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LUT Mechanical Engineering

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POSSIBILITY OF PRESS FORMING WOOD FILMS INTO PRIMARY PACKAGING

Examiners: Professor Henry Lindell
M. Sc. (Tech) Sami Matthews

ABSTRACT

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In recent times the packaging industry is finding means to maximise profit. Wood used to be the most advantageous and everyday material for packaging, worktables, counters, constructions, interiors, tools and as materials and utensils in the food companies in the world. The use of wood has declined vigorously, and other materials like plastic, ceramic, stainless steel, concrete, and aluminium have taken its place. One way that the industry could reduce its cost is by finding possibilities of using wood for primary packaging after which it can be safely recycled or burned as a carbon source for energy.

Therefore, the main objective of this thesis is to investigate the possibility of press-forming a wood film into primary packaging. In order to achieve the stated objectives, discussion on

major characteristics of wood in terms of structure, types and application were studied. Two different wood species, pine and birch were used for the experimental work. These were provided by a local carpentry *workshop in Lappeenranta* and a *workshop in Ruokolahti* supervised by Professor Timo Kärki. Laboratory tests were carried out at *Lappeenranta University of Technology* FMS workshop on Stenhøj EPS40 M hydraulic C-frame press coupled with National Instruments VI Logger and on the Adjustable packaging line machine at LUT Packaging laboratory. The tests succeeded better on the LUT packaging line than on the Stenhoj equipment due to the integrated heating system in the machine.

However, there is much work to be done before the quality of a tray produced from the wood film is comparable to that of the wood plastic composite tray.

ACKNOWLEDGEMENTS

This master's thesis has been carried out at the Laboratory of Packaging Technology and FMS Laboratory using the LUT Flexible Packaging line and Stenhoj pressing machine in the Department of Mechanical Engineering, Lappeenranta University of Technology.

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Edward Nyarko
Mach, 2015
Lappeenranta, Finland

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LIST OF SYMBOLS AND ABBREVIATIONS

CCA	Chromate Copper Arsenate
°C	Degree Celsius
Dbh	Diameter at breast height
FMS	Flexible Manufacturing Systems
HPL	High Pressure Laminate
KN	Kilo newton
Hr	Hour
LUT	Lappeenranta University of Technology
MC	Moisture Content
MDF	Medium Density Fiber Board
Min	Minute
mm	Millimeter
MOE	Modulus of Elasticity
NEMA	National Electrical Manufacturer’s Association
OSB	Oriented Strand Board
%	Percentage
PSA	Pressure Sensitive Adhesive
WPC	Wood Plastic Composite

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1 INTRODUCTION

One of the significant raw materials often used for packaging and at the same time the most important raw material for the production of paper and board is wood (Hischier, Althaus & Werner, 2004, pp. 50-58). Huge sums of money are spent on packaging sustenance and different things every year where nearly sixty percent of all packaging is for nourishment items. Today packaging is fruitful industry and all the more frequently it is the way the packaging looks that induces and draws the attention to purchase the item contained. Figure 1, shows a familiar thermoformed wood designed for primary packaging.

Figure 1. Thermoformed wood (Groupe-lacroix.com, 2015).

In fact, wood as a primary package is the world's most vital renewable material and valuable fuel utilized around the world, and an imperative crude material for paper/board.

Wood has been uniquely characterized as a regular material for homes and different structures, furniture, apparatuses, vehicles, and prettifying items. Currently, for the same reasoning, wood is appreciated for a large number of uses including packaging in modern gadgets. It has also long been accepted that, the importance of exposing the wooden material to high temperatures can boost resistance to moisture absorption and ultimately durability (Wiermann, 2010, pp. 1-46).

Wood is essentially comprised of cellulose, hemicelluloses, extractives and minor sums (under 10%) of extra materials contained in a cell structure. Changes in the qualities and extent of these parts and contrasts in cell structure make woods stiff or flexible, heavy or light and hard or soft. Wood is as valuable as engineering material as ever, and in many cases, technological advances have made it even more useful.

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Wood has a high degree of quality to weight and an exceptional record for strength and execution as a structural material. Dry wood has great protecting properties against high temperature, sound and power. The experimental part of this thesis consists of different wood ply testing. There is already a method called crimping, which is commonly used in the furniture industry. This method is widely used in production of, for example chair back and seat components.

Kamdem et al. (2004, pp. 347-355), made an experiment by consolidating reused plastic and wood particles from Chromate Copper Arsenate (CCA) treated wood to perform tray pressing (Bledzki, 1999, pp. 221-274.). In this case, the assembling of wood plastic composites (WPCs) has made an exceptional position in the commercial center for a material that has astounding quality properties, workability, and rot safety (Kamdem et al., 2004, pp. 347-355). Subsequently, wood may have more advantages should it prove to be press-formed. In addition, Nadir Ayrilmis also experimented that the surface flatness of the WPC boards enhanced with expanding WPC thickness, plastic substance and hot-pressing temperature, while it declined with expanding wood flour size and gave best results in tray pressing (Ayrilmis, Benthien & Thoemen, 2012, pp. 325-33.).

1.1 Objectives of the thesis

The main goals of this thesis are to:

- Investigate the possibility of press forming wood films into primary packaging.
- Determine how wood films can be utilized in press forming.
- Investigate the suitability of how a variety of wood products can be press formed into primary packaging

Wood as a packaging material tends to dissipate vibrations under some conditions of use, and yet it is has not been proved to be press formed (tray pressing).

1.2 Delimitations

Primary packaging from wood film materials has been a major task for the packaging industry. Due to the number of wood films produced from the forest timbers, only two wood species will be considered

1.3 Wood Species

All wood is made up of carbon, hydrogen, oxygen, hemicelluloses, lignin, extractives and minor amounts (generally under 10%) of superfluous materials contained in the cell structure. Changes in the proportions and characteristics of these segments and contrasts in cell structure make woods dense or light, rigid or flexible and hard or soft. The properties of a single species are relatively constant within limits; therefore, selection of wood by species alone may sometimes be adequate. However, to use wood to its best advantage and most effectively in engineering applications, specific characteristics or physical properties must be considered (Wiermann, 2010, pp.1-46).

Generally, some wood species are used for numerous purposes, while different less accessible or less required species are unused or used for few needs. White oak for instance is classed to be extreme, solid and durable and it was highly prized for shipbuilding, scaffolds, vessels, animal dwelling place timbers, farm devices, train track crossties, boundary posts and floor covering. Black walnut and cherry woods on the other hand were primarily used for furniture and cupboards.

It was commonly acknowledged that wood from trees grown in certain locations under specific environments was stronger and more easily worked with tools, or with preferable grain of trees grown in different areas. Modern research on wood has substantiated that location and growth conditions do significantly influence its properties.

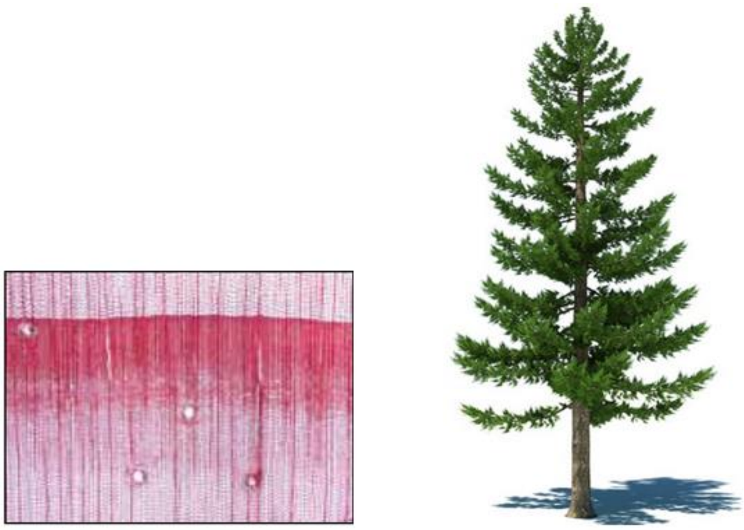
Essential elements that keep wood in the forefront of raw materials are numerous and they vary, however the primary trademark is its accessibility in numerous species, sizes, shapes, and circumstances to suit pretty much every interest. Wood has a high strength to weight proportion and an outstanding record for robustness and performance as a structural material (Wiermann, 2010, pp.1-46).

The grain designs and colours of wood make it a tastefully satisfying material and its appearance may be effectively improved by varnishes, stains, polishes and different completions. It is effectively molded with devices and attached with glues, nails, screws, fasteners and dowels. Damaged wood is effortlessly repaired, and wood structures are effectively redesigned or altered. Likewise, wood resist oxidation, corrosion, saltwater and other destructive materials, it has high rescue esteem, it has good shock resistance, it can be treated with additives and fire retardants and it can be can be combined with almost any other material for both functional and aesthetic uses (Wiermann, 2010, pp.1-46).

Pine together with spruce, is the main raw material used in the saw milling and paper industries in Finland. Spruce is the most suitable raw material for mechanical pulp making and pine for chemical pulping. Birch is used in sawmills, plywood and furniture industries and in chemical pulp making. Other, less commercially valued tree species can be utilized more efficiently in joinery and artisan professions in the regional level.

1.3.1 Pine

Pine is the most widely recognized tree species in Finland. Pine, spruce and birch constitute for 97 percent of general capacity of timber in Finnish woodlands. Having just few tree species is typical for the boreal coniferous zone (Koskisen, 2003a, p. 6).



Pine Radiata

Figure 2. Pine wood (Jayawickrama, 2001, pp. 51-56).

The most essential conifers used in the forest plantation is Radiata pine (*Pinus radiata*). The timber of this species is rated as very useful, due to its ease of drying, treatability and machinability. The Modulus of Elasticity (MOE) of a radiata pine tree is well known to increases as the tree ages. This happens because the Modulus of elasticity increases quickly with increasing age or ring number from the pith; older trees have a greater proportion of stiff mature wood (Jayawickrama, 2001, pp. 51-56.).

Properties of pine wood include: it is effortlessly cut/carved, it can undoubtedly acknowledge paint, it can have aesthetic bunches and it is genuinely cheap. It is likewise commonly light and it's promptly accessible. Pines are either white or yellow in color, and produce resins also.

The primary wood-based industries includes those that convert wood to thin slices (veneer), particles (flakes, chips) or fiber pulps and reconvene the elements to deliver different sorts of designed boards, for example, plywood, overlaid lacquer logs, particleboard, arranged strand board, paperboard, paper and fiberboard items. An alternate more current wood industry is the creation of overlaid wood items. The wood industry has additionally delivered small amounts of railroad lines, cooperage, shakes and shingles.

Information of the natural substance of wood and other tree-related materials has happened to expanding enthusiasm amid last few years (Saarelaa et al., 1998, pp. 51-56).

1.3.2 Spruce

The most common spruce grown in Finland is Norway spruce (*Picea abies)*. The term spruce includes three species: red (*Picea rubens*), white (*Picea glauca*) and black *(Picea mariana*). Spruce is a straight-trunked, densely branched, dark green conifer with its crown endings in a sharp tip (Koskisen, 2003a, 6p). The wood of the spruce indigenous to Finland is light yellow in colour and there is no colour difference between the sapwood and the heartwood. The annual rings stand out distinctly in the cross section of the trunk. Its needles are dark green. Spruce is a shade-tolerant tree species and its nourishment consists of water and other minerals. Spruce grows within the coniferous forest zones of the northern and southern parts of the globe. Spruce, maple and ebony trees are used for musical instrument such as guitars but spruce is the number one unique on the list of strength-to-weight ratio for all the woods in the world. Spruce has a density of 300-640 kg/m^3 and is easy to work on.

The wood of the Norway spruce is often used in the lumber industry and also have vital twisting properties, pounding quality (vertical and parallel to grain) and hardness (Wiermann 2010, pp.1-46). It is also often utilized in the creation of stringed instruments because it resonates well.

Cross-section of swan spruce timber.

Picea abies - Norway Spruce Tree

Figure 3. Spruce wood demo (Koskisen, 2003b, p. 6).

The wood has medium to fine texture and is without characteristic odor and has excellent properties for mechanical pulping and papermaking. On the basis of weight, Norway spruce rates high in strength properties and can be obtained in long, perfect and straight-grained pieces.

1.3.3 Birch

The three best essential species of birch are Silver birch (Betula pendula), European white birch (Betula pubescens) and yellow birch (Betula alleghaniensis) (Heräjärvi, 2005). These three species are the basis of most birch timber and veneer but the first two species are the most commonly known in Europe.

