TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Department of Engineering

OPTIMAL PRESSING PARAMETERS FOR SCARF-JOINTED VENEER

PIKI-JÄTKATUD SPOONI OPTIMAALSED PRESSIMISPARAMEETRID

MASTER THESIS

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AUTHOR'S DECLARATION

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

25 May 2018

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Thesis is in accordance with terms and requirements

25 May 2018

Supervisor: ….........................

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THESIS TASK

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1. Develop optimal pressing parameters for scarf jointing veneer.
2. Study the impact of pressing parameters to the joint.

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INTRODUCTION

Wood is one of the oldest renewable resource. Wood itself is a rather easily processed material, but to an extent, due to the irregularity of its structure and characteristics, which cause longstanding source of problems. To overcome this problem, wood logs can be peeled in order to produce veneer sheets.

Veneer sheets alone do not have good mechanical properties. One way to improve these mechanical properties is to combine several sheets of veneer with the use of adhesives, thus producing a layered element, which has enhanced properties when compared to plain veneer sheets. Plywood consists of veneer sheets laid upon each other, which are coated with different adhesives and finally pressed in a hot-press, which uses certain pressures and temperatures to combine the veneer sheets into plywood.

In order to produce larger scale plywood, scarf-jointing technology is used. It is based on joining two veneer sheets end-to-end with an angular cut on both sides and adhesive inbetween the cuts. This allows to produce plywood panels up to twice of size. Tarmeko Spoon AS uses this scarf-jointing technology, resulting in a larger piece of veneer, thus a possibility to produce larger plywood panels. The problem with scarf-jointing begins with the hot pressing parameters causing delamination. This delamination is caused by the adhesive bond inbetween the joint. This adhesive bond and its strength is influenced by the hot pressing parameters, such as pressing temperature, time and adhesive amount inbetween the scarf-joint.

This project is presented by Tarmeko Spoon AS, which produces plywood products. This company uses experienced technology to produce furniture, accessories and both plywood and veneer.

The goal of this thesis is to determine the impact of pressing parameters used for scarf-jointing veneer sheets and to find the optimal pressing parameters for scarf-jointing veneer in order to reduce delamination. The mechanical properties achieved by with different pressing parameters will be studied.

1 LITERATURE REVIEW

1.1 History of Tarmeko Spoon AS

Tarmeko Group is located in Tartu and its specialization is mainly furniture production and wood processing. The cartel “Wood” was founded in 1947 and lasted for 9 years. This cartel was the basis for the development of a furniture factory. In 1969, the furniture factory in Tartu was established. This furniture factory was the developing factor of igneous traditions and skills of woodworking [1].

The late 1980s were the merge of Tartu furniture factury and the Forest Plant were united, thus Tarmeko was created. After some years, the name of the company became RAS Tarmeko. The year 1992 resulted in the privatization of the company [1].

In 2005, the departments of Tarmeko were declared independent. 5 different divisions were established: Tarmeko Metal OÜ, AS Tarmeko Spoon, Tarmeko Pehmemööbel OÜ, Tarmeko LPD OÜ and Tarmeko KV OÜ.

Tarmeko Metal OÜ is one of the largest designer, installer and launcher of different types of fully automated colour and hauling lines in the local market. Tarmeko Spoon AS is the producer of rotary veneer and the seller and producer of plywood. Tarmeko Pehmemööbel OÜ is the producer of special orders, as well as designer products in the upholstered furniture portfolio. Tarmeko LPD OÜ specializes in the production of glued and bent plywood details and finished furniture. Tarmeko KV OÜ is the subunit of Tarmeko that is dealing with the development of real estate. All Tarmeko Group factories belong to Tarmeko KV OÜ [1].

Nowadays, Tarmeko Spoon AS is a fraction of Tarmeko Group, which is managed by Tarmeko KV OÜ and owned by Nerapil OÜ [1].

1.2 Plywood and veneer production technology

Plywood is an excellent material, which is nowadays used in a wide range of applications, which include construction, furniture, packages, fencing, etc. The demand of plywood nowadays has grown significantly due to so numerous application possibilities.

Over the years the cost of logs has increased, thus the producing cost of veneer has also increased. One of the main problems comes from the compression of the veneers in the hot press. This hot pressing process causes densification of the veneers which leads to a loss of wood volume, which means less final product.

1.3 Plywood manufacture preparation process

The manufacturing of plywood consists of seven main steps: log debarking and cutting to length, log soaking in hot water, veneer peeling, drying, hot pressing and sawing and sanding.

1.3.1 Debarking and cutting to length

The first step of plywood manufacturing is the cutting to length and debarking. Felled trees are bucked in the forest. Felled trees have different parts, some are meant for lumber, others for pulp and plywood industries. Each category has its own specification, such as length, number of defects and the diameter [2]. The logs are cut to length in the factory.

Debarking is the process in which the major amount of bark on the log is removed, in order to produce proper unit for the peeling process. This process has an excess of wood bark and wood waste. After bucking and debarking, the logs are transported to soaking baths.

1.3.2 Soaking and heating of logs

The second step of plywood manufacturing usually is the heating of the log, which is done by soaking the logs in water at elevated temperatures, which helps the log to soften and thus the peeling process of the log is smoother. Softer logs help to minimise the knife checks. Having less knife checks in the veneer sheet leads to a lesser required adhesive coating. The soaking process also affects the colour of wood. Also, the chemistry of the of the wood is affected, leading to a discoloration among veneer sheets.

The softening of wood logs is caused by the glass transition temperature (T_g) exceeding of wood polymers [3]. At lower temperatures, the T_g of the wood components is rather high. At the dry state, the isolated cellulose owns a T_g around 230-250℃, hemicellulose has a T_g around 150-200℃ and lignin has the T_g of 130-200℃ [3] [4]. The availability of moisture in the wood structure substantially lowers these temperatures, the softening of lignin begins around 77-128℃ and the softening of hemicellulose around 54-56℃ [3] [4]. The information obtained by the isolated components of the wood give an indication about how the wood behaves at elevated temperatures.

Both the moisture content and the temperature have an impact on the mechanical properties of wood [5] [6] [7]. In general, when the temperature and the moisture content are elevated, the mechanical properties of the wood will decrease.

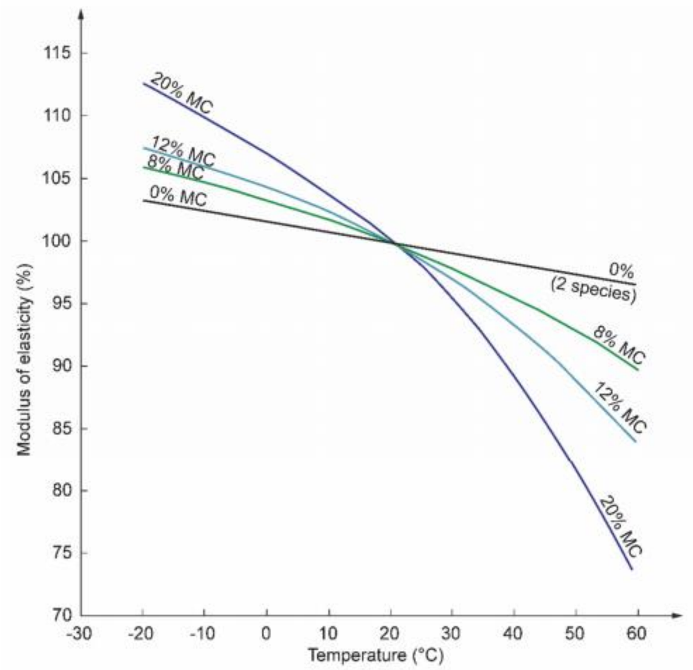

Figure 1. The effects of temperature and moisture content on the modulus of elasticity of wood [5].

A freshly felled Birch tree has moisture content around 71-80%, depending on the felling season [8] [9] [10]. It has been noted, that silver birch does not form heartwood, thus leading to a more uniform moisture content throughout the tree [11]. This information confirms, that the moisture content of birch logs will be more then the fibre saturation point (FSP) during the preheating and the soaking process, also during the peeling. Adding moisture content to the wood is important in the case of the wood log having moisture content under the FSP. If the log has moisture content over the FSP, the mechanical properties should not be affected [12].

It is important to take into account the heating medium of the wood logs, in order to select an optimal heating system. It is noted that the heating of logs in water is 5-10% slower than that of heating with steam, but overall, heating in water gives a more uniform temperature throughout the log [13]. It is notable that heating along the grain is around 2-2,5 times faster than across the grain [14]. Overall, most of the logs are compared to their cross sections, thus leading to heating across the grain being the controlling factor of the heating process.

The temperature of log heating is dependant on the wood species and many other factors, thus it is impossible to suggest an optimal temperature for wood of a certain species. A lot of heating systems involve saving time, heat capacity or cost [15]. Fortunately, positive cutting results can be achieved over a wide range of temperatures. Lower density wood species (less than 400 kg m^{-3}) can be cut at ambient temperatures near 35-40°C, medium density wood species (around 460-550 kg m^{-3}) at around 60-70°C and dense wood (600 kg m^{-3} and higher) at around 90°C. The soaking time is usually 24 hours. When the logs are removed from the soaking, the outer layers of the log begins to cool down, but the inner layers of the log still increase in temperature [16]. At the peeling process, the inner and outer layers of the wood log should have a similar temperature.

1.3.3 Veneer peeling

Although, the soaking and heating of the log affect the mechanical properties of the wood and allow it ot be more smoothly cut, the peeling process is an important factor in forming the veneer surface and its properties. The surface of the peeled veneer depends on 2 major factors: cutting speed and peeling settings. The peeling settings are highly important in the veneer manufacturing and differ for different wood species [16]. The cutting speed of the veneer does not show any major effects on the veneer quality at the speeds around 50-150 m/min^{-1} [13].

The peeling process affects the surface physical properties and the final quality of the veneer [17]. Two of the most important factors are the lathe checks and the roughness of the veneer. The development of lathe checks in the veneer peeling process is caused by the stress created by the bending of the veneer over the cutting knife [16]. There are two sides to veneer peeling: the loose side, in which the check initiate, and the tight side, which is opposite to the loose side.

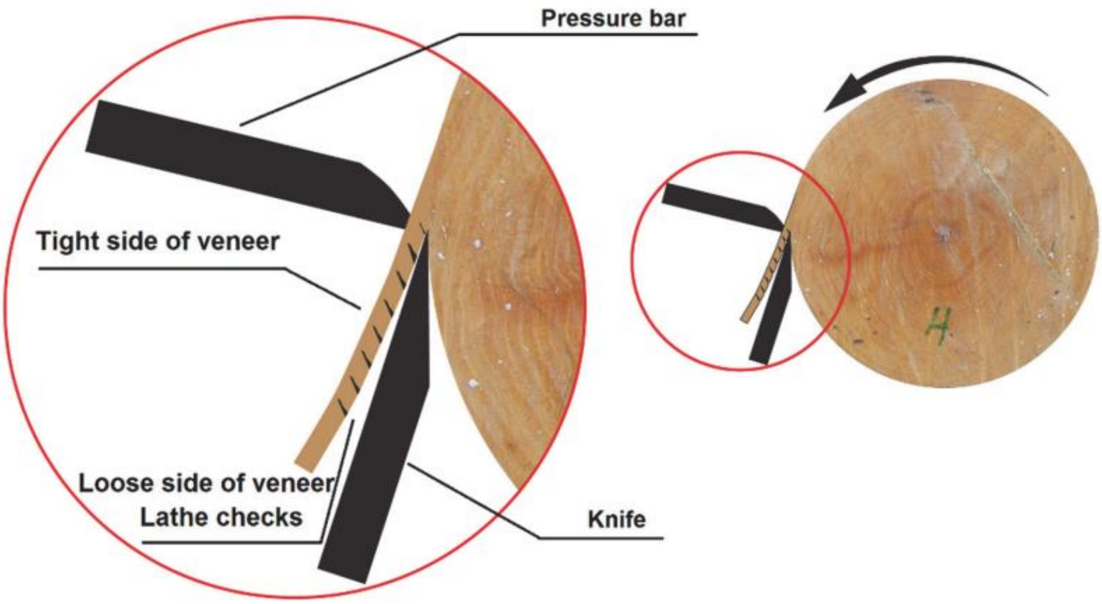

Figure 2. Lathe checks forming at veneer peeling [23].

The roughness of the veneer surface is dependant on the sharpness of the knife. The depth and frequency of the lathe checks is dependant on the compression rate [18]. The properties of lathe checks, the frequency and the depth, have a relation – deeper checks are less frequent and shallower checks are more frequent [19] [20] [21]. Higher temperatures show a lower number of deeper checks development [22]. This is beneficial due to shallower checks being less detrimental to the final strength properties perpendicular to the grain of the veneer sheet [15].

1.3.4 Veneer drying

Veneer drying is a process, which dries the peeled veneer sheets in a continuous dryer. The purpose of this process is to reduce the initial moisture content (25-100%) down to 3-5%. This process produces veneer sheets, which are ready for hot pressing. It has been noted that impregnating the veneer sheets, that are used in making plywood, with different salts before the pressing process, the compression strength of the treated veneer sheets is improved and due to this improvement, the loss in compression under any pressing conditions is reduced. Impregnating wood with aqueous solutions increases the compression resistance of the veneer [24].

The drying of veneer and the effects of it on the surface properties has been studied well. In order to achieve better adhesive bond formation, it is important to avoid any kind of over-drying. The effects of over-drying is the inactivation of the surface of the veneer sheet, thus reducing the quality of the adhesive bond [25].

Birch plywood industries usually dry the veneer sheets at around 160-180°C for 3 to 4 minutes. The final moisture content of the veneer sheets with these conditions will be around 3-8%.

1.3.5 Hot pressing of plywood

Hot pressing stage consists of a few steps. The first step is the application of adhesives onto the veneer sheets, which is followed by the stacking. Depending on the final application of the plywood, the veneer sheets will be stacked ontop of eachother in 2 different ways. The plies are generally assembled so the grain of one ply is at right angles to the grain of the next layer. For producing larger scale plywood panels, scarf-jointed veneer is used in the middle layers as the lengthwise layer. An odd number of plies are almost always used [24]. The conventional plywood is laid up, so the veneer sheet grain orientation is rotated after each layer. After the stacking procedure, the veneer sheets go under a cold press, which uses different pressures, temperatures and pressing times in order to produce plywood. Cold pressing helps the phenol formaldehyde to absorb in the veneer sheets and the plywood panel is pressed to a suitable thickness to ease the process of plywood panel loading and unloading. These parameters depend on the wood species, as well as the final application of the plywood. Hot pressing is carried out under temperatures higher than 100°C, urea adhesives around 100°C and phenol adhesives around 130°C, so this process also reduces the moisture content of the product.

