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

EFFECT OF DIFFERENT HARDWOOD SPECIES ON THE NOVEL PLYWOOD LIQUID COATING PHYSICAL PROPERTIES

ERINEVATE LEHTPUULIIKIDE MÕJU UUDSE VINEERI VEDELPEALISTUSE FÜÜSIKALISTELE OMADUSTELE

MASTER'S THESIS

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Tallinn 2022

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THESIS TASK

Student: Anas Maher Labib Abdelkhalek 201873 KVEM
Study programme, Master of wood, textile and plastics technology
main speciality: Technology of wood
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Thesis topic:

(in English) Effect of different hardwood species on the novel plywood liquid coating physical properties

(in Estonian) Erinevate lehtpuuliikide mõju uudse vineeri vedelpealistuse füüsikalistele omadustele

Thesis main objectives:

1. To evaluate the effect of different hardwood veneers on liquid coating durability and mechanical strength.
2. To evaluate the performance of liquid coatings compared to traditional thermosetting overlays.
3. To assess the application of liquid coating to plywood panels.

Thesis tasks and time schedule:

No	Task description	Deadline
1	Choose thesis topic	02.2021
2	Topic approval	03.2021
3	Writing literature review	05.2021
4	Set project goals and methods	09.2021
5	Split project tasks with Kadri	10.2021
6	Panel preparation	01.2022
7	Sample preparation	02.2022
8	Conducting tests	03.2022
9	Data presentation and analysis	04.2022
10	Writing thesis	05.2022
11	Pre defence	13.05.2022
12	Thesis submission	24.05.2022
13	Thesis Defense	03.06.2022

Language: English… **Deadline for submission of thesis:** Tuesday 24.05.2022

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PREFACE

This work was carried out at Tallinn University of Technology's, Department of Material and Environmental Technology, Laboratory of Wood Technology, and an additional help from department of Mechanical and Industrial Engineering, Research Laboratory of Tribology and Materials Testing for scratch test.

This topic (Effect of different hardwood species on the novel plywood liquid coating Dynea physical properties) has been suggested by Dr. Heikko Kallakas to be an individual work project to study mechanical performance of Dynea products on the plywood surface.

This master thesis evaluates the novel Dynea liquid coating effects on mechanical surface performance of birch plywood panels veneered with fresh face veneers from different hardwood species (birhch, aspen, black alder) with additional hardwood veneers. It aims to evaluate both Dynea liquid coating and mechanical performance of used substrate.

LIST OF APPREVIATIONS

MDO - Medium Density Overlay
PSF - Phenolic surface film
PF - Phenol Formaldehyde
MF - Melamine Formaldehyde
COF - Coeffecient of friction value
HBW – Surface hardness value

1 INTRODUCTION

Plywood has been a successful engineered product for decades used for different purposes for a shared function, which is direct contact with loads or mechanical uses, for that many inventions were introduced to improve the exposed surface layer of plywood against different contacts and the landscape of these materials is continuously changing as the market demand and more restrictions being introduced.

The mechanical durability has not remained the only factor when choosing the type of coating, as more natural or synthetic products are already available in the market, but also environmental impact, ease of application, chemical stability, cost, disposal and shelf life, etc.

Plywood is one of the original flexible materials utilized in construction and other decoration or non-structural uses. Besides the fact that plywood could be a structural element itself, it is generally more expensive than other comparative wooden boards with similar services. However, for the plywood to stay in durable shape for longer time, it requires proper treatment, finishing, or coating with either liquids, films or other available treatments. Knowing the right sort of wrap-up or coating will help anticipate surface checking or splitting and guarantee long-term strength and durability.

This work investigates and lists the different methods and tools used for coating plywood for other exterior uses and conditions. It compares two products available on the market, PF and Dynea liquid coating. Also, it is applicable in finding out best practices for plywood utilization exterior uses according to European standards.

This research is based on literature reviews for the chemical compounds and expected outcomes based on plywood's unique properties and grades. The physical tests will be applied on plywood specimens with different qualities and veneer compositions.

The aim of this thesis is to investigate the mechanical performance of phenolic film overlay and novel *Dynea* liquid coating applied to different wood species veneers on plywood surfaces (Aspen - *Populus tremula L.*, Black Alder - *Alnus glutinosa L.*, and Birch - *Betula pendula Roth*). After the surface coatings, surface physical properties will be tested to evaluate the coating's durability. To achieve this aim, the following research questions are set:

- What are the different surface treatments used for concrete casting?

- What are the common mechanical tests and standards for formwork panels and exterior plywood?
- What is the process of applying liquid overlay on plywood panels?

2 LITERATURE REVIEW

2.1 Nature of wood

Wood assembles itself biologically and is a polymer structure in nature (Fengel & Wegener, 2003). They also suggest that wood is adaptive to constantly changing environmental factors. The critical constituent biopolymers in wood are cellulose, lignin, and hemicellulose). There is continuous oxidation that leads to wood deterioration. Oxidative processes include chemical, photo-oxidation, decomposition resulting from heat effects, and destructive effects resulting from environmental conditions (moisture, sunlight, wind, and extreme conditions) (Tanasa, 2021) One of the significant ways that prevent wood destruction is coating using a protective layer (Mahltig, 2008) The layer that coats the surface will chemically modify it. Today, there is an increase in demand for wood and wood products.

People have widely used wood in production, construction purposes, and other uses because wood has unique qualities (Yan et al., 2019) The only unfortunate issue is that the element is flammable. The ease with which the wood can catch fire is a threat to people's lives and property, thus its applicability becomes less (Guo et al., 2019) Research indicates that it is possible to improve wood’s fire retardancy using nanotechnology (Papadopoulos, 2019). To be specific, the coating may prevent the further spreading of a fire while the process does not alter any physical and mechanical features in the elements (Huang et al., 2019). One of the coating methods in literature is the water-based intumescent flame retardant (IFR) coating. It is common in wood waterproofing techniques. It is cheaper, minimizes pollution effects, and improves the building's physical characteristics compared to solvent-based coats.

There are many approaches to surface treatment, including painting, water repellent coatings, high-density overlay, medium-density overlay, and metallic overlays. The most common method is coating. Today, the interest in improving wood coatings has increased. Coating prevents or minimizes the destructive effects on the environment. Additionally, the coating ensures that there is the preservation of the member’s aesthetic value (Huang et al., 2019).

2.2 Engineered wood

For a long time in history, people have been using different adhesives to bond wood material or products together (Keimel, 2003). Despite this fact, successfully making these bonded wood elements is continuously challenging because of the changing wood sources and effects. Additionally, there are daily needs towards reduced costs and superior performance. In the recent past, wood products from engineering works have an outward structural solid wood. Due to these changes and how they interact, there has been an increase in the demand to bond a wider variety of wood substrates to attain better results than past practices (Koning, 2010). There is a need for these products to remain intact for many years without breaking.

The wood industry manufactures numerous products, including plywood. Plywood finds many uses in the construction and finishing practices. The industry is interested in the determination of cheap and environmentally friendly techniques of wood treatment. Some of the preservation methods that people used in the olden days include plant oil coating. Today, most approaches still imply these methodologies. The most recent techniques encompass bio-based natural substances like extracts from plants, vegetable oil, wax, and many others.

A versatile construction members is plywood. It is vital, can stay for a longer period, and is cheaper than other wood products compared to its strength. There is a need to ensure that plywood remains in its correct form for a longer time, hence the need for a good finish (Muller, 2003).

To date, engineers have developed better adhesives and bonding elements using intelligent empirical techniques from the concepts of wood bonds. From these techniques, approximately 65% of available wood materials are bonded (Pizzi, 2016) Consequently, it does not imply that it is the end of innovations in the adhesive field. There are numerous market changes and unaddressed concerns still looming, and both present critical challenges (Frihart, 2011). To counteract these issues in time and a cost-effective approach, wood bonding engineers must know how bonds operate. Another critical issue that they must look into is why the same bonds fail. The two concepts call for techniques that go beyond standardized tests and visual examinations.

The engineering field has many construction materials used to achieve desirable strength, quality, and durability. Plywood is one of these materials because it has wide applications in the construction industry (Muller, 2003) (Chandigarh, 2001). It is simply a combination of thin wooden sheets arranged in layers. The manufacture of plywood entails installing rigid sheets onto or underneath one or more wood veneer pieces and sticking them together using glue (Wood Solutions, 2014) Examples of these wooden veneers include thin, rigid sheets and fiberboards of average density. Usually, the piles are organized wooden grains in neighboring stacks to have a 900 rotations to peel off the wooden log. Each plywood could have several layers stuck together. The number of layers used usually is odd number. For instance, a three or five-ply piece has three or five veneers glued together. plywood members are also composite materials because they have at least two materials-fiber sheets and sticky or glue material (Logan, 2014).

We have several categories of plywood, and each type is suitable for a specific use. The most common ones are softwoods, hardwoods, tropical, aircraft, and particular-purpose plywood. In most cases, plywood is used in the building industry but vehicles internal parts and packages (Ernes, 1970) The synthesis of plywood is in such a way as to increase the distance between the outer layers so that the member can accommodate higher bending forces/stresses. After all these bonding techniques, there is a need to coat the plywood surface.

2.3 Wood coating

The significance of the coating process includes the transformation of the product's physical appearance (making the wood surface look more decadent and more elegant), protection of the wood surface from dirty material and water. Wood is used in buildings and for applications like making window frames, cladding, and making outside living areas like decks, fences, and outdoor furniture pieces. If we do not protect the wood surfaces with a coat, most of the wood will deteriorate extremely fast in outdoor conditions. Exterior wood coatings must possess inherent characteristics for better results. The coating must resist all the ultra-violet radiation, be adhesive on wooden surfaces, offer resistance against ingress of liquids, and provide a good balance between hardness and how wood is flexible.

A class of coating that has broad applicability in the construction industry is polyester coating. The type has good flexibility and elastic properties. Moreover, they may show the best impacts, scratch, and stain resistance. These categories of surface coatings also display good adhesive qualities, particularly on metals. Pre-coated sheets have exhibited pronounced use in the past years, while the construction industry has increasingly used polyester coatings on a wide scale. (Schmitthenner 1983) (Robertson 1956) have elaborated well on polyester-based coil coatings. The coated coil is supposed to meet strict requirements before finding use in façade sheeting. These stringent requirements call for the usage of primers with three key roles; promote adhesive properties on pre-treated surfaces, protect a surface against corrosive effects.

Enhancing resistance to corrosion or protection to corrosion dictates that the coating material ought to work together with anti-corrosion pigments. We can formulate paints with the best resistances to weather changes using average molecular weight polyesters (Schmitthenner, 1988) The other category can coat which uses colors to decorate metallic surfaces used in packaging. Examples are food material containers, collapsible tubing, cans used to hold aerosol sprays, and caps. The manufacturer applies paint to a flat sheet, prints, and stacks up ready for storage, and finally stamps and forms. Can coats call for several requirements, including resistance to scratches, adequate elasticity that allows form works, and draw ability while retaining the paint appearance? The final product must display paint stability regarding what the article is holding. Moreover, it must resist external stains, and if preserving food, it must not be toxic, and its odor and tests should be neutral. Polyester coats provide excellent characteristics, particularly elasticity and hardness.

There are numerous other categories of coatings suited for different applications. Automotive paints find wide applications in the auto-industries, industrial coatings, 2-component paints, powder coatings, radiation-curable coatings, and adhesives. According to (Laleicke P., 2015), numerous wood composites have a low resistance to moisture and temperature extremes. These materials or products may fail when they experience deterioration in adhesive bonds, irreversible swelling, and instabilities in their structures. Therefore, the wood preservation industry has come a long way from crude treatment technologies. Today, there is a struggle to develop new methods that are cheaper, economical, and environmentally friendly. Despite this approach, engineers and constructors must balance to get the best surface coating materials for wood and wood products such as plywood. There is a need to examine the different plywood surface coating materials available in the market. There exist two leading products in the market which need a critical review to compare their suitability in the coating process.

2.4 Plywood for external uses

Plywood is a well-known type of engineered wood that is easy to modify according to its use cases, type of weathering, abrasion conditions, and whether it will be used as a structural element or not (Muller, 2003) Many of these criteria will determine the proper treatment and coating method based on market availability and manufacturing capability.

Figure 2.1. Plywood façade cladding (Plyterra, 2011)

This research sheds light on plywood panels for concrete casting and other construction site work. It will also consider the other harsh condition use cases such as roofing and subflooring, etc.. This service condition has multiple parameters to be considered when selecting materials for the purpose, these variables are listed to be tested in accordance to typical industry practices.

The first factor is mechanical wear and abrasion resistance. The outdoor conditions of continuous exposure to wind with travelled micro dust or sand and other contaminants to hit the surfaces. These materials act as an abrasive agent for some areas, and they cause aggressive abrasion over time, so the coating must form a protective layer or film to help reduce the surface decay of the veneer (Wypych, 2018).

Wetting resistance, wood is a hygroscopic material, and it swells quickly when in contact with water especially with low-density species with high moisture contents by nature. Usually, indoor wood can be treated with a low moisture balance by heating or by impregnation, or other treatments. For outdoor uses, it is essential to transform wood into hydrophobic material by treating wood against wetting is necessary for external suitability (van den Bulcke et al., 2009).

Ultra violet stability, a significant decay agents for any exterior purpose materials. Exposure to ultra violet waves for extended times as of years without losing its many properties to determines the durability of material against direct sun, and natural wood cannot resist ultra violet (Wypych, 2018). an additional agent is necessary for externally used products more significantly for façade cladding (Figure 2.1).

Resistance to acidity and chemicals and atmospheric conditions may differ for wood products. Optimizing plywood products for concrete casting using overlaid films on top of plywood to extend plywood service life and durability, also for exterior conditions, it must resist a various range of chemicals and other erosion agents, while the last 3 factors are fundamentally important to be evaluated but thesis only aims to work on mechanical wear evaluation stated in first factor (Kojima et al., 2011)

2.5 Types of plywood coating compounds

2.1.1 Melamine Formaldehyde

Melamine Formaldehyde (MF) is usually applicable for interior surfaces for UV drawbacks also, the different curing conditions will affect the results of MF such as MF impregnated papers will lack mechanical properties to standard MF resin. MF is a transparent polymeric resin or overlaid sheets applied over wood and wood-based panels.

The MF formation originated in 1933 by CIBA and used for cellulosic, mineral, or wood flour plastic composites, and they produced glossy plastics like dishware or countertops. Later, it was used for surfacing plywood and combined with other natural products. The main applications of this resin are in the high-pressure laminates for flooring. (Seymour et al., 1989) MF is also widely used as coating for wood-based panels such as plywood and MDF (Dorieh et al., 2022).

MFs (Melamine Formaldehyde) resins form when formaldehyde condenses with melamine to yield Hexa-hydroxymethyl derivative. When heated with an acid, it further condenses, and it is cross-linkages. To control the cross-linking process, condensation may take place in the presence of Benzoguanamine and Acetoguamine.
MF is a durable polymeric resin considered a hard and stiff thermoset adhesive with advantageous properties under various conditions for its hydrophobic nature, high boil resistance, transparency, flame retardancy, surface smoothness, better hardness, and scratch resistance.

MF is applicable in a wide variety of products for its affordability related to its properties and ease of manufacturing. The curing of the resin determines the product's properties as mechanical and thermal properties.

Figure 2.2. Cured melamine plywood flooring slates (Kastamonu, 2016)

2.1.2 Phenol-Formaldehyde

Phenol-Formaldehyde (PF) Resin or Phenol resin, or Bakelite resin, is a reaction between phenols (benzene alcoholic aromatic extraction) with the reactive gas derived from methane (formaldehyde) This compound (Figure 2.3) was the first polymeric resin to be used in the first quarter of the 20's century commercially, held several commercial names such as (Prystal 1930s) In the last few years, investigations on lignin reveal that it is a promising natural substitute for petrochemicals in PF (Phenol Formaldehyde) resin manufacture because they have similarities in their structures (Tejado et al., 2007).

Advantages of plywood coated with PF is the ability to be used for outdoor uses for longer times compared to uncoated plywood, PF is used for surface coating, a binding material, or a stand-alone thermoset resin or thin paper (Grinins et al., 2021).

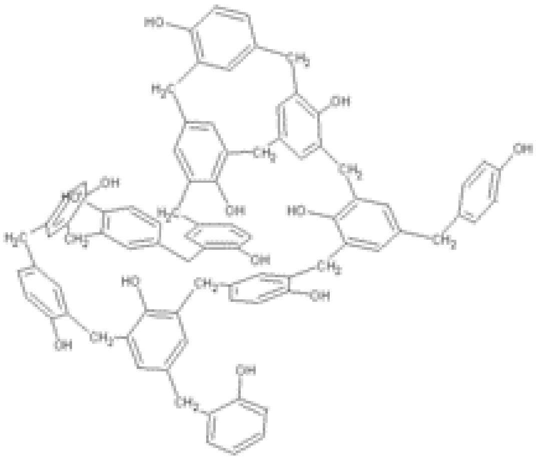


Figure 2.3. Bakelite 3D chemical structure (Wikimedia, 2012)

Bakelite trademarked plastic resins made a remarkable achievement for laminated or molded components for electrical equipment.

The importance of PF has developed over the years until today, which is widely applicable for adhesion and bonding of veneers and plywood and other structural products made of fibers or wood and other materials.

There are two methods of producing the PF currently in use for polymeric PF. In the first method, the reaction between phenol and formaldehyde catalyzes under a water-based solution to yield a low molecular pre-polymer called resole. Usually, it has a ratio of 1.5:1 formaldehyde to phenol.