Silver Birch

White Birch

Figure 4. Birch wood (Heräjärvi, 2005).

Birch is a well-known wood species in woodland zones as well as in civil environment edifying the scene and the natural differences. In terms of wood that is hard, heavy, strong and it has a good ability to resist shock, both silver and white birch are not to be left out. The wood is fine and has a uniform in texture. The white and silver birch are used largely for the production of cabinets, furniture, wooden ware, boxes, baskets, crates, cooperage, internal woodworks and doors; the uses of veneer plywood is applies doors, furniture, cladding, aircraft, and other fields.

1.3.4 Birch Tree Appearance

The birch tree appears in the form of the specifications below.

- Maximum height ca. 30 m
- Maximum dbh (diameter at breast height) for trees in forest is ca. 40 cm
- Volume of matured trees is from 0.5 to 1.0 m^3
- Percentage of sawn log is approximately 40-60

There are deficiencies dismissing log-sized timber into pulpwood, for example, stem structure (crooks, scope, and parts), heart decay and extensive/vertical extensions. Silver birch has better stem structure, advanced and last cutting size than white birch. Silver birch has better stem form, growth and final cutting size than white birch. Silver birch is used predominantly by the wood product industries.

1.3.5 Properties of birch wood

The birch wood is heavy, hard and porous (Wiermann, 2010, pp. 1-46) The wood material is characteristically light colour, somewhat yellowish in colour in the wake of drying and it is anything but difficult to saw, lacquer, screw, cut, plane, paint, nail, vanish and paste. Birch is helpless against colour imperfections brought about by a stem digger ***Phytobia betulae,*** however genuine heartwood does not exist. . At the age of 70-90 years, the wood material near the pith is darkened by decay.

Birch Timber

Figure 5. Logs of birch wood (Heräjärvi, 2005).

1.3.6 Birch Utilization

About two third of the reaped birch is utilized as a part of chemical and mechanical pulping whilst the product of wood industry uses ca. 1.3million m^3 of quality birch logs yearly. It is evaluated that plywood and veneer commercial enterprises use ca. 1.1 million m^3 and 0.25-0.3 million m^3 used by the saw mills. The other uses for the birch wood are for particle board industry, generative fuel, xylitol, residential supplies, birch bark handiworks, sap refreshments, steam bath (sauna) apparatus etc.

Figure 6. Birch wood film (Heräjärvi, 2005).

1.4 Lamination Techniques

Laminated wood product comprised of at least first and second adjacent sawn wood strips, each of said strips, when cut, having corresponding first and second opposed edges, and first and second opposed faces, said strips being oriented so that the first edge of said first strip abuts the first edge of said second strip and said first faces lie in a common plane (Pat. US 5968625 A, 1999, 11p).

The lamination system has been utilized to produce variety of shapes (bended, decreased and ribbed) of wood layers to suit engineering and structural capacities. Likewise, short wood pieces can be utilized for this reason and it is conceivable to uproot quality diminishing qualities because of bunches, shakes or drying in light of the fact that the lamination need not be thick when prepared before assembling. By improving the laminate, dried and little thickness of wood without debases can be utilized. Overlay may be situated because of quality principles concerning species, thickness, evaluations and blemishes. Laminated timber has less irregularity in quality and firmness contrasted with impressive sawn timber (Keskin, 2009, pp. 796-803).

Lamination is a processing approach to produce a composite structure with improved strength, stability and appearance by using two or more materials stacked in multiple layers. A wide range of materials are known to laminate to each other, and the process is continued until the laminate has the desired properties. Finally, the laminate is permanently assembled by heat, pressure, welding or adhesives (Thermoforming laminates, 1996, pp. 162-163)

Technological advancement in the field of lamination has led to different ways in which wood can be laminated. Film lamination, extended film lamination and glued lamination are a few such processing approaches.

In this chapter, a detailed discussion on the fundamentals of lamination is provided. A complete overview of the different types of available commercial laminates is given. Furthermore, different laminating techniques currently used in commercial lamination are presented.

1.4.1 Typical Commercial Laminates

The structure of laminates consists of a laminating film and an adhesive backing. Each laminating film is either cold or heat-assist film and is available in different grades for variety of applications. Adhesives backing are either pressure-sensitive or thermal adhesives, but a crossover between thermal and Pressure Sensitive Adhesive (PSA) is available for certain applications, each with its own particular set of focal points and disadvantages.

In cold films applications pressure sensitive glues are utilized and these are subsequently referred to as PSA films. These films oblige a discharge liner and weight is expected to initiate the bonding agent. These films are anything but difficult to utilize, they tie to nearly anything and function admirably in outdoor environment, but they are expensive compared to heat-assist films. PSA items broadly utilized as a part of packages, automotive gadgets, electrical and correspondence industry, construction modeling industry, home individual consideration, medical industry etc. **(**Sun, Li & Liu, 2013**,** pp. 98-106**).**

Generally, PSA adhesives are made of acrylics, for precision, and they are available in two basic types: solvent-based for long-term outdoor durability, and aqueous or water-based which is traditionally used for interior applications.

High temperature films help utilizes an adhesive that is a hybrid in the middle of heat and PS adhesives, however they are still viewed as PSA films. They additionally have a discharge liner, however adhesives are triggered at a much lower temperature about 170°C and provide more aggressive binding power. In addition, they stand extra reactive to low temperature than a conventional Pressure Sensitive Adhesive film. The incomplete lamination that brings about colour shift is overcome by mostly using heat-assist films to laminate the vinyl. (Mergentime, 2007.)

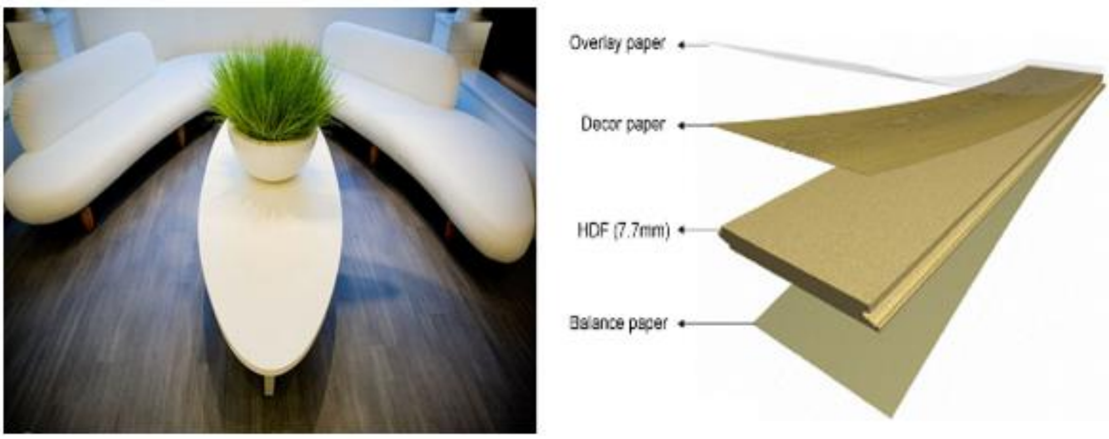


Figure 7. Structure of Commercial Flooring laminates (An, Kim & Kim, 2011, pp. 44-51).

1.4.2 High pressure laminates

High-pressure laminates (HPL) are also characterized as elastic laminates. These consist of superimposed layers of a thermoset, resin impregnated or resin-coated films bounded together by heat and pressure (Ashter, 2014, pp. 16). In standard publication of LD 3-2005, entitled High-Pressure Decorative Laminates the National Electrical Manufacturers Association (NEMA) defines a high-pressure laminate as materials that have been overlaid at pressures of more than 5.0 MPa utilizing thermosetting buildup pitches as covers. The most well-known resins utilized are phenol-formaldehyde and melamine-formaldehyde thermoset gums (Compositepanel.org, 2015).

The immense dominant part of high-weight laminates utilized as overlays on wood substrates are created by mounding a discretionary alpha-cellulose sheet and an improving paper sheet, both pervaded with melamine resin, over different Kraft paper sheets impregnated with phenolic resin, and consolidating the sheets together in a press, at temperatures over 130 °C and pressures as high as 8274 MPa. The discretionary alpha-cellulose sheet, well known as flooring products, becomes completely clear during the pressing procedure; it is utilized mainly with print patterns and add additional wear resistance to the surface. HP laminate could be used in a range of applications from countertops, cabinets and store fittings to furniture, post-forming applications and much more (Ashter, 2014, pp. 17).

The last thickness of the shield is controlled by the quantity of spreads of Kraft paper, the measure of resin retained by the paper and the weight utilized as a part of the press. This resin filled paper is mostly utilized as a decorating and protecting shield for compound wood plates (particleboard) and for intermediate density fiberboard (ROBERTS & EVANS, 2005, pp. 95-104). The surface finish (that is, composition and shine level) is bestowed to the surface of the shield while the overlay is being pressed, by a coarse steel caul plate or an emblazoned discharge paper sheet. HP shields are accessible in a huge number of robust hues, printed samples and facades, in sheets of diverse measurements.

Figure 8. High Pressure laminate floor (Bisson, Deomano & Do, 2014).

HP overlay is a scanty, steady, compact, rigid and abrasion safe material that has superb tasteful bid and strength. It is overlaid on particleboard or Medium Density Fiberboard substrates for both upright and level end client applications, for example, ledges, tabletops, sink tops, furniture, cabinetry and case products (Ashter, 2014, pp. 16.). Figure 9, shows several layered impregnating papers applicable on high laminate flooring as illustrated in figure 8.

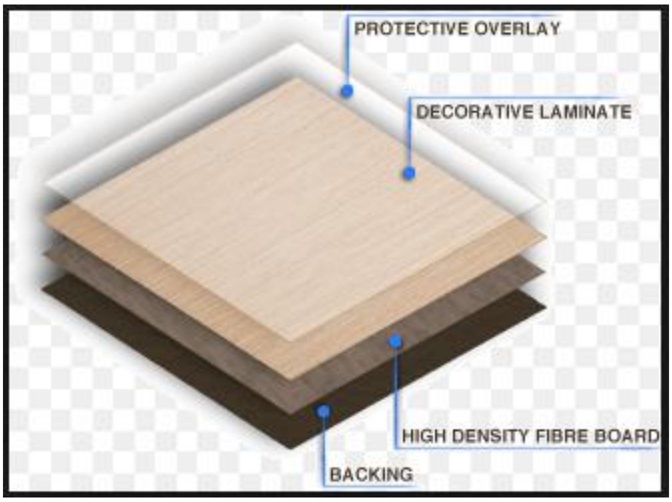


Figure 9. HPL (Impregnating layers of Kraft paper) (Kandelbauer & Teischinger, 2009, pp. 367-378)

It is likewise thought to be a standout amongst the strongest ornamental surface materials and it is accessible with extraordinary execution properties including compounds, fire and wear safety (Bisson, Deomano & Do, 2014.)

1.4.3 Thermally Fused Papers

Many names are given to papers in this overlay category such as low pressure papers, saturated papers, direct pressure or merely melamine overlays, and they are used in low weight/thermofusing overlay. With a specific end goal to meet the specific prerequisites for their final utility, a large portion of the wood-based boards are layered with décor papers, which can enhance the mechanical properties of sheets and oppose the assimilation of water and humidity (Liu and Zhu, 2014, pp. 132-137).

Decorative phenolic and polyester are sub-categories of thermally fused papers. These ornamental papers normally have grammages around 60 and 130 g/m^2, and their paper creation is similar to the arrangement of the enhancing sheets utilized for HPL. They are immersed with responsive resins, which are then somewhat treated by the producer, to support and storing of the paper. Laminating hot presses enables the full curing to be achieved, when hard resins are formed and perpetual thermoset securities between the paper and the substrate. Cover of permeated sheets on top of wood-based boards takes place in presses at temperatures around 160 and 180 ◦C. Depending on the type of product, the forced time succession of modern press equipment ranges from 6-30 s for few cycle presses to several minutes in multi-platen presses (Kandelbauer et al., 2009, pp. 556-565.)

Thermally melded papers are self-bonded, i.e., the pitch in the paper runs into the panel amid overlay to produce a lasting connection between the advanced surface and the board substrate. There is no need for any extra cement framework. The three most normal thermoset adhesive frameworks utilized as a part of the creation of immersed papers for less weight/thermofusing spread are polyester, melamine formaldehyde and enlivening phenolic pitches. When twofold stage impregnation materials are accessible, saturating urea formaldehyde resin may be used to broaden the melamine resin in the focal point of the saturated sheet (Ashter, 2014, pp. 16).

