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IMPROVEMENT OF THE ADHESIVE JOINT OF THE BIRCH VENEER PEELED FROM FALSE HEARTWOOD

Master´s thesis

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Declaration

Hereby I declare that this master's thesis, my original investigation and achievement, submitted for the master degree at Tallinn University of Technology has not been previously submitted for any degree of examination.

All the work of the authors, important aspects from literature and data from elsewhere used in this thesis are cited or (in case of unpublished work) authorship is shown in text.

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VÄÄRLÜLIPUIDUGA KASESPOONI LIIMLIITE PARENDAMINE TARMEKO LPDs

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Aim and tasks of the master's thesis:

Aim of this thesis is to define false heartwood of birch wood, to study the chemical and mechanical properties of the coloured birch veneer. Also improving the adhesive joint by finding filler, which would eliminate the delamination problem and by that turn the birch wood waste into minimum.

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LIST OF SYMBOLS AND ABBREVATIONS

ABES – Automated Bonding Evaluation System

EMC – Equilibrium Moisture Content

FH – False Heartwood

MC – Moisture Content

MF – Melamine-Formaldehyde

PF – Phenol-Formaldehyde

UF – Urea-Formaldehyde

VOC – Volatile Organic Compound

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INTRODUCTION

Most of the plywood produced in Estonia is made from birch wood, but some of the wood is useless due to the discoloration and unknown properties. According to Tarmeko LPD and UPM Kymmene Otepää Ltd., about 10% of birch logs have brown coloured wood more or less. [1] So far the brown coloured wood have not been used in plywood production, due to its unknown properties, but it is used for heating. Due to the fact that brown coloured birch wood have been tested and studied quite many times, it is still undefined. According to various sources, in this thesis the brown coloured wood is called as false heartwood. [10]

Theme is actual because the amount of false heartwood in birch trees increases with ageing and in Estonia many people have private land, which is mismanaged and therefore the wood is getting old. In further future the amount of false heartwood part of the birch will increase and normal part will decrease, that is why it is important to find a way how to use it.

Using false heartwood veneer layers in plywood manufacturing causes delamination between veneer layers. Delamination means that adhesive used as bonding veneer layers together sags through the layers, and veneer layers delaminate. Problem was set by Tarmeko LPD, who have tried to use false heartwood in producing bed frame slats. One way to solve the delamination problem is to use a suitable filler in adhesive and it could ensure the false heartwood usage. As a result, wood waste could be minimized.

The aim of this work is bircwood waste minimization by increasing the use of birch false heartwood veneer in glue laminated products production.

In order to achieve the aim of this thesis the following subtasks are proposed. To define and study the chemical, physical and mechanical properties of false heartwood in birch wood. To do chemical, physical and mechanical test of the false heartwood. To improve the adhesion properties of the adhesives the different filler materials should be considered.

1. LITERATURE REVIEW

1.1 Tarmeko LPD

Tarmeko Group is specialized in wood processing and furniture production. Both the production and the management is always located in Tartu through history. Furniture industry began in the post-war small cartels and wood workshops. In 1947 cartel "Wood" was founded, which grew out of the same name in the furniture factory. It belonged to the five leading industries include furniture in Estonia and employed 300 people. Furniture factory was founded in 1969 in Tartu. Tarmeko developed into a major organization which employed 1,400 people at peak hours. Furniture factory in Tartu Seventies was the USSR's largest office furniture manufacturer. Factory included a lot of different departments and worked throughout the cycle since the adoption of the logs to finished goods. At the time of the planned economy was a market in which there was no need to advertise the products, items of furniture were loaded into trains and sent directly to the factory yard of the USSR into space, where the production deficit conditions immediately realized. [1]

At the end of the 1980s Tartu Wood and Furniture Combined was connected and it was named Tarmeko. The early 90's was the name of the company was RAS Tarmeko (National joint-stock company). After Estonia regained its independence, in 1992 it was privatization. In 2005 Tarmeko was changed into independent enterprises, in order to achieve better results in bringing down the rights and responsibility. [2]

Nowadays, Tarmeko LPD is located near Tartu County in Luunja operates as manufacturing company, which is specialized mainly in the production of glued and bent plywood parts and furniture. Most of the plywood is made from birch, but also alder is used. It was founded in 2007 and it has about 80 employees. In 2013 the annual turnover was 4.3 million euros. Yearly production output is 15000 m^3 of veneer. Production area is 3500 m^2.

Tarmeko has great experience in export and the main export markets for example are Sweden and Finland. Greater emphasis is going to outsourcing the production, but also manufactured products, such as children's furniture. They are also producing bed slats. Tarmeko’s products are environmentally friendly and FSC-certified, which means that the company's products have passed tests and are safe to use. Tarmeko product portfolio is very wide and exported to several countries.

Tarmeko LPD is part of Tarmeko group, which is formed of Tarmeko Soft Furnishings OÜ, Tarmeko Metal OÜ and AS Tarmeko Spoon. All the named companies together with Tarmeko LPD belongs to Tarmeko KV OÜ, which in turn belongs to OÜ Nerepil. [2]

1.2 Veneer and plywood production technology in Tarmeko LPD

Structural plywood is a panel product of peeled veneer layers glued together so that the grain direction of some wood veneers run perpendicular to, and others parallel to, the long axis of the panel. Mostly the grain of every other layer is applied parallel to the first. To maintain a balance from one face of the panel to the other, an uneven number of veneers is often used.

EVS-EN 313-2: 1999 by a layer of wood and plywood, defined as follows: plywood is material, which consists of collection of wood (veneer) layers and they are connected in adjacent layers of the fibers in the direction generally perpendicular. Veneer is a thin sheet of wood, with a thickness not exceeding 7 mm. [3]

Plywood is one of the most widely used composite material in the modern world. The positive aspects are strength, flexibility and endurance. Plywood is manufactured with an odd number of veneer layers. Veneer layers are pressed and heated - the glue dries when exposed to heat and veneer layers are pressed into plywood. Then plywood is cut and sanded if necessary. Each of the next layer of the wood grain direction is perpendicular to the previous one, the top and the bottom layer are parallel to lines of the wood grain. This layout is used to ensure the maximum stability as possible of the plywood, because the presence of several divergent layers of plywood curve decreases the risk of buckling. Plywood swells, twists, and shrinks less than normal wood. Peeled veneer yield is generally between 60 and 70 percent. Bark, wood leftovers and core material are used for producing energy by heating. Whole plywood processing is shortly described in Figure 10. [4]

1.2.1 Soaking

The wood trunks are put to a conveyer, which leads the material into water tanks (Figure 1 and Figure 2). Wooden materials is steamed in large, covered basin, so that the wood becomes more pliable and softer. This reduces growth stress between the wood fibres. It softens the wood and knots and reduces cutting power consumption and producing a higher volume of smoother higher-quality veneer. After steaming the wood is saturated, which means that cell wall fibres

and lumens are filled with water and therefore lignin plasticizes. The steaming takes about 24-48 hours in 40 - 50°C. The exact heating time required depends on the density of the wood, diameter of the bolt, bath temperature, initial wood temperature and the temperature required for satisfactory rotary peeling.

Figure 1. Loading the logs onto conveyer in Tarmeko LPD - (Authors photo 2015)

Figure 2. Water tank - (Authors photo 2015)

1.2.2 Debarking

Debarking (Figure 3) of the log removes the bark as well as foreign materials, like stones, metal parts and soil. Debarking is important to protect the peeling knife. Bark cut off is used for making energy for the production.

Ring barker is the most commonly used technology of debarking in the saw-mill and veneer industry. It is the most cost-effective method when considering the volume of logs used for production. Among the known methods, ring barking is the least damaging to the wood. In ring barking, the logs are fed into the machine one at a time. This means that the size and quality requirements placed on the wood determine whether or not ring barking is feasible.

Debarking improves the processes of a modern production plant in many ways. A common reason for debarking in Scandinavia is related to quality requirements concerning the woodchips produced as a by-product. The chips that are used as raw material by the pulp industry must be sufficiently - clean of impurities to be suitable for producing pulp, which is then made into paper. [4]

Figure 3. Debarking of logs - (Authors photo 2015)

1.2.3 Rotary cut veneer

With rotary cutting, the log or bolt is placed in a lathe and continuously turned against a knife. The log is “unrolled” much like a ribbon. The veneer is then clipped to width, visible wood defects are removed, and the veneer is dried. It is often used on doors for inexpensive plywood from hardwood and wall paneling. The logs have generally small diameter, and rotary cutting can increase sheets. [5]

In order to obtain an optimum cylinder from the peeled trunk roll, it is measured and digitized using lasers and then automatically centered (Figure 4). After that, it is loaded into the peeler.

The length and width and thickness are set by the order. Standard thicknesses of the veneer are 1.1mm and 1.5mm. [1]

During peeling, an endless strip is created (Figure 5), some manufactures are using high speed camera with electronic image processing for detection of wood defects, it is necessary for optimizing the material cutting. Clippers cut even veneer layers and the veneers are stored and send to the dryer. In high-speed plywood mills, a series of band conveyers are used to handle the ribbons of veneers, which peel rate is 1.5-4.0 $m*s^{-1}$. The trays are about 36 m long, and it handles the veneer which comes out from the entire 380 mm diameter trunk. [1]

Clippers are high-speed knives that chop the veneer ribbons to needed widths. In structural veneer mills, veneer is clipped automatically with speed up to 7.5 $m*s^{-1}$. Veneer is cut to widths, which has a little spare for drying, so that the veneer would not shrink into wrong size. [5]

Figure 4. Rotary peeled - (Authors photo 2015)

Figure 5. Peeled veneer - (Authors photo 2015)

Exploring veneer surface shows hairline cracks running parallel to the grain, called lathe checks on loose side of the veneer. It is a result of peeling a flat-surfaced veneer from a round tree stem. The face of veneer from the outside of the round bolt is called the tight side because it has no checks. Mostly the loose side of the veneer is oriented inward toward the glue line, which works as a checks repairer and improver. It is very important because if sanded grade of plywood is coated, lathe checks may open and become visible as checks in the finish. [4]

1.2.4 Drying and grading

There are many types of dryers for structural veneer mills: forced air roller-restraint, platen type heated by steam and radio frequency. Mostly used dryer is forced air roller-restraint. Its hot air speeds up to 20 $m*s^{-1}$, which removes the boundary layer of moist air that can act as an insulator in dryers with low-velocity air circulation. Dryer temperatures are generally not more than 205ºC and drying time is about 8-11 minutes. Ideal moisture content of dried veneer is 3-6%. [5]

The veneer is moist due to the steaming process. Drying takes about 5-8 minutes depending on the thickness and kiln. After drying the veneer layers have the humidity of 5-10%.

It is important to dry veneer correctly, otherwise it will over dry. Over drying will make the veneer brittle and hard to handle without causing damage. Buckle also increases as the moisture

content is reduced. For the domestic market, the ends of the veneer are clipped, and light edge clipping may also occur. The square footage of veneer in each flitch is measured for pricing purposes. With large or exceptional logs, which contain two or more flitches, the flitches are often numbered consecutively so they can be kept together and sold as one lot. The veneer is then bundled in crates, ready for shipment on the domestic market.

In the dryer's outlet, the dried veneers are graded manually and visually into class from A, BB, BC, C. Best quality is A class and worst is C (Figure 6). Grades are based on the occurrence of knots and their sizes across the sheets of veneer. False heartwood veneer is classified separately. After grading, high value veneer can be upgraded by sewing or taping splits, plugging and patching holes and filling cracks.

Figure 6. Sorting by classes. From left to right – Class A, BB, BC and C - (Authors photo 2015)

1.2.5 Gluing and pressing

After drying and sorting the veneer layers goes to gluing unit (Figure 7), where the layers go through the glue rolls and one side of the veneer is glued. About 140 - 160 g of urea formaldehyde resin with hardener per m^2 on one layer is rolled. After gluing, the veneer layers are put together crosswise and then sent to electric storey press (Figure 8). Material is in the press about 2-7 minutes it depends on the thickness of material and in temperature of 100 ±

2ºC. [4] After pressing the plywood is cooled down and almost ready for processing in production.

