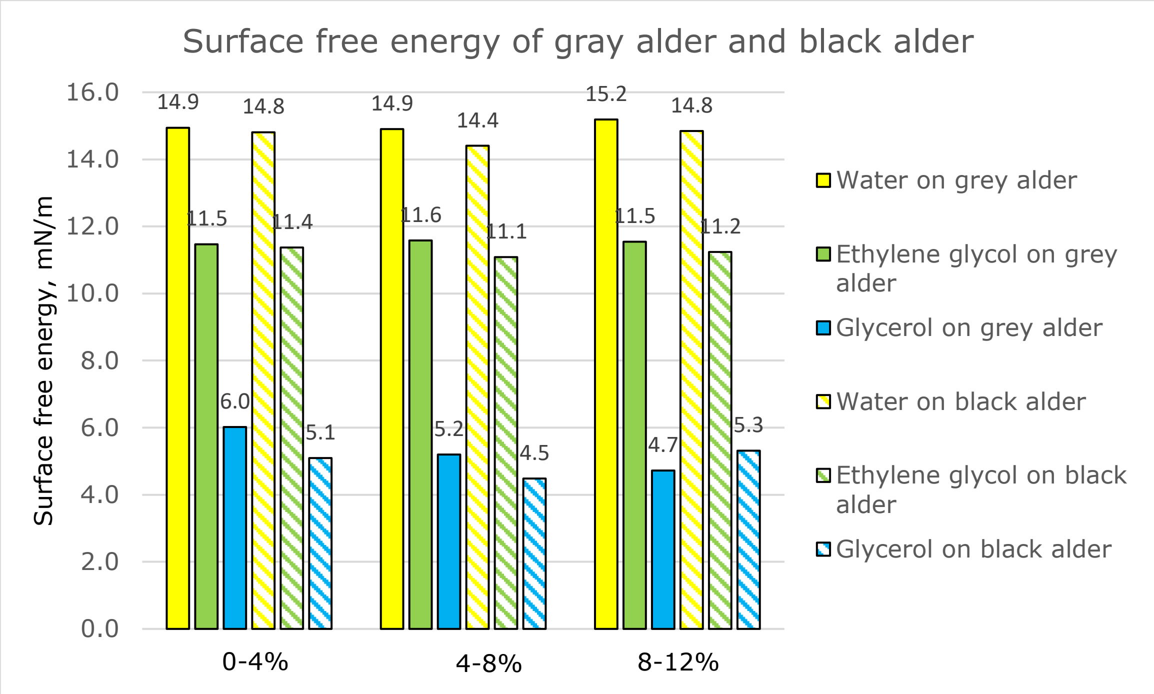


Figure 3.5 Surface free energy of grey alder and black alder veneers with different MC

Surface free energy calculations show that there is no significant difference between grey alder and black alder surface properties. Greatest surface free energy was measured grey alder with 0-4% of MC and the lowest surface free energy has black alder with 4-8% of MC.

Test results show that grey alder veneer has slightly greater surface free energy than black alder veneer. It means that greater work needs to be done to increase the liquid absorption on surface per unit. According to those results, grey alder and black alder veneer surface is quite similar for adhesion.

3.3 Shear strength of the adhesive joint

Purpose of this test was to assess how moisture content of the veneer affects bond quality in the plywood. The second aim was to determine which moisture content is most favourable to make plywood from those wood species. Veneers were dried in three different MC range and they were glued together with two different adhesives.

Specimens were processed according to European standard EVS-EN 314-2:1999 [33]. Shear strength test pieces were boiled in the water for 6 hours and afterwards soaked in the cold water for 24 hours. This kind of treatment should meet 2nd class plywood, which corresponds to the humid conditions of use [33].

Following charts describe grey alder and black alder veneer moisture content effect on shear strength.