The adhesive bond inbetween plywood veneer layers is a very complicated phenomen, which involves a lot of different factors, which influence the bond formations and its performance. Controlling the bonding is a rather complicated challenge, due to the materialds heterogeneity and the various process parameters. Marra (1992) proposed an idea, that if all the parameters, which affect the bond quality, were taken into account, the theoretical strength of the adhesive bond would be around 483 MPa. In reality, this number is too big, thus has not been achieved so far [26].

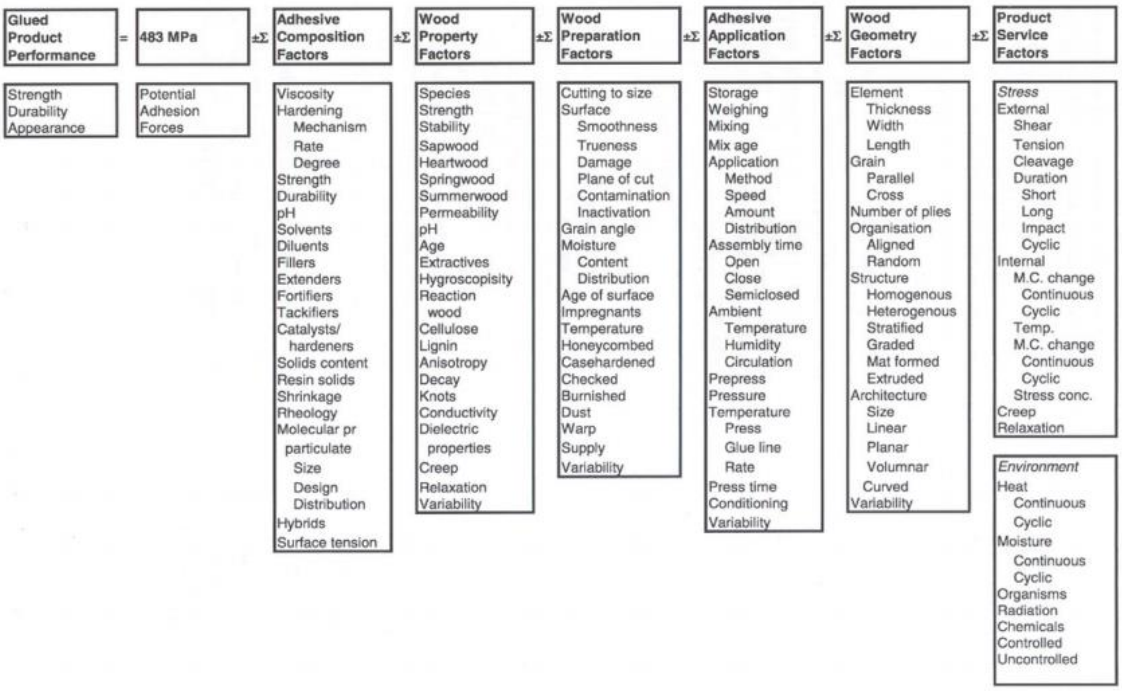

Figure 3. Factors affecting the wood-adhesive bond performance [26].

In order to ensure the best bond quality of adhesives, the adsorption of veneer sheets was investigated [27]. Baldan proposed an idea, that the physical adsorption can be investigated by the measurements of the contact angle. Adhesive, in plywood industries, is usually applied to the surface of the veneer sheets as a liquid. The contact angle θ between the adhesive and the surface in the equilibrium state relates to the surface energies introduces by Young's equation [23].

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \times \cos\theta \text{ , [23]}$$

Where γ_{sv} is the interfacial energy between the solid-vapour; γ_{lv} is the liquid-vapour interfacial energy; γ_{sl} is the interfacial energy between the solid and the liquid drop and θ is the wetting or contact angle between the solid-liquid interface [23].

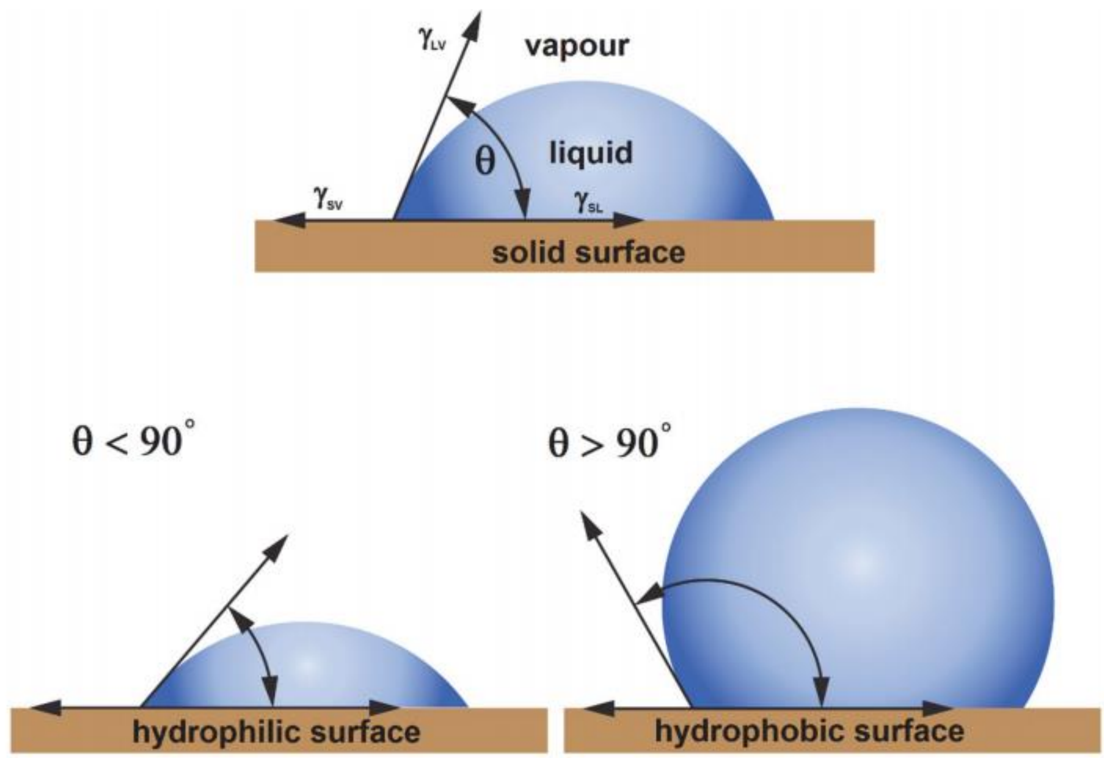

Figure 4. Contact angle measurements [23].

The contact angle measurements depend on the surface roughness and chemical compostion. Due to this, the determination of the contact angle on wood's surface is unclear and this leads to the application of Young's equation, when calculating the surface energy, being conjectural. Despite this uncertainty, the contact angle is still measured on wood in order to calculate the surface energy, which is associated with the formation of the adhesive bonds [28] [29].

Surface roughnening of veneer sheets is one way to improve the bonding quality of adhesives [30]. Petrie introduces the idea of enhanced adhesion on roughened surfaces may be caused by mechanical interlocking, cleaner surface formation, highly reactive surface formation or increase of the contact surface area [31].

Different adhesives usually form stronger bonds to porous surfaces rather than smooth ones [32]. The roughness of the surface of wood has been used as a prediction parameter for bond quality and formation. Surfaces that have a high roughness tend to be detrimental, denying the intimate contact of adhesive on the woods surface [26]. Surfaces with higher roughness show a decrease in adhesive bond strength. Surface roughness increase is also related to the elevated temperatures at soaking and peeling, although there are studies that show the decrease of surface roughness at higher temperatures [33]. These reverse ideas are explained by the different measurement techniques or the different roughness magnitudes measurements.

Measurements of the surface roughness do not consider the lathe checks that are developed on the veneer sheet during peeling stage. Lathe checks are different, they have various angles in the veneer sheets. The surface roughness measurements cannot be measured by with the traditional evaluation methods. So far, there have not been any surface roughness measurements that take into account the lathe checks in the adhesive bonding.

1.3.6 Trimming, cutting to size and sanding of plywood

The final procedure of plywood manufacturing composes of three steps: trimming, sawing and sanding.

After the plywood panels are removed from the hot press, they are trimmed. Trimming helps to obtain smoother edges to the plywood panel. This process also gives the rough dimensions of the plywood panel, from which the final products can be sawed out.

During the sawing process, the trimmed plywood panel is sawn into desired dimensions, depending on the order. The typical plywood panel produced in Tarmeko Spoon AS has the dimensions of 1525×1525 mm.

The final treatment of the plywood panels is also dependant on the order. Plywood panels, which were hot pressed using urea formaldehyde is usually not treated. Phenol formaldehyde plywood panels are mainly film faced. Plywood can have a typical sanded treatment, as well as many laminates in order to give the plywood a better look. It is also notable, that a huge part of plywood is ordered without any final treatments, which means no laminates or sanding.

After the final alterations of the plywood panel are done, the panels are stacked, wrapped, packed and sent to the customers.

1.4 Deformations of plywood due to hot pressing

Deformations of final plywood panels has been an issue for some time. These deformations occur due to different pressing parameters and also different veneer properties.

The deformations of the plywood are a problem due to development of lower thickness of the panels, thus lower mechanical properties of the product.

1.4.1 Deformations due to varying pressing parameters

The main deformation is the loss of thickness, which occurs when gluing sheets of veneer into a plywood panel, the sum of the thickness of veneers should make up the total thickness of the plywood board after gluing. The “rule of thumb” for many years has been that hot pressing usually leads up to a 5% compression loss. This means that thickness loss of the veneer board can vary greatly. These type of compression losses are affected by several variables: veneer species, drying method of the veneer, moisture content of wood, temperature and pressure during pressing. Species of similar density tend to have similar compression losses. Drying the veneers leads to a higher compression loss, which, on the other hand, can be offset by using lower compression pressure during hot pressing. Also, it is notable that higher moisture content of wood leads to a higher compression loss. One of the main factors, which can help during the hot pressing process is lowering the press’ temperature and/or pressure, but that leads to a production loss due to longer pressing time, because it is needed to insure the adhesive cure [34].

Hot pressing 7 sheets of veneer together, whilst using urea formaldehyde, proposes a problematic finding. Veneer sheets, with the thickness of 1,5 mm each, are coated with this adhesive and then put under a hot press. The theoretical result refers to the plywood having 7 times the veneer thickness, that is 10,5 mm. The practical outcome of this process has a result scaling from 9,5-10,2 mm. This is mainly affected by the pressing pressure, moisture content of veneer and the amount of adhesive used.

When a visco-elastic substance, wood, is subjected to a higher pressure, both elastic and viscous deformations may occur. The elastic properties of wood come from the highly crystallized cellulose. The viscous properties are associated with the amorphous lignin. There are much more components in the wood, which occur in smaller quantities, thus the effect on the visco-elastic properties of wood is not as great, but this also depends on the type of wood [35].

The hot pressing method, in which a certain pressure and temperature is applied to the veneer sheets over a certain interval of time in order to make a veneer board, leads to visco-elastic deformations, which is equal to the sum of the instantaneous elastic deformation, the delayed elastic deformation and the permanent viscous deformation [35]. After applying pressure and a certain temperature to wood at an increased humidity, there occurs an increase of viscous deformation of the deformation. This is a reason why permanent viscous deformations occur during hot pressing, which leads to a non-recoverable loss of thickness of the veneer board.

1.4.2 Deformation due to different veneer sheet properties

The hot pressing of veneer sheets together under a certain pressure and temperature leads to a volume loss which can be termed to be caused by densification of wood. This densification of wood leads to a lower percentage of final product, which nowadays is becoming more and more of a problem due to the high cost of veneer.

Currier noticed a compression loss variation of 5-10% under 175 psi pressure, which depended on the density of the test samples [36]. The volume losses could have been also halved while using reduced pressures at the pressing cycles. Another notable fact was, that the compression also tended to lessen as the wood panels absorbed moisture from the air.

Patent US2068759 A suggests that using veneer sheets with moisture content higher than 4% leads to steam explosions and surface cracks, which are usually undesirable results. Also, having the moisture content higher than 4% requires a longer pressing time in order to permit the excessive moisture to form steam and escape through the edges of the veneer. The ideal way to manufacture plywood is to dry the veneer to a moisture content between 2-3% and not over 4%, using the veneer right after it has been removed from the drier, which means the sheets cannot absorb moisture from the surrounding environment, thus leading to a lower chance of steam explosions and surface cracks [37].

Using veneer sheets with higher than 4% moisture content does not only have a tendency for surface cracks and steam explosions. The higher percentage of moisture content also refers to the cell walls of wood being more collapsible, therefore having the higher variations of thickness losses after the hot pressing method is used. This leads to a small conclusion, which states that using lower moisture content of veneer sheets means less pressing time which ensures more uniform thickness throughout the plywood [37].

Both moisture content and temperature have a big impact on the mechanical properties of wood. These effects must be taken into consideration in the structural use of wood. The main effects that change due to the different moisture contents of wood are mechanical properties, including modulus of elasticity (both parallel and perpendicular to the grain), shear modulus, bending strength, tensile strength, compressive strength.

If we take a wood sample (clear wood) which has been in an environment, which gives it a 12% moisture content and if we change that moisture content, increase or decrease, the mechanical properties tend to change [38].

The increase in moisture content reduces all the properties previously named. For example, a relative change in properties from 12% to 20% moisture content wood has a 20% decrease in shear modulus and a 25% decrease in bending strength [38].

Taking the same sample (12% moisture content) and conditioning it from 12% moisture content to 6% moisture content, all the previously named properties increase, most importantly the bending strength increases 30% and the shear modulus increases 20% [38].

1.4.3 Effects of deformations

The decrease of the veneer board volume is caused by woods plastic deformation, which is affected by the pressure, temperature, moisture content of wood, etc. The decrease of the volume of the veneer board is an undesirable result. There are some cases where the decrease of the volume can be beneficial, i.e. if the objective is to increase the mechanical strength of the veneer board. The main mechanical properties of wood are bending strength, tensile strength, shear strength of the adhesive connection and rigidity. One of the main goals while manufacturing plywood is acquiring high and constant strength properties in all directions of the product. This can be achieved by increasing the number of plies [38].

The tensile strength of the plywood is proportional to the longitudinal fibers of the same direction as the tension. One of the main quality indicators of plywood is the strength equality factor. The uniform tensile strength, in both length and width, can be achieved when the thickness of both longitudinal and transverse fibers are in equal amounts [38].

Aircraft plywood is one of the examples of high-strength plywood, which is usually made from mahogany (*Swietenia genus)* and birch (*Betula Pendula*). This plywood uses adhesives which have an increased resistance to both humidity and heat [38].

