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SCHOOL OF ENGINEERING
Department of Materials and Environmental Technology

RESEARCH OF VENEER WETTABILITY OF DIFFERENT WOOD SPECIES

ERINEVATE PUIDULIIKIDE SPOONI MÄRGUVUSE UURIMINE

MASTER THESIS

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Tallinn 2021

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Research of veneer wettability of different wood species.

Erinevate puiduliikide spooni märguvuse uurimine.

Thesis main objectives:

1. Investigate the effect of soaking temperature on wettability of four widely spread Estonian wood species: Birch (Betula pendula), Aspen (Populus tremuloides), Black alder (Alnus glutinosa), Grey alder (Alnus incana)
2. Research the influence of log soaking temperatures on wettability along the logs.

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INTRODUCTION

The wood properties of veneers are initially similar to those of lumber. However, the process of manufacturing of veneer has own significant effect on physical and chemical surface properties of veneer. Thus, there is a need to research veneer separately from other wood products from the same species.

Veneer is a material for plywood production which is a fast-growing sector in Estonia due to lots of investments into the new and already existing factories.

Birch (Betula pendula) veneer is widely used for plywood production in our region and birch veneer properties are well-researched. However, there is a growing interest of manufacturers in using alternate domestic species. But not much research on suitability of other species has been carried out yet.

The physical appearance is a primary factor in the process of searching for possible substitutes for birch veneer. However, it is crucial to know and understand which factors are important for veneer production and use in order to achieve the great quality of a product and to understand its field of use. One of the most important factors is effect of various soaking temperatures on production of veneer from different species and its influence on wettability of veneer surfaces.

The wood wettability reflects the composite chemical and morphological character of the wood. It is an important indicator of bonding strength which is crucial for plywood production. The more information is available for the manufacturers, the more precise are predictions on material behaviour.

The present research work includes the experimental data of the effect of soaking temperature on wettability of four widely spread Estonian wood species: Birch (*Betula pendula*), Aspen (*Populus tremuloides*), Black alder (*Alnus glutinosa*), Grey alder (*Alnus incana*), respectively. Also, the research on the influence of log soaking temperatures on wettability along the logs is conducted. Birch is used as reference specie to compare its properties with other chosen species.

This study is divided into three main chapters. The first chapter is a literature overview. It consists of brief description of used species, effects of different internal and external factors on veneer properties, overview of veneer adhesion. The second chapter demonstrates used materials and methods. The third chapter contains the results with discussion and conclusions.

The aim of thesis was to investigate the effect of 20°C, 40°C, 70°C soaking temperatures on wettability of birch, aspen, black alder, grey alder and to research those temperatures the wettability along the logs.

1 LITERATURE REVIEW

1.1 Specie overeview

1.1.1 Birch (Betula pendula)

Birch is known not only for the ability to tolerate different climates and areas, but also for high genetic variability. Moreover, by claiming forest gaps and quickly increasing soil functioning and biodiversity it improves forest resilience. This specie has great resistance to climatic stresses and damages. In Estonia, the birch is the most popular hardwood specie [15]. Also, it is heavily used in industry and well-researched.

However, there are known drawbacks of birch wood material. For example, the long storage in log yards is not recommended for birch logs as there is high probability of fungal discolorations, stains, and insect damage developed rapidly for the specie. Because of the common crooks, caused by longitudinally fluffy and cross-sectionally light, hard, tight, and glossy reaction wood, tooling can be relatively difficult [16]. The utilisation of birch wood is also complicated by the relatively small size of logs, high number of branches, ovality of logs, knottiness, frequent decay, and rapid discoloration [16]. Still, birch is suitable specie for the plywood industry due to its relatively straight grain with uniform texture contributing to the good workability, finishing with machines and hands [40]. Drying process of birch is fast but there is a tendecny of warping. Using birch is more natural for mass production than for high-quality production due to its pale and inexpressive appearance [41].

Birch wood is diffuse-porous and possesses small proportion of summer wood, density of which does not differ dramatically from density of spring wood. Thus, birch wood maintains homogeneous structure. Vessels, rays, and fibres proportions in the birch wood are about 18%, 7% and 75% by volume, respectively. The chemical composition of birch wood consists of 0.18% ash, 22.78% lignin, 24.74% pentosans, 42.56% cellulose [19]. In different areas of the trunk the variability of cell size and proportion is observed [16]. Fibre proportion decreases while the parenchyma and vessel number increase from breast height to the crown. Simultaneously, the proportion of fibres increases from core to surface in radial direction followed by density increase [17]. Fibre length and diameter, vessel element's length and the cell wall thickness tend to increase from the pith to the surface of the trunk, as the cells get shorter from the butt to the top of the trunk. Fibre length, fibre wall thickness and distance from the pith correlate positively with the density of birch wood. At the same time, the density and the height in the trunk have negative correlation [16]. Birch (B. pendula) wood is known to have medium density - 630-670 kg/m^3 [22].

1.1.2 Aspen (Populus tremuloides)

Aspen is one of the most widely spread hardwood species in Estonian forests. This spicy is biologically highly adaptable and can grow in different conditions [18].

The aspen wood has chipped or fuzzy grain surface. However, it is easy to glue. It is also lightweight and soft. Aspen has small size and thus production of high-quality material is low. Knots, high susceptibility to heart rot, bacterial wet wood and tension wood are the main reasons for low quality of aspen veneer [20]. Aspen wood has smaller density and a significantly rougher surface than birch [8]. Aspen tends to deform while being dried [42].

Aspen is a diffuse-porous hardwood specie. Vessels, rays, and fibres proportions are about 34%, 11% and 55% by volume. The chemical composition of aspen wood is 0.32% ash, 18.24% lignin, 24.47% pentosans, 47.11% cellulose [18]. Aspen has relatively low density - 490-540 kg/m^3.

1.1.3 Black alder (Alnus glutinosa)

Black alder is the least spread wood specie in Estonia out of four presented [26]. It is homogeneous wood with diffuse pores, small vessels with thin walls, numerous small medullary rays which causes wood grain to be fine [27].

Black alder has good workability but, due to low density (average density is 495 kg/m3), wood is relatively soft and tends to have high probability of checks emergence [42]. However, black alder is easy to bond [43] and has good water permeability [27].

1.1.4 Grey alder (Alnus incana)

Grey alder is widely distributed wood specie in Estonia. The growing stock and area of grey alder stands in Estonia has been increasing continually for more than half a century [23]. Grey alder enriches nearby soils with nitrogen [24]. Grey alder wood is, however, mostly used as firewood [25].

Grey alder wood is soft and brittle and has good workability [39]. Average grey alder density in Estonia is equal to 396 kg/m^3 [23].

1.2 Wood properties

Wood is known to be a highly chemically and structurally variable material [10]. Structural variance reflects the types of cells in wood as well as their organizational patterns, while chemical variance shows differences in wall constituents and their quantities.

The wood cell wall mostly consists of cellulose and hemicellulose. Characteristics and proportions variatoons of these components and differences in cellular structure influences wood weight, flexiblity, softnesss etc. Also, the cell walls are hygroscopic due to the hydroxyl groups on these chemicals. Lignin holds cells together and is known to be a hydrophobic molecule. Thus, the cell walls have affinity for water, but the water absorption is limited by the presence of lignin. Water in wood is known to have severe impact on properties of wood, and wood–water relations influence the wood industry [31].

Majority of wood properties variation withing a tree and between different species is linked with density [9]. Density is equal to weight or mass of wood divided by the volume of the specimen at a given moisture content. Solid wood cell walls have a density of 1,500 kg$\times$m^{-3} in all the wood species. Although, density varies with void volume and cell wall thickness between wood species and within a species [31]. Differences in porosity and in cell wall thickness is the cause why some species of wood possess more wood substance per unit volume when compared to other species. Selection of particular wood specie for specific use is done knowing specie's properties like density, strength, grain pattern, hardness, etc. [10]

Wood properties can differ withing single log due to the following factors:

- Stem wood being structurally and chemically distinct from root wood and upper branch wood [10].
- Spread of nitrogen differs with radial position and has the highest concentration in the outer sapwood and pith zones [10].
- Noticeable high variability of extractive contents within the heartwood both radially and longitudinally [12].
- The presence of the juvenile wood in the stem centre which possesses shorter fibres and lower density is seen in many species [44].
- Reaction wood, severely affecting wood properties [45].

- Knots, causing fibre continuity interruption and change in wood fibres direction around it and thus influencing wood material properties [9].

The wood in the tree trunk is divided into two zones – sapwood (region of stem where parenchyma cells are still alive and metabolically active) and heartwood (region of stem surrounded by sapwood) each of which have important distinct functions [31] (See Figure 1.1).

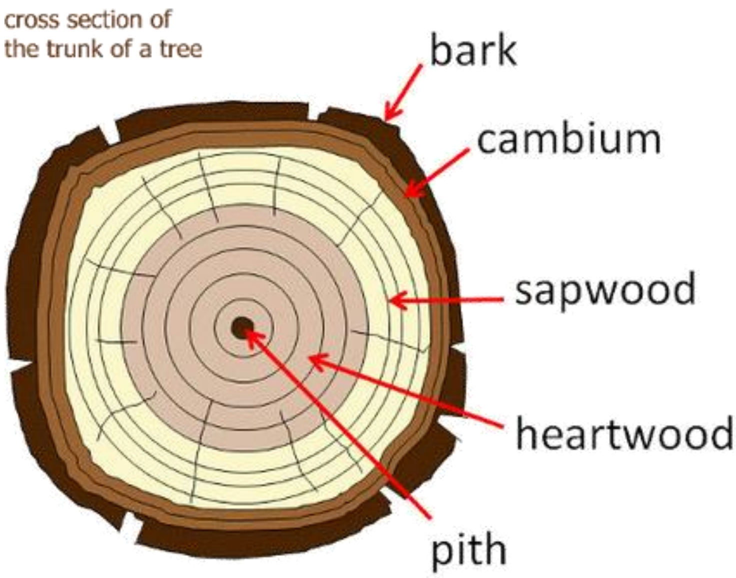

Figure 1.1 Cross section of the tree trunk [46]

Sapwood is conducting sap, stores, and synthesises biochemicals. Storage of photosynthate in form of starch is one of the main issues for woodworking. In some species excess of starch leads to anaerobic bacteria or sap-stain fungi growth which can lead to wood material being commercially unusable [31].