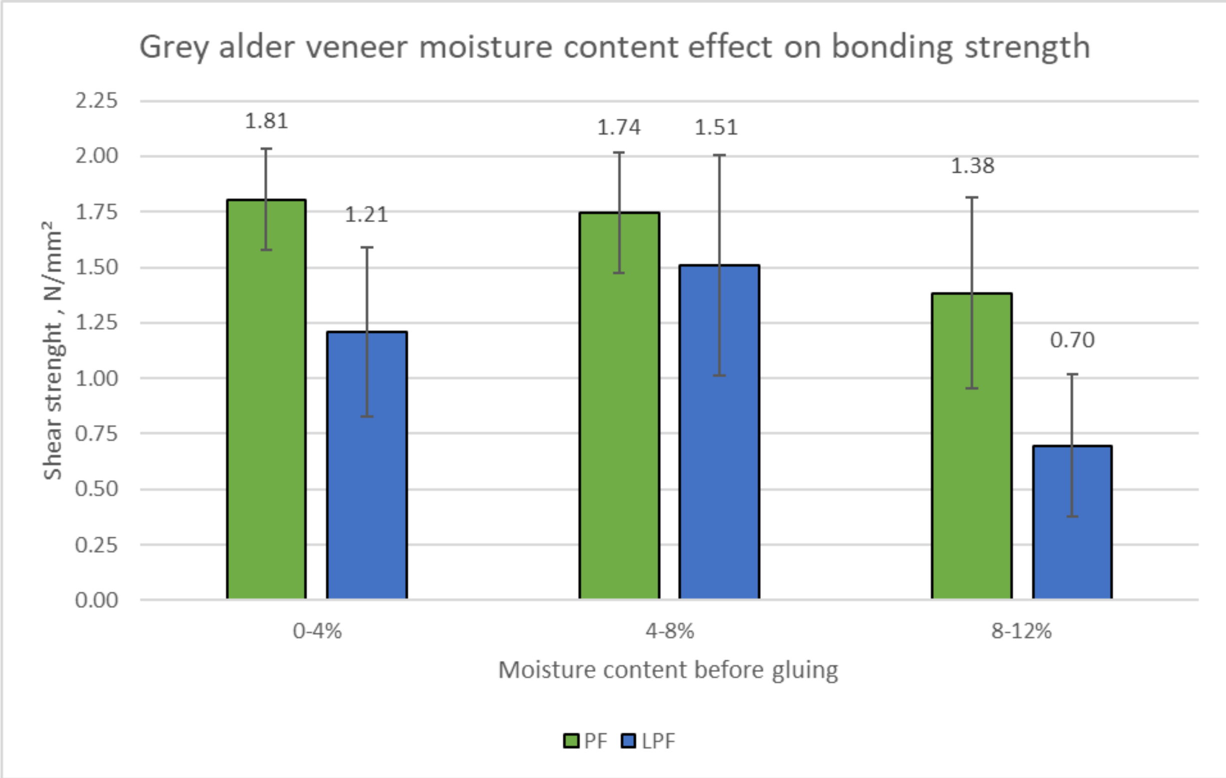


Figure 3.6 Grey alder veneer MC effect on shear strength

As it is shown in Figure 3.6 MC has a significant effect on the bond quality. MC ranges between 0-4% and 4-8% are more favourable for making plywood panels. PF and LPF adhesives both showed that shear strength is lower on plywood panels that were made from veneers 8-12% of MC. This was also confirmed by plywood pressing failure. Three plywood panels out of six were made successfully.

Bonding quality was the best with the veneers that were 0-4% of MC before gluing and by using PF adhesive. However LPF showed that most favourable is MC range between 4-8%.