Normal end-use uses of thermally joined papers combine spread deck, kitchen cabinets and ledges, racking, store contraptions and home office furniture.

Figure 10. Thermally fuse impregnated papers (Kandelbauer et al., 2009, pp. 556-565).

1.5 Vinyl Films

Vinyl films are produced using polyvinyl chloride and can be utilized in multitude of applications (Compositepanel.org). They arrive in varieties of thickness, from 0.051 to 0.11 mm and different grades of flexibility. These types of overlays are commonly expelled or calendared and are partitioned to almost six classifications.

1.5.1 Reverse-printed rigid film

The print plan and base coat are imprinted in in the back of a transparent film, in converse request (i.e. the print is applied first followed by the base coat).

Divider paneling utilizes these type of films (generally as a part of recreational vehicles), kitchen cupboards, furniture and fabricated lodging (Bisson, Deomano & Do, 2014.)

1.5.2 Semi-rigid pure film

These films are printed backwards. They are emblazoned and can be covered with scrape safe coverings. They extend from 0.10 to 0.20 mm in thickness. Many of them can be miter-collapsed (compositelpanel.org).

1.5.3 Interpose film

These films are semi-unbending, two-employ coats. The dinky base film is top printed and an acceptable coat is covered on top of the printed film. These films are proposed for miter-collapsing and level sheet overlay, and reach from 0.14 to 0.20 mm in thickness. Some are available with scrape safe top covering (Bisson, Deomano & Do, 2014).

1.5.4 Solid color film

These are also semi-unbending films. The film is fundamentally shaded and could be top-printed or embellished. These type of films are utilized widely as a part of industrial housing, viable paneling, entertaining vehicles, and portable dividers. Normal artefacts are utilized as a part of furniture, kitchen cupboards, in apparatuses and presentations, and in office furniture uses (Bisson, Deomano & Do, 2014). Thin film interference is a dominant approach to structural coloration, involving single layer reflectors and multilayer reflectors. The single layer reflectors are found commonly in nature, where light is reflected and interfered from the upper and lower boundaries with its neighbors (Jia et al., 2014, pp. 10-16.)

They range in thickness from 0.089 to 0.20 mm. Some films are realistic with scuff resistant for upper coatings.

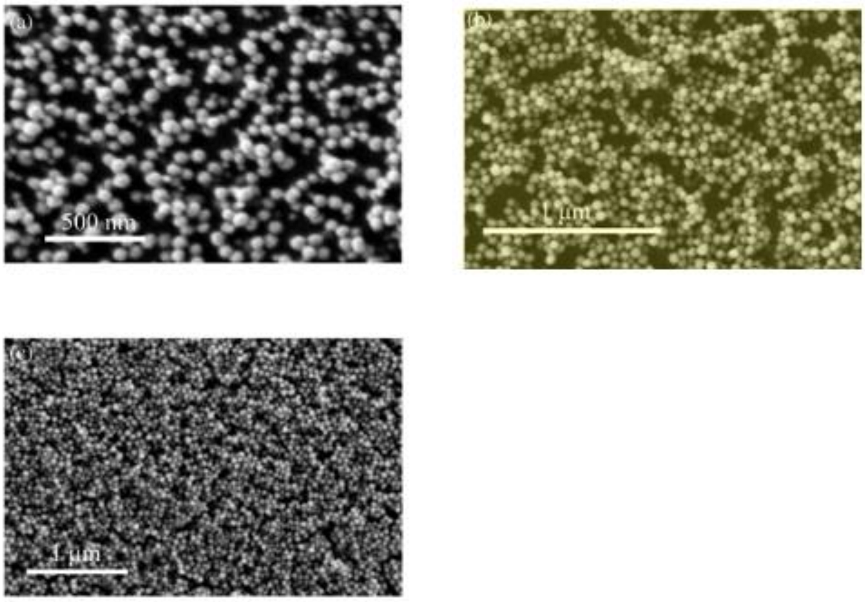


Figure 11. Images of thin solid film of various cycles. a) 2-cycle b) 4-cycle c) 20-cycle (Jia et al., 2014).

1.5.5 Thermoformed overlay film

These construction of this film is either a single-ply or two-ply. Gauges range from 0.010 to 0.030 inches (0.25 to 0.76 mm) and the films may be printed with a wood grain or decorative configuration (Bisson, Deomano & Do, 2014). They might likewise be embossed and/or covered with scrape and stain-safe coatings. Preparations to advance attachment are accessible. These films are intended for thermoforming with high temperature and pressure in a film press or vacuum shaping process. Beautiful impacts can be accomplished with two-ply films when a switch is utilized to uncover an alternate shading in the bottom ply of the film. The films might likewise be level covered or miter-collapsed. Raised board panel entryways and free-structured furniture parts are the most prominent applications for this kind of film.

1.5.6 Wrapping films

These are unbending vinyl films in gauges extending from 0.005 to 0.010 inches (0.13 to 0.25 mm). The films may be printed with a wood grain or enhancing pattern may be decorated and/or may be covered with scratch and stain-safe coatings. These films are intended for wrapping profiles, in the same way as picture edges and furniture trim, furthermore they can be flat laminated and miter-folded.

1.6 Wood Veneers

Wood veneer is a building material made from very thin sheets of usually in the order of 0.5 to 1 mm from lumber (Blomme et al., 2010, pp. 180-187). It can be acquired by peeling off the storage compartment of a tree by a sharp blade and glued over a plywood or hardboard base to make furniture, woodwork and other compositional components. Wood finishes offer numerous points of interest to developers and mortgage holders and are accessible in different types to address the needs of any application (Bisson, Deomano & Do, 2014.) The veneers utilized in the lamination industry incorporate real wood veneers that are rotary cut, flat cut, rift cut or quarter cut from a variety of wood species, both domestic and imported (Hall & Giglio, 2011, pp. 520) as illustrated in Figure 12. The veneers are cut or peeled to a thickness between 1/25 to 1/50 inch (1.0 to 0.50mm) and are accessible with a paper or fleece backing, giving differing degrees of adaptability.

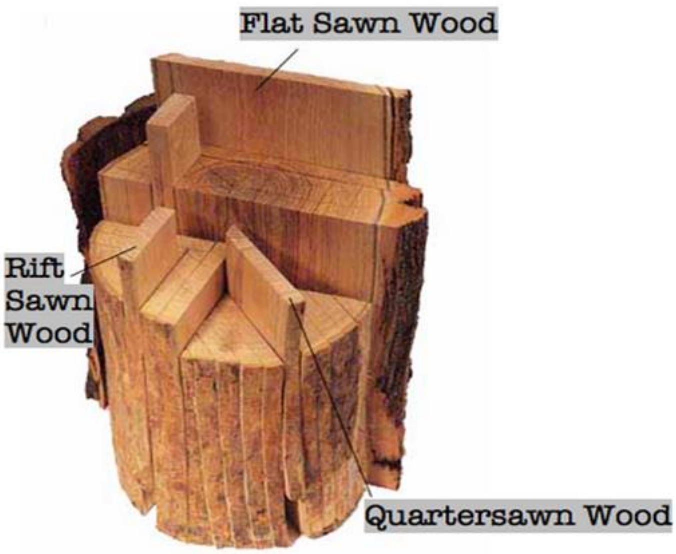


Figure 12. Veneer cuts (Hall and Giglio, 2011, pp. 520).

Flat or plain sliced units are made by placing half of a log onto a flat surface and slicing off parallel layers, which produces lots of grain variation. Quarter-cut veneers are sliced at a right angle to the log's rings to create a very even, striped grain pattern. Rift cut veneers are cut at 15 degrees to the growth rings to create a speckled look known as fletching.

1.7 Heating and Drying of Wood

The objective of wood drying is to bring the moisture content close to the expected value that a finished product will have in service. In the stove-drying method, specimens are taken from representative boards or pieces of a quantity of the wood. They should be free from knots and different anomalies, such as bark and pitch cavities. Specimens from lumber should be full cross sections (Bergman, 2010, pp.1-2.). To void drying or uptake of moisture, each specimen must instantly be measured. In the determination, the sample is warmed in an oven to 100 °C and kept there until no appreciable weight change occurred.

Water in wood regularly moves from high to low zones of moisture substance, which implies that the surface of the wood is dried. Drying of wood can be differentiated into two stages: movement of water from the inside to the wood surface and vanishing of water from the surface. The surface fibres of most species attain to moisture equilibrium with the surrounding air not long after in the wake of drying begins. On the off chance that air flow is excessively abate, a more drawn out time is needed for the wood surface to attain to moisture equilibrium. This is one reason why air circulation is so vital in oven drying. In the case that air flow is excessively reduced, the drying rate is slower and this might cause fungus to grow on the surface of lumber (Bergman, 2010, pp.2-3.). In the event that drying is excessively quick, electrical energy in running the fans is wasted, and in specific species the surface and other drying deformities can develop if relative humidity and air speed are not controlled.

1.8 Determination of Moisture Content

Wood, in the same way as other characteristic materials (Zelinka, Glass & Derome, 2014, pp. 67-74.), is hygroscopic; it takes on moisture from the neighboring environment. Moisture exchange between wood and air relies on upon the relative humidity and temperature of the air and the current measure of water in the wood. This measure of moisture has an imperative effect on the wood properties and performance. The measure of moisture in wood is usually conveyed as a rate of wood mass when oven dried. The oven drying strategy has been the

most generally acknowledged technique for deciding moisture content. This is direct method and there is a need of cutting the wood (Glass & Zelinka, 2007, pp. 1-2.).
The physical and mechanical properties of wood are often based on the moisture content of the wood. Moisture Content is characterized as the ratio of the mass of water to the mass of dry wood, expressed either as a percentage or decimal (Glass & Zelinka, 2007, pp. 1-2). This depends on the temperature and relative humidity of the ambient air, and also on the previous moisture history of the wood. The Moisture content (MC) is normally expressed as a percentage and can be calculated from equation 1.

$$MC = \frac{M_{water}}{M_{wood}}(100\%) \quad (1)$$

Where m_{water} is the mass of water in wood and m_{wood} is the mass of the oven dry wood. Operationally, the moisture content of a given piece of wood can be calculated by equation 2 (Laurila, Havimo & Lauhanen, 2014, pp. 286-289).

$$MC = \frac{M_{wet}}{M_{dry}}\ (100\%) \quad (2)$$

Where m_{wet} is the mass of the specimen at a given moisture content and m_{dry} is the mass of the oven dried sample (Chen, 2003, pp. 447-457).

Table 1 gives the normal moisture content of green heartwood and green sapwood of some local species. Wood in service is presented to both long haul (regular) and short-term (every day) changes in relative humidity and temperature of encircling air which incite changes in wood moisture content (Simpson, 1910, pp. 463.) Figure 13 demonstrates a chart of moisture content of wood when presented to the humidity and temperature.

Table 1. Average moisture content of green wood, by species (Glass & Zelinka, 2007, pp. 1-2).