Most plywood mills prepress batches of laid-up panels in cold press prior to final pressing in the hot press. This process makes loading to hot press easier and reduces veneer shifting. Hot pressing is done in hydraulically powered heated multi opening press. The purpose of press is twofold: to bring the layers of veneer tightly together and to heat the adhesive to the temperature required for resin polymerization. For plywood heated plates are used to transfer the heat energy to the wood composite system.

Figure 7. Roller glue spreader - (Authors photo 2015)

Figure 8. High frequency press - (Authors photo 2015)

There are five primary considerations when selecting plywood panels for a specific use:

1. durability of the glue line needed to avoid delamination;
2. strength requirements for panels to be used structurally;
3. quality needed to the faces to accomplish the appearance desired;
4. special requirements such as fire or decay resistance;
5. market cost differences.

1.2.6 Sizing and sanding

Plywood which comes out of the high frequency press edges are trimmed and if necessary sawed into wanted size. Plywood is then sanded and the plywood is ready to be processed in CNC. There is also plywood, which is not sanded, because the surface quality is not important. It is used in construction.

1.2.7 Making the bed frame slats

Making the bed frame slats is different from the usual plywood production. First, veneer layers are not glued together crosswise, but in one direction. This gives them the U shape. Also both side of the veneer is covered with glue. After pressing the material goes through edging saw, which cuts the slats into equal size and the phases are cut into the edges. Readymade slats are shown in Figure 9.

Figure 9. Bed frame slats - (Authors photo 2015)

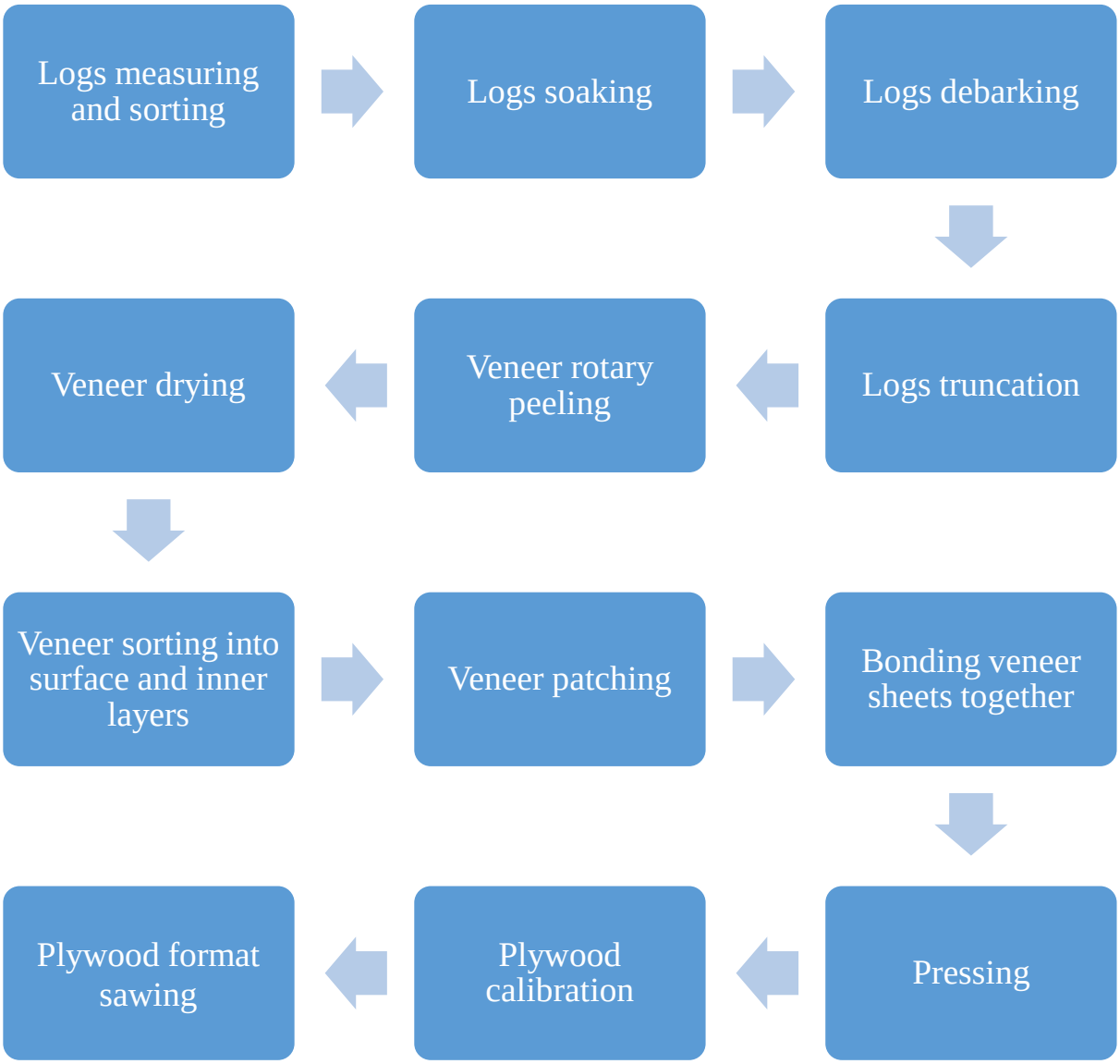

Figure 10. Block diagram of plywood production

1.3 Birch

Silver birch *(Betula pendula)*, is a species of tree in the family *Betulaceae*, native to Europe and parts of Asia. Birch is most common hardwood in Estonia. It has a beautiful white strain and long drooping branches. Birch grows in wooded meadows, mixed and deciduous forests in almost all communities. Birch stands represent a majority of 26.9% of Estonian forests with 181 m^3/ha, while pine-dominated stands second place. Birch forests are mostly in East and North-East Estonia, less is in South-Eastern Estonia. [6]

Birch can grow up to 35 meters high and average age of 100 - 150 years old. The leaves are bare, thin, leathery, rhombus shaped with a long sharp tip. At age 10-15, the bark is brown colour, which is covered with white wax spots. From only 20 years bark becomes white and smooth and from 60 years the bark becomes stronger. White birch is characterized by abundant snow white shell found in horizontal black leathers and refined, often underhung branches. [7]

Birch wood as a rearing tree is found to have very versatile usage, which makes its price higher compared to other tree species. The wood colour is yellowish white, rather hard, tough and elastic, but decays very quickly. Birch is frugal in climate and has a high cold resistance. It is also undemanding to soil fertility, preferring lighter or sandy loam soils. Birch is a light-demanding deciduous species, and therefore it cannot grow in the shade. Pure birch woods are achieved with maintenance of cutting. [8]

Birch wood users are plywood and veneer industries, as well as for furniture and lumber and as a part of parquet. Both the furniture and the parquet are produced in solid wood as well as a component of laminated timber components.

In case of birch the highest quality definer is the colour. Visually, how big part of the stem has false heartwood. Next important thing is, how much knots are in the material. By those properties, the quality class of birch wood is defined. Highest quality and price has the knot free and without false heartwood in birch wood. The cheapest and lowest quality class is material with knots and false heartwood. High quality material is mostly used in furniture industry, where the appearance is important, but the low quality material is only used in hidden parts such as furniture frames or in inner layers of the plywood. [9]

1.4 Birch false heartwood

The false heartwood part of the birch is quite unknown. Based on information from Henrik Heräjärvi, the phenomena is called discolouration at the first phase of decay/rot and later on the hard rot. In the hard rot phase the mechanical properties of wood have not been affected too much and such wood can be accepted, e.g., in core veneers in plywood. Later, the hard rot turns into soft rot that is not acceptable for plywood production due to the fact that the peeler cannot grip the bolt tight enough, even though there would be nice white veneers available in the surface of the log. Basically all birch trees get discoloured heart sooner or later. In case of European white birch (*Betula pubescens* Ehrh.) the stems start discolouring at the age of 50-70 years, depending on the site etc. The better quality species, Silver birch (*Betula pendula* Roth) starts discolouring at 70-80 years age, at latest. Sometimes there can be found 100-year-old birch trees with pure white cross section at the butt, but that is the case only very seldom. Discolouration starts from the ground level and climbs higher as the tree gets older. [10]

Discolouration is usually caused by fungi (eg. bracket fungi of the family *Polyporaceae*, class *Hymenomycetes*) - a disease causing the rotting and false heart wooding of parts of plants, which results the cause of wood softening and cracking. False heartwood-rot fungi attacks cellulose and hemicelluloses and breaks the polymeric structures of their molecules. In addition, the lignin structure is modified mainly through demethoxylation and demethylation (removal of a methyl group).

Historically, degradation of cellulose was considered a purely enzymatic process. Later it was revealed that the hyphae of false heartwood-rot fungi predominantly grow in the lumen of wood and are attached to the S_3 layer by their special sheaths. The S_2 layer of the wood cell wall is intensely degraded, whereas the S_3 layer may remain relatively ungraded until it decays (Figure 11). Degradation is not localized near the hyphae of fungi, which means that the degradation reagents produced by false heartwood-rot fungi are capable of diffusing into the wood cell wall. [11]

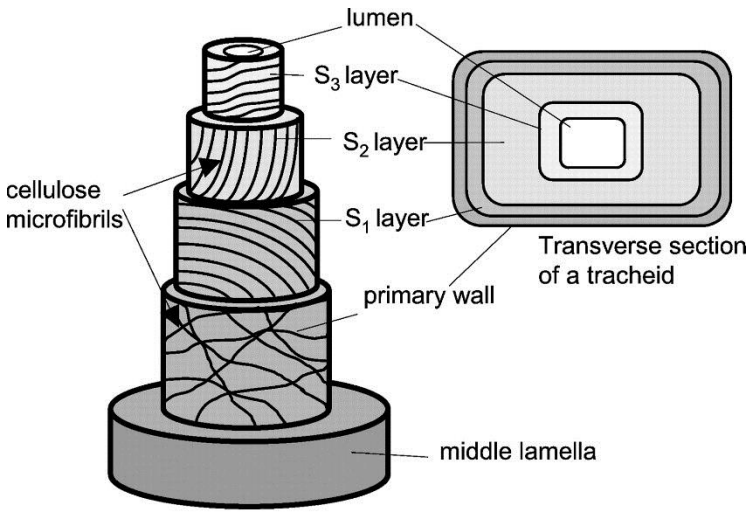

Figure 11. Wood layers [12]

The fungus occupies the trunk either via roots or via some physical damages in the stem. The process is related with the decrease in vitality of the tree as a result of ageing. As described above, the process of discolouring, as soon as turning into soft rot, effects on the mechanical properties of wood, as well. It is not well studied in the literature regarding the health effects of such discoloured birch wood. False heartwood rot wood is like any other decay fungus, not eatable, but there is no problem of touching it, or breathing the odour of discoloured wood. Although, there are no confident information about it. [13]

1.5 Urea formaldehyde resin

About 90% or more of the world's board production is made with urea formaldehyde (UF) resins. UF resins, the most well-known amino resins, have many advantages such as low cost, ease of use under a wide variety of curing conditions, the fastest reaction time in hot press, water solubility, low cure temperatures, resistance to microorganisms and to abrasion, excellent thermal properties, and their colourless qualities, especially the cured resin compared to other resins. However, UF resins are not suitable to produce boards with good exterior exposure resistance. The biggest drawback of UF resins also is that they release formaldehyde into the environment during curing when they are used as a binder component. [14]

In industrial production, urea resins are made by the condensation of formaldehyde and urea in an aqueous solution, using ammonia as an alkaline catalyst. The condensation reaction gives a colourless, syrupy solution. Formaldehyde HCHO, is a colourless gas at room temperature with

an extremely unpleasant and stifling smell. It is a very reactive gas, classified as a volatile organic compound (VOC). [15]

Like melamine formaldehyde resin, urea formaldehyde resin is very hard, scratch-resistant material with good chemical resistance, good electrical qualities and heat resistance up to 170ºC. Urea-formaldehyde resins are formed by the condensation reaction of formaldehyde HCHO and urea CO $(NH_2)_2$. They cure at elevated temperatures with appropriate catalysts.

