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

THE INFLUENCE OF LOG SOAKING TEMPERATURE ON GRAY ALDER *(ALNUS INCANA)* AND BLACK ALDER *(ALNUS GLUTINOSA)* PLYWOOD STRENGTH PROPERTIES

PALGI LEOTUSTEMPERATUURIDE MÕJU HALL LEPA *(ALNUS INCANA)* JA SANGLEPA *(ALNUS GLUTINOSA)* VINEERI TUGEVUSOMADUSTELE

MASTER´S THESIS

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Tallinn 2020

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 is in accordance with terms and requirements

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Accepted for defence

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THESIS TASK

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Study programme, KVEM12/15 - Wood-, plastic- and textile technology

main speciality: Wood technology

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Thesis topic:

(in English) The influence of log soaking temperature on gray alder *(Alnus incana)* and black alder *(Alnus glutinosa)* plywood strength properties.

(in Estonian) Palgi leotustemperatuuride mõju hall lepa *(Alnus incana)* ja sanglepa *(Alnus glutinosa)* vineeri tugevusomadustele.

Thesis main objectives:

1. Determine the suitable log soaking temperature for gray alder and black alder plywood bonding quality.
2. Investigate the lignin-substituted phenol-formaldehyde adhesive bonding quality compared to typical phenol-formaldehyde adhesive bonding properties

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Thesis topic selection	25.01.2019
2.	Literature review and test methods description	15.03.2019
3.	Preparing test specimens	15.05.2019
4.	Testing of specimens	04.06.2019
5.	Thesis submission	13.01.2020
6.	Defense of a thesis	20.01.2020

Language: English **Deadline for submission of thesis:** "13." January 2020 a

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LCD - Lath check depth

LPF – Lignin-phenol-formaldehyde

PF – Phenol-formaldehyde

MOE - Modulus of elasticity

Long – Longitudinal wood grain direction

Per – Perpendicular wood grain direction

wt. % – Weight percentage

INTRODUCTION

It is discussed worldwide that fossil fuel reserves are limited but somehow, we must reduce CO_2 emissions, according to this, one option is to use wood as biofuel. Renewable resources will gain more importance in the near future because of the prices of fossil fuels. [1]

One topic is to use renewable energy and fossil fuels. In the other hand we have to understand that wood is renewable material. Wood based materials can be just as effective like metal or concrete. For example, fiberboard, plywood, wood- plastic composites, particleboard and laminated veneer lumber can provide a replacement for solid wood while maintaining the necessary structural properties with beneficial productivity and low cost. In commercial, industrial and residential buildings, these products are widely in use. In North America, the wood- based products are main construction materials in residential housing. In addition, more common in world is to build to mid-rise and high-rise in timber constructions. [2]

In interior, furniture manufacturing and exterior building production, the plywood is widely in use. In 2017, the plywood global production reached about 157 million m^3 and it is increasing. The continuously growing trend involve tougher requirements for the properties of plywood, in especially dimensional stability and strength are strict topics. Tree species, wood moisture, number of layers, tree quality, veneer thickness and adhesive have important role in plywood. The most important characteristic in plywood material is density. [3]

As mentioned above, plywood is a very well-known construction material all over the world. Most common wood specie for production of plywood in Northern Europe is birch. There are different types of adhesives used in plywood production. The most common adhesive to produce waterproof plywood is phenol- formaldehyde adhesive. Just like attempting to discover alternative wood species, efforts are also to invent more environmentally friendly and cheaper solution for plywood bonding. One new alternative product is the proposed lignin-substituted phenol- formaldehyde adhesive.

The aim of this master thesis is to investigate the effect of log soaking temperature on the gray alder and black alder plywood strength properties. In addition, it is investigated whether lignin-substituted phenol-formaldehyde adhesives has similar properties to conventional phenol-formaldehyde adhesive. This thesis contains following main chapters: literature overview about gray alder and black alder, materials and methods about plywood manufacturing processes. Finally, results and discussion where are bending strength, modulus of elasticity and bonding quality test results.

1 LITERATURE OVERVIEW

Literature review includes topics that are necessary to understand the Master´s thesis main target. The chapter starts with gray alder and black alder descriptions and moves to plywood manufacturing processes where are described in detail how log soaking temperature affects veneer peeling process, lath check depth (LCD) and affect to bonding quality. Furthermore, will be described the lignin-phenol-formaldehyde (LPF) and phenol formaldehyde (PF) adhesives.

1.1 Gray alder *(Alnus incana)*

Gray alder is fast growing at early stage and is able to reproduce from root suckers and sprouts. It is adjusted to growth boreal regions and in prevailing temperate. At the age of 15-20 years is the culmination of annual growth but in good conditions gray alder have had high woody biomass production after 20 years of growth. The biomass production of gray alder is comparable or even higher than birch. Usually over 40 years of age are beginning to emerge the signs of decay. One of the biggest advantages compared with birch, willow and poplar is that the gray alder is not susceptible to damages by insects and mammals. [4]

Alders have ability to bind atmospheric nitrogen and because of that, they are biologically valuable tree species. The binding of atmospheric nitrogen is possible by the symbiotic *Frankia* in root nodules. [5]

Annual amount of nitrogen bound vary by site type, age of tree and stand density. The estimated symbiotic nitrogen binding in age of 5-30 year-old gray alder in Sweden, Estonia and Norway forest is 42-150 kg ha^{-1} a^{-1}. In autumn before the falling of leaves, the nutrients are re-translocated from senescent leaves to other parts of the trees and it is common for deciduous trees. The nutrient cycling varies by tree species. Gray alder is quite wasteful in re-translocating nitrogen from senescent leaves compared to the other tree species. Alder does not have selection pressure to develop processes to store nitrogen in root nodules and for that reason compared with other European tree species, alder’s nitrogen content is generally 2-3 times higher. Because of high nitrogen and low lignin content the alders have a soil fortify effect and are easily decomposable. Studies indicated that first generation seed originated stands and self- thinning proceeds slower than seed originated stands. [4]

1.2 Black alder *(Alnus glutinosa)*

Black alder is widespread from mid- Scandinavia to the Mediterranean countries, including northern Marocco and Algeria and naturally all of Europe. [6]

Normally black alder grows between 10 and 25 meter tall and individuals normally live to around 60 years. The bark is smooth and in brown color at first, in growing process it goes darker, fissured and roughen with age. Alders are monoecious and catkins ripen in the autumn in the previous year, in the following spring they are appearing. The fruits resemble small pinecones and by nature it is woody. [7]

Black alder species does not grow into regions where the daily temperature is around 0 °C. Black alder has good potential for biomass production on the sites that correspond closely to its autecological optimum like other precious broadleaves. Black alder grows as fast as ash, maple or cherry in these conditions. Black alder is also important species outside the forest in open landscapes, especially river margins and in linear stands along stream. Black alder leaves have no mechanism for controlling water transportation that means the tree can suffer in warm periods in summer because of water deficits during dry conditions. Black alder can grow well on acid and basic soils with pH values between 4.2 to 7.5. Just as gray alder, the black alder can bond nitrogen in symbiotic root nodules (Figure 1.1) due to bacteria in the genus *Frankia.* In the soils where pH range is between 5.5-7.2 the nodulation can occur. [6]

The wood of black alder is porous and soft, but it is durable under water. It is in use for underwater supports, bridge piles and boats, for heavy construction uses it is not generally strong enough, but it is relatively easy to process and often used in carpentry products. [7]

Figure 1.1 Root nodules of black alder [6]

1.3 Plywood manufacturing processes

Veneer is thin layer of wood usually 1-4 mm in thickness, removed from log using a rotary peeling process. Other forms of veneer such as sliced or sawn veneers also exist. The process of rotary veneer production is to remove a continuous thin ribbon of wood from a peeler block periphery-using knife that is positioned parallel to the grain. The block rotated against the knife using a drive mechanism that varies in design and approach, depending on the technology being used. [8]

Veneer-based product manufacturing typically involves three main stages: veneer manufacture (block storage, handling and peeling); veneer clipping, drying and up-grading and panel lay-up, pressing and finishing (Figure 1.2). [8]

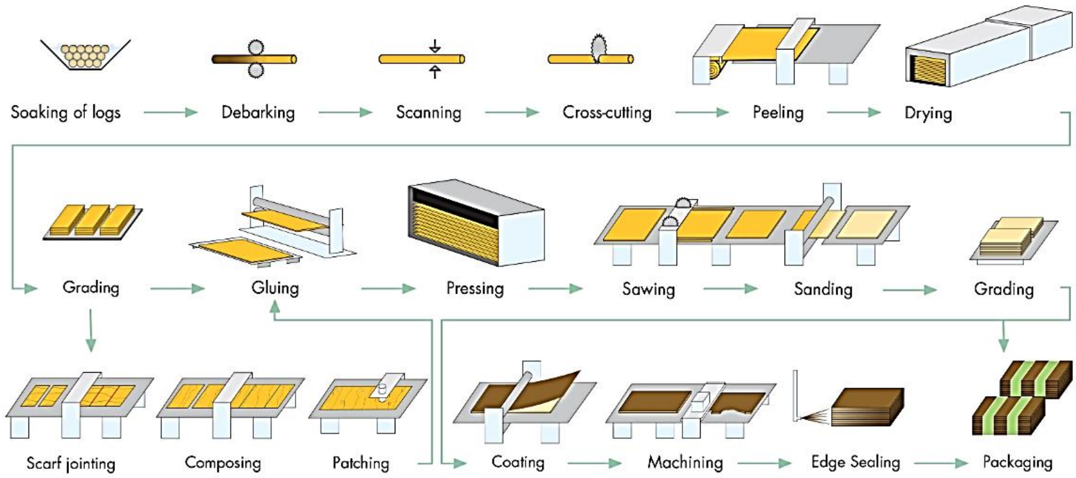

Figure 1.2 Plywood Production process [9]

1.1.1 Grading, sorting and handling

It is important to select logs according to required specifications corresponding quality and size. In plywood manufacturing companies, logs are sorted according to the size, quality and species. After soaking, it is important to store logs in right way- off the ground and protect where necessary from drying and biological attack from insects. [8]

1.1.2 Log debarking, pre-conditioning and round-up

In advanced manufacturing companies, 3D-scanners are in use, which identify stones, dirt and other debris in order to avoid damage to peeler knives and other equipment.