Extractives formed by parenchyma cells at the heartwood–sapwood boundary are stored in heartwood. Extractives can affect wood characteristics drastically. For instance, some species (e.g., Tectona grandis) acquire water resistance because the of waxes and oils in heartwood. Moreover, the value of a wood material for industry can be directly affected by various extractives [31].

Sapwood tends to possess higher wettability compared with heartwood due to the extractive content of the heartwood [30].

Moreover, wood properties are influenced by outside factors like temperature, moisture, weathering, etc.

1.3 Adhesion properties of veneer

Veneer adhesion is a complicated system. First of all, the complexity is caused by nature of wood itself. Moreover, numerous factors such as felling season, heating temperature, microstructure of different wood specie, storage conditions can influence adhesion. In addition, different adhesives and adhesive application affect the process. Furthermore, chemical composition of wood plays significant role in adhesion process. To understand the process of adhesion of wood, it is crucial to understand the structure of wood material on both microscopic and macroscopic levels [8].

There are three main characteristics of veneer surfaces defining the extent of adhesion. These are wettability, surface quality, and moisture content.

Wood surfaces extractives contribute to surface inactivation through physical and chemical means. Majority of widely used adhesives for wood are waterborne and they cannot properly wet and penetrate extractive-covered surfaces [31].

Airborne chemical contaminants can also inactivate a wood surface [31].

Wood assemblies bonded with adhesive tend to increase in strength with wood density up to a range of 700 - 800 $kg \times m^{-3}$ (moisture content 12%). Below these numbers, bonding is typically uncomplicated, and the wood strength is the limit of the assembly strength. However, above these numbers it is hard to produce high-strength joints with high wood failure. There are several reasons why high-density wood bonding is problematic. Thicker cell walls and smaller diameter lumens complicate adhesive penetration into the wood, limiting mechanical interlock to less than two cells deep. Moreover, higher extractives concentration is natural for high-density species. Also, these species swell and shrink more with changes in moisture content [31].

To ensure good bond formation the proper preparation of the veneer surface must be conducted. That means cleaned, smooth and chemically receptive of used adhesive surface. This influences the bond strength, aging resistance and improves the adhesion leading to better bonding [31]. The veneer wettability, adhesion penetration and flow that can disturb bond formation and further on the quality of end-product are affected by surface properties [35]. Wood surface contains extractives, oils, stains, and other contaminants which can have negative effect on bonding. Such contaminants are hydrophobic and interfere with veneer-adhesive bonding. In theory, to ensure best adhesion, it is recommended that the surface should be sanded or planned within 24 hours [35]. After re-creating and cleaning the surface, it should not take long time to handle the substrate before bonding. Moreover, it is preferable to condition the wood to the moisture content level complying with its end-use condition.

1.3.1 Wettability

Wettability is closely related to glue-bond quality [30]. Wettability is one of veneer surface properties helping to describe the behaviour of the surface during bonding and predicting how the adhesive-wood bond will perform [34].

The wood wettability reflects the composite chemical and morphological character of the wood. Wettability is an important indicator of bonding strength [11]. The type of the wood species affects differently the wetting behaviour of wood. High water wettability can be caused by various hydrophilic components on the wood surface such as hemicelluloses. However, the presence of extractives on the wood surface can also influence the wettability depending upon the wood species [13]. Other characteristics that can influence wettability include the degree of polymerization of some surface polymers, the degree of surface crystallinity, surface thermodynamics, surface roughness, location of wood (sapwood, heartwood), pH value, aging time of exposed surface, machining conditions and the presence of monolayers on the wood surface [11].

The method of contact angle measuring is widely used to characterize the wood wettability by investigating physical adsorption [14].

Adhesive is usually being applied for veneer surface in a liquid form and thus it possesses the contact angle θ with a surface in the equilibrium state related to the surface energies by Young's equation. [7]

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} cos\theta \qquad (1.1)$$

where γ_{sv} is the interfacial energy between the solid-vapour, γ_{lv} is the interfacial energy between liquid-vapour, γ_{sl} is the interfacial energy between the solid and the liquid drop and θ is the contact angle between the solid-liquid interface. [7]

Sessile drop contact angle measuring method is a widely spread and simple approach to prediction of bonding strength and wettability of wood. Low-value contact angle is likely indicating the occurrence of over-penetration, causing the starved joint. Nevertheless, high-value contact angle shows not sufficient enough penetration possibly leading to deficient wood-adhesive interaction. Moreover, it is noticed that in association with surface morphology, the surface roughness reduces the contact angle of a droplet on a hydrophilic surface or the contact angle of a droplet on a hydrophobic surface will increase. [8]

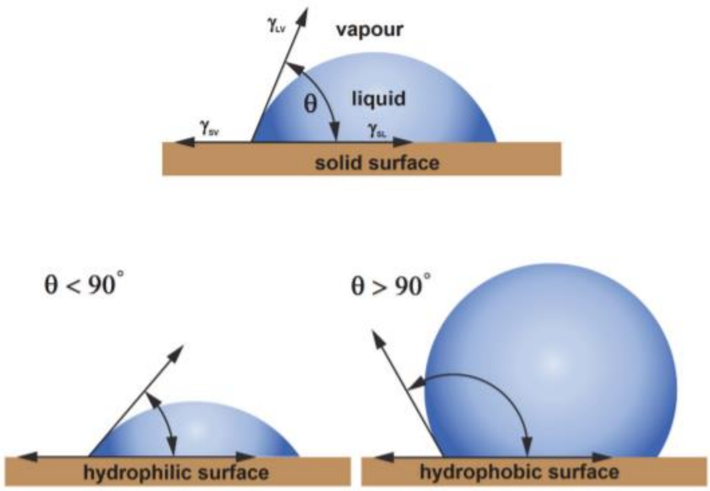

Figure 1.4 Contact angle [7]

According to the theory contact angle (CA) is the angle between the wood surface and a tangent, drawn on the drop-surface, passing through the triple-point atmosphere-liquid-solid. It is used to predict wetting and adhesion properties of wood by calculating solid–vapour surface tension and surface free energy of a solid [2].

Bondability of wood can be reduced by chemical interference. However, it is more difficult to detect than the mechanical defects of wood surfaces. Extractives migration to the surface and over drying can cause chemical interference. However, the CA test can reveal much about the condition of a wood surface [31].

The direct measurement of the tangent angle at the three-phase contact point on a sessile drop profile is the most used technique for CA measuring [47].

Because of the nature of wood surface, CA measurements are hard to conduct. Such aspects like porosity, hygroscopic nature, anatomic complexity, heterogeneity, extractive content, lathe checks amount and depth, over drying can affect the measurements [14]. Also, measurements are time dependent. The water droplet is absorbed into the surface constantly changing the CA and the droplet size. From both experimental and a statistical point of view, this approach is problematic and inconsistent.

Sessile drop method is used in this work to measure CA. It is the most widely spread CA determining method. In this method, CA is measured using the image of a sessile drop at three-phase contact line between the drop contour and the projection of the surface. Spherical shape of droplet is acquired to minimize surface area.

As the CA values are connected to wettability, the CA value at some point of time does not necessarily represent the accurate condition of the substrate considering its wetting properties. CA values of a liquids change with time which makes wettability time dependent. Different species veneers prepared with different parameters absorb liquids differently. Time dependence of wettability is the rate of absorption. To compare veneers received from different species and prepared with different parameters, it is necessary to compare the results at a certain period of time.

1.3.2 Surface quality

Veneer surface, due to its nature, contains natural roughness and heterogeneity [34].

The substrates on veneer surface and their qualities have severe influence on satisfactory bond performance. Smooth wood surface, free of contaminants and surface irregularities is desirable for the industry. Otherwise, surface complicates the wetting, adhesion and the development of bond strength [35].

Besides the physical, mechanical, and anatomical properties of wood, the surface quality of finished products is the next step of important characteristics of wood. It can be influenced by numerous factors such as the direction of slicing, the geometry of the blade and its sharpness, the thickness of the cut part, any lack of precision of the sharpening tool as well as the technological parameters [36].

Even if visual examination shows veneer smoothness, microscopic examination will demonstrate surface irregularities causing blockages and air pockets preventing the complete wetting of a surface. These conditions lead to stress concentrations after bonding [31].

Bonding is better with smooth surfaces. Higher roughness increases the glue usage leading to higher production costs. Not to allow high production costs and to increase the product quality, it is needed to pay attention to veneer surface properties.

1.3.3 Moisture content

Wood takes on moisture from the surrounding environment which makes it hygroscopic material. Depending on amount of extractives and wood chemistry, wood can take up 25% to 30% of its dry weight in water. Relative humidity and temperature of the air along with the current amount of water in the wood affect moisture exchange between wood and air. This has an important influence on properties of wood and affects usability of wood material. Also, wood dimensional changes, taking place simultaneously with moisture content (MC) changes, have many important consequences on bonding [31].

The wood moisture content and water in adhesive significantly affect the wetting, flow, penetration, and cure of waterborne wood adhesives. It is known that optimum adhesive properties tend to appear at 6% to 14% of moisture content. Moreover, wood surface can resist wetting at moisture content below 3%. However, too high MC also causes bonding difficulties for normal waterborne adhesives. Water and low-molecular weight portions of the adhesive migrate less effectively into wet wood cell walls than into drier cell walls [13].

MC includes water or water vapor absorbed into cell walls and free water within the lumina. The wood moisture content affects many physical and mechanical properties of wood [31]. It is expressed as a percentage and is being represented by formula:

$$MC = \frac{m_{water}}{m_{wood}} \times 100\% \qquad (1.2)$$

where m_{water} - mass of water in the wood, m_{wood} – mass of the oven dried wood. Also, MC of specific sample can be calculated as:

$$MC = \frac{m_{wet} - m_{dry}}{m_{dry}} \times 100\% \qquad (1.3)$$

Where m_{wet} - mass of the sample at specific MC, m_{dry} – mass of the oven dried sample.