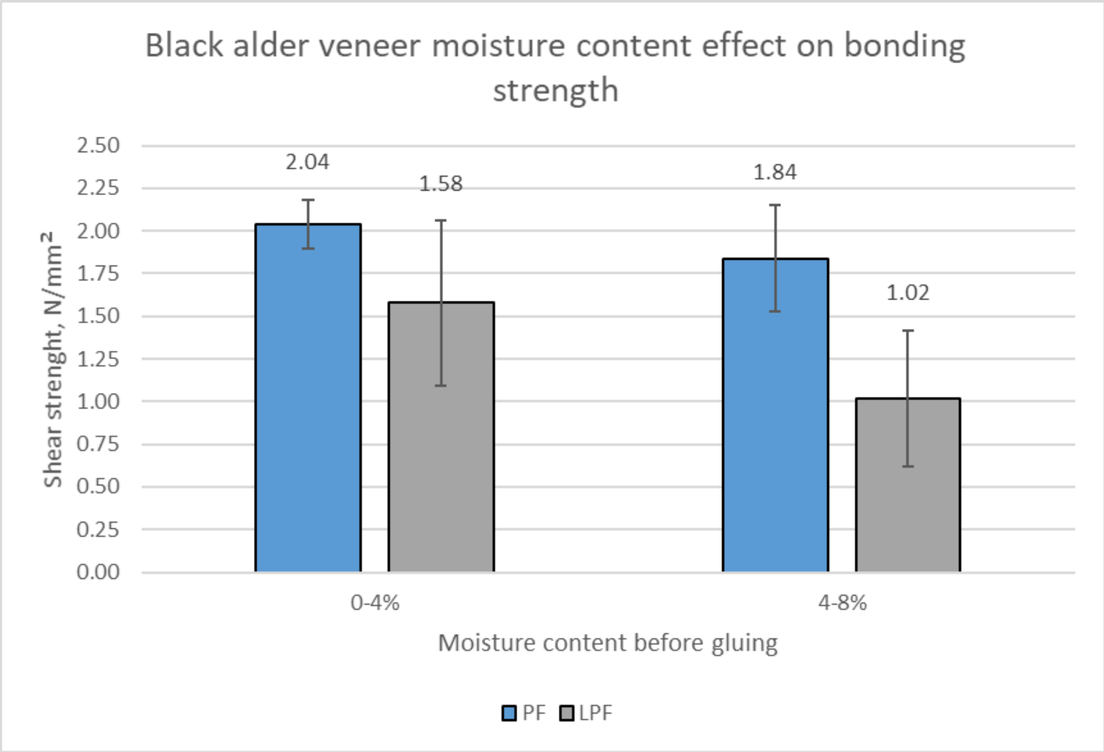


Figure 3.7 Black alder veneer MC effect on shear strength

Shear strength tests with black alder specimens showed that lower moisture content of the veneer before gluing is more favourable. Making plywood panels from the veneers with 8-12% of MC failed completely.

Comparing to those two adhesives, PF showed considerably better results than LPF in the bonding test. It may be affected due to the pressing parameters which were same in both cases.

Based on different studies, it is stated that water affects the adhesive penetration. Wood with high MC will not absorb water and resin as effectively as wood with low MC. As a result of that, the plywood panel begins to accumulate water vapour pressure while hot pressing. That was also the main cause why gluing together veneers with 8-12% of MC failed.

In every case, PF showed better results than LPF adhesive. It might have been caused due to using same pressing mode for both adhesives, while LPF may need longer curing time.

The highest shear strength was measured on black alder plywood that was made of veneers 0-4% of MC. The average of six specimens was measured 2.01 N/mm^2 which is 11% higher than highest grey alder result. This result is also approximate to the research where influence of the birch veneer densification on shear strength was measured [44]. Adhesion consumption was 150 g/m^2 and specimens were treated according to EN 314-2 class 2 requirements. 7 –ply plywood made of non-densified birch veneers was measured 2.03 N/mm^2 [33], [43].

Table 3.1. Plywood bonding quality

No.	Specimen id.	Max. Load (N)	Shear strength (N/mm^2)	Wood failure, (%)	Result
1	I1	1128.76	1.81	80	Pass
2	I2	756.71	1.21	20	Pass
3	J1	1090.41	1.74	82	Pass
4	J2	943.14	1.51	29	Pass
5	K1	864.14	1.38	0	Pass
6	K2	434.45	0.7	0	Fail
7	X1	1274.43	2.04	90	Pass
8	X2	987.51	1.58	8	Pass
9	Y1	1149.51	1.84	46	Pass
10	Y2	636.65	1.02	4	Pass

Plywood bonding quality can be evaluated by shear strength and wood failure. When shear strength is bigger than 1 N/mm^2 [33] then it can be considered as successful bond. According to the plywood bonding quality test, most of the specimens passed the test, expect plywood panels that were made of the veneers with 8-12% of MC and with LPF adhesive, where shear strength was 0.7 N/mm^2. Next chapter brings out percentage of wood failure more precisely.

3.3.1 Percentage of wood failure

Percentage of wood failure is determined by visual observation of shear strength specimens. Observation is determined according to European standard EVS-EN 314-1:2005 [32]. Adhesive-wood bond strength exceeds the strength of wood when the failure occurs in the wood. From this, it may be inferred highest shear strength results should respond to highest percentage of wood failure.

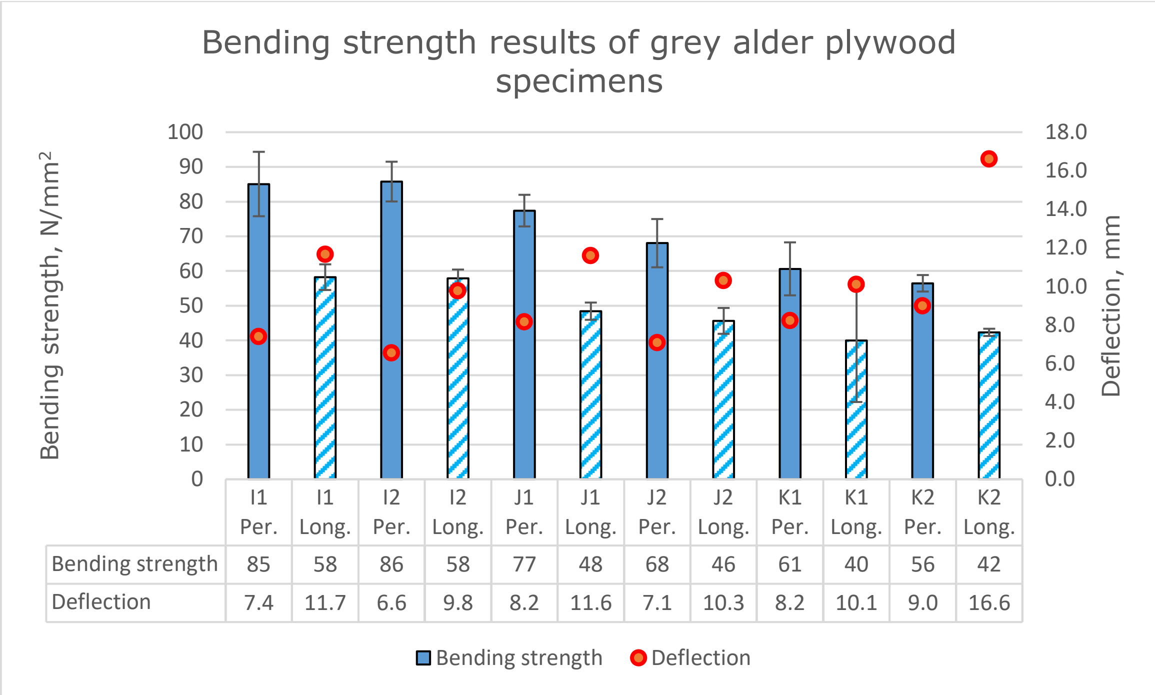
Figure 3.8 Effect of veneer moisture content on percentage of wood failure