It is determined that hydrothermal treatment before debarking process makes wood more soften and because of that the peeling process is more effective. The practice has been shown that hydrothermal treatment reduces peeling process time. [10]

The decision whether to pre-condition or not is a matter of the advantages for each individual peeling operation. Normally hardwood with density of 500–700 kg/m^3 are heated to 50–70 °C. It is important that desired temperature is reached across the full diameter of the log. [8]

1.1.3 Log peeling

Spindleless lathes are proving to be an effective processing method for forest resources such as young fast-grown plantation hardwoods where tree diameters are small (e.g. often less than 200 mm) block qualities are comparatively low (at least compared to blocks from mature native forests) and blocks are prone to end-splitting. [8]

When the peeling with the spindled lathe are used, the first step is the positioning the blocks in the lathe in order to maximize the recovery of veneer. The disadvantage this peeling process is that it results the large peeler core (center part of log which residue after peeling process). [11]

In more sophisticated operations using spindled lathes, scanning systems support the optimal positioning. [8]

1.1.4 Clipping and sorting

Veneer sorting depends on client requirements, according to size, long bands, quality, cross bands, fishtails, sapwood and heartwood. To get highest amount of accurately sized product with acceptable quality necessary clipping strategy must be used. [8]

1.1.5 Veneer drying

Veneer must separate into types that will dry different rates often it is necessary to separate heartwood from sapwood. [8] There are small difference between tangential and radial drying rates, but sliced veneer will take more drying time than rotary-cut veneer of the same thickness. [12] The veneer moisture content depends on customer demands, which is the end use of the veneer. According to this must determine drier target moisture content. After peeling process, it is important to dry the veneer as soon as possible to avoid deterioration (molds, veneer distortion or buckling). Always after drying process, the veneer moisture content to be measured to see, if it is in range of 2.5-6% and then re-dry if necessary. [8]

1.1.6 Veneer grading, patching, joining, sorting

Sorting the veneer according quality, cross band, long band and mechanical properties (modulus of elasticity (MOE)) where suitable testing equipment is available and structural products are targeted). Veneer can crack in some process (peeling, drying) and then it is necessary to fix the veneer through composing and patching. In some cases, the preference is to patch panels instead. [8]

1.1.7 Preservation

Veneers and veneer-based products may also have to be treated with preservative, depending on the final intended application. Preservative treatment will enhance the durability and service life of veneer-based wood products by preventing or minimizing biological degradation. [8]

1.4 Log soaking temperature and effects for veneer and plywood

It is expected that higher soaking temperature decreases surface roughness, gives smaller lathe checks and better integrity. Higher soaking temperature also make a veneer surface more fibrous that results in strong adhesive bond development. The industrial soaking process for birch is normally at temperatures 40 °C. Birch and Alder wood densities are in range of 550-650 kg/m^3 and for that reason, we can apply same soaking conditions for both. In industrial plywood production, the logs are soaked at temperature not exceeding 40 °C. The effect of high soaking temperatures (70 °C) increases the wettability and bond strength with phenol-formaldehyde adhesive. Soaking logs at 70 °C rather than at 20 °C prior to peeling yields veneer surface with lighter and less reddish and yellowish color. [13]

The soaking temperature clearly affected the lathe check depth (Figure 1.3), which has previously been shown to have a direct impact on plywood shear strength. This tearing at higher temperature will cause cell wall elements to fail and produce surface with a “hairy” structure and larger surface area. The larger surface area gives better interaction with the adhesive that could potentially yield a stronger bond especially if the extra surface is well connected to the underlying veneer. Soaking temperature also has some effect on the roughness of the loose side of the veneer but does not have significant effect on the roughness of the tight side measured by the stylus method. The new integrity test also showed that large fiber bundles were easily removed from the loose side of the veneers peeled at 20 °C, which also had deeper lathe checks. The number of weakly attached surface particles was higher on the loose side in every size class. [14]

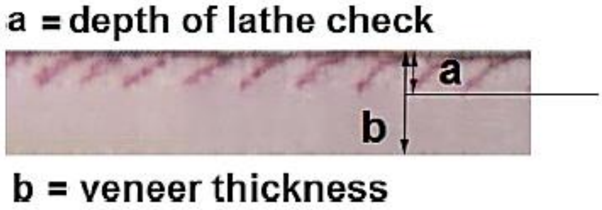

Figure 1.3 Overview of veneer lathe check depth (LCD) measurement [14]

1.5 Lathe check depth and veneer surface roughness

Given that lathe checks can weaken the wood veneer macroscopically and have a remarkable effect on bonding quality, the presence of checks and their characteristics was used as the first level of acumination to assess the effect of soaking. The results show that the LCD of veneers from logs soaked at 20 °C was around 23% of veneer thickness versus around 16% of veneers from logs soaked at 70 °C (Table 1.1). According to the date analysis, the groups were statistically different, suggesting the soaking temperature does influence LCD. [15]

Table 1.1 Effect of soaking temperature on the roughness and lathe checks dept of veneer [15]

Soaking temp. (°C)	Veneer side	LCD (%)	Average roughness values (µm)		
			R_a	R_{max}	R_z
20	Tight		7.44a (1.44)	62.32a (9.95)	48.25a (6.80)
	Loose	23.7a (6.5)	9.19b (2.32)	67.30b (11.35)	53.34b (8.27)
70	Tight		7.99a (1.17)	64.62a (10.23)	51.36a (6.13)
	Loose	16.0b (3.8)	7.99a (1.42)	63.54a (11.87)	48.66a (7.15)

Though the logs soaked at 20 °C and 70 °C were peeled under the same conditions, the LCD was significantly lower in veneer peeled form logs soaked at 70 °C. This suggests that reducing the LCD by heating logs before peeling could have direct benefit in terms of plywood strength by minimizing the initiation of glue line failure [15].

1.6 Plywood adhesives

Wood adhesives have played an important role in the efficient and development use of wood in forest product and furniture industry. Wood is porous and anisotropic material with many inherited anatomical features. In hardwood species, major features are longitudinal fibers and vessel elements, in softwood- longitudinal tracheids. Large lumens of their cells provide a good pathway for flow of fluid resin. Occlusions in the pits or high- molecular weight resins may exist flow. [16]

In the longitudinal direction, the wood is least resistance to hydrodynamic flow, following through the vessels of hardwood or the lumens in the long and slander tracheid of softwood. When vessels do not have pit membrane and connected end-to-end with perforation plates then this cell type dominates the penetration of adhesives in hardwoods. [14]

1.1.8 Phenol-formaldehyde based adhesives

Phenol formaldehyde (PF) resol resins are made from formaldehyde and phenol in the presence of an acid or a basic catalyst. PF resins have long been used as adhesive in the production of wood-based panels such as plywood, fiberboard, and particleboard, due to their excellent bonding performance, water resistance and durability. [17]

Phenol formaldehyde in commercial form is a colorless liquid with a pungent odor. Its principal uses are in the manufacture of thermoset resins. [17] Formaldehyde with phenol, resorcinol, urea and melamine are the most common wood adhesives. [16] The oldest class of synthetic polymers are phenol formaldehyde (PF), this developed at the beginning of the 20th century. [18]

PF is widely used in both field- laminations and composites because of their outstanding durability, which derives from PF good adhesion to wood and the prefect stability of the adhesive. [19] PF molecule involves first formation of the hydroxymethyl group, followed but partial polymerization to the oligomer that makes up the adhesive (Figure 1.4). [20]

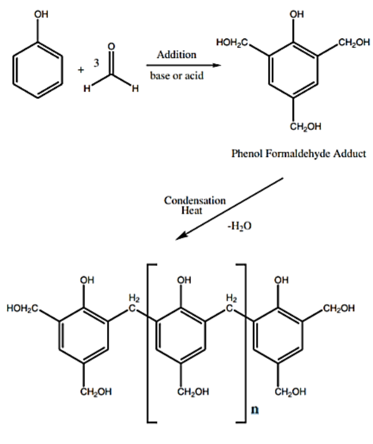

Figure 1.4 Phenol-formaldehyde oligomer [20]

1.1.9 Lignin phenol- formaldehyde adhesive

Last ten years, there has been increasing interest to use lignin as an alternative to phenols due to the structural similarities between lignin and phenols, low cost of lignin, as well as wide availability of lignin. The most heat-resistant component in wood is lignin, which has great potential of using in the adhesives of heat- resistant phenolic resins. In addition, lignin-based adhesives are more durable to attack by microorganisms and lignin has good moisture resistance. [21]

The kraft lignin and lignosulfonate mostly come from pulping and paper making industries. However, these lignin materials have low activity. Lignin-phenol-formaldehyde (LPF) adhesives need higher temperature or longer hot-pressing time, which also adds the difficulty in industrial application. [22] To increase the potential reactive sites of lignin toward formaldehyde various chemical modifications such as phenylation, methylation, liquefaction, pyrolysis, oxidation or hydrolysis must be done. [21]

In North America there are now encouraging signs that pre-reacted lignin can be added in material up to 20% to 30% of synthetic phenolic resins for plywood without making longer pressing time. LPF have been used in manufacturing particleboard, fiberboard and plywood and the amount of lignin in LPF for these products can increase up to 40% to 70% if a high molecular weight fraction obtained from alkaline pulping of wood, is applied [22].

Lignin is composed of phenylpropane units that are linked together. Lignin structure comes from p-hydroxycinnamoyl alcohols by to a phenoxy radical (R). The R has delocated unpaired electrons and these are reacting at three different sites of the radical. Phenyl propanoid units of lignin: R, $R_2 = H$, OCH_3, $R_3 = H, CH_3, CH_2$ and/or S=possible linkage to other phenyl propanoid units (Figure 1.5). Lining in technical spent liquors cannot be as effectively cross-linked as synthetic PF resins. At least, it is necessary to provide higher press temperatures at longer heating times [19].

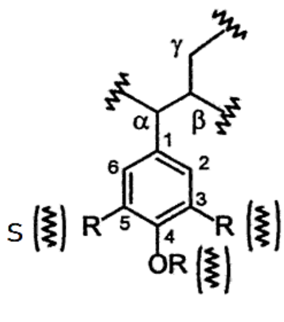

Figure 1.5 Lignin molecule with phenoxy radical (R) [19]

2 MATERIALS AND METHODS

2.1 Test plan

Plywood manufacturing process includes several different steps. The plywood for this thesis is made in Tallinn University of Technology, Laboratory of Wood Technology. In this study, the alder (gray and black) logs to are used produce plywood. The main target was to figure out which soaking temperature provides the best gluing results for plywood. Soaking temperatures will be 20 °C, 40 °C and 70 °C. In addition, two types of glues: phenol-formaldehyde and lignin substituted phenol-formaldehyde glue are used for comparison. To get test samples the following steps are done (Figure 2.1):

1. Cutting logs to peeler blocks with the size of 1.2-1.4 m
2. Soaking
3. Debarking
4. Veneer peeling
5. Cutting 450*450 mm veneer sheets
6. Drying with water vapor generator
7. Gluing veneer sheets
8. Hot pressing – cycle 9 minutes
9. Specimen testing according to the standard EVS-EN 310:2002- Wood-based panels- Determination of modulus of elasticity in bending and bending strength
10. Specimen testing according to the standard EVS-EN 314-1:2005- Plywood. Bonding quality

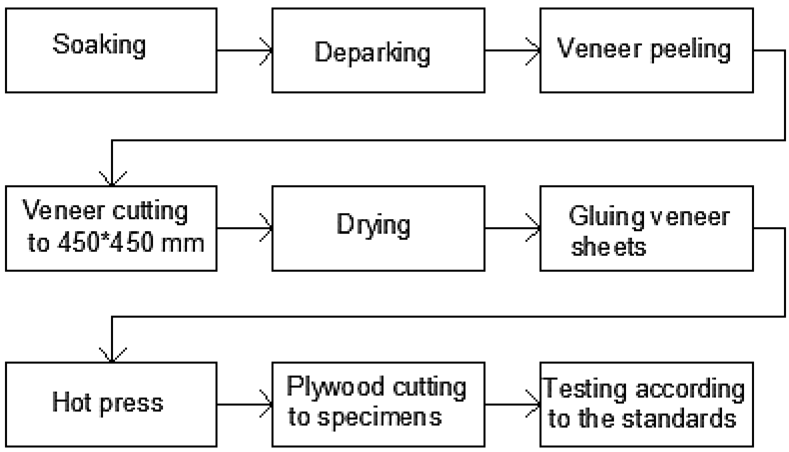

Figure 2.1 Plywood manufacturing processes in this study

2.2 Materials processing methods

2.1.1 Log soaking

Before the peeling process, it is necessary to heat up logs and for that, there are different methods. The common technology today in production is soaking logs in the baths at elevated temperature or steaming. It is important to heat up the logs before peeling process because heated and wet wood is softer. Soft wood surface after the peeling process is smoother and it decrease adhesive consumption required for adequate bonding. Soaking at elevated temperature affects the color of the wood also. [15]

This study includes three different soaking temperatures: 20 °C, 40 °C and 70 °C. On the Figure 2.2 it is shown gray alder soaking at the 40 °C. The soaking duration must be at least 24 hours.

Figure 2.2 Gray alder Logs soaking at 40 °C

2.1.2 Debarking logs

Tree has been growing in the forest about 20 years and collected a lot of dust, rocks and weapon bullets into the bark. The debarking gives the premise that in the next process the peeling knives cannot be damaged. After 24 hours of log soaking the bark is soft and ready for peeling the bark off from log. For that process the special debarking knives are used (Figure 2.3). In the veneer or plywood manufacturing companies debarking machines are used for that process.