Some species tend to have a higher moisture content in one part of the tree than on another one [33].

It is found by previous studies that some ammounts of free water is forced out during cutting process. This water tends to play a role of a lubricant between the wood, knife and pressure bar [33].

It is stated that the moisture content is important but not the main factor determining suitability of a specie for veneer production [33].

Property of wood to absorb water plays significant role on veneer production, drying and bonding [33].

The contact with water induces swift changes in the moisture content of wood. Moreover, it may possibly increase the moisture content of wood above fibre saturation.

Absorption of water above wood fibre saturation point causes air in the cell lumina to be replaced by water. Water absorption can continue until the maximum moisture content is reached [31]. Wood with moisture content higher than fibre saturation point, however, not exceedingly high suits the best for cutting into veneer [33].

Water absorption rate depends on number of factors. Fastest absorption rate is typical for longitudinal direction [31].

Over fibre saturation point wood material is dimensionally stable. Below fibre saturation point wood material swells if it gets moisture or shrinks if it loses moisture. Both shrinking and swelling can result in decrease of wood material manufactural value [31].

Water vapor absorption levels depend on wood species. Most species can absorb water vapor to increase their mass approximately 30% above an oven dried MC condition. This water is hydrogen bound within the cell wall matrix of hemicelluloses and cellulose [31].

Water vapour absorption depends on the relative humidity (RH) of the surrounding air.

1.4 Main effects on wood properties

1.4.1 Manufacturing process

Manufacturing process of logs is one of the main aspects that affects the properties and quality of veneer. Veneer properties strongly depend on it. This chapter focuses on rotary-cut veneer production and its effects on veneer quality.

Figure 1.2. presents the general manufacturing process of veneer. After logs arriving to yard, the latest must be measured, sorted, and later stored by quality. Before debarking logs are passed through softening process so that wood can be processed into smooth veneer with even thickness. Softening also guarantees easier peeling and protects against extensive mechanical damage from peeling tool. Usual softening method is 24-hour soaking [29].

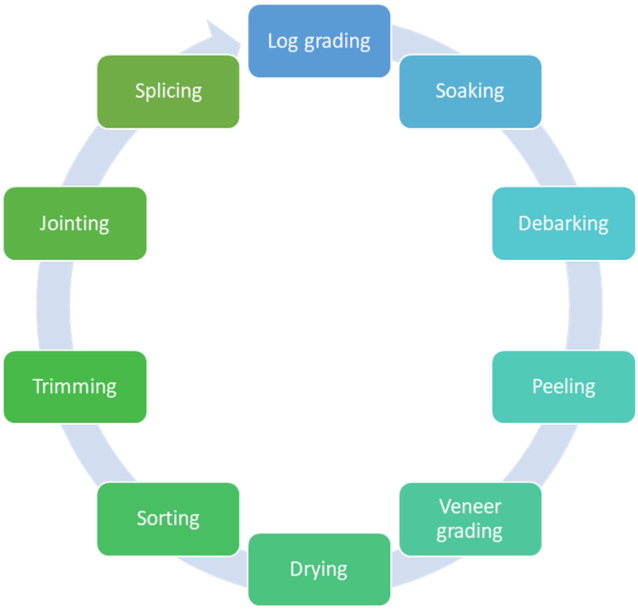

Figure 1.2 Manufacturing process of veneer

The moisturised and debarked logs are sent to rotary cutting (peeling) to produce thin layers – veneer. Hardwood veneer thickness is usually 1.5 mm [29]. In the peeling process two surface sides of veneer are produced: a blade-checked loose side and a tight side (See Figure 1.3). Pressure bar is applied on tight side to minimise lathe checks. Knowing surface side is essential for the adhesion. Sharpness of blade is well known to have a great effect on surface roughness and compression rate which subsequently affects both depth and frequency of lathe checks [7].

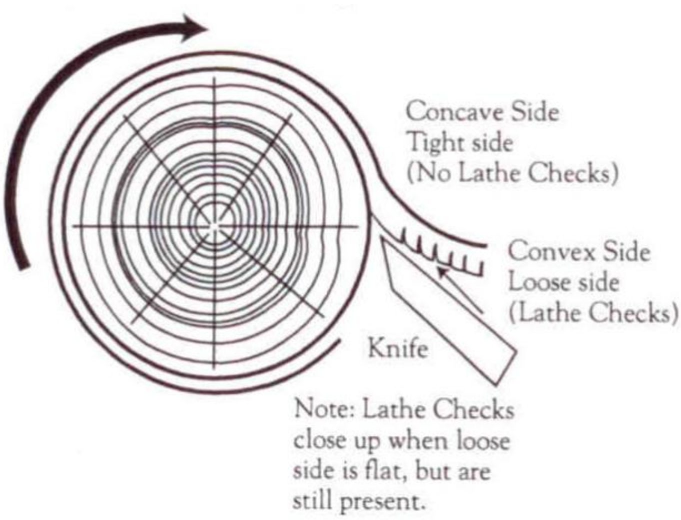

Figure 1.3 Formation of lathe checks [32]

Wood changes also its dimensions while drying or otherwise, absorbing water. To avoid critical dimension changes and provide high quality of product, drying is used to reduce the moisture content to the needed level before further processing. However, it is important to avoid over drying as it is unfavourable for sufficient adhesive bond formation. Over drying causes inactivation of veneer surface and leads to reduced bond quality [7].

Long slices of veneer are usually cut into smaller sheets or proceeded to the next stage of the veneer production process as continues long slice. The veneer is dried under pressure in hot air dryer. The moisture content varies among all sheets and thus it must be monitored in order to have control over the quality of the veneer. Under drying of veneer, the adhesive penetration decreases. In turn, it can cause growth of mould. However, overdying causes surface inactivation. Both scenarios influence causes poor adhesion and low-quality product [28]. After drying, veneer sheets are graded and sorted.

Manufacturing processes, including cutting, and drying can have significant effect on physical and chemical surface properties of veneer. When using rotary-cut veneer in plywood production, the loose side of veneer should be bonded, and the tight side finished. However, this is dictated by the fact that the open checks in the veneer faces create finish imperfections and adhesive overpenetration into lathe checks. On the other hand, usually it is not a difficulty if the adhesive spread rate is set correctly. High temperatures drying or moderate temperatures drying for prolonged periods inactivates the veneer surfaces, causing poor wetting of veneer which causes poor bonding [31].

Overdrying and overheating complicates the adhesion by causing extractives to diffuse to the surface, by reorienting surface molecules and exposing the less polar portion, by oxidizing or pyrolyzing the wood, or by irreversibly closing the larger micropores of cell walls [31].

Lathe check depth and pulling direction tend to have severe influence on a shear strength of plywood. Increase of lathe check depth from 40 to 80% causes decrease of plywood shear strength by approximately 40% during open test. However, during closed test lathe check depth seems to have minor effect on strength properties [7].

Open test results indicate failure very close to the bond line, which can potentially show a low percent wood failure. Moreover, closed test results reveal the wood failures deeper in the veneer, on the tops of the lathe checks [7].

1.4.2 Soaking time and temperature

It has been previously noted by researchers that better bonding requires effective wetting as it is essential for establishing close contact between surface and an adhesive [5]. Moreover, the studies on birch logs have shown that the soaking temperature affects the strength of the adhesion bond [3]. Contact angle measurements reveal contrast between hot- and cold-soaked birch veneers. This potentially indicates difference in bond strength. The bond strength values tend to decrease moderately for veneers peeled from the cooled logs. However, bond strength test results of hot-soaked and cold-peeled veneers are noticeably higher than of cold-soaked and cold-peeled ones. Veneer surface analyses display that hot-soaked, but cooled veneers are more similar to hot-soaked and hot-peeled ones, than to cold-peeled ones. The previous research results have indicated soaking temperature effects on not only softening of the material in the peeling process, but additionally on irreversible chemical changes in logs that tend to affect bond strength [3].

The research study by Anti Rohumaa [7] has shown that the heating of birch logs results in production of veneers with closer allocated lathe checks of smaller depth that is advantageous as shallow lathe checks are less detrimental to veneer strength perpendicular to the grain. High temperature heating causes less periodic check formation that is governed by wood anatomy and thus tends to be less predictable [4].

Besides, temperature of soaking seems to have minor effect on the veneer loose side roughness. However, it does not significantly affect tight side roughness [6].

1.4.3 Felling season

The study by Anti Rohumaa, et al. [5] has revealed that log felling season affects strength properties of veneers produced from logs soaked at 20 °C, but the ones soaked at 70°C tend to show more uniform strength results that cancel the effects of felling season. Winter felled logs are most sensitive to the effects of soaking temperature. Changing quantity and character of metabolites from different seasons tends to cause different wetting behaviour and bond strengths.

Different wetting behaviour and bond strengths of material from logs cut during different seasons are probably caused by changing quantity and character of the metabolites. In autumn and winter, birch wood contains more starch and other extractives as an energy reserve. The logs fellen during winter tend to be more susceptible to the effects of soaking temperature [7].

Extractives show tendency of migrating to the wood surface during the drying process which causes reduction in wettability. Moreover, over-drying of wood can worsen the effect leading to poor bonding [5].

A felling season tends to have notable impact on bond strength for material soaked with lower temperature.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Veneers

For this research, the veneers of four different wood species, birch (*Betula pendula*), aspen (*Populus tremuloides*), grey alder (*Alnus incana*) and black alder (*Alnus glutinosa*), were chosen for further investigation. Any visible surface defects of veneer sheets were avoided.

Firstly, logs were selected from the yard. The aim of manual selection was to avoid any defects and to obtain straightest logs that could be easily pealed. After selection logs were instantly placed into water bath for soaking.