Figure 2.4. Phenolic film coated plywood (salvati timbers, 2021)

The other way of producing PF is a base reaction with <1:1 formaldehyde to phenol ratio. It is called Novolacs compound, and the main difference between the two reactions besides the ratios is that the resole is a one-step reaction while the novellas are 2 step reactions since it requires a catalyst or cross-linker agent to react. It usually exists in liquid form or solution. It could be cured to a solid thermoset network polymer by lay-up veneers in the presence of the resin as in-between heating the layers assembly under heat and pressure to form plywood panel.

Phenolic resins are dark orange or brown colored (Figure 2.4). In producing semi-transparent resin, it is necessary to control the chemical reaction (using Melamine) to make a transparent phenol resin but mostly it looks yellowish to the surface.

PF overlay panels, also called Film-faced plywood is a type of plywood panel which has a phenolic film finish on one or both sides of the panel and is usually utilized for concrete forming and high abrasion applications (ProFace, 2021).

PSF has an opaque brownish appearance and relies upon being used for decorative purposes, the finishing papers require heat and pressure to be applied to the plywood or other wood-based panel surfaces. PSF has high durability and opaque surface, usually used in concrete forming panels as the MDO. (PSF Surface Coating, 2021)(Setiarso, P. et al., 2018).

Figure 2.5. Phenolic resin form faced plywood (ProFace 2021)

2.1.3 Comparison table between MF and PF

Both compounds are thermoset plastics, but they have different properties and uses. PF is generally used in outdoor settings while MF is more common for indoor uses, one main difference beside the properties set in the (Table 2.1) is opacity of the coating where MF tends to be transparent coating while PF is opaquer.

Table 2.1. General information, MF – PF (Fengel D. et al., 2003)

Title	Comparison Topic	MF Resin	PF Resin
Mechanical Properties	Elastic (Young's, Tensile) Modulus, GPa	7	3.8
	Elongation at Break, %	1	2
	Tensile Strength: Ultimate (UTS), MPa	30	48
	Stiffness to Weight: Axial, points	2.6	1.6
	Stiffness to Weight: Bending, points	43	40
	Strength to Weight: Axial points	5.6	10
	Strength to Weight: Bending, points	14	23
Thermal Properties	Maximum Temperature: Autoignition, °C	350	450
	Maximum Temperature: Decomposition, °C	350	260
	Specific Heat Capacity, J/kg-K	1200	1400
	Thermal Conductivity, W/m-K	0.5	0.25
	Thermal Expansion, µm/m-K	60	120
	Thermal Diffusivity, mm2/s	0.28	0.14
	Thermal Shock Resistance, points	5.1	7.5
Electrical Properties	Dielectric Strength (Breakdown Potential), kV/mm	30	46
	Electrical Resistivity Order of Magnitude, 10x Ω-m	9	11
Density	Density, g/cm3	1.5	1.3

2.1.4 Liquid overlay

Liquid overlay is a smart alternative to paint, coating, PSF, and MDO paper. A coating liquid without fiber-lifting with good abrasion and scratch properties along with good chemical resistance (Dynea, 2018) The Dynea paperless liquid coating can be applied using typical household tools such as paint roller, brush or in in higher volumes with curtain coater or roller coater on high-value boards from all wood species and board types such as (Plywood, Particle Board, OSB, MDF (Medium Density Fiberboards), HDF, Solid wood.

Dynea liquid coating consists of two main components which give its unique characteristics, one is the component 2 in a paste form and the other one is the component 1 in a powder form that can be ready to install by mixing then applying directly to the target panel or solid wood then using heat and pressure to cure as a thin film after cooling down.

The typical application rate is 120 g/m2 and less than 10 minutes is allowed before hot pressure at 110 °C and 0.8-1 N/mm2 for 3 minutes. as an alternative to PSF, paint, or MDO coating and it can be used in a wide range of spaces like industrial decoration, utility rooms. Truck flooring, priming before final finishing layers, also in concrete shuttering and packaging (Dynea, 2018).

Advantages of Dynea novel liquid coating products are, good machinability of the coated product, Re-coatable with different technologies, Application of coating by roller spreader on wood-based surfaces, it meets the newest regulations on OEL. While the performance and appearance are, smooth surface without fiber lifting, transparent and opaque options, matt and gloss finish, can be applied on flat and curved surfaces, abrasion-resistant coating, high release, slip-resistant and nonskid, high visibility, suitable for use with wire mesh, suitable for 3d texture.

2.1.5 Medium Density Overlay

Medium Density Overlay (MDO) is is a type of durable plywood generally made from grade B & C veneers with polymeric resin-impregnated surfaces to form waterproof panels suitable for exterior and weathering uses. an impregnated veneer finishing to the plywood panels and it is usually used for exterior cladding and structural members for its aesthetically appealing and low heat transfer rates.

MDO is sometimes mixed up with MDF, but they are different panels and also in different uses and price ranges, MDO is more durable than MDF and can be used in wet and moisture applications such as formwork and outdoor installations, unlike most MDFs (Chandigarh T., 2001).

MDO is usually impregnated with urea-formaldehyde or phenol-formaldehyde adhesives, it has a chemical release agent for concrete formwork applications (APA, 2011).

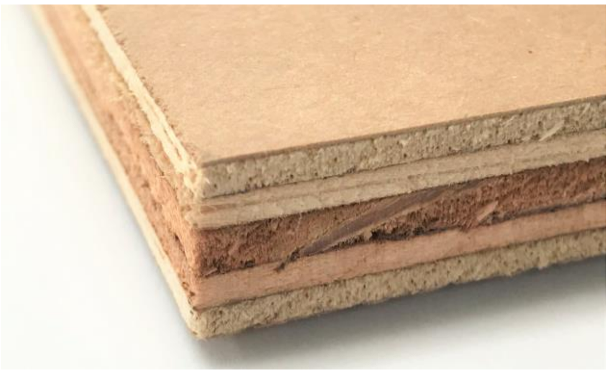


Figure 2.6. Medium density overlay (Justpaint, 2018)

2.1.6 Comparison between different coating methods

(Table 2.2) a commercial comparison between common products in the market for external use plywood coated panels compared to Dynea products. This information might be misleading due to the absence of accurate testing results and graphs showing the actual results in the same testing conditions.

This table will be used to verify the Dynea claim of its advantages over other products in the market, it will also be a reference for choosing the right testing parameters.

Table 2.2. Commercial data to compare between available products (Dynea, 2018)

	Paint/ Lacquers	**PSF**	**Dynea**	**MDO**	**PF**	**MF**
Flexibility in dimensions	Low	-	High	-	High	Mid
Transparency	Mid	-	High	-	Low	-
Fiber free	-	High	High	High	-	-
Abrasion Durability	-	Mid	High	Mid	High	High
Process Efficiency	Low	Mid	High	Mid	High	Mid

2.1.7 Test parameters

Wide varieties of tests might determine overall performance of concrete formwork panels, especially with different varieties of panels used for the same purpose, few parameters are shared among different test standards which form the baseline of testing. This work aims to determine the surface mechanical strength through 3 different tests, surface hardness by Brinell method, scratch test with conical stylus and abrasion resistance by Taber machine.

Brinell hardness test provides a fast and efficient way to measure material surface quality, the Brinell test can indicial several mechanical properties such as toughness and surface elasticity and hardness, an advantage of is it require small portions of materials to conduct tests. Brinell hardness test can be used for different substrates from metals, plastics and natural materials such as wood (Giannakopoulos, et al., 1994) While it provides a quality check for material mechanical properties but has not been thoroughly studied as an analytical testing method, however the material ability to deform by recession or projection is a proof of material elasticity and compressability (R. Hill, et al., 1989).

Scratch test is key method to determine material's surface layer adherence characteristics and it is considered as a combination of various stresses such as indentation, friction and internal stresses, which provides a valuable assessment to coating qualities and suitability to substrate material (Bull, S. et al., 1988). In order to understand the main characteristics and parameters that can affect functionality of wood-based panels, testing according to intended uses in contact with outdoor activities such as resistance to wear, scratch, indentation and other parameters that influence product functionality and suitability to intended uses (Hermann, et al., 2021). Density is a key factor to limit material shrinkage and swells when exposing material to moisture, especially with high performance application (Èrki, T. K. 2001).

Three mechanical tests (Table 2.3) are useful indicator of different surface coating durability at the same time to shed the light on other aspects of new products or materials, in the mentioned tests a significant differences according to the type of veneer, beside the coating. The plywood used for construction formwork panels does benefit from higher surface strength but main focus remains to maintain surface strength and prevent coating penetration that might be caused by concentrated concrete loads or shocks with sharp angled aggregates for formwork plywood panels applications.

Table 2.3. A reference test set is brought by Metsä Wood Eesti AS overlay properties test set (Metsä Wood, 2014)

Property	**Test**	**Result unit**
Abrasion resistance	EN 438-2	[rounds]
Surface hardness	EN ISO 1534	HB
Scratch resistance	EN ISO 1518/ EN 438-2	A* [N]

3 MATERIALS AND METHODS

3.1 Wood material

Wood material was acquired by State Forest Management Centre on September 2021 from the same stand in Kibuna, Saue county, Harjumaa. The mean stand age was 65. The logs were brought to the logging yard of Tallinn University of Technology, Laboratory of Wood Technology and kept in an open-air conditions using wooden studs to keep the logs from direct ground contact and to ensure a reasonable natural outdoor setting. Logs were stored about 6 months before peeling. Logs had diameter ranges around 20~30 cm on average (Table 3.1).

3 different hardwood species, Birch (*Betula pendula Roth*), Black Alder (*Alnus glutinosa L.*), and Aspen (*Populus tremuloides L.*) were chosen to be glued over 12 mm unsanded birch plywood, quality class WG/WG (acquired from the company Estonian Plywood AS – EstPLY) to validate the behavior of several types of wood species in surface coating.Chosen logs were carefully picked to ensure minimum knots, cracks, checks and rot, however 2 logs (Aspen + Birch) were waste due to excessive presence of loose knots that can easily fall due drying.

3.2 Peeling and drying

The peeling and veneering procedure include soaking in 40°C for 48h before debarking logs manually with debarking knives, followed by metal check using hand-held metal detector, moisture content check using Hydromette HT 85T electronic moisture meter and diameter check using digital Vernier Caliper - precision (0.01 mm) (Table 3.1).

Figure 3.1. Rejected veneer

Then manually placing the logs into the Raute peeling lathe (dimensions 8.5 x 2.9 x 4 m, weight 17 t, engine power 66 kW). Peeling was done at room temperature ~18 °C and relative humidity of 30%. The peeling parameters were: speed was 60 m/min, sharpening angle 20° and the nosebar pressure was 8.57% to obtain the veneer with nominal thickness of 1.5 mm.

For each type of wood specie veneer (Birch, Black Alder and Aspen) a minimum of 48 veneer sheets were needed to cover 24 core plywood panels. Chosen veneer sheets were carefully cut to avoid knots (Figure 3.1).

Table 3.1. The list of peeled logs

Log no.	Species	Avg. diameter. cm	Avg. Surface temp. °C	Moisture content. %	Veneer sheets obtained
109.1	Aspen	28	29	71	-
112.0	Aspen	25	32	70	35
113.0	Aspen	24	30	66	23
129.0	Aspen	24	28	54	-
133.0	Aspen	31	35	71	23
114.0	Birch	20.5	29.5	44	8
114.1	Birch	19.5	27.5	50	20
114	Birch	19	30	52	-
119.0	Birch	23	24	62	14
124	Birch	23	26	62	18
128.0	Birch	25.5	28	40	26
115.0	Black alder	19.5	27.5	64	17
115.1	Black alder	19	27	60.5	8
120	Black alder	26.5	31	61	17
123	Black alder	32	28	66.5	34
123.1	Black alder	30	29	66	27

Veneer sheets were cut using Wärtsilä VAL1000CP veneer guillotine machine (dimensions 1.8 x 1.7 x 1.15 m, weight 0.2 t) to size of 850 x 450 mm. The numbering system for the veneer was as follows (log number, species initial, sample numeric, soaking temperature °C, soaking time h, drying temperature for 2 minutes) i.e.:

113 (Given by the technician)/A (Aspen)/01 (chronological order of veneer)/40 (soaking temperature - degrees)/48 (soaking time - hours)/180 (drying temperature – degrees); 113/A/01/40/48/180.

For drying, the Raute laboratory veneer drier (dimensions 3.2 x 2 x 2 m, weight 1.2 t) were used to achieve moisture content 4.5±1.5% (Table 3.2) before gluing veneer on plywood panels. Dryer temperature were set at 180 °C. Birch, black alder and aspen veneers were dried for 2, 2:15 and 2:30 minutes respectively according to initial moisture content then stored at the conditioned storage room at 28 °C and 10% relative humidity (Figure 3.2).

Figure 3.2. Stored veneer

Table 3.2. Veneer moisture content, random samples.

Specimen	Moisture content
1	4.6%
2	5.0%
3	4.7%
4	4.2%

3.3 Veneering & Sanding

12 mm thick birch plywood (WG/ WG) produced by Estonian Plywood AS was used as the core panel for all veneered panels. Veneering has been done manually using glue

roller Black Bros 22-D machine with dimensions 1.9 x 0.8 x 1.4 m for coating glue over plywood panels. Hydraulic hot press Infor was used for pre-pressing and hot pressing. A phenolic glue was made with PF resin Prefere 14J021 and Prefere hardener with mixing ratio of 68 wt% resin, 14 wt% hardener and 18 wt% water content. Glue mixing was done at ~1200 rpm for 1h (Figure 3.3), pre-press was set to press in batches of up to 7 panels on top of each other for 10 minutes. Glue viscosity was determined to be 2 min 30 sec using GOST 4 mm flow cup. Targeted glue consumption on the glue roller was set 160 g/m^2 (Figure 3.4).

Figure 3.3. Glue mixing at 1200 rpm

Manual veneering and placing created shifted edges which decreased the net area of the panels after trimming.

Figure 3.4. Gluing using roller- coater Black Bros 22-D

Major difficulties during the process were the roller- coater adjustment, same readings were not guaranteed, but overall, it results within ~15% (±25 g) maximum variations of glue spread rate. Only a few panels were over or under calculated spread rate.
Using Infor hydraulic hot press, a stacked 7 panels (Figure 3.5) were pre pressed together for 10 minutes before separately pressed for another 4.5 mins at 135 °C and 1.4 MPa of pressure for all panels (Figure 3.6).

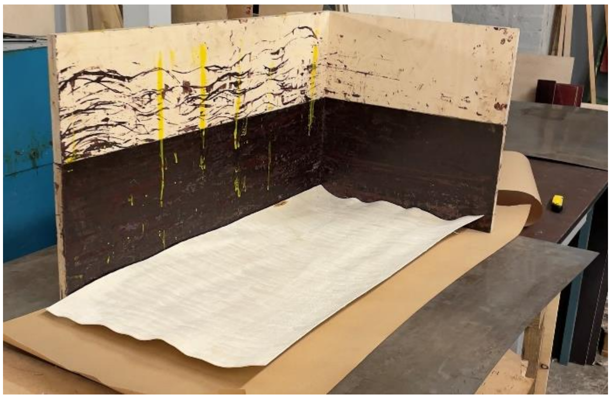


Figure 3.5. Veneer lay up

The manual machine sander was used with grit size P80 as recommended by Dynea company. It was hard to guarantee even surface for all veneer types even with an average of 1 minute of sanding for each panel side.

Figure 3.6. Veneered panels before trim

In the following graphs (Figure 3.7) (Figure 3.8) (Figure 3.9), the differences between calculated glue spread rate 160 g/m^2 and actually achieved glue spread rates are shown.

Most of the panels were within calculated spread rate, however few were different. Panels were numbered by hardwood veneer species initials and chronological order.