The actual amount of the volume loss is affected by 4 certain conditions, which are: moisture content of wood, specific gravity of wood, the temperature and pressing pressure. The volume loss usually varies from 5-15%, thus introducing a problem of economical importance. Using a certain pressure at pressing is difficult, due to the wood changing its dimensions under pressure, so the pressure applied needs to be monitored and manually or mechanically controlled [38].

1.5 High temperature hot pressing

Hot pressing temperature has an important impact on the final product and its quality. Temperatures above 200°C lead to a much shorter curing time of adhesives and thus lead to a higher productivity of products. One important factor is the energy consumption, which is visibly higher than that of lower temperature hot pressing [39].

One other disadvantage of higher pressing temperature in combination with higher moisture contents of veneer sheets leads to excessive penetration of adhesive into the veneer, thus leading to a higher compression coefficient of plywood product. This excessive adhesive penetration is also called „hungry gluing“ (partial unstable bond), which decrease the bonding strength [39].

Another problem with high temperature hot pressing happens within the glueline. The gas-vapour mixture, which develops in the glue line, is higher with increasing the temperature. This leads to bubbles being formed within the glueline. Higher pressing pressures can increase the number of these bubbles up to 10% at around 118-120°C and reduce at temperatures of 110-115°C, thus lowering the number of defects in the final product [39].

Using temperatures too high at the hot pressing process might give faster curing time for the adhesive, but there is a drawback – if the pressing is done under too high temperatures, the adhesive will dissolve, leading to poor properties. There may occur some defects, reduction of hardness and thus the strenght of the product itself. Using the right temperature ensures the uniform required properties. Hot pressing process is dependant on the species of wood, that is used to produce veneer sheets, the specific wood characteristics determine the appropriate hot press temperature range [39].

Using reasonable temperatures at hot pressing leads to the ability to control the evaporation of different volatile elements. Also, right temperatures help the plywood keep its moisture content in the required range, around 8 to 12 %, this also prevents excessive bubbles forming in the glueline [39]. Using the reasonable temperature at hot pressing also increases the plasticity of wood, leading to denser products.

1.6 Scarf-jointing of veneer sheets

Scarf-jointing is a procedure, which is meant for manufacturing longer gheets. This process includes gluing veneer sheets upon each other in their grain direction and thus leading to an elongated sheet. The ends of the veneer sheets are cut so, that there will be enough room for the adhesive bond, so the sheets stick together, leaving behind a uniform thickness veneer sheet [40].

Wood, over the course of time, has been an important construction material due to its light weight and strength characteristics. The limiting factor of wood manufacturing is caused by the non-uniform structure of wood, mainly natural defects in the wood. The other limiting factor is based on the size of the log, of which the veneer is produced from, this leads to a careful selection of bought-in lumber.

Scarf-jointing is a method of manufacturing veneer sheets, making them longer, thus leading to a more optimum natural characteristic of wood. This process consists of cutting of sheets, spreading adhesive and pressing. The normal size veneer sheets are scarf-jointed in order to manufacture sheets with required longer lengths [40].

Scarf-jointing of veneer sheets can have up to 90% of the mechanical strength of clear wood and they also show a behaviour, which is common to clear wood [40].

Tarmeko Spoon AS uses scarf jointing to form elongated veneer sheets. This process uses different adhesives and temperatures and pressures at hot pressing. The conventional size veneer sheets are cut under an angle of roughly 3-4^{o}, as seen on figure 5, afterwards adhesive is applied and the sheets are hot pressed. The main problem with scarf-jointing is the adhesive bond. The bond tends not to have enough strength, thus leading to cracks or breakage between two veneer sheets. In order to overcome this problem, tests, using different pressing parameters, need to be studied. Tarmeko Spoon AS uses both phenol resins and melamine adhesive. Phenol is the most common adhesive due to its moisture resistance and brown adhesive joint. Melamine adhesives gives a lighter brown adhesive joint, which is mainly used for interior elements.

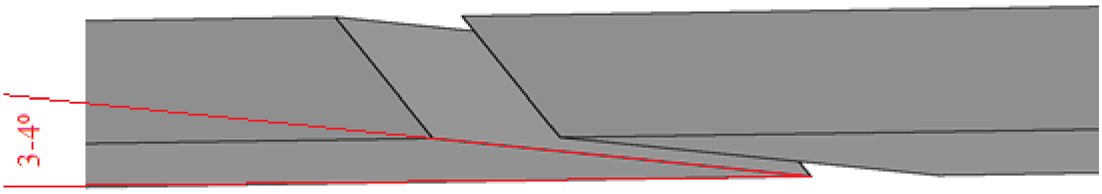

Figure 5. Scarf jointing concept – 2 veneer sheets jointed under roughly 3-4^{o}.

Scarf-jointing as a process also introduces a small problem. In the manufacturing of scarf-jointed veneer, the overlapping area, which is cut under an angle, is roughly 2,5 cm in length, totalling in 5 cm per sheet. Also, the veneer sheets, which are used in this process usually are a bit wider, so the edges need to be sawn off, thus leading to a high waste of material. Figure 6 illustrates the edge trimming of the initial veneer sheet.

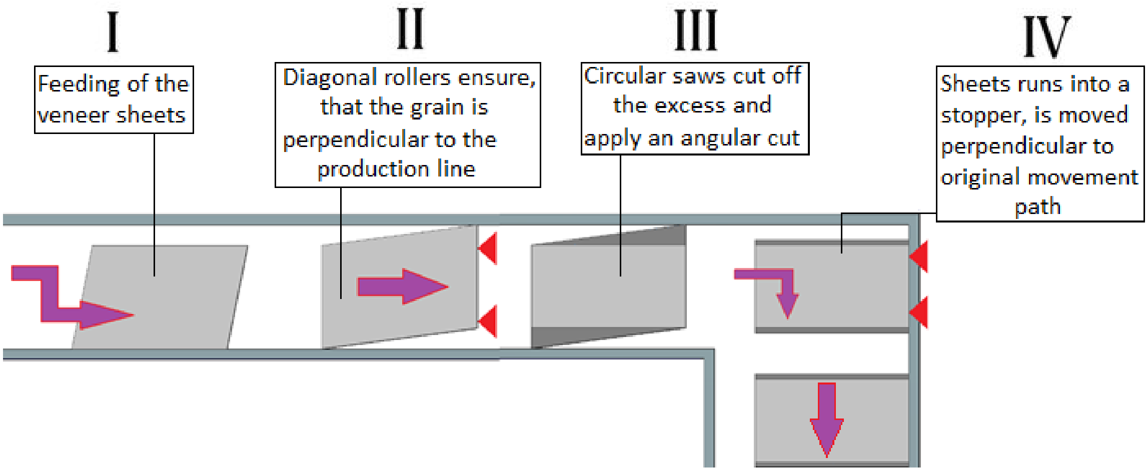

Figure 6. Edge trimming of the veneer sheet in scarf jointing.

Depending on the initial veneer sheet, a few cm are cut of on opposite sides of the veneer sheets. The waste of raw material is rated at few percents, which over a year-span is quite much.

1.6.1 Typical scarf-jointing production line

The typical scarf-jointing production line consists of several components, which include a veneer sheet feeding machine, conveyor belts, circular saws, adhesive applicator, a hot press, guillotine and a veneer sheet stacker.

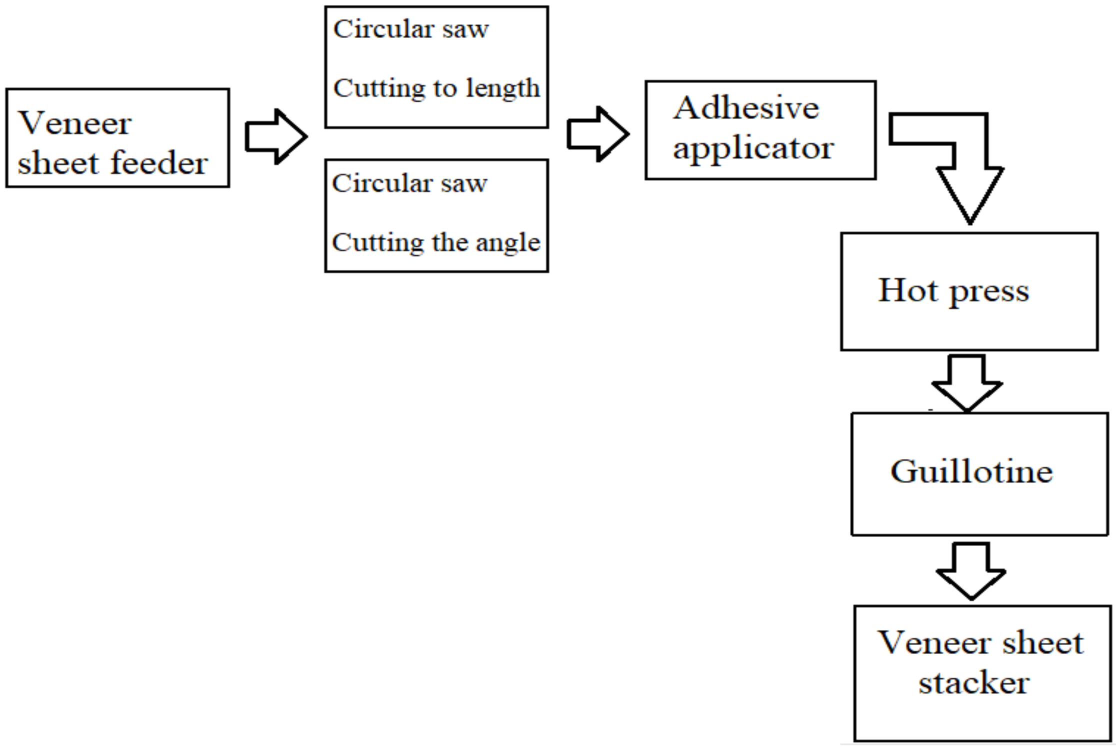

Figure 7. Conventional scarf jointing production line.

The process starts with the veneer sheet feeding machine picking up a veneer sheet from the veneer stack and placing it on conveyor belts, which run in a diagonal alignement to ensure that the veneer sheets end up parallelly on the production line. This placement ensures that the circular saws cut the veneer sheet perpendicular to the grain, so that the hot pressing process has a straight uniform surface, thus leading to ideal pressing position.

Figure 8. Veneer feeding machine followed by diagonal rollers.

The circular saws cut the veneer sheet in the correct width and also apply an angular cut to opposite sides of the veneer sheet. This angular cut is usually around 3^{o} to 4^{o}. The angular cut of each veneer sheet must be the identical in order for the joint area to fit perfectly. After the cutting stage, this machine also applies a uniform thin line of adhesive to one side, which is cut under an angle and the adhesive is instantly spread using a roller.

Figure 9. Circular saws followed by a conveyor belt.

The sheets, which are cut in the right width and have the sides cut under an angle, are moved by a conveyor belt to an area, where the sheet start to move perpendicular to it’s original movement path and is afterwards hot pressed with a sheet that follows the first one. Hot pressing is carried out roughly around 4-6 seconds and 250℃, depending on the adhesive used.

Figure 10. Cross conveyor belts followed by the scarf-jointing press.

After the hot pressing, the product is a long veneer sheet, which will be cut in the required length and afterwards will be placed on the final sheet stacker. The cutting is done by the guillotine in one quick motion.

Figure 11. Scarf jointing hot press followed by the guillotine.

On figure 12, the veneer stacker can be seen. The veneer sheet goes through the guillotine and is cut with the right length. The cut veneer sheet is then placed on two bases, which move to sides after the sheet is transported on them, letting the final scarf jointed veneer sheet fall on the veneer stack.

Figure 12. The scarf jointed veneer stacker.

The production of scarf jointed veneer sheets is a fully automatic system, but it has it flaws. The veneer sheets that are placed on the rollers in the beginning of the production process need to be rated if they are suitable or not for the production. Another weakness of this system is the hot pressing stage, where the veneer sheets need to face the hot pressing direction. Even the slightest driftage of the sheets needs to be removed manually, in order to complete the hot pressing stage to obtain uniform veneer sheets.

1.6.2 Discoloration of scarf-jointed area caused by the cutting angle of veneer sheets

One of the problems with scarf-jointing two veneer sheets into one is the discoloration that is caused by the cutting angle of the veneer sheets. This discoloration occurs in the length of the hot pressing plate and is caused by the reduced veneer thickness at the joint. Due to scarf-jointing with

PF adhesives requiring higher temperatures at hot pressing, the veneer sheet itself is burned a bit, leading to discoloration. Figure 13 illustrates the average veneer sheet thickness after hot pressing.

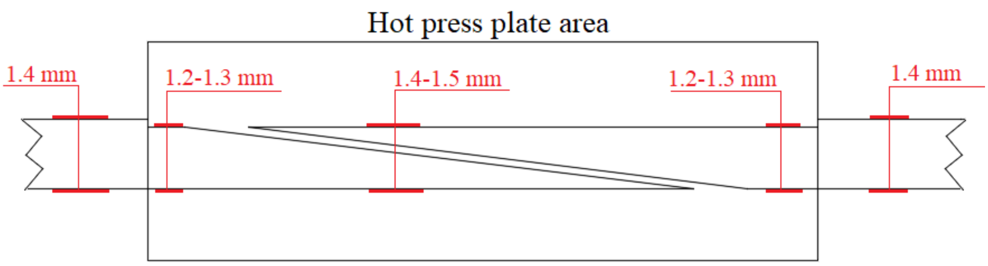

Figure 13. Scarf jointed veneer thickness after hot pressing.

As it can be seen on figure 13, the veneer sheet has a thickness of 1,4 mm. The overlapping area of the joint has a thickness greater than the initial veneer sheet, around 1,4-1,5 mm. The thickness of the plain veneer sheet under the press decreases to 1,2-1,3 mm under pressure.

Discoloration is not only a problem for the visual aspect. The other standpoint lies in the adhesion between two veneer sheets, the absorption of the veneer itself reduces at higher temperatures. High temperatures have an impact on the cellular structure of wood.

The reason behind passage of gases and liquids are the pits within the structure of wood. Due to high temperature pressing, the adhesive that is applied to the surface of the angular cut at the end of the veneer sheets is not absorbed by the veneer sheet, leading to delamination and thus to a useless product, which cannot be used in production of plywood. High temperature influences the pits and modifies them to be less absorbent. This means that high temperature pressing should be avoided due to modification of pits. This problem can be avoided by testing different adhesives that require lower not so high temperatures.

To further investigate this problem, certain test need to be carried out, varying the cutting angle of the veneer sheets before scarf-jointing and using different adhesives.

2 MATERIALS AND METHODS

2.1 Birch

Birch is a thin-leaved hardwood, belonging in the *Betulaceae* family, which is similar to the *Fagaceae* family. Birch usually grows as a small-medium sized tree. It is common to in the areas with northern temperatures and climates. In Estonia, the most common hardwood is Birch. It can be commonly seen in gardens and parks [41].