The logs were soaked at various temperatures, 20°C, 40°C and 70°C, respectively. The soaking time was 24h for all used logs and it did not change.

According to the documents provided by Laboratory of Wood Technology, the logs used in the present study were felled in the spring of 2020 in Keila and Piirsalu forest units in Läänemaa county, Estonia. The length of the logs was approximately 2.4 m and the average age of trees was 60 years. Prior the peeling, the logs were stored in the yard of Wood Technology building. Before the peeling process the selected logs were soaked in water bath at temperatures of 20°C, 40°C and 70°C for 24 hours. Right after the soaking the moisture content of the logs was measured, logs were checked with hand metal detector and then manually debarked.

2.2 Methods

2.2.1 Peeling process

The rotary peeling was performed using Taltech peeling lathe (see Figure 2.1) to prepare the veneer sheets with the thickness of 1.5 mm. After peeling process, the veneers were cut into 420x420 mm pieces and dried at temperature around 160°C for 2 minutes and 45 seconds – 3 minutes and 45 seconds. The drying was used to achieve the stable moisture content of the peeled veneers equal to, 4.5 ± 1.5%, respectively.

Figure 2.1 Raute veneer peeling machine [38]

Moisture content was measured using small veneer pieces weighting up to 1 g. The pieces were taken from bigger veneer sheet. Samples were weighted and placed into the ventilated oven at 103 °C ± 2 °C for short period of time and then weighted again. The process was repeated until mass decrease of samples became insufficient. The moisture content was then calculated using formula 1.3. MC measurement was performed for each log before mass veneer drying took place.

2.2.2 Veneer sheets preparation by cutting

Prior to cutting into smaller samples the veneer sheets were conditioned at temperature of 26 °C and air humidity of 10 wt% in the conditioned storage room for at least 48 h (Figure 2.2). According to ASTM D7998-19 standard [1], strips of veneer are to be cut from portions of wood veneer having clear grain to provide strips of 120±0.2 mm length parallel to the grain ±4° and width of 20 mm ± 0.5 mm across the grain.

Figure 2.2 Stored samples

The specimens for further research were cut by using hand guillotine. The schematic plan for specimens cutting is presented in Figure 2.3.

Figure 2.3 Selection of veneer sheets for testing (Image is schematic and does not represent constant order of selection. Sheet were selected after visually good surface quality and with fulfilling a need to select 3 random sheets from regions closer to bark, 3 from regions closer to pith and 3 from regions between)

Then, for wettability measuring 9 sheets of the veneer from each log (3 from regions closer to bark, 3 from regions closer to pith and 3 from regions between) were selected (See Figure 2.2). Since vast amount of veneer sheets was produced from each log, there was an opportunity to select sheets without any visible defects and with fine surface. Then, 10 samples from each sheet (Figure 2.4) were cut out using the laboratory guillotine (see Figure 2.5).

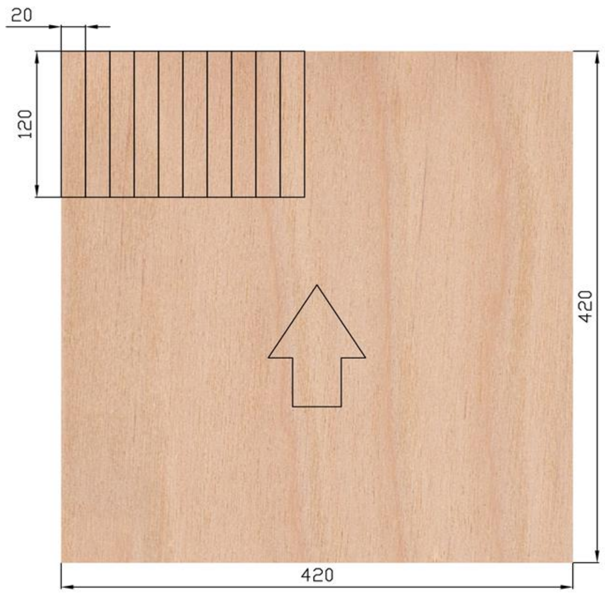

Figure 2.4 Specimen cutting plan, grain directon indicated with an arrow

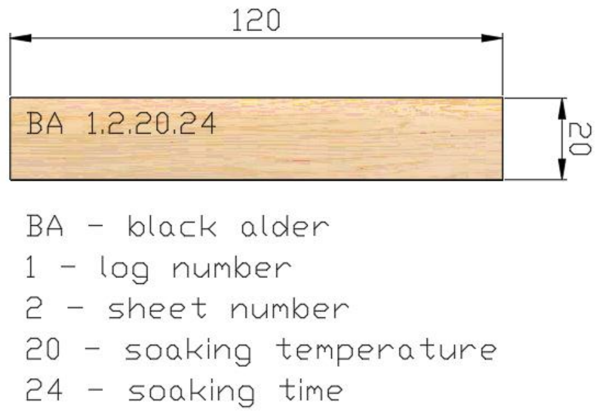

Figure 2.5 Sample for contact angle (CA) testing with example of coding system

2.3 Contact angle measuring

To investigate the wettability of the wood veneer the Sessile drop method by measuring contact angle (CA) was applied. The aim of the present research was to use distilled water for studying wettability.

DataPhysics OCA 20 and SCA 20 software were used for the droplet contour analysis and CA value determining. A static sessile drop was the research object. Test station (See Figure 2.6) consisted of lighting source (1), test station with holders (2), dosing syringe with distilled water (3), optical system catching the image of a droplet (4) and monitor with video output (5).

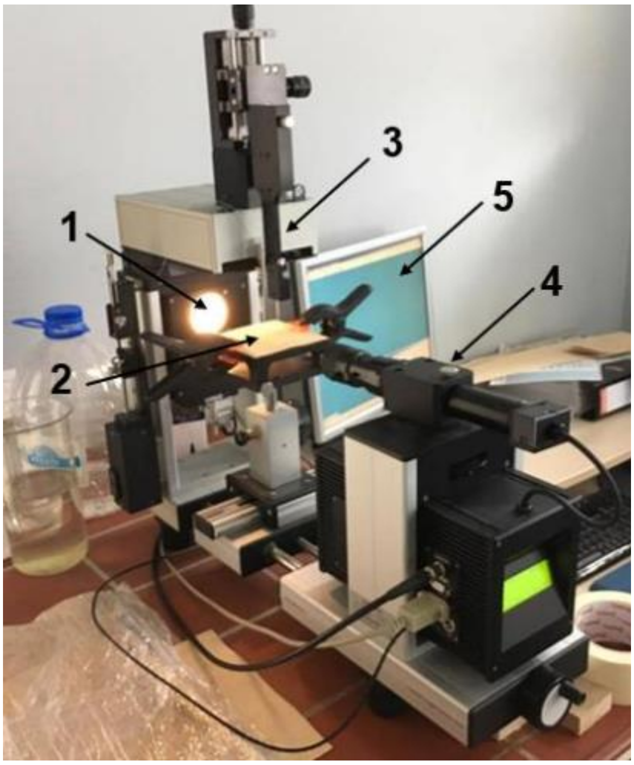

Figure 2.6 Testing system (Lighting source (1), test station with holders (2), dosing syringe with distilled water (3), optical system catching the image of a droplet (4) and monitor with video output (5)) [34]

In the present study the specimen of the cut veneer was placed on the test station with tight side facing a droplet and fixed by the clamps to avoid displacement and to provide as smooth and straight surface as possible. Smoothness of the veneer surface was controlled to achieve useful results. The software installed on the work computer was helping with finding best spots for droplets. The quality of the image seen on the screen was adjusted with zooming.

After adjusting, distilled water was used to create droplets on the veneer surface (Figure 2.7) by using the syringe fixed on the measuring device. The droplets were starting to spread on veneer surface and the whole process was captured by the device camera. The contact angle recording by the software was started at the moment when a droplet came into contact with the surface of a sample. Total observation time for each droplet was 40 s. First measurement took place straight after droplet contacting the specimen surface; next values were measured according to the scheme:

- 0 s – 1 s, with 125 ms intervals
- 1 s – 30 s, with 5 s intervals
- 30 s – 40 s, with 10 s intervals

The measurements were performed according to the standard EVS-EN 828:2013 [2]. Total of 200 measurements were taken for each sample. All measurements were done in the conditioned room at the constant air humidity of 40%. To maintain the optimal necessary humidity the air moisturizer device was used during measuring.

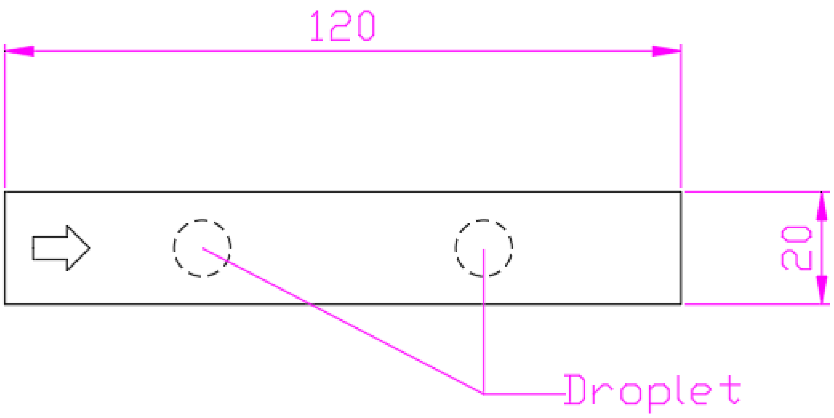

Figure 2.7 Scheme of contact angle measurement, grain directon indicated with an arrow

All measurement were done according to the test plan that is presented in Table 2.1. The data concerning specimens can be found from Table 2.2.