Formaldehyde is an industrial chemical which is used widely in building industry and other chemicals are made of it, it is also used to make household products. In home, formaldehyde can be found from coatings or in adhesive and comes in many synthetic resin mixtures. Some of the more common synthetic resins are phenol-formaldehyde (PF), melamine-formaldehyde (MF), and urea-formaldehyde (UF). UF is highly water-soluble and therefore is the most problematic mixture for indoor air pollution with VOC. [15]

Like phenol formaldehyde and melamine formaldehyde resins, urea-formaldehyde resins are used primarily as wood adhesives. However, UF is less durable than the other two resins, and it do not have sufficient weather resistance to be used in exterior applications. Because urea-formaldehyde resins are lighter in colour than phenol-formaldehyde resins, they are traditionally used for interior plywood and decorative materials. Urea-formaldehyde resins are used mostly as adhesives for the bonding of plywood, particleboard, and other structured wood products. [16]

Nowadays, wood-based panels are widely used indoors, and the formaldehyde and VOCs emitted from these panels has become one of the major causes of degrading indoor air quality, which can negatively affect human comfort, health and productivity. Formaldehyde has been classified as a carcinogenic substance that can cause nasopharyngeal cancer in humans. The concerns over the release of free formaldehyde (VOC) into the air have led to substitution by phenolics. [17]

Urea formaldehyde used in this research is product of Achema trademark KF-LE. It is a whitish liquid with mass fraction of non-volatile substances 65 ± 2 %. Relative viscosity with shell diameter of 4 mm is 120-160 s. pH range is between 7.5 and 8.7. [18]

Hardener used in this thesis is Casco 2545, which is specially meant for urea formaldehyde resin. It is suitable for hot and high frequency pressing and it has long usage time. Casco 2545

is grey liquid with pH range of 3.0 – 5.0. Its density is 1430 kg/m^3. Usage temperature is 70-200ºC. [19]

1.6 Fillers

Fillers ensures the necessary glue flow, reduce shrinkage, internal tensions and creep, solve the thermal expansion factors, increase the heat resistance, impact strength and reduce costs. Metals, metal oxides and –nitrides, salts, minerals, soot, wood-, wheat- and coconut or walnut shell flour are used as fillers. Also polymeric powders, mineral and polymeric fibres are used. Important is the particle size of the filler, the surface properties, bonding with the resin and neutrality. [20]

There are several fillers to choose between. For a further examination kaolin, aerosil, montmorillonite, wood flour, wheat flour and calcium carbonate was chosen.

1.6.1 Kaolin

Kaolin $Al_2 Si_2 O_5 (OH)_4$, also called as china clay, is a soft white clay that is an essential ingredient in the manufacture of china and porcelain and is widely used in the making of paper, rubber, paint, and many other products.

Naturally kaolin is a white and soft powder which, under the electron microscope, is seen to consist of roughly hexagonal, platy crystals ranging in size from about 0.1 micrometre to 10 micrometres or even larger.

Approximately 40 percent of the kaolin produced is used in the filling and coating of paper. In filling, the kaolin is mixed with the cellulose fibre and forms an integral part of the paper sheet to give it body, colour, opacity, and printability. In coating, the kaolin is plated along with an adhesive on the paper's surface to give gloss, colour, high opacity, and greater printability. Kaolin used for coating is prepared so that most of the kaolinite particles are less than two micrometers in diameter. [21]

1.6.2 Aerosil

Aerosil SiO_2/Al_2O_3, can be found in nature in crystalline form (as quartz sand), and it is the most abundant component of the earth's crust. Amorphous silica is industrially manufactured in a variety of forms - including silica gels, precipitated silica, fumed silica, and colloidal silica.

Colloidal silica consists of dense, amorphous particles of SiO_2. The building blocks of these particles are randomly-distributed [SiO4]-tetrahedra. This random distribution is what makes amorphous silica different from crystalline silica - ordered on a molecular level. Sodium silicates are alkaline solutions with pH ranges of 12-13. [22]

In boat industry the aerosil is commonly used filler. The filler is applied to the epoxy resin in order to make it thicker. The thickened epoxy resin is used for making fillets between the panels and the frames. It is important to use aerosil, because the fillet needs some structural properties that the filler will apply to the epoxy resin. Adding aerosil to the epoxy makes it harder to grind, therefore the best thing to do is to smooth the fillets carefully before they harden. [23]

1.6.3 Montmorillonite

Nanoclays $(Al, Mg)_8(Si_4O_{10})_3(OH)_{10} *12H_2O$ are nanoparticles of layered mineral silicates. Depending on chemical composition and nanoparticle morphology, nanoclays are organized into several classes such as montmorillonite, bentonite, kaolinite, hectorite, and halloysite.

Plate-like montmorillonite is the most common nanoclay used in materials applications. Montmorillonite consists of ~ 1 nm thick aluminosilicate layers surface-substituted with metal cations and stacked in ~ 10 μm-sized multilayer stacks. Depending on surface modification of the clay layers, montmorillonite can be dispersed in a polymer matrix to form polymer-clay nanocomposite. Within the nanocomposite individual nm-thick clay layers become fully separated to form plate-like nanoparticles with very high (nm × μm) aspect ratio. [24]

The use of nanoclay improves the physical properties of the materials because it increases the mass of material. Mechanical strength increases substantially, and this requires only a small part of the nanoclay impurity (less than 5%). So, in particular, nanoclay is rather additive than a filler. Compared to other additives, such as glass, coal, talc. Nanoclay material does not change the viscosity or density very much. The reason why clay nanoparticles improve the physical and mechanical properties of composite materials lies in the large specific surface area of clay. [25]

It has been studied that the montmorillonite type nanoclay added urea-formaldehyde (UF) improved the thermogravimetric properties, increased starting temperature, increased maximum peak temperature, increased mass remnant in the different temperature periods

studied of the reactions present in the adhesives and increased entropy factor and activation energy of the kinetics of decomposition of the resin. In addition, UF adhesives with the modified nanoclay affect other physical features, slightly increasing the viscosity of the resin and the brightness and the yellowness of the adhesives, especially in the proportion of 1.5%. Nano-clay added in UF adhesive improved shear strength of the glue line and the percentage of wood (PWF) failure. Shear strength was not affected by nanoclay addition in UF adhesive under dry conditions. However, under wet conditions, both 1.0 and 1.5 wt% of nanoclay into adhesive increased shear strength in the adhesive. In the UF adhesive, PWF increased 10% under dry conditions and 25–50% under wet conditions. [26]

1.6.4 Wood dust

Wood dust is a finely-ground wood. When the mesh size is above 20 mesh or below 850 microns, a product becomes generally considered to be wood dust. Wood dust is considered to be dry when its moisture content is 8% or less. Wood dust is hydroscopic and will absorb moisture from the atmosphere over time. The color range of wood flour can be as broad as white to false heartwood.

Wood dust, generated by the processing of wood, is composed of cellulose, hemicelluloses, and lignin compounds. A variety of biologically active, low molecular weight compounds may also be present, depending on the species. These extractives include alcohols, terpenes, sterols, glycerols, tannins, flavonoids, quinones, lignans, alkaloids, and proteins. [27]

1.6.5 Wheat flour

Wheat flour $(C_6H_{10}O_5)n$ is a powder made from the grinding of wheat used for human consumption. More wheat flour is produced than any other flour. Wheat varieties are called "soft" or "weak" if gluten content is low, and are called "hard" or "strong. Hard flour, or bread flour, is high in gluten, with 12% to 14% gluten content, its dough has elastic toughness that holds its shape well once baked. Soft flour is comparatively low in gluten and thus results in a loaf with a finer, crumbly texture. Soft flour is usually divided into cake flour, which is the lowest in gluten, and pastry flour, which has slightly more gluten than cake flour.[28]

In table 1 wheat flour properties are presented. Wheat flour is very similar to wood as a material. Much finer than wood dust from sawing or sanding, so creates smoother surfaces. Cake flour is almost wood colour (light). It is also available everywhere and cheap. Although it increases

viscosity, which is not good as a filler. Wheat flour particle size can be from 50 to 100 μm. Its density is about 528 kg/m^3 and moisture content less than 12%. Wheat flour is slightly alkaline with a pH 6-6.8. [29]

It has been studied that, the tackifier effect on UF-glue and slab pre-press strengthening efficiency of grain powders ordered from big to small as follows: wheat gluten, wheat flour, simulated flour, wheat starch, and maize powder. Different researchers have made tests with SEM images, IR and XRD spectra do not show clear evidence of chemical reaction between wheat flour and UF-glue around room temperature. The starch separated from mixture of flour with UF-glue keeps its crystallite properties such as polarizing and gelatinizes when head enough. Test data show that for same compositions the viscosity of the mixture of suspension with UF-glue is bigger than that of the mixture of dry powder with UF-glue. Hydration extent of grain molecules plays a key role to tackify UF glue and poly(vinyl acetate) latex ; the hydration extent of grain molecules is higher when grain powder is added into water forming suspension than when grain powder is added directly into UF-glue and into poly(vinyl acetate) latex. [30]

1.6.6 Calcium Carbonate

Calcium carbonate $CaCO_3$ is a chemical compound with the formula $CaCO_3$. It is formed by three main elements: carbon, oxygen and calcium. It is a common substance found in rocks in all parts of the world, and is the main component of shells of marine organisms like snails, coal balls, pearls, and eggshells. Calcium carbonate is the active ingredient in agricultural lime, and is created when calcium ions in hard water react with carbonate ions creating limescale.

Calcium carbonate is a white odourless powder with chalky taste. It has high density with value 2711 kg/m^3, although the particle size is up to 30 μm. Moisture content average is 3% with a pH of 9. [21]

Table 1 shows the comparison of the fillers. Based on the table, six fillers were chosen for the experiment. Charcoal was eliminated due to its colour. Others have very good prospects as potential fillers.

In Figure 12 almost all (except wood dust) chosen fillers and adhesive are presented.

Figure 12. Fillers, from left to right - wheat flour, $CaCO_3$, montmorillonite, kaolin, aerosil and UF is in the bottles - (Authors photo 2015)

Table 1. Filler property comparison

Filler / **Properties**	**Kaolin**	**Aerosil**	**Montmorillonite**	**Wood dust**	**Wheat flour**	**Calcium Carbonate**
Formula	$Al_2Si_2O_5(OH)_4$	SiO_2/Al_2O_3	$(Al,Mg)_8(Si_4O_{10})_3(OH)_{10}$ *$12H_2O$	-	$(C_6H_{10}O_5)n$	$CaCO_3$
Appearance	White powder	White powder	Green	Light brown	White powder	White powder
Particle size, µm	≥90	30	1 to 3	74-500	50 to 100	≤30
Density, kg/m^3	2600	2200	2300	288	528	2711
MC (%)	≤0.5	3	5	<8	12	3
pH	6.0-8.0	3.5-6.0	7	3.5 to 4.6	6 to 6.8	9
Price, €/kg	2.23	4.72	9.00	Free*	1.32	0.96

*Free for wood processing industries

2. MATERIALS AND METHODS

2.1 Material properties

For the further experimentations surface of the material was explored with microscope. Unfortunately it did not give any good results, only thing seen from the microscope was colour and some major cracks. It is very important to notice that veneer layer cut from the false heartwood part has more irregularities than normal veneer. The cut layer has very different thicknesses in different parts, the false heartwood rot is also divided unevenly. Veneer parts which are with darker false heartwood have evidently more cracks.

2.1.1 Moisture content measurements

A green wood contains about 50% of water, part of the moisture is situated in bound water and free water in lumens. Moisture, which is located in the cell walls, is a hygroscopic, water-related, or the pair of fibrils (the cell wall is composed of fibrils), and the surface forms a continuous water molecules between the layers, where thickness can be up to a few hundred molecules.