Birch grows as a straight one-stem tree. With age, the bark of the tree changes to greyish or brownish red. After 30-40 years, the trunk of the tree starts to split and the trunk develops a thick dark grey bark. The older Birch trees can live up to 150-250 years. Birch trees usually grow up to 20-30 m high. The highest Birch in Estonia was recorded in Järveselja, which was 38 m tall [41].

Birch has a very small amount of sapwood, which is nearly white in colour. The heartwood of Birch varies from a creamy to a light brown colour. Birch itself has a rather wavy figure, which can be best seen at Birch veneer peeling [41].

Birch has a relatively high denisity, around 650-700 kg/m^3. This high density had leads to better mechanical properties – greater strength and rigidity, high shock resistance. This makes this hardwood ideal for applications, which uses nails or screws. One drawback of this hardness, tho, is the hand treatment being difficult. The main problem with Birch is the decay resistance, which tends to be low. For treatments, Birch finishes and sands quite well. Birch is an ideal hardwood for working with varnishes and different paints. Before finishing Birch with colour or varnishes, it needs to have a penetrating sealer applied to avoid blotches [42].

The main enemies of Birch trees are leaf pests, such as forest-frost (*Operophera fagata*), Birch leafminer (*Fenusa pumila*) and pale tussock (*Calliteara pudibunda*). Under the bark of mature Birch trees, Birch bark beetle (*Scolytus ratzeburgi*) can be seen [41].

Over the past periods, the industry that is based on making plywood and plywood products has had an increasing demand in production and so more and more heartwood is used. False heartwood refers to a brown-like area in the center of the tree and this is known as false heartwood, which is one of the significant problems which affects Birch and its' appearance [41].

The appearance is a problem mainly in the sawmilling industry, due to not having enough end-uses where the discoloration of wood is acceptable. The proportion of false heartwood in Birch increases rapidly in the trees' lifespan. The primary cause of false heartwood formation is in relations with the injuries that the tree trunk might have experienced in the growing stage. Together with the trees' age and the injuries, the type of false heartwoods' type and size is influenced. Studies showed, that from 498 felled Beech trees, 150 contained false heartwood, which is approximately 30%. The high percentage of trees, which are affected by false heartwood, is wide spread all over Europe [43].

According to many manufacturers of plywood and veneer, around 10% of the Birch log is lost due to the effects of false heartwood [43].

2.2 Adhesive for scarf-jointing

For the resin component of the adhesive, phenol formaldehyde PF 101 was used, which is a thermosetting resin used in the preparation of test samples of the shear strength tests, which will be discussed later.

PF 101 is a brownish-red resin in a liquid state. The odor of this resin resembles light phenol and formaldehyde. The pH of this resin is 12 and relative denisity with respect to water is 1,18. The boiling point of this resin is 110℃, which is much lower than the hot pressing temperatures used. The reactivity and the chemical stability of this resin are stable under normal conditions. There is a possibility of hazardous reactions and instability occuring due to certain storage and usage conditions. Heated environments may cause pressure in sealed containers. Also heating can cause polymerization. PF 101 incompatible materials include acids and oxidizing materials. When exposed to metal, there is a risk of highly flammable hydrogens forming. Mixing this resin with air may cause explosive mixtures. Normal usage and storage conditions should not produce hazardous breakdown products, so the usage of this material is safe.

PF 101 is used with the hardener AD 7. They are mixed with the ratios of 95-98% PF 101 and 2-5% AD 7.

AD 7 is used in scarf-jointing as a hardener for the resins. It is a colourless and odourless liquid, which makes it easily mixable with the PF resin. It has an average pH of 7,5-8,0. The boiling point of this hardener is lower than that of resin, being around 100℃. The relative density with respect to water is 1,23.

The chemical stability and reactivity of the hardener are stable under normal conditions. Normal conditions of storage and use do not cause hazardous reactions. This hardener is reactive and incompitable with oxidizing materials and acids. There are no decomposition products produced under normal storage and usage conditions. The storage of this hardener is 2 months starting from the production date, so the lifespan of this hardener is quite low.

2.3 Preparation of test samples for shear strength test

In order to obtain the test samples for shear strength testing, the test samples must be produced. With the help of Tarmeko Spoon AS, various birch veneer sheets with an angular cut on one side, PF 101 adhesive and AD 7 hardener were obtained.

In order to produce scarf jointed test specimen, two veneer sheets needed to be cut in the equal width. The cutting of the sheets was done using a small hand-operated guillotine. The veneer sheet, which is afterwards applied adhesive on, is weighed and recorded.

Carrying out this test in a laboratory differs from the real production. The angular cut on each of the veneer sheets needs to be 25 mm in length. The lay-up of the angular cuts on the veneer sheets need to be measured, so the overlapping area would be exactly 25 mm. This measuring is done in the industry by automated machines, thus leading to various overlapping areas, the error in this case in the industrial production can be 1-1,2 mm.

For the adhesive between the overlapping area, PF 101 and hardener AD 7 is used. The adhesive consists of 95-98% of PF 101 and 2-5% hardener AD 7. The two components are measured with a mechanical scale and mixed in a beaker using a glass rod. The components need to be thoroughly mixed for 1 minute.

The application of adhesive is carried out by using a plastic syringe in order to leave behind a uniform line of adhesive, as can be seen in the industrial production. The adhesive is spread with a plastic roller, which runs over the glueline once, as in the real production. After the application of adhesive, the sheet with the adhesive is weighed in order to determine the glue consumption. Two of the sheets are laid upon eachother with the angular cut face to face and the overlapping are being 25 mm. The joined sheets are put inbetween the pressure plates of the hot-press.

Adhesive consumption calculation is as follows:

$$C_{ad} = \frac{m_2 - m_1}{25 \times w} \times 10^6 \quad (2.1)$$

Where C_{ad} is the adhesive consumption, g/m²; m_1 is the initial mass of the veneer sheet, g; m_2 is the mass of the veneer sheet with adhesive, g; w is the width of the scarfed area on the veneer sheet, mm.

In the European standard 205 the dimensions of the test samples are 150±2 mm and 20±2 mm, the test slip length is 80±2 mm and the overlapping area length is 10±2 mm [46]. This standard can be used as a base for this test.

The scarf jointed veneer sheets are first trimmed with a hand guillotine on both sides before hot pressing to get a straight edge, then the two sheets are hot-pressed at high temperature for several seconds and various pressures. The next step is cutting the sheet into length and afterwards cutting the right width slips from the sheet. It is important to ensure that the adhesive area is right in the middle of the test sample. The length is 150 mm, width is 20 mm and the overlapping area in the middle is 25 mm. On figure 14, in which the cutting principle can be seen.

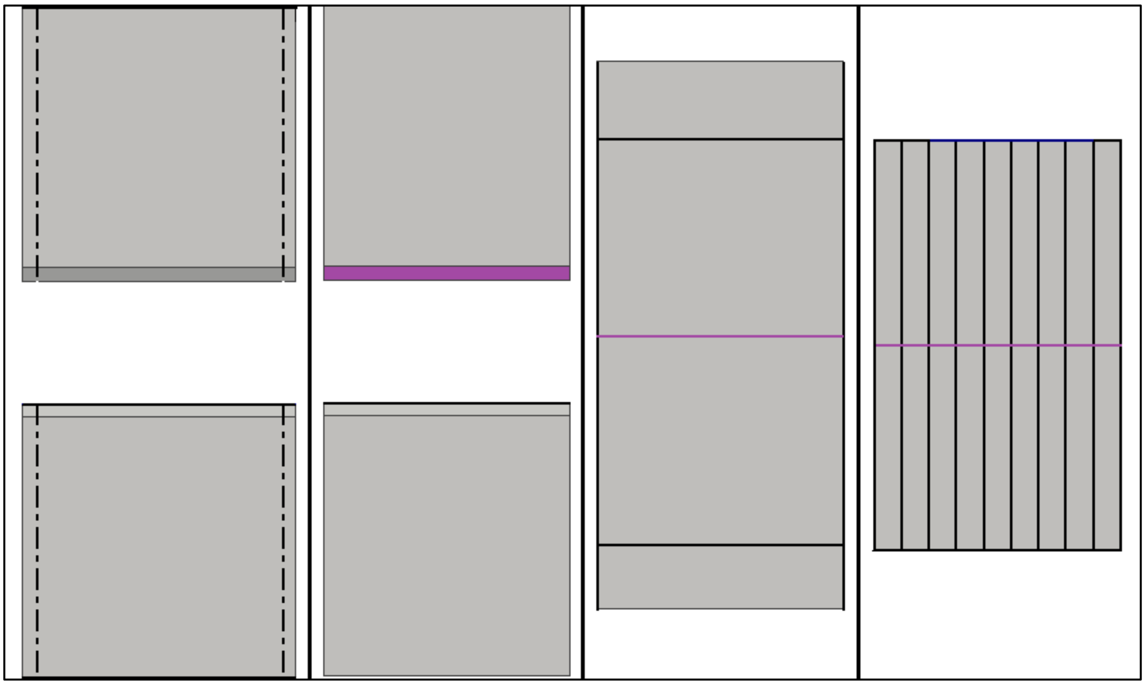

Figure 14. Cutting of the test samples from hot pressed veneer sheets.

2.4 Conditioning of the veneer sheets to required moisture contents

The conditioning of the veneer sheets will be done in a climate cabinet. As seen on figure 15, the moisture content of wood can be modified by using different temperatures and realitve humidities. In order to achieve the required moisture contents, the veneer sheets must be weighed before the conditioning to get the initial mass of the sheets and dried, using the oven-dry method to find out the initial moisture content of the veneer sheets [44].

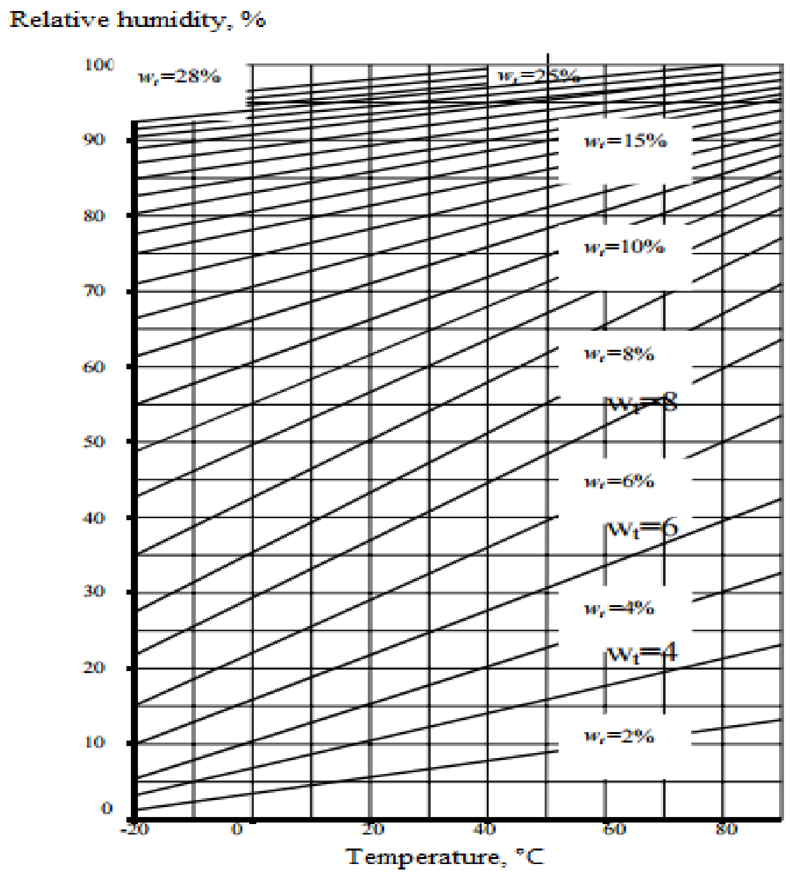

Figure 15. Temperature and relative humidity effect on the moisture content [44]

Conditioning is an unstable process and needs to be monitored as frequently as possible to ensure that the desired moisture contents are achieved and the veneer sheets do not have more or less moisture content than intended.

2.5 Moisture content of veneer sheets

Oven-drying is a method which includes drying sheets in an 100℃ oven, veneer sheets will be weighed every half an hour until the mass of the sheets is constant after several weighs. The constant mass is usually achieved after 3-4 hours but holding the samples in the oven overnight gives the best results.

$$Moisture\ content\ (MC) = \frac{Initial\ weight - Weight\ after\ oven\ drying}{Weight\ after\ oven\ drying} \times 100\%, [44] \qquad (2.2)$$

2.6 Shear strength tests

Brich veneer sheets have a quite high shear strength. When producing longer veneer sheets, it is important to strengthen the joint area between two big veneer sheets. The jointed area must have atleast the same shear strength as the plain veneer sheet, being lower than that leads to delamination between the jointed area, which is highly undesirable. In order to reinforce the jointed area between two veneer sheets, adhesives have to be used. These adhesives need to provide a high shear strength for the joint.

In order to carry out shear strength test, Instron 5866 is used, which has electromechanical load frames that are designed to apply load to a test sample with the help of moving crossheads. On figure 16, the moving crossheads, bottom and top, with a test sample inbetween can be seen. The upper and lower clamps are holding the test sample tightly with vacuum and the crossheads start to move away from eachother, stretching the test sample until it breaks. The shear strength is calculated and recorded via a computer, which is connected to Intsron.

Figure 16. Instron crosshead clamps with a test sample inbetween.

For testing, scarf jointed veneer sheets were made, using a hot-press. The hot-pressed veneer sheets were cut to the right dimensions. Each veneer sheet produced around 6 to 7 test samples, depending on the pressing. The suitable test samples have 25 mm overlapping adhesive area, contain no major defects, such as holes, and do not have too much excess adhesive outside of the adhesive area.

Shear strength is the maximum load applied to the parallel direction of the test sample divided by the surface area of the adhesive area and can be calculated with the formula (2.3):

$$\sigma = \frac{P}{lb}\ , MPa, [45] \tag{2.3}$$

where P is the force used, N; l is the length of the shear plane, mm; b is the width of the shear plane, mm.

2.7 Testing of shear strength and evaluation results

After the preparation and conditioning of the test samples, shear strength tests are recorded with Instron 5866. The speed during the test is 20 mm/min, the load is 10 kN. The distance between clamps is 80 mm.

For the results, shear strength will be recorded by Instron with the aid of a computer with special software. The results are analysed according to the pressing pressure, adhesive amount, hardener to resin ratio and pressing time.

Standard EN 314 includes a scheme, where the wood failure in percentage is shown. Standard EN 205 states, that the failure of wood fibres should be graded as follows: 0%, 25%, 50%, 75% and 100% [46] [47]. Higher wood failure refers to the adhesive inbetween the layers has been stronger than the wood fibres. Higher wood failure means better bonding quality.