As it is shown in the figure, the highest percentage of wood failure was evaluated with specimens with PH adhesive. Black alder specimens gave the best result, where wood failure occurred on average 90% in wood. Grey alder specimens with moisture content 0-4% and 4-8% gave quite a similar result of the wood failure, while the effect of moisture content was greater in black alder specimens.

These results correspond well with shear strength results. LPF specimens showed very small failure of wood. Most of the breakage took place in an adhesive joint.

3.4 Bending strength of the plywood

Purpose of this test was to get to know how veneer MC affects the plywood panel bending strength properties and how big that impact is. Bending strength test was carried out by testing specimens from both grain directions: perpendicular and longitudinal. Following figures describe the results of the bending strength of grey alder and black alder plywood specimens.

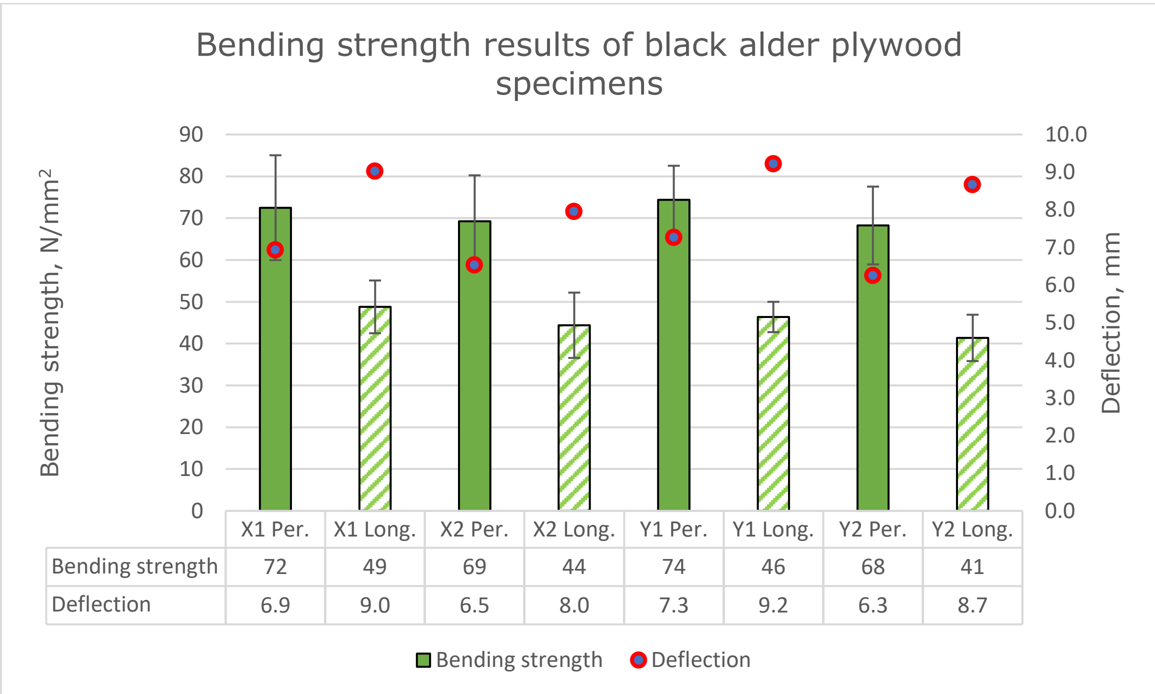


	I1 Per.	I1 Long.	I2 Per.	I2 Long.	J1 Per.	J1 Long.	J2 Per.	J2 Long.	K1 Per.	K1 Long.	K2 Per.	K2 Long.
Bending strength	85	58	86	58	77	48	68	46	61	40	56	42
Deflection	7.4	11.7	6.6	9.8	8.2	11.6	7.1	10.3	8.2	10.1	9.0	16.6

Figure 3.9 Bending strength of grey alder plywood specimens

Grey alder plywood bending strength test shows that plywood that was made from the veneers with 0-4% of MC has highest load per mm^2. This result is confirmed with both adhesives. Plywood that was made from the veneer 8-12% of MC has approximately 70% of the strength of the highest result.