Table 2.1 Test plan

Specie	No of used samples	Date
Birch 20°C	18	08.02.21
Birch 40°C	9	23.11.20
Birch 70°C	18	02.12.20/19.02.21
Aspen 20°C	18	08.02.21/25.02.21
Aspen 40°C	18	11.12.20/11.02.21
Aspen 70°C	9	17.12.20
Black alder 20°C	9	18.12.20
Black alder 40°C	9	06.11.20
Black alder 70°C	9	18.11.20
Grey alder 20°C	9	21.12.20
Grey alder 40°C	9	02.10.20
Grey alder 70°C	9	16.10.20
Total	144	

The reason for number of produced samples being significantly higher than the number of tested samples is that there may occur necessity for further testing. All samples are organized and stored in laboratory storage room. In case of some species more samples were produced due to the availability of additional material (e.g., Birch 20°C).

Table 2.2 Specimen data

Specie	Log MC, %	Log t, °C	Drying time, s	Dry veneer MC, %	Testing room t, °C	Testing room RH, %
Birch 20°C	Not known	Not known	Not known	Not known	20	35
Birch 40°C	68	30	165	4.5	22	30
Birch 70°C	70/78	42/46	180	5.2/4.8	21/19	20/34
Aspen 20°C	70/68	19/20	180	4.8	20/21	35/40
Aspen 40°C	67/69	28/26	180	5/4.8	21/20	33/34
Aspen 70°C	Not known	Not known	180	5	20	32
Black alder 20°C	Not known	Not known	Not known	Not known	20	34
Black alder 40°C	66	26	165	4.5	21	24
Black alder 70°C	73	36	225	4.5	23	44
Grey alder 20°C	Not known	Not known	Not known	Not known	22	45
Grey alder 40°C	69	30	165	4.8	25	36
Grey alder 70°C	75	43	165	4.5	22	25

3 RESULTS AND DISCUSSION

3.1 The influence of soaking temperature on wood wettability

The results of contact angle measurements presented in Figures 3.1 – 3.4 demonstrate the effect of different soaking temperatures on the wettability of birch, aspen, grey and black alder veneers.

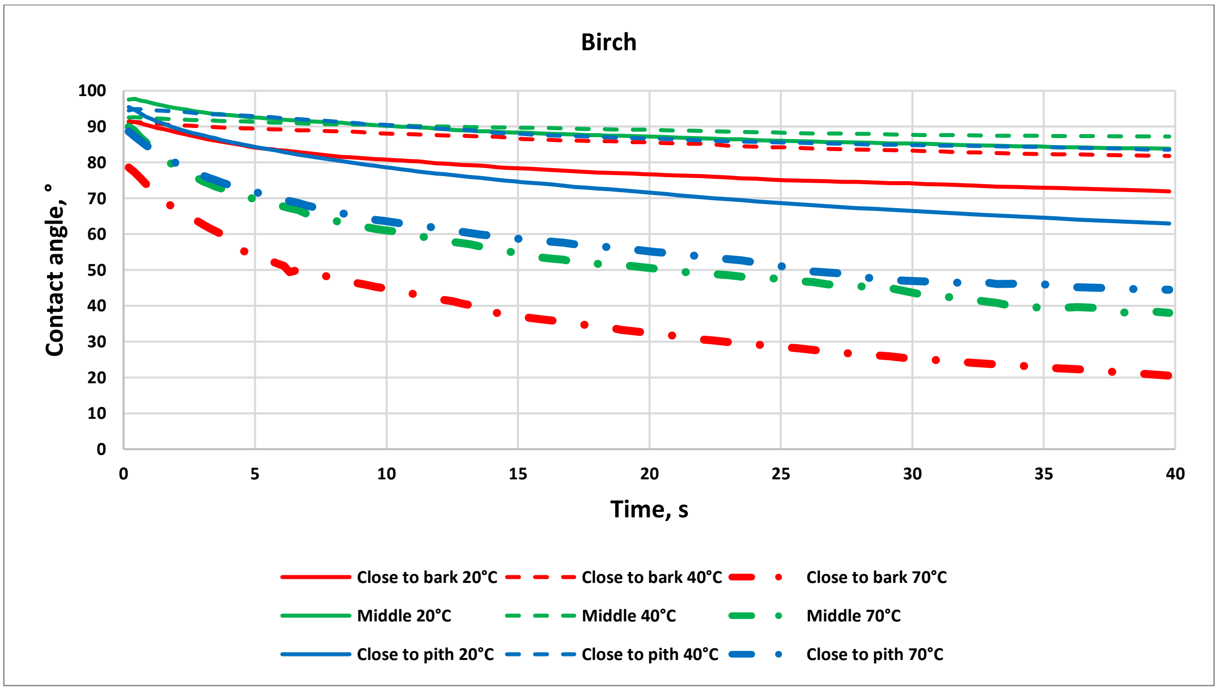

Figure 3.1 Effect of soaking temperatures on birch wettability

Figure 3.1 shows the changes in birch veneer wettability along the log, close to bark, in the middle of the log, and close to pith, respectively. The veneer samples soaked at different temperatures are presented in Figure 3.1 to investigate the influence of soaking temperature. Being the most homogeneous wood specie among the four ones investigated in the present study the birch veneer specimens tend to have the steadiest contact angle drop rates and thus the lowest wettability.

The sharpest contact angle value decrease is noticed in the samples prepared from the logs soaked at 70°C. In case of the birch soaked with such parameters the most dramatic CA drop is observed on sapwood area veneers and the wettability steadily decreases the closer samples are to the pith. The average decline of CA on samples that were initially closer to bark is 58.08° over 40 s observation time, while the average decline on specimens from close-to-pith area is 44.16°, which is 31.5% slower. The possible reason can be less uniform veneer produced from sapwood, with more loose fibres.

Wettability of birch samples from logs soaked in 20°C is significantly lower. Here the reduction of CA is most noticeable on samples from the near-pith regions – average CA decrease is equal to 32.49° over 40 s. This shows reverse tendency with 70°C samples where heartwood was the most hydrophobic. Samples from near-bark region lost 19.52° in average and samples from middle region – 13.73°. The fact of wettability decrease from heartwood to sapwood can be connected to mechanical defects on veneer surface Some hard-particle residues may sometimes be trapped between the knife and the wood and they can create scratches on veneer surface. Also, knife may be damaged by those particles and create damage on veneer surface itself.

40°C samples tend to show the least hydrophilic nature. However, the effect on the wettability of log regions is similar to the lower temperature samples. Decrease of CA on specimens taken from area near pith is 10.93° over 40 s. The samples from area initially closer to bark have average CA loss equal to 9.37°. This is only 16.6% less, than of the ones closer to the pith. The samples from middle are the most hydrophobic of all birch samples – the average CA decrease over 40 s is 5.32°. Overall, statistically impact of part of log is insufficient. This may indicate that after 40°C soaking effect of heartwood extractives is not sufficient and wood properties are uniform along the log.

Figure 3.2 shows the influence of different soaking temperatures on aspen veneer wettability. Aspen demonstrated not only higher wettability, but also less homogeneous nature when compared to birch. The reason is that aspen wood has smaller density (see Table 3.3) and a significantly rougher surface than birch [8].

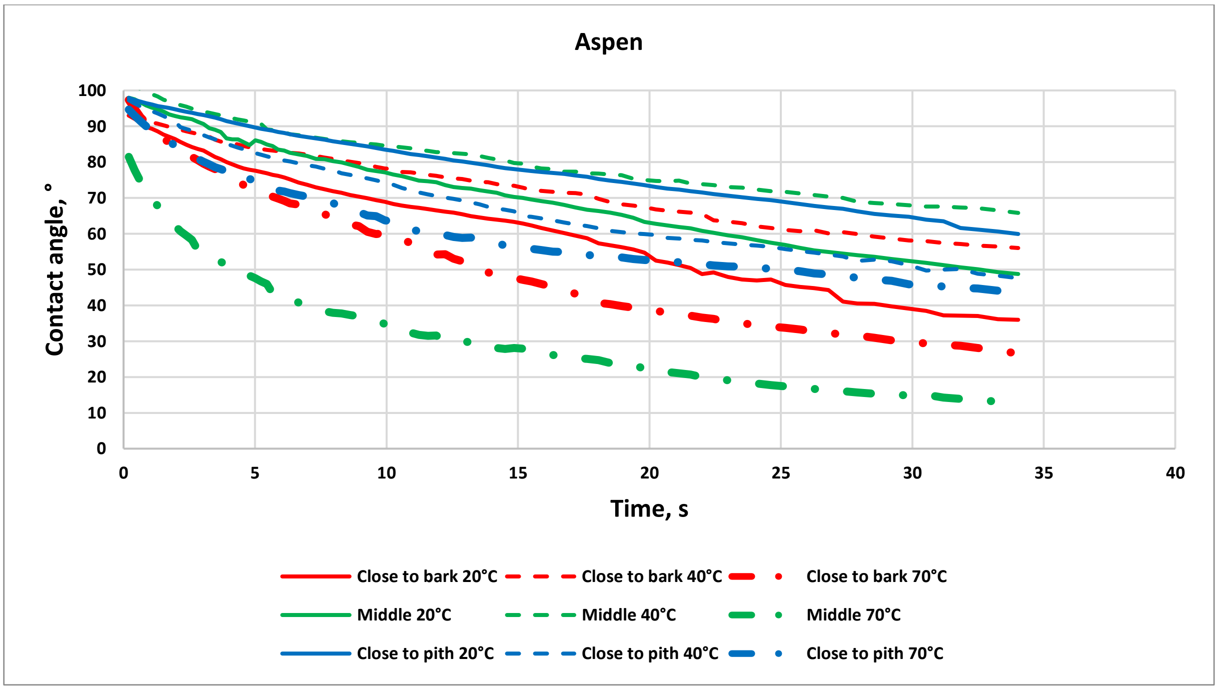

Figure 3.2 Effect of soaking temperatures on aspen wettability

From Figure 3.2 it can be seen that similar to the birch, aspen tends to obtain most hydrophilic veneer surface when being soaked at 70°C. Samples from the sapwood tend to have higher wettability than samples from the heartwood. This tendency is identical to the birch. The veneer obtained from the areas close to the bark tends to lose 70.80° after less than 35 s in average while veneer from closer to pith areas loses only 50.99° which is 38.9% less. Overall, surface quality of aspen veneer after 70° soaking is relatively poor due to the specie's nature. Tests had to be redone many times as around half of droplets were instantly spread over the rough veneer surface. This was most probably caused by the loose fibres on the sample surface, disrupting the measurement process.