The EMC (equilibrium moisture content) is the property of the wood absorbing moisture until it equilibrates with moisture of the surrounding air. Thus, the dried wood can take the moisture inside later again from the surrounding environment, if the moisture is big enough (inside the wood there is lignin, which is a substance absorbing the moisture into itself). Wood hygroscopicity is disadvantage, because with the wood moisture content change the shape and size will change also and that property decreases the resistance of the rot fungi's. [31]

Wood MC depends on the wood species, time of year and location. Softwood sapwood are considerably wetter than the heartwood (the nutrients are transported along the sapwood and is therefore wetter), hardwood does not have so great difference. If the wood is kept in the open air for a long time a MC changes because of the absorption and desorption process.

Wood MC was measured according to standard EVS-EN 322:2002. Its principle is that by weighing each test weight loss, which considers the degree of drying sampling mode up to a constant weight at (103±2) ºC, and it is calculated as a percentage of the weight loss of the test sample mass after drying. The results are used to evaluate all the tiles from moisture. Absolute

dry veneer is obtained in dryer oven, which is able to keep the temperature in 103 ± 2 ºC. Requirement for test piece is minimum weight of 20 g, shape and measures are not important. Test pieces may not have loose fragments or sawdust. Wood moisture content is presented in formula 2.1. [32]

$$H = \frac{m_{\mathrm{H}} - m_0}{m_0} * 100\% \quad (2.1)$$

Where,

H is moisture, %

m_{H} is total weight of moisture wood, g

m_0 is weight of absolute dry wood, g.

2.1.2 Density measurements

For describing material properties one important aspect is density. Density is the mass per unit volume of the substance - the mass of material, and the volume ratio, which is expressed in g/cm^3 or kg/m^3. Wood is a material with porous structure which total volume includes both large and small cavities. Wood natural state, marked wood volume density of the weight, a single unit volume (with all cavities in the wood substance) in weight.

Since wood is a hygroscopic material, it will have a greater or lesser extent, to the moisture of water. For wood density moisture content must be know, because the density can vary within a wide range of different humidity. A distinction should be known between wood density and wood density of the substance. Wood density shows the weight per unit volume in the natural state, all the cavities in the wood.

Measuring was done by standard EVS-EN 323:2002, which principle is that, the density of each sample is determined at the same humidity, measured as the ratio of mass and volume. The results are used to evaluate the density of all boards. Requirement for the test pieces were square shaped, with nominal length of 50 mm. Density formula is presented in formula 2.2. [33]

$$\rho = \frac{m}{V} \quad (2.2)$$

Where,

ρ is the density, g/m^3

m is the mass of the material, g

V is the volume of the material, m^3

2.1.3 pH measurements of the veneer

The vast majority of wood based panels are made using formaldehyde-based resins. The curing rates of such resins are very dependent on the pH of the environment in which they cure and so the pH of the wood species used can have an effect on adhesive cure.

The pH scale is an indicator of the concentration of hydrogen ions (H+) in solution such that solutions with a pH of 7 are considered neutral, whereas those with a pH of less than 7 are acidic and those higher than 7 are alkaline, or basic.

All wood species have a pH and most species are naturally acidic, with the vast majority having a pH of between 4.0 and 5.5. An indication of the pH of a wood can be obtained by soaking wood particles in distilled water and measuring the pH of the solution some time after. [34]

pH measurement is based on the use of a pH sensitive electrode (usually glass), a reference electrode, and a temperature element to provide a temperature signal to the pH analyser. The pH electrode uses a specially formulated, pH sensitive glass in contact with the solution, which develops a potential (voltage) proportional to the pH of the solution. The reference electrode is designed to maintain a constant potential at any given temperature, and serves to complete the pH measuring circuit within the solution. It provides a known reference potential for the pH electrode. The difference in the potentials of the pH and reference electrodes provides a millivolt signal proportional to pH. pH measuring was done with Mettler Toledo MP220 device, which is seen in Figure 13.

Figure 13. Measuring the pH - (Authors photo 2015)

2.1.4 Surface roughness measurements

Surface roughness is a measure of the texture of a manufactured surface. It is based on a statistical representation of the high frequency surface deviations (peaks and values) from the local mean surface height. Filtering is used to separate the high frequency texture data from lower frequency machining features. Surface roughness can be measured using contact methods involving dragging a stylus across the part, or using non-contact optical methods.

Ra (Figure 14) is the most commonly used surface roughness definition, which shows profile ordinate arithmetic. Ra is all ordinate values of z(x) arithmetic average value of a single source at $l_{r.}$ [35]

Purpose of this measurement is to compare normal and false heartwood veneer surfaces.

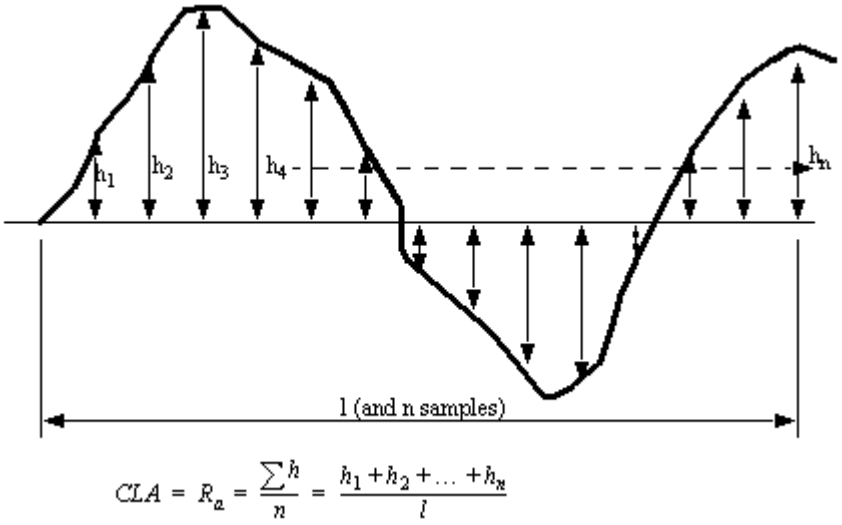

Figure 14. Ra measuring graphic [35]

2.1.5 Measuring the contact angle

OCA 20 is video-supported contact angle measuring instrument Data Physics shown in Figure 15. It is developed for measuring the static and dynamic contact angles according to the "Sessile & Captive Drop Method" and the "Pendant Drop Method", to determine the surface free energy of solid bodies and their components also for determining the surface and interface tension of liquids from the drop or lamella contour.

Figure 15. Contact angle system with liquids used in tests – (Authors photo 2015)

The micro-controller module in the OCA 20 ensures movement, reproducibility and precision in liquid handling and during measurement. All the information measured during the test are presented in the connected computer, which is supported by the intuitively controllable software of the SCA series. Program has built up on exact and reliable methods for drop contour evaluation with statistic error analysis. [36]

Purpose of the test

Get to know how well the false heartwood rot veneer absorbs moisture compared to normal veneer. Comparing two different veneers based on standard EVS-EN 828:2013. Based on standard three solutions were chosen: water, ethylene glycol and glycerol.

Description of test procedure

1. Testing device (Figure 16) is prepared, all the contacts are set so the picture from the screen should be as sharp as possible.
2. Testing specimen is fixed to the test plate with tape, because false heartwood rot veneer is very wavy but the surface of the specimen has to be straight.
3. Testing needle for liquid is filled with solution. The needle is attached to its place.
4. If the specimen is ready one drop of solution is dripped onto specimen. In 120 second the contact angle have to be fixed in the computer program. Program gives left and right contact angle measured from the solution drop.
5. 20 drops of every solution is dripped onto normal and false heartwood rot veneer specimen. Total amount of drops are 120. Important is drip drops to different areas of the veneer. An example of veneer with drops are presented in Figure 17.[37]

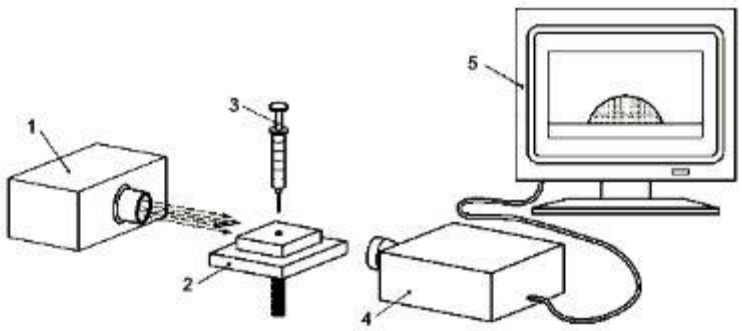

Figure 16. Contact angle measuring system. 1 - lightning, 2 - sample carrier, 3 - dosage, 4 – optical system, 5 – screen [37]

Calculations

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

For the further calculations the Young-Dupre formula is needed.

The Young-Dupre formula 2.2 defines the work of adhesion obtained during wetting:

$$W_{ad} = \sigma_L + \sigma_L * \cos\theta = \sigma_L * (1 + \cos\theta), \quad (2.2)$$

Where,

σ_L is surface tension,

$\cos\theta$ is the measured contact angle average.

Next surface free energy was calculated.

Surface free energy formula 2.3:

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

Where,

σ_S is equal to work of adhesion;

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

$\sqrt{\sigma_S^P * \sigma_L^P}$) is polar dispersion.

2.1.6 Tensile strength

Tensile strength is the maximum load that a material can support without fracture when being stretched, divided by the original cross-sectional area of the material. Tensile strength is calculated according to the formula 2.4 which is force per unit area and its unit is N/mm^2. When stresses less than the tensile strength are removed, a material returns either completely or partially to its original shape and size. As the stress reaches the value of the tensile strength,

however, a material, if ductile, that has already begun to flow plastically rapidly forms a constricted region called a neck, where it then fractures. [38]

Tensile strength was measured with Instron 5866 (in Figure 17), which parcels distance was 150mm, tensile speed 10 mm/min and force sensor 500 N. Other machine parameters are shown in Table 2.

Table 2. Instron 5866 parameters [39]

Data	**Parameter**
Product Category	Mechanical Testing Equipment
Mechanical test	Adhesion; Compression; Fatigue; Shear or Torsion; Flexure or Bending; Universal
Force/load	1020 kg
Stroke/Travel	1249 mm
Speed	1.67E-5 to 8.33 mm/sec
Temperature	10 to 38C
Humidity	10 to 90%
Accuracy/ Other	1597 mm Height, 909 mm Width; 700 mm Depth; 136 kg Weight
Display/User Interface	Computer Interface; Application Software

Figure 17. Instron 5866 with false heartwood veneer specimen – (Authors photo 2015)

For this test, the specimens were cut and the specimens were hermetically sealed to a plastic bag for the time the testing was taken. It was important to keep the moisture content as similar as used in production. There were 40 pcs of both specimens tested.

Specimen were attached between the claws of the Instron 5866 and tested afterwards. Testing point is that the upper claw starts to tensile the specimen as long as it cracks and then the computer calculates the force. After the tensile strength test the specimen's width and thickness were measured from the cracked parts.

For the tensile strength calculations maximum load was divided with width and thickness multiply, the formula is shown in equation 2.4.

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

Where,

F is maximum load, N

A is width and thickness multiplied, mm^2.

2.1.7 Viscosity of adhesive and filler mix

Wettability is a necessary factor for good adhesion, but besides the wetting of the surface phenomena depends on the ability of the adhesive to flow or spread over the surface or in other words it depends on rheological properties of the liquid adhesive.