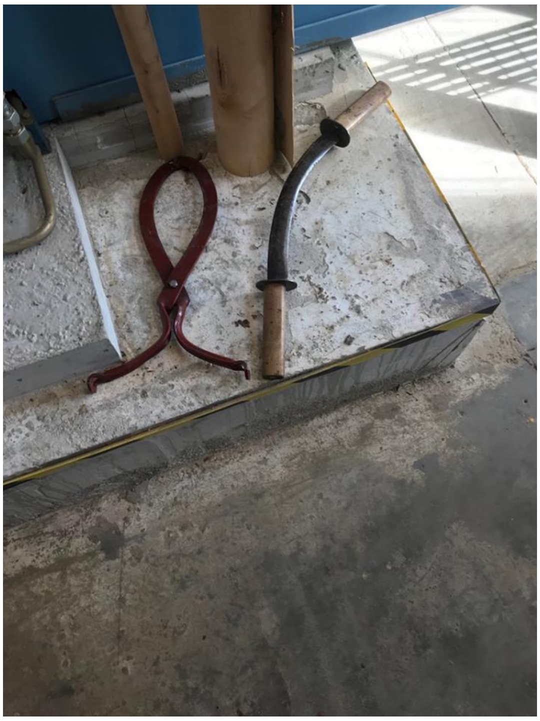

Figure 2.3 Debarking knife on the right

2.1.3 Peeling process

The peeling process has two main variables: peeling speed (59 m/min) and cutting settings (knife angle). These parameters main affect is seen in the lathe checks. When the pressure bar is exerting pressure too strongly then the lathe checks are deep, and the veneer surface is rough. The adhesive consumption will be bigger than it should be. It is known that the peeling settings vary for different raw materials. Cutting speed is not so effective for veneer quality than peeling settings when it is the range of 50 to 150 m per minute. Despite that, the veneer quality and physical properties is in correlation with peeling process. The side which the checks initiate has been termed the "loose side" and the other side of veneer is the "tight side" (Figure 2.4). [15]

In this study the plywood consists of 7- layers with 1.5 mm thickness that is because of this product panels are more suitable for plywood bonding quality testing according to EN-314. Veneer peeling machine was produced by Finland company Raute (Figure 2.5).

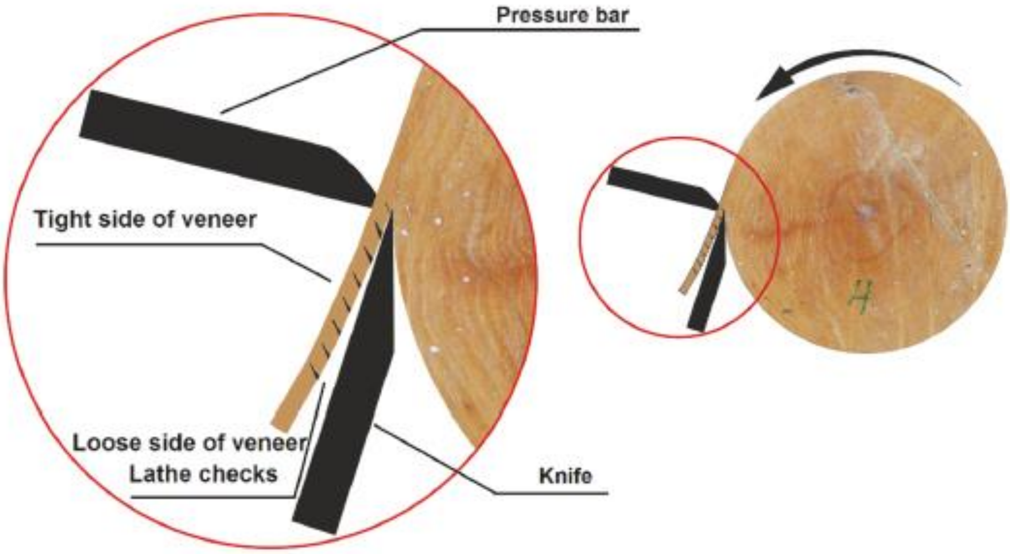

Figure 2.4 Tight and loose side explanation in peeling process [15]

Figure 2.5 Route veneer peeling machine

2.1.4 Veneer cutting for plywood

For cutting veneer to the final dimension for drying veneer, the veneer clipper was used. During the peeling, the veneer length was cut to size of 1000 mm to fit perfectly to veneer clipper. After first cutting the veneer layer dimensions are 450*1000 mm. It is well known that in the drying process the veneer shrinks in linear direction. Final product (plywood) dimensions must be around 400*400 mm and considering to this veneer has to cut be a second time from 450*450 mm (Figure 2.6), those dimensions are final before drying process.

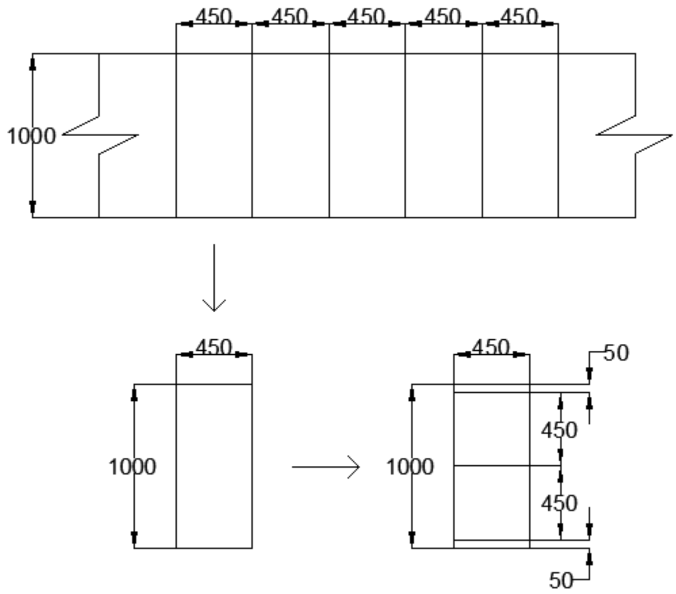

Figure 2.6 Veneer cutting process

On the Figure 2.7 shows veneer clipper with is in use at TalTech Laboratory of Wood Technology. Guillotine working process is simple. The table has marked line on 450 mm and for cutting have to push two bottoms in the same time then blade does the cut. Pushing two bottoms in the same time is for safety. Before pushing the bottoms, there is no any danger to damage someone`s health.

Figure 2.7 Guillotine for veneer cutting

2.1.5 Veneer drying

In this study, I used TalTech Laboratory of Wood Technology veneer drier (Raute) (Figure 2.8) where you can load veneer sheets from above and veneer sheets are fixed with two metal frames on both sides. Fixed sheets descend into the drying machine where temperature was in the range of 170-180 °C and moisture content in the range of 600-700 g/kg (Figure 2.9). Drying time was between 3:20-3:30 min.

It is necessary to know that over-drying will affect in bonding quality, over-drying makes veneer surface inactivate and adhesive do not bond with veneer surface. That issue is common in plywood industry. Nevertheless, if drying process uses the hot steam then it reduces risk of over drying the veneer surface. [15] Final veneer moisture content result should be between 4.5±1.5 % (Figure 2.10).

Figure 2.8 Veneer drying machine in TalTech Laboratory of Wood Technology

Figure 2.9 Vaisala Dew Point Transmitter DMT346

Figure 2.10 Dried veneer sheet with moisture content 4.4%

2.1.6 Adhesive recipe and mixing

In this study two different types of adhesives were used: phenol-formaldehyde (PF) and lignin- phenol- formaldehyde (LPF). The adhesive manufacturer is Prefere Resins Finland Oy. For making the right concentration of adhesive, the common plywood production glue is used. First, have to clarify the final adhesive quantity. PF adhesive consists of resin (14J021) 68 wt. %, hardener (24J662) 14% wt. and water 18 wt. %. LPF adhesive consists of resin (EXPH051) 73 wt. %, hardener (EXPH9500) 13 wt. % and water 14 wt. %. The recipes are specified by the manufacturer (Prefere Resins Finland Oy).

Mixing process starts with weighing resin to the container, when the exact % of resin is added then have to include water with correct % of total mass. Finally, the hardener is added, it must be added gradually to avoid lumps. All the process occurs during the mixing machine works.

2.1.7 Gluing and hot press

In TalTech Laboratory of Wood Technology hot hydraulic press Infor was used for plywood making (Figure 2.11). Temperature in the hot press was 130 °C. One pressing cycle took time 9 min. The program was set according to PF adhesive standard pressing time (3.0 mm + 0.5 * plywood thickness in mm). The pressing program was configured accordingly: 0-75 seconds (sec) the high pressure to the plywood panel was 1.8 MPa, 75-450 sec, then mid pressure at 1.4 MPa and then 450-540 sec pressure was lowered down to 0.4 MPa to allow the moisture to come out from the panel before opening the press.

The average glue consumption for one side of veneer is 32.4 g (1 m^2=160 g). Gluing machine (Figure 2.12) manufacturer is Black Bros. co. INC, Glue Spreader series 500.

The final product (Figure 2.13) must be 10.5 mm thick; it means that it made 7-layers veneer. It includes 3 sheets of veneer which are glued from both sides and 4 veneer sheets which do not have glue.

Figure 2.11 Hot press machine from Infor manufacturer

Figure 2.12 Black Bros. co. INC, Glue Spreader series 500

Figure 2.13 Glued veneer sheets before hot pressing process

2.3 Analysis methods

2.1.8 Determination of modulus of elasticity in bending and bending strength

EN 310:2002 European Standard specify a process of determining the obvious modulus of elasticity in flatwise flexion and the bending strength of wood-based panels of symbolic thickness similar to or major than 3 mm. [24]

It is decided that the bending strength and the modulus of elasticity in bending test piece is supported at two points and the load applies to the center of a test piece. Using the slant of the linear area of the load-driftage curve is main for calculating modulus of elasticity. The test method contains shear likewise as bending because of that the value calculated in the apparent modulus not based on the true modulus. The proportion of the bending moment (M) at maximum load to the moment of its full cross section is main principle to calculate which each test piece the bending strength. [24]

Elasticity means that deflection prepared by low stress below the proportional limit are fully recoverable after stress is removed. When loaded to pressure levels above the proportional limit, plastic driftage or failure take place. Most commonly, the stress-strain curve of wood composites is direct below the proportional limits. The modulus of elasticity (MOE) is the slope of the linear curve. MOE is a measure of the endurance to bending deformation, which is proportional to the stiffness. [25]

2.1.8.1 Testing apparatus

The testing apparatus must follow principle which are brought out in EN 310:2002 standard. Apparatus must have two parallel, cylindrical roller-bearing supports which length exceeding the width of the test specimen and (15±0.5) mm of diameter. Supports might be adaptable to regulate distance between them according to the test piece dimensions. A cylindrical loading head have to placed parallel to the supports and equal distances from them. Cylindrical loading head length and diameter must be (30±0.5) mm (Figure 2.14). The instrument is appropriate when it can measure the variation of the test specimen in the middle of the span with a punctuality of 0.1 mm. The instrument is appropriate when it can measure the load applied to the test specimen with a punctuality of 1% of the measured value. [24]

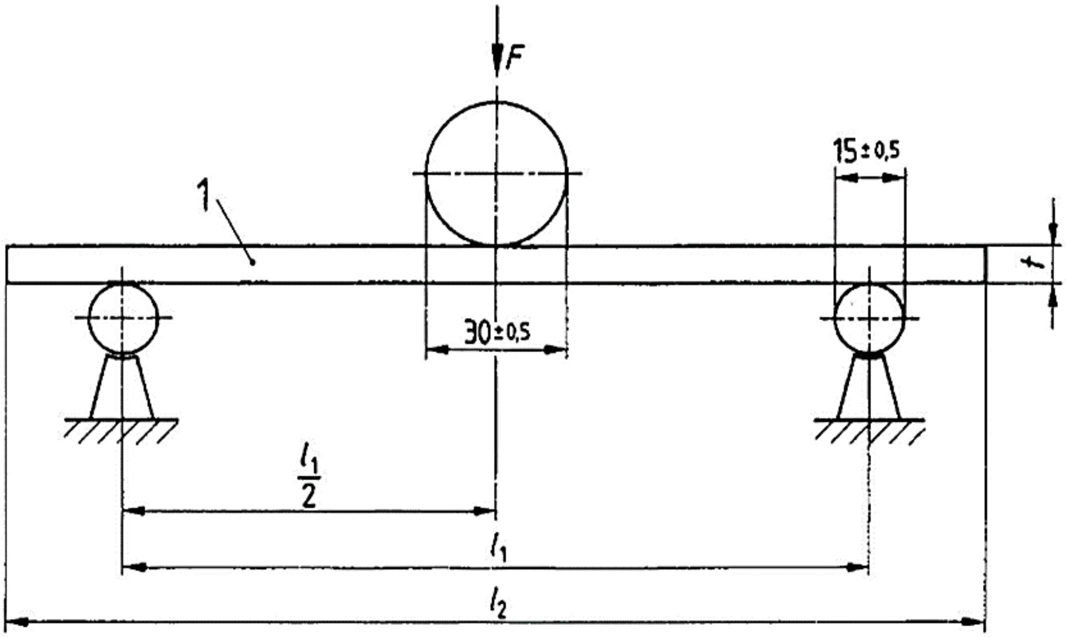

Figure 2.14 Testing apparatus according to the standard [24]

Dimensions are described in millimeters.