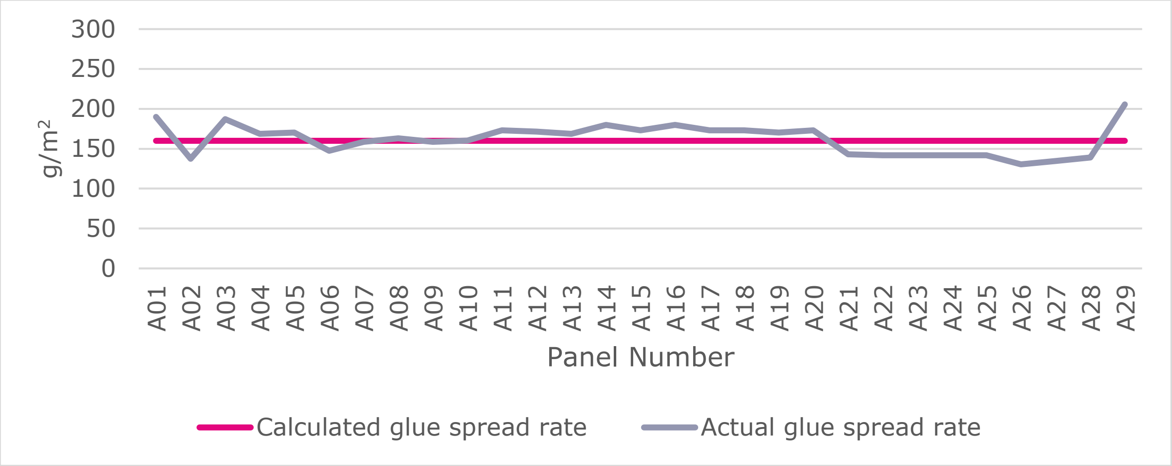


Figure 3.7. Aspen glue spread rate

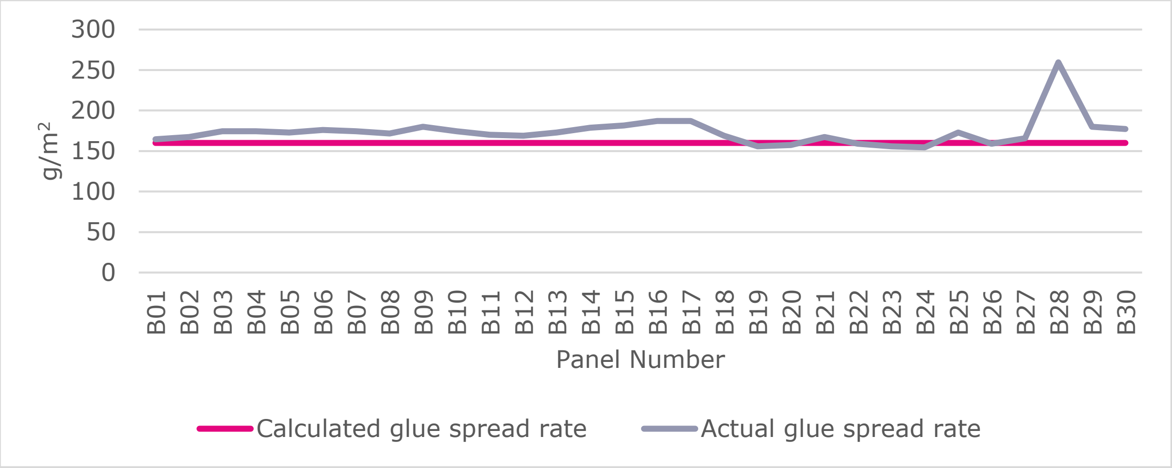


Figure 3.8. Birch glue spread rate

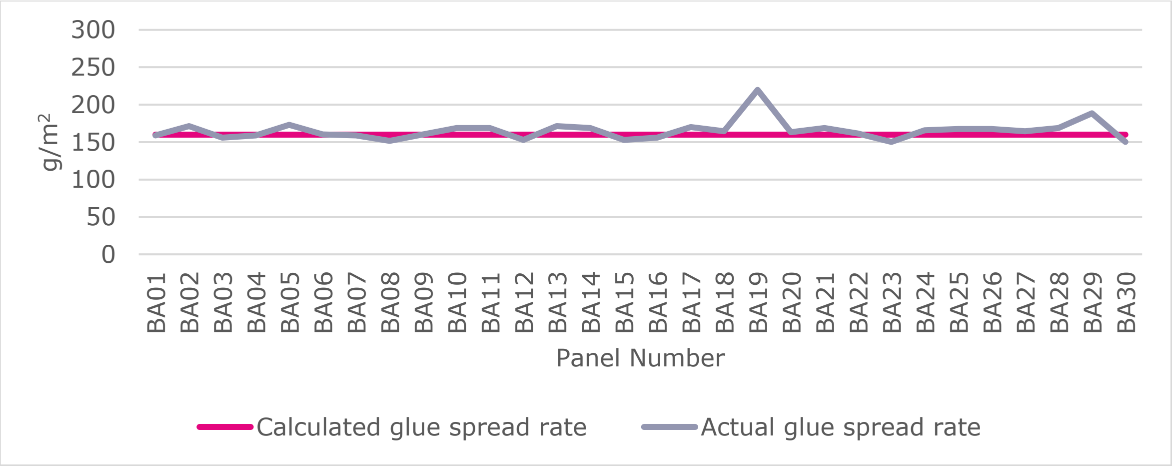


Figure 3.9. Black alder glue spread rate

3.4 Coating

After veneering, trimming edges and sanding plywood panels, 5 variations of surface coating were applied: phenolic film and 2 types of Dynea liquid coating (S1 and S2) with 2 spread rates for each type. Panels were selected randomly from the glued panels see (Figure 3.7), (Figure 3.8), (Figure 3.9). Few panels were not used to avoid defects or as backup. Panels with maximum and minimum glue spread rate were also excluded.

Dynea liquid coating 1 (S2) with 2 variations of spread rates 120 and 140 g/m^2 will be referedreferred to by S1 120 and S1 140. Dynea liquid coating 2 (S2) with 2 variations of spread rates 120 and 140 g/m will be referedreferred to by S2 120 and S2 140.

3.1.1 Dynea liquid coating 1

Dynea liquid coating 1 (S1) was prepared in the component 2:component 1 ratio of (w:w) 60:40. Dynea Component 1 should be added under stirring directly to Dynea Component 2 to give a liquid formulation that after pressing gives a transparent coating to the board surface. Stirring was done until a homogenous liquid with the correct application viscosity is achieved. Stirring was done at 900 rpm for 1h see (Table 3.3-1).

A total of 40 panels were produced with 2 different spread rates of 120 and 140 g/m2 see (Figure 3.10) (Figure 3.11) (Figure 3.12) (Figure 3.13). The mix was prepared in 2 batches with the same parameters. The stirring remained for 15 mins of after adding all ingredients. The viscosity remained high at 420 s with a GOST 4 mm flow cup. An additional water was added to achieve 150 s targeted viscosity. Batch details are shown in (Table 3.3-1).

Table 3.3-1. Dynea S1 mixture summary

Parameter	**Dynea liquid coating 1**
Component 2/Component 1 ratio (w:w)	60:40
Water (%)	15
Spread rate (g/m^2)	120 and 140
Viscosity (s)	~150
Pressing time (s)	180
Pressing temperature (°C)	120
Pressing pressure (MPa)	0.5

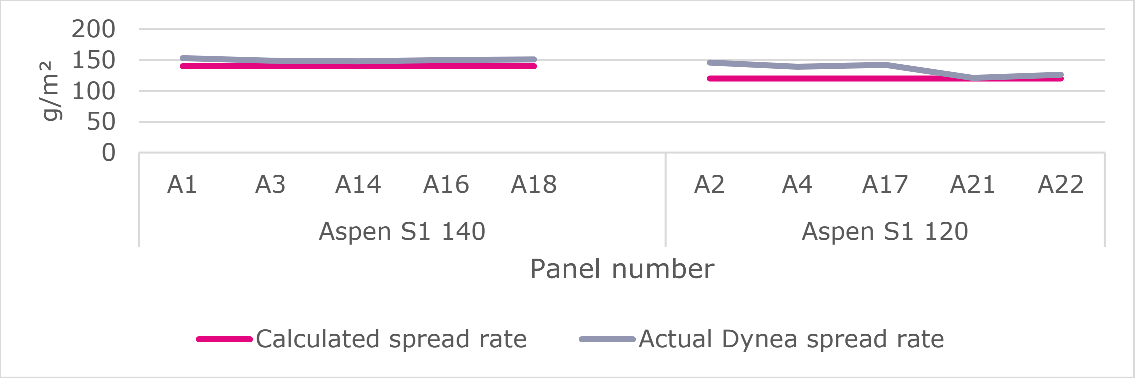


Figure 3.10. Dynea Aspen S1 140 and 120 actual spread rate

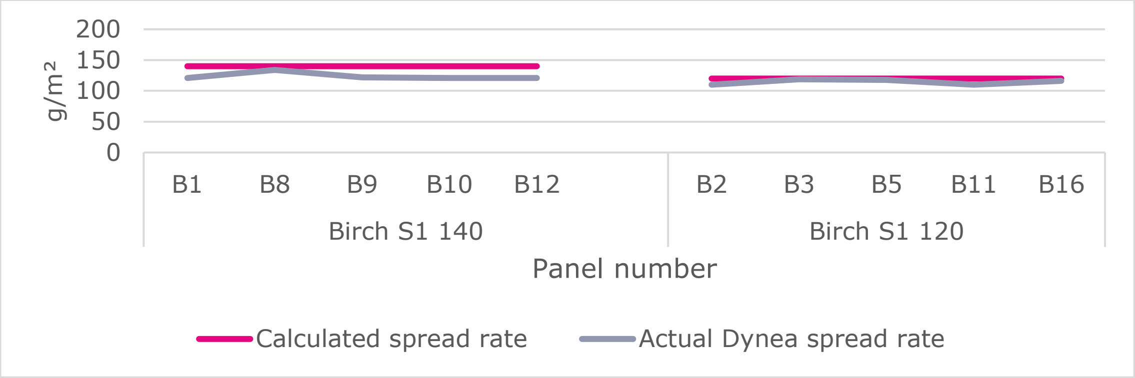


Figure 2. Dynea Birch S1 140 and 120 actual spread rate

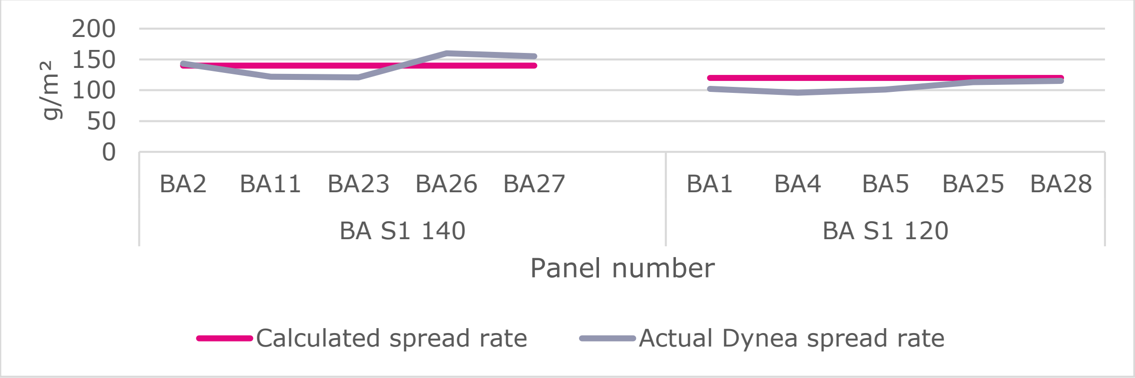


Figure 3.12. Dynea Black Alder S1 140 and 120 actual spread rate

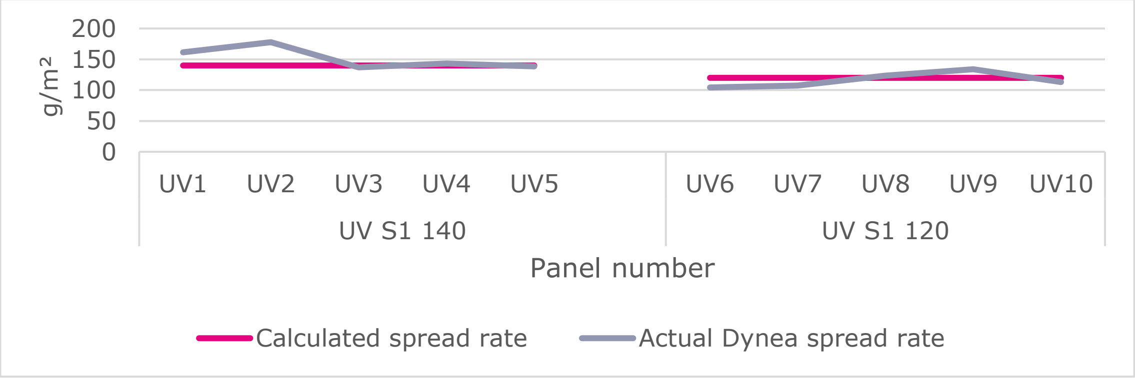


Figure 3.13. Dynea Unveneered S1 140 and 120 actual spread rate

Unexpected events have happened during coating because of manual sanding machine instead of a belt sander and certain areas on the panels were recessed so it has not properly coated or showed no coating.

Also, some panels were still uncured or wet after hot pressing, so it has been repressed again - mostly Aspen veneered panels. Certain panels could not achieve proper spread rate, so it went through roller coater 2x times as well. Overall, achieving calculated spread rates was challenging due to lack of experience of controlling machines, machine unexpected failing, or bad sanding.

The coating was successful and 5 panels from each group were produced. Many defects appeared over the surface such as peeled coating or coating stripes but not in both sides of the panels and we managed to take good samples.

3.1.2 Dynea liquid coating 2

The first attempt for coating plywood panels with Dynea liquid coating 2 (S2) was not successful for several reasons, starting with the wavy surface which influences material distribution over the surface but mostly would be caused by machine pressure inconsistency.

The procedure of Dynea liquid coating 2 application is done by mixing 2 components, an Component 2 and a Component 1 93:7 ratio (w:w), then mixed in 1500 rpm for an hour before spread over roller coater and hot pressing.

According to the Dynea company’s recommendation to overcome the drawback of squeezed out material in S1 due to immediate press, we let the first set of panels (Batch 1) dry before being put to press. Even with this strategy noticeable flaws and visible lines of uncoated areas were developed and the dry veneer surface was visible for many panels.

To overcome this issue, we immediately pressed the rest of Batch 1 with 140 g/m^2 spread rate but More issues – peeling, stripes, wet patches - have been observed. After investigation, it turned out that Infor hydraulic hot press was achieving wrong pressure values, and that was the reason behind bad curing. For these problems and inconsistency of the batches, Batch 1 was canceled and reproduced with newly produced Dynea component 2 and component 1 (Table 3.3-2).

Batch 1 (Canceled):

Viscosity was determined with the flow cup for 158 sec, using time was 35 min to produce all panels. Pressing started about 1 h after all of the boards were coated. Boards were dry to touch. A lot of stripes were observed on the panel surface also peeling and branching defects (Figure 3.14).

Batch 2:

Part 1- Viscosity was determined with the flow cup for 220 s, using time 45 min (19 boards), A little bit of peeling of the coating was obrerved, less peeling and stripes. see (Table 3.3-2).

Table 3.3-2. Dynea mixture summary.

Parameter	**Dynea liquid coating 2**
Component 2/Component 1 ratio (w:w)	93:7
Water (%)	-
Spread rate (g/m^2)	120 and 140
Viscosity (s)	220
Pressing time (s)	180 s
Pressing temperature (°C)	120
Pressing pressure (MPa)	0.5

Figure 3.14. S2 120 spread rate, set to dry before press, bad spread issues

The results of the first attempt were highly deviated from the calculated spread rates, using the same settings for all the boards of the same spread rate, and same amount of coating material over the roller coater, the obtained panels were taken from 2nd batch see (Figure 3.15) (Figure 3.16) (Figure 3.17) (Figure 3.18).