Adhesives are shear thinning or pseudo-ductile liquids, which means that their viscosity decreases when the shear rate increases. Non-newton flow can be presented with thixotropic. The difference in the normal shift of a liquid is that they are liquid similar substances in the absence of shear thinning, and a slight displacement of one of the voltage depends on the shear rate at the time. While stirring or moving surfaces glue liquefies, but it thickens right away when the termination of mechanical agitation stops. To ensure good adhesion of the glue it must become a sufficiently liquid at some point, to ensure that the necessary flowability is obtained for surfaces fast wetting and with pore filling. The relatively low viscosity of the adhesive is

maintained for a certain period and the subsequent rapid solidification must be appropriately timed with each other. [34]

Filler and adhesive mixture viscosity was measured with Brookfield viscosimeter (Figure 18), which employs the principle of rotational viscometer - the torque required to turn an object, such as a spindle, in a fluid indicates the viscosity of the fluid. Torque is applied through a calibrated spring to a disk or bob spindle immersed in test fluid and the spring deflection measures the viscous drag of the fluid against the spindle. The amount of viscous drag is proportional to the amount of torque required to rotate the spindle, and thus to the viscosity of a Newtonian fluid. In the case of non-Newtonian fluids, Brookfield viscosities measured under the same conditions (model, spindle, speed, temperature, time of test, container, and any other sample preparation procedures that may affect the behaviour of the fluid) can be compared. When developing a new test method, trial and error is often necessary in order to determine the proper spindle and speeds. Successful test methods will deliver a % torque reading between 10 and 100. [40]

Figure 18. Brookfield viscosimeter – (Authors photo 2015)

2.1.8 Automated bonding evaluation system

The Automated Bonding Evaluation System (ABES) enables the strength development characteristics of a diversity of combinations of adhesive and substrate to be explored under

controlled conditions. A key function is the provision of data on the effect of temperature on the rate of bond strength development for precisely formed miniature test bonds. Such information enables the compatibility of adhesives for product manufacture and assembly processes to be evaluated. In addition it is being used to evaluate and compare the bonding characteristics of adhesive formulations. ABES device is shown in Figure 19. [41]

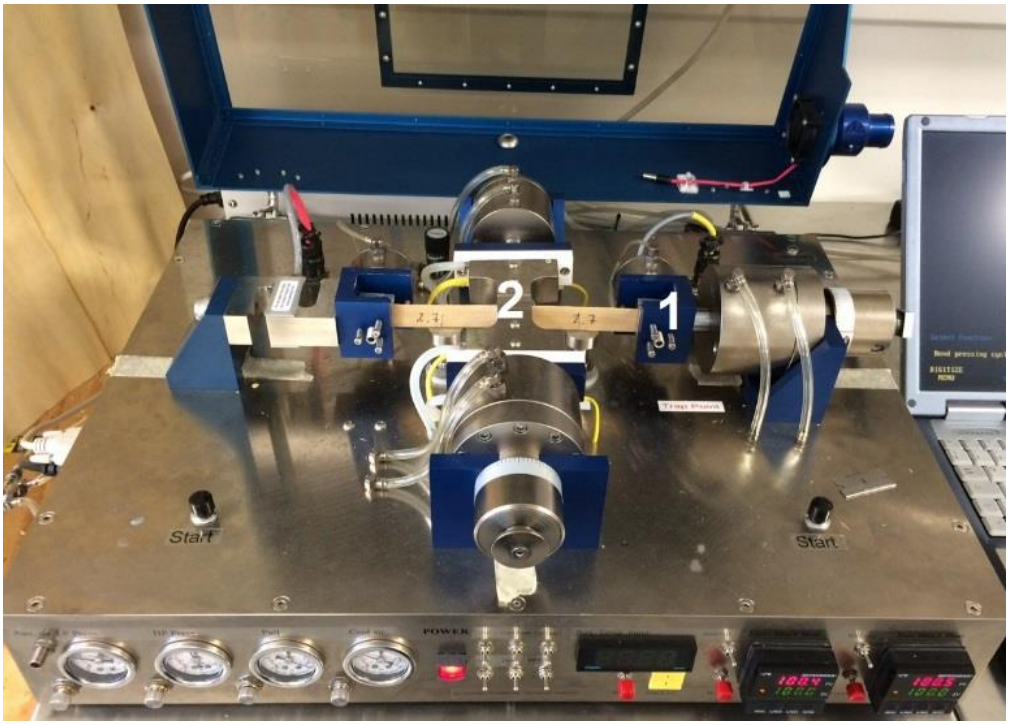

Figure 19. ABES machine. 1- specimen fixing claw, 2- hot press claws – (Authors photo 2015)

Aim of this test was evaluate bonding properties of false heartwood veneers glued with adhesive and filler mixtures.

2.1.9 Shear strength of the adhesive joint

For testing seven layer plywood was made in TUT in Woodhouse. For pressing an old plywood presser was used. Veneer layers were cut into 320 x 320 mm pieces. Producing the plywood, most important is to calculate the amount of adhesive needed for every veneer layer. Following the exactness gives the best results. Formula for adhesive amount per veneer layer is shown in equation 2.5.

$$Adhesive\ amount = (0.32\ m * 0.32\ m) * 100g \quad (2.5)$$

100 g is the amount of 1 m^2 used in Tarmeko LPD. So for the result 10.24 g of adhesive per each veneer layer was needed. The exact measuring was made so, that veneer layer were weighted, then adhesive was applied with roller and weighted again, if the weight was smaller some more adhesive was added and if the weight was bigger, some adhesive was removed with paper.

When seven layers were glued together the sample was under press for 7 minutes, which means rule of the thumb is one minute per layer. After pressing the readymade plywood samples cooled down in room temperature.

Two days after the plywood samples were cut into test specimens with measures 100x25x10 mm and 250x50x10 mm. Total amount of specimens were about 300.

Shear strength is a material's ability to resist forces that can cause the internal structure of the material to slide against itself. Adhesives tend to have high shear strength.

The shear strength is the load that an object is able to withstand in a direction parallel to the face of the material, as opposed to perpendicular to the surface. The formula of shear strength is shown in equation 2.6.

$$\tau = \frac{F}{A} \tag{2.6}$$

Where,

τ is shear strength,

F is force applied,

A is the cross-sectional area of material with area parallel to the applied force vector. [42]

Description

For measuring the shear strength Instron 5866 was used. Test specimen with measures 100 x 25 x 10 mm and it had two cuts in both sides for testing the middle layer adhesion joint. Specimen were attached to claws and the upper claw started to pull the specimen, it is seen in Figure 20. After the joint broke, maximum load and strength per N/mm^2 were given by the computer.

Plywood with four different adhesive mixes and two different plywood's were tested. 15 samples of each were tested. So the total amount of test specimens were 120.

Figure 20. Shear strength testing in Instron 5866 – (Authors photo)

2.1.10 Bending strength of the plywood

Mechanical parameter for bending strength, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. Test was performed according to standard EVS-EN 310:2002. The formula of bending strength is given in equation 2.7.

$$f_m = \frac{3 * F_{\max} * l_1}{2 * b * t^2} \tag{2.7}$$

Where,

$F_{\max}$ is maximum compressive load, N

l_1 is distance between centres of supports, mm

b is the width of specimen, mm

t^2 is thickness of the specimen, mm. [43]

Description

For bending strength Instron 5866 were used, but two contrivances were attached to claws, which is seen in Figure 21. The specimen was put on top of the lower supports. Important is to put the specimen right in the middle of the support to give exact results. Span of lower supports parts was 200 mm. Specimen's measures were 250 x 50 x 10 mm.

Plywood with four different adhesive mixes and two different plywood's were tested. Five samples of each were tested. For the total 40 specimens were tested.

Figure 21. Bending strength in Instron 5866 – (Authors photo)

Purpose of this test was to find out the highest bending strength in plywood specimens with different filler and adhesive mixture.

2.2 Test plan

Purpose of testing was to compare false heartwood and normal veneer material properties. Also the adhesive and filler mixture viscosities and adhesive joints between veneer layers were measured. Finally plywood made from false heartwood and normal veneer were tested with shear strength and bending strength. Overview of the done tests are presented in Table 3.

Table 3. Test plan

Data / **Measurements**	**Week**	**Time, h**	**Specimen dimensions, mm**	**Nr of specimens**
Moisture content	1	0.5	150 x 50 x 1.5	8
Density	1	0.5	150 x 50 x 1.5	8
pH	9	0.5	Wood dust + water	4
Surface roughness	12	1.5	150 x 50 x1.5	6
Contact angle	3	3	50 x 50 x 1.5	6
Tensile strength	9	4	150 x 50 x 1.5	80
Viscosity	5	4	100 g of adhesive + 5/10 g of filler	25
ABES	6	6	100 x 15 x 0.7	100
Shear strength	11	3	100 x 25 x 10	120
Bending strength	11	2	250 x 50 x 10	40

For comparing material properties moisture and density was measured. Moisture was measured after industrial drying in temperature 103ºC to absolute dry wood. For density veneer layers with dimensions 150 x 50 x 1.5 mm were weighted.

pH is a very important indicator when material is described. For testing false and normal wood was grinded into small particle size and the dust was mixed mechanically with water about 30 minutes. After that time pH was measured with Toledo MP220.

Surface roughness was measured with Mahr Perthometer Concept. Four specimens of normal and false veneer was measured and from each material four different places were measured. Total of 24 measuring's were done.

Next contact angle was measured according to standard EVS-EN 828:2013 - Adhesives - Wettability - Determination by measurement of contact angle and surface free energy of solid surface. For that veneer pieces with measures 50 x 50 mm were cut and tested.

Tensile strength of veneer were measured with veneer pieces 150 x 50 x 1.5. 40 pieces of both veneers were tested with same conditions as in the industry, which means it was measured with veneer which had been soaked in water tanks for 48 hours, to remain the similarities pieces were kept in plastic bag.

Adhesive and filler mixture viscosities were measured in TUT laboratory. 100g of urea formaldehyde was measured and added 5 and 10 g of fillers. After 30 minutes of mechanical stirring the viscosity were measured three times each mixture. Total amount of 25 times viscosities were measured. Gauge nozzle size were 4CGS and 6CGS only for wood dust, due to its high viscosity.

ABES testing was done in Finland in Aalto University. About 6-7 veneer pieces of false heartwood veneer were measured with different concentration and filler. Before testing veneer were cut into measure of 100 x 15 x 0.7 mm. Total of 100 tests were done.

For measuring plywood shear strength and bending strength, plywood was pressed in TUT Wood building. Plywood was made of normal and false heartwood veneer layers, with seven layers. Plywood was with measures 320 x 320 x 10 mm. After pressing and cooling down in 06.05.2015 plywood was cut into pieces of 100 x 25 x10 mm for shear strength and 250 x 50 x 10 mm for bending strength.

All the tests were performed in room conditions of 22ºC and with humidity of 30%.

3. RESULTS AND DISCUSSION

3.1 Moisture content and density measurements

Moisture content and density was measured to get basic information about materials differences. Veneer MC was measured according to standard EVS-EN 322:2002. Its principle is that by weighing each specimen before the test and after drying to a constant weight at (103±2) ºC, and it is calculated as a percentage of the weight loss of the test sample mass after drying. The results are used to evaluate all the tiles from moisture. Absolute dry veneer is obtained in dryer oven, which is able to keep the temperature in 103 ± 2 ºC. Test pieces may not have loose fragments or sawdust.

Density measuring was done according to standard EVS-EN 323:2002, which principle is that, the density of each sample is determined at the same humidity, measured as the ratio of mass and volume. The results are used to evaluate the density of all boards. Requirement for the test pieces were square shaped, with nominal length of 50 mm.