1 - test piece

F - load

$l_1 - 20\,t$

$l_2 - l_1 + 50$

t= thickness of test piece

Test specimens are cut out from both transverse, longitudinal and they shall be rectangular. The width has to be (50±1) mm. [24]

At the Tallinn University of Technology is in use Instron (5866) apparatus (Figure 2.15). The modulus of elasticity in bending and bending strength was made on a 23.05.2019. In the working room the temperature was 24 °C.

Figure 2.15 Instron 5866 apparatus for EN 310:2002 test at Tallinn University of Technology

2.1.8.2 Conditioning

To get constant mass for test pieces then shall be atmosphere relative humidity of (65±2) % and a temperature of (20±2) °C for conditioning. When the test piece mass different is not more than 0,1% after interval of 24 h of conditioning then constant mass is considered to be reached. [24]

2.1.8.3 Procedure

The supports must fix and distance between center point to support have to within 1 mm for both of them. Distance between supports shall be 20 times the nominal thickness of test specimen, but not less than 100 mm and not more than 1000 mm. [20] Test piece have to place on the supports. Specimen overhang on both sides need to be same proceeding the instrument load head. [24]

Of crosshead movement throughout the test shall be applied at a constant rate. The measure of loading must be adapted that the maximum load is arrive within (60±30) s. The deflection must be measure in the middle of the test specimen to a punctuality of 0,1 mm. Entry the maximum load to a punctuality of 1 % of the measured value. Complete tests with according to the two directions of the samples, in longitudinal and transverse directions. [24]

2.1.8.4 Modulus of elasticity

According to the formula is calculated modulus of elasticity, E_m, in N/mm^2 with each test piece: [24]

$$E_m = \frac{l_1^3(F_2 - F_1)}{4bt^3(a_2 - a_1)} \qquad (2.1)$$

where

l_1- distance between supports according to the center point, mm
b - test specimen width, mm
t - test specimen thickness, mm
$F_2 - F_1$ - growth of load on the direct-line section of the load-driftage curve, in N. F_1 must be roughly 10% and F_2 must be roughly 40% of the maximum load
$a_2 - a_1$ - growth of driftage at the center of the test specimen
The modulus of elasticity for longitudinal and transverse directions must take from the same plywood board. [24]

2.1.8.5 Bending strength

According to the formula is calculated bending strength f_m, in N/mm^2, with each test piece: [24]

$$f_m = \frac{3F_{max}l_1}{2bt^2} \qquad (2.2)$$

where

f_{max} - is the maximum load, in N
l_1, b and t are in mm as defined in 2.3.5
The bending strength for longitudinal and transverse directions have to take from the same plywood board. [24]

2.1.9 Plywood bonding quality

2.1.9.1 Shape and size

The plywood bonding quality test carried out according to the standard EN 314-1:2005. The overall view of prepared plywood pieces is shown in Figure 2.16. The glue lines under test is perpendicular to the length of test specimen between the grain direction of the layer, according to that have to cut test pieces. The test specimen has to be prepared and the notch is made to allow the control of each glue line of the panel. The saw cuts must extend into the layer between the glue lines under veneer layer. Full panel thickness test specimen shall be used for plywood with 3 to 9 layers. Plywood with more than 9 layers, extra layers may be eliminated by sanding, cutting or planning. [26]

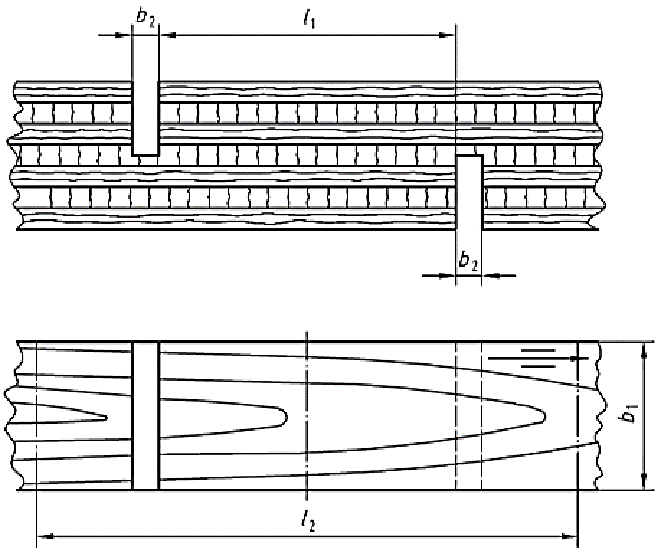

Figure 2.16 Test specimen example of 7-layers plywood [26]

where

b_1= (25±0,5) mm (shear width of test piece)
b_2= 2,5 mm to 4 mm (saw cut width)
l_1= (25±0,5) mm (shear length)
l_2= 50 mm (distance between clamps)

2.1.9.2 Physical test

Test specimens must soak in water-bath which is controlled thermostatically and capable of preserving a temperature of (20±3) °C. Next step is to put test samples to boiling tank which is suitable to keep boiling water temperature (100) °C. Followed by a ventilated drying oven which have to be suitable to hold temperature of (60±3) °C at all points. Finally measuring the specimens with instrument accuracy of 0.1 mm. [26]

At the Tallinn University of Technology is in use Instron (5966) apparatus (Figure 2.17). The plywood bonding quality test was made on a 5.06.2019. In the working room the temperature was 26 °C.

Figure 2.17 Instron 5866 apparatus for EN314-1:2005 test at Tallinn University of Technology

2.1.9.3 Sequence of pre-treatment

Test specimens must soak in water 24 h at temperature of (20±3) °C. Then put the test pieces to the water which is boiling for 6 h and after that into the water at (20±3) °C, for 1 h. Each test specimen must be well separated to completely immerse in water. [26]

2.1.9.4 Procedure

The width and length of shear area shall be measured to a punctually of 0.1 mm and that before water treatment. The test pieces have to put in centre of the clamping machine in such way that the load can be forward from the test machine. If there take place slipping, then it allows only in the starting stage of the loading. The clamps have the faces which hold the pressure on test specimen. The load must apply at a constant speed, so the tearing occurs within (30±10) s. The Instron program was configured on the speed 10 mm/min. The specimen breaking load must determine to a punctually of 1%. The shear strength has to calculate in Newton per square millimeter (N/mm^2). [25]

In the shear test area occurs the failure in the wood or in the glue lines between the saw cuts. If the cross-grain breaking is within 50% or the failure occurs outside the test area, then the result must be dismissed. If 20% or more of test specimens are failure outside the test area, then it will be necessary to resample. The obvious wood failure percentage shall be recorded by use of the guidelines and comparison with the pictures (EN 314-1:2005 Annex A). [26]

2.1.9.5 Expression of results

According to the formula is calculated shear strength f_v of with each test piece in Newtons (N) per square millimeter (N/mm^2): [26]

$$f_v = \frac{F}{l_1 x b_1} \quad (2.3)$$

where

F - failing of the specimen, N

l_1 - length of the shear region, mm

b_1 - width of the share region, mm

The sear strength has to calculated to 0.01 N/mm^2 and calculate standard deviation. [22]

The wood failure visual test will be done by according to the standard EN 314-1:2005 where are described how to identify failure in %. [26]

3 RESULTS AND DISCUSSION

Results and discussion topic start with explanation of gray alder and black alder testing results in modulus of elasticity. Then moves to bending strength results and chapter ends with bonding quality results in different log soaking temperatures. Bonding quality is expressed with shear strength and visual wood failure analysis.

3.1 Modulus of elasticity in bending

Modulus of elasticity was tested with black alder and gray alder plywood which logs were soaked at different temperatures. With every soaking temperature (20 °C, 40 °C, 70 °C) was tested 15 test pieces and average MOE was calculated. The test results are separated according to veneer direction- longitudinal or perpendicular.

The Figure 3.1 shows the results of modulus of elasticity with different log soaking temperatures where veneer direction in plywood specimens were longitudinal. The Figure 3.2 shows the results of modulus of elasticity where veneer direction in plywood specimens were perpendicular. The exact values of the testing results with gray alder and black alder are brought out in Table 3.1.

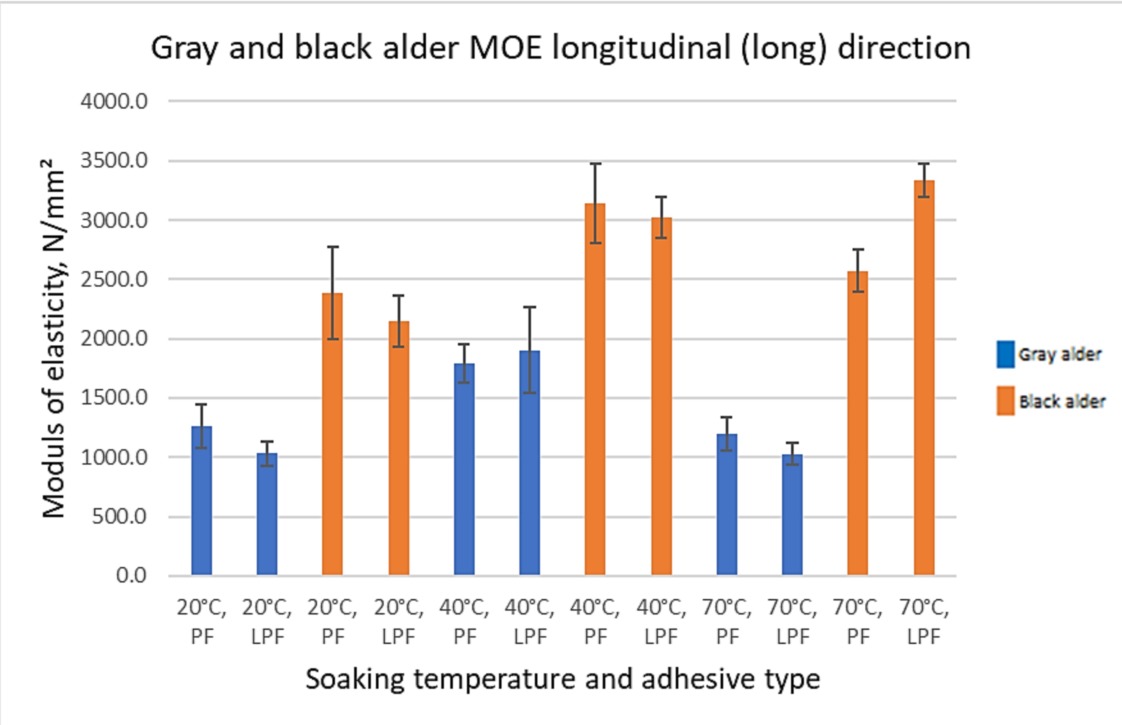

Figure 3.1 Long. direction MOE testing results with gray alder and black alder

The Figure 3.1 shows that in longitudinal direction the black alder and gray alder test results are different from each other- when compare soaking temperatures. The results show that black alder test pieces in every soaking temperature has higher modulus of elasticity compared to the gray alder test pieces.