Species	Moisture content (%) Heartwood	Sapwood
Hardwoods		
Alder, red	—	97
Apple	81	74
Ash, black	95	—
Ash, green	—	58
Ash, white	46	44
Aspen	95	113
Basswood, American	81	133
Beech, American	55	72
Birch, paper	89	72
Birch, sweet	75	70
Birch, yellow	74	72
Cherry, black	58	—
Chestnut, American	120	—
Cottonwood	162	146
Elm, American	95	92
Elm, cedar	66	61
Elm, rock	44	57
Hackberry	61	65
Hickory, bitternut	80	54
Hickory, mockernut	70	52
Hickory, pignut	71	49
Hickory, red	69	52
Hickory, sand	68	50
Hickory, water	97	62
Magnolia	80	104
Maple, silver	58	97
Maple, sugar	65	72
Oak, California black	76	75
Oak, northern red	80	69
Oak, southern red	83	75
Oak, water	81	81
Oak, white	64	78
Oak, willow	82	74
Sweetgum	79	137
Sycamore, American	114	130
Tupelo, black	87	115
Tupelo, swamp	101	108
Tupelo, water	150	116
Walnut, black	90	73
Yellow-poplar	83	106

Species	Moisture content (%) Heartwood	Sapwood
Softwoods		
Baldcypress	121	171
Cedar, eastern red	33	—
Cedar, incense	40	213
Cedar, Port-Orford	50	98
Cedar, western red	58	249
Cedar, yellow	32	166
Douglas-fir, coast type	37	115
Fir, balsam	88	173
Fir, grand	91	136
Fir, noble	34	115
Fir, Pacific silver	55	164
Fir, white	98	160
Hemlock, eastern	97	119
Hemlock, western	85	170
Larch, western	54	119
Pine, loblolly	33	110
Pine, lodgepole	41	120
Pine, longleaf	31	106
Pine, ponderosa	40	148
Pine, red	32	134
Pine, shortleaf	32	122
Pine, sugar	98	219
Pine, western white	62	148
Redwood, old growth	86	210
Spruce, black	52	113
Spruce, Engelmann	51	173
Spruce, Sitka	41	142
Tamarack	49	—

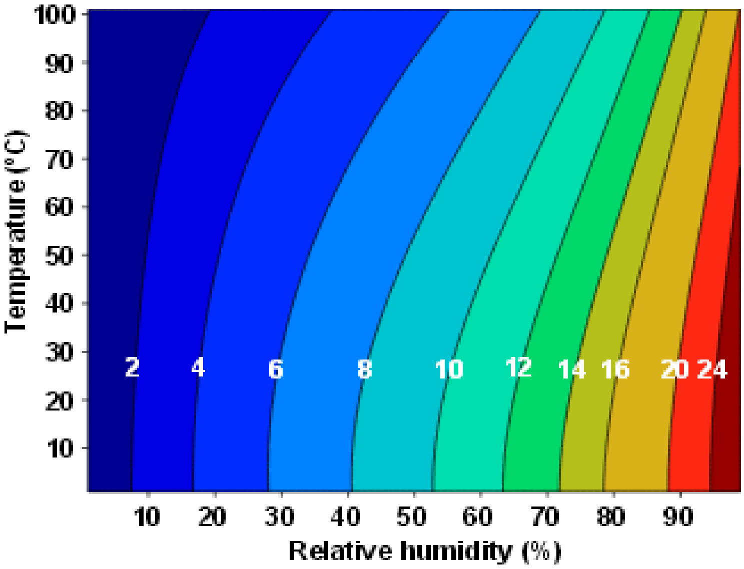


Figure 13. Equilibrium moisture content of wood (labeled contours) as a function of relative humidity and temperature (Glass & Zelinka, 2007, pp. 2-3).

2 MATERIALS AND METHODS

This chapter gives the in depth knowledge of how the experiment was carried out and the resources used to test the hypothesis (materials).

2.1 Experimental Setup and Description

In order to verify on the stated objectives of this thesis, three different test were carried out using the following two materials:

1) Radiata (pine)
2) Yellow (birch)

The aim was to ascertain the possibility of these materials to be press formed into primary packaging as stated previously.

Equipment used in this experiment were Stenhøj EPS40 M hydraulic C-frame press coupled to National Instruments CA-1000 Connector Accessory Enclosure with National Instruments VI Logger version 2.01 in logging computer, kitchen oven and Adam Equipment's PMB 53 Moisture Analyzer for measuring moisture content.

Sample 1, is pine veneer films provided in two thicknesses by a local carpentry workshop in Lappeenranta. The veneer film pieces measures 210 x 150 x 1 mm and 210 x 150 x 0.6 mm respectively. A total number of 8 pieces were tested. The first 5 pieces were oven heated in water at 100 °C for 5 minutes. The three other species were oven heated at 90°C for 5 minutes**.** Sample 2 and 3 which is pieces of birch film measures 220 x 183 x 0.5 mm and 228 x 190 x 1 mm were provided by a workshop in Ruokolahti supervised by Professor Timo Kärki in the Department of Mechanical Engineering, Lappeenranta University. The various wood films were placed in the oven and heated for different periods of time. After each heating period the wood was removed and placed under the Stenhoj pressing machine and pressed for 2 minutes as was shown in Figure 15.

A series of pressing experiments were conducted with the Stenhøj EPS40 M hydraulic C-frame press coupled with National Instruments VI Logger. The effectiveness of the experiment was determined by the differences in heating period, temperature and pressing time of different wood species (Hansson & Antti, 2006, pp. 467-470.). Descriptions of grades and pictures of the wood species pressed are contained in the results of the thesis in chapter 3. The second experiment was carried out at the LUT packaging laboratory with the Adjustable packaging line machine as illustrated in Figure 14. There were different measurements of wood film used in performing this experiment.

Samples of birch wood veneer were soaked in water for different period of times namely 2, 4 hours and even 5 days. These were then pressed by the LUT adjustable packaging line machine as shown in appendix II (1/6)

Figure 14. Press forming module of LUT adjustable packaging line

Figure 15. LUT Stenhoj machine pressing demonstration.

2.2 Forming Method

The pressing and drawing of parts from slender film of wood, composites or slim sheet requires careful investigation of the forming procedure involved in order to get the defined shape or size without further adjustment. Variables which must be considered incorporate the impact of the punch and radii, the punch to die leeway, the heat treatment of the tooling, the lubricant and the press speed, the press power and the holding force. All these variables will influence the quality of the final part. Improper tooling outline may prompt fizzled or wrinkling, clasping or inadequate formation of the part been pressed (Browne & Battikha, 1995, pp. 218-223.). The thin film of wood is placed between the punch and the die which is supported by a block beneath which is latter held in a hollow die. This process known as flexible forming designed to be used on flanges and relatively simple configuration.

2.3 Forming tool (Equipment)

Stenhøj EPS40 M hydraulic C-frame press coupled to National Instruments CA-1000 Connector Accessory Enclosure with National Instruments VI Logger version 2.01 in logging computer was used in this work. It is a hydraulic machine devoted for the creation of little, center and expansive arrangement in profound draw, punching, bowing, assembling, stamping, straightening, composite pressing and hot pressing. The press is furnished with a heap cell and a relocation transducer, the instrument is interfaced with a PC via a data acquisition board, and Lab Windows software is used to process and analyze the load/displacement data, see figure 16.

Figure 16. STENHØJ flexible pressing machine. (FMS workshop, LUT).

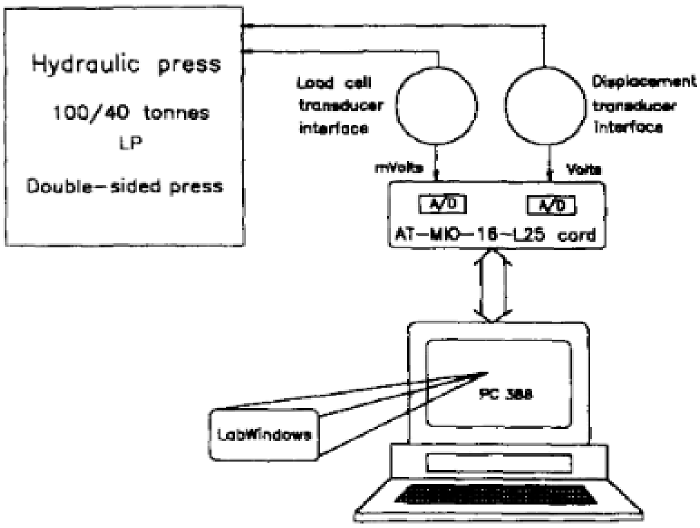


Figure 17. The interface between the hydraulic press and the PC (Browne and Battikha, 1995, pp. 218-223.).

The Stenhoj LP pressing machine can also be used for the following:

- Automotive and sub supplier commercial ventures
- Electro- and house holding machines commercial ventures
- Metal- and plastic commercial ventures
- Steel- and sheet metal commercial ventures
- Tool shops and toolmakers
- Forging industries

2.4 Measuring Equipment (Adam Equipment's PMB 53 Moisture Analyzer)

The moisture content of a piece of wood was determined by Adam Equipment's PMB 53 Moisture.

Adam's PMB 53 can accurately and quickly analyze the moisture content in wood in a few minutes. The specimen is placed into the heating chamber and heats is applied to the sample using the PMB's energy-efficient incandescent light. The light dissipates moisture and calculates the amount of moisture weight loss to get the moisture content (Adam Equipment, 2015).

Figure 18. Adam Equipment's PMB 53 Moisture Analyzer (Adam Equipment, 2015).

Readings were taken from samples where the wood is representative of the whole piece and is free of defects such as checks, decay, holes, gum or resin veins or knots illustrated in figure 18.

2.5 Kitchen Oven

Whirlpool AKZ 323/IX was used in experiments to heat the specimen. It is measured 595 x 538 x 595 mm and have operation frequency of 50Hz. The normal oven output power is 3.65 KW with a volume of 65 litres as shown in figure 19.

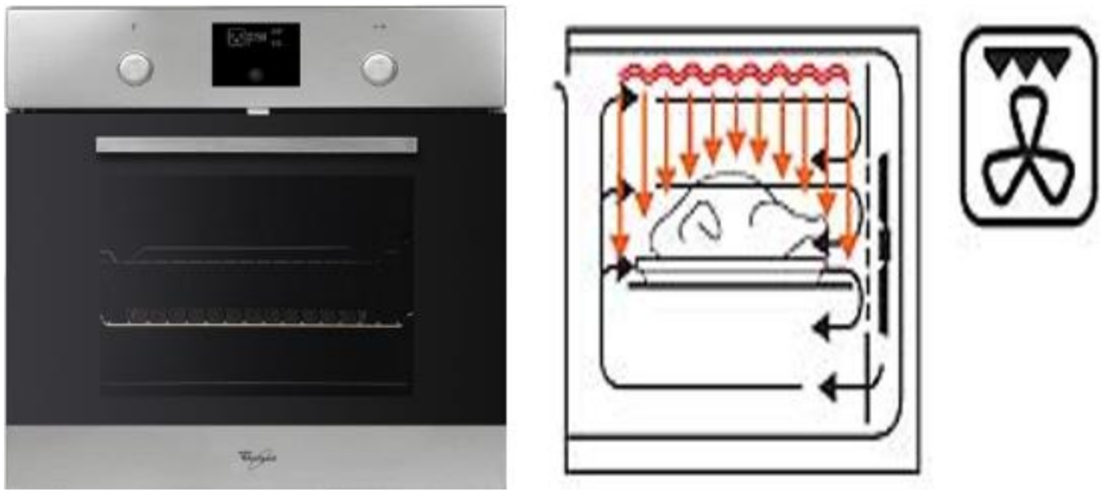


Figure 19. Oven (Whirlpool AKZ 323/IX) www.whirlpool.fi

In the oven, warming is affected by the top center element (yellow arrows) and the heat is distributed by the fan (black arrows) resulting in evenly heating of the wood film. This represents an undeniable advantage over customary convection warming, where the required vitality flux needs an 'outside-to-inside' main thrust which typically requires extraordinarily high surface temperatures that can disintegration of the heating object. In line with this, the oven offer more adaptability to fulfill safety and quality (Sanchez, Banga & Alonso, 2000, pp. 21-29)

The oven in Figure 19, was used to heat the wood film to attain its moistening temperature before pressing. The heating and moistening involves inserting wood specimen in a bowl filled with water. The wood products was rapidly heated to the boiling point of water throughout their whole volumes. Temperature and moisture distribution during drying are highly exceedingly related with the internal drying stresses (Du, Wang & Cai, 2005, pp. 2421-2436). The oven is built-in with a regulator to adjust the fan output power and the time of heating (Al-Harahsheh, Al-Muhtaseb & Magee, 2009, pp. 524-531).

Due to radiation, the heat is dissipated from the resistor heating element into the material to change its appearance and moisture content. The control of the amount of temperature of the oven was taken into consideration to get the optimal time needed for the test.

The penetration depth of the oven temperature did not greatly affect the wood film during heating. The appropriate heat generation depends on the rate of temperature increase, which depends in turn on the sample size, thermal properties and other factors. In a regular kitchen oven that heats with a constant power, the update frequency in simulations could be simplified by indirectly applying the time step interval (Liu et al., 2014, pp. 142-153.)

After the moistened wood film is heated, it was directly taken to the Stenhoj pressing machine for pressing. The overall goal was achieved after the wood films has been pressed with different temperature degrees and time. Three separate laboratory experiments were carried out. Out of the three experiments, two test were carried out at the Mechanical welding lab with the Stenhoj pressing machine and the other one carried out at the Packaging laboratory.

2.6 Response of wood to heating

When the wood is heated in the water, the moisture content increases leading to an advantage factor (Oloyede & Groombridge, 2000, pp. 67-73). It can be seen from Equation 2 in chapter one, that the increase in advantage factor causes decrease in the drying process. This can result in very effective pressing leading to a quality work.

3 RESULTS AND ANALYSIS

This section discusses results obtained on the three experimental test carried out on pine and birch wood films. In the experiments, a wide range of operating conditions was considered such as heating temperature of the wood films, moisture content and material holdup. The experimental results are discussed below.