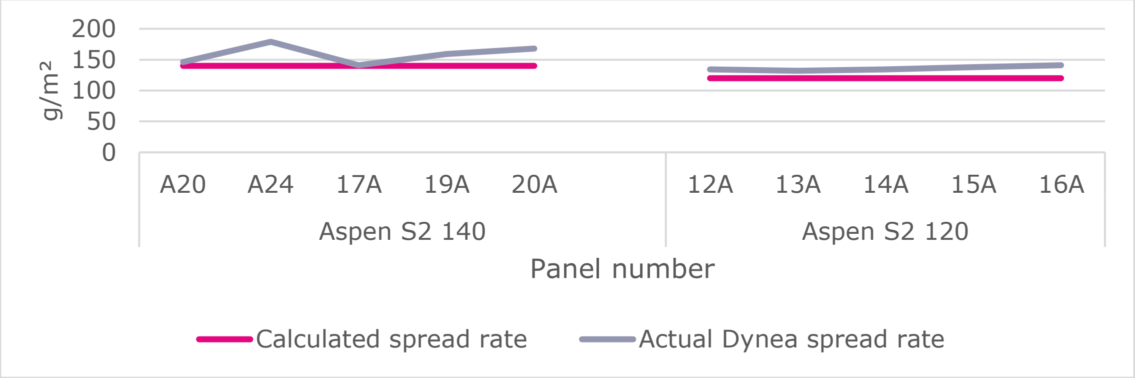


Figure 3.15. Dynea Aspen S2 140/120 actual spread rate

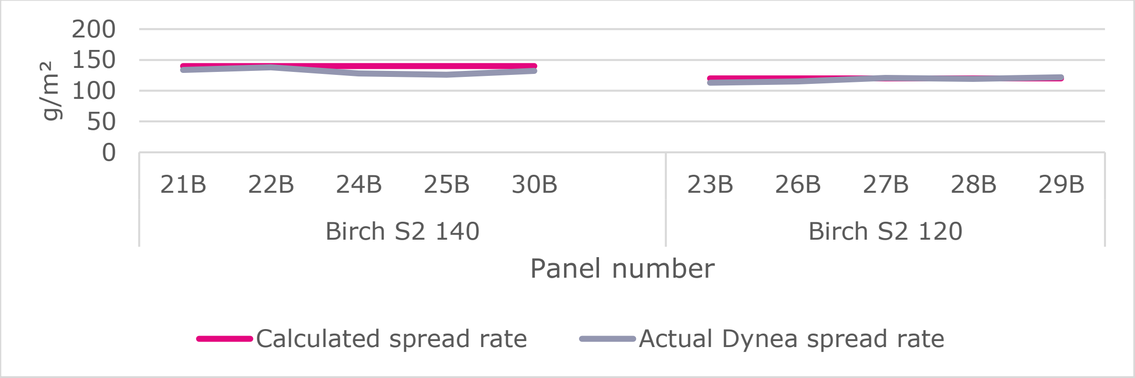


Figure 3.16. Dynea Birch S2 140/120 actual spread rate

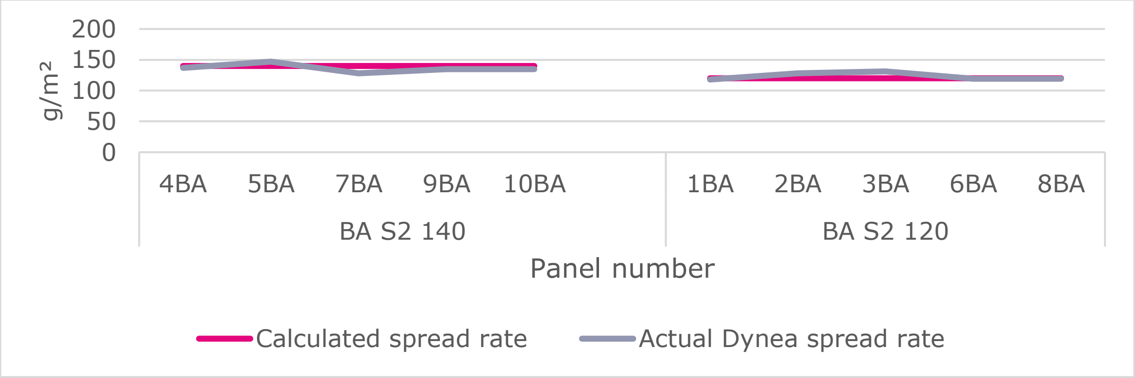


Figure 3.17. Dynea Black Alder S2 140/120 actual spread rate

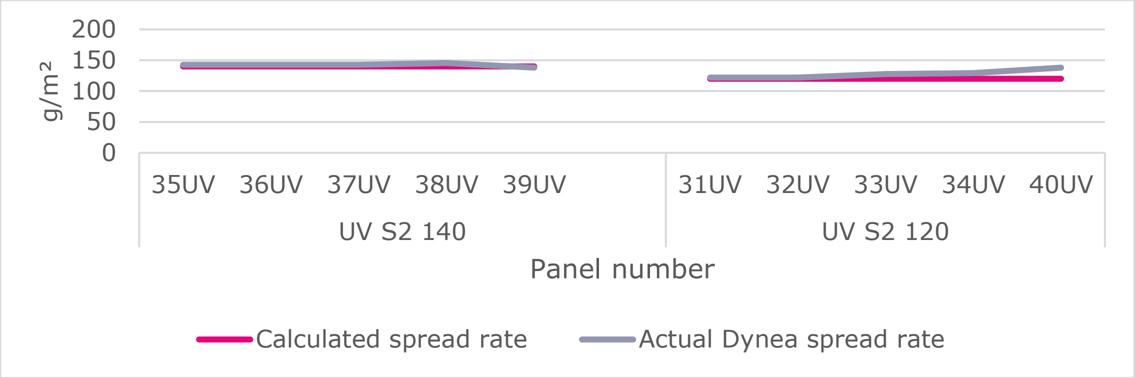


Figure 3.18. Dynea Unveneered S2 140/120 actual spread rate

3.1.3 Phenolic paper overlay

To compare 3 sets of coated panels with different coating materials, a standardized phenolic paper is added to the experiment produced by Surfactor Finland Oy, (width 1560 mm, quantity 2184 m^2) will be referred to as PF.

The phenolic film was stored in a freezer at -20 °C until ready to be used. According to manufacturer recommendation, pressing with a baking paper for 5 minutes at 130 °C was done. The panels were pressed at 135 °C for 8 minutes and covered with plastic thermal film - Mylar® A 190 - 500µm (Figure 3.19).

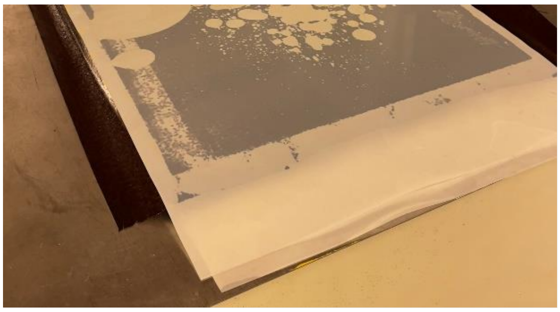


Figure 3.19. Pressed PF panels with Mylar® A 190 - 500µm

3.5 Cutting to sample size

The determination of the specimen size was set based on the sum of all standards in total 72 different test specimens from one type of material were cut over 3 boards of size 820 x 400 mm (Table 3.4). The layout has been produced by MaxCut 2 software, assuming blade thickness of 3 mm with 10 mm edge trim.

Table 3.4. Panel material and variations

NO.	**Core plywood**	**Surface veneer**	**Coating**	**Spread rate (g/m^2)**	**Total number of Panels**	**No. of test samples**
1	Birch	-	Dynea S1	120	5	72
2				140		
3		Aspen		120		
4				140		
5		Birch		120		
6				140		
7		Alder		120		
8				140		
9		-	Dynea S2	120		
10				140		
11		Aspen		120		
12				140		
13		Birch		120		
14				140		
15		Alder		120		
16				140		
17		-	Phenolic Film	-		
18				-		
19		Aspen		-		
20				-		
21		Birch		-		
22				-		
23		Alder		-		
24				-		
	Total				**120**	**1728**

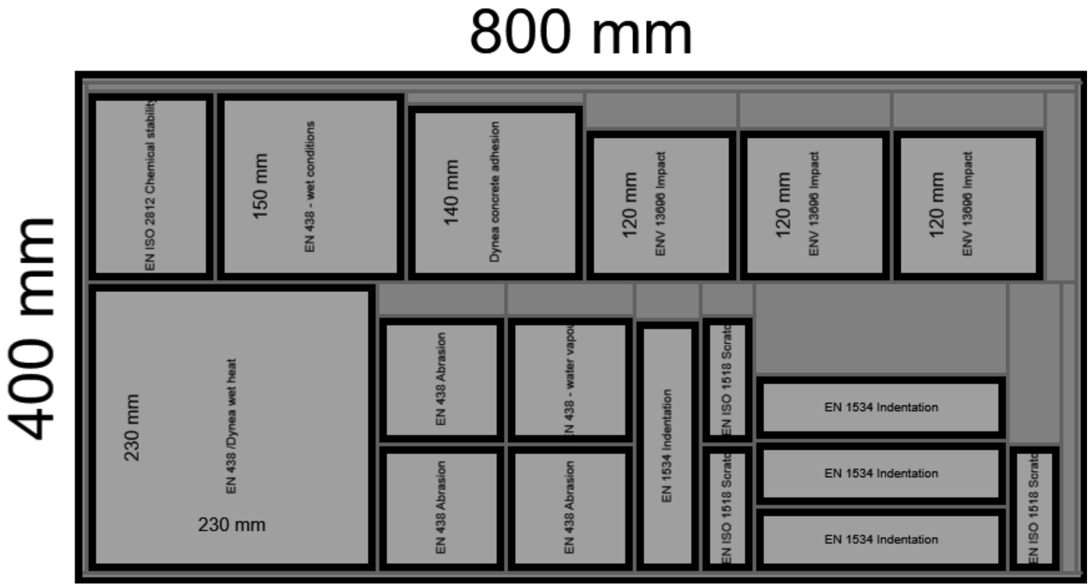


Figure 3.20. Cutting layout *(MaxCut 2)*

Panels were cut according to the plan (Figure 3.2) with excess samples for more room of evaluation and choices of best samples to be tested. Total number of samples were around 1728 of different sizes, only 140 were used in this research.

3.6 Testing

Tests included in this chapter are presented in Table 3.5. In the following sections are the tests to evaluate plywood surface coating scratch, hardness and toughness.

Table 3.5. Surface mechanical testing standards and parameters.

Test standard	**Aim**	**Number of samples per test**	**Sample size (mm)**	
			W	**L**
Brinell hardness test EN 1534	To evaluate surface indentation and hardness	3	50	200
Scratch test with conical stylus EN 438 – 2 ch. 25 – EN 1518	To evaluate surface adhesion quality	1	40	100
Taber test EN 13696 – EN 438-2 ch. 10	To evaluate surface abrasion resistance	3	100	100

3.1.1 Brinell Hardness

Starting by conditioning the samples in a conditioning chamber at 20 °C, 40% RH for +48h before testing. ZwickRoell Z050 universal electromechanical testing machine was used for testing. The results were obtained by gradually increasing the load from 0-1 kN in 15 s then maintain the 1 kN load (102 kg) for 25 s for each reading. 3 readings were taken from each sample and 3 samples were used of each variation (Figure 3.21). The readings were taken from minimally defected spots within each sample (Table 3.5). 2 measurements were collected: indentation diameter and surface hardness.

Using 10 mm diameter hardened steel ball. The Brinell hardness number (HBW) is calculated see (Formula 3.1).

Formula 3.1. hardnedss formula

$$HBW = \frac{P}{\pi D[D - (D^2 - d^2)^{1/2}]}$$

Where HBW is a unitless value, *D* is the ball diameter (mm), *d* is the average resultant diameter, recovered circular indentation (mm) and *P* is the applied load (kg). HBW is calculated by dividing the applied load by the surface indentation area.

Table 3.6. Conditioning chamber parameters

Temperature	20°C
Relative humidity	40%
Time	48h

Figure 3.21. EN 1534 Brinell test procedure

3.1.2 Abrasion resistance (Taber)

The Taber test according to standard EN 438-2 ch. 10 - resistance to surface wear - is a useful method to evaluate surface wear and abrasion resistance, but in this case and according to Dynea – the manufacturer of Dynea products – *Dynea* material is not designed to withstand abrasion but it serves the purpose.

Taber test conducted in accordance to Dynea recommendations of using the samples sizes and 100x100 mm sample. Test was done by using rotary Taber 5155 Abraser with CS-0 abrasive rubber wheels and S-42 abrasive paper strips glued to the wheels and 500g loading on the side of the abrasive wheels, connected to a suction device.

The results were obtained by applying abrasive wheels to the sample and start rotating for 100 revolutions then add 50 more revolutions if needed until IP is reached seeright. When the wear reaches at least 3 quarters of the rotating circle it is called IP (initial wear point). 2 measurements were collected, revolution counts and wear depth using thickness gauge percecion (0.001 mm).

3.1.3 Scratch resistance with a stylus

Test was done in TalTech Department of Mechanical and Industrial Engineering, Research Laboratory of Tribology and Materials Testing, by using conical tip stylus of 90 degrees mounted to CETR (Bruker) UMT-2 - Universal Mechanical Tester (Figure 3.23). Clamping a coated test panel on the panel holder with the coating facing upwards and positioning the test panel so that the distance between scratches to be at least 5 mm while 10 mm from the panel edges. Gradually applying force from 0.1 kg to 0.8 kg on linear movement (Figure 3.22) also (Figure 4.3 and 4.4) for 70 mm length, and 5 mm/s speed. Obtained results were coefficient of friction throughout the testing period of 14 seconds.

Figure 3.22. First attempt using a steel ball instead of cone

3.7 Statistical analysis

Analyses were done using Excel spreadsheet software - made by Microsoft. Using custom standard deviation to evaluate standard deviation of obtained data and single-factor ANOVA single-factor test to evaluate data variance (95% confidence).

4 RESULTS AND DISCUSSION

4.1.1 Brinell Hardness

Testing surface hardness using EN 1534 Brinell hardness test shows result fluctuation with different type of coating in both diameter and surface hardness, especially within same surface material type i.e. birch veneered plywood and unveneered birch plywood has ~10% diameter differences and mostly similar surface hardness (Figure 4.1 – 4.2).

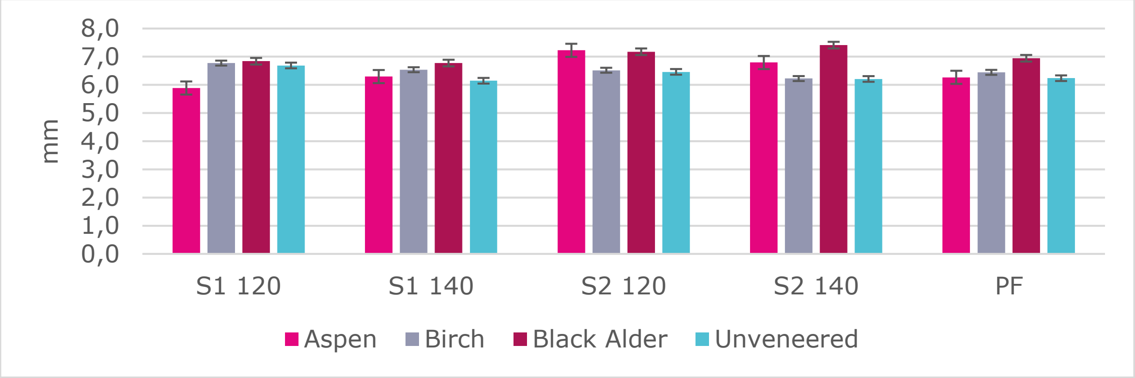


Figure 4.1. Brinell average diameter (mm)

Aspen has maximum inconsistent results in both graphs with significant changes of surface hardness depending on coating type, while birch veneered panels were more stable against Brinell test. Black alder, birch and unveneered plywood recorded same hierarchy in diameter size among different coating while aspen does not follow the pattern (Figure 4.2).

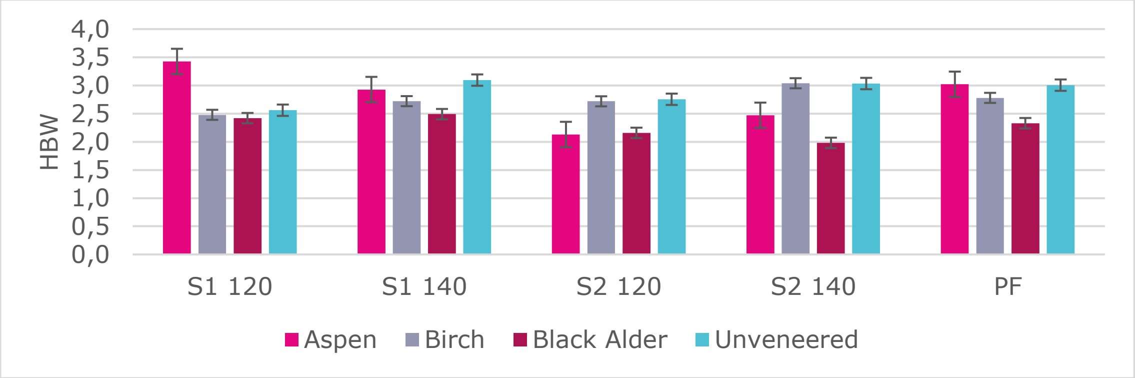


Figure 4.2. Brinell average hardness (HBW)

4.1.2 Scratch resistance with a stylus

The original scratch test was designed to use EN 13696 as a guide to measure surface quality, but it meant to be for metal substrates to measure conductivity and the specimens were cut according to it (40*100 mm), an adjustment was made to use same samples by using EN 438-2 ch. 25/ EN 1518 Scratch resistance with stylus as a reference. A new test was designed using same samples instead of revolving method to scratch material surface by a cone shaped tip. the load gradually and consistently increased from 0.1 kg to 0.8 over 14 s. 3 trials (Figure 4.3 – 4.4) were done for each sample material and samples with isotropic surfaces were selected.

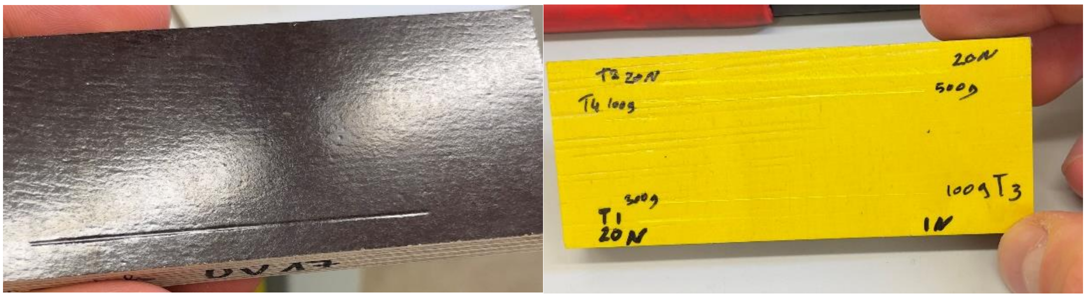


Figure 4.3. Adjustment samples

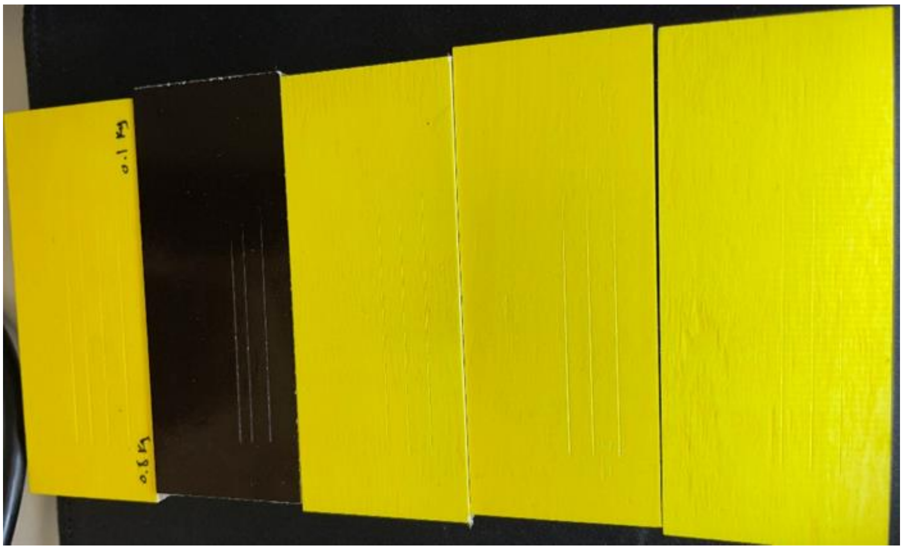


Figure 4.4. Scratch test samples

Aspen average coefficient of friction (Figure 4.5) shows a noisy graph indicating an anisotropic surface with an uneven surface. Even with smooth film surface as the phenolic film. When the load increases, an inconsistent friction resistance indicates air gaps or density differences of the surface. The high coefficient of friction of Aspen S1 120 sample may be caused by low spread rate which is relatively solved in higher spread rates at A S1 140 sample.