When comparing two adhesives, PF shows better results in every test. It may be caused because of the hot pressing time of the panels.



	X1 Per.	X1 Long.	X2 Per.	X2 Long.	Y1 Per.	Y1 Long.	Y2 Per.	Y2 Long.
Bending strength	72	49	69	44	74	46	68	41
Deflection	6.9	9.0	6.5	8.0	7.3	9.2	6.3	8.7

Figure 3.10 Bending strength of black alder plywood specimens

Black alder bending strength results show that plywood, which was made from veneers with 4-8% of MC, has the highest bending strength. Black alder bending strength overall results are more even than grey alder plywood bending strength results.

Previous studies have presented that bending strength of birch plywood is 78 N/mm^2 [45]. Comparing the two results, the perpendicular bending strength of grey alder and black alder is quite similar, exception being grey alder plywood that was made of the veneers 0-4% of MC, where highest bending strength was measured. 86 N/mm^2 is 14% higher than black alder plywood highest result. This is somewhat surprising since black alder should have greater wood density according to the literature. Reason for this highest result remain unclear.

3.4.1 Modulus of elasticity

MOE is measure of stress-strain relationship which helps to evaluate material stiffness. Following charts describe grey alder and black alder plywood specimens MOEs.

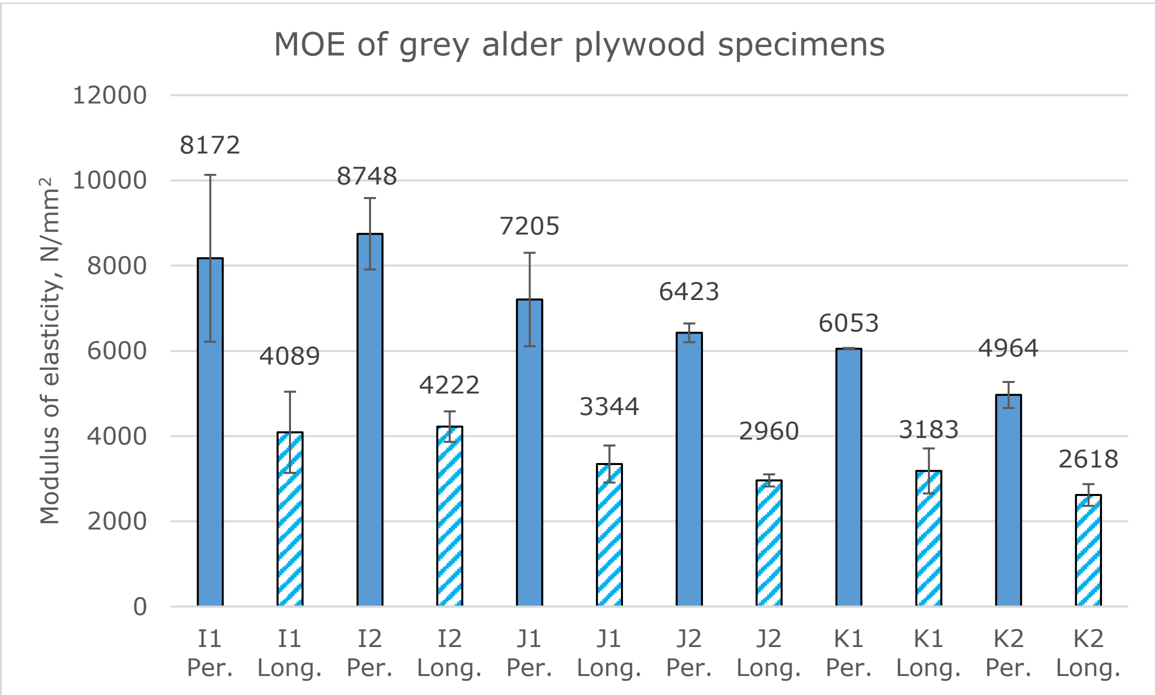


Figure 3.11 Modulus of elasticity of grey alder plywood specimens

As it is shown in Figure 3.10 the best results came out of the specimens that were made with veneers with lower MC. The best result was measured in grey alder plywood that was made form veneers 0-4% of MC. However, fluctuation of results is also quite high based on standard derivation calculations.