3 TESTING PARAMETERS

In the tests of this thesis, the only adhesive used was liquid phenol-formaldehyde (PF) resin Bakelite® PF 101 with hardener Hexion® AD 7. Both components were provided by Tarmeko Spoon AS.

3.1 Moisture content of test samples

In order to carry out the shear strength tests, the test samples need to be conditioned to 5% moisture content. Previously performed shear strength tests, which were carried out with 12% moisture content of test samples, showed a significantly low number of considerable results, this led to an uncertainty of the results.

The conditioning of the scarf-jointed veneer test samples was done by the use of a climate cabinet with the settings of 10% relative humidity and 20℃. Five random test samples were taken out of the climate cabinet for oven drying in order to determine the moisture content of the test samples. Table 1 represents the results of the conditioning and oven drying of the test samples, according to formula (2.2).

Table 1. Oven drying of conditioned scarf-jointed veneer test samples.

	Time, min						
Mass, g	**30**	**60**	**90**	**120**	**150**	**180**	**MC, %**
5,93	5,66	5,63	5,65	5,64	5,62	5,62	**5,228**
5,35	5,1	5,09	5,09	5,08	5,07	5,07	**5,234**
5,27	5,03	5,02	5,02	5,02	5,00	5,00	**5,123**
5,26	4,99	5,00	5,00	5,00	4,99	4,99	**5,133**
4,04	3,84	3,84	3,84	3,84	3,83	3,83	**5,198**

3.2 Adhesive consumption of test samples

In order to find out the realtion between the adhesive amount and the shear strength, the veneer sheets need to be weighed before and after the application of adhesive prior to hot pressing. In each series, which consisted of two veneer sheets with an angular cut, adhesive was applied to the angular cut of one veneer sheet.

The adhesive consumption is therefore compared to the average shear strength of the shearing test results. Adhesive amount is also taken into consideration when rating the wood fibre failure of the test samples.

Tarmeko Spoon AS uses an average adhesive consumption of 160 g/m².

It can be noted that using too little or too much of adhesive inbetween the angular cuts of the test sample veneer sheets may lead to insufficient shear strength and lower wood fibre failure, thus proving that the adhesive consumption is off. In order to find out the optimal adhesive consumption, tests need to be carried out by using a wide range of adhesive consumption with different hardener quanitities.

The pressing pressure for these tests was 10 kg/cm², pressing time was 10 seconds and pressing temperature was 200°C.

3.3 Hot pressing time of test samples

In order to evaluate the optimal time range of the hot pressing in order to achieve the best results in shear strength, different times must be used during hot pressing. Hot pressing at Tarmeko Spoon AS takes time between 4 to 5 seconds.

The hot pressing time is highly dependant on the hot pressing temperature of the veneer sheets. Higher temperatures require lower pressing time and lower temperatures require longer pressing time. In order to find the optimal pressing time at different temperatures, 4 different hot pressing times are used: 4, 6, 8 and 10 seconds. The pressing pressure for these tests was 10 kg/cm².

3.4 Hot pressing temperature

In order to find the optimal pressing temperature for ideal scarf-jointed veneer sheets, different pressing temperatures must be investigated. Hot pressing at Tarmeko Spoon AS, using PF 101, is carried out around 250°C.

As mentioned previously, the hot pressing time is related the hot pressing temperature. Due to using 4 different times at hot pressing, also 4 different temperatures will be used: 230°C, 240°C, 250°C and 260°C. The pressing pressure for these tests was 10 kg/cm². In total, 160 test samples are needed to investigate how both pressing temperature and pressing time influence the final shear strength of the test samples.

For hot pressing time and temperature tests adhesive, PF 101 was mixed with 5% hardener AD 7, and the average adhesive consumption was in the range of 190-195 g/m². This consumption was achieved by using a small syringe to apply the adhesive. The mass of the adhesive was weighed constantly to ensure adhesive consumption in the desired range.

3.5 Requirements for bonding quality

The bond quality of the adhesive and veneer sheets was evaluated using the standard EN-314, which includes a wood failure scheme. The percentage of wood failure was evaluated visually according to the standard.

EN-314 also states, if shear strength is above 1 N/mm², it is not required to evaluate the wood failure [47]. To illustrate the delamination aspect better, wood failure will be investigated on all the test samples.

4 TESTING RESULTS

The effect of pressing time, temperature and the amount of hardener in the adhesive were studied in order to bring about the problem that Tarmeko Spoon AS has: i.e. how does the pressing time effect the final strength of the adhesive bond inbetween veneer sheets during scarf-jointing process? The results show the optimal pressing parameters in order to achieve the best shear strength and prevent the occurance of delamination in the adhesion area of the scarf-joi nt. This is followed by the evaluation of veneer-adhesive bond quality – wood failure. For the shear strength calculation, formula (2.3) was used and for adhesive consumption calculation, formula (2.1) was used. The complete tests results can be seen on Appendices 1-9.

4.1 Adhesive consumption

Test samples were prepared and hot-pressed with different adhesive amounts. The adhesive amount $C_{adhesive}$ was calculated by dividing the adhesive mass with the surface area of the angular cut area. The length of that area is described as l, and the width is 20 mm, with which the surface area of the adhesive area is calculated (see Appendix 1).

Two separate test series were recorded, one with 2% hardener and other with 5% hardener in the final adhesive. On the tables 2 and 3, the results of shear strength tests can be seen, which were carried out on test samples, which had 2% and 5% hardener in the final adhesive mixture. It must be noted that each test serie consisted of 9 test specimens.

Table 2. Adhesive consumption and average shear strength of 2% hardener test samples.

Test serie	Shear strength, N/mm²	Standard deviation	$C_{adhesive}$, g/m²
1	4,49	0,6	232,0
2	2,65	1,2	47,1
3	4,94	1,6	165,0
4	3,78	0,9	97,0
5	5,02	1,1	160,4
6	4,44	0,8	144,7
7	5,38	1,3	24,5

Table 3. Adhesive consumption and average shear strength of 5% hardener test samples.

Test serie	Shear strength, N/mm^2	Standard deviation	$C_{adhesive}$, g/m^2
1	4,12	1,1	151,8
2	6,46	0,9	231,0
3	5,23	0,7	253,8
4	6,25	1,0	201,5
5	4,88	1,3	265,1
6	6,31	1,9	212,3
7	4,81	1,0	235,8

Figure 17 illustrates the adhesive consumption effect on the average shear strength of the test samples for both adhesives with 2% and 5% hardener, showing that both excessive and lesser adhesive consumption have a similar effect. It can be noted, that too high and too low adhesive consumption leads to a lower maximum shear strength.

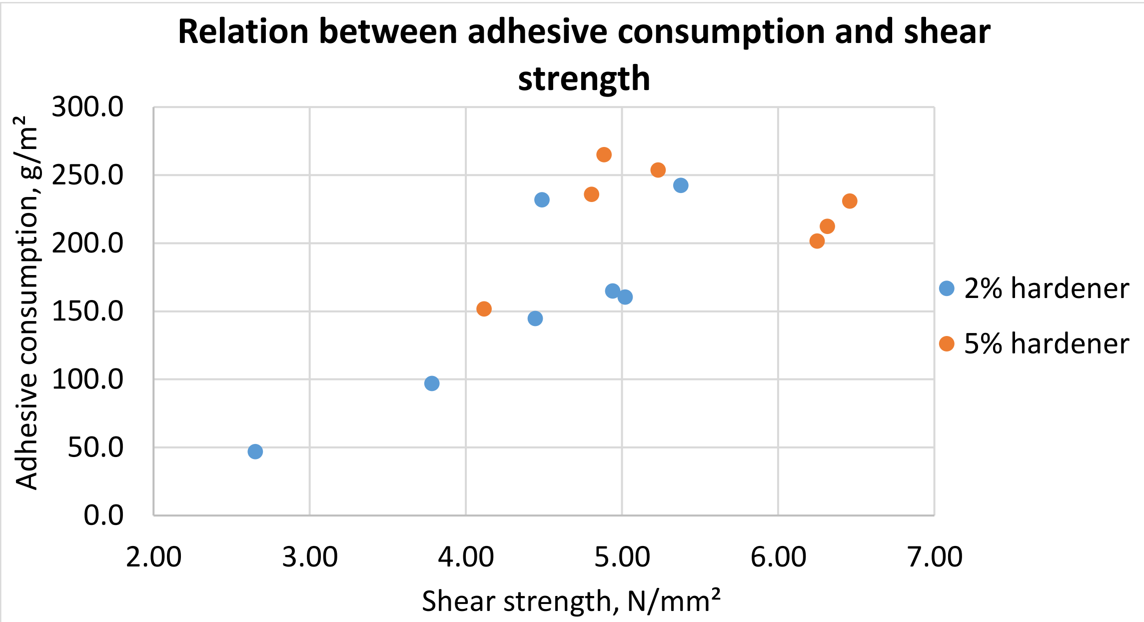

Figure 17. Effect of adhesive consumption on the average shear strength of both 2% and 5% hardener test samples.

From the 2% hardener test samples we can see, that the maximum results were recorded with the glue consumption of 160 g/m^2, 165 g/m^2 and 242 g/m^2, which is an average of 189 g/m^2, which results in an average shear strength of 5,11 N/mm^2.

From the 5% hardener test samples it can be noted, that the maximum shear strength were recorder on four different adhesive consumption, 202 g/m^2, 212 g/m^2 and 231 g/m^2, with the average of 215 g/m^2, which results in an average 6,34 N/mm^2 shear strength. The adhesive consumption is related to the hardener amount in the final adhesive mixture, higher amouts of hardener lead to higher shear strengths.

Taking into consideration both the 2% and 5% hardener adhesives, the optimal adhesive consumption should range from 189 g/m² to 215 g/m².

4.2 Pressing time and temperature

Test samples were prepared and hot-pressed with different adhesive amounts. The adhesive amount $C_{adhesive}$ was calculated in the same way as mentioned in the previous subheading. The tests were carried out according to table 4 containing the testing schedule.

Table 4. Testing series for time and temperature effect of the shear strength.

	Temperature, ℃			
Time, sec	**230**	**240**	**250**	**260**
4	10	10	10	10
6	10	10	10	10
8	10	10	10	10
10	10	10	10	10

Tables 5 and 6 and figure 18 contain the average results, both shear load and strength, for each series and its corresponding pressing temperature and time.

Table 5. The average shear load of test samples at given pressing times and temperatures.

	Shear load, N			
Pressing time, sec	**230 ℃**	**240 ℃**	**250 ℃**	**260 ℃**
4	2405	1605	1182	956
6	2208	891	1620	1582
8	2241	1136	1890	1312
10	2258	1808	1741	1872

As seen on table 5, the average shear load at both 4 seconds and 10 seconds shows a similar behaviour, decreasing with the increase of temperature. Also, both 6 second and 8 second shear load own a similar behaviour, decreasing at 240°C, increasing at 250°C and finally decreasing again at 260°C.

Table 6. Average shear strength at different pressing times and temperatures.

Time, sec	230 °C	Standard deviation	240 °C	Standard deviation	250 °C	Standard deviation	260 °C	Standard deviation
4	4,81	0,91	3,21	0,57	2,37	0,77	1,91	0,53
6	4,42	1,15	1,78	0,46	3,24	0,32	3,17	1,38
8	4,48	0,70	2,27	0,69	3,78	0,71	2,62	0,89
10	4,52	0,40	3,62	0,67	3,48	0,60	3,74	0,60

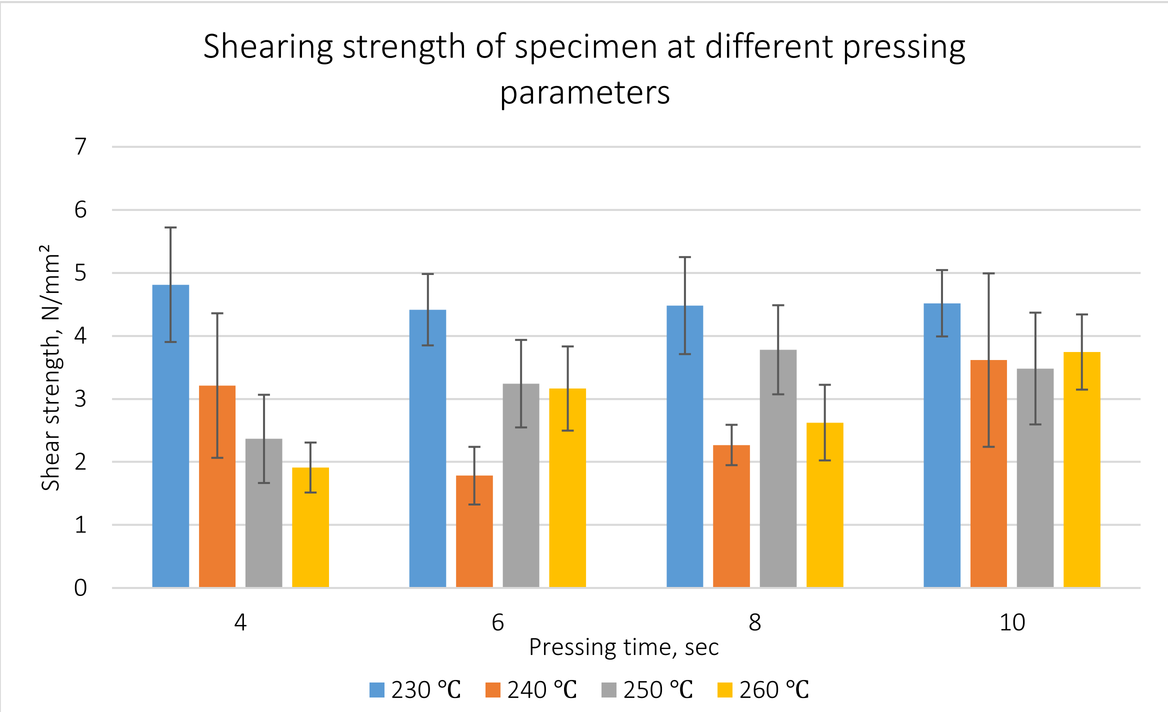

Figure 18. Average shear strength at different pressing times and temperatures.

Figure 18 represents the average shear strength of each test. It can be noted that the highest shear strength of 240°C and 260°C test samples were achieved at 10 seconds of hot pressing. The highest shear strength of 230°C hot pressing was achieved at 4 seconds. The highest shear strength of 250°C hot pressing was achieved at 8 seconds.

4.3 Wood failure at different pressing parameters

The failure of wood corrolates to the adhesive strength. Higher wood failure refers to a higher adhesive bond strength, minimal wood failure refers to lower shear strength. In order to evaluate the effects of pressing parameters on the wood failure, two subcategories must be investigated: pressing time and pressing temperature. The wood failure was evaluated via visual inspection.