Table 4. Moisture content and density measurement of normal veneer

Normal samples nr	**Initial weight, g**	**After 1 h**	**After 2 h**	**Difference**	**MC, %**	**Volume, cm^3**	**Density, g/cm^3**
1	8.22	5.68	5.67	2.55	4.50	11.25	0.50
2	8.80	5.65	5.66	3.14	5.55	11.25	0.50
3	8.94	5.57	5.56	3.38	6.08	11.25	0.49
StDev	0.38	0.06	0.06	0.43	0.80		0.01
Average			**5.63**		**5.37**		**0.50**

Table 5. Moisture content and density measurement of false heartwood veneer

FH samples nr	**Initial weight, g**	**After 1 h**	**After 2 h**	**Difference**	**MC, %**	**Volume, cm^3**	**Density, g/cm^3**
1	8.38	4.67	4.66	3.72	7.98	11.25	0.42
2	8.98	5.19	5.20	3.78	7.27	11.25	0.46
3	8.28	4.69	4.68	3.60	7.69	11.25	0.41
4	9.09	5.00	4.99	4.10	8.22	11.25	0.44
StDev	0.41	0.25	0.26	0.21	0.41		0.02
Average			**4.88**		**7.79**		**0.43**

As it can be seen from Table 4 and 5 false heartwood moisture content is higher than in normal veneers. It is important, because bond formation effects of moisture content begin with amount and rate of water absorption. The more water in the wood, the slower it will absorb moisture during curing process. This means that a film of water-dispersed glue placed on dry wood surface will dry out faster than a similar film on wood of high moisture content. This effect will play important role in the assembly time period, which causes decreasing of MC movement. The length of assembly time then determines how prepared the glue is to receive pressure or heat. The maximum assembly time may have to be shorter for dry wood and for wood with high moisture content in order to avoid dry out or pre-hardening. With high moisture content wood, the minimum assembly time is more important and it may need to be lengthened to ensure optimum mobility and avoid over penetration and starved joint.

Density has also a great importance of bonding. The higher the density the lower amount of adhesive is needed. With density decreasing the adhesive amount increases, because lower density wood has more open pores which lets the adhesive be impermeability through the layer. In order to stop this more and more adhesive is needed, but adding more and more adhesive causes over penetration and the pores keep being opened. As seen from the Table 4 and 5 density variety between normal (0.50 $g/cm^{3)}$ and FH (0.43 g/cm^3) veneer is not that great. Based on the information got from the density measurements, density should not be the reason of the delamination.

3.2 pH measurements

pH of the material was measured and results are presented in Table 6. For that the false heartwood and normal veneer were grinded into very small pieces 50 mesh and mixed into distillated water. Then the pH of the three mixtures was measured to get the accurate result. As the result false heartwood veneer had the pH of 5.40 and the normal veneer 5.17, they are both slightly acidic. According to Wood Science book, the average birch wood pH is 5-6.5, so the measured results are in the scale range. [12] As seen from results, there are a small variety between normal wood and false heartwood. It gives confirmation that any kind of reaction with adhesive should be excluded and the pH is not the reason of delamination.

Table 6. pH measurements

Nr	**pH of normal**	**pH of FH**
1	5.20	5.38
2	5.14	5.40
3	5.16	5.41
StDev	0.03	0.02
AVG	5.17	5.40

3.3 Surface roughness measurements

Surface roughness was measured using a Mahr Perthometer Concept profilometer. For measuring the length of a valued source the Mahr parameters catalogue in accordance with DIN EN ISO 4288 standard values in place. First a sample surface roughness is measured, according to Ra value obtained the standard is selected according to the respective λ_c (the estimated length of the source). Selected λ_c is multiplied by seven and the measurement of the full length in millimeters are calculated. Such method of determining the measuring parameters ensures more accurate measurement results. Table 7 presents the used parameters for measurements.

Table 7. Surface roughness measuring parameters

The length of the measurement (λ_c x 7)	**Measuring range (µm)**	**Measuring force (mN)**
2.5 x 7	± 250	0.75

Purpose of this measuring was to collect information about normal and FH veneer surface roughness. Based on the information it can be told, how the surface roughness affects the adhesive bonding with the material. Results are presented in Table 8.

Table 8. Surface roughness measurement

Nr	**Normal, Ra**	**Normal, Rz**	**FH, Ra**	**FH, Rz**
1	10.06	74.23	23.48	137.43
2	7.48	53.90	21.78	131.74
3	8.25	65.05	27.53	162.30
4	13.52	92.83	36.84	194.98
5	8.85	76.12	33.04	162.41
6	6.06	51.70	30.68	153.61
7	9.60	63.56	12.79	87.61
8	10.30	80.58	12.68	84.89
9	10.85	101.36	17.03	120.39
StDev	2.15	16.72	8.74	36.02
AVG	9.44	73.26	23.98	137.26

The measuring was done from the loose side of the veneer. Based on data from Table 8, normal veneer has stable surface roughness (average of 9.44) compared to FH veneer (average of 23.98), which surface is with high various roughness's. Comparing to previous studies, the birch surface roughness along the grain should be 7.77, so the results differ from each other a little bit. [44] With high surface roughness comes a huge problem in gluing veneer layers together. The reason for high surface roughness is presented in paragraph 3.1 where the moisture content was measured. The FH is so moist that after cutting it into veneer sheet it dries so that the cracks and gaps are easy to come. If the material has deep gaps and same amount of adhesive is used as in normal veneer it is obvious, that the layers do not bond together same well as normal. That is why the delamination problem comes in, and using more adhesive with this kind of material does not help, because the better spots from the material gets over penetrated and the gaps are still emptier than the rest of the surface. The only reasonable solution for filling the gaps is to use filler, which eliminates the gaps.

Another possible way to eliminate the problem is to use different drying method, which would dry the material slower so that the gaps and cracks will not occur. Only thing is that drying

differently will not provide the material equal to normal one, so the higher surface roughness will still occur and filler for adhesive is needed.

3.4 Contact angle measurements

Measuring the wetting of the adhesive/substrate boundary surface of the test pieces of veneer was used in selected liquid metering diving resulting meniscus shape. From measuring results adhesion characterizing parameters are calculated.

In this test two different veneers were compared by standard EVS-EN 828:2013. Based on standard three solutions were chosen: water/normal veneer and FH veneer, ethylene glycol/normal veneer and FH veneer and glycerol/normal veneer and FH veneer. Glycerol on normal veener is shown in Figure 22.

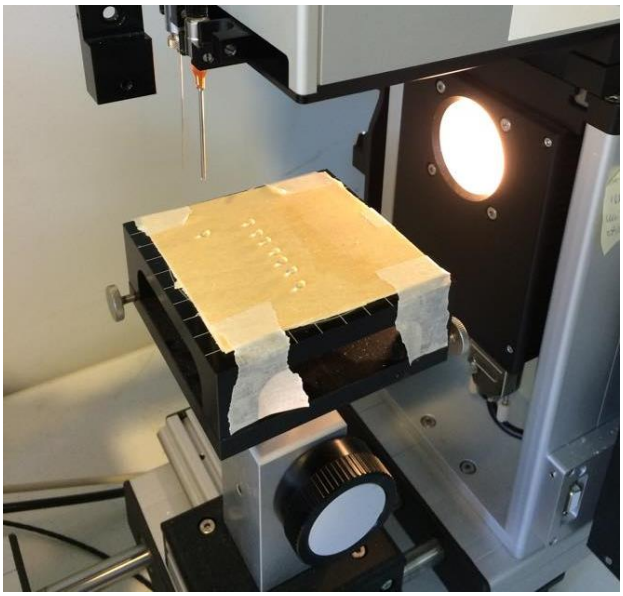

Figure 22. Glycerol drops on normal veneer – (Authors photo 2015)

Ten drops each of three different liquids were dosed onto a plane test piece surface. For each drop, the left and right contact angles were measured by computer. From the average contact angles of each liquid combined with its surface tension and its polar and disperse proportions, the surface free energy of the solid body was calculated, subdivided into the polar and the disperse proportions.

The results are given below in Table 9.

Table 9. Contact angle measurements

	Water on FH	**Water on normal**	**Ethylene glycol on FH**	**Ethylene glycol on normal**	**Glycerol on FH**	**Glycerol on normal**
Average CA	65.5	60.00	41.70	35.10	81.90	96.30
Standard Deviation	181	15.8	5.6	5	8.4	9.9
Cos θ	0.41	0.50	0.75	0.82	0.14	0.11
Surface tension mN/m	72.80	72.80	47.70	47.70	63.40	63.40
Disperse proportion mN/m	21.80	21.80	30.90	30.90	37.00	37.00
Polar proportion mN/m	51.00	51.00	16.80	16.80	26.40	26.40
Work of adhesion, W_{ad}	102.94	109.20	83.47	86.72	72.34	56.49
Surface free energy, γ_{SL}	30.13	36.40	35.77	39.02	8.94	6.91

As shown in Table 9, contact angles measured on two veneers with solution have small differences. Although false heartwood veneers have two out of three measurements larger contact angle than normal veneer. The reason of this is that false heartwood veneer has higher moisture content and due to that the solution permeability is not as good as in normal veneer.

The work of adhesion W_{ad} is the work which must be done to separate two adjacent phases 1 and 2 of a liquid-liquid or liquid-solid phase boundary from one another. Conversely, it is the energy which is released in the process of wetting. As seen from results, better work of adhesion has FH veneer, which means a greater energy needs to be released to the surface in the process of wetting.

Greater surface free energy is also in FH veneer, which means a greater work needs to be done to increase the liquid surface of one unit. The greater surface free energy measured values gives

the information that surface free energy of FH veneer is lower than normal veneers and because of that bond formation with adhesive is not good.

3.5 Tensile strength

From calculations, the false heartwood veneers-average tensile strength is 0.6 N/mm^2. Normal veneers average tensile strength is 0.61 N/mm^2. As the result, the average maximum load of false heartwood veneer was 37.48 N, the extension of maximum load was 1.04 mm. Average widths from break point was 50.02 ± 0.1 mm and thickness 1.3 ± 0.1 mm (varies from 0.49 up to 1.99 mm). Normal veneers average maximum load was 47.69 N, the extension of maximum load was 0.82 mm, average width from crack 50.1 mm and thickness 1.3 mm (varies from 1.45 up to 1.76 mm). Results are presented in Table 10, where lilac presents normal veneer and orange false heartwood veneer. According to previous studies [44], the tensile strength of birch non-densified veneer perpendicular to grain gives result of 0.76-1.98 N/mm^2, it is bigger compared to the results presented in Table 10, but the difference is small so the result is decisive.

Table 10. Tensile strength measurements

Measurings / **Test specimen**	Average thickness, mm	Average width, mm	Average maximum load, N	Tensile strength, N/mm^2
Normal veneer	1.56(0.08)	50.10(0.21)	47.69(8.83)	0.61(0.11)
FH veneer	1.31(0.29)	50.02(0.31)	37.48(12.68)	0.60(0.25)

*StDev is marked in parenthesis

To sum up the Table 10 false heartwood and normal veneer have quite similar average tensile strength results, but to look to the table it is seen, that false heartwood veneer have great variations. Reason of that is the singularity of the false heartwood veneer, it is so different even in a small surface, so the results cannot be taken one on one. In production it is never known which kind of false heartwood veneer will come out. Compared to literature tensile strength of birch is

To compare the lowest and highest results of false heartwood and normal veneer which are 0.41 normal and 0.13 FH (see from Appendix 1) it is obvious that false heartwood veneer cannot be trustful. And the highest results 0.80 (normal) and 1.05 (false heartwood) it seems false heartwood is better, but to look at the variance (0.92) it can only be concluded that it is just exceptional result.

As seen in Table 10, there can be seen one property, which has important role and that is material thickness. Normal veneer average thickness is 1.56 mm but false heartwood veneer has average of 1.31 mm, this brings a presumption that in delamination the essential factor is thickness, which is causing it. So much smaller thickness is caused by the material high moisture content, which after drying do not give the thickness needed. If such material with high variety in thickness is used in inner layers of making the plywood, it will delaminate, because there is so great space between layers interaction. Filler can make this space go smaller, but on the other hand it also lifts the whole material surface.

3.6 Viscosity of adhesive and filler mix

Adhesive and filler mixture viscosity is very important factor when choosing the most suitable blend for plywood production. Due to the fact that the mix have to go through the pipe with pump pressure, the viscosity must be quite similar to the UF viscosity, otherwise it cannot be used with old technology and new one needs to be taken in use.