In the first test, pine wood films were pressed with the Stenhøj EPS40 M hydraulic C-frame press coupled to National Instruments CA-1000 Connector Accessory Enclosure with National Instruments VI Logger version 2.01 in logging computer.

Table 2. Laboratory experiment 1a for Radiata pine.

Experiment 1a. Radiata Pine	Thickness of wood film (mm)	Moistening time (hr)	Moisture content (MC) %	Heated temperature (**°C)**	Pressing distance (mm)	Heating period (min)	Moisture content after heating (%)	Pressing time (min)
Test point 1	0.6	0.25	53.02	100	12.6	5	1.11	2
Test point 2	0.6	0.5	57.30	100	12.2	5	1.02	3
Test point 3	0.6	1	68.92	90(water-soaked)	12.9	10	5.39	5
Test point 4	0.6	2	61.60	90	10	10	5.28	5

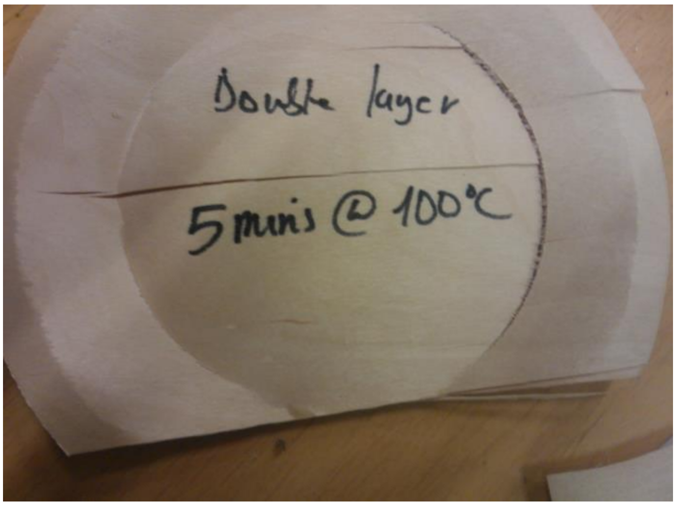


Figure 20. Sample for test point 2 of radiata pine wood film experiment 1a

Table 2 presents the values of different parameters used for each species of radiata pine wood film. Figure 20 shows double ply of radiata pine wood film which was pressed under the temperature of 100°C for a period of 5 minutes. Due to its low moisture content and fragility of the wood, it can be seen from figure 20 that cracks occurred at its corners causing the wood ends to be totally broken. However, the rupture at its bending corners and the ends is attributed to its thickness being less that 1mm.

Figure 21. Sample of radiata pine wood film for test point 3.

Figure 21 shows a sample of radiata pine wood film. During the experiment it was observed that because of its higher moisture content level, the film remains unbroken but returns to its original shape two (2) minutes after pressing. It can be deducted that, the lower the heating temperature, the higher the pressing time needed in order to achieve steady pressed shape.

Table 3. Laboratory experiment 1b for Yellow Birch

Experiment 1b Yellow Birch	Thickness of wood film (mm)	Moisture content (%)	Heating temperature (°C)	Pressing distance (mm)	Heating period (min)	Moisture content after heating (%)	Pressing time (min)
Test point 1	3.5	10.09	100	17.6	5	7.44	2
Test point 2	3.5	10.09	100	16.42	5	7.6	3
Test point 3	3.5	10.09	90(heated in water)	17.9	10	7.54	4
Test point 4	1	10.6	100	14.4	10	2.12	5

Table 3 presents various parameters used in the second test for yellow birch. As illustrated in table 3, the heating temperature remains almost constant and therefore the results obtained with pressing can only differ with regards to the film thickness. The details of the other test samples are presented in appendix 1.

Figure 22. Sample experiment 1b of yellow birch for test point 2

Figure 22, shows a typical birch wood film of 3.5mm thick heated in oven at a temperature of 100°C. It was pressed under the Stenhoj Machine for five (5) minutes. As presented in figure 22, it can be seen that the cracks which occurred at its ends is as a result of pressing the wood in the direction of the fiber grain. This also occurs probably due to the dryness of the wood at a higher temperature.

Figure 23. Sample experiment 1b of yellow birch, test point 4

Figure 23, shows a sample of birch wood with a thickness of 1mm. The sample got ruptured at all corners and ends due to its thickness and dryness. It was observed that, the drying rate increases with an increase in cracking causing severe deformation of the wood film as shown in Figure 23. The results of the other samples in the test are presented in appendix 2.

Table 4. Laboratory experiment test 2a for Birch veneer cut

Experiment 2a Birch veneer cut	Material thickness (mm)	Moisturizing time (hr)	Heating time (min)	Oven temperature (°C)	Applied load (KN)	Press holding time (min)
Test point 1	0.7	2	5	60	0.3	5
Test point 2	0.7	1	5	60	0.2	10
Test point 3	0.7	3.15	5	60	0.4	5

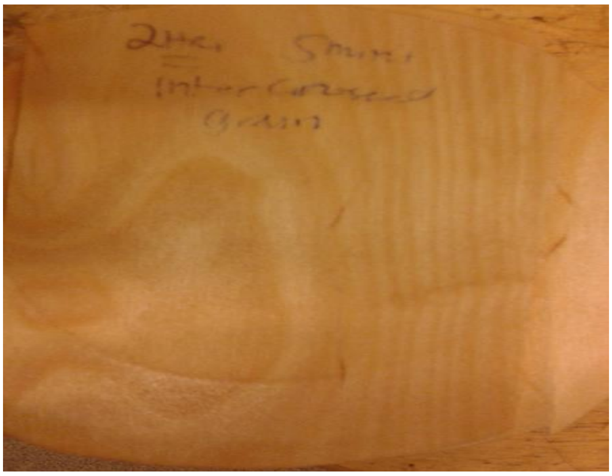


Figure 24. Sample experiment 2a of birch veneer cut for test point 2

In table 4, the parameters for the second experiment carried on birch veneer cut wood are given. From figure 24 and 25, it can be observed that there exists variation in the behavior of the samples pressed due to different moisturizing times. Figure 25 points out that, as the moisturizing time increases the load applied must also be increased in order to keep the wood film in shape. However, due to the higher moisture content in the birch veneer cut wood film the sample returns to its original shape in a time interval of two (2) minutes after the press has been done. Though there were less changes of press formation, see figure 25, this was due to less time of moisturizing and increased time in pressing.

Figure 25. Sample experiment 2a of birch veneer cut for test point 4

Table 5. Laboratory experiment 2b for Birch veneer turned

Experiment 2b Birch veneer turned	Material thickness (mm)	Moisturizing time (hr)	Heating time (min)	Oven temperature (°C)	Applied load	Press holding time (min)
Test point 1	1.5	3.2	5	60	0.2	5
Test point 2	0.5	1	5	60	0.3	5
Test point 3	1.5	3.25	5	60	0.3	10
Test point 4	1.5	3.09	5	60	0.2	5

The parameters in table 5 provide information of birch veneer when turned. In this test, the oven temperature and heating time were held constant while the moisturizing time was varied in order to find out the pressing conditions. Figure 26, shows two layer wood film pressed together with a thickness of 0.5 millimeter each. There was a significant changes in the formation but there was a crack based on wood dryness.

Figure 26. Sample experiment 2b of birch veneer when turned for test point 2.

Figure 27 points out that, as a longer moisturizing time was used there is slight rate of change in shape. The formation was good without cracks because of its high moisture content but the sample returns to its original shape few minutes after pressing. It was also observed that, major cracks occurred in the direction of the fiber grain. When the wood film was pressed against the direction of the fiber grain, the result obtained was good as illustrated in Figure 27.

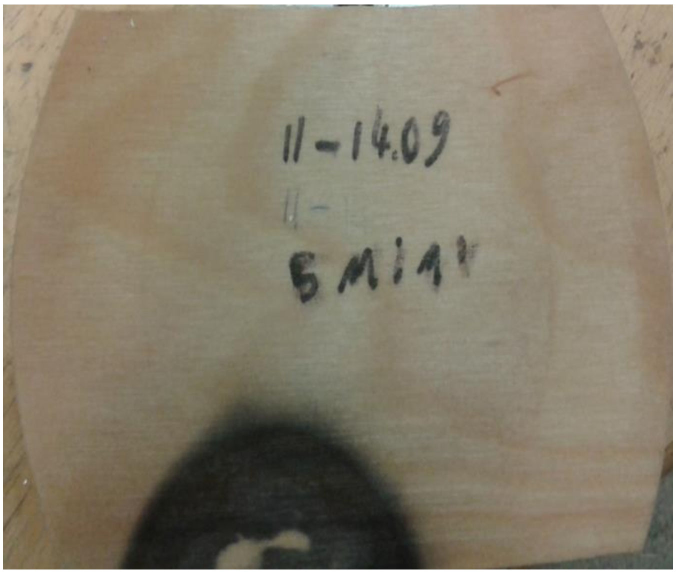


Figure 27. Sample experiment 2b of birch veneer when turned for test point 4.

Table 6. Laboratory experiment 3

Test and material (Birch)	Material thickness (mm)	Moisturizing time (hr)	Tool heating temperature (°C)	Piston length (mm)	Applied load (KN)	Press holding time (min)	Depth after pressing (mm)
Test point 1	0.5	2	120	10	50	1	1
Test point 2	0.5	2	120	10	50	2	1
Test point 3	1	3	120	10	47	2	2
Test point 4	0.5	24	120	10	50	2	1
Test point 5	0.5	48	120	10	50	5	2
Test point 6	1	4	120	10	50	5	3
Test point 7	1	10	130	10	50	2	2
Test point 8	1	10	140	10	50	2	3
Test point 9	1	5	140	10	50	2	1
Test point 10	0.5	5	140	10	50	2	3
Test point 11	1	6	140	10	50	2	2
Test point 12	0.5	3	140	10	50	5	2
Test point 13	0.5	6	140	10	50	5	2
Test point 14	0.5	7	140	10	50	5	4

The information of the tray forming of experiment 3 is given in table 6. It was observed that, heating the male tool at higher temperature, pressing the wood film against the fiber grain and providing of a high moistening time of about 48 hours, gives good forming shape as illustrated in figure 28. Another test was also done by pressing the wood film in the same direction of fiber grain at a temperature of 120°C. A major crack occurred in its direction of fiber grain as shown in Figure 29. There was a significant change seen in the figure 28, as there was a depth of 4 mm after pressing. The result obtained was as a result of increased temperature and pressing time.

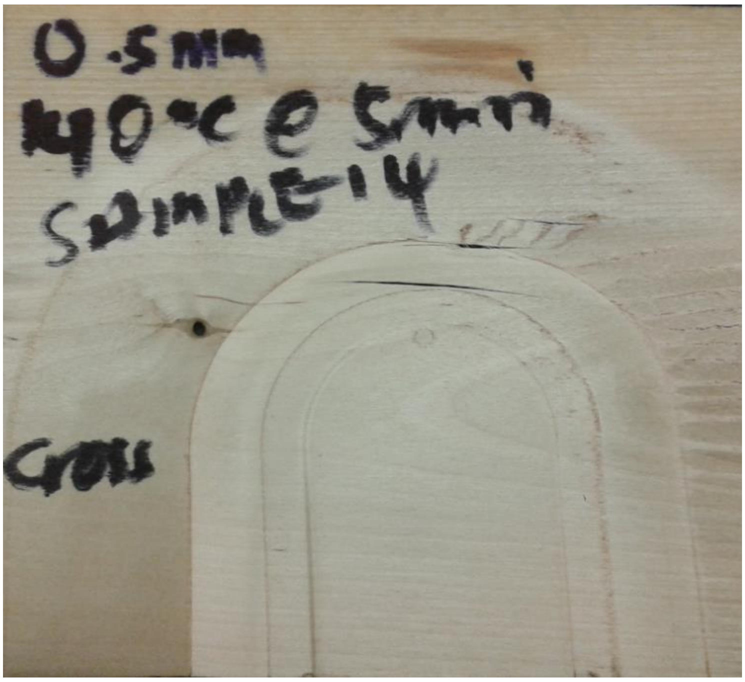


Figure 28. Birch forming test 3 of Sample 14

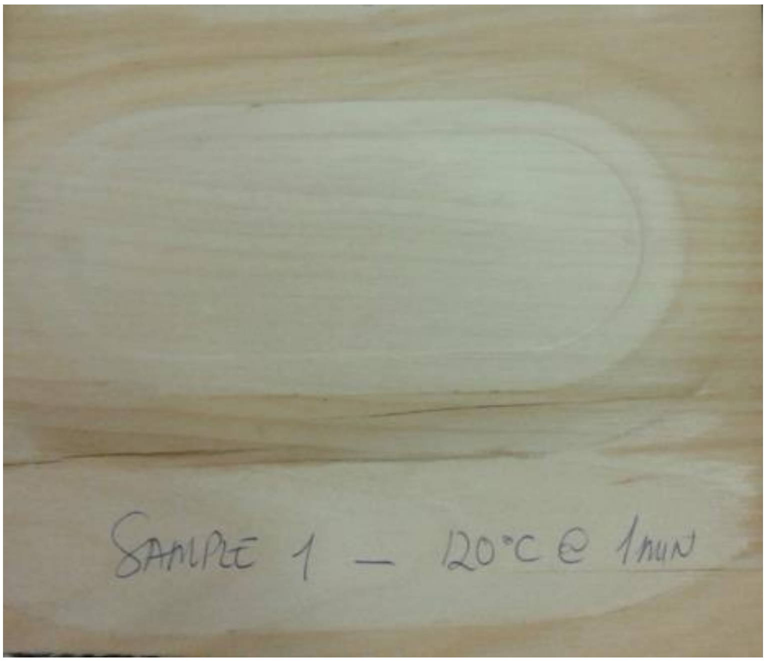


Figure 29. Birch forming test 3 of Sample 1.