Wettability of aspen veneer from logs soaked in 20°C water is less than wettability of 70°C aspen veneer but not as low as wettability of 40°C veneer. This tendency also makes aspen very comparable to the birch. Veneer obtained from aspen logs soaked in 20°C has highest wettability in sapwood region and it decreases significantly in heartwood region – from losing 57.02° after 40 s observation on samples from near bark regions to 38.01° on specimens from near pith region. The difference is equal to 50%. The possible reason is effect of hydrophobic heartwood extractives.

However, the samples of 40°C-soaked aspen demonstrate different tendency of soaking temperature effect on log regions. Here, heartwood is the most hydrophilic part of the logs and sapwood is much more hydrophobic. If near-pith region veneer loses 49.67°

then near-bark region veneer loses 34.3% less - 36.99° over the same time period. Table 3.2 and Figure 3.6 show high CA value dispersion of 40°C aspen specimens. The reason for different tendency of soaking temperature effect on log regions in this temperature class is most probably caused by roughness of veneer surface and not sufficient precision of results.

From Figure 3.3 the wettability of black alder is seen. Black alder veneer wettability properties are different from species above. The difference of black alder from previous species starts to become more recognisable during 40°C soaking. If in case of birch or alder, wettability of veneer produced from 20°C-soaked logs was slightly higher, then in case of black alder it is vice versa.

Once again, 70°C water soaking demonstrates the most severe effect on increase of veneer wettability. After being produced with such parameters black alder veneer has slightly higher wettability closer bark. The observed average CA decrease in this region is 59.37°. In case of veneer initially closer to the log pith decrease is 4.4% less - 56.85°. Generally, the fact, that after 70°C soaking wettability is higher in sapwood, makes black alder comparable to birch or aspen. Overall, the impact of log part is weak in this case as the wettability of all regions is quite homogeneous. The possible reason is neutralization of heartwood extractives after 70°C soaking, leading to uniform wood properties along the log.

Black alder veneer produced from logs soaked in 40°C water bath has lowest wettability closer to pith. In sapwood the average CA decrease is 47.07° during observation time and in heartwood CA drop is 57.06° during the same time. The difference is 21.2%.

Same tendency is relevant for black alder veneer samples produced from logs soaked in 20°C water. Here sapwood is also more hydrophilic. The CA reduces by 36.26° in average closer to the bark. In regions closer to pith the reduction is 30.3% smaller and is equal to 27.84°.

Both 20°C and 40°C black alder temperature group results show higher wettability of sapwood. This is most probably caused by the influence of hydrophobic heartwood extractives effect of which is present even after 40°C soaking.

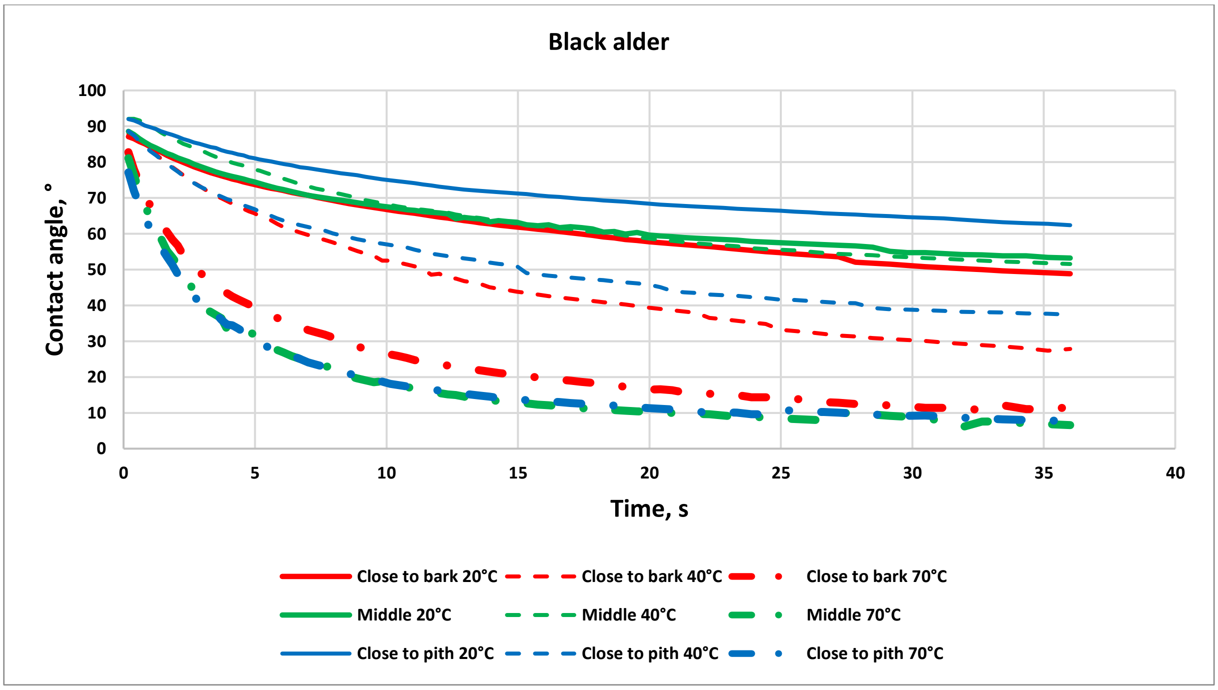

Figure 3.3 Effect of soaking temperatures on black alder wettability

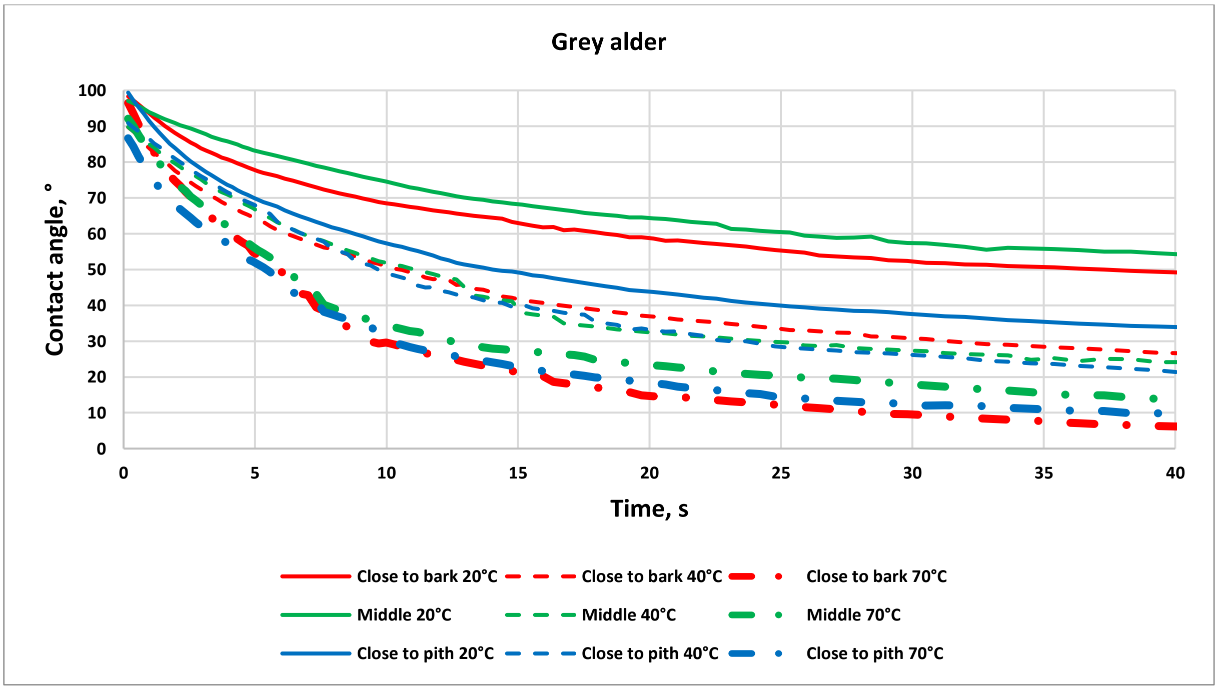

Figure 3.4 Effect of soaking temperatures on grey alder wettability

Figure 3.4 shows the influence of three different soaking temperatures on grey alder veneer wettability. The behaviour of grey alder veneer is more similar to birch (see Figure 3.1) than black alder or aspen.

As with all the species presented before, the grey alder veneer wettability increases the most after the logs are being soaked in 70°C water bath. Sapwood is more hydrophilic than heartwood. Closer to the bark the contact angle decrease is 70.15° over 40 s. Closer to the pith the decrease is 60.01° over 40 s. Difference is 16.9%.

Similar to the black alder, grey alder veneer produced from logs soaked in 40°C has increased wettability when being compared to 20°C veneer. The wettability decreases from heartwood to sapwood. Closer to the pith the decrease of CA during observed time is 60.88° in average. Closer to the bark it is 16.3% less - 52.36°.

Wettability of grey alder samples from logs soaked in 20°C is slightly lower. Heartwood is more hydrophilic than sapwood. In close-to-pith regions droplets placed on veneer surface lose 51.25° in average after 40 s. In closer to bark regions this value is 28.1% lower and is equal to 40° in average. This may indicate the weak presence of extractives in grey alder heartwood.

Table 3.1 Difference in values of CA of sapwood and heartwood after 40 s observation

Specie	Soaking t, °C	Sapwood CA decrease, °	Heartwood CA decrease, °	Difference, %
Birch	20	19.5	32.5	66
Birch	40	9.4	10.9	17
Birch	70	58.1	44.2	32
Aspen	20	57.0	38.0	50
Aspen	40	37.0	49.7	34
Aspen	70	70.8	51.0	39
Black alder	20	36.3	27.8	30
Black alder	40	57.1	47.1	21
Black alder	70	59.4	56.8	4
Gray alder	20	40.0	51.3	28
Gray alder	40	52.4	60.9	16
Gray alder	70	70.2	60.0	17

Table 3.1 shows the average CA values of sapwood and heartwood specimens after 40 s observation. Also, it demonstrates how big is the difference of CA values on different regions of the same log.