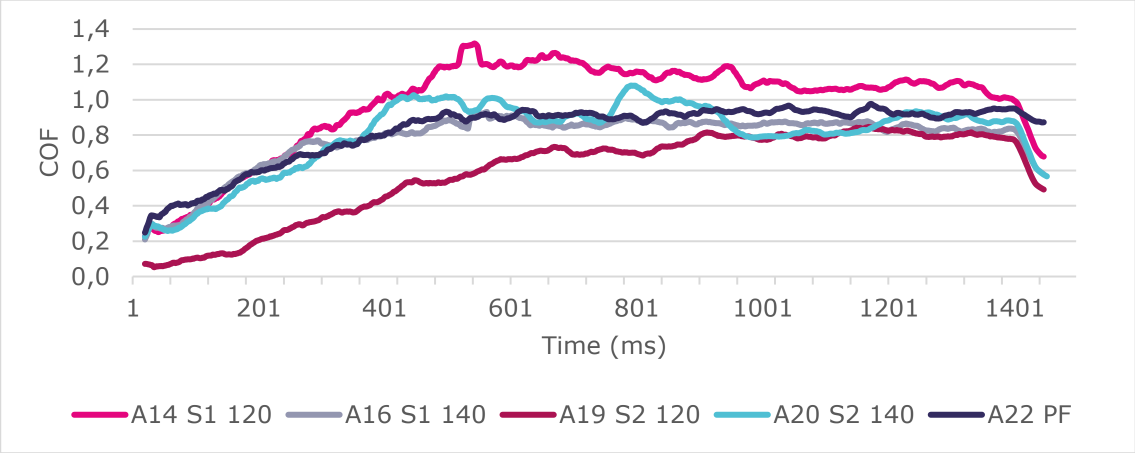


Figure 4.5. Aspen scratch test average coeffecient of friction

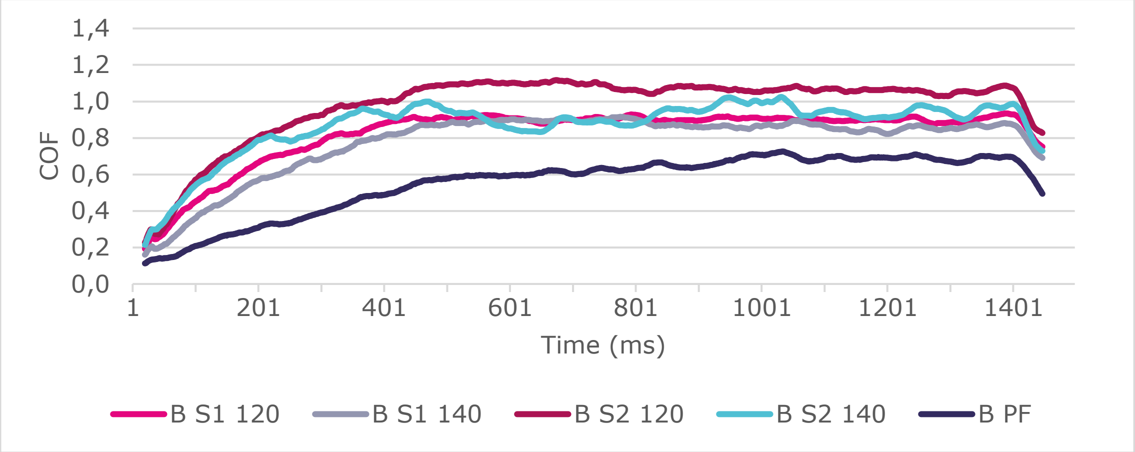


Figure 4.6. Birch scratch test average coeffecient of friction

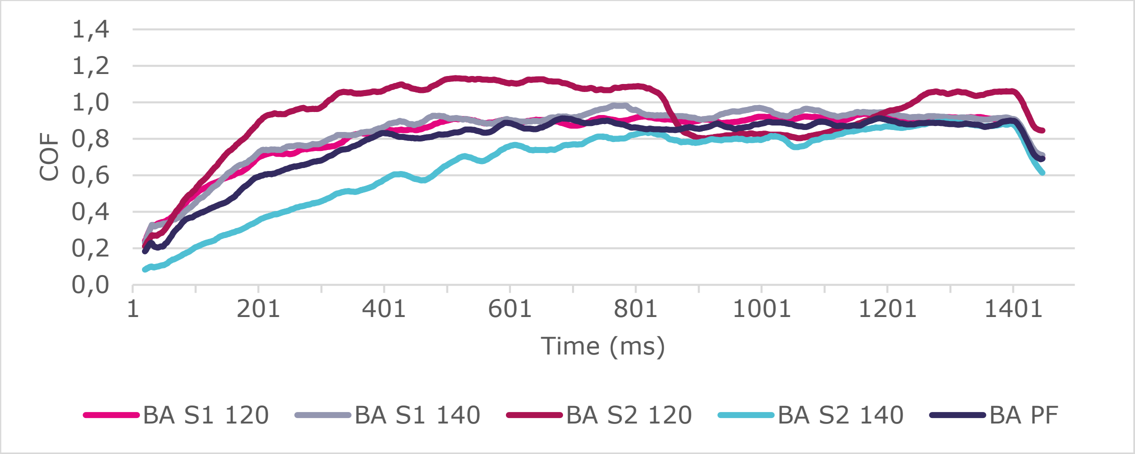


Figure 4.7. Black alder scratch test average coeffecient of friction

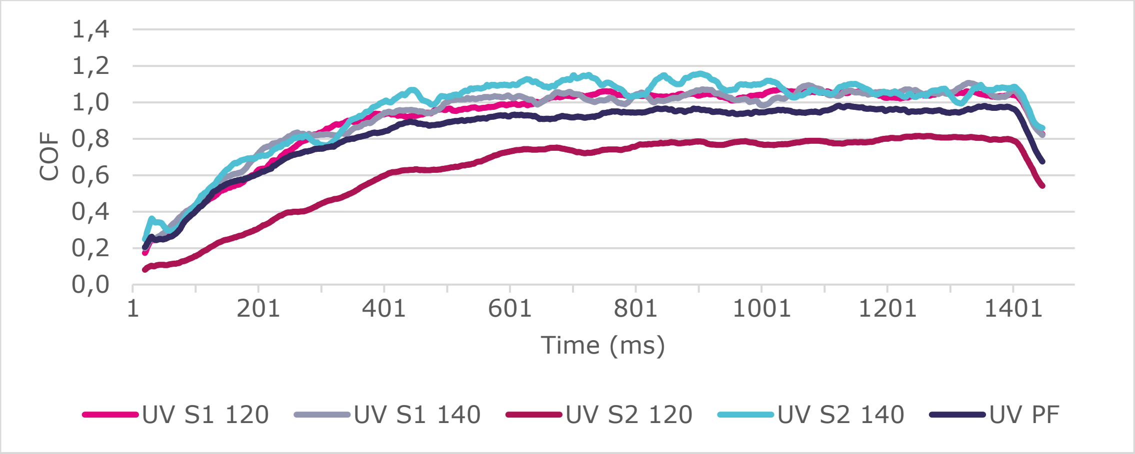


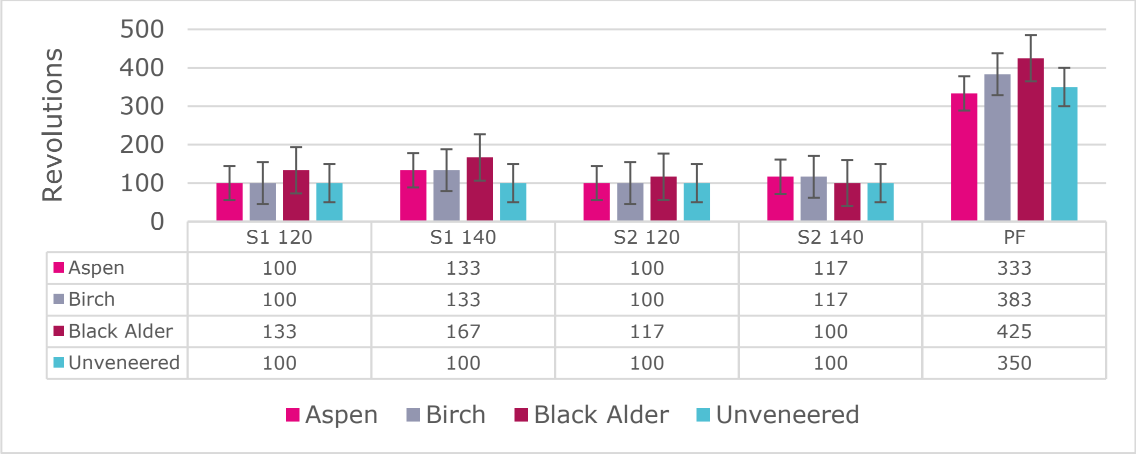
Figure 4.8. Unveneered scratch test average coeffecient of friction

4.1.3 Abrasion resistance (Taber)

Obtaining the results of reaching initial wear point IP was done using experimental samples, (Figure 4.9).

It is clearly visible that the difference between S1, S2 and the Phenolic film in reaching initial wear point (IP). The PF samples needed significantly more revolutions to reach IP in comparison with S1 and S2. The following graph (Figure 4.10) shows the average revolutions count for each sample while (Figure 4.11) shows the depth of wear of abraded samples.

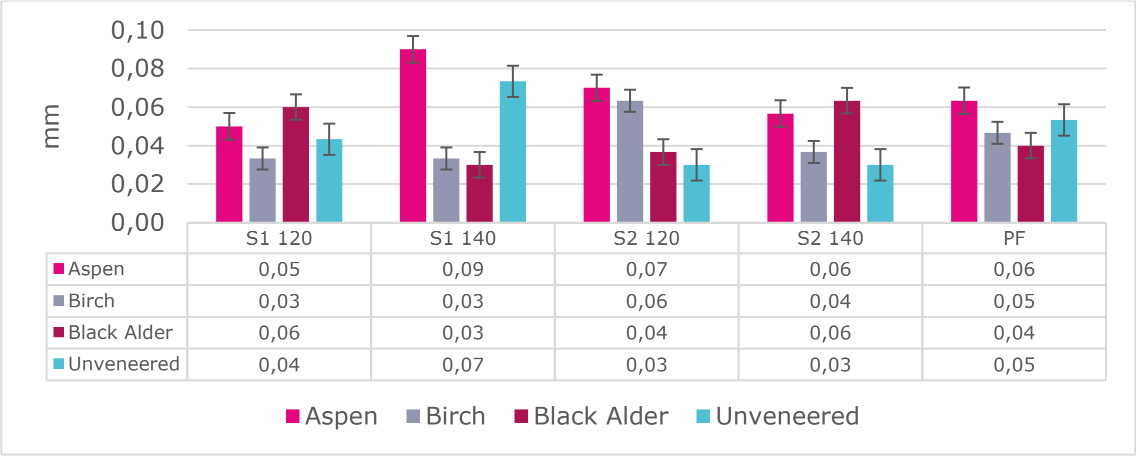
Figure 4.9. Taber abrasion test example 800, 400, 100 revolutions respectively



	S1 120	S1 140	S2 120	S2 140	PF
Aspen	100	133	100	117	333
Birch	100	133	100	117	383
Black Alder	133	167	117	100	425
Unveneered	100	100	100	100	350

Figure 4.10. Taber test revolution counts

While the revolutions count is important to reach IP but the wear depth is also an indication to surface durability. Aspen veneered panels have more tendency for surface wear compared to the rest of veneer samples. Aspen and Black alder showed ~50% inconsistent difference within same coating system and different spread rates.



	S1 120	S1 140	S2 120	S2 140	PF
Aspen	0,05	0,09	0,07	0,06	0,06
Birch	0,03	0,03	0,06	0,04	0,05
Black Alder	0,06	0,03	0,04	0,06	0,04
Unveneered	0,04	0,07	0,03	0,03	0,05

Figure 4.11. Taber test wear depth

4.2 Analysis

Aspen in general was the least even surface with many raising grains and uneven surface even with sanding while black alder is harder to be classified because it shows inconsistent pattern during the performed tests. It is important to mention that unveneered panels were fully birch plywood and birch veneered panels only had an additional layer of birch veneer over core birch panels. However, significant differences were observed during the Taber test. A reason for that could be the different water content among coating systems or veneer specific gravity which caused a significant average difference in some samples (Hochmańska-Kaniewska, et al., 2022). Revolution counts to reach IP was relatively similar to similarly tests PF plywood (P. Král, et al., 2008).

The indentation test recorded variations among the same species with different coatings. An interesting result of aspen A S1 120 sample was observed, where it has a record highest hardness, ~25% difference (Figure 4.5) among the rest of the test samples. However, black alder remains the weakest surface during indentation test, with almost similar results for phenolic film panels at ~3 (HBW). slightly harder than gold according to the hardness chart of different materials (F. Mohs, 1822).

The conical stylus used for scratch test pointed out a major difference between PF paper coating and liquid coating and not only the application method but the behavior against scratch stresses (figure 4.12) and how the top coat layer behaves. The phenolic film coated panels have an opaque smooth surface but it did not demonstrate stretchability when in contact with the conical tip. Opposite results were observed while testing Dynea S1 and S2 panels during scratch or indentation tests, The surface layer tends to deform or compress and rather than peeled off or break by the applied load. This indicates an advantage to liquid coating especially with added water as it is in Dynea S1. Scratch test with S2 samples produced least coefficient of friction in 3 of 4 samples which may indicates smoother surface of S2 over S1 (Kazem, et al., 2014).

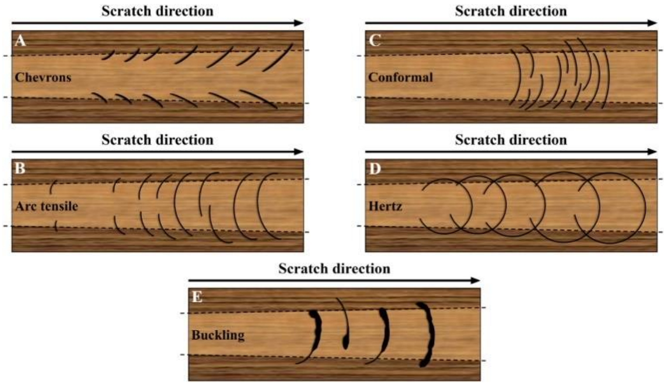


Figure 4.12. Scratch stresses (Seymour et al., 1989)

(Figure 4.6) and (Figure 4.8) shows 2 birch samples: the first one is a plywood core panel veneered with birch face veneer layer while the other is company made birch unveneered core plywood., The first one has longitudinal grain direction when performing scratch test unlike the unveneered group with crosswise grain direction. A noticeable difference between both groups in the amount of noise produced and relatively higher average coefficient of friction with same substrate was observed. This indicates higher surface roughness and a 3D profiler may give a thorough understanding of the surface reaction to scratch stresses (Figure 4.11). It is more likely for the tested surface to achieve lower COF over time as the surface becomes smoother which suggests it can be used multiple times with a better result (Cosemans, et al., 2003).

While it was quite straight forward to set parameters and evaluate results for indentation and scratch tests, they were not sufficient to understand material wear properties which is significant factor when selecting environment exposed material. The significance of Taber test helped to evaluate the thickness of penetrated material to the substrate to form a protective layer. If the coating layer is not completely adhered to the substrate it may result in low IP and also bad or uneven spread rate of liquid coating. In general, the outer veneer layer adhesion and uniformity determine the overall performance of Taber test (P. Král, et al., 2008).

The goal was to reach initial point IP where 2/3 of sub material is already visible and it was difficult at first to detect the natural substrate color from Dynea coating yellow color. The glossiness difference helps to identify initial point of wear efficiently. Phenolic film samples of different veneer substrates showed a significant difference compared with Dynea products to reach IP, by up to 4.5X more revolutions to reach same wear depth (Figure 4.2/4.3 – BA PF/ BA S2 120). This major difference has been discussed with Dynea - the manufacturer – and they suggested that Dynea products were not designed to resist high abrasion conditions and it is used for truck loading and concrete casting with least customer complains.

Wear depth is useful indicator to material density but also weight before and after testing could help to understand material wear (P. Král, et al., 2008). Whether the coating material has improved abrasion resistance, aspen samples tended to lose more material when measured the wear depth against abrasion which indicates the material low densinty drawback.

It was hard to guarantee even surface with manual sanding (Figure 4.13), some patches will always be recessed more than the rest which affect even spread rate mainly and can be an issue for certain tests to ensure correct specimen selection and reduce wasted material.

Figure 4.13. Recessed sanded edge

While mixing, the liquid coating gets too vicious so adding water is the solution. However, after curing and water evaporation the actual spread rate will be different, a margin equivalent to water added might be added to ensure same spread rate. Also roller-coater is not ideal for material spreading after sanding. Sanding is a major factor in determining surface coating quality (F. H. Kaufert., 1943).