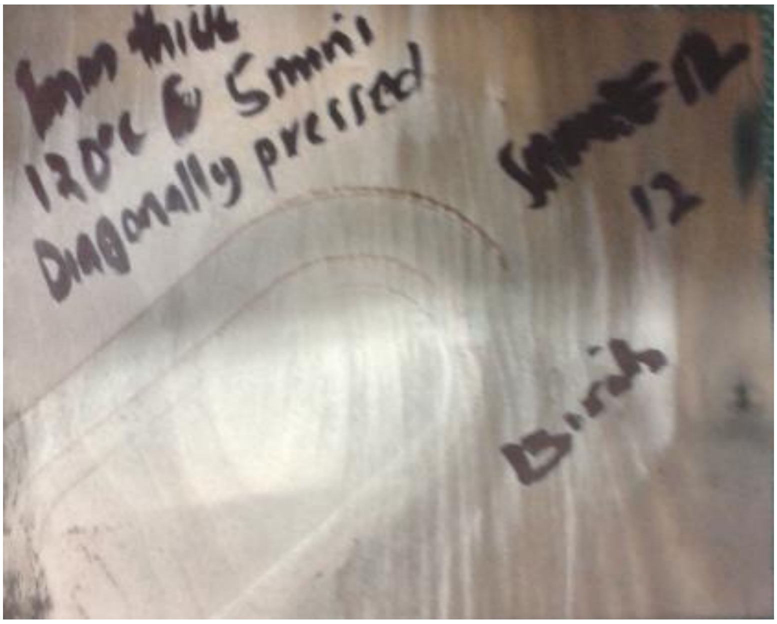


Figure 30. Birch forming test 3 of Sample 12 (Diagonally pressed)

Figure 30, shows a forming test of birch wood film. The wood film was pressed against the fiber grain in a different direction of orientation. The picture clearly shows a depth of 2mm without any crack due to its inclination by pressing it diagonally. The rest of the sample pictures obtained can be seen in appendices II of 1/6, 2/6, 3/6, 4/6, 5/6, and 6/6

4 DISCUSSION AND CONCLUSIONS

The objective of this thesis was to investigate the possibility of press-forming wood films into primary packaging. The results from the study shows that there were some challenges in obtaining a tray pressed from the wood film though the two studied wood species behaved similarly in the pressing test. The challenges were as follows:

1. Cracking in the direction of the fiber grain
2. Cracking in the bending corners
3. Uneven drying of the pressed wood film
4. Colour change of the wood film after moistening.

The objectives were reached to some extent with the LUT packaging line due to the integrated heating system in the press forming unit.

However, development work and preparations are needed before the pressing is done. Further studies should concentrate on the following given recommendations:

1. The male/pressing tool should be heated whilst pressing.
2. The wood film should be pressed in the opposite direction of the fiber grain
3. Parallel process and multiple tools should be designed for mass production
4. The duration of the pressing process should be increased
5. There should be more time for steaming or moistening of the wood film.
6. The thickness of the wood film should be more than 3mm
7. The wood film should be laminated before pressing for future benefit as was discussed briefly in chapter 2
8. Colour changes of the wood film after moistening should be eliminated therefore test should be done on fresh wood which has already some degree of moisture.
9. Wood film should be pressed in different direction of orientation, example diagonal.
10. Applied pressing load on the Stenhoj pressing machine should be increased 10 times of 0.2 KN as was used in this study.
11. The tool should be geometrically designed in such a way that, the other part of the pressed wood will dry uniformly in tandem with the heat affected zone
12. The diameter of the piston pressing wood film should be more than 15 mm.

From the above recommendations, it can be concluded that more light should be thrown on preparation of the wood film and designing of the pressing machine.

REFERENCES

Adam Equipment. 2015. Moisture Analyzer Clearly Shines In Glass Manufacturing Applications. [Viewed 12th of January 2015]. Available: http://www.adamequipment.com/news/index.php/lang-/news/58-adam-equipments-pmb-53-moisture-analyzer-clearly-shines-in-glass-manufacturing-applications

Al-Harahsheh, M., Al-Muhtaseb, A. & Magee, T. 2009. Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Engineering and Processing: Process Intensification, Vol. 48, Iss. 1, pp. 524-531.

An, J., Kim, S. & Kim, H. 2011. Formaldehyde and TVOC emission behavior of laminate flooring by structure of laminate flooring and heating condition. Journal of Hazardous Materials, Vol. 187, Iss. 1-3, pp. 44-51.

Ashter, S. A. 2014. Thermoforming of single and multilayer laminates: Plastic Films Technologies, Testing and Applications. United Kingdom. 352p.

Ayrilmis, N., Benthien, J. & Thoemen, H. 2012. Effects of formulation variables on surface properties of wood plastic composites. Composites Part B: Engineering, Vol. 43, Iss. 2, pp. 325-331.

Bergman, R. 2010. [Chapter 13:] Drying and Control of Moisture Content and Dimensional Changes. In: C. Risbrudt and M. Ritter, ed. Wood Handbook - Wood as an Engineering Material, 10th ed. Madison, WI: U.S. Department of Agriculture, Forest Service, pp. 1-2.

Bisson, D., Deomano, E. & Do, B. 2014. Veneer, Edge Banding, Furniture, Cabinetry, Case Goods -Composite Panel Association. Decorativesurfaces.org. [Viewed 16th of November 2014]. Available: http://www.decorativesurfaces.org/products/decorative-surfaces/veneer.html.

Bledzki, A. 1999. Composites reinforced with cellulose based fibers. Progress in Polymer Science, Vol. 24, Iss. 2, pp. 221-274.

Blomme, E., Bulcaen, D., Cool, T., Declercq, F. & Lust, P. 2010. Air-coupled ultrasonic assessment of wood veneer. Ultrasonics, Vol. 50, Iss. 2, pp. 180-187.

Browne, D. & Battikha, E. 1995. Optimization of aluminium sheet forming using a flexible die. Journal of Materials Processing Technology, Vol. 55, Iss. 3-4, pp. 218-223.

Chen, C. 2003. Evaluation of Air Oven Moisture Content Determination Methods for Rough Rice. Biosystems Engineering, Vol. 86, Iss. 4, pp. 447-457.

Compositepanel.org, 2015. Education, Resources, News and Product Locator for the Decorative Surfacing Industry- Composite Panel Association. [Viewed 21st of October 2014]. Available: http://www.compositepanel.org/

Pat. US 5968625 A. Laminated Wood Products. (Hudson, D. V.) Appl. US 08/990, 496. Publ. 1999-10-19. 11 p

Du, G., Wang, S. & Cai, Z. 2005. Microwave Drying of Wood Strands. Drying Technology, Vol. 23, Iss. 12, pp. 2421-2436.

Glass, S. & Zelinka, S. 2007. [Chapter 4:] Moisture Relations and Physical Properties of Wood. R. Ross, ed., Wood Handbook: Wood and Engineering Material, 20th edition. New York: United State Department of Agriculture (USDA). 1-2p.

Groupe-lacroix.com, 2015. WOOD RANGE. Lacroix emballages Group. [Viewed 12th of January 2015]. Available: http://www.groupe-lacroix.com/en/category/29/thermoformed-wood.

Hall, D. & Giglio, N. 2011. Graphic Standards Field Guide to Residential Construction. Hoboken. New Jersey: John Wiley & Sons, Inc. 236 p.

Hansson, L. & Antti, A. 2006. The effect of drying method and temperature level on the hardness of wood. Journal of Materials Processing Technology, Vol. 171, Iss.3, pp. 467-470.

Heräjärvi, H. 2005. Birch properties and utilization. Joensuu: Finnish Forest Research Institute Metla. [Viewed 19th of September 2014]. Available http://www.valbro.uni-freiburg.de/pdf/birch_prop_and_util.pdf

Hischier, R., Althaus, H. & Werner, F. 2004. Developments in Wood and Packaging Materials Life Cycle Inventories in ecoinvent (9 pp). The International Journal of Life Cycle Assessment, Vol. 10, Iss. 1, pp. 50-58.

Jayawickrama, K. 2001. Breeding radiata pine for wood stiffness: review and analysis. Australian Forestry, Vol. 64, Iss. 1, pp. 51-56.

Jia, Y., Zhang, Y., Zhou, Q., Fan, Q. & Shao, J. 2014. Structural colors of the SiO2/polyethyleneimine thin films on poly(ethylene terephthalate) substrates. Thin Solid Films, Vol. 569, pp. 10-16.

Jyske, T., Mäkinen, H. & Saranpää, P. 2008. Wood density within Norway spruce stems. Silva Fennica, Vol. 42, Iss. 3, pp. 439–455.

Kamdem, D., Jiang, H., Cui, W., Freed, J. & Matuana, L. 2004. Properties of wood plastic composites made of recycled HDPE and wood flour from CCA-treated wood removed from service. Composites Part A: Applied Science and Manufacturing, Vol. 35, Iss. 3, pp. 347-355.

Kandelbauer, A. & Teischinger, A. 2009. On the warping behaviour of particleboards coated with melamine formaldehyde resin impregnated papers. European Journal of Wood and Wood Products.

Kandelbauer, A., Wuzella, G., Mahendran, A., Taudes, I. & Widsten, P. 2009. Model-free kinetic analysis of melamine-formaldehyde resin cure. Chemical Engineering Journal, Vol.

152, Iss. 2-3, pp. 556-565.

Keskin, H. 2009. Impact of impregnation chemical on the bending strength of solid and laminated wood materials. Materials & Design, Vol. 30, Iss. 3, pp. 796-803.

Koskisen, Oy, 2003a. FINNISH TIMBER - DIVERSE BUILDING AND INTERIOR FITTING MATERIALS. [Viewed 18th of October 2014]. 6p. Available: http://link.koskisen.com

Koskisen, Oy, 2003b. FINNISH TIMBER - DIVERSE BUILDING AND INTERIOR FITTING MATERIALS. [Viewed 24th of October 2014]. 6p. Available: http://link.koskisen.com

Laurila, J., Havimo, M. & Lauhanen, R. 2014. Compression drying of energy wood. Fuel Processing Technology, Vol. 124, pp. 286-289.

Liu, S., Ogiwara, Y., Fukuoka, M. & Sakai, N. 2014. Investigation and modeling of temperature changes in food heated in a flatbed microwave oven. Journal of Food Engineering, Vol. 131, pp. 142-153.

Liu, Y. and Zhu, X. 2014. Measurement of formaldehyde and VOCs emissions from wood-based panels with nanomaterial-added melamine-impregnated paper. Construction and Building Materials, Vol. 66, pp. 132-137.

Majumdar S., A. ed., 1995. Handbook of Industrial Drying. 2nd edition. 270, Madison Avenue, New York: Marcel Dekker, 899 p.

Mergentime, K. 2007. Take Another Look at Laminating Films. [Viewed 7th October 2014]. Available: http://sdgmag.com/article/take-another-look-laminating-films

Oloyede, A. & Groombridge, P. 2000. The influence of microwave heating on the mechanical properties of wood. Journal of Materials Processing Technology, Vol. 100, Iss.

1-3, pp. 67-73.