Black alder plywood specimens show much more consistent results compared to the grey alder specimens. Average MOE of black alder plywood specimens is lower than grey alder specimens. There are no noticeable differences between plywood panels that were made 0-4% of MC and 4-8% of MC. MOE of black alder are described in following Figure 3.12.

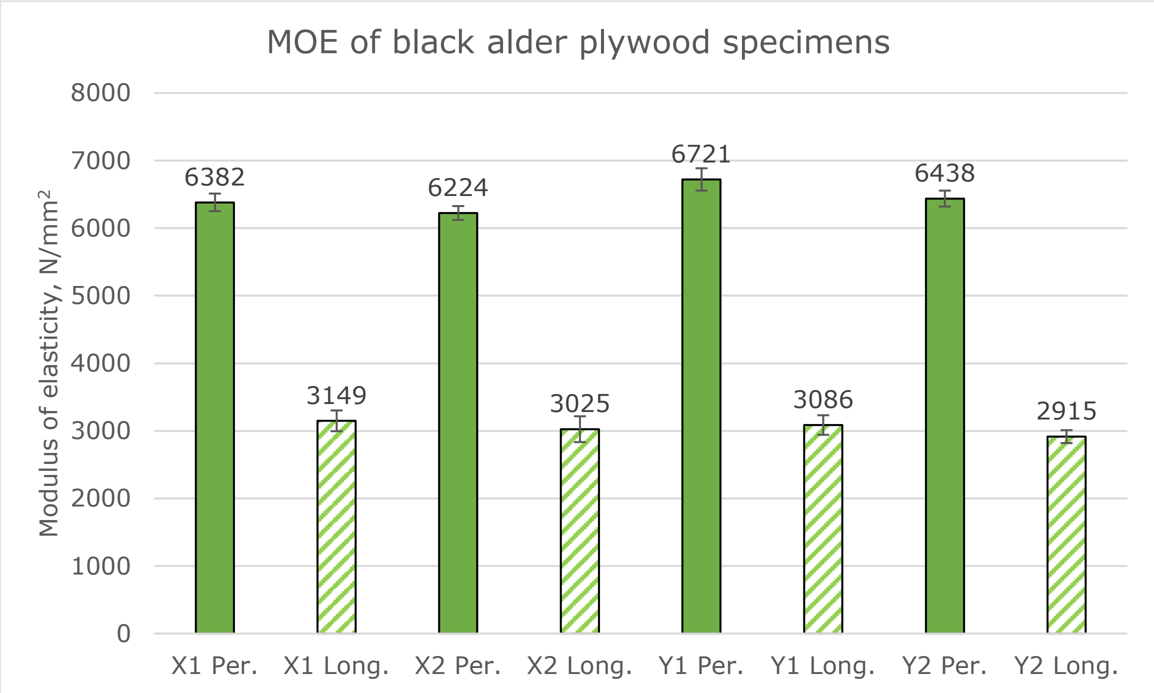


Figure 3.12 Modulus of elasticity of black alder plywood specimens

Based on previous research, plywood that is used in cargo containment system MOE was measured 6278 MPa perpendicularly and 4849 MPa longitudinally [46]. Comparing these results with the results of this work, it turns out black alder plywood perpendicular MOE remains same magnitude, while longitudinal MOE is 35% smaller.

Following Table 3.2 brings out the plywood panel classes of the plywood panels that were tested in this research. Plywood panel classes are determined according to the European standard EN 636 [47].

Table 3.2. Plywood panel classes according to the European Standard EN 636 [47]

Panel marking	Adhesive type	Grain direction	Bending strength, (N/mm^2)	Class	MOE, (N/mm^2)	Class	EN 636 Plywood panel class
I	1	Per.	85	F50	8172	E90	F50/35 E90/40
		Long.	58	F35	4089	E40	
	2	Per.	86	F50	8748	E90	F50/35 E90/40
		Long.	58	F35	4222	E40	
J	1	Per.	77	F50	7205	E80	F50/30 E80/35
		Long.	48	F30	3344	E35	

Table 3.2. Sequel

Panel marking	Adhesive type	Grain driection	Bending strength, (N/mm^2)	Class	MOE, (N/mm^2)	Class	Plywood panel class
J	2	Per.	68	F40	6423	E70	F40/30 E70/30
		Long.	46	F30	2960	E30	
K	1	Per.	61	F40	6053	E60	F40/25 E60/35
		Long.	40	F25	3183	E35	
	2	Per.	56	F35	4964	E50	F35/25 E50/25
		Long.	42	F25	2618	E25	
X	1	Per.	72	F40	6382	E70	F40/30 E70/30
		Long.	49	F30	3149	E30	
	2	Per.	69	F40	6224	E60	F40/25 E60/30
		Long.	44	F25	3025	E30	
Y	1	Per.	74	F40	6721	E70	F40/30 E70/30
		Long.	46	F30	3086	E30	
	2	Per.	68	F40	6438	E70	F40/25 E70/30
		Long.	41	F25	2915	E30	

CONCLUSIONS

The aim of this research was to evaluate how MC of the grey alder and black alder veneers affects plywood strength properties. There were three different MC ranges selected for the veneers: 0-4%, 4-8% and 8-12%. Plywood panel production was done by using PF and LPF based adhesives.