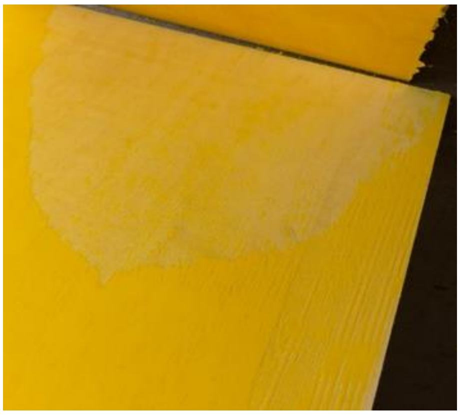


Figure 4.14. Random batch with less spread material

Aspen veneer showed uncured Dynea post pressing in 2 separate occasions where the panel was completely uncured after 3 minutes hot press as stated in the datasheet. Hence this behavior has no explanation by far as most of aspen veneered panels were totally cured after one press.

The presented defects in either S1 and S2 were peeling of the surface, striped coating (Figure 4.14) and branching is not limited to a type of surface veneer or a coating system, but it varies from panel to panel. For example, black alder veneered panels showed more defects over the rest. Aspen was more consistent in terms of quality but generally less desirable for concrete formwork or façade cladding applications. Dynea, the manufacturer of Dynea products has suggested the aging of the coating batch or the long waiting time before press (10 minutes). After thorough investigation it was clear that the problem was the hot press pressure adjustment.

The short service life of Dynea S2 mix was a challenge to achieve a full batch with a similar mixture and the rest of mixed material went to waste as no way to store it for later uses. It was also difficult to clean Dynea S2 out of roller-coater machine unlike S1 which has higher water content and relatively easier to clean with warm water. Scratch and indentation tests were pointing almost similar material properties from different angles, however both are measuring basic parameters such as length, width and loads without deep understanding to material deformation or failure, would be useful to use a magnifier or accurate 3D scanner to evaluate material damages caused by the tests.

Running statistical analysis was important to understand how significant are the obtained data (Table 4.1), Brinell test results were not significant according to ANOVA test since P-values > 0.05. rest of obtaines results in both Taber test and scratch test are significant data and accountable.

Table 4.1. ANOVA test results for obtained results

	P-value
Wear depth	0.022436
UV HBW	11.4089
A HBW	11.4089
BA HBW	6.102291
B HBW	2.552405
B COF	0
BA COF	0
A COF	0
UV COF	0

It is important to thoroughly investigate site practices to ensure better user manual is being produced. For the time being this product is being treated as an alternative to phenolic film panels, which might give wrong perception as a weaker alternative. Using it as a primary case study compared to other liquid coating products could be useful.

SUMMARY

This research studied different veneered plywood panel surface characteristics and set multiple goals to be achieved throughout the process. The main goal was to compare different coating products using standardized tests and the same testing condition, methods, and types of equipment. Also, to explore and investigate exterior use, concrete formwork use conditions and other related factors that might be affected during service life of plywood. This research assess formwork panels coating strength based on a thorough literature review and thorough experimental study based on EN standardized tests and apparatus.

Comparing surface mechanical performance of veneered plywood coated with phenolic film coating and Dynea liquid coating liquid coating 1 and liquid coating 2 was the aim of the research work. According to the overall performance the PF samples were in generally better and significantly more durable in some cases such as number of revolutions in Taber test. The obtained results can be used to recommend certain uses of tested Dynea coating systems especially within highly abrasive environments such as outdoor uses or direct contact with coarse materials or sharp objects.

The obtained results indicate the differences between the novel paperless Dynea products and the successful PF product for concrete formwork panels. The comparison shows many similarities for both solutions which puts Dynea S1 and S2 as a good competitor to PF films within same scope of tests, with an advantage of S1 for longer mixture service life and relatively similar results for scratch and indentation tests.

In general, the different surface veneers have a direct effect on the overall performance of the liquid coating, and it is connected to wood specie density. It is visible in abrasion test results where PF acted as an independent layer against abrasion while S1 and S2 samples were highly affected by the density and adhesion to wood surface. Therefore, it is important to select higher density wood species when applying liquid coating while it might be less important for PF coating for the same uses.

KOKKUVÕTE

Selles lõputöös uuriti erinevate pinnaspoonidega vineeride pinnaomadusi ja püstitati mitu eesmärki, mida kogu protsessi jooksul saavutada. Põhieesmärk oli võrrelda erinevaid pinnakatteid, kasutades standardiseeritud teste ja samu katsetingimusi, meetodeid ja seadmetüüpe. Lisaks uuriti väliskasutust, betooni raketise kasutustingimusi ja muid seotud tegureid, mis võivad vineeri kasutusea jooksul mõjutada. Lõputöös hinnatakse betooni raketise paneelide katte tugevust, tuginedes põhjalikule kirjanduse ülevaatele ja põhjalikule eksperimentaalsele uuringule, mis põhines EN standardiseeritud katsetel ja seadmetel.

Lõputöö eesmärgiks oli fenoolkilekattega kaetud vineeri ja Dyneai vedelpelistuse süsteem 1 ja süsteemi 2 pinnamehaaniliste näitajate võrdlemine. Vastavalt tulemustele olid PF proovid üldiselt paremad ja mõnel juhul oluliselt vastupidavamad ning näiteks kulumiskindlus Taberi katses oli kõrgem.

Saadud tulemused näitavad erinevusi uudsete paberivabade Dyneai toodete ja PF toote vahel. Tulemuste võrdlused näitavad palju sarnasusi mõlema lahenduse puhul, mis teeb Dynea S1 ja S2 fenoolkattega vineeridele heaks alternatiiviks. Kusjuures S1 eeliseks on segu pikem kasutusiga ning suhteliselt sarnane kriimustuskindlus.

Tulemused näitavad, et erinevatel pinnaspoonidel on otsene mõju vedela pinnakatte üldisele toimimisele ja see on seotud puiduliigi tihedusega. Fenoolkattega vineeridel ei olnud nähta pinnaspooni omaduste mõju kulumiskatsetes, samas aga Dynea vedelpealistuse kulumiskatsed sõltusid pinnaspooni kvaliteedist ja puiduliigist. Seetõttu on vedelpealistuse pealekandmisel oluline valida suurema tihedusega puiduliigid, samas kui fenoolkatte puhul võib see samadel kasutusaladel olla vähem oluline.

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تم بحمد الله

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APPENDICES

Table 2.1. General information, MF – PF (Fengel, D. et al., 2003)

Title	Comparison Topic	MF Resin	PF Resin
Mechanical Properties	Elastic (Young's, Tensile) Modulus, GPa	7	3.8
	Elongation at Break, %	1	2
	Tensile Strength: Ultimate (UTS), MPa	30	48
	Stiffness to Weight: Axial, points	2.6	1.6
	Stiffness to Weight: Bending, points	43	40
	Strength to Weight: Axial points	5.6	10
	Strength to Weight: Bending, points	14	23
Thermal Properties	Maximum Temperature: Autoignition, °C	350	450
	Maximum Temperature: Decomposition, °C	350	260
	Specific Heat Capacity, J/kg-K	1200	1400
	Thermal Conductivity, W/m-K	0.5	0.25
	Thermal Expansion, µm/m-K	60	120
	Thermal Diffusivity, mm2/s	0.28	0.14
	Thermal Shock Resistance, points	5.1	7.5
Electrical Properties	Dielectric Strength (Breakdown Potential), kV/mm	30	46
	Electrical Resistivity Order of Magnitude, 10x Ω-m	9	11
Density	Density, g/cm3	1.5	1.3

Table 2.2. Commercial data to compare between available products (Dynea, 2018)

	Paint/ Lacquers	PSF	Dynea	MDO	PF	MF
Flexibility in dimensions	Low	-	High	-	High	Mid
Transparency	Mid	-	High	-	Low	-
Fiber free	-	High	High	High	-	-
Abrasion Durability	-	Mid	High	Mid	High	High
Process Efficiency	Low	Mid	High	Mid	High	Mid

Table 2.3. A reference test set is brought by *Metsa* overlay properties test set.

Property	Test	Result unit
Abrasion resistance	EN 438-2	[rounds]
Surface hardness	EN ISO 1534	HB
Scratch resistance	EN ISO 1518/ EN 438-2	A* [N]

Table 3.1. The list of peeled logs

Log no.	Species	Avg. diameter. cm	Avg. Surface temp. °C	Moisture content. %	Veneer sheets obtained
109.1	aspen	28	29	71	-
112.0	aspen	25	32	70	35
113.0	aspen	24	30	66	23
129.0	aspen	24	28	54	-
133.0	aspen	31	35	71	23
114.0	birch	20.5	29.5	44	8
114.1	birch	19.5	27.5	50	20
114	birch	19	30	52	-
119.0	birch	23	24	62	14
124	birch	23	26	62	18
128.0	birch	25.5	28	40	26
115.0	black alder	19.5	27.5	64	17
115.1	black alder	19	27	60.5	8
120	black alder	26.5	31	61	17
123	black alder	32	28	66.5	34
123.1	black alder	30	29	66	27

Table 3.2. Veneer moisture content, random samples.

Specimen	Moisture content
1	4.6%
2	5.0%
3	4.7%
4	4.2%

Table 3.3-1. Dynea S1 mixture summary

Parameter	Dynea liquid coating 1
Component 2/Component 1 ratio (w:w)	60:40
Water content (%)	~15
Spread rate, g/m2	120 and 140
Viscosity (s)	~150
Pressing time (s)	180
Pressing temperature (°C)	120
Pressing pressure (MPa)	0.5

Table 3.3-2. Dynea S2 mixture summary

Parameter	Dynea System 2
Component 2/Component 1 ratio (w:w)	93/7
Water content (%)	-
Pot life (23°C) (min)	30-45
Spread rate, g/m2	120 and 140
Viscosity (s)	~210
Pressing time (s)	180
Pressing temperature (°C)	120
Pressing pressure (MPa)	0.5

Table 3.4. Panel material and variations

	Panel material	Surface veneer	Coating	Spread rate	Total Panels	No. of samples
1	Birch	-	Dynea S1	120	5 x820x430	72
2				140		
3		Aspen		120		
4				140		
5		Birch		120		
6				140		
7		Alder		120		
8				140		
9		-	Dynea S2	120		
10				140		
11		Aspen		120		
12				140		
13		Birch		120		
14				140		
15		Alder		120		
16				140		
17		-	Phenolic Film	-		
18				-		
19		Aspen		-		
20				-		
21		Birch		-		
22				-		
23		Alder		-		
24				-		
					120	1728

Table 3.5. Surface mechanical testing standards and parameters

Test standard	**Aim**	**Number of samples**	**Sample size (mm)**	
			W	**L**
Bernil test EN 1534	to evaluate surface indentation and hardness	3	50	200
Scratch test with conical stylus EN 438 – 2 ch. 25 – EN 1518	To evaluate surface adhesion quality	1	40	100
Taber test EN 13696 – EN 438-2 ch. 10	to evaluate surface abrasion resistance	3	100	100

Table 3.6. Conditioning chamber parameters

Temperature	20°C
Relative humidity	40%
Time	48h

Table 4.1. ANOVA test results for obtained results

	P-value
Wear depth	0.022436
UV HBW	11.4089
A HBW	11.4089
BA HBW	6.102291
B HBW	2.552405
B COF	0
BA COF	0
A COF	0
UV COF	0

GRAPHICAL MATERIAL

Figure 2.1. Plywood façade cladding (Plyterra, 2011)

Figure 2.2. Cured melamine plywood flooring slates (Kastamonu, 2016)

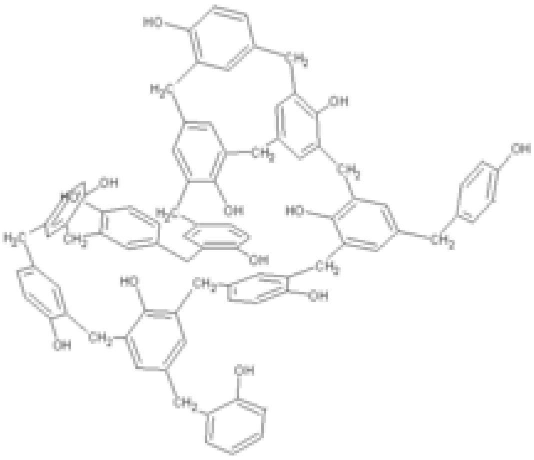


Figure 2.3. Bakelite 3D chemical structure (Wikimedia, 2012)

Figure 2.4. Phenolic film coated plywood (Salvati Timbers, 2021)

Figure 2.5. Phenolic resin form faced plywood (proFace, 2021)

Figure 2.6. Medium density overlay (Justpaint, 2018)