Black alder logs that have been soaked at 20 °C and used PF or LPF adhesive for bonding has averagely 98% higher modulus of elasticity result than gray alder. Black alder logs that have been soaked at 40 °C and used PF or LPF adhesive for bonding has averagely 67% higher modulus of elasticity result than gray alder. Black alder logs that have been soaked at 70 °C and used PF or LPF adhesive for bonding has averagely 169% higher modulus of elasticity result than gray alder.

The biggest difference in soaking temperatures are comparing gray alder with black alder at 70 °C. When to compare different log soaking temperatures, then the highest results in MOE coming out at 40 °C and the lowest results are performing at 20 °C. If to took into standard deviation, then the overall best result (3336.5 N/mm^2) in longitudinal direction tested specimens comes out in black alder specimens at soaking temperature 70 °C with LPF adhesive.

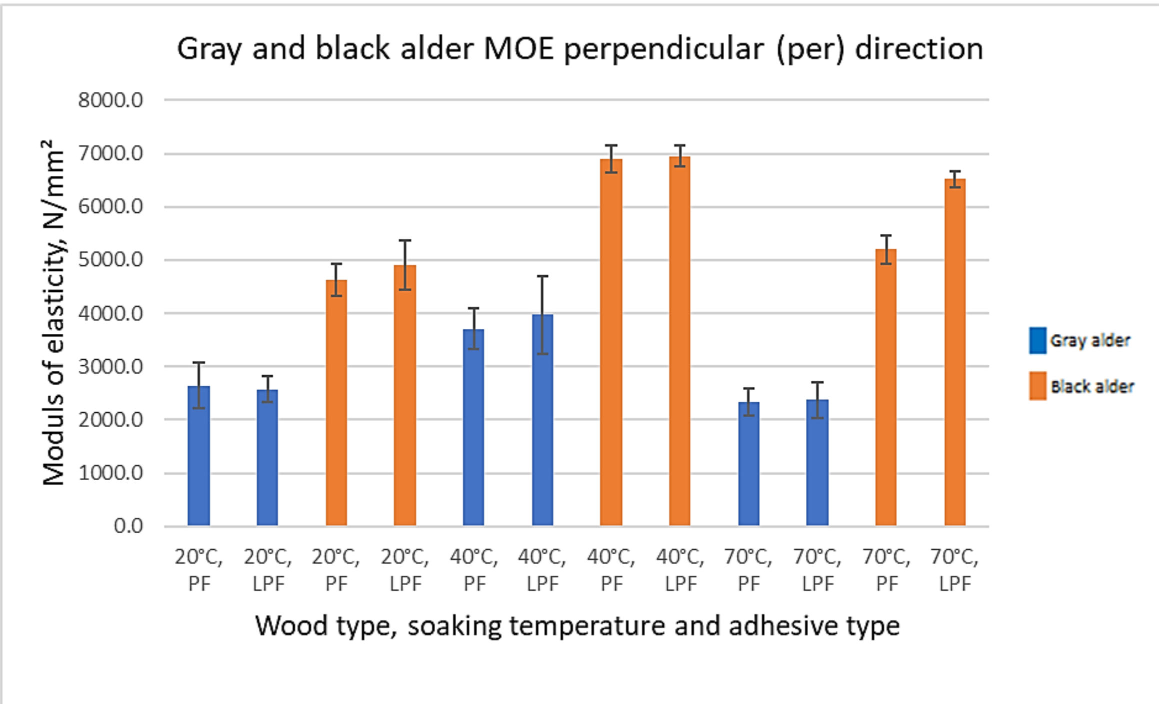

Figure 3.2 Per. direction MOE testing results with gray alder and black alder

The Figure 3.2 shows that in perpendicular direction the black alder and gray alder test results are different from each other exactly like longitudinal direction- when compare soaking temperatures.

The results show that black alder test pieces in every soaking temperature has higher modulus of elasticity compared to the gray alder test pieces. Black alder logs that have been soaked at 20 °C and used PF or LPF adhesive for bonding had averagely 83% higher modulus of elasticity result than gray alder. Black alder logs that have been soaked at 40 °C and used PF or LPF adhesive for bonding had averagely 80% higher modulus of elasticity result than gray alder. Black alder logs that have been soaked at 70 °C and used PF or LPF adhesive for bonding has averagely 149% higher modulus of elasticity result than gray alder.

The biggest difference in MOE are with soaking temperatures at 70 °C. When to compare different log soaking temperatures, then the highest results in MOE coming out at 40 °C and the lowest results are performing at 20 °C. If to look into standard deviation, then the overall best result (6952.6 N/mm^2) in perpendicular direction tested specimens comes out in black alder specimens at soaking temperature 40 °C with LPF adhesive.

The prior things, which contributes to plywood properties and bond strength is the temperature history of the log. Soaking affects in the softening of wood, but it also causes unconvertible changes in wood chemistry, which have a priceless effect on bond strength process. [27]

The Table A 13.1 (appendix 13) shows the exact average results of 15 test specimens of every wood type, soaking temperature and adhesive type. In addition is showed standard deviation of test results which caused by poor quality of pressure process, bonding process or wood failure.

3.2 Bending strength

The deformations depend on the veneer wood grain direction in the plywood and the crosswise strength of veneer sheet. The actual result of maximum bending strength in tension region depends on the span length but is regulated according to the EN 310:2002 European Standard. [28]

Bending strength was tested with black alder and gray alder plywood which logs were soaked at different temperatures. With every soaking temperature (20 °C, 40 °C, 70 °C) 15 test pieces were tested and average bending strength was calculated. The test results are separated according to veneer direction: longitudinal or perpendicular.

The Figure 3.3 shows the results of bending strength with different log soaking temperatures of gray alder. The Figure 3.4 shows the results of bending strength with different log soaking temperatures of black alder. The exact values of the testing results with gray alder and black alder are brought out in Table 3.2.

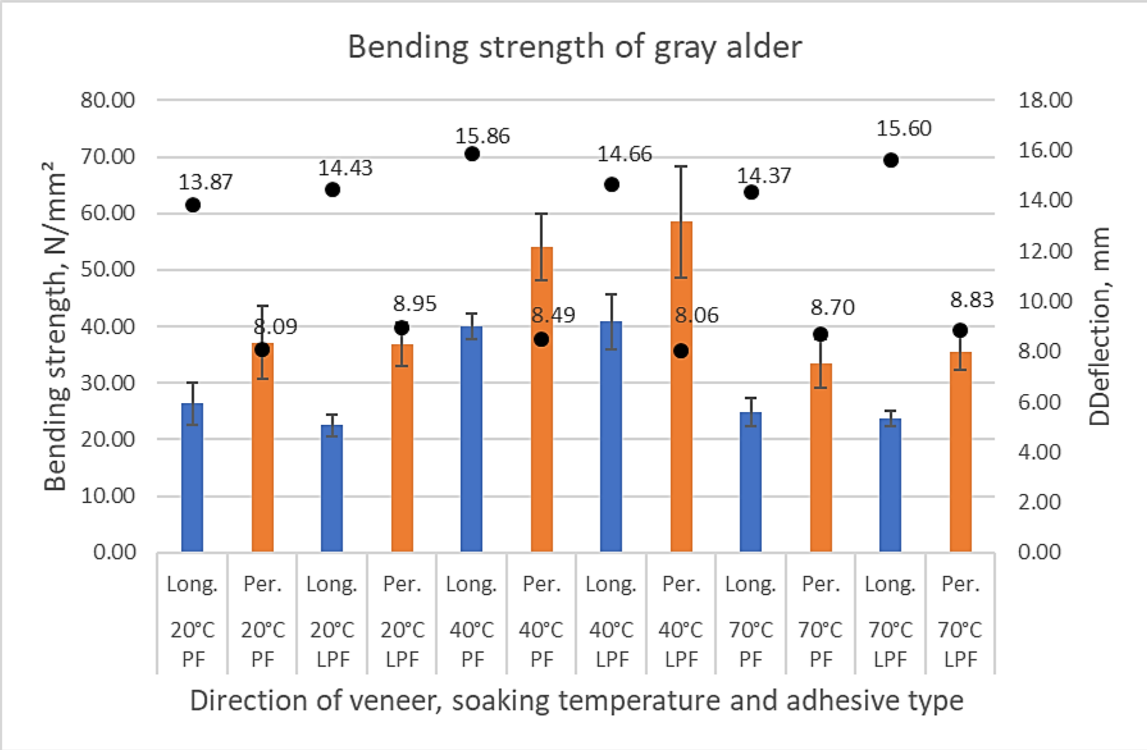

Figure 3.3 Bending strength of gray alder

The Figure 3.3 shows that in perpendicular direction the gray alder test results are different from each other exactly like longitudinal direction- when compare soaking temperatures.

The results show that gray alder test pieces in every soaking temperature has higher bending strength in perpendicular than longitudinal direction. Gray alder logs that have been soaked at 20 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 51% higher bending strength result than longitudinal direction. Gray alder logs that have been soaked at 40 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 39% higher bending strength result than longitudinal direction. Gray alder logs that have been soaked at 70 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 42% higher bending strength result than longitudinal direction.

If to compare different log soaking temperatures, then the highest results in bending strength coming out at 40 °C and the lowest results are performing at 20 °C. If to investigate the standard deviation, then the overall best result (58.49 N/mm^2) in perpendicular direction tested specimens comes out at soaking temperature of 40 °C and used LPF adhesive.

The dark points on the Figure 3.3 shows deflection in millimeters. Results shows that the compressive extension is similar at every soaking temperature compared longitudinal and perpendicular direction tested specimens separately. The maximum fluctuation (15.86 mm) took place in longitudinal direction specimens with was soaked at 40 °C and used PF adhesive. The minimum fluctuation (8.06 mm) took place in perpendicular direction specimens with was soaked at 40 °C and used LPF adhesive.

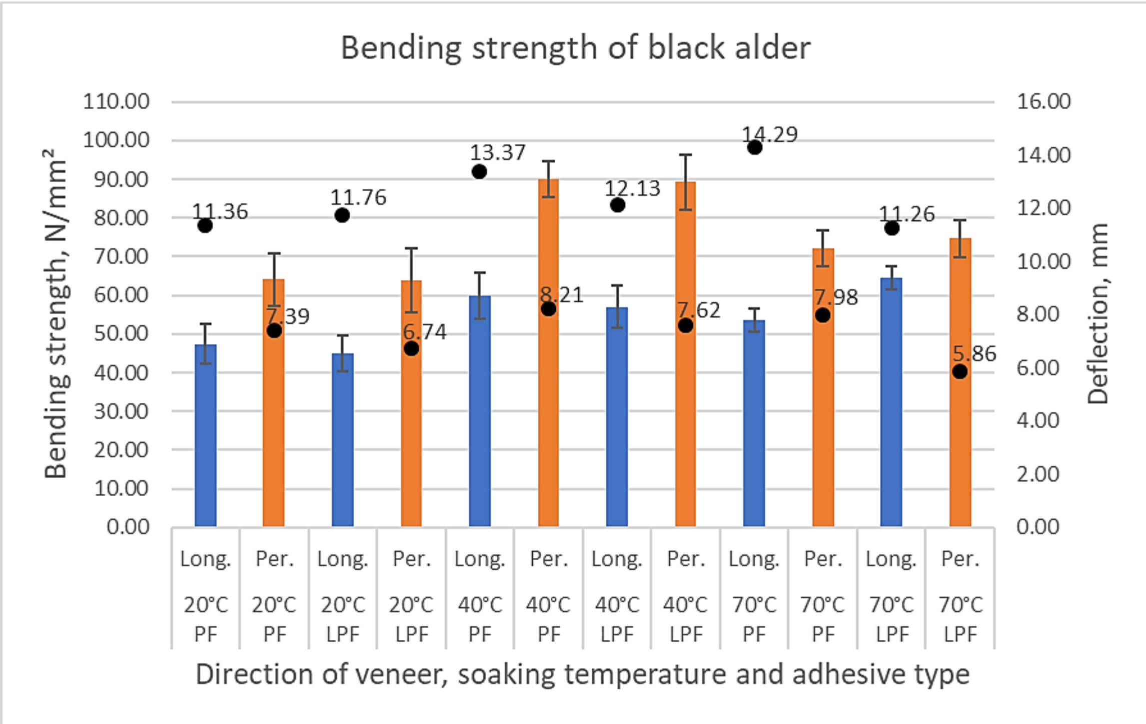

Figure 3.4 Bending strength of black alder

The Figure 3.4 shows that in perpendicular direction the black alder test results are different from each other exactly like longitudinal direction- when compare soaking temperatures. The results show that black alder test pieces in every soaking temperature has higher bending strength in perpendicular than longitudinal direction.