According to the data analysis and Table 3.1 presented above it is complicated to find bond between soaking temperature and its effect on the difference of heartwood and sapwood wettability. The only noticeable trend is related to 70°C soaking. Received results show that after soaking any species in 70°C water bath the wettability of veneer from sapwood region will be higher that the wettability of the heartwood region.

Some other trends that can be seen from analysis above:

- Average value of difference in sapwood and heartwood wettability is sufficiently higher after 20°C soaking. If in case of 40°C and 70°C soaking average difference is 22.1% and 22.9% respectively, then in case of 20°C soaking it is equal to 43.7%. This is most probably caused by the presence of hydrophobic extractives in heartwood and the fact that 20°C soaking is not sufficient to neutralize the effect of those extractives on wood wettability.

- Black alder is the only specie that always has higher wettability of veneer from sapwood region. This tendency is present in all temperature groups.

- Aspen has highest average value of difference in sapwood and heartwood wettability (41%) and black and grey alders sufficiently lower - 18.64% and 20.43% respectively. This is caused by the roughness and non-uniformity of aspen wood surface.

Figure 3.5 demonstrates effect of different soaking temperatures on average values of contact angle after 40 s of measurement for the four species. It was decided to use the CA values at 40 s moment because in case of aspen and black alder water droplet was almost always absorbed after longer contact time.

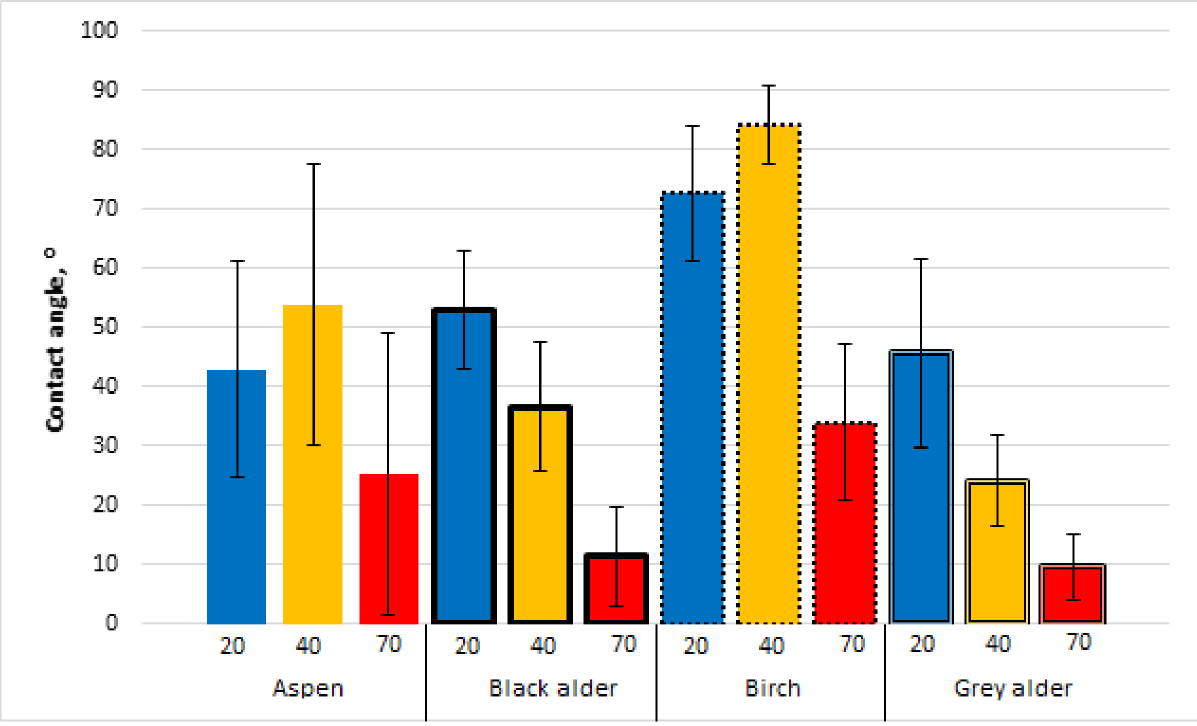

Figure 3.5 CA values and standard deviation after 40 s observation (AS = Aspen, BA = Black alder, BR = Birch, GA =Grey alder)

According to ANOVA analysis, there is no significant statistical difference between results on aspen specimens produced from logs soaked in 20°C and 40°C water bath. However, specimens from the 70°C logs show different tendency.

Aspen shows the biggest standard deviation of results on samples from all temperature groups. 18.1% in case of 20°C samples, 23.7% and 23.8% in case of 40°C and 70°C samples, respectively. This significant variability of values is most probably caused by surface quality of aspen samples. Some droplets were spread and absorbed very quickly; others had opposite behaviour. Even though only the best samples were selected for testing, aspen specimens had very uneven surface with loose fibres. This was also observed by Treial [8].

Overall, aspen shows some interesting results when it comes to the wettability of veneer samples. Wettability of veneer produced from logs soaked in 20°C is the highest among all studied species. After 40 s of CA decrease observation the average value of CA on aspen veneer samples is equal to 42.9°. The standard deviation is quite high as can be seen from the Table 3.2 and the Figure 3.6. This can be a possible mark of uneven surface [20] which strongly affects wettability.

40°C specimens are 25.4% more hydrophobic than 20°C specimens. Average CA value is 53.8°. This is the second highest average contact angle value in this temperature group after birch. The contact angle values of 20°C and 40°C-soaked aspen samples are not significantly different according to the statistical analysis. In research mentioned above [8] it is mentioned that surface roughness of 20°C aspen is comparable to 40°C aspen. However, Treial [8] unexpectedly received big difference in contact angle values. This was connected to the fact that MC of two veneers were different which was in turn also causing differences in CA values as the higher the moisture content, the lower the contact angle [8]. In case of current research veneers were conditioned at the same parameters in order to achieve MC of approximately 5%. Because of that the CA values are statistically quite similar.

As expected from analysing data of previous graphs, 70°C samples have sharply higher wettability. The average CA value is only 25.4°. According to research conducted by Treial [8], 70°C soaking temperature increases the roughness of aspen. This is the possible reason why results of 70°C-soaked samples are statistically significantly differ from 20°C and 40°C-soaked samples. Also, same research points out that aspen specimens produced from logs soaked in 40°C water have lowest roughness. This is possible explanation of the lowest wettability of aspen in this specific temperature group.

Black alder differs statistically from aspen. In general, this specie is not remarkable as it does not have the best wettability in any temperature class. Standard deviation in all temperature groups is very similar and it is significantly lower than of aspen.

The lowest wettability of black alder veneer is seen on samples from logs soaked at 20°C. Here, average CA after 40 s is 53°. Standard deviation is equal to 10.1%.

Wettability of 40°C black alder samples is 44.4% higher than 20°C black alder samples. The average CA at the time of experiment end is 36.7° and the standard deviation is 10.8%.

70°C specimens tend to have much higher wettability – 11.4° with 8.5% standard deviation. This is more than three times lower value than the value of 40°C samples and a possible indicator of overpenetration. The sharp difference is caused by surface quality of veneer produced after 70°C soaking. As in case with aspen, black alder veneer had loose fibres and rough surface. The droplets were spreading instantly. However, the difference is standard deviation of aspen and black alder results show, that black alder veneer surface was more uniform. If in case of aspen some droplets were absorbed instantly and some acted in opposite manner, then in case of black alder almost all droplets were immediately spread.

Even though previous comparison of Figures 3.3 and 3.4 showed different model in contact angle behaviour on black and grey alder veneers, statistical analysis demonstrates opposite trend – cases of both alders are quite similar. However, in every temperature class grey alder has higher wettability. Moreover, it has the highest wettability in 40°C and 70°C temperature classes of all presented species.

Average CA value after 40 s testing is 45.7° on grey alder samples produced from logs soaked in 20°C water bath. Standard deviation is equal to 15.8%. This is slightly less, than value on black alder. The explanation can be the roughness. Smoother surface tends to have lower wettability [8] and in her research Mäetalu [39] found that the grey alder veneer has slightly rougher surface than the black alder veneer and much rougher surface than the birch veneer. This can be also relevant to 40°C and 70°C grey alder samples.

Average CA at 40°C grey alder veneer is 89.6% smaller and is equal to 24.1° with standard deviation of 7.7%.

The wettability of grey alder veneer produced from logs soaked in 70°C water is statistically 148.4% lower than the wettability of 40°C samples. Average CA after the same time period is equal to 9.7° with 5.5% standard deviation. Such a low value of contact angle is a sign of possible over penetration leading to weak bonding. Overall, standard deviation of CA values on 40°C and 70°C grey alder veneer is the lowest of all species. This can indicate that veneer of this specie produced with given parameters has the most uniform surface and majority of droplets behave in the same manner.

Birch has the lowest wettability in all temperature classes. In general, the trends of the effect of soaking temperature on wettability are similar to aspen, however CA values differ drastically. The most possible reason of birch samples having the lowest wettability is the low surface roughness compared to other species [39].

After 40 s of CA decrease observation, the average value of CA on 20°C birch veneer samples is equal to 72.7° with standard deviation of 11.4%.

Wettability of 40°C birch veneer is even 15.8% less – average CA after 40 s is equal to 84.2° with 6.7% standard deviation. Birch veneer produced from logs soaked in 70°C water bath tends to have the highest wettability. Here, the average CA value is equal to 34°.

The Table 3.2 demonstrates the data used for creation of Figure 3.5 and plays supportive role to show numbers mentioned in graph analyse above.