Figure 3.1. Rejected veneer

Figure 3.2. Stored veneer

Figure 3.3. Glue mixing at 1200 rpm

Figure 3.4. Gluing using roller coater Black Bros 22-D

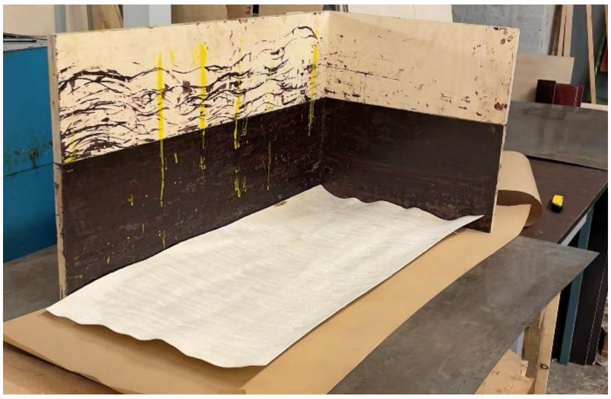


Figure 3.5. Veneer lay up

Figure 3.6. Veneered panels before trim

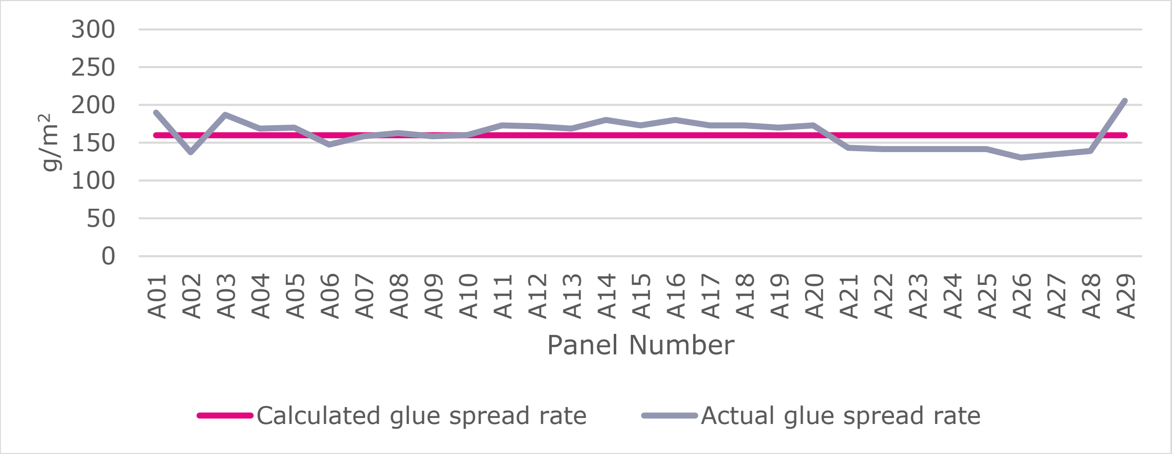


Figure 3.7. Aspen glue spread rate

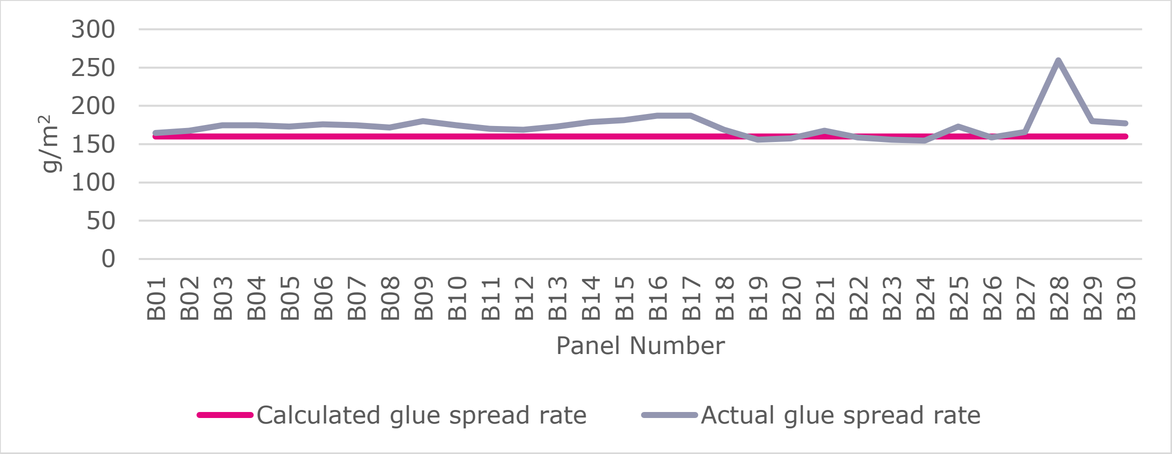


Figure 3.8. Birch glue spread rate

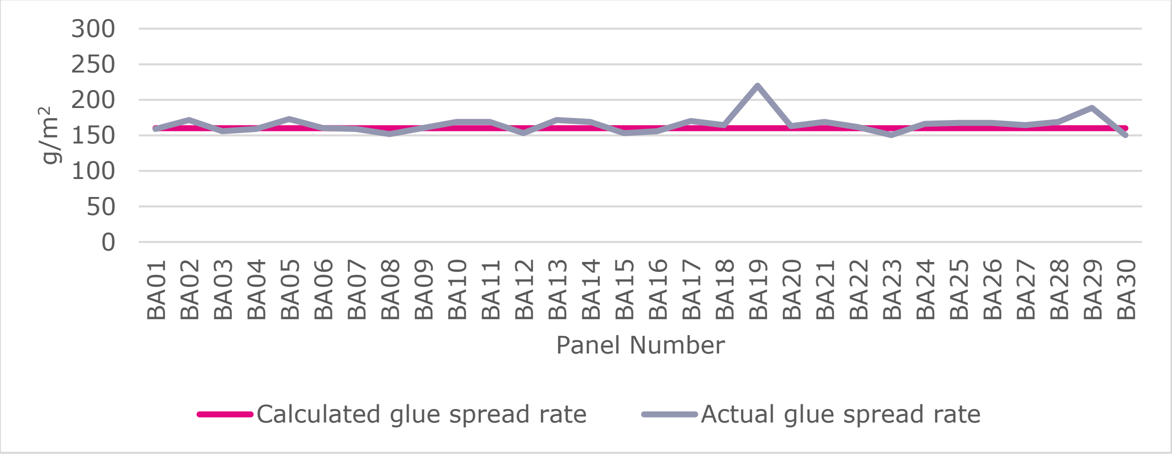


Figure 3.9. Black alder glue spread rate

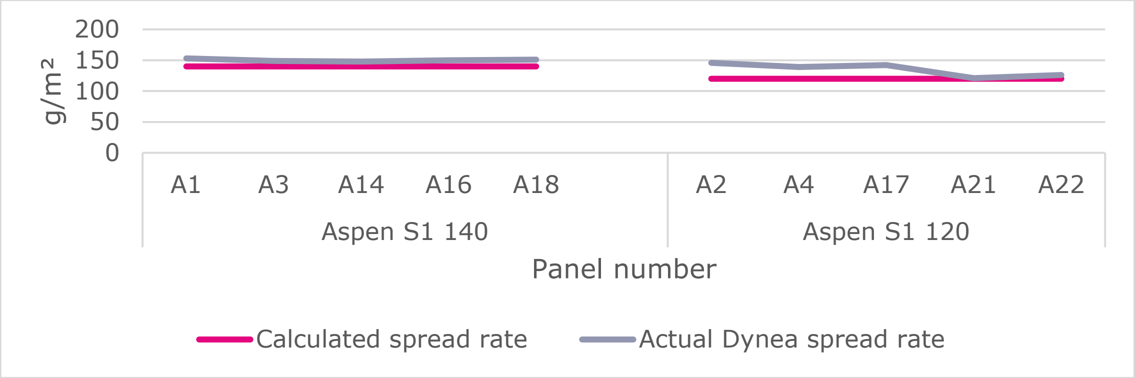


Figure 3.10. Dynea Aspen S1 140 and 120 actual spread rate

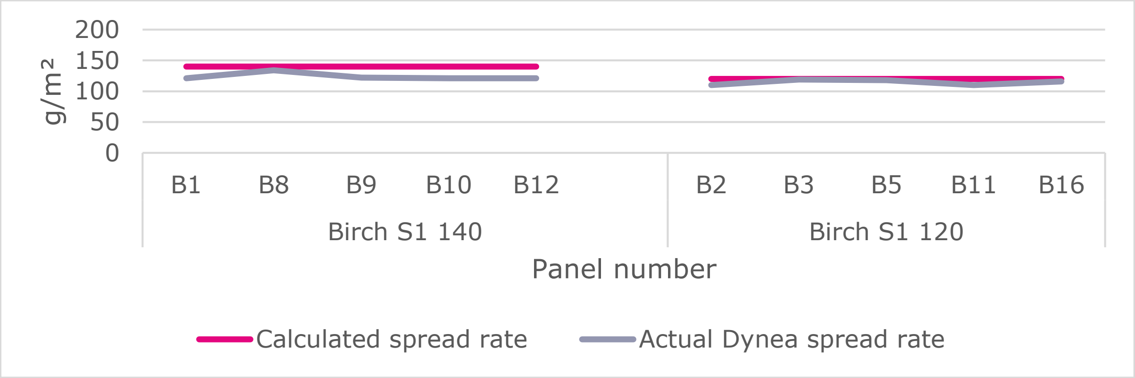


Figure 4. Dynea Birch S1 140 and 120 actual spread rate

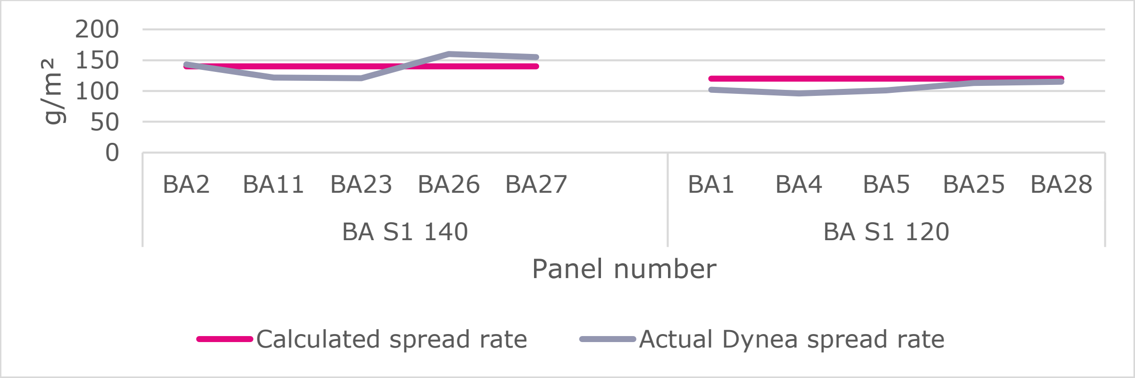


Figure 3.12. Dynea Black Alder S1 140 and 120 actual spread rate

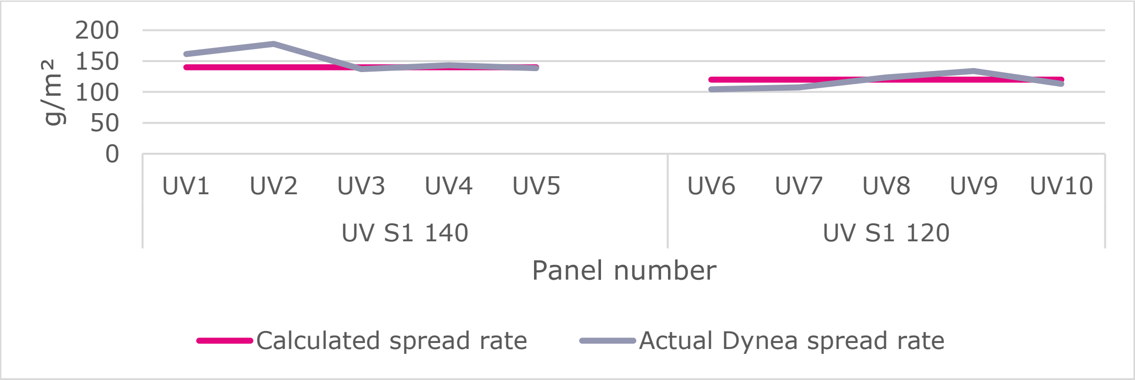


Figure 3.13. Dynea Unveneered S1 140 and 120 actual spread rate

Figure 3.14. S2 120 spread rate, set to dry before press, bad spread issues

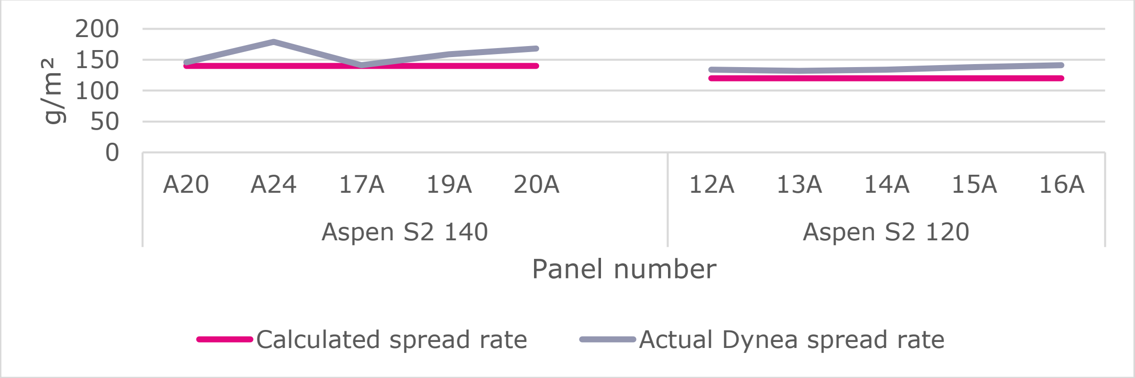


Figure 3.15. Dynea Aspen S2 140/120 actual spread rate

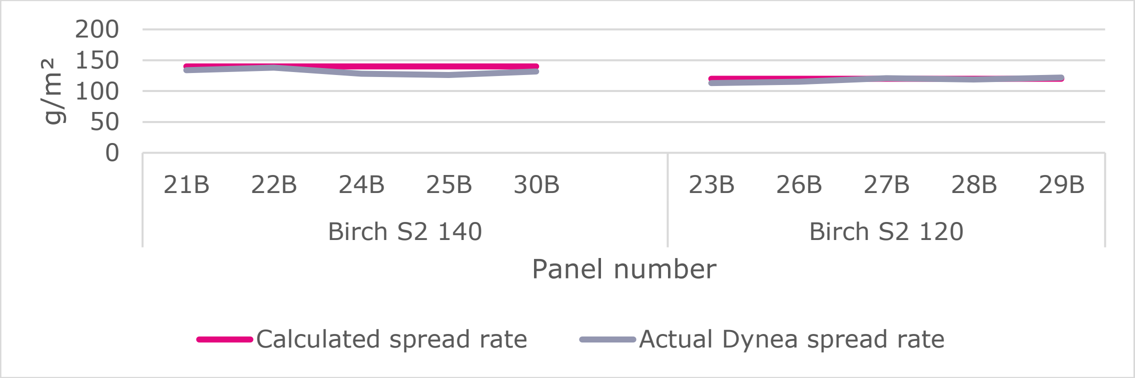


Figure 3.16. Dynea Birch S2 140/120 actual spread rate

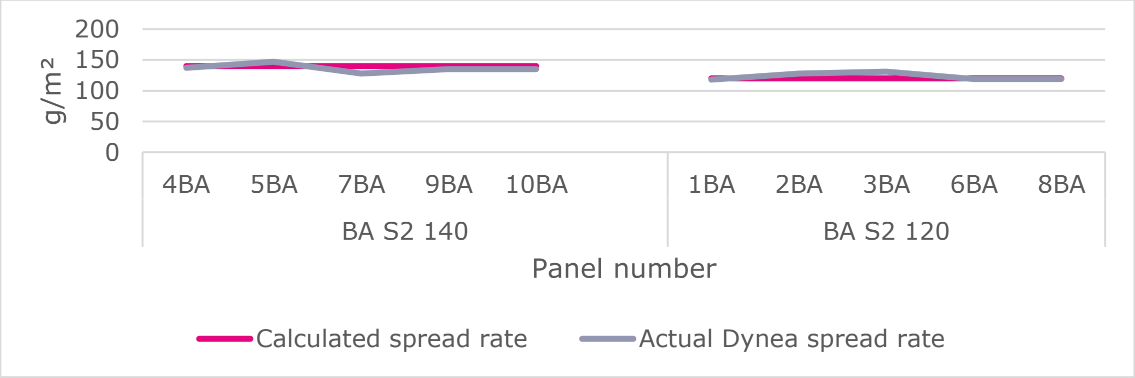


Figure 3.17. Dynea Black Alder S2 140/120 actual spread rate

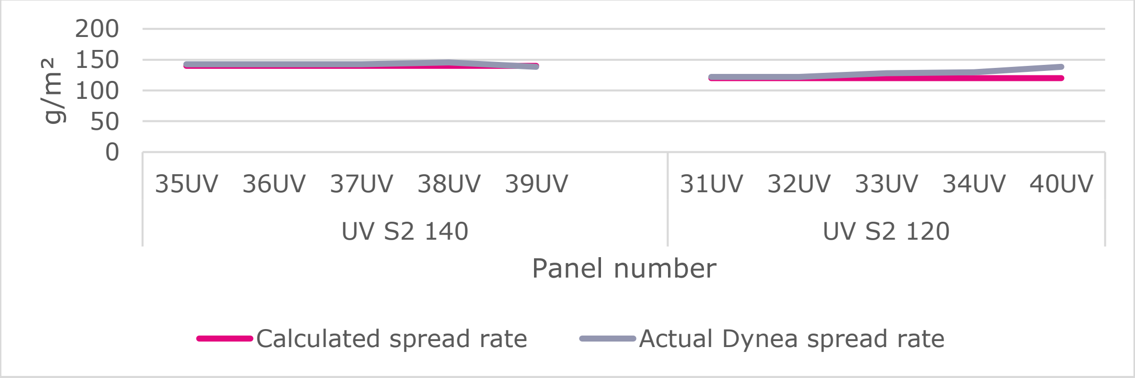


Figure 3.18. Dynea Unveneered S2 140/120 actual spread rate

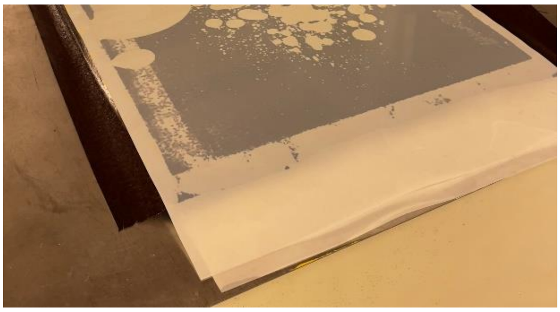


Figure 3.19. Pressed PF panels with Mylar® A 190 - 500µm

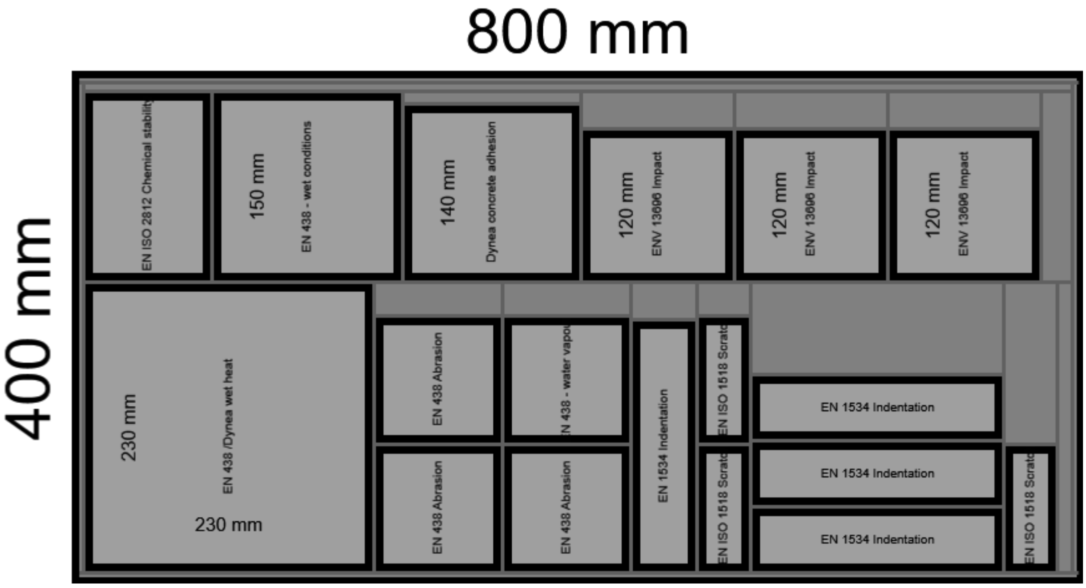


Figure 3.20. Cutting layout (MaxCut 2)