Black alder logs that have been soaked at 20 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 39% higher bending strength result than longitudinal direction. Black alder logs that have been soaked at 40 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 53% higher bending strength result than longitudinal direction. Black alder logs that have been soaked at 70 °C, used PF or LPF adhesive for bonding and plywood is tested in perpendicular direction, has averagely 25% higher bending strength result than longitudinal direction.

If to compare different log soaking temperatures, then the highest results in bending strength coming out at 40 °C and the lowest results are performing at 20 °C. If to take into standard deviation, then the overall best result (90.07 N/mm^2) in perpendicular direction tested specimens comes out at soaking temperature of 40 °C and used PF adhesive.

The dark points on the Figure 3.4 shows deflection in millimeters. Results shows that the compressive extension is similar at every soaking temperature compared longitudinal and perpendicular direction tested specimens separately. The maximum fluctuation (14.29 mm) took place in longitudinal direction specimens with was soaked at 70 °C and used PF adhesive. The minimum fluctuation (5.86 mm) took place in perpendicular direction specimens with was soaked at 70 °C and used LPF adhesive.

The Table A 14.1 (appendix 14) shows the exact average results of 15 test specimens of every wood type, soaking temperature and adhesive type. In addition is showed standard deviation of test results which caused by poor quality of pressure process, bonding process or wood failure.

As mentioned on Figures 3.3 and 3.4 the highest test results came out with specimens which were in perpendicular direction.

To compare gray alder and black alder bending strength results in taken together every soaking temperature then black alder test specimen has averagely 87% higher test results than gray alder. If to look gray alder at the temperature 20 °C the results shows that specimens which was made of PF adhesive has averagely 17% higher results than LPF in both veneer direction. If to look gray alder at the temperature 40 °C the results shows that specimens which was made of LPF adhesive has averagely 5% higher results than PF in both veneer direction. When to look gray alder at the temperature 70 °C the results shows that specimens which was made of PF has in longitudinal direction 6% higher results than LPF and in perpendicular direction has LPF 5% better results than PF adhesive. If to look black alder at the temperature 20 °C the results shows that specimens which was made of PF adhesive has averagely 3% higher results than LPF in both veneer direction. If to look black alder at the temperature 40 °C the results shows that specimens which was made of PF adhesive has averagely 3% higher results than LPF in both veneer direction. If to look black alder at the temperature 70 °C the results shows that specimens which was made of LPF adhesive has averagely 12% higher results than PF in both veneer direction.

One of the reasons why the results are these, can be relation of bonding quality. Both of wood species showed most stable results at 40 °C. Can say that at 70 °C the wood veneer surface is too smooth and at 20 °C rough.

If to analyze the results at one specific log soaking temperature and compare the adhesives, then it is complicate to figure out which adhesive is more reasonable to use. For gray alder is more suitable to use LPF than PF. For black alder is more proper to use PF than LPF. If to compare gray alder and black alder bending strength results, then more appropriate is to use black alder as plywood material.

3.3 Bonding quality

This chapter describes gray alder and black alder specimen shear strength according to the EN 314-1:2005 standard. The aim is to figure out which adhesive (LPF, PF) have highest shear strength results and compare the bonding quality at different log soaking temperatures. In the Table 3.1 and 3.2 are presented determination of the percentage of apparent cohesive wood failure by comparison (see also Figures in appendix 1-12).

In this study, shear strength of 15 pieces were measured and most of the specimens were breaking at the adhesive area. That means the adhesive interphase perform worse than wood veneer.

The test results are separated according to wood type. The Figure 3.5 shows the results of shear strength with different log soaking temperatures and with different adhesives of gray alder. The Figure 3.6 shows the results of shear strength with different log soaking temperatures and with different adhesives of black alder.

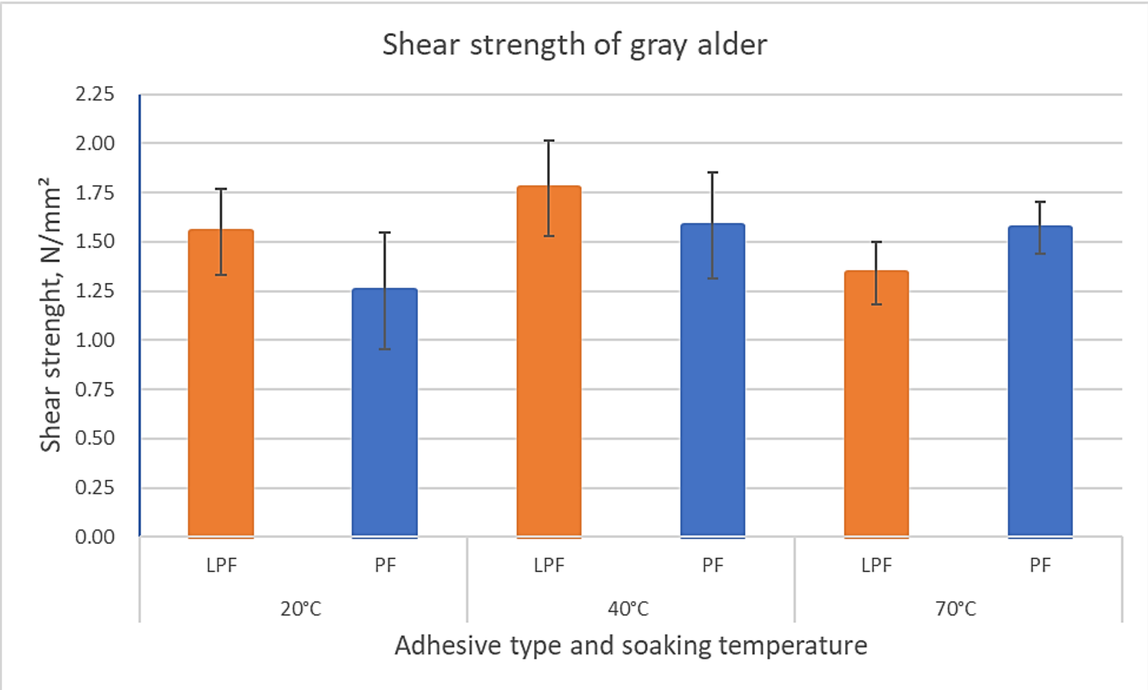

Figure 3.5 Shear strength of gray alder

Figure 3.5 shows that gray alder specimens which was soaked at 20 °C and used LPF adhesive has 24% (difference 0.3 N/mm^2) better share strength result than in same conditions prepared specimens with PF adhesive. Gray alder specimens which was soaked at 40 °C and used LPF adhesive has 12% (difference 0.19 N/mm^2) better share strength result than in same conditions prepared specimens with PF adhesive. Gray alder specimens which was soaked at 70 °C and used PF adhesive has 17% (difference 0.23 N/mm^2) better share strength result than in same conditions prepared specimens with LPF adhesive.

If to compare different log soaking temperatures and adhesives, then the highest (1.77 N/mm^2) shear strength result coming out at 40 °C with LPF adhesive and the lowest (1.25 N/mm^2) result is performing at 20 °C. with PF adhesive.

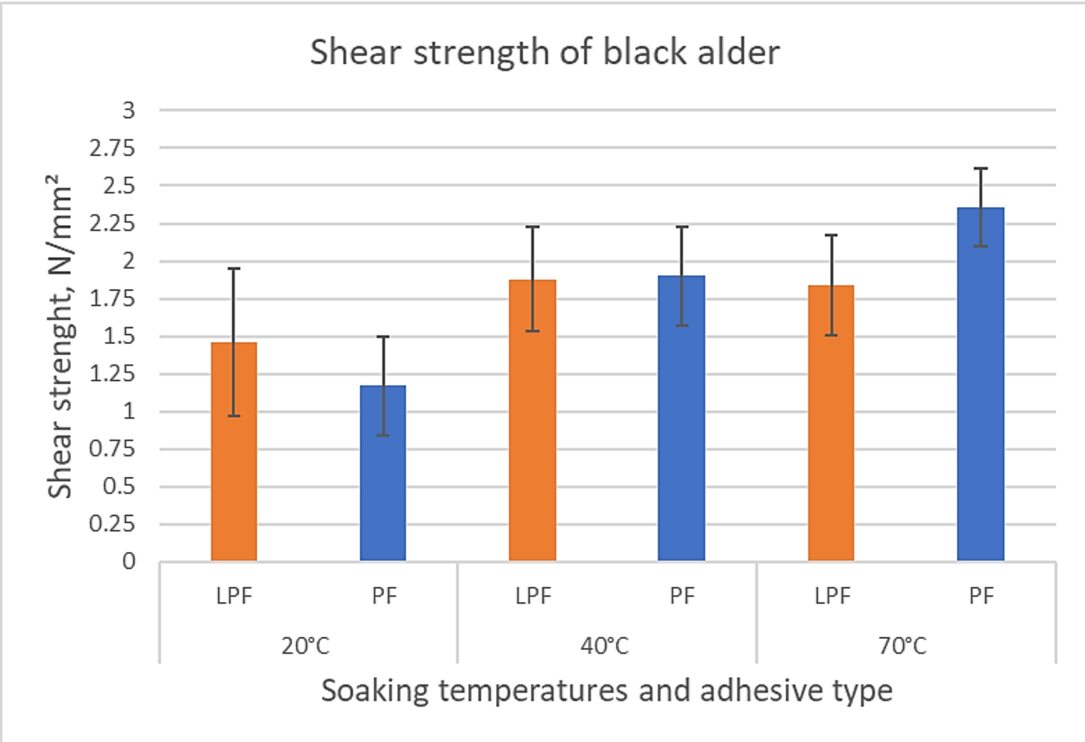

Figure 3.6 Shear strength of black alder

Figure 3.6 shows that black alder specimens which was soaked at 20 °C and used LPF adhesive has 25% (difference 0.29 N/mm^2) better share strength result than in same conditions prepared specimens with PF adhesive. Black alder specimens which was soaked at 40 °C and used PF adhesive has 1% (difference 0.02 N/mm^2) better share strength result than in same conditions prepared specimens with LPF adhesive. Black alder specimens which was soaked at 70 °C and used PF adhesive has 28% (difference 0.52 N/mm^2) better share strength result than in same conditions prepared specimens with LPF adhesive. If to compare different log soaking temperatures and adhesives, then the highest (2.36 N/mm^2) shear strength result coming out at 70 °C with PF adhesive and the lowest (1.17 N/mm^2) result is performing at 20 °C. with PF adhesive.

If to analyze the results at one specific log soaking temperature and compare the adhesives, then it is complicate to figure out which adhesive is more reasonable to use as plywood. For gray alder is more suitable to use LPF than PF. For black alder is more proper to use PF than LPF. If to compare gray alder and black alder shear strength results, then more reasonable is to use black alder as plywood material.