4.3.1 Wood failure due to different pressing times

The effect of pressing time effects the final wood failure significantly. Figures 19-22 illustrate the effect of pressing time on the wood failure. For each series at given temperatures, 10 test samples were used.

Figure 19. Wood failure with 4 second hot pressing.

Hot pressing at temperatures 230°C, 240°C, 250°C and 260°C shows a significant number of specimen with wood failure less than 50%. 19 test specimen achieved wood failure higher than 50%.

Figure 20. Wood failure with 6 second hot pressing.

Hot pressing for 6 seconds shows a higher number of cases, where the wood failure is less than 50%. 18 test specimen achieved wood failure more than 50%.

Figure 21. Wood failure with 8 second hot pressing.

Hot pressing for 8 seconds showed an increase in adhesive bond strength. 23 specimen out of 40 showed wood failure above 50%.

Figure 22. Wood failure with 10 second hot pressing.

Hot pressing for 10 seconds yielded the best results. 80% of the test specimen achieved wood failure more than 50%. 8 out of 40 test specimen had wood failure less than 50%.

4.3.2 Wood failure due to different pressing temperatures

The effects of different pressing temperatures influence the final wood failure notably. Figures 23-26 illustrate the effect of pressing temperature on the wood failure. For each series at given temperatures, 40 test samples were used.

Figure 23. Wood failure of test specimen at 230°C hot pressing.

On figure 23, it must be noted that the lowest shear load recorded was over 1500 N. The average shear load of 40 test samples was 2278 N. Comparing this result to figures 24-26 gives a clear overview of the delamination problem. At elevated temperatures, the delamination occurs more, due to lower shear strength. Hot pressing at 230°C shows that 27 test specimen had wood failure 50% or more.

Figure 24. Wood failure of test specimen at 240°C hot pressing.

Hot pressing at 240°C shows a lower average bearable shear load, this leads to a higher occurance of delamination. The average shear load of 40 test samples was 1360 N. At this given temperature, 18 of the test specimen showed wood failure 50% or more.

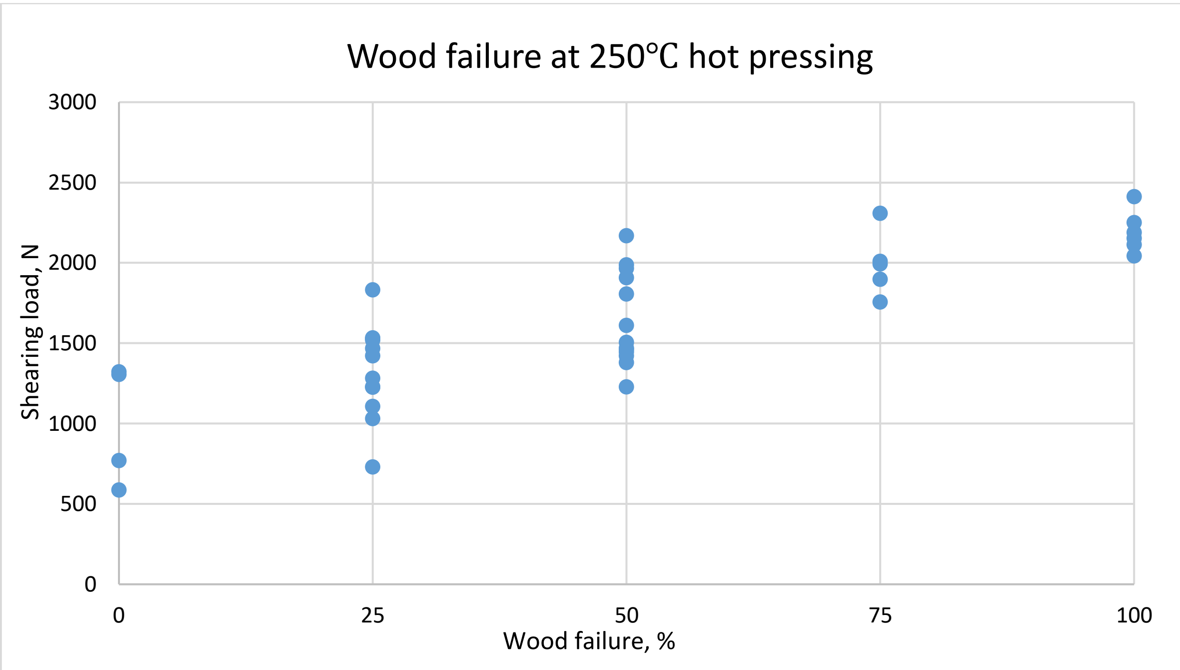

Figure 25. Wood failure of test specimen at 250°C hot pressing.

Hot pressing at 250°C has higher average bearable shear load than that of 240°C. The average shear load of 40 test samples was 1608 N. 24 test specimens out of 40 showed wood failure 50% or more.

Figure 26. Wood failure of test specimen at 260°C hot pressing.

Hot pressing at 260°C shows a slight decrease in the average shear load for 40 test specimens when compared to the results of hot pressing at 250°C, being 1537 N. 23 test specimen out of 40 showed wood failure 50% or more.

These results show that the highest wood failure and shear load were achieved in the case of 230°C hot pressing. The idea the results present refers to the elevation of temperature having a great impact on the percentage of wood failure.

5 ANALYZIS OF TEST RESULTS

The effects of adhesive consumption and the pressing parameters have a significant impact on the final mechanical strength of scarf-jointed veneer. The aim of this thesis is to find the optimal pressing parameters for scarf-jointed veneer in order to overcome the delamination of the adhesive bond area and understand, how these parameters effect this delamination problem.

5.1 Adhesive consumption effects

The adhesive consumption tests were carried out in order to bring an understanding of delamination in the adhesive area: i.e. how does the adhesive amount in the adhesive bond area effect the final shear strength of scarf-joints.

Scarf-jointed veneer is produced in Tarmeko Spoon AS are produced with the average adhesive consumption of 160g/m². In the description of the adhesive and its hardener, the recommended average adhesive consumption is in the range of 140-200 g/m². The test results show that the optimal adhesive consumption at pressing pressure of 10 kg/cm² and temperature of 200°C prove the optimal adhesive consumption to be in the range of 189 g/m² to 220 g/m².

Using the higher section of the recommended adhesive consumption is related to the scarf-joint itself. For the joint, it is simple for the adhesive to leave in the bond area, which is related to the angular cut on each veneer sheet that is used to produce scarf-jointed veneer. The adhesive thickness in the bond area is much greater prior to the hot pressing. During hot pressing, a major portion of the adhesive is pressed out of the adhesive area, this means that the average adhesive consumption in the adhesive area is much lower than that of prior to hot pressing. On figure 27, the excess adhesive being pressed out of the adhesive area can be seen, the distance between A and B is 1,25 cm. This shows, that using excessive amount of adhesive leads to a waste of adhesive and the shear strength tests implement the idea of lower shear strength at elevated adhesive consumption.

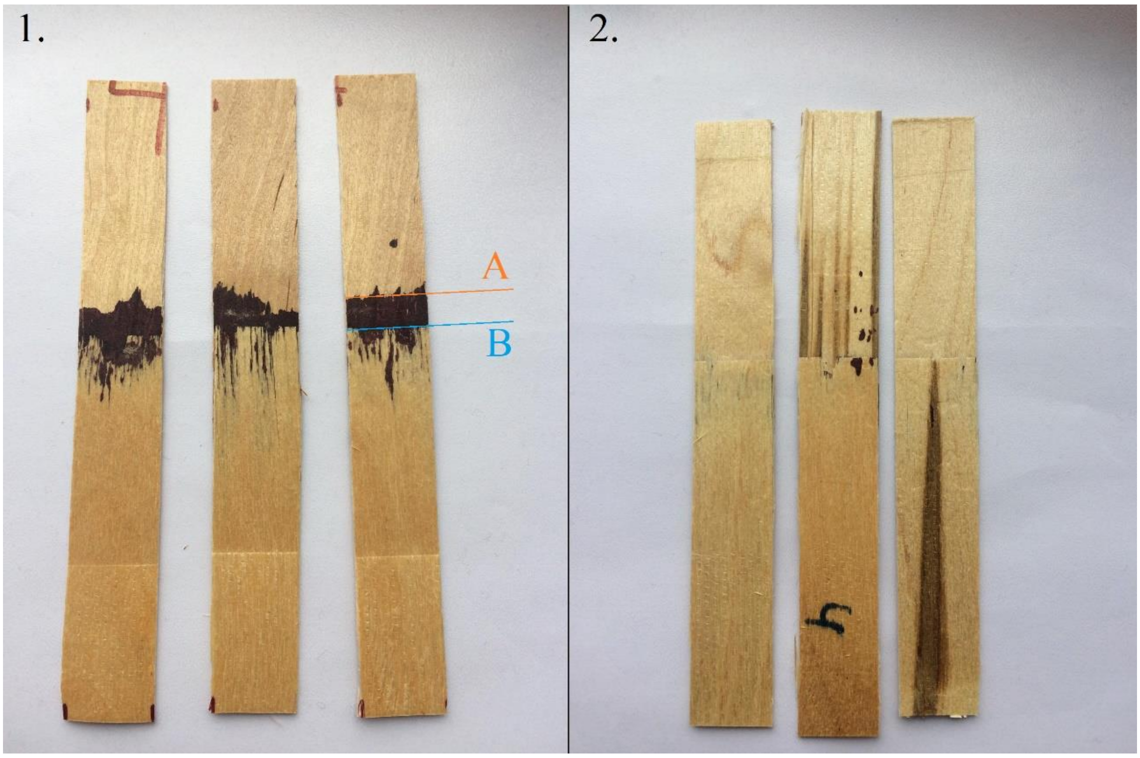

Figure 27. Idea of adhesive amounts: 1) Excess adhesive 2) lack of adhesive.

In the scarf-jointing industry, the desired result is illustrated on figure 27 with the number 1. The lack of adhesive inbetween the veneer layers is illustrated with the number 2. This occurance of excess adhesive outside of the adhesive area proves, that the adhesive area inbetween the veneer sheets is filled with enough adhesive, so there are no regions inbetween the veneer sheets that are not coated with adhesive. This excess of adhesive has a positive effect up until a certain point.

The tests suggest, that the shear strength of the scarf-joint is related to the adhesive amount inbetween the two veneer sheet scarfs. The amount of adhesive corrolates to the thickness of the adhesive layer. There are 3 different cases of adhesive usage: low amounts, excessive amounts and optimal amounts.

Using lower amounts of adhesives leads to a lack of bondage area, thus a more uneven bond, which might not cover the whole area inbetween the veneer angular cuts. The adhesive layer in this case is minimal and at certain adhesive amounts non-existent. This refers to a weaker adhesive bond being created, thus leading to a lower shear strength and higher occurance of delamination.

Using excessive amounts of adhesive leads to a whole new problem related to the boiling point of the adhesive. Higher amounts of adhesive lead to a higher excess of adhesive outside of the adhesive layer. This higher quantity of excess under pressure and at temperatures over 200°C leads to the boiling of the adhesive, thus producing bubble-like structure in the area between A and B showed on figure 27. The formation of this bubble-like structure prohibits the movement of excess adhesive inbetween the scarf-joint, in the case of higher adhesive consumption, the adhesive area starts to develop a bubble-like structure itself. The bubbles have a brittle characteristic, which means lower amounts of force is required to break the adhesive bond. The thickness in the case of bubble-like structure is higher than desired. This leads to a lower shear strength of the scarf-joint itself.

Using the optimal adhesive consumption, as the test results suggested, is the best option in order to produce proper scarf-joints. The optimal adhesive consumption is high enough to fill the adhesive layer inbetween the veneer scarf and press the excess adhesive out. This excessive adhesive is not enough to allow the boiling of the adhesive, since the pressed-out adhesive has a minimal thickness. After all the excess adhesive is pushed out of the adhesive layer, the scarf-joint is left with the minimal thickness.

This shows the increase of joint strength at a lower thickness of the adhesive layer.

The optimal adhesive consumption should involve a bit of excess to overcome the problems that the structure of wood presents. Veneer peeling process produces a number of lathe checks on the veneer sheet. Also, at the beginning of the scarf-jointing process, the veneer sheets go through a sawing step, where the ends of the veneer sheet are cut under and angle. This sawing introduces a number of cracks and dents in the angular cut area, which is later on the are for the adhesive bond. In order to fill the cracks and voids in the adhesive area, the average adhesive consumption should include a small quantity of excess.

5.2 Effect of pressing temperature and time

In order to evaluate the effect of pressing temperature and time on the shear strength of the scarf joint, the two factors need to be looked at as a whole. As the results suggested, a similar behaviour of different series can be seen. Figure 28 illustrates this phenomen.

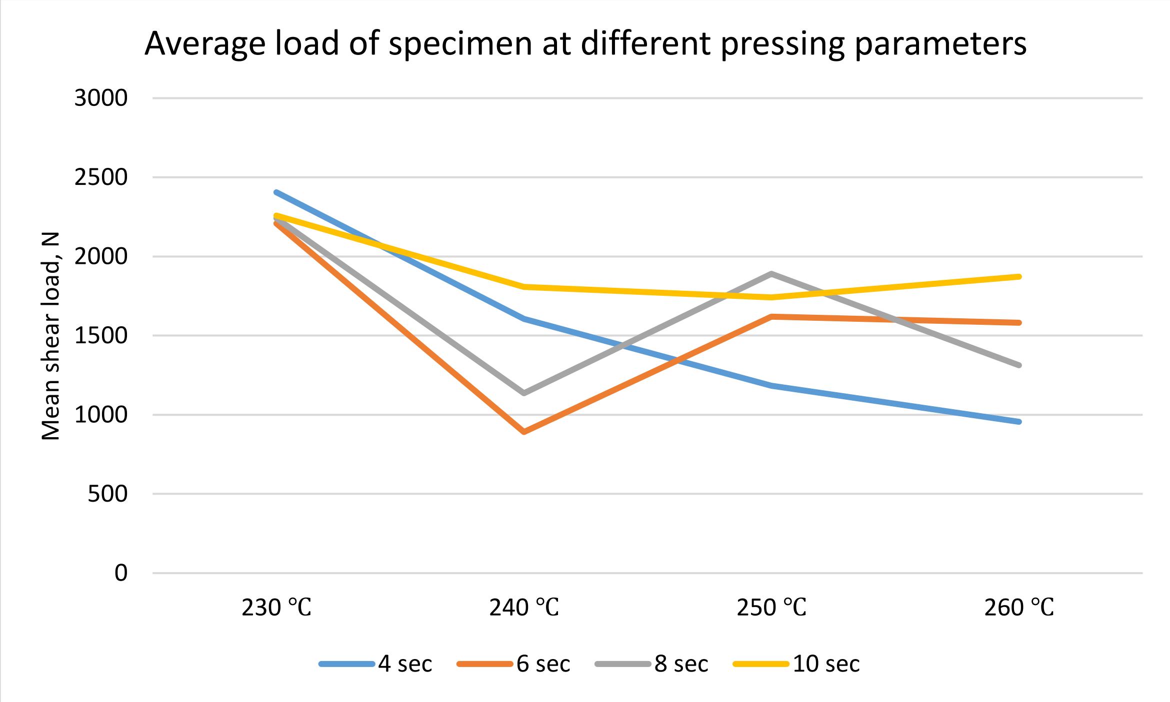

Figure 28. The effect of temperature and time on the average shear load of scarf-joints.