Grey alder and black alder can be successfully rotary cut into veneers and used as raw material for making a plywood panel. However, 8-12% of MC for pressing is too high because water starts to evaporate between the layers and prevents proper adhesive bond formation. With that MC, 4 panels out of 12 were made successfully.

Test results, by comparing these two wood species, were somewhat surprising. Veneer tensile strength showed that grey alder has a higher tensile strength per mm^2, which is odd because black alder has more density according to the literature.

CA measurements were done by using three selected liquids: water, ethylene glycol and glycerol. Wettability test showed no significant difference between the veneers with different MC. Surface free energy was calculated for both wood species by using average CAs. Surface free energy was mostly the same for both wood species in every MC range.

Study revealed that LPF adhesive should have been treated different from PF adhesive. Lignin based resin may need longer pressing time for curing. Because of that the strength properties of LPF plywood specimens are significantly lower. Following discussion focus more on PF based plywood specimens.

The highest shear strength for grey alder specimens were given by plywood that was made from veneers 0-4% of MC. Percentage of wood failure was almost the same for specimens that were produced 0-4% and 4-8% of MC. Black alder plywood specimens showed that 0-4% of MC is the most favourable for adhesion, it is proved by the highest shear strength results and the highest percentage of wood failure.

Bending strength test showed that 0-4% of MC is most favourable for grey alder production. At the same time MOE`s standard derivation shows that this type of specimens bending strength fluctuated the most. Reason for that fluctuation is difficult to find at the moment. Same test showed no significant bending strength differences between black alder plywood specimens that were produced at 0-4% and 4-8% of MC.

Comparing grey alder and black alder plywood properties to the literature data it can be claimed that those wood species can be used successfully as cheaper alternative for birch plywood. Grey alder and black alder strength properties remain somewhat below for birch plywood strength properties but not significantly. Veneer sheets from grey alder or black alder can be successfully used for decorative purpose or veneer sheets can be pressed into a plywood panel. Ideally veneer MC before pressing should be 2-4%.

For further research plywood pressing parameters and veneer thickness change should be investigated more seriously. Thickness of the plywood boards fluctuated a lot.

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RESÜMEE

Põhjamaistes regioonides kasvab hulgaliselt eri liiki puid, kuhu hulka kuuluvad ka hall lepp ja sanglepp. Lepad kuuluvad kaseliste sugukonda. Kaske kasutatakse laialdaselt vineeri tootmiseks, mis leiab kasutust nii ehitusel, kui ka mööblitööstuses.

Antud magistritöö eesmärk oli uurida hall lepa ja sanglepa spooni niiskussisalduse mõju spooni risttõmbetugevusele ning märgavusomadustele. Samuti uuriti kuidas niiskussisaldus mõjutab vineeri tugevusomadusi – liimliite nihketugevust ning vineeri paindetugevust.

Niiskussisalduse mõju uurimiseks kuivatati spoonilehed kolme erinevasse lõpp niiskuse vahemikku: 0-4%, 4-8% ning 8-12%. Vineerplaatide tootmiseks kasutati kahte erinevat fenool-formaldehüüdvaikliimi. Ühe niiskussisaldusega spoonilehtedest toodeti 3 seitsmekihilist vineerplaati ühe liimiga ning 3 teise liimiga, kahe puiduliigi kohta kokku 36 plaati.

Märgavusomaduste hindamiseks kasutati standartit EVS-EN 828:2013, kust valiti välja kolm vedelikku: destilleritud vesi, etüleenglükool ning glütserool. Mõõtmiste tegemisteks kasutati tilgaseadet Data Physics OCA 20.

Spooni risttõmbe tugevuse, nihketugevuse ning paindetugevuse hindamiseks kasutati seadet Instron 5866. Liimliite nihketugevus viidi läbi vastavalt standarditele EVS-EN 314-1:2005 ja EVS-EN 314-2:1999. Nihke katsekehasid eeltöödeldi vastavalt klass 2 omadustele, mis vastab niisketele kasutustingimustele.

Vineerplaatide valmistamisel selgus, et spooni niiskussisaldus 8-10% on liiga kõrge. Kuumpressimisel tekkinud veeaur ei lasknud moodustada korralikku liimliidet ning selle tulemusel plaadid kõverdusid ning tulid osaliselt liimliitest lahti.