Chosen fillers were weighted both 5g and 10g and added to 100g of adhesive. After 20 minutes of mechanical stirring the liquids were ready to measure viscosities. Ready stirred mixes are in Figure 23. Brookfield viscometer was used for measuring. Spindle size used was 4CGS, with 10g of wood dust 6CGS spindle was used. Different spindles were used because 10g wood dust had so high viscosity that the viscometer gave no results.

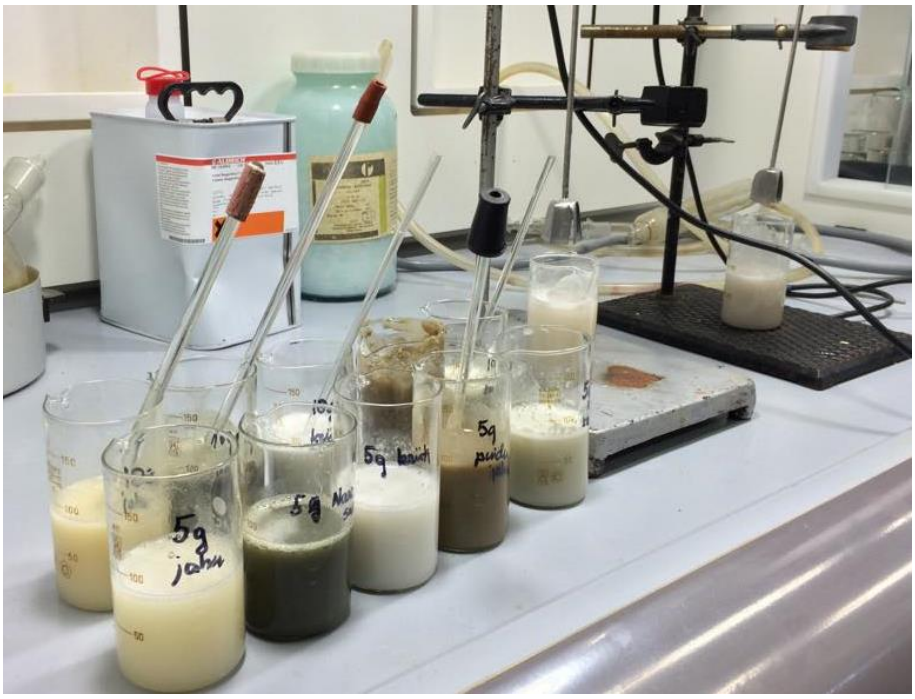

Figure 23. Stirred mixtures - (Authors photo 2015)

Viscometer spindle moved about 2 minutes in the liquid to collect information. Spindle speed was 20 rpm.

Table 11 shows measured viscosities and comparison with the UF viscosity. As it seems, the lowest viscosity only 5mPa*s higher, has 5g of $CaCO_3$ in 100g of UF. 5 g of montmorillonite also gave quite good viscosity. From the results, the highest viscosities had 10g of aerosil, 10g of wheat flour and both 5g and 10g of wood dust. Due to the results first thoughts were that mixes with too high viscosity are out of range and the ones which gave quite similar results to UF viscosity will give good further results in ABES measuring.

Table 11. Measured viscosities

Measurements / Fillers	Viscosity, cP, mPa*s	Standard Deviation	Difference compared to UF
Aerosil 5%	325	5.29	145
Aerosil 10%	650	4.51	470
Montmorillonite 5%	204	3.00	24
Montmorillonite 10%	230	3.06	50
Chalk 5%	185	2.08	5
Chalk 10%	225	2.08	45
Kaolin 5%	220	1.53	40
Kaolin 10%	260	1.64	80
Wheat flour 5%	240	2.52	60
Wheat flour 10%	800	2.08	620
Wood dust 5%	1650	4.73	1470
Wood Dust 10%	11000	4.16	10820
UF	180	3.79	-

3.7 ABES test results

Small specimens were cut with pneumatic cutter into size 25x117 mm and contact surface 5x20 mm, winter wood was used. For one test two pieces of specimens were needed. Over 200 test specimens were cut. For previously mixed adhesive and filler solutions hardener were added and mixed together.

For testing, the ABES machine force for test specimen were set into 1.6 MPa, press into 100°C and testing time to 160 seconds.

Test started with dripping adhesive and filler mix onto one veneer layer corner. The glue drop was divided on the edge of the veneer layer with another veneer layer, so that both of the veneer edge surface were covered with the mix. Then two specimens were placed between ABES machine claws and the hot press claws. After pushing the button, hot press presses the two specimens together in 160 seconds and after that time right claw pulls one veneer layer, so that the bonded surfaces would break either from the wood or from the adhesive. Results are presented in computer.

Purpose of this test was to eliminate filler and adhesive mix, which gives the lowest results. Measured test results are presented in Figure 24.

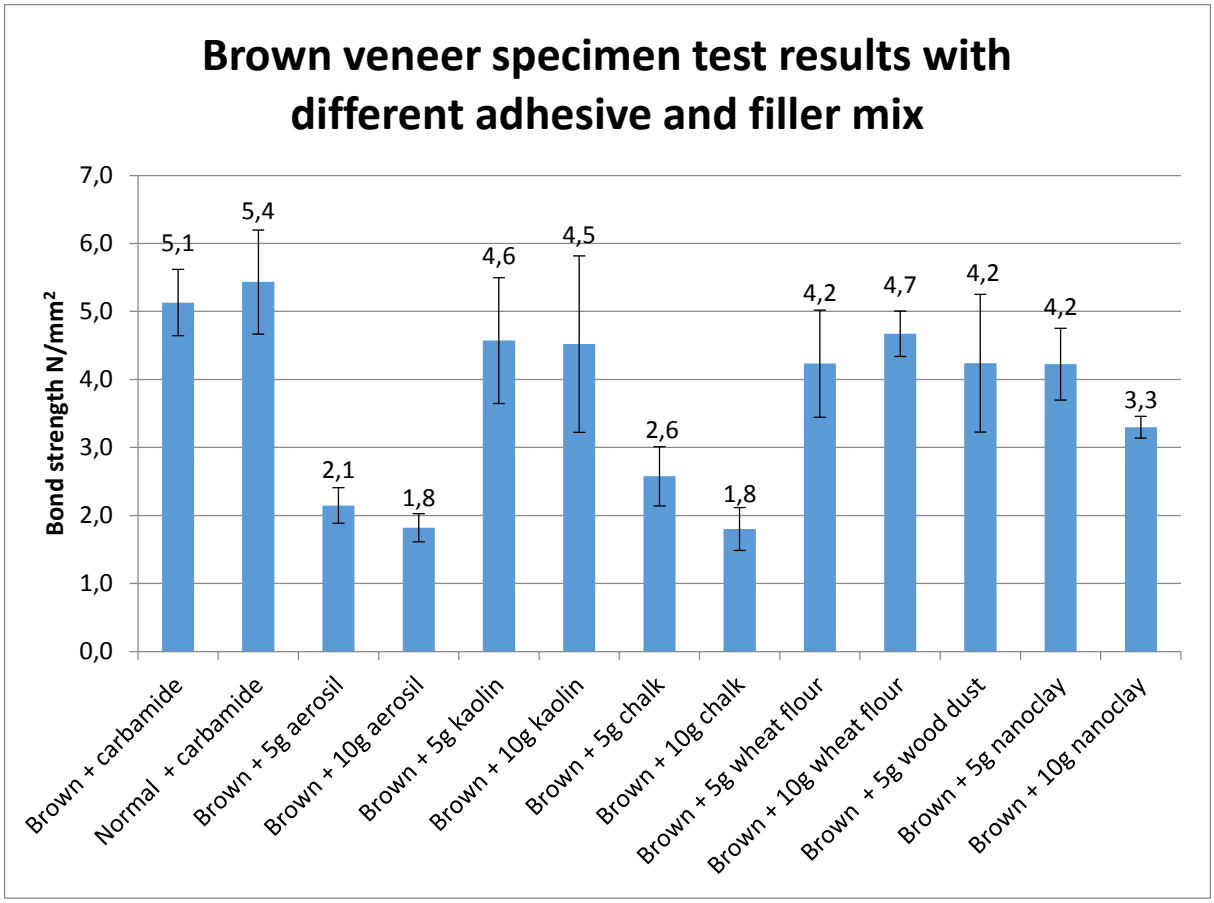

Figure 24. ABES test results

From Figure 24 can be read out that none of the fillers give higher bond strength compared to pure UF with shear strength of 5.4 N/mm^2. Nevertheless, best results were provided by kaolin 4.5 N/mm^2, wheat flour 4.7N/mm^2 and wood dust 4.2 N/mm^2. Nanoclay also gave good results 4.2 N/mm^2, but due to its high price, further testing is not reasonable.

According to previous studies made in Aalto University the results were 4-6 N/mm^2. [45] Comparing the results with data from Figure 24, it is seen, that some of the results are similar, like kaolin, wheat flour, nanclay and wood dust as filler. Others, aerosil and chalk gave negligible results.

From the Figure 24, it seems that 5g of filler gives higher results compared to 10g of filler. It does not go on with wheat flour, because 10g wheat flour additive gives better results than 5g.

In the end of the test, three main fillers were chosen for making the plywood – kaolin, wheat flour and wood dust. Figure 25 shows example of tested specimens.

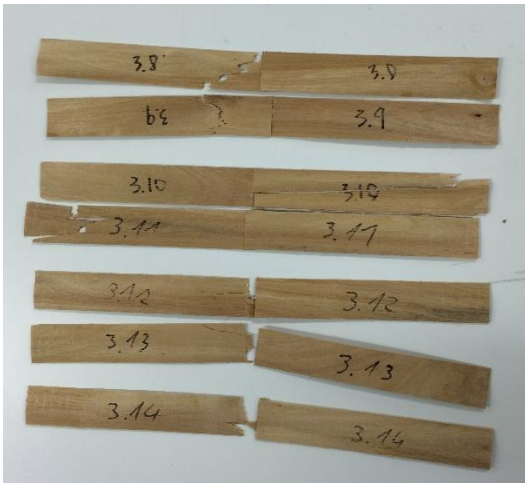

Figure 25. Tested specimens

3.8 Shear strength of adhesive joint

Purpose of this test was to ascertain how strong the adhesive joint between veneer layers is. This way the weak ones can be eliminated and the strong ones may be used in future.

For the comparison normal veneer with UF was taken in count. As it turns out, this joint does not give the best result as may thought before. The strongest result is given by the union of normal veneer with wood dust and the second one is false heartwood veneer with wheat flour.

Table 12. Measured maximum load and shear strength

	Max load mean, N	**Shear strength mean N/mm^2**	**Proportion**
FH + UF	728.33	1.17(0.33)	
Normal + UF	1293.55	2.07(0.50)	0.57
FH + wood dust	593.64	0.95(0.42)	
Normal + wood dust	1926.15	3.08(0.66)	0.31
FH + kaolin	1052.35	1.68(0.53)	
Normal + kaolin	1081.76	1.73(0.55)	0.97
FH + wheat flour	1297.99	2.08(0.67)	
Normal + wheat flour	1189.81	1.90(0.91)	1.02

*StDev is marked in parenthesis

For finding the best filler and adhesive mix the proportion between false heartwood and normal veneer calculation was done (false heartwood veneer result was divided with normal veneer result). Based on Table 12 most homogenous (consisting of parts that are similar to each other or are of the same type) filler and adhesive mix has wheat flour, proportion between them is 1.02. Kaolin as filler gave similar result also with proportion of 0.97. Comparing the results with previous studies the shear strength of birch plywood has been measured of 2.1 N/mm^2, which is higher than average shear strength presented in Table 12. [46] The difference may be due to the filler additive, because comparing studied result with UF results the difference is small (0.03), so the results are considerable.

3.9 Bending strength of the plywood

Purpose of this test was getting results of the best of plywood, where different filler and adhesive mixture was used. Measured and calculated information is represented in Table 13.