Hot pressing for 10 seconds and 4 seconds show a similar behaviour, as well as the 6 and 8 second hot pressing.

As we can see on figure 28, the average mean load of the 4 and 10 second hot pressing shearing test reduces, when increasing the hot pressing temperature. This can be explained by the adhesive being a thermoset. The results imply that the adhesive used in these tests activates at higher temperatures, which is followed by a degradation of the adhesive bond and after achieving even higher temperature of the adhesive inbetween the scarf joint, the adhesive seems to reactivate, which permits the adhesive to gain strength again.

At the 4 second hot pressing, it can be noted that the adhesive activates only once. With a single activation of the adhesive, the bond at elevated temperatures is decreasing, due to the low boiling point of both the hardener and the resin itself, being around 100-110°C. At the 4 second hot pressing at different temperatures, the activation and slow degradation can be seen. The lower temperature, 230°C, seems to have, out of all the investigated temperatures, an activating effect on the adhesive. Hot pressing for 4 seconds at higher temperatures shows, that the temperature of the adhesive is enough to start slowly degrading, thus leading to a lower shear strength of the joint.

At both 6 and 8 second hot pressing, indentification of the reactivation can be seen. At 230°C hot pressing, the adhesive inbetween the joint has achieved enough heat to activate the adhesive, thus high shear strength of the joint is developed. Hot pressing at 240℃ shows a loss of average shear load, which refers to the end of activation and the start of degradation of the adhesive. At 250℃, the adhesive achieves enough temperature to reactivate, thus leading to an icrease of average shear load. Around 260℃ hot pressing for 6 or 8 seconds, the secondary degradation process of the adhesive can be seen.

Hot pressing at 230℃ for 10 seconds introduces the idea of the adhesive being activated, degraded once and reactivated during the heating process of the joint area. This can be presumed after investigating the adhesive behaviour at 4, 6 and 8 seconds of hot pressing. At higher temperatures the adhesive shows a decrease in the average shear load, meaning that the reactivation of the adhesive did already occur at 230℃. There are no results that suggest a third activation of the adhesive between pressing temperatures 230℃ to 260℃ with the timespan of 4 to 10 seconds.

This behaviour of the adhesive bond refers to the phenol-formaldehyde resin being a novolac. This means that the adhesive can activate and be reactivated with the addition of heat or formaldehyde [48]. Due to the elevation of temperature, one out of two requirements are satisfied, which proves the reactivation of the adhesive.

The test results shown on figure 28 show, that the first activation of the adhesive gives the joint a higher average shear load. For these purposes, the optimal hot pressing temperature is considered to be 230℃ and the optimal pressing time is 4 seconds.

5.3 Wood failure at different pressing parameters

In order to evaluate wood failure of the test specimen, pressing time and pressing temperature will be investigated separately.

Wood failure at different pressing times gave a clear overview of the delamination possibilities. From all the test results it can be seen that the highest wood failure was achieved at the longest pressing time, 10 seconds. Wood failure at 50% and above relates to stronger adhesion properties. Figure 29 illustrates wood failure at different pressing times.

Figure 29. Wood failure above and uner 50% at different pressing times.

The highest number of wood failure at 50% and above was recorded at the tests, where the pressing time was 10 seconds, which was 32 specimens out of 40. 50% and more wood failure was recorded 19 times at 4 seconds, 18 times at 6 seconds and 23 times at 8 seconds hot pressing. This shows that the highest bonding quality was recorded at the pressing time of 10 seconds.

This analysis shows that increasing the pressing time results in higher wood failure, however, the highest bond strength was recorded with the 4 second hot pressing.

If the pressing temperature is taken into consideration, the results show a differet behaviour, not varying as much. Lower temperature at pressing, in the scale from 230°C to 260°C, leads to a higher percentage of wood failure. At 230°C, the wood failure was recorded 50% and above with 26 test samples. At 240°C the same failure was recorded on 17 test samples, at 250°C on 24 test samples and at 260°C on 23 test samples.

It must be noted that the first activation of the adhesive, thus lower pressing temperatures, leads to the highest joint strength. This strength decreases with the elevation of the pressing temperature, due to degradation after the first activation of the adhesive.

On the other hand, longer pressing time leads to a higher wood failure. This means that the adhesive has more time to flow into all the cracks and voids of the scarf area, thus leading to a greater wood failure. Although, the adhesive does not have as high strength as the shorter pressing times, it allows more wood fibres to be removed from the surface of the scarf area during shear strength tests.

From the aspect of delamination, higher wood failure is desired. Highest wood failure is recorded with the 10 second hot pressing samples, although, as the test results suggest, it does not refer to higher joint shear strength.

SUMMARY

The procedure of testing the scarf joint strength and its delamination causes showed that hot pressing temperature, pressing time and adhesive consumption have a strong influence on the measured shear strength of the joint tested according to standard EN-314, even though these tests are meant for plywood and not for single lap joint. For this reason, standard EN 205 was takes as a basis as well. As pressing temperature and time were increase, a decrease in shear strength and increase of delamination was recorded. Also, too high and too low adhesive consumption led to a decrease in shear strength.

Adhesive consumption measurements showed that using too little amounts of it leads to an uneven distribution. On the other hand, using adhesive amounts too high leads to formation of bubbles in the scarf area, thus weakening the joints strength. Describing the optimal adhesive consumption requires a wide range, due to the irregularities of the scarfed veneer sheets.

Wood failure was investigated with all the test, where pressing time and temperature were varied. The results show a clear indication of lower hot pressing temperatures having higher shear strength. The behaviour of the thermoset adhesive in the joint area shows two activations of the adhesive: primary and secondary. The primary activation of the adhesive yielded higher shear strength.

Although, it must be noted that highest wood failure was recorded with 10 second hot pressing – 80% of test specimen had wood failure over 50%. In contrast, 4, 6 and 8 second hot pressing test specimen showed an average around 50% of test samples having wood failure greater than 50%. This refers to the highest hot pressing time producing the best results. On the other hand, taking into consideration the optimal pressing temperature, highest wood failure was recorded with 4 second hot pressing.

Based on the various hot pressing tests and taking into account the delamination aspect, the following results of optimal pressing parameters are pointed out:

- Hot pressing temperature around 230°C.
- Hot pressing time of 10 seconds.
- Adhesive consumption in the range of 189-215 g/m².

KOKKUVÕTE

Puit on üks vanimaid taastuvaid resursse. Puit on iseenesest teatud piirini kergesti töödeldav materjal, mis tuleneb puidu ebakorrapärasest struktuurist ja omadustest, mis omakorda on põhjustanud kauakestvaid probleeme. Selle probleemi vältimiseks on kasutusele võetud puidu koorimine, mille abil on võimalik toota puidu spooni.

Tavalistel spoonilehtedel ei ole häid mehaanilisi omadusi. Viis nende mehaaniliste omaduste parendamiseks on kasutada mitut spoonikihti ja liimi, mille abil on võimalik toota vineeri. Vineeri mehaaniline tugevus moodustab kuni 90% tavalise puidu tugevusest. Vineeri saab toota kandes spoonilehtedele liimi ning ladudes neid teineteise peale, mis lõpuks kuum-pressitakse teatud temperatuuril ja survel.

Vineeri paneelid on teatud maksimaalse suurusega, mis on tingitud pöörleva treipingi tera laiusest. Suurema formaadiga vineeri on võimalik toota kasutades piki-jätkamist. See protsess hõlmab endas spoonilehtede jätkamist kaldse nurga all. Kaldsele nurgale kantakse peale liimiriba, mis ajatakse rullikuga laiali ning seejärel saadetakse kuum-pressimisse. Kuum-pressimisele järgneb pikkusesse lõikamine, mis viiakse läbi giljotiini abil. Tõsine probleem sellise liite juures delamineerumine, mis on tingitud liimliitest. Liimliite tugevus sõltub pressimisparameetritest nagu näiteks pressimise temperatuur, surve, aeg ja liimi kogus.

Selle magistritöö on välja pakutud Tarmeko Spoon AS poolt ning töö eesmärkideks on uurida kuidas liimliite tugevust mõjutavad pressimise tegurid ning välja töötada optimaalsed pressimisparameetrid piki-jätkatud spoonile, et vähendada delamineerumist liites. Eesmärgi täitmiseks uuriti liimliite nihketugevust ja puidust purunemist.

Liimliite tugevuse mõõtmiseks kasutati katsekehi, mis valmistati kase spoonist ning kõvendiga fenoolformaldehüüd liimist, mis on termoset. Nende mõõtmiste jaoks kasutati Instron 5866 mõõtemasinat. Mõõtmiste aluseks oli võetud standarid EN-314 ning EN-205.

Kasutades liiga vähestes kogustes liimi, on tulemuseks ebaühtlane liimi jagunemine. Kasutades liimi liiga suurtes kogustes, tekivad liimliite vahele ja ümbrusesse liimi mulled. Mõlemal juhul on tegemist nõrgendatud liimliitega, mis soodustab delaminatsiooni. Optimaalse liimikulu kirjeldamiseks tuleb kasutada laia vahemikku, mis tuleneb puidu ebakorrapärasest struktuurist.

Antud töös uuriti liimliite tugevust ning puidust purunemist, varieerides pressimise temperatuuri ja aega. Tulemusena selgus, et liimliites kasutatav liim aktiveerub kaks korda, esimese aktiveerumise korral saavutatakse kõrgemad nihketugevused. Kuum-pressimine madalamatel temperatuuridel saavutab tugevama liimliite tugevuse.

Puidust purunemine oli kõige kõrgem pikema aja kuum-pressimisel, kuid liimliite nihketugevused olid märgatavalt madalamad. Võttes arvesse optimaalset kuum-pressimise temperatuuri ning saavutatud nihketugevusi erinevatel pressimise aegadel, saavutas kõige tugevama liimliite ajaliselt kõige lühem kuum-pressimine.

Töö tulemusena iseloomustatakse kolme põhilist optimaalset pressimisparameetrit: pressimise temperatuur, aeg ning liimikulu. Et saada selgem ülevaade delamineerumise probleemist, hinnati ka puidust purunemist. Katsete tulemusena selgus, et minimaalne delaminatsioon esineb kasutades pressimise temperatuuri 230℃, pressimisaega 10 sekundit ning liimikulu vahemikus 189-215 g/m^2.

Kokkuvõtteks võib öelda, et magistritöö eesmärgid said täidetud ning oli edukas. Antud tulemusi saab kasutada Tarmeko Spoon AS piki-jätkatud spooni tootmisel.

REFERENCES

1) Tarmeko LPD webpage, www.tarmeko.ee [Online] (20.05.2018)
2) Kauffman, H.J. (1972). American axes; a survey of their development and their makers. Brattleboro, Vt.: S. Greene Press, 109.
3) Salmén, L. (1982). Temperature and water induced softening behaviour of wood fiber-based materials. Royal Institute of Technology Stockholm.
4) Goring, D.A. (1963). Thermal softening of lignin, hemicellulose and cellulose. Pulp and Paper magazine of Canada 64:T517T527.
5) Sulzberger, P. (1953). The effect of temperature on the strength of wood. Aeron.Res.Cons.Comm.Rep.ACA46, Melbourne.
6) Siimes, F. (1967). The effect of specific gravity, moisture content, temperature and heating time on the tension and compression strength and elasticity properties perpendicular to the grain of Finnish pine spruce and birch wood and the significance of these factors on the checking of timber at kiln drying. VTT Publications 84.
7) Gerhards, C.C. (1982). Effect of moisture content and temperature on the mechanical properties of wood: an analysis of immediate effects. Wood and fiber 14:436.
8) Jalava, M. (1932). Changes in the moisture content, volume and form of wood. Valtioneuvoston kirjapaino, Helsinki 18:157
9) Hakkila, P. (1962). Forest seasoning of wood intended for fuel chips. Metsätutkimus laitoksen julkaisuja, Helsinki 54:182
10) Kärkkäinen, M. (2007). Wood structure and properties. Karisti Oy, Hämeenlinna: 468
11) Piispanen, R., Saranpää, P. (2001). Variation of nonstructural carbohydrates in silver birch (Betula pendula Rothwood). Trees 15:444451
12) Kollmann, F.F., Côté Jr, W.A. (1968). Principles of wood science and technology. vol. I. Solid Wood. In: Principles of Wood Science and Technology. Vol. I. Solid Wood. SpringerVerlag.
13) Lutz, J.F. (1978). Wood veneer: Log selection, cutting, and drying. US Department of Agriculture, Technical Bulletin 1577
14) Fleischer, H.0. (1959). Heating rates for logs, bolts and flitches to be cut into veneer. USDA, Forest Service. Report 2149
15) Kontinen, P., Kivistö, A., Söyrilä, P., Usenius, A. (1992). Automation of plywood manu facturing. VTT Publications 756.
16) Sellers, T. (1985). Plywood and adhesive technology. CRC Press.
17) Siimes, F., Liiri, O. (1951). Technical investigation of plywood I. VTT Publications 95.
18) Lutz, J.F. (1974). Techniques for peeling, slicing and drying veneer. USDA Forest Service. Research Paper FPL 228
19) McMillin, C.W. (1958). The relation of mechanical properties of wood and nosebar pressure in the production of veneer. Forest Products Journal 8(1):2332.
20) Koch, P. (1965). Effects of seven variables on properties of southern pine plywood. Part II, Maximizing wet shear strength. Forest Prod. J. 15:463465
21) Korpijaakko, S. (1999). Koivuviilun lujuuteen vaikuttavat tekijät erityisesti raskaan kuljetusvälineteollisuuden lattiavanerien valmistuksen kannalta. Helsinki University of Technology, Department of Forest Products Technology Espoo 112.