Figure 3.21. EN 1534 Brinell test procedure

Figure 3.22. First attempt using a steel ball instead of cone

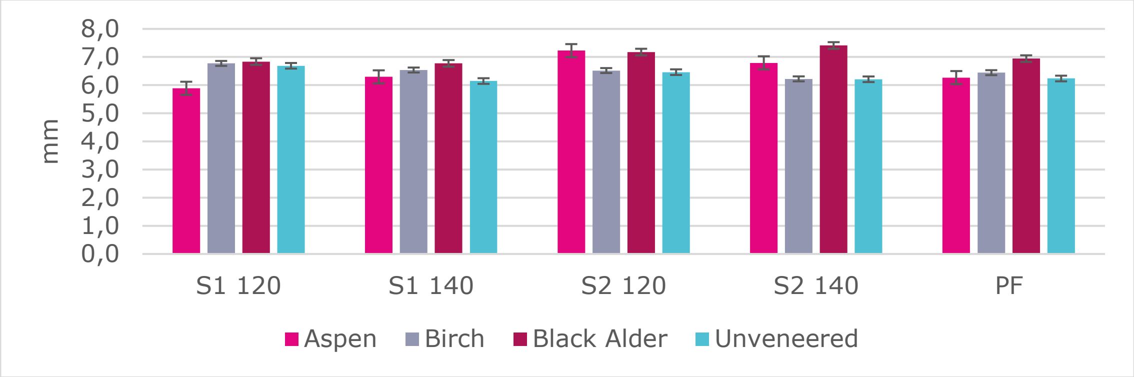


Figure 4.1. Brinell average diameter

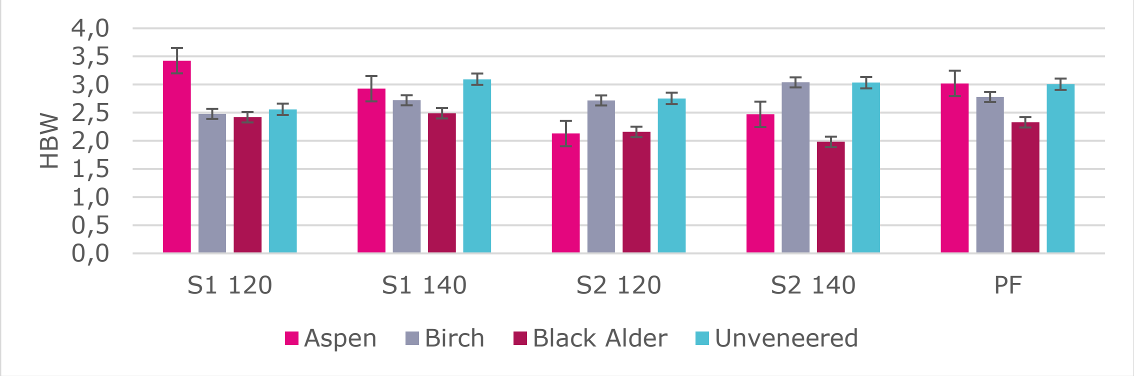


Figure 4.2. Brinell average hardness

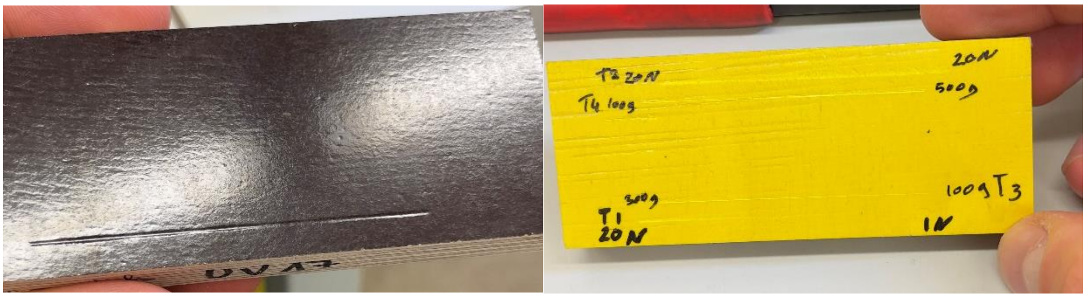


Figure 4.3. Adjustment samples

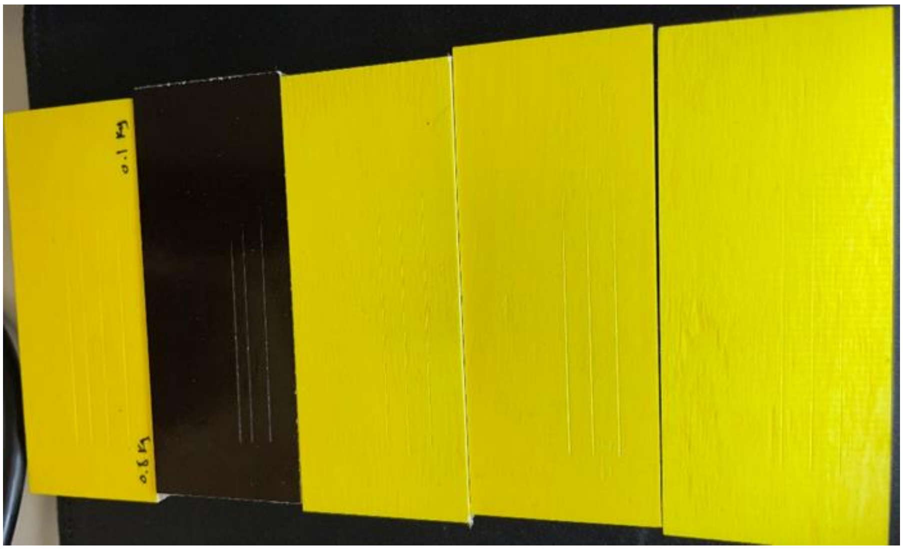


Figure 4.4. Scratch test samples

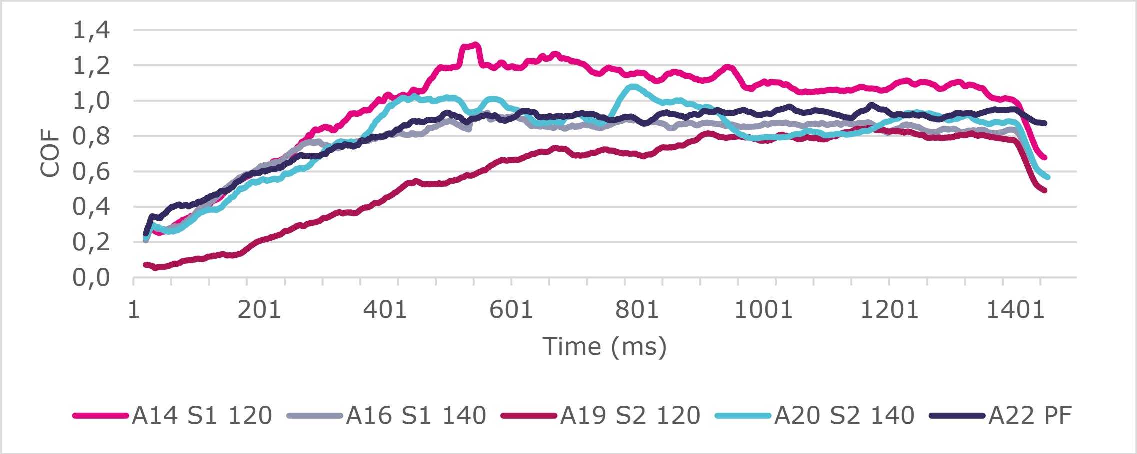


Figure 4.5. Aspen scratch test average coeffecient of friction (COF)

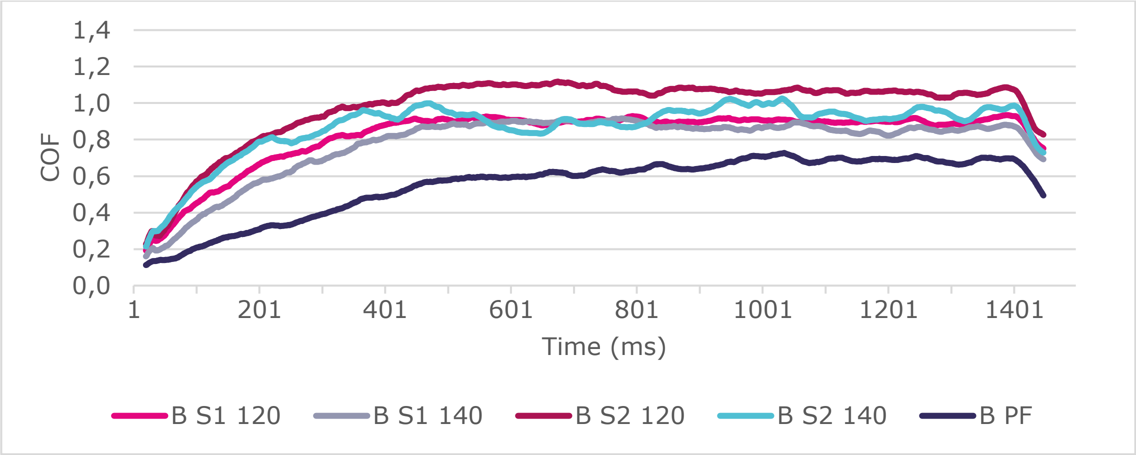


Figure 4.6. Birch scratch test average coeffecient of friction (COF)

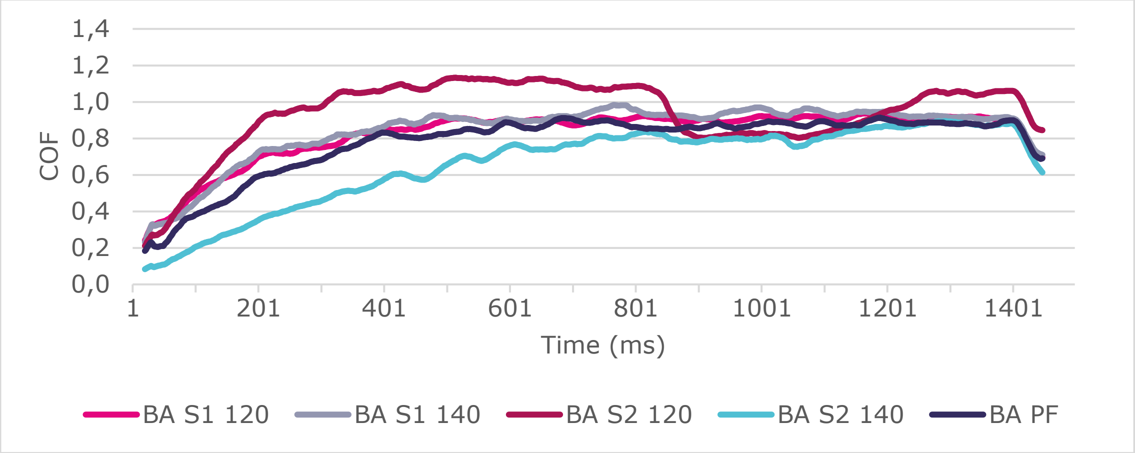


Figure 4.7. Black alder scratch test average coeffecient of friction (COF)

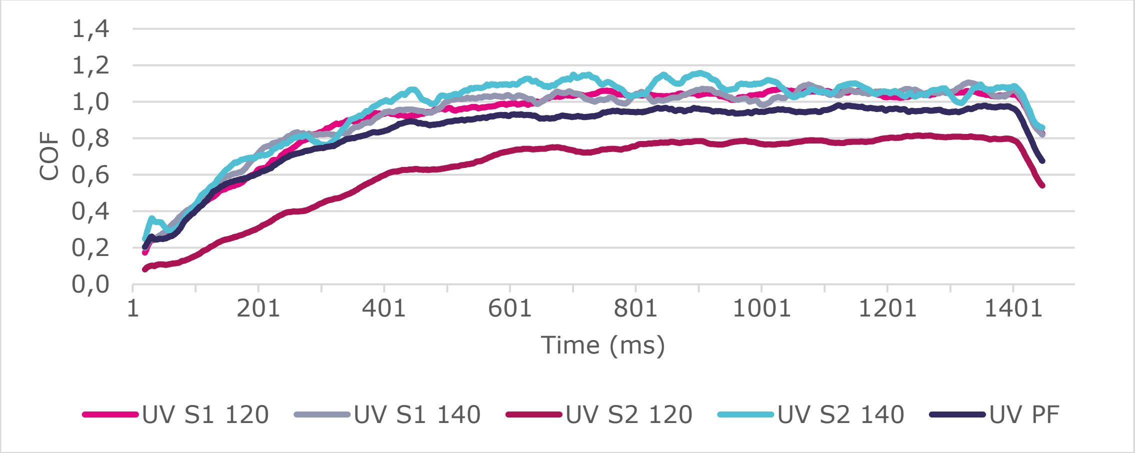
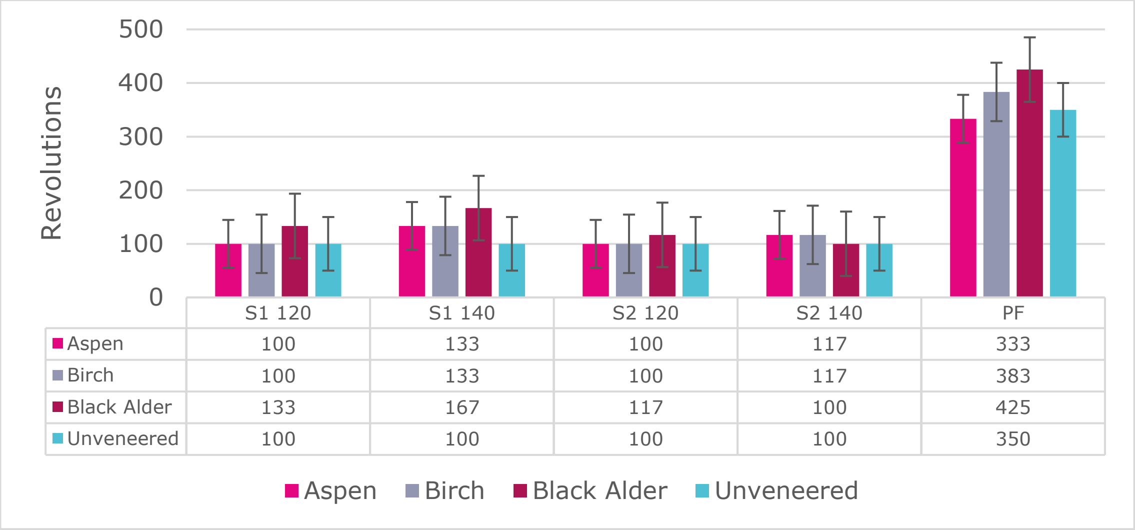


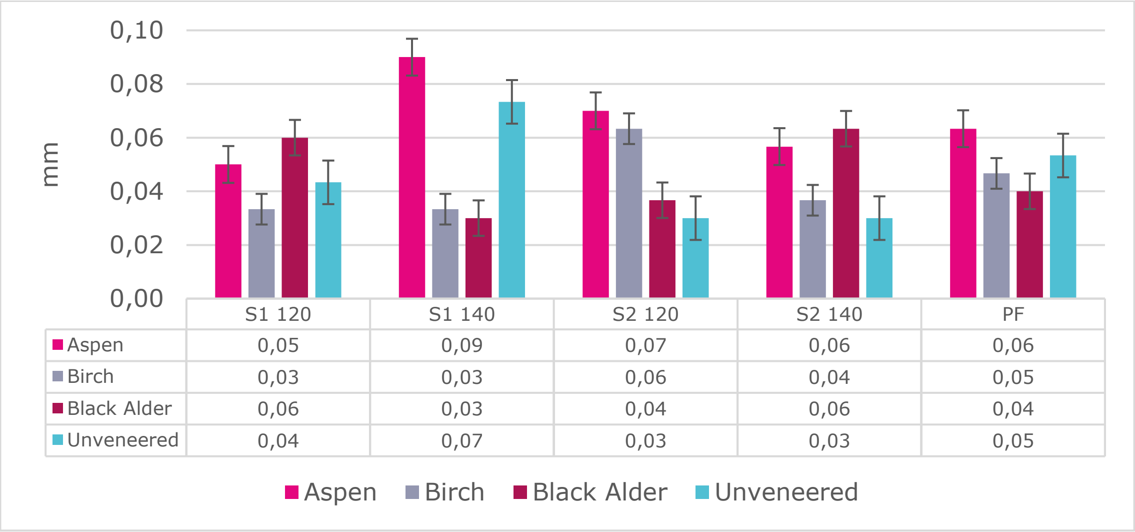
Figure 4.8. Unveneered scratch test average coeffecient of friction (COF)

Figure 4.9. Taber abrasion test example 800, 400, 100 revolutions respectively



	S1 120	S1 140	S2 120	S2 140	PF
Aspen	100	133	100	117	333
Birch	100	133	100	117	383
Black Alder	133	167	117	100	425
Unveneered	100	100	100	100	350

Figure 4.10. Taber test revolution counts



	S1 120	S1 140	S2 120	S2 140	PF
Aspen	0,05	0,09	0,07	0,06	0,06
Birch	0,03	0,03	0,06	0,04	0,05
Black Alder	0,06	0,03	0,04	0,06	0,04
Unveneered	0,04	0,07	0,03	0,03	0,05

Figure 4.11. Taber test wear depth (mm)

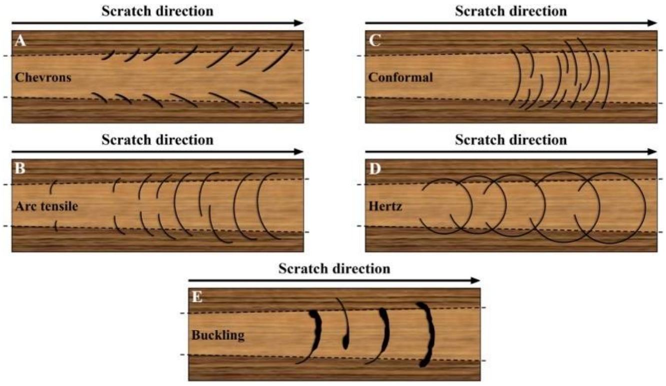


Figure 4.12. Scratch stresses (Springer, 1989)

Figure 4.13. Recessed sanded edge

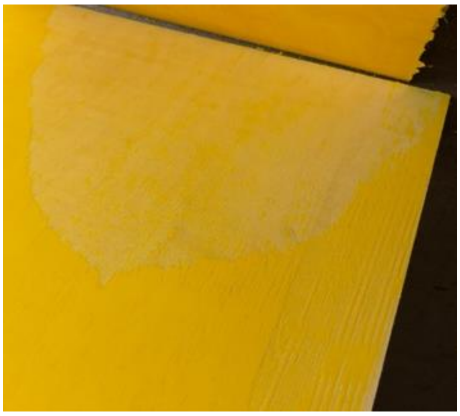


Figure 4.14. Random batch with less spread material