Table 13. Measured data and calculations of bending strength

Measurements / **Combination**	**Modulus of elasticity. N/mm^2**	**Maximum Compressive load, N**	**Compressive extension at max compr. load, mm**	**Bending strength, N/mm^2**	**Proportion**
FH + UF	8387.97	787.71	4.67	47.26	
Normal + UF	9584.41	382.87	3.33	22.97	2.06
FH + kaolin	10304.13	832.76	5.48	49.97	
Normal + kaolin	4794.59	638.70	4.65	38.32	1.30
FH + flour	10555.44	617.94	3.98	37.08	
Normal + flour	15096.67	1093.78	4.51	65.63	0.56
FH + wood dust	11594.72	1267.27	7.53	76.04	
Normal + wood dust	9778.19	1215.01	10.42	72.90	1.04

From the Table 13 bending strength is the factor based on which is the best mixture. As shown from the results highest bending strength per mm^2 has false heartwood veneer with wood dust as filler 76.04 N/mm^2. Quite same result 72.90 N/mm^2 is given by normal veneer with same filler as mentioned before. When best shear strength was measured with wheat flour, in bending strength the wood dust is better, it is because wood dust gives the stiffness and stronger adhesive layer.

In previous studies presented bending strength of birch plywood is 78 N/mm^2, comparing the two results, the bending strength in study is higher, but the wood dust results are similar to it. [46] Normal veneer bonded with UF resin weak result was unexpected, but the reasons for that can be many. The pressure temperature was uneven, material was cut from heartwood, so its properties are not comparable to the study results. The great result of wood dust as filler can be caused of the wood dust properties. It has the smallest particle size, which insures the uneven spots filling between FH veneer and adhesive layer.

CONCLUSIONS

The aim of this thesis is birchwood waste minimization by increasing the use of birch false heartwood veneer in glue laminated products production.

In order to achieve the aim of this thesis the following subtasks are proposed. To define and study the chemical, physical and mechanical properties of false heartwood of birch wood. To do chemical, physical and mechanical test of the false heartwood

To improve the adhesion properties of the adhesives the different filler materials should be considered.

In this work birch false heartwood is defined as discoloured material, with similar properties to normal wood, but with difference of strong surface properties variations, like higher contact angle and roughness, which causes problems with lamination.

The studied material properties were density, moisture content, pH, surface roughness and contact angle. For bonding evaluation ABES method was applied. Plywood made of normal and FH veneer sheets were tested according to shear strength and bending strength determination standards. Based on this research the following results are pointed out:

- FH veneer has higher MC, but lower density compared to normal. This means that the material preparation for delamination starts from the raw material – FH veneer is dried in same conditions as normal veneer.
- FH and normal veneers pH range is similar, they are both slightly acidic. pH has no influence on delamination and it does not help to define the material.
- FH surface roughness is 60% bigger than normal veneers, and that is the main reason for the delamination – FH surface has so many cracks and deep spots. Normal veneer has stable surface roughness.
- FH surface contact angle is a bit higher 1.3% than normal veneers and because of that FH veneer has low solution permeability due to its high moisture content – reason for delamination, because adhesive leaves the moist parts of the material.
- FH and normal veneers tensile strength values are same, but FH has greater amount of varieties in thickness, which causes the opened spots between material layers and adhesive – layers delaminate.

- According to ABES test method, best shear strength of adhesive and filler mixture was given by kaolin, wheat flour and wood dust.
- Shear strength of adhesive joint gave the best results with wheat flour, which result was better 18.6% compared to pure UF used in plywood. Wheat flour makes the adhesive mixture stickier and raises the viscosity, which guarantees the stronger adhesive joint.
- Bending strength of the plywood gave the best results with wood dust, which gave the extra strength between layers.

For using FH material in future for plywood production, definitely wood dust or wheat flour needs to be used as adhesive filler to avoid the delamination between veneer layers.

The results of this research work are applicable for plywood manufacturers to use birch heart wood veneer in production of different products, which reduces the amount of wood waste.

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ABSTRACT

Purpose of this research work was to define birch false heartwood physical and mechanical properties and find a proper filler material for urea formaldehyde adhesive to eliminate the delamination problem in plywood production.

False heartwood phenomena is called discolouration at the first phase of decay/rot and later on the hard rot. In the hard rot phase the mechanical properties of wood have not been affected too much and such wood can be accepted. Basically all birch trees get discoloured heart sooner or later.

The differences between birch normal and false heartwood properties were studied by density, moisture content, pH, surface roughness and surface contact angle measurements. Fillers used for testing was wood dust, wheat flour, kaolin, aerosil, nanoclay and calcium carbonate. The mechanical properties of the false heartwood veneer and plywood were studied by ABES method and shear strength and bending strength according to standards EN-314 and EN-310, respectively.

As a result false heartwood has lower physical and mechanical properties compared to normal – its surface contact angle is higher than for normal veneers and due to that veneer layers could delaminate. Another result of glued joint shear test demonstrated that urea-formaldehyde resin filler materials wood dust and wheat flour gave the best mechanical strength test results for using them in the plywood production.

The aim of the thesis was achieved and solution for improving the adhesive joint between birch false heartwood veneers was proposed.

Keywords: Birch false heartwood, adhesive joint, fillers, plywood

RESÜMEE

Eestis toodetakse vineeri kasepuidust, kuid märkimisväärne osa kases tüvepuidust võib olla pruunika värvusega väärlülipuit ning selle omadused on ebaselged. Tarmeko LPD ja UPM Kymmene Otepää Ltd esindajate andmete kohaselt on sisaldab umbes 10% kasepuidust väärlülipuitu. [1] Siiani on väärlülipuiduga kaske kasutatud energia tootmiseks ning vähesel määral ka vineeri tootmiseks. Väärlülipuiduga kase osa on tunduvalt niiskem kui värvusemuutusteta kasepuit, samuti on selle pinnakihis palju ebatasasusi, ehk materjal on väga ebaühtlase pinnakaredusega.

Selle magistritöö eesmärkideks oli kase väärlülipuidu mehaaniliste ja keemiliste omaduste välja selgitamine. Väärlülipuiduga kasespooni liimliite parendamine sobiva täiteaine lisamisega karbamiidliimi, mis lahendaks vineeri kihtide vahelise delamineerumise probleemi ning sellega väheneksid puidu tootmisjääkide tekkekogused. Eesmärgi täitmiseks uuriti nii kase väärlülipuidu kui ka tavalise värvusmuutusteta kase spooni omadusi. Liimaine omaduste parendamiseks uuriti täiteainete (puidu tolmu, nisu jahu, nanosavi, aerosiili, kriiti ja kaoliini) mõju väärlülipuiduga kasespooni liimliite nihketugevusele.

Materjali omaduste kirjeldamiseks viidi läbi katsetamised, mille hulka kuulusid tiheduse, niiskussisalduse, pH, pinnakareduse, pinna kontaktnurga mõõtmine ning spooni tõmbetugevuse testimine. Nende mõõtmiste jaoks kasutati Metler Toledo pH mõõtmisseadet, pinnakareduse mõõtmiseks Mahr Perthometer Concept profiilomeetrit, kontaktnurga mõõtmiseks OCA 20 seadet ning spooni tõmbetugevuseks Instron 5866 seadet. Liimi ja täiteainete viskoossus mõõdeti Brookfield viskosimeetriga, ning liimliite tugevuse mõõtmiseks kasutati ABES meetodit. Värvusmuutuseta ja väärlülipuidust vineeri katsetati Instron 5866 seadmega, milles mõõdeti nii nihke- kui paindetugevust vastavalt standarditele EN-314 ja EN-310.

Töö tulemusena iseloomustatakse väärlülipuitu kui värvi muutnud puitmaterjali, millel on sarnased omadused värvi muutuseta kasepuiduga, kuid pinnaomaduste suurte erinevustega, nagu suurem pinn kontakt nurk ja karedus mis võivad põhjustada probleeme delamineerumisega.

Katsete tulemusena selgus, et parimaid nihketugevuse tulemusi andis täiteaine ja liimi segudest puidu tolm ning nisu jahu. Mõlema täiteaine kaustamine on tehnologiliselt lihtne, mõlemad täiteained on kergesti kättesaadavad ning hinnalt soodsad.

Töö kokkuvõtteks võib öelda, et eesmärgid said täiedetud ning uurimustöö oli väga edukas. Kindlasti saab antud töö tulemusi kasutada kase väärlülipuidust vineeri tootmise protsessis.

APPENDIX 1

Nr	Width, mm	Thickness, mm	Max load, N	Tensile strength, N/mm^2	Width, mm	Thickness, mm	Max load, N	Tensile strength, N/mm^2
1	50.17	1.53	53.42	0.69	50.32	1.32	38.07	0.57
2	50.11	1.42	50.38	0.70	50.06	1.42	21.38	0.30
3	50.51	1.61	61.03	0.75	50.00	1.48	20.91	0.28
4	50.03	1.45	32.80	0.45	49.97	1.31	39.88	0.60
5	49.97	1.60	46.95	0.58	50.16	1.35	44.35	0.65
6	50.11	1.53	48.98	0.63	50.40	1.40	60.40	0.85
7	50.21	1.49	58.89	0.78	49.21	1.23	48.03	0.79
8	50.20	1.51	60.32	0.79	50.11	1.02	41.23	0.80
9	50.15	1.61	65.38	0.80	50.14	0.87	42.46	0.97
10	50.05	1.63	40.36	0.49	50.15	1.55	37.45	0.48
11	50.03	1.50	55.11	0.73	50.15	1.47	26.86	0.36
12	50.13	1.47	26.15	0.35	50.20	1.60	38.72	0.48
13	50.26	1.45	41.89	0.57	50.21	1.46	46.54	0.63
14	50.21	1.48	48.80	0.65	50.20	1.61	24.56	0.30
15	49.90	1.50	49.66	0.66	49.47	0.99	24.57	0.50
16	50.03	1.65	41.14	0.49	50.19	1.24	43.48	0.69
17	50.18	1.55	48.56	0.62	49.84	1.99	34.21	0.34
18	50.20	1.50	59.99	0.79	49.99	1.35	16.73	0.24
19	50.40	1.54	50.59	0.65	50.25	1.44	61.01	0.84
20	49.80	1.51	42.29	0.56	49.96	1.37	45.00	0.65
21	50.17	1.56	45.46	0.58	50.23	1.33	61.49	0.92
22	49.91	1.57	34.50	0.44	49.96	1.07	53.44	0.99
23	50.04	1.60	50.94	0.63	50.23	1.26	45.45	0.71
24	50.18	1.66	61.20	0.73	50.11	1.49	37.92	0.50
25	50.05	1.67	55.71	0.66	50.08	1.61	44.92	0.55
26	50.27	1.48	37.75	0.50	49.95	1.54	24.28	0.31
27	50.22	1.60	46.67	0.58	50.23	1.16	30.05	0.51
28	50.24	1.53	44.39	0.57	50.11	1.16	43.13	0.74
29	50.18	1.61	51.37	0.63	50.08	1.25	50.28	0.80
30	50.08	1.62	33.05	0.40	48.72	1.22	51.66	0.86
31	50.37	1.56	41.01	0.52	50.17	1.67	11.14	0.13
32	50.03	1.76	40.99	0.46	50.20	0.49	21.54	0.87
33	50.32	1.61	43.85	0.54	49.80	1.56	34.36	0.44
34	50.09	1.56	43.07	0.55	50.35	0.79	41.96	1.05
35	50.12	1.76	39.08	0.44	50.26	1.51	27.85	0.36
36	50.11	1.61	52.74	0.65	50.07	0.99	27.05	0.54

37	49.10	1.53	55.95	0.74	50.20	1.65	24.20	0.29
38	50.25	1.59	44.13	0.55	50.24	0.92	39.18	0.84
39	50.26	1.56	53.10	0.67	50.23	0.91	39.67	0.86
40	50.21	1.52	54.95	0.72	50.09	1.49	16.02	0.21
StDev	0.21	0.07	8.83	0.11	0.30	0.28	12.68	0.24
AVG	**50.12**	**1.56**	**47.82**	**0.61**	**50.06**	**1.31**	**37.04**	**0.60**