ROBERTS, R. & EVANS, P. 2005. Effects of manufacturing variables on surface quality and distribution of melamine formaldehyde resin in paper laminates. Composites Part A: Applied Science and Manufacturing, Vol. 36, Iss. 1, pp. 95-104.

Saarelaa, K., Lill, J., Harju, L., Lindroos, A. & Heselius, S. 1998. Multi-Element Analysis of Dry-Ashed Honey Samples by Thick-Target PIXE. International Journal of Environmental Analytical Chemistry, Vol. 69, Iss. 4, pp. 273-285.

Sanchez, I., Banga, J. and Alonso, A. 2000. Temperature control in microwave combination ovens. Journal of Food Engineering, Vol. 46, Iss. 1, pp. 21-29.

Simpson, W. 1910. [Chapter 12] Drying and Control of Moisture Content and Dimensional Changes. R. Ross, ed., Wood handbook: Wood as an engineering material, 20th Edition. United States Department of Agriculture, 463 p.

Sun, S., Li, M. and Liu, A. 2013. A review on mechanical properties of pressure sensitive adhesives. International Journal of Adhesion and Adhesives, Vol. 41, pp. 98-106.

Thermoforming laminates. 1996. Manufacturing Engineer, Vol. 75, Iss. 4, pp. 162-163.

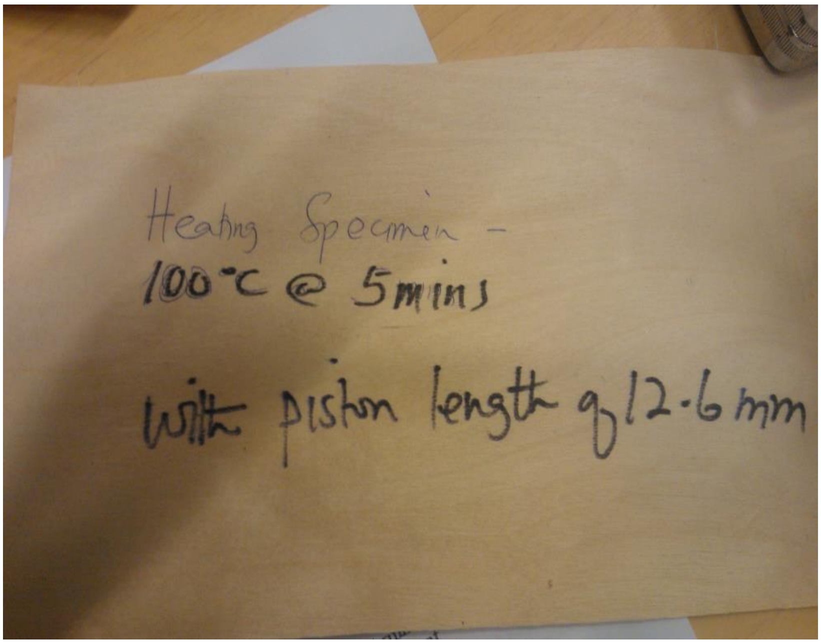
Whirlpool. 2015. Whirlpool, Sensing the difference. [Viewed 20th of February 2015]. Available: http://docs.whirlpool.eu/_doc/PR858532361000fi.pdf

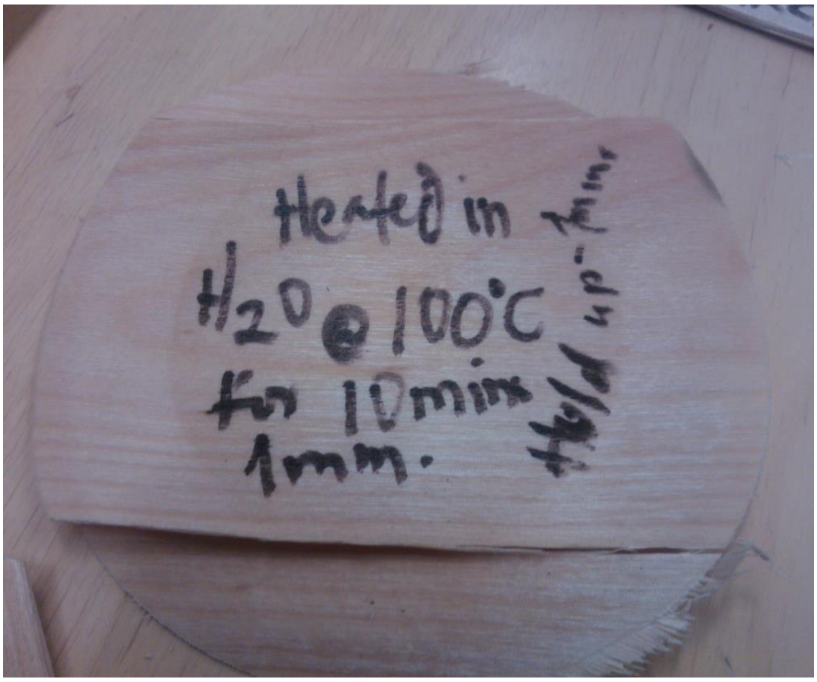
Wiermann, M. 2010 [Chapter 1]. Characteristics and Availability of Commercially important woods. Wood Handbook: Wood as an Engineering Material, 10th Edition. United States Department of Agriculture (USDA), pp.1-46.

Zelinka, S., Glass, S. & Derome, D. 2014. The effect of moisture content on the corrosion of fasteners embedded in wood subjected to alkaline copper quaternary treatment. Corrosion

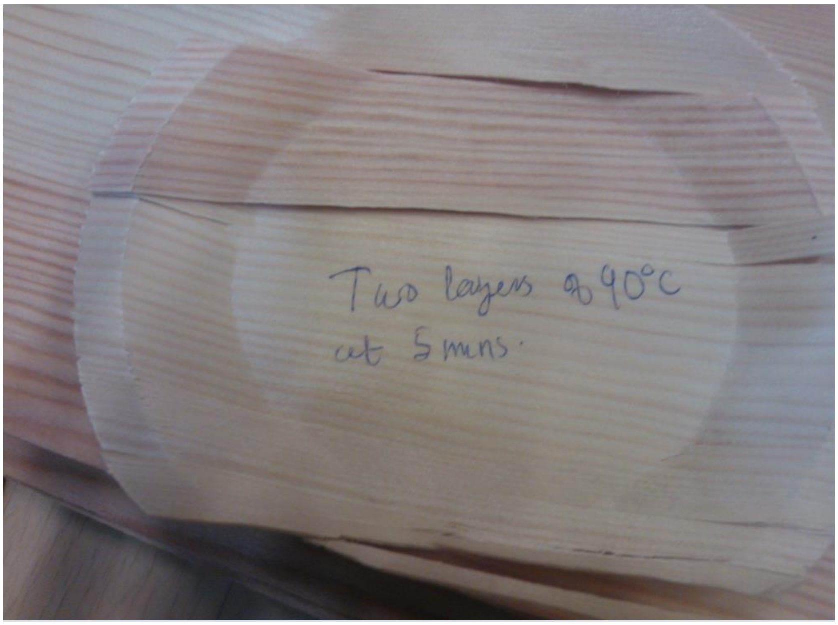
Science, Vol. 83, pp. 67-74

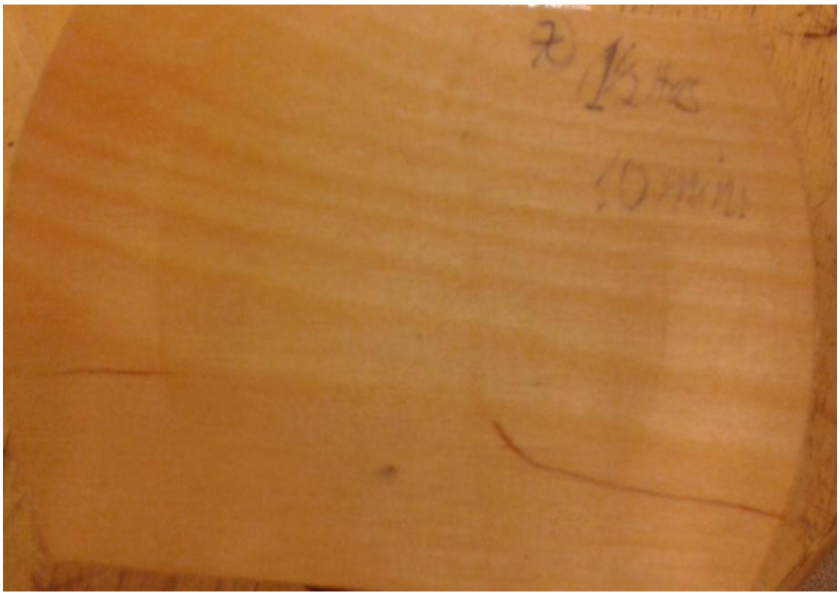
Samples of pine wood tested on Stenhoj Pressing machine



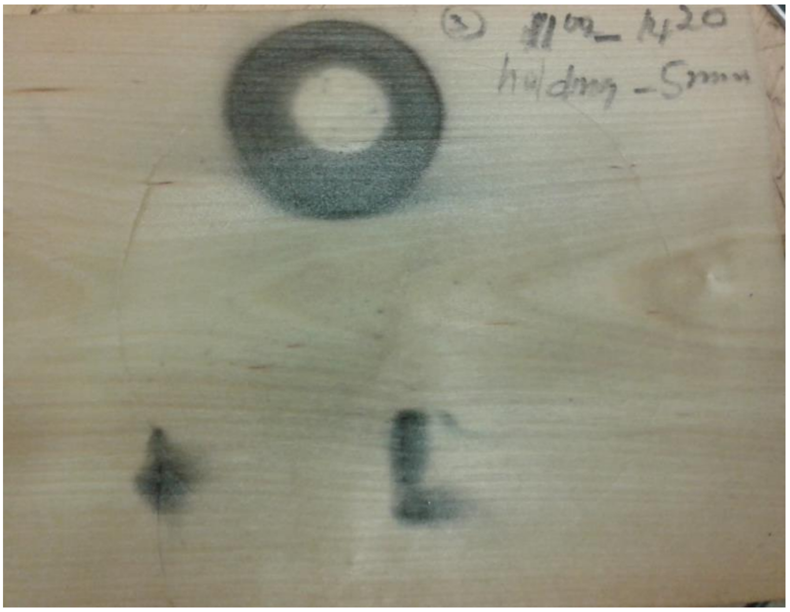


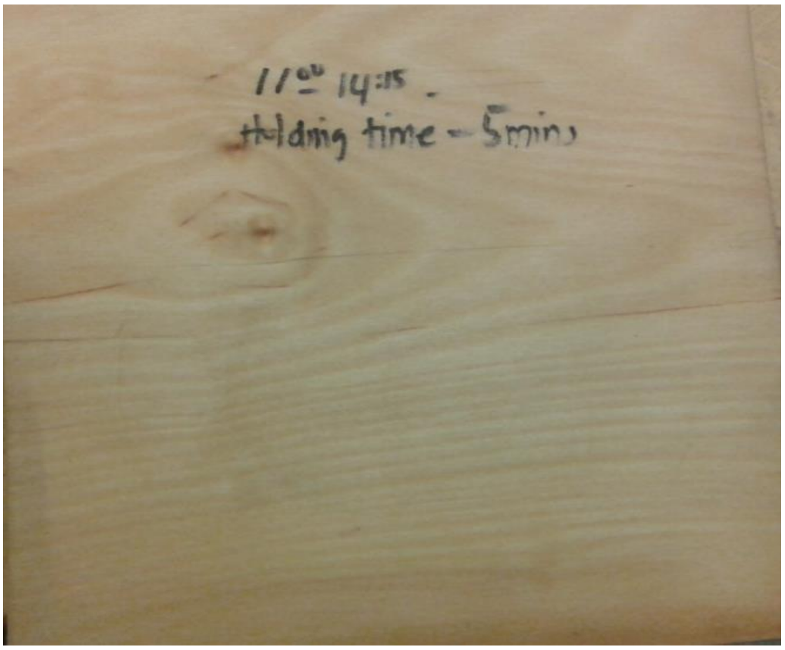
Samples of Birch veneer turned submerged in water.