Table 3.2 Descriptive statistics analysis results

	AS 20	*AS 40*	*AS 70*	*BA 20*	*BA 40*	*BA 70*	*BR 20*	*BR 40*	*BR 70*	*GA 20*	*GA 40*	*GA 70*
Mean	42.92875	53.77111	25.38125	52.95111	36.68818	11.44786	72.71611	84.19222	33.96889	45.67222	24.12636	9.667059
Standard Error	4.523325	5.607085	5.932314	2.384358	3.259331	2.263406	2.697847	1.589511	3.095324	3.723536	1.632097	1.330466
Median	44.78	51.31	16.875	54.93	34.05	10.9	71.5	84.31	33.945	39.505	22.98	7.11
Standard Deviation	18.0933	23.78885	23.72926	10.11598	10.80998	8.468891	11.44599	6.743723	13.13235	15.79762	7.655216	5.485653
Sample Variance	327.3675	565.9093	563.0776	102.333	116.8556	71.72211	131.0108	45.47781	172.4585	249.5649	58.60233	30.09238
Kurtosis	-0.31028	-1.72289	2.80356	-0.68549	-0.52531	8.057559	-0.2114	-0.06303	-1.18768	-0.94606	0.216242	1.031839
Skewness	-0.30388	0.065675	1.877012	-0.1091	0.367075	2.539494	0.582148	0.348202	0.014636	0.522271	0.216676	1.233141
Range	67.99	67.84	78.8	38.22	34.14	34.22	39.18	26.31	40.9	51.7	32.49	20.09
Minimum	7.04	19.91	5.01	33.92	19.89	3.69	56.72	73.16	13.2	21.94	8.84	3.5
Maximum	75.03	87.75	83.81	72.14	54.03	37.91	95.9	99.47	54.1	73.64	41.33	23.59
Sum	686.86	967.88	406.1	953.12	403.57	160.27	1308.89	1515.46	611.44	822.1	530.78	164.34
Count	16	18	16	18	11	14	18	18	18	18	22	17
Confidence Level(95,0%	9.641239	11.82992	12.64443	5.030556	7.262242	4.889792	5.691959	3.353575	6.530562	7.855974	3.394133	2.820462

Figure 3.6 gives an idea of how diverse the CA values are. The X-axis represents the sheet number. The closer the x value is to the 0, the nearer veneer sheet was to the bark.

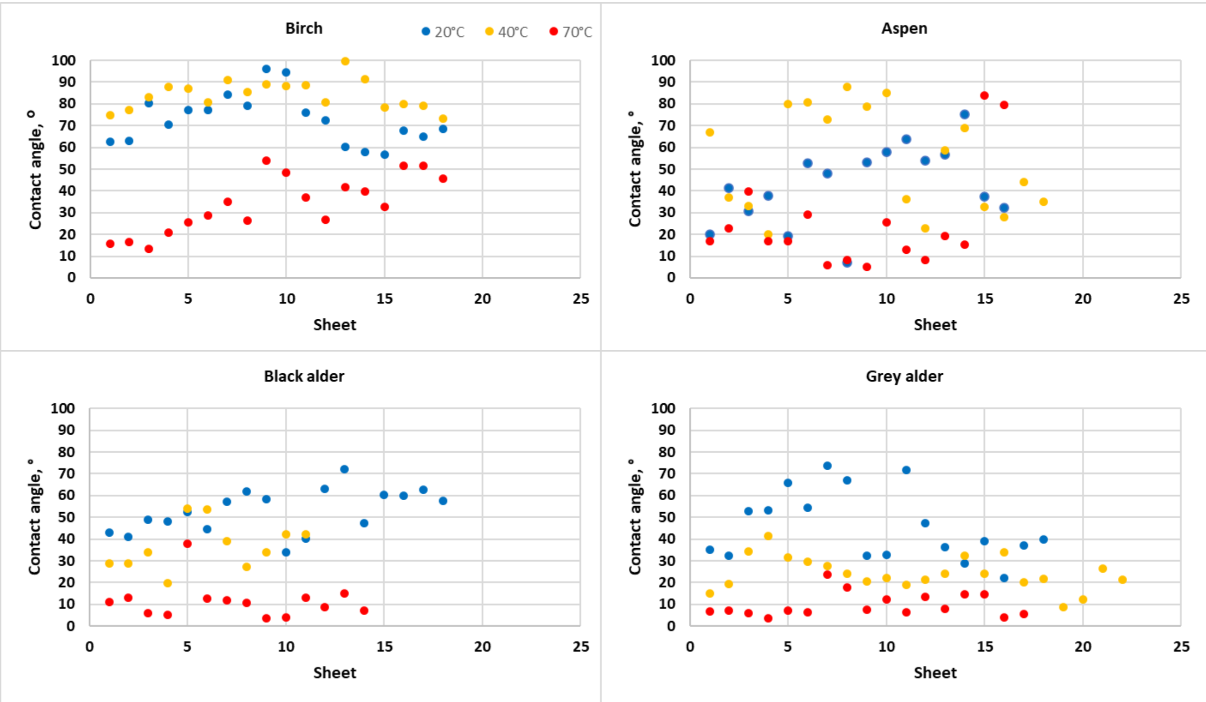

Figure 3.6 CA value dispersion

Table 3.3 Average density and CA values at the 40 s

Specie	Average density, kg/m^3	Average CA at the end of experiment, °
Birch	650 [22]	63.6
Aspen	515 [8]	40.7
Black alder	495 [42]	33.7
Grey alder	396 [23]	26.5

3.2 Conclusions

Overall, wettability of all species tends to correlate with specie density. Birch has the highest average density of all researched species and lowest wettability. This trend is observed on all other species as the density decreases, wettability increases from aspen to grey alder (See Table 3.3).

Aspen has the closest CA values to birch, and this is considered to be good as birch is the reference specie. However, aspen's results demonstrate the biggest values of standard deviation. From the visual examination of samples and the literature study the most likely reasons are the surface quality of aspen [8] [20] [42]. Loose fibres, deformation during drying, fuzzy grain surface negatively affect the consistency of the results. Also, aspen has highest average value of difference in sapwood and heartwood wettability. Overall, data received during current aspen research is quite similar to the research conducted by Treial [8].

Statistical analysis showed that there is no big difference between effect of 20°C soaking and 40°C soaking. However, 70°C soaking affects results much more. Samples from all the species tend to show higher wettability in this temperature class. Also, 70°C specimens tend to be prone to over penetration. Moreover, analyse of test results demonstrates that after soaking any specie in 70°C water bath the wettability of veneer from sapwood region will be higher that the wettability of the heartwood region.

Experimental data analysis also shows that the highest difference in sapwood and heartwood wettability is caused by 20°C soaking. This can be explained by the effect of wood extractives and the fact that soaking in 20°C water is not enough to reduce their effect on wettability.

All in all, it can be stated that the effect of soaking temperature on wettability is proven. Both 20°C and 70°C soaking have different effect on veneer wettability but the effect of 70°C soaking is statistically much more significant.

Soaking temperatures have contrasting effects on different species. Most probably, the CA behaviour differences are connected to wood density and surface roughness. However, all specie properties are affected by soaking temperature.

Statistical analysis demonstrates that in general soaking temperature does not have any sufficient effect on log regions.

Birch is the most homogeneous specie and possesses lowest wettability after any temperature soaking.

SUMMARY

The aim of present research work was to investigate the effect of soaking temperature on wettability of four widely spread Estonian wood species: Birch (*Betula pendula*), Aspen (*Populus tremuloides*), Black alder (*Alnus glutinosa*), Grey alder (*Alnus incana*), respectively. Also, the research on the influence of log soaking temperatures on wettability along the logs was conducted. Birch is used as reference specie to compare its properties with other chosen species.

The results showed that different soaking temperatures affect the species in different maners. 70°C soaking has the greatest influence on properties of all four species and 20°C soaking affects the wettability along the logs. Still, statistically 20°C and 40°C soaking are very similar.

Aspen has the closest wettability to birch of all three alternative species. However, it has unique surface properties that negatively affect the consistency of measurements.

Black and grey alder are statistically very similar. Nevertheless, grey alder has lower wettability in all the temperature groups. Both alders differ sufficiently from birch.

Black alder, grey alder and aspen veneers are not widely researched yet. This makes current work scientifically valuable This data is valuable for plywood manufacturers. Provided results will be crucial when bonding strength of the species will be studied. However, conclusions of the thesis are not to be used alone. Further testing of other factors affecting bonding of the species are to be done.

KOKKUVÕTE

Käesoleva uurimistöö eesmärgiks oli uurida leotustemperatuuri mõju neljale laialt levinud Eesti puiduliigi kask (*Betula pendula*), haab (*Populus tremuloides*), sanglepp (*Alnus glutinosa*), hall lepp (*Alnus incana*) märgumisele. Lisaks viidi läbi uuringud, et vaadata leotustemperatuuri mõju märgumisele kogu palgi ulatuses. Kaske kasutati võrdlusliigina.

Tulemused näitasid, et erinevad leotustemperatuurid mõjutavad puiduliike erinevatel viisidel. Leotusel 70°C juures on suurim mõju kõigile neljale puiduliigile. Leotusel 20°C juures on katseliselt leitud mõju märgumisele kogu palgi ulatuses. . Siiski, statistiliselt on 20°C ja 40°C leotamise mõju näitas väga sarnast trendi.

Võtrreldes kolm puiduliiki (haab, hall lepp ja sanglepp) haava märgumise käitumineoli kõige sarnasem kasele. Seevastu on tal aga pinna omadused, mis mõjutavad negatiivselt mõõtmiste järjepidevust.

Tulemuste statistiline analüüs näitas sarnasust sang- ja halli leppa märgumisel. Sellegipoolest on halli lepa märgumise tase kõige madalam kõigist temperatuurigruppidest. Mõlema lepa tulemused erinevad väga kase mürgumise tulmustest.

Sanglepa, halli lepa ja haava spooni pole veel palju uuritud. See teeb käesoleva töö tulemused teaduslikult väärtuslikuks. Need andmed on väärtuslikud vineeritootjatele. Saadud tulemused on puiduliikide sidumistugevuse uurimisel ka olulised.

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