Results can be influenced by several things like glue line thickness. It is known that the bonding strength decreases if to increase glue line thickness. With a thicker glue line occur higher internal stress. The glue shrinkage can lead to the lower shear strength. [29]

Table 3.1 Wood fibre failure in percentage of gray alder

Specimen nr	**Wood type, soaking temperature °C, adhesive type**					
-	Gray alder 20°C PF	Gray alder 20°C LPF	Gray alder 40°C PF	Gray alder 40°C LPF	Gray alder 70°C PF	Gray alder 70°C LPF
1	30%	30%	20%	20%	40%	20%
2	20%	40%	20%	20%	20%	30%
3	20%	30%	30%	70%	60%	20%
4	30%	20%	0%	30%	40%	20%
5	30%	10%	20%	40%	40%	30%
6	40%	30%	0%	10%	20%	50%
7	50%	40%	20%	30%	20%	20%
8	10%	40%	20%	10%	10%	20%
9	30%	20%	40%	10%	10%	10%
10	50%	40%	30%	30%	20%	10%
11	10%	40%	20%	50%	20%	10%
12	50%	50%	30%	30%	50%	20%
13	70%	30%	20%	40%	30%	50%
14	70%	60%	50%	20%	10%	70%
15	50%	50%	50%	20%	10%	20%
Average %	**37%**	**35%**	**25%**	**29%**	**27%**	**27%**
Average max load (N)	781.12	965.72	988.44	1107.05	981.69	865.87
Average Shear strength (N/mm²)	1.25	1.55	1.58	1.77	1.57	1.34
RESULTS	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**

The Table 3.1 shows wood fibre failure in percentage of gray alder which results are measured visually (see appendices 1-6). At the temperature of 20 °C is the wood fibre failure on average 36%, at the temperature 40 °C is the wood fibre failure on average 27% and at the temperature 70 °C is the wood fibre failure on average 27%. If to compare different log soaking temperatures and adhesives, then the highest (37%) wood failure result is coming out at 20 °C with PF adhesive and the lowest (25%) wood failure result is performing at 40 °C with PF adhesive. All the specimen groups passed the test.

Table 3.2 Wood fibre failure in percentage of black alder

Specimen nr	**Wood type, soaking temperature °C, adhesive type**					
-	Black alder 20°C PF	Black alder 20°C LPF	Black alder 40°C PF	Black alder 40°C LPF	Black alder 70°C PF	Black alder 70°C LPF
1	10%	0%	20%	20%	10%	40%
2	10%	0%	20%	20%	20%	30%
3	30%	50%	30%	10%	10%	20%
4	20%	20%	60%	40%	10%	20%
5	20%	10%	30%	50%	10%	10%
6	10%	0%	30%	0%	10%	10%
7	0%	0%	10%	10%	10%	40%
8	10%	20%	30%	10%	20%	30%
9	10%	10%	0%	20%	0%	30%
10	10%	20%	10%	20%	0%	20%
11	20%	0%	40%	30%	10%	30%
12	20%	30%	20%	40%	10%	20%
13	40%	30%	50%	10%	40%	30%
14	30%	60%	50%	-	0%	0%
15	10%	30%	10%	30%	0%	20%
Average %	**17%**	**19%**	**27%**	**22%**	**11%**	**23%**
Average max load (N)	728.13	915.31	1190.15	1175.64	1476.72	1149.17
Average Shear strength (N/mm²)	1.17	1.46	1.90	1.88	2.36	1.84
RESULTS	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**

The Table 3.2 shows wood fibre failure in percentage of black alder which results are measured visually (see appendices 7-12). At the temperature 20 °C is the wood fibre failure on average 18%, at the temperature 40 °C is the wood fibre failure on average 24.5% and at the temperature 70 °C is the wood fibre failure on average 17%. If to compare different log soaking temperatures and adhesives, then the highest (27%) wood failure result is coming out at 40 °C with PF adhesive and the lowest (11%) wood failure result is performing at 70 °C with PF adhesive.

According to standard EN 314-2:1999 is required that shear strength must be more than 1 N/mm^2 to pass the test. All the specimens with every log soaking temperature with both adhesives passed the test though the wood failure % was low, despite that the shear strength was received.

If to analyze the results, then black alder wood fibre failure is less than gray alder.

Reasons can be specific density value of black alder compared to gray alder. Has been detected that shear strength of veneer increases accordingly to specific density. [30] Based on this, it can be assumed that black alder specific gravity is higher.

CONCLUSION

This study has tested the bending strength and modulus of elasticity (MOE) and shear strength of gray alder and black alder plywood at different log soaking temperatures (20 °C, 40 °C, 70 °C).

If to analyse the results within longitudinal direction of plywood, the highest modulus of elasticity (MOE) (3336.5 N/mm^2) was observed for the black alder test specimens at soaking temperature 70 °C with lignin-phenol-formaldehyde (LPF) adhesive. The lowest MOE result (1030.4 N/mm^2) was produced by gray alder at soaking temperature 20 °C and used LPF adhesive. If to analyse the results within perpendicular direction of plywood, the highest MOE (6952.6 N/mm^2) was observed for the black alder test specimens at soaking temperature of 40 °C with lignin-phenol-formaldehyde (LPF) adhesive. The lowest MOE result (2331.7 N/mm^2) was produced by gray alder at soaking temperature 70 °C and used phenol-formaldehyde adhesive.

The highest gray alder bending strength result (58.49 N/mm^2) in perpendicular direction came out at soaking temperature 40 °C and used LPF adhesive. The lowest bending strength result occurred at soaking temperature of 20 °C, when used LPF adhesive and direction was longitudinal. The highest black alder bending strength result (90.07 N/mm^2) in perpendicular direction come out at soaking temperature 40 °C and used PF adhesive. The lowest bending strength result occurred at soaking temperature of 20 °C, when used LPF adhesive and direction was longitudinal.

If to compare gray alder and black alder bending strength and MOE results, can be inferred, that black alder plywood is stiffer than gray alder.

The highest shear strength result (1.77 N/mm^2) of gray alder come out at log soaking temperature 40 °C with LPF adhesive. The lowest shear strength result (1.25 N/mm^2) occur at log soaking temperature 20 °C with PF adhesive. The highest shear strength result (2.36 N/mm^2) of black alder come out at log soaking temperature 70 °C with PF adhesive. The lowest shear strength result (1.17 N/mm^2) occur at log soaking temperature 20 °C with PF adhesive.

Shear strength results shows that the black alder veneer can create stronger bonding connections between layers than the gray alder.

When to analyse the test results, then it is difficult to say which of the adhesives (LPF, PF) is more justified to use in plywood production. Based on the results which come out in this study then for gray alder is recommended to use LPF adhesive and for black alder PF adhesive. It cannot say that LPF adhesive results was significantly worse than with

PF. Can be said that LPF adhesive has proved itself during the test and is suitable for production of plywood for alders.

The results show that black alder at soaking temperature 40 °C gives the most stable bending strength and MOE results, which would make such a combination most suitable for plywood production.

RESÜMEE

Selles uurimsutöös on võrreldud hall lepa ja sanglepa painedtugevust ja elastsusmoodulit standardi EN 310:2002 alusel ning seda erinevatel palgi leotustemperatuuridel (20 °C, 40 °C, 70 °C). Lisaks on katsetatud liimühenduse (ligniin fenoolformaldehüüd ja fenoolformaldehüüd) tugevust EN 314-1:2005 standardi alusel ja analüüsitud puidukiu purunemist EN 314-2:1999 standardi alusel.

Kui analüüsida tulemusi, kus välimised spooni kihid on piki suunas, siis kõige parem elastusmoodul (3336.5 N/mm^2) ilmnes sanglepa katsekehadega, mille palgid olid leotatud 70 °C juures koos ligniin fenoolformaldehüüd liimiga (LPF). Kõige halvema elastsusmooduli tulemuse (1030.4 N/mm^2) andis välja hall lepp, mille palgid olid leotatud 20 °C juures ja kasutatud ligniin fenoolformaldehüüdi. Kui analüüsida tulemusi, kus välimised spooni kihid on risti suunas, siis kõige parem elastusmoodul (6952,6 N/mm^2) ilmnes sanglepa katsekehadega, mille palgid olid leotatud 40 °C juures koos LPF liimiga. Kõige halvema elastsusmooduli tulemuse (2331.7 N/mm^2) andis välja hall lepp, mille palgid olid leotatud 70 °C juures ja kasutatud fenoolformaldehüüdi (PF).

Kõige parema paindetugevuse (58.49 N/mm^2) hall lepa puhul tuli esile leotustemperatuuril 40 °C, kus kasutati LPF liimi ja vineeri välimised spooni kihid olid risti suunas. Kõige halvem paindetugevus hall lepa puhul tuli esile leotustemperatuuril 20 °C, kus kasutati LPF liimi ja vineeri välimised spooni kihid olid piki suunas. Kõige parema paindetugevuse (90.07 N/mm^2) sanglepa puhul tuli esile leotustemperatuuril 40 °C, kus kasutati PF liimi ja vineeri välimised spooni kihid olid risti suunas. Kõige halvem paindetugevus sanglepa puhul tuli esile leotustemperatuuril 20 °C, kus kasutati LPF liimi ja vineeri välimised spooni kihid olid piki suunas.

Kui võrrelda hall lepa ja sanglepa elastsusmooduli ja paindetugevuse tulemusi, siis saab öelda, et sanglepp on jäigem kui hall lepp.

Hall lepa liimühenduse parimad tugevusomadused (1.77 N/mm^2) tulevad välja palgi leotustemperatuuril 40 °C, kui on kasutatud LPF liimi. Halvimad tugevusomadused (1.25 N/mm^2) tulevad välja palgi leotustemperatuuridel 20 °C, kui on kasutatud PF liimi. Sanglepa liimühenduse parimad tugevusomadused (2.36 N/mm^2) tulevad välja palgi leotustemperatuuril 70 °C, kui on kasutatud PF liimi. Halvimad tugevusomadused (1.17 N/mm^2) tulevad välja palgi leotustemperatuuridel 20 °C, kui on kasutatud PF liimi.

Nihketugevuse testi tulemused näitavad, et sanglepp on võimeline looma paremad liimühenduse sidemed spooni kihtide vahel, kui seda suudab hall lepp.

Analüüsides katsete tulemusi, siis on keeruline öelda, kumb liimidest (LPF, PF) on rohkem õigustatud. Lähtudes katsete tulemustest, siis hall lepa puhul eelistaks kasutada LPF liimi ja sanglepa puhul PF liimi, kuid ei saa väita, et LPF liim oleks märkimisväärselt halvemad tulemused andnud sanglepa puhul. Võib öelda, et LPF liim on ennast katsete käigus õigustanud ning on sobilik vineeri tootmiseks lepa puhul.

Katseid analüüsides saame teada, et sanglepp 40 °C palgi leotustemperatuuril annab kõige stabiilsemad paindetugevuse ja elastmooduli tulemused, millest tulenevalt selline kombinatsioon oleks kõige sobilikum vineeri tootmiseks.