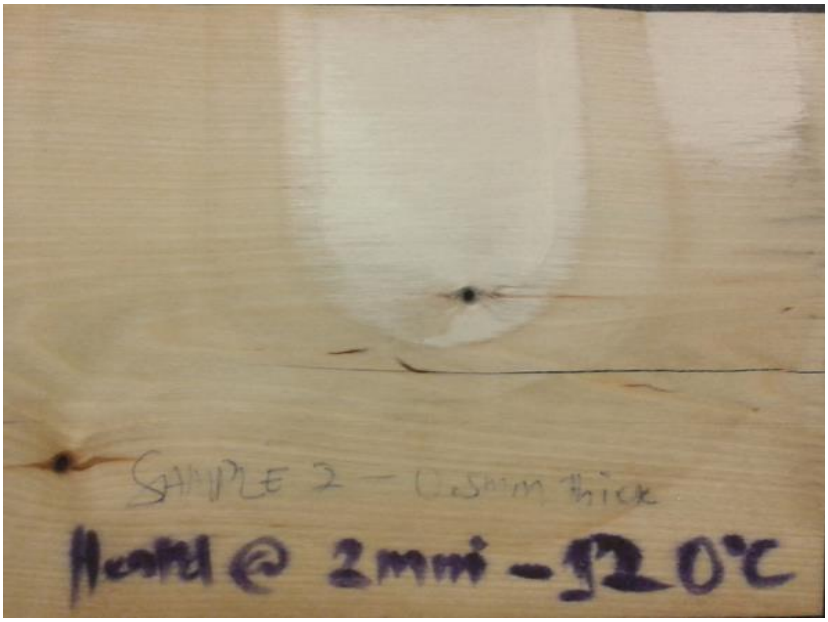


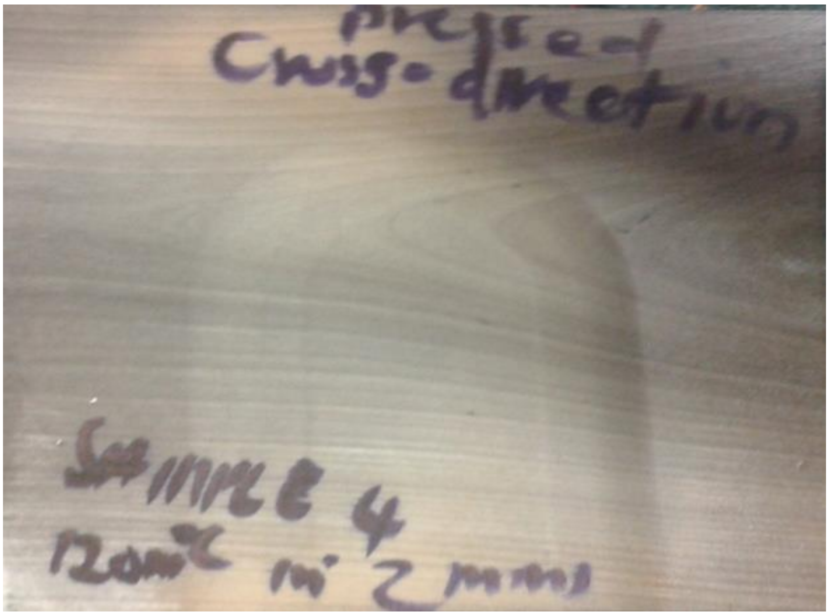
Samples birch veneer cut flattened few minutes after pressing.



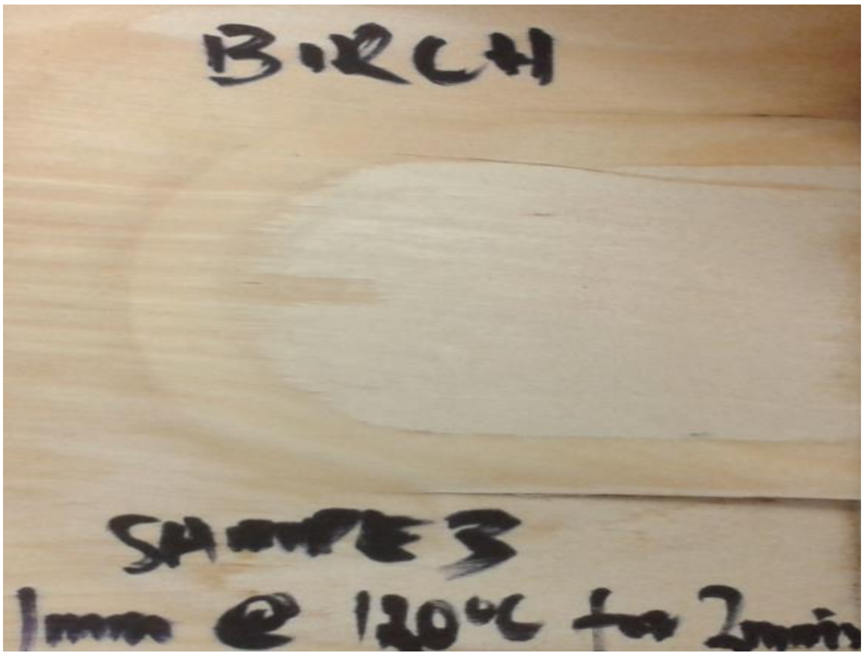


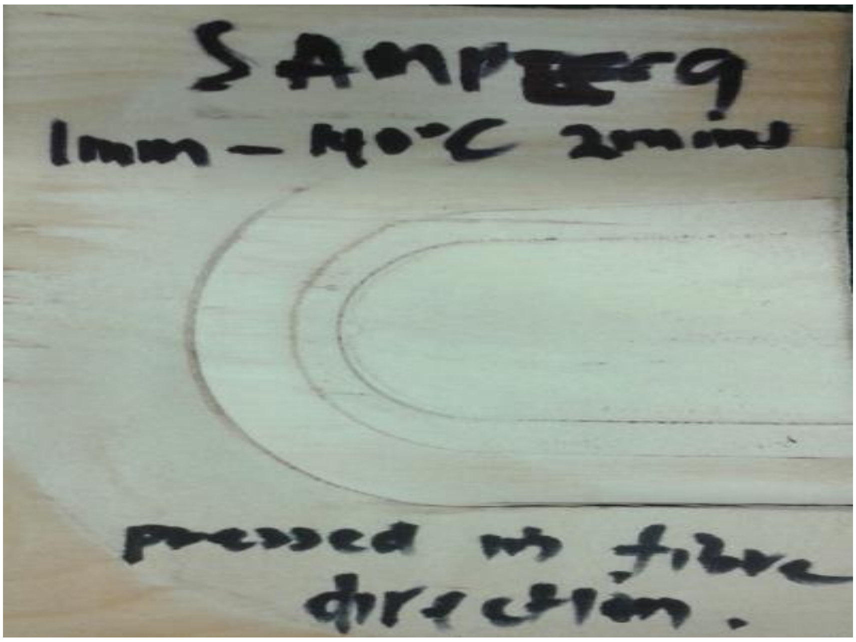
Sample of birch wood pressed in opposite direction of fiber grain.



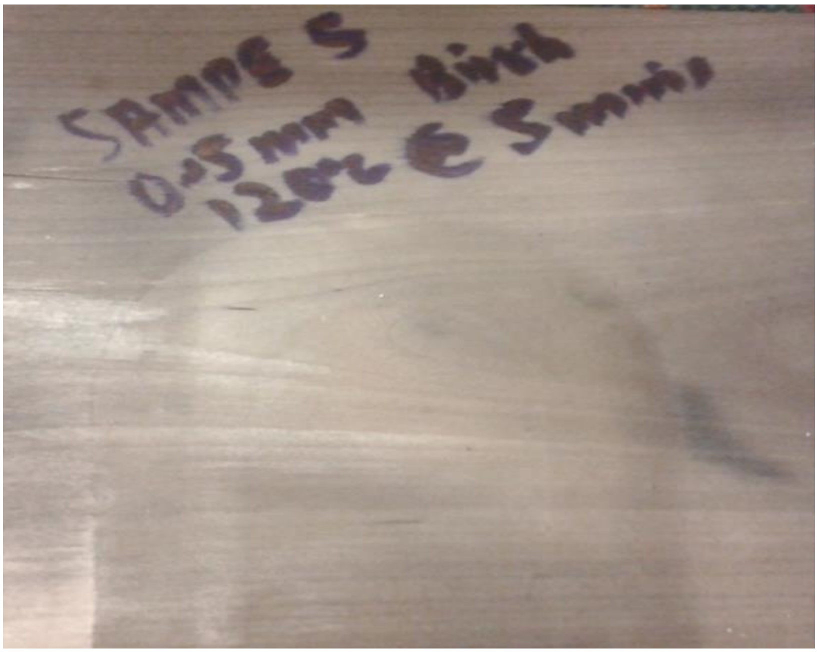


Picture 8. Sample of birch wood pressed in the same direction of fiber grain

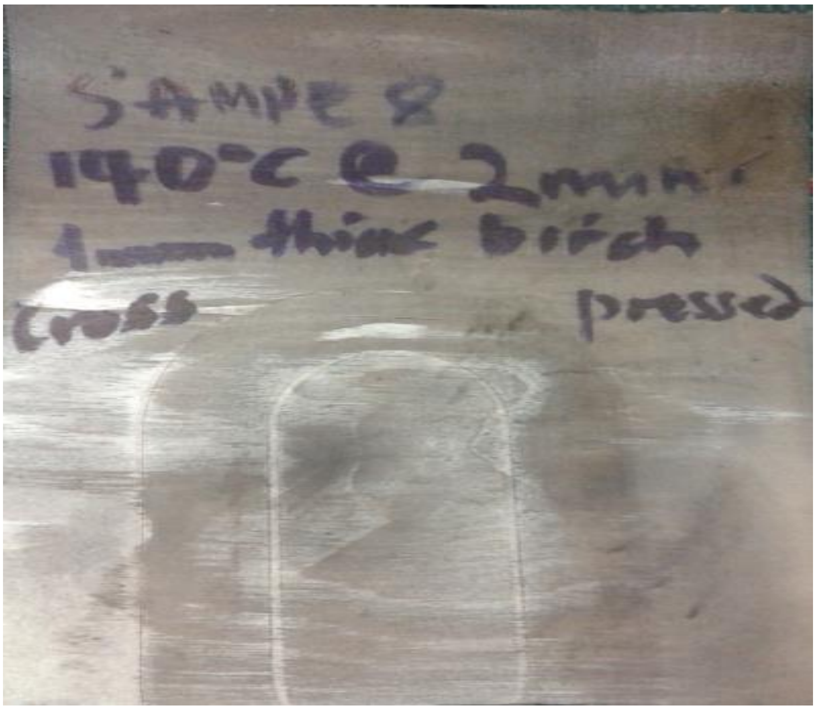




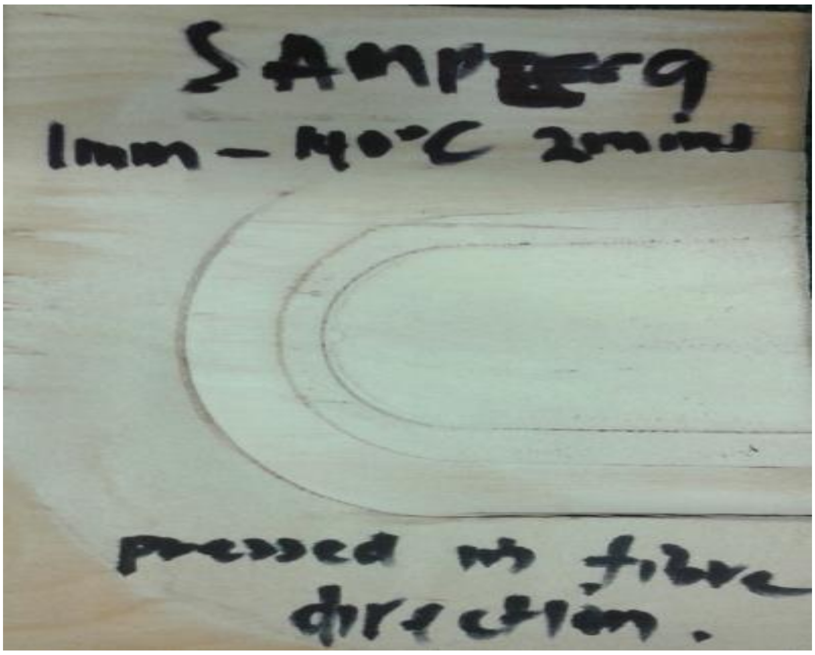
Sample of birch wood pressed and hold for 5 minutes under the packaging line machine



Sample of birch wood showing wetted surfaces after pressing under intense heat of 130 and 10°C respectively.



Sample of birch wood pressed under the temperature 140°C



Sample of birch wood pressed under the temperature 140°C in diagonal orientation