22) Meriluoto, J. (1965). The influence of raw material factors on the quantity and quality of rotary cut birch veneer. Uudenmaan kirjapaino OY. Helsinki
23) Rohumaa, A. (2016). The impact of log pre-heating on birch veneer surface quality, bond formation and plywood performance. Doctoral dissertations 144/2016.
24) Goldstein, I. S., Oberley, W. J. (1964). Process for making plywood : US 3137607 A. [Online] esp@cenet (12.03.2018)
25) Christiansen, A.W. (1990). How Overdrying Wood Reduces Its Bonding to Phenol Formaldehyde Adhesives: A Critical Review of the Literature. Part I. Physical Responses. Wood and Fiber Science 22:441459.
26) Marra, A.A. (1992). Technology of wood bonding. Van Nostrand Reinhold, New York, NY, USA.
27) Baldan, A. (2012). Adhesion phenomena in bonded joints. Int J Adhes Adhes 38:95116.
28) Hse, C. (1972). Wettability of southern pine veneer by phenol formaldehyde wood adhesives. Forest Products Journal 22(1):5156
29) Aydin, I., Colakoglu, G., Hiziroglu, S. (2006). Surface characteristics of spruce veneers and shear strength of plywood as a function of log temperature in peeling process. Int. J. Solids Structures 43:614061476147.
30) Gent, A., Lai, S. (1995). Adhesion and Autohesion of Rubber Compounds: Effect of Surface Roughness. Rubber Chemistry and Technology 68:1325.
31) Petrie, E.M. (2000). Handbook of adhesives and sealants. McGrawHill Professional.
32) Packham, D.E. (2003). Surface energy, surface topography and adhesion. Int J Adhes Adhes 23:437448.
33) Stanley E. Corder, George H. Atherton, (1963). Effect of Peeling Temperatures on Douglas Fir Veneer, Oregon State University, Forest Research Laboratory, pp 31.
34) Wellons, J. D., Krahmer, R. L., Sandoe, M. D., Jokerst, R. (1982). Compression losses in hot pressed plywood, 20, 3.
35) Resnik, J., Tesavnik, F. (1995). Thickness loss when gluing veneer sheets into boards in the hot press or by high-frequency – Holz Roh Werkstoff, 53, 113-115.
36) Currier, R. A., (1962). Compression of Douglas-fir plywood in various hot pressing cycles. Information Circular 17. Forest Res. Lab. Oregon State Univ., Corvallis, Oreg. 35 pp.
37) Nevin, V. J., (1937). Method of making plywood, Patent US2068759 A. [Online] esp@cenet (10.12.2017)
38) Gerhards, C. C., (1980). Effect of moisture content and temperature on the mechanical properties of wood: an analysis of immediate effects. 6 pp.
39) Sedliačik, J., Bekhta, P., Potapova, O., (2010). Technology of low-temperature production of plywood bonded with modified phenol-formaldehyde resin. Wood research. 55. 123-130 pp.
40) Lahtinen, P. K., (1985). Procedure for manufacturing elongated glued beams. Patent US4608106 A. [Online] esp@cenet (16.12.2017)
41) Eesti Entsüklopeedia, www.entsyklopeedia.ee [Online] (19.04.2015)
42) Heavey, J., (2018). Birch – The north country's alluring blonde, [Online] esp@cenet (10.04.2018)
43) Michalec, J., Strnad, P., (2008). Present and future use of commercially important European heardwoods, Växjo University, School of Technology and Design, pp 11-12.
44) Poobus, A., Tiikma, T., (2001). Kuivatustehnika, TTÜ Soojustehnika Instituut. pp 15.

45) Construction Products Regulation Impact of EU Timber Regulation European Standards. (2004). Plywood – Bond quality – Test methods: European standard EN 314-2. [Online] esp@cenet (10.10.2017)
46) Adhesives – Wood adhesives for non-structural applications – Determination of tensile shear strength of lap joints. (2016). European standard EN 205. [Online] esp@cenet (28.12.2017)
47) Plywood – Bonding Quality. (1999). European standard EN 314-1. [Online] esp@cenet (10.11.2017)
48) A. Gardziella, L.A. Pilato, A. Knop, Phenolic Resins: Chemistry, Applications, Standardization, Safety and Ecology, 2nd edition, Springer, 2000

Appendix 1 Adhesive consumption measurements

Table 7. Adhesive consumption test measurements.

Serie	Hardener, %	m_1, g	m_2, g	$m_{adhesive}$, g	length, mm	surface area, mm²	F_{mean}, N	Adhesive consumption, g/m²	Shear strength, N/mm²
1	2	35,6	36,5	0,9	150	37,5	2243,5	232,0	4,5
2	2	80,6	81,0	0,4	306	76,5	1325,7	47,1	2,7
3	2	65,2	65,8	0,6	158	39,5	2470,3	165,0	4,9
4	2	42,9	43,3	0,4	165	41,3	1891,5	97,0	3,8
5	2	48,4	49,2	0,8	202	50,5	2510,1	160,4	5,0
6	2	49,2	49,8	0,7	188	47,0	2221,8	144,7	4,4
7	2	65,3	66,8	1,6	259	64,8	2688,5	242,5	5,4
8	5	14,0	14,7	0,7	118	29,5	2057,8	151,8	4,1
9	5	11,9	12,6	0,7	123	30,8	3229,3	231,0	6,5
10	5	17,8	18,7	0,9	145	36,3	2615,3	253,8	5,2
11	5	15,9	16,6	0,7	133	33,3	3124,3	201,5	6,2
12	5	19,8	21,0	1,1	172	43,0	2442,4	265,1	4,9
13	5	17,1	17,8	0,7	130	32,5	3156,9	212,3	6,3
14	5	18,9	19,7	0,8	134	33,5	2402,5	235,8	4,8

Appendix 2 Shear strength at 230℃

Table 8. Shear strenght of scarf joints pressed at 230°C.

	Pressing time, sec							
	4		6		8		10	
Sample, no.	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**
1	2697,7	5,4	2552,0	5,1	2056,0	4,1	1976,4	4,0
2	2386,3	4,8	2444,9	4,9	2399,1	4,8	2510,2	5,0
3	2724,7	5,5	2026,5	4,1	2610,3	5,2	2578,2	5,2
4	2086,7	4,2	2244,5	4,5	1702,3	3,4	1996,2	4,0
5	1668,0	3,3	2056,2	4,1	2560,9	5,1	2500,2	5,0
6	2267,6	4,5	1957,0	3,9	2368,6	4,7	2058,6	4,1
7	1770,2	3,5	2357,1	4,7	1522,3	3,0	1998,4	4,0
8	2575,2	5,2	2647,6	5,3	2667,0	5,3	2209,5	4,4
9	2904,1	5,8	1798,2	3,6	2376,2	4,8	2144,7	4,3
10	2975,5	6,0	2000,6	4,0	2152,0	4,3	2613,2	5,2
Average	**2405,6**	**4,8**	**2208,4**	**4,4**	**2241,5**	**4,5**	**2258,6**	**4,5**
Standard deviation	**454,4**	**0,9**	**283,1**	**0,6**	**384,2**	**0,8**	**262,7**	**0,5**

Appendix 3 Shear strength at 240℃

Table 9. Shear strength of scarf joints pressed at 240℃.

	Pressing time, sec							
	4		6		8		10	
Sample, no.	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**
1	1244,9	2,5	953,0	1,9	1137,0	2,3	2498,4	5,0
2	2313,0	4,6	616,7	1,2	1227,4	2,5	1382,8	2,8
3	1930,3	3,9	1189,1	2,4	996,1	2,0	2307,3	4,6
4	1909,6	3,8	699,0	1,4	1332,4	2,7	1891,2	3,8
5	1048,5	2,1	809,8	1,6	1406,6	2,8	2824,7	5,7
6	1377,8	2,8	552,2	1,1	1153,3	2,3	2341,2	4,7
7	1980,3	4,0	816,3	1,6	891,7	1,8	1507,0	3,0
8	991,9	2,0	995,0	2,0	972,4	1,9	1677,3	3,4
9	840,1	1,7	1164,5	2,3	1076,8	2,2	813,0	1,6
10	2418,9	4,8	1116,0	2,2	1167,0	2,3	840,6	1,7
Average	**1605,5**	**3,2**	**891,2**	**1,8**	**1136,1**	**2,3**	**1808,3**	**3,6**
Standard deviation	**573**	**1,1**	**228**	**0,5**	**160,2**	**0,3**	**688,4**	**1,4**

Appendix 4 Shear strength at 250℃

Table 10. Shear strength of scarf joints pressed at 250℃.

	Pressing time, sec							
	4		6		8		10	
Sample, no.	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**
1	1504,8	3,0	2043,6	4,1	1806,5	3,6	2111,6	4,2
2	1460,9	2,9	2249,3	4,5	1907,0	3,8	2009,2	4,0
3	1228,2	2,5	1224,8	2,5	2167,6	4,3	1987,3	4,0
4	586,8	1,2	1518,2	3,0	2307,4	4,6	1106,5	2,2
5	770,0	1,5	1445,2	2,9	1993,1	4,0	1896,8	3,8
6	1378,7	2,8	1228,2	2,5	1420,6	2,8	1611,2	3,2
7	1281,0	2,6	1965,4	3,9	1830,8	3,7	1320,7	2,6
8	1465,9	2,9	1531,8	3,1	1306,1	2,6	2188,7	4,4
9	729,6	1,5	1468,3	2,9	1755,3	3,5	2153,2	4,3
10	1420,6	2,9	1529,3	3,1	2412,3	4,8	1031,4	2,1
Average	**1182,7**	**2,4**	**1620,4**	**3,2**	**1890,7**	**3,8**	**1741,7**	**3,5**
Standard deviation	**349,4**	**0,7**	**347,1**	**0,7**	**353,5**	**0,7**	**442,7**	**0,9**

Appendix 5 Shear strength at 260℃

Table 11. Shear strength of scarf joints pressed at 260°C.

	Pressing time, sec							
	4		**6**		**8**		**10**	
Sample, no.	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**	**Maximum load, N**	**Shear strength, N/mm²**
1	927,3	1,9	1082,3	2,2	1241,7	2,5	1736,4	3,5
2	817,3	1,6	1097,7	2,2	1160,3	2,3	1663,5	3,3
3	1231,6	2,5	1614,0	3,2	1089,9	2,2	2224,5	4,5
4	675,5	1,4	1603,1	3,2	1006,1	2.0	1447,9	2,9
5	778,2	1,6	1545,1	3,1	1250,3	2,5	2079,2	4,2
6	850,6	1,7	1731,4	3,5	1684,9	3,4	1893,2	3,8
7	1155,1	2,3	1683,0	3,4	1301,7	2,6	2331,5	4,7
8	858,0	1,7	2238,5	4,5	1533,0	3,1	2102,2	4,2
9	1243,9	2,5	1769,4	3,5	1885,0	3,8	1666,5	3,3
10	1022,1	2,0	1455,5	2,9	968,1	1,9	1576,2	3,2
Average	**955,9**	**1,9**	**1582,0**	**3,2**	**1312,1**	**2,6**	**1872,1**	**3,7**
Standard deviation	**198,3**	**0,4**	**333,6**	**0,7**	**299,9**	**0,6**	**298,7**	**0,6**

Appendix 6 Wood failure at 4 second hot pressing

Table 12. Wood failure of scarf joints at 4 second hot pressing.

Temperature, ℃	Maximum load, N	Wood failure, %
230	927,3	10
230	817,3	10
230	1231,6	30
230	675,5	0
230	778,2	10
230	850,6	10
230	1155,1	40
230	858,0	0
230	1243,9	30
230	1022,1	20
240	1504,8	50
240	1460,9	50
240	1228,2	40
240	586,8	10
240	770,0	0
240	1378,7	40
240	1281,0	20
240	1465,9	30
240	729,6	30
240	1420,6	60
250	1244,9	30
250	2313,0	90
250	1930,3	60
250	1909,6	70
250	1048,5	20
250	1377,8	30
250	1980,3	20
250	991,9	40
250	840,1	10
250	2418,9	80
260	2697,7	80
260	2386,3	60
260	2724,7	80
260	2086,7	90
260	1668,0	30
260	2267,6	50
260	1770,2	20
260	2575,2	100
260	2904,1	80
260	2975,5	70

Appendix 7 Wood failure at 6 second hot pressing

Table 13. Wood failure of scarf joints at 6 second hot pressing.

Temperature, ℃	Maximum load, N	Wood failure, %
230	1082,3	20
230	1097,7	20
230	1614,0	30
230	1603,1	40
230	1545,1	50
230	1731,4	60
230	1683,0	50
230	2238,5	90
230	1769,4	50
230	1455,5	40
240	2043,6	100
240	2249,3	100
240	1224,8	20
240	1518,2	30
240	1445,2	40
240	1228,2	20
240	1965,4	50
240	1531,8	30
240	1468,3	40
240	1529,3	20
250	953,0	20
250	616,7	10
250	1189,1	40
250	699,0	10
250	809,8	10
250	552,2	0
250	816,3	10
250	995,0	20
250	1164,5	30
250	1116,0	40
260	2552,0	30
260	2444,9	20
260	2026,5	10
260	2244,5	50
260	2056,2	10
260	1957,0	20
260	2357,1	20
260	2647,6	100
260	1798,2	100
260	2000,6	50

Appendix 8 Wood failure at 8 second hot pressing

Table 14. Wood failure of scarf joints at 8 second hot pressing.

Temperature, °C	Maximum load, N	Wood failure, %
230	1241,7	30
230	1160,3	40
230	1089,9	60
230	1006,1	30
230	1250,3	70
230	1684,9	90
230	1301,7	40
230	1533,0	60
230	1885,0	60
230	968,1	20
240	1806,5	40
240	1907,0	40
240	2167,6	60
240	2307,4	80
240	1993,1	70
240	1420,6	30
240	1830,8	30
240	1306,1	10
240	1755,3	80
240	2412,3	100
250	1137,0	50
250	1227,4	40
250	996,1	10
250	1332,4	30
250	1406,6	40
250	1153,3	30
250	891,7	20
250	972,4	10
250	1076,8	10
250	1167,0	20
260	2056,0	100
260	2399,1	30
260	2610,3	100
260	1702,3	10
260	2560,9	30
260	2368,6	60
260	1522,3	20
260	2667,0	100
260	2376,2	50
260	2152,0	40

Appendix 9 Wood failure at 10 second hot pressing

Table 15. Wood failure of scarf joints at 10 second hot pressing.

Temperature, ℃	Maximum load, N	Wood failure, %
230	1736,4	80
230	1663,5	20
230	2224,5	70
230	1447,9	40
230	2079,2	70
230	1893,2	60
230	2331,5	90
230	2102,2	70
230	1666,5	40
230	1576,2	20
240	2111,6	90
240	2009,2	80
240	1987,3	50
240	1106,5	20
240	1896,8	70
240	1611,2	60
240	1320,7	10
240	2188,7	90
240	2153,2	100
240	1031,4	20
250	2498,4	80
250	1382,8	90
250	2307,3	100
250	1891,2	40
250	2824,7	90
250	2341,2	100
250	1507,0	50
250	1677,3	60
250	813,0	10
250	840,6	20
260	1976,4	40
260	2510,2	90
260	2578,2	90
260	1996,2	30
260	2500,2	80
260	2058,6	100
260	1998,4	100
260	2209,5	100
260	2144,7	50
260	2613,2	70