Töö tulemusena selgus, et hall lepa ning sanglepa spooni märgavusomadused on üsna sarnased. Katsetest selgus veel, et vineeri tootmiseks oli kõige sobivam spooni niiskussisaldus 0-4%. Seda tõestas nii liimliite katse kui ka paidetugevus katse.

Hall lepa ning sanglepa vineeri tugevusomadused jäävad alla kasevineeri tugevusomadustele, kui mitte oluliselt. Katsetulemusi võrreldi teiste uurimustega.

APPENDIX 1

Figure A 1.1. Grey alder shear strength specimens

Figure A 1.2. Grey alder shear strength specimens

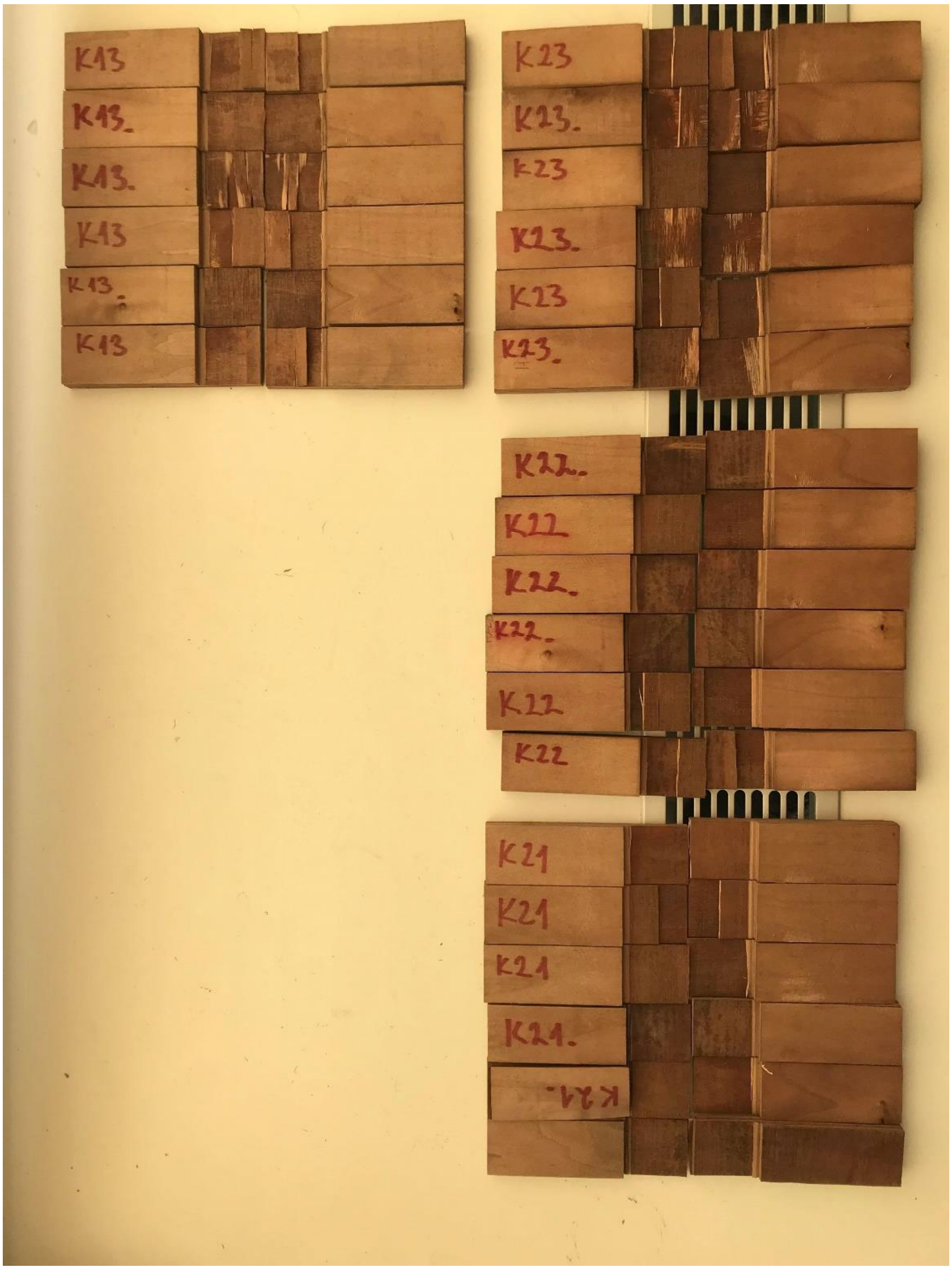

Figure A 1.3. Grey alder shear strength specimens

Figure A 1.4. Black alder shear strength specimens

Figure A 1.5. Black alder shear strength specimens