REFERENCES

[1] Aosaar J., Varik M., Lõhmus K., Uri V, "Stemwood Density in Young Gray Alder (Alnus incana (L.) Moench) and Hybrid Alder (Alnus hybrida A. Br.) Stands Growing on Abandoned Agricultural Land", Baltic Forestry 17(2): 256-261, 2011

[2] W. Wang, M. Zammarano, J.R. Shields, E. D. Knowlton, I. Kim, J. A. Gales, M. S. Hoehler, J- Li., "A novel application of silicone-based flame-retardant adhesive in olywood", Ministry of Education Key Laboratory of Wood Materials Science and Utilization, Beijing Key Laboratory of Wood Science and Engineering, 35 Qinghua East Road, Haidian District, Beijing 100083, China. 2019

[3] P. Bekhta, E-A. Salca, A. Lunguleasa, "Some properties of plywood panels manufactured from combinations of thermally densified and non- densified veneers of different thickness in on structure", (a) Department of Wood-Based Composites, Cellulose and Paper, Ukrainian National Forestry University, Ukraine, (b) Faculty of Wood Engineering, Transilvania University of Brasov, Romania, 2017

[4] Hytönen J., Saarmalmi A, "Biomass production of coppiced gray alder and the effect of fertilization", Silva Fennica vol. 49 no. 1 article in 1260. 16p. 2015

[5] L. Rytter, "Gray alder in forestry: a review", Norwegian journal of Agricultural Sciences. Supplement no 24: 65 – 84. ISSN 1806-1600. 1996

[6] H. Claessens, A. Oosterban, P. Savill, J. Rondeux, "A Review of the characteristics of black alder (*Alnus glutinosa* (L.) Gaertin.) and their implications for silvicultural practices", Unit of Forest and Nature Management, Gembloux Afto-Bio tech, University of Liege, 2, Passage de Deportes, 5030 Gembloux, Liege, Belgium. 2010

[7] Daniele de Rigo, Giovanni Caudullo, T. Houston Durrant, "Alnus glutinosa in Europe: distribution, habitat, usage and threats", European Atlas of Forrest Tree Species. Publ. Off. EU, Luxembourg, pp. e01f3c0+, 2016

[8] William Leggate, Robert McGavin, Henri Bailleres, "A guide to manufacturing rotatary veneer and products from small logs", Forest Product Innovations, Salisbury Research Facility, Department of Agriculture and Fishering. Queesland, Australia, 2017

[9] UPM Plywood Oy, WISA Plywood production process, 2019 [WWW] https://www.wisaplywood.com/products/about-plywood/

[10] P. Borysiuk, P. Boruszewski, G. Kowaluk, I. Nizialek, E. Gregorzewska, "Critical analysis of plywood production system model", Warsaw University of Life Sciences, Faculty of Wood Technology, Poland. 2013

[11] McGavin R. and Leggate W, "Comparison of processing methods for small diameter logs: Sawing versus rotary peeling", Queensland Department of Agriculture and Fishering, Horticulture and Forestry Science, Salisbury Research Facility, Queensland, Australia. 2019

[12] John F. Lutz, USDA Forest Service Research Paper FPL 228, "Techniques for peeling slicing, and drying veneer", Forest Products Laboratory, Forest Service, U.S Department of Agriculture. 1974

[13] A. Yamamoto, A. Rohumaa, E. Kontturi, M. Hughes, T. Vuorinen, "The chemical characteristic of squeezable sap from silver birch (Betula pendula) logs hydrothermally treated at 70°C: the effect of treatment time on the concentration of water extracts", Department of Forest Products Technology, School of Chemical Technology, Aalto University, P.O Box 16300, 00076 Espoo, Finland. Springer-Verlag Berlin Heidelberg. 2015

[14] A. Rohumaa, T. Antikainen, C. G. Hunt, C. R. Frihart, M. Hughes, "The influence of log soaking temperature on surface quality and integrity performance of birch (*Betula pendula* Roth) veneer", Department of Forest Products Technology, School of Chemical Technology, Aalto University, P.O Box 16300, 00076 Espoo, Finland. Springer-Verlag Berlin Heidelberg. 2015

[15] Anti Rohumaa, "The impact of log preheating on birch veneer surface quality, bond formation and plywood performance", Aalto University, School of Chemical Technology, Department of forest products Technology. Dectoral dissertations, Helsinki, 2016

[16] Onul Ülker, "Wood Adhesive and Bonding Theory", Department of Interior Architecture and Environmental Design, Fine Arts Faculty, Kirikkale University, Kirikkale, Turkey. 2016

[17] Nadir Ayrilmis, Günay Özbay, "Technological properties of plywood bonded with phenol-formaldehyde resol resin synthesized with Bio-Oil", Lk 494. Istanbul University, Aksaray University, Turkey, 2017

[18] William D. Detlefsen, "Phenolic resins: some chemistry, technology and history", Springfield, OR, 97477,USA. 2002

[19] A. Pizzi, "Advanced Wood Adhesives Technology", University de Nancy 1, Epinal, France and University of Witwatersrand Johannesburg, South Africa. Marcel Dekker Inc. 1994

[20] Charles R. Frihart, "Wood Adhesion and Adhesives", USDA, Forest Sevice, Forest Products Laboratory, Madison, Wi. CRC Press LLC. 2005

[21] Homaira Siddiqui, "Production of Lignin-Based phenolic Resins Using De-polymerized Kraft Lignin and Process Optimization", The University of Western Ontario. 2013

[22] Wei Zhang, Yufeng Ma, Chunpeng Wang, Shouhai Li, Mingming Zhang, Fuxiang Chu "Preparation and properties for lignin-phenol-formaldehyde resins based on different biorafinery residues of agricultural biomass", Chinese Academy of Forestry, Beijing 100091, China, 2013

[23] A.Pizzi, "Handbook of Adhesive Technology", Second edition revised and expanded. University de Nancy 1, Epinal, France. Marcel Dekker Inc. 2003

[24] Estonian Standard department, "Wood-based panels- Determination of modulus of elasticity in bending and bending strength", Eesti Standardikeskus MTÜ. 2002

[25] Forest Production Laboratory, "Wood handbook- Wood as an engineering material", General Technical Report FPL-GTR-190, U.S. Department of Agriculture, Forest Service, Forest Products laboratory. 508 p. Madison, WI. 2010

[26] Estonian Standart department, "Plywood. Bonding quality", Eesti Standardikeskus MTÜ, 2005

[27] Anti Rohumaa, Akim Yamamoto, Christopher G. Hunt, Charles R. Frihart, Mark Hughes, Jaan Kers, "Effect of log soaking and the temperature of peeling on the properties of Rotary-cut birch (Betula pendula Roth) veneer bonded with phenol-formaldehyde adhesive", A: Department of Forest Products Technology, School of Chemical Technology, Aalto University, Espoo, Dinland. B: US Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, USA. C: Department of Polymer Materials, University of Technology, Tallinn, Estonia. 2016

[28] G. Schneeweib, S. Felber, "Review on the Bending Strength of Wood and Influencing Factors", Institute of Materials Science and Technology, Vienna University of Technology, A-1040, Vienna, Austria. 2013

[29] P. Bekhta (a), E-A. Salca (b), "Influence of veneer densification on the shear strength and temperature behaviour inside the plywood during hot press", (a) Department of Wood-Based Composites, Cellulose and Paper, Ukrainian National Forestry University, Ukraine, (b) Faculty of Wood Engineering, Transilvania University of Brasov, Romania, 2017

[30] D. Toksoy, G. Cursel, I. Aydin, S. Colak, C. Demirkir, "Technological and economic comparison of the usage of beech amd alder wood in plywood and laminated veneer lumber manufacturing", Karadeniz Technical University, Faculty of Forestry, Trabzon, Turkey. 2005

APPENDIX

Appendix 1 Figure of gray alder at 20°C with LPF

Figure A 1.1 Gray alder at 20°C with LPF

Appendix 2 Figure of gray alder at 20°C with PF

Figure A 2.1 Gray alder at 20°C with PF

Appendix 3 Figure of gray alder at 40°C with LPF

Figure A 3.1 Gray alder at 40°C with LPF

Appendix 4 Figure of gray alder at 40°C with PF

Figure A 4.1 Gray alder at 40°C with PF

Appendix 5 Figure of gray alder at 70°C with LPF

Figure A 5.1 Gray alder at 70°C with LPF

Appendix 6 Figure of gray alder at 70°C with PF

Figure A 6.1 Gray alder at 70°C with PF

Appendix 7 Figure of black alder at 20°C with LPF

Figure A 7.1 Black alder at 20°C with LPF

Appendix 8 Figure of black alder at 20°C with PF

Figure A 8.1 Black alder at 20°C with PF

Appendix 9 Figure of black alder at 40°C with LPF

Figure A 9.1 Black alder at 40°C with LPF

Appendix 10 Figure of black alder at 40°C with PF

Figure A 10.1 Black alder at 40°C with PF

Appendix 11 Figure of black alder at 70°C with LPF

Figure A 11.1 Black alder at 70°C with LPF

Appendix 12 Figure of black alder at 70°C with PF

Figure A 12.1 Black alder at 70°C with PF

Appendix 13 Table of MOE exact results

Table A 13.1 Table of MOE exact results

Wood type, temperature (°C), adhesive type	Direction of veneer (long. or per.)	MOE (N/mm²)	Stdv (N/mm²)
Gray alder, 20°C, PF	Long.	1260.2	184.2
Gray alder, 20°C, PF	Per.	2643.3	422.4
Gray alder, 20°C, LPF	Long.	1030.4	103.4
Gray alder, 20°C, LPF	Per.	2570.4	248.6
Black alder, 20°C, PF	Long.	2382.7	386.2
Black alder, 20°C, PF	Per.	4625.0	302.2
Black alder, 20°C, LPF	Long.	2147.1	218.9
Black alder, 20°C, LPF	Per.	4898.9	458.9
Gray alder, 40°C, PF	Long.	1790.5	162.6
Gray alder, 40°C, PF	Per.	3709.8	381.0
Gray alder, 40°C, LPF	Long.	1903.8	358.8
Gray alder, 40°C, LPF	Per.	3971.7	733.2
Black alder, 40°C, PF	Long.	3141.1	331.4
Black alder, 40°C, PF	Per.	6894.4	262.7
Black alder, 40°C, LPF	Long.	3019.9	176.0
Black alder, 40°C, LPF	Per.	6952.6	192.4
Gray alder, 70°C, PF	Long.	1202.2	140.1
Gray alder, 70°C, PF	Per.	2331.7	253.6
Gray alder, 70°C, LPF	Long.	1029.7	96.3
Gray alder, 70°C, LPF	Per.	2370.2	335.2
Black alder, 70°C, PF	Long.	2568.1	178.1
Black alder, 70°C, PF	Per.	5195.9	276.2
Black alder, 70°C, LPF	Long.	3336.5	140.5
Black alder, 70°C, LPF	Per.	6522.0	151.1

Appendix 14 Table of Bending strength exact results

Table A 14.1 Bending strength exact result

Wood type, temperature (°C), adhesive type	Direction of veneer (long. or per.)	Maximum Compressive load (N)	Stdv (N)	Compressive extension at maximum compressive load (mm)	Stdv (mm)	Bending strength (N/mm^2)
Gray alder 20°C PF	Long.	401.55	55.99	13.87	1.92	26.35
Gray alder 20°C PF	Per.	566.50	97.24	8.09	0.88	37.18
Gray alder 20°C LPF	Long.	343.04	30.46	14.43	2.41	22.51
Gray alder 20°C LPF	Per.	562.32	59.03	8.95	0.86	36.90
Gray alder 40°C PF	Long.	610.05	33.32	15.86	2.22	40.03
Gray alder 40°C PF	Per.	824.48	90.65	849	1.17	54.11
Gray alder 40°C LPF	Long.	622.09	75.39	14,.66	1.23	40.82
Gray alder 40°C LPF	Per.	891.21	149.98	8.06	0.72	58.49
Gray alder 70°C PF	Long.	427.58	148.64	14.37	1.73	24.90
Gray alder 70°C PF	Per.	511.20	65.55	870	1.25	33.55
Gray alder 70°C LPF	Long.	360.22	23.14	15,.60	0.99	23.66
Gray alder 70°C LPF	Per.	539.91	48.28	883	1.90	35.43
Black alder 20°C PF	Long.	703.19	63.95	11,.36	1.44	47.36
Black alder 20°C PF	Per.	950.12	79.23	7.39	0.91	64.09
Black alder 20°C LPF	Long.	696.80	67.24	11.76	0.94	44.97
Black alder 20°C LPF	Per.	989.83	126.60	6.74	0,.99	63.89
Black alder 40°C PF	Long.	913.12	90.36	13.37	130	59.92
Black alder 40°C PF	Per.	1372.52	69.64	8.21	0.66	90.07
Black alder 40°C LPF	Long.	869.34	81.08	12.13	1.88	57.05
Black alder 40°C LPF	Per.	1361.34	108.80	7.62	0.90	89.34
Black alder 70°C PF	Long.	782.78	94.16	14.29	2.26	53.48
Black alder 70°C PF	Per.	1100.03	69.08	7.98	0.58	72.19
Black alder 70°C LPF	Long.	982.06	45.69	11.26	0.97	64.45
Black alder 70°C LPF	Per.	1137.41	71.10	5.86	0